Bio4Fuels Annual Report 2017

Norwegian Centre for Sustainable Bio-Based Fuels and Energy

BIO4FUELS

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

The Research Council of Norway

Biokraft, Skogn, Norway. Drone photo by Kenneth Kvande

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.

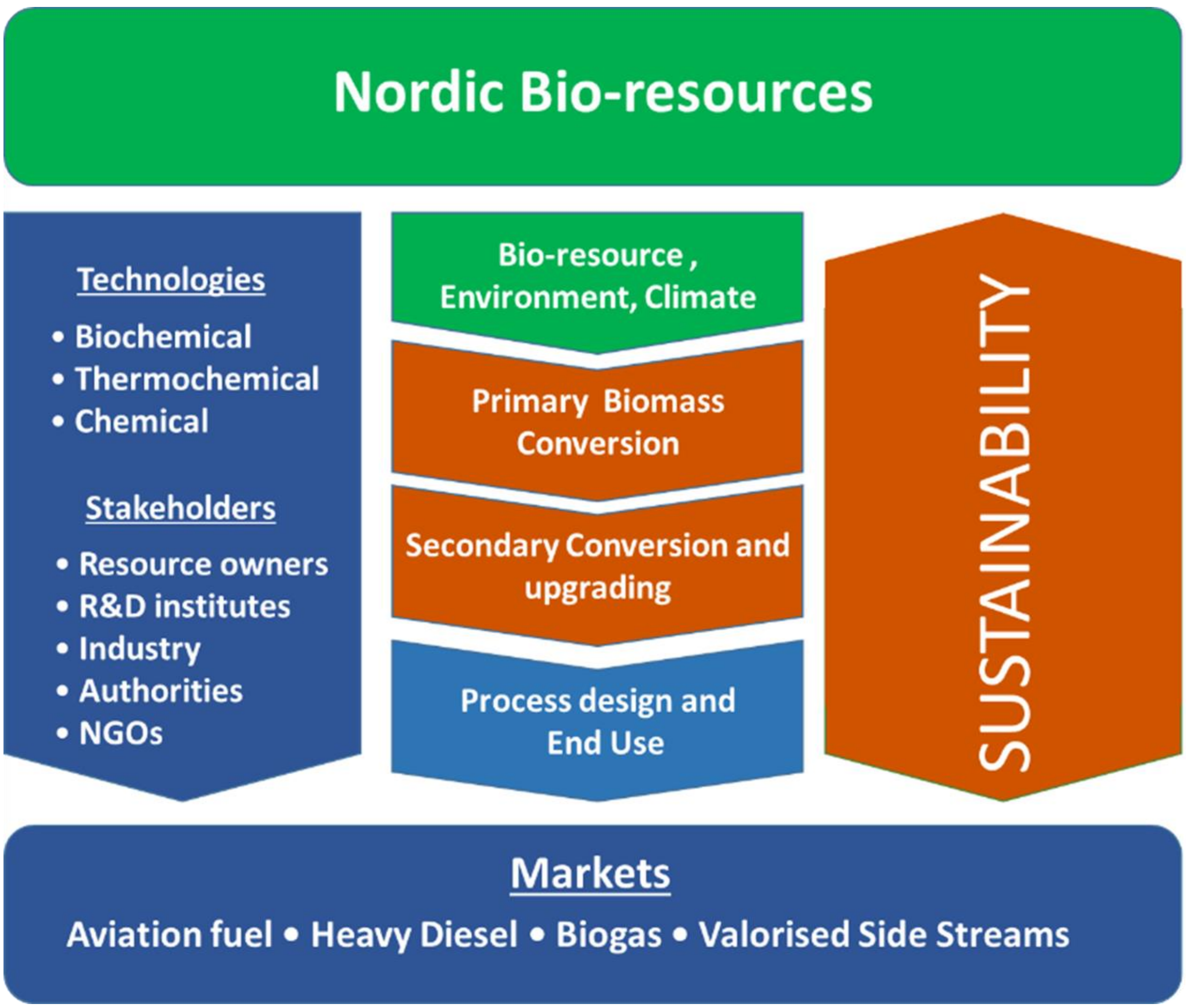


TABLE OF CONTENTS

Pictures from Avinor and Volvo

FROM THE CHAIR OF THE BOARD AND CENTRE LEADER

The establishment of a centre for research and innovation related to biofuels is a milestone with respect to Norway's ambitions of achieving progress with respect to reduction of emissions within the transport sector. As a chair and member of the board, we have a strong responsibility to ensure that this unique consortium of stakeholders and research partners pool their efforts towards concrete achievements within research towards sustainable approaches for advanced biofuel production in Norway. We are also privileged to have a number of technology providers from outside of Norway involved in the Centre; this gives the Centre access to the leading industrial perspectives within Europe.
In addition to being chair, I also represent the interests of UMOE and we have a strong focus on renewable energy, both nationally and internationally. Our experience shows that there are clear challenges with respect to achieving an economic basis for producing biofuels – so Bio4Fuels centre's activities should be targeted towards innovations that can be capitalised on by the stakeholders, in addition to establishing a strong network of world class research groups.

Hans Aasnæs,
Chair of the Board

The realization of Bio4Fuels FME Centre is the result of a lot of the hard work by many of those representing the key research partners and of the encouraging interest, support and feedback of the stakeholders. After almost one year of operation, we are even more aware of the challenges and opportunities that the Centre faces on behalf of the Scientists and the Stakeholders linked to Bio4Fuels. This is both in terms of the need to make available innovations that can address society's needs for alternative solutions for biofuels as part of the transport sector energy mix, as well as having considered basis for many of the questions that arise in this rapidly evolving sector. As scientists in the Centre, we have high ambitions to make our mark, delivering on the goals of science and innovation, as well as considering the alternative choices of value-chains that best fit the Norwegian and Nordic context for the production of Biofuels.

Duncan Akporiaye
Centre leader

SUMMARY

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

There are four main routes identified for Bio4Fuels:

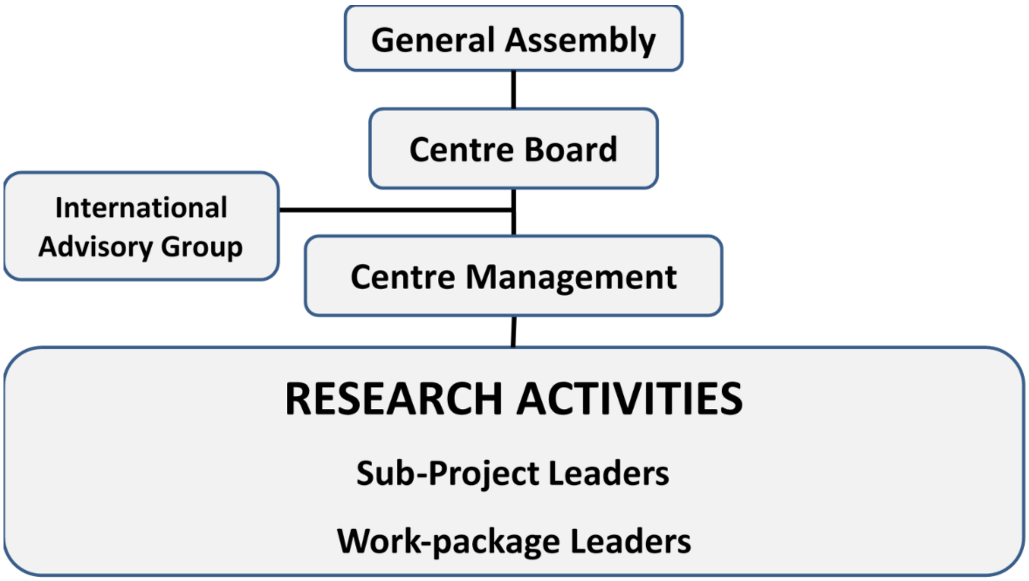
- Breaking down the biomass to separate out the sugars in the biomass for use in fermentation to produce "Bioethanol". This can be blended up to certain levels into existing fuels.
- Fermentation of the biomass in the absence of oxygen to produce a "Biogas". This Biogas can be upgraded to methane, liquified 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 main routes from Biomass to Biofuels, it is also important to convert side streams and biproducts from the processes to products of higher value than fuels. This can be important to help the overall economics of the commercial process. The main issues being addressed for viable commercial production of Biofuels from Biomass are related to the economics and sustainability of the processes. The research activities in the Bio4Fuels Centre address these central issues through:

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

In the first period of the operation of the Centre, a successful Kick-off meeting was arranged in February, with an international guest list of industrial presenters from all over Europe and the US. This provided industrial perspective of the state of the art for technology along the whole value chain. Using the kick-off as a platform, the Centre has now established a highly competent board, with industry as majority stakeholders, making use of the wide experience of Hans Aasnæs of UMOE as the Chairperson. The Centre has also established an International Advisory Group with representatives from key research sectors from Finland, United Kingdom and United States. Bio4Fuels organised the first annual "Bio4Fuels" days meeting, with an excursion to visit the production of Paper (Norske Skog AS) and Biogass (Biokraft AS) at Skogn near Trondheim. The research partners have been active in dissemination, including with respect to newspaper media and have been successful in getting funding for the second phase of the NorBioLab II infrastructure platform as coordinated by RISE PFI.

BIO4FUELS ORGANIZATION



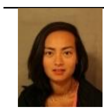
Centre Board and Management

The Bio4Fuels' Board:

	**Hans Aasnæs**	**UMOE AS**	**Chair**
	Hilde Merete Brandsrud	Østfold County Council	Representing Stakeholders
	Olav A. Veum	Norges skogeierforbund	Representing Resource partners
	Ingo Machenbach	Silva Green Fuel	Representing End Users
	Paal Jahre Nilsen	CAMBI	Representing Technology partners
	Petter Røkke	SINTEF	Centre Leader Institute
	Ragnhild Solheim	NMBU	Host Institute
	Terese Løvås	NTNU	R&D partner
	Philip Andre Reme*	PFI	R&D partner
	*Trond Værnes*	*Research Council of Norway*	*Observer*

**Rotation between PFI, HSN, IFE, NIBIO*

THE BIO4FUELS' MANAGEMENT TEAM:

	Dr. Duncan Akporiaye	SINTEF	Centre Leader
	Prof. Svein Jarle Horn	NMBU	Deputy Centre Leader (On sabbatical until Q2/2018
	Prof. Torjus Bolkesjø	NMBU	Acting Deputy Centre Leader (until Q2/2018)
	Dr. Janne Beate Utåker	NMBU	Administrative Manager
	Dr. Odd Jarle Skjelhaugen	NMBU	Industrial Liaison
	Christel Celine Nguyen	NMBU	Financial Officer

THE INTERNATIONAL ADVISORY GROUP (IAG)

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

BIO4FUELS STAKEHOLDERS

Research partners in Norway
NMBU – The Norwegian University of Life Sciences
SINTEF
NTNU – The Norwegian University for Science and Technology
NIBIO – The Norwegian Institute of Bioeconomi,
IFE – Institute for Energy Technology
RISE PFI – Research Institutes of Sweden – Paper and Fiber Institute
HSN – The Univeristy 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
Ragn Cells AS	Value from organic waste
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
Hyperthermix AS	High temperature biogas production from waste biomass
Norse Biotech AS	Consultancy on biofuels production plants
Synsel Energi Norway AS	Consultancy and investment on 2G biorefineries
Zeg Power AS	Electricity and hydrogen production from hydrocarbons
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

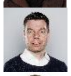
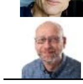
Biofuel and biochemical producers	Main interest
Silva Green Fuel AS	Biodesel from forest biomass
Biozin AS	Forest based crude oil for biorefineries
Perstorp Bioproducts AB (SE)	High quality biodiesel
Borregaard	Forest-based high value chemicals and bioethanol
Biokraft	Biogas from paper mill side-streams and fish waste

Ecopro AS	Biogas from organic waste
Norske Skog Saugbrugs	Biogas from biorefinery side-streams
Solenis Norway AS	Industry chemicals from woody biomass
Alginor ASA	Seaweed products from a multifunctional biorefinery

Biofuels distributors and end users	Main interest
Eco1 as	Biodiesel and biooil distribution in Norway
St1 Norge as	Bioethanol production and distribution in Norway
Preem (SE)	Biofuels production and distribution in Sweden/Norway
Volvo Group Trucks Technology (SE)	Truck engines powered by biofuels
Avinor	BioJetFuels for Norwegian airports

Government and State PartnersF	
Østfold Fylkeskommunene	Sustainability, Resource Use, Transport policy, Technical Economics
Hedmark Fylkeskommunene	Sustainability, Resource Use, Transport policy, Technical Economics
Akershus Fylkeskommunene	Sustainability, Resource Use, Transport policy, Technical Economics
Oppland Fylkeskommunene	Sustainability, Resource Use, Transport policy, Technical Economics
Trøndelag Fylkeskommunene	Sustainability, Resource Use, Transport policy, Technical Economics
Follorådet Fylkeskommunene	Sustainability, Resource Use, Transport policy, Technical Economics
Miljødirektoratet	Sustainability, Resource Use, Transport policy
Statens Vegvesen	Sustainability, Resource Use, Transport policy, Technical Economics
NVE	Sustainability, Resource Use, Transport policy, Technical Economics
Innovasjon Norg	Sustainability, Resource Use, Transport policy, Technical Economics
Enova	Sustainability, Resource Use, Transport policy, Technical Economics

Work Packages and Sub Projects

	Name	institution	Main research area
	Rasmus Astrup (leader WP 1.1)	NIBIO	Resources and Ecosystem processes
	Francesco Cherubini (leader WP 1.2)	NTNU	Bio-Resources, Environment, Climate
	Torjus Bolkesjø (leaderWP 1.3)	NMBU	Energy, Fuels and Economics
	Per Carlsson (leader WP 2.1)	SINTEF	Gasification
	Kai Toven (leader WP 2.2)	RISE PFI	Pyrolysis
	Judit Sandquist (leader WP 2.3)	NTNU	Hydrothermal Liquefaction
	Øyvind Eriksen (leader WP 2.4)	RISE PFI	Pretreatment and Fractionation
	Aniko Varnai (leader WP 2.5)	NMBU	Enzymatic Saccharification
	Edd Blekkan (leader WP 3.1)	NTNU	Gas Conditioning
	Roman Tschentscher (leader WP 3.2)	SINTEF	Thermochemical upgrading of bio oils
	De Chen (leader WP 3.3)	NTNU	Chemo-catalytic conversion
	Alexander Wentzel (leader WP 3.4)	SINTEF	Fermentation
	Tormod Briseid (leader WP 3.5)	NIBIO	Anaerobic digestion and gas upgrading
	Heinz Preisig (leader WP 4.1)	NTNU	Modelling Tool for Biorefineries
	Bernd Wittgens (leader WP 4.2)	SINTEF	Techno-Economic Evaluation and Scale of Economy
	Klaus Jens (leader WP 4.3)	HSN	Preparing for piloting and up-scale
	Terese Løvås (leader WP 4.4)	NTNU	Product quality and End Use
	Francesco Cherubini (leader SP1)	NTNU	Bio-resource, Environment and Climate
	Berta Güell (leader SP2)	SINTEF	Primary Biomass Conversion
	Vincent Eijsink (leader SP3)	NMBU	Secondary Conversion and Upgrading
	Bernd Wittgens (leader SP4)	SINTEF	Process design and End Use

HIGHLIGHTS FROM 2017

BIO4FUELS KICK OFF

The formal kick-off of the Bio4Fuels Centre was carried out on 9th/10th of February at Ås at the host institution NMBU. This event brought together approximately 100 participants, including most of the Centre's stakeholders. As shown from the program and the picture gallery below, the Centre was formally opened by the Minister of Education and the Research Council of Norway. The kick-off meeting highlighted the international focus of the Centre, including both physical and live video-link presentations from US collaborators at SANDIA and PNNL. The Nordic perspective was also well represented with a number of presentations from Finland and Sweden. The perspective and state of the art of the Bio4Fuels value-chain was also a central theme throughout the two days, with key aspects of the value chain being represented by national and international technology providers, in addition to presentations by scientists from the Centre.

Pictures from the opening session of the Bio4Fuels Kick-off; Research Council of Norway (Rune Volla); Ministry of Education and Research (State Secretary Bjørn Haugstad); Rector NMBU (Mari Sundli Tveit);

Bio4Fuels Kick-off, 9th February 2017
Opening
Research Council of Norway(Rune Volla)
Ministry of Education and Research (State Secretary Bjørn Haugstad)
Rector NMBU (Mari Sundli Tveit)
SINTEF (Eli Aamot)
UMOE, TBD (Hans Aasnæs)
Plenary Presentations
PNNL, Bioenergy: A U.S. Perspective, (John Holladay/Duncan)
VTT, Nordic perspective to bioeconomy (Jussi Manninen)
Lanzatech, Gas Fermentation: Making sustainable fuels and chemicals at scale (Sean Simpson)
Norwegian Environment Agency, Emissions Reduction in the Transport Sector (Siri Sorteberg)
ST1 (Thomas Hansen)
F3, fossil free fuels: a systems perspective on the transition towards a fossil free transport sector (Johanna Mossberg)
Sustainability perspectives (Jakob Lagerkrantz)
Silva Green Fuels, Challenges in producing advanced biofuels (Ingo Machenbach)
Borregaard, Biofuels in a biorefinery perspective (Martin Lersch)
NorBioLab, Norwegian Biorefinery Laboratory – versatile research tools for bioprocess development (Karin Øyaas)

Bio4Fuels Kick-off, 10th February 2017	
Sub Project 1 (SP1)– Bioresources	Chair: Francesco Cherubini, professor, NTNU
Unexplored potentials in waste for biofuels production	Johnny Stuen, Technical director, EGE
Why do forest owners supports new biobased industry in Norway ?	Olav Veum, Norwegian Forest Owners Federation
Forest resource availability and the effects of utilization on ecosystem processes and climate	Rasmus Astrup, Senior Researcher, NIBIO
Coffee break	
SP2 Conversion Technologies	Chair: Berta Matas Güell, Senior Scientist, SINTEF
Enzyme technology for biomass conversion	Anne Stenbæk, Dept. Manager, Biomass Technology EU, Novozymes
Fast Pyrolysis: a short cut for biomass to refineries	Robbie Venderbosch, Senior engineer, Biomass Technology Group BTG
Bioprocessing of lignocellulosic biomass	Aniko Varnai, postdoctoral researcher, NMBU
Lunch	
SP3 Upgrading Technologies	Chair: Vincent Eijsink, professor, NMBU
Upgrading of syn-gas from biomass gasification	Stephen Poulston, Research scientist, Johnson Matthey
Advanced biofuels from wood using the biotech route	Alexander Wentzel, senior research scientist, SINTEF
Coffee	
SP4 End Use	Chair: Bernd Wittgens, senior adviser, SINTEF
Drop in fuels from the forest – today and in the future	Åsa Håkansson, Business Developer -Research and Product Development, PREEM
The Co-optima Project: Biofuel production and design predicated upon engine performance criteria,	Anthe George, Scientist, Senior Member of the Technical Staff at SANDIA National Laboratories
Biofuels in use, performance and emissions	Terese Løvås, professor, NTNU
Closing Remarks	Duncan Akporiaye, Vice president research, SINTEF. Centre Leader

BIO4FUELS DAYS 2017

Pictures from the Bio4Fuels Days, (clockwise from top left); Plenary session, Visit to Biokraft AS construction site; visit to Norske Skog Skogn paper mill.

The first "Bio4Fuels Days" annual event was also organized during 2017, as the first step in establishing this 2-meeting as a central meeting stage. The format was selected to address two key aspects of the Centre's activities: the first day being an open national/international forum for discussion and networking on the key aspects of research towards Biofuels followed by the second day, internal for the Centre's stakeholders and partners to reviewing scientific progress and provide direction and input to research activities. As shown below in the Bio4Fuels program and picture gallery, the two days continued to keep focus on national and international perspectives and gave the first opportunity for the International Advisory group to be acquainted with Bio4Fuels. One of the highlights of the two days was the visit hosted by Norsk Skog Skogn and Biokraft to their respective sites at SKOGN.

Bio4Fuels Day 1 – 2nd November

			National and International Perspectives	Presenter
09:00	00:20	09:20	Welcome	Duncan Akporiaye, Centre leader
09:20	00:15	09:35	National Transport Plan	Sollie Ole Kristian, Vegvesen
09:35	00:25	10:00	International Advisory Board	Prof. Patricia Thornley, Univ. Manchester
10:00	00:25	10:25	International Advisory Board	Prof. Kristiina Kruus, VTT
10:25	00:25	10:50	International Advisory Board	Dr. David Dayton, RTI International
10:50	00:40	11:30		Coffee
			Bio4Fuels Value Chain	**Presenter**
11:30	00:15	11:45	Status of Biofuels Research in Norway	Trond Værness, Research Council of Norway
11:45	00:20	12:05	Regional Development and planning	Cecilie Agnalt, Østforld fylkeskommune: On behalf of Østfold; Akershus; Hedmark; Oppland; Sør-Trøndelag;
12:05	00:20	12:25	New developments in enzymes research	Vincent Eijsink, NMBU
12:25	00:25	12:50	Biofuels End Use	Ingemar Magnusson, Volvo Group
12:50	00:25	13:15	Economics of two Biofuels Value Chains	Raf Roelant, PDC
13:15	01:15	14:30		Lunch
14:30	**04:00**	**18:30**	**Site visit to Biokraft AS and Norske Skog Skogn**	

Bio4Fuels Day 2 – 3rd November

09:00	**01:30**	**10:30**	**Development of Workplan 2018**	
			Cluster 1: Biochemical Processing	Aniko Varnai
			Cluster 2: Thermochemical Processing	Per Carlsson
			Cluster 3: Sustainability and Process Design	Bernd Wittgens
			Cluster 4: Stakeholder Engagement	Odd Jarle Skjelhaugen
10:30	00:30	11:00	Coffee	
11:00	01:30	12:30	**Development of Workplan 2018**	
			Cluster 1: Biochemical Processing	Tormod Briseid
			Cluster 2: Thermochemical Processing	Edd Anders Blekkan
			Cluster 3: Sustainability and Process Design	Francesco Cherubini
			Cluster 4: Stakeholder Engagement	Duncan Akporiaye
12:30	01:00	13:30	Lunch	
13:30	**01:00**	**14:30**	**Plenary presentation of draft workplan**	
	15		Cluster 1: Biochemical Processing	
	15		Cluster 2: Thermochemical Processing	
	15		Cluster 3: Sustainability and Process Design	
	15		Cluster 4: Stakeholder Engagement	
14:30	00:20	14:50	Input from the International Advisory Group	
14:50	00:10	15:00	Closing remarks	

BIO4FUELS INSIGHTS

PHD STUDENT LINE DEGN HANSEN

Working at: the Norwegian University of Life Sciences (NMBU)
Research group: Bioprocess, technology and biorefining (BioRef)
Work Package: WP2.5 - Enzymatic Saccharification
Supervisors: Aniko Varnai, Svein Jarle Horn and Vincent Eijsink
BSc: Biochemistry (Copenhagen University)
MSc: Food Biotechnology and Biorefining (Wageningen University)

Newly recruited Bio4Fuels PhD student Line D. Hansen next to a 30 liter reactor used for high-dry matter enzymatic saccharification reactions. The biorefinery at NMBU allows experiments at small pilot scale and is part of the national NorBioLab infrastructure for biorefining.
Photo: Christine K. Kristiansen

Line is one of five PhD students who was recruited to Bio4Fuels in 2017. Her aim is to optimize and characterize cellulose / hemicellulose degrading enzymes using Norwegian spruce as raw material. WP2.5 is in close cooperation with industry partners in Bio4Fuels, receiving raw material from Borregaard,St1 and RISE-PFI and enzymes from Novozymes®.

Line receives feedstock from St1 in the form of pre-treated Norwegian spruce. To degrade the cellulose and the hemicellulose in this material she uses enzymes in the form of

- commercially available enzyme cocktails from Novozymes®
- selected enzymes designed locally at NMBU including lytic polysaccharide monooxygenases (LPMOs).

Raw material for enzymatic degra-dation of cellulose and hemicel-lulose from Norwegian Spruce
Photo: Christine K. Kristiansen

Line's research involves optimizing enzymes in both bench-scale and pre-pilot plant scale (at the NMBU biorefinery). She analyzes performance of enzyme blends under varying conditions with respect to co-reactants, temperature, pH, reaction length etc.

Using commercially available enzyme cocktails is sometimes a challenge given their proprietary nature. On the other hand, these enzyme cocktails have been thoroughly tested and are already in industrial use. The "in-house" designed enzymes are the result of protein engineering and directed evolution of key enzymes involved in biomass processing in bacteria and fungi. Line is currently testing the most promising of these enzymes in laboratory-scale analysis. Once she has established enzyme reactions with a certain efficiency, she can scale up her saccharification experiments to *small pilot scale* in the biorefinery at NMBU.

NOVEL ENZYMATIC MECHANISM THAT REVOLUTIONIZE BIOREFINING, PUBLISHED IN NATURE

In a groundbreaking study, Bastien Bissaro, a guest researcher at NMBU from INRA, France, and the NMBU team led by Vincent Eijsink have now discovered that the mechanism by which the enzymes called LPMOs (lytic polysaccharide monooxygenases) break down cellulose, is different from what was previously thought. The results were published in Nature Chemical Biology, on August 28, 2017.

What has been discovered is that LPMOs do not need oxygen but hydrogen peroxide, which is a cheap liquid chemical. Although this finding may seem small to some, it actually goes against well-established dogmas in biochemistry. Moreover, and most importantly, since the mechanism of these enzymes is different than previously thought, the way to harness their potential in industrial biorefining needs to be reconsidered.

Figure: 3D model of LPMO enzyme

Building on their discovery, Bissaro et al show that by controlling the supply of hydrogen peroxide, one can achieve stable enzymatic cellulose conversion processes, much higher conversion rates than previously thought possible and higher glucose yields.

These findings are of great commercial interest. They have implications for the enzymatic conversion of biomass in industrial biorefining. The research team continues collaborating closely with the Bio4Fuels partners Novozymes and Borregaard, and piloting of new processing routes are in progress.

As Anne Stenbæk, Dept. Manager Biomass Technology in Novozymes puts it: "Novozymes has a great interest in LPMO action and is currently studying if and how the recent findings at NMBU may be incorporated in industrial biomass conversion processes". And Gudbrand Rødsrud, Technology Director Business Development in Borregaard: "These findings are of great interest to Borregaard, and we are looking forward to exploring novel opportunities together with the Bio4Fuels consortium".

MODELLING TOOL FOR BIOREFINERIES

A prototype of a modelling tool for biorefining has been developed by Heinz Presig and his team at NTNU. The tool provides high flexibility and enables fast definition of new models and adaptations of existing models. It integrates the physical configuration, the thermodynamics of the various involved materials and the kinetics of both chemical and biological processes. The current version of the program will be further developed and verified with process data from an indNor/EnergiX-project associated to Bio4Fuels.

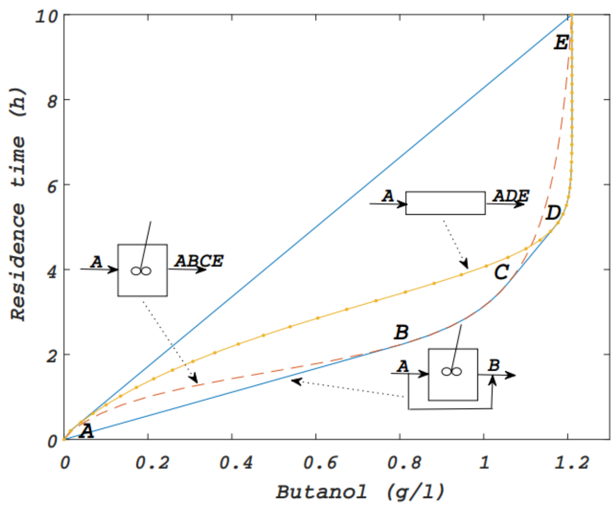


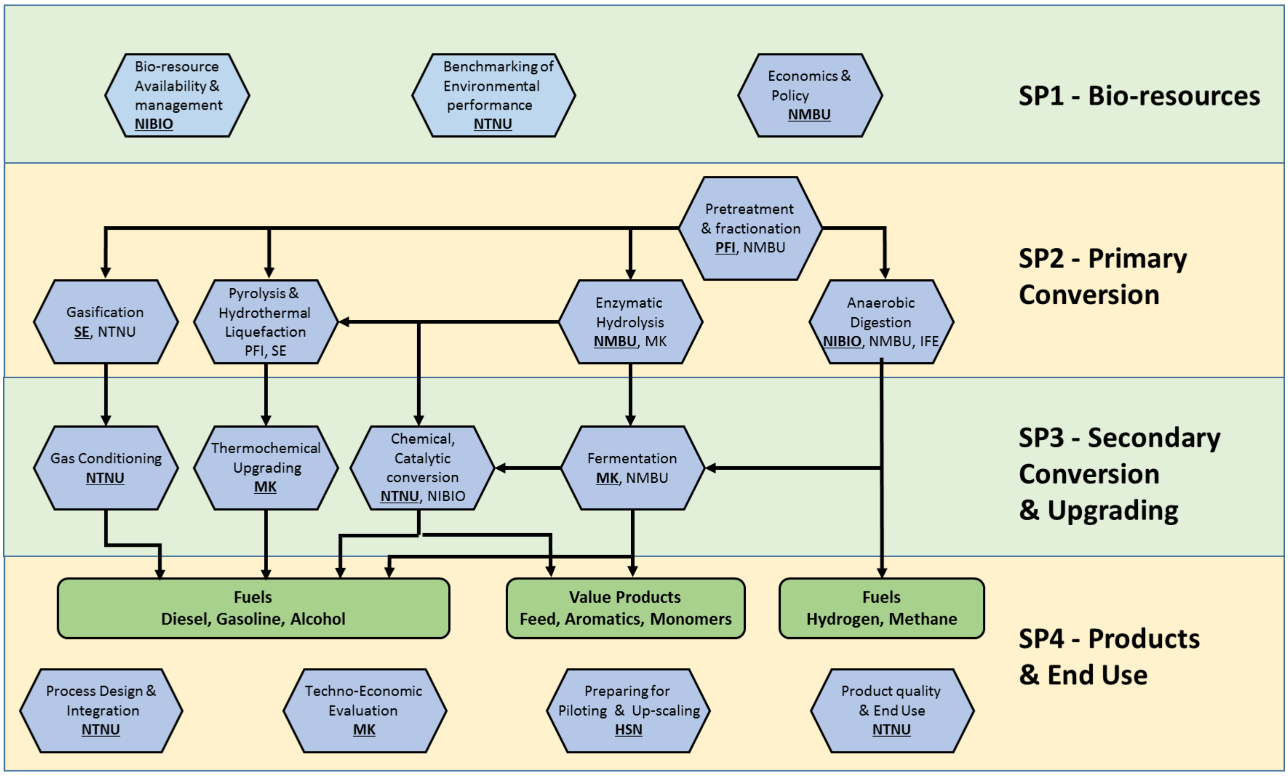
Figure: All the model information concentrated

The modelling tool represents a valuable addition to Bio4Fuels for testing and evaluating a large number of processes relevant for the analysis of value chains and process design.

The tool is of high international interest. It was invited to be presented as keynote lecture in the 27th European Symposium on Computer-Aided Process Engineering (ESCAPE-27), Spain 1-5. October 2017 and consequently published. (Elve, Arne Tobias & Preisig, Heinz A. From Ontology to Executable Program Code. Computer-aided Chemical Engineering, Volume 40. 2017 s. 2318-2322). An attainable region analysis was published in the same outlet (Birgen et al, ibid s. 2893-2898).

Scientific Activities

The scientific activities in Bio4Fuels are structured according to the value chains going from accessibility and sustainability of bioresources through to the economics for production and end use.
As shown below, the high level value chain (SP) establishes interaction across focussed research activities (workpackages) addressing the four challenges of bioresources (SP1), Primary conversion (SP2), Upgrading (SP3) and end use. Within this organisation, Bio4Fuels has the flexibility to coordinate activities along focussed value chains looking at addressing specific challenges of the main technologies for conversion and upgrading. These include thermochemical, chemical and biochemical conversion approaches.



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.

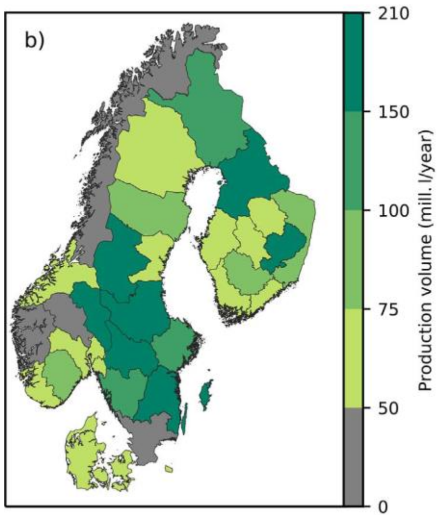
CLIMATE AND ENVIRONMENT

Our research focused on the development of a novel integrated framework to undertake climate impact analysis of biofuels in Norway. It involved the consideration of current and future biofuel polices and targets, and the identification of the major drivers, spatial resolution, and temporal dimension required for this improved climate impact assessment. We developed a preliminary version of the integrated assessment framework, where the biofuel system is linked with the background economy database for both the individual conversion pathways and the large-scale deployment at a national level. It allows a comprehensive quantification of the climate benefits of biofuel value chains, taking into consideration spatially explicit biomass resource availability, future potentials, logistics, and technology conversion options, and also important peculiarities of biomass to energy systems (in terms of biogenic carbon dynamics, multiple steps in the value chain, and different biomass components and uses). The assessment also takes into account a complex variety of climate forcing agents associated with bioresource extraction and utilization pathways, from greenhouse gas (GHG) emissions and near term climate forcers, to a suite of biophysical mechanisms like those involving changes in surface energy fluxes and water balances. In this initial phase of development, biofuel pathways are being considered under a state-of-the-art technology description form literature, aiming at set up the assessment framework. A publication is currently under preparation focusing on the preliminary application of this framework to a promising biofuel pathway in Norway. Next steps of the assessment will include additional climate change stressors and upscaling of the most promising value chains identified in Bio4Fuels at a National Norwegian level for producing biofuels and biomaterials.

Energy, Fuels and Economics

The main activity in WP1.3 has been to develop model tools for holistic assessments of the economics of biofuels in a wider forest sector and energy system context. In addition, we have performed a case study addressing how variations and uncertainty in different market drivers in the forest sector value chain affect harvest levels and forest industry production levels in Norway. We conclude that exchange rates Euro and US dollar to Norwegian kroner) and the development of international forest product markets are the most important uncertainty factors affecting harvest levels and forest industries in Norway. Another case study undertaken in cooperation with the BioNEXT project addresses the best locations for biofuel production investments based on resource availability, transportation costs, competition for biomass from other industries, cost levels and so forth. In the study, we find that several Norwegian regions appears attractive to such investments in a Nordic context, but the results are sensitive to future exchange rates and competitiveness of the sawmilling industry. The production and consumption of newsprint (for newspapers) and other printing paper has been declining in all regions of the world over the last decade. This development represents a threat to the existing Norwegian forest industry, but it may also imply new opportunities for new industries, like biofuel production. The forest sector model analysis performed so far also confirms the importance for the sawmilling industry as the "engine" in the Norwegian forest sector since it is both is the main driver for harvesting through sawlogs demand and a large supplier of biomass (chips and other sawmilling residues) for purposes, like bioenergy.

PhD student Eirik Ogner Jåstad (right) and researcher Per Kristian Rørstad (left) discussing the latest model results.



Optimal spatial distribution of biofuel production capacity under a Nordic 10% blending mandate. Source: Mustapha et al. (2017) (left) discussing the latest model results.

SP2: Primary Biomass Conversion
- Saccharification of softwood - Energy efficiency and feedstock flexibility
SP Leader: Berta Matas Güell

WP2.1	Gasification (Per Carlsson, SINTEF ER)
WP2.2	Pyrolysis (K. Toven, PFI)
WP2.3	Hydrothermal Liquefaction (Judit Sandquist, SINTEF ER)
WP2.4	Pretreatment and Fractionation (K. Øyaas, PFI)
WP2.5	Enzymatic Saccharification (A.Varnai, NMBU)

BACKGROUND AND APPROACHES

The activities in this subproject addresses the first difficult step in the breakdown of the biomass feedstock to an intermediate state using a variety of approaches.

Using thermochemical steps, gasification activities will be focused on process economy and feedstock flexibility, with the key challenge being in downscaling. Better heat integration and heat utilization aims to remove the dependency on low grade heat utilization such as district heating grids. The main research ambition is to have identified and improved a suitable gasification technology that can be integrated into a complete value chain, from feedstock to biofuels.

The pyrolysis approach for producing liquid bio-oils, gas and biochar will be based on fast pyrolysis technology, addressing the challenges of enhancing energy recovery from lignocellulosic feedstocks by linking fast pyrolysis with anaerobic digestion; and developing technology for direct conversion of lignocellulose feedstocks into gasoline range hydrocarbons by combining fast pyrolysis with direct vapour upgrading.

The alternative Hydrothermal Liquefaction approach aims to further development and establishment of HTL plants towards commercialization and deployment. This will include identification, evaluation and preparation of biomass feedstocks/blends, including side-streams from other value chains (e.g. lignin-rich streams), relevant for the production of biocrude through HTL. Process conditions for stable continuous operation, with goals of mitigation of the feedstock dependence on the biocrude quality and stability and minimization of the organic matter in aqueous phase.

With respect to biochemical approaches, pretreatment, fractionation and enzymatic saccharification will be addressed. Focus of the pretreatment and fractionation activities will be on pre-extraction of hemicelluloses, high lignin separation efficiency and effective breaking of the crystalline lignocellulose structure to make the carbohydrate fraction more accessible via optimization of steam pre-treatment technologies and water based hemicelluloses pre-extraction process and organosolv based lignin separation.

Focus on improvement of saccharification for wood processing will be directed to identify enzyme activities critical for softwood conversion, developing efficient processes for saccharification of softwood at high dry matter (DM) and development of new enzyme cocktails for commercially feasible softwood saccharification.

GASIFICATION

Develop mathematical tools that can be used to predict slag behavior; composition, viscosity, flowability and sintering.

Experimental campaigns with a new, beyond state of the art gasification technology that can operate with a sticky slag. Key technological improvements involve the heat recovery and the gasification reactor system.

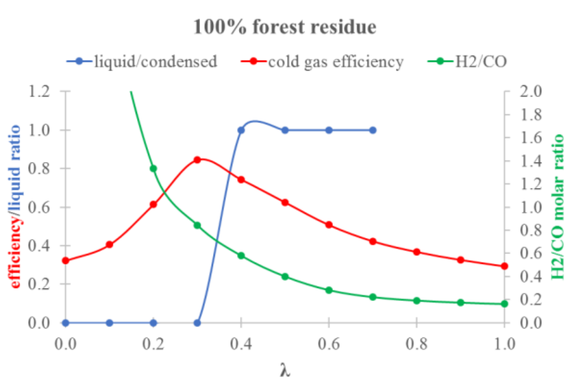
Gasification of waste and by-products including side-streams identified in the Bio4Fuels value chains and in other industry (demolition wood, forest residues, biogas residues etc.).

The main challenge: Biomass have ash fusion temperatures ranging from ~800 °C to >1500 °C (here, straw to beech).

The two dominating gasification technologies have similar thermodynamic energy efficiency. Entrained flow technologies are operated well above the ash fusion temperature and fluidized beds are operated well below the ash fusion temperature.

None of the available gasification technologies can operate close to the ash fusion temperature where the ash is sticky and has a high viscosity.

Typically, the highest thermodynamic efficiency can be found close to where the ash is partly molten, see the figure below

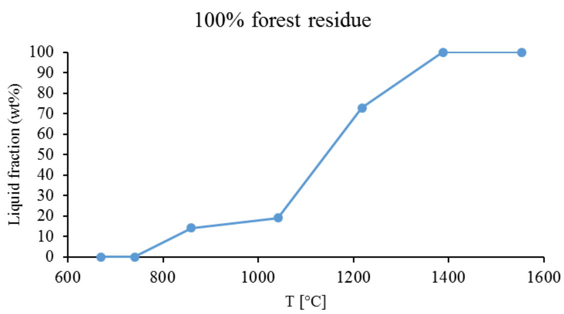


We are separating the challenge into two parts, one is focused on developing modeling tools and one is focused on experimental campaigns with challenging fuels (from an ash perspective).

The modeling tools are being developed to predict the behavior of different fuels with emphasis on the ash behavior, i.e. melting/fusion temperature, viscosity and flowability. In short, the tool will expand on the blue curve in the figure on the left side so not only complete melting tendencies are provided but also the actual behavior of the ash in the critical semi molten (sticky) slag temperature range. In addition, the tool provides gas composition, thermodynamic efficiency and insight to preferred operating conditions.

The experimental work will be performed in a newly developed gasification reactor which can be operated in two modes. The first mode is as a conventional entrained flow reactor; where the fuel enters from the top and the ash (and gas) exits the reactor at the bottom. The second mode is as a molten bed reactor where the ash forms a bed at the bottom, and gas exits the reactor from the side. The main benefits are assumed to be that larger fuel particles can be used and that a stickier slag can be tolerated. Hence, a much larger fuel flexibility would be obtained. This second mode is the focus in Bio4Fuels.

A first version of the modeling tool has been tested, and preliminary results can be seen in the figure below.



In addition, a first version of the viscosity sub-model has been developed. However, since the semi molten slag is a binary two-phase system, interpretation of the data is still challenging and further refinement of the viscosity model is needed. To complement the modeling work, we have established a cooperation with USN. We will work together in a newly funded research project (supported by RCN) to further develop the model and also validate the results with detailed experiments using, among others, ash melting microscopy and thermogravimetric analysis.

Pyrolysis

The main activity in work package 2.2 Pyrolysis in 2017 has been to establish techniques for operating the Pyrolysis Process Development Unit established at RISE PFI as part of Norwegian Biorefinery Laboratory (NorBioLab). Main operator for the Pyrolysis Process Development Unit at RISE PFI is Dr Javier Celaya Romeo. By now techniques for running the reaction system in different modes have been established.

Dr Javier Celaya Romeo at RISE PFI is evaluating the pyrolysis oil quality. The Pyrolysis Process Development Unit established at RISE PFI as part of NorBioLab is shown in the background.

Hydrothermal liquefaction

Results so far towards the objective "Feedstock flexibility" and "Processing":
The following aspect was investigated: Ash-related operational challenges such as corrosion and fouling (deposition) of the reactor walls.
The following solution was proposed: The development of a thermodynamic equilibrium model to assess inorganics chemistry with the aim to be applied as an effective, fast and cheap scanning tool to predict operational challenges and develop measures to mitigate them in industrial applications.

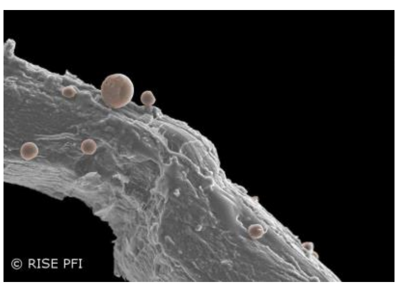
Building on previous surveys and in-house experiments and knowledge, it was decided to expand and further develop an existing hydrothermal model developed by O. Yakaboylu (see Supercritical water gasification of wet biomass: modelling and experiments, PhD thesis, Delft University of Technology, 2016) in close dialogue/collaboration with O. Yakaboylu (Delft University) and the company Gensos (NL).
Evaluation of the results from the SCWG sub-model (the one extensively presented in the PhD thesis) and preliminary calculations using the sub-model covering sub-critical conditions (160-350°C, 230-300 bar) were performed.
A thorough examination of the various databases for the sub-critical sub-model (gas, solution, solid) was carried out including necessary upgrades of data (for compounds already included) using primarily data from the SUPCRT92 database (available for free).
The inclusion of biochar in the databases was carried out. The inclusion is based on an average stochiometric composition (CxHyOz) of the biochar rather than pure carbon as previously.
Other missing compounds (e.g. furfural, 5-HMF and levoglucosan) were identified and will be included in the databases if good thermodynamic data can be found/extrapolated.

PRETREATMENT AND FRACTIONATION

The main research activities in 2017 for work package 2.4 - Pretreatment and fractionation have been focusing on implementation of existing pre-treatment technologies and the development of a new organosolv based lignin separation process.

Work related to existing pre-treatment technologies (e.g. hot water extraction, sulphite pre-treatment) have made it possible to effectively separate the constituents of a feedstock from Norway Spruce. Trials with hemicellulose pre-extraction have demonstrated the suitability of producing a substrate for efficient down-stream processing. Pre-treatment trials using existing technologies have made RISE PFI able to provide the other partners in the centre material for further research purposes.

The development of a new pre-treatment technology for efficient lignin isolation has been another focus. Short pre-treatment times combined with liquor displacement will ensure low carbohydrate degradation, low formation of inhibitors and effective removal of lignin from the biomass. Initial organosolv experiments using conventional batch reactors were done successfully. However, re-deposition of lignin on the biomass after pre-treatment is one of the main challenges arising from such pre-treatments (see Figure 1 below), a challenge we aim to overcome in 2018 by the use of the new displacement reactor system established as a part of the NorBioLab project.



Scanning Electron Microscope image depicting droplets of lignin deposited on a Norway spruce fibre after organosolv pre-treatment in a conventional batch reactor (lignin shaded red).

ENZYMATIC SACCHARIFICATION

The work will build on major breakthroughs made at NMBU in 2016 and 2017 (Bissaro et al., Nature Chem Biol, 2017, 13:1123-1128), which reveal new avenues towards more efficient enzymatic saccharification processes. These recent findings show how the activity of one of the key enzymes involved in biomass processing, the lytic polysaccharide monooxygenases, or LPMOs, can be controlled and boosted. While the emerging novel enzymatic scenarios are highly promising and may eventually lead to major improvements, they require a new "mind-set" when it comes to designing both laboratory experiments and industrial processes. This transition takes time and has been the focus of the work in 2017. Notably, work in this WP started not before autumn 2017, whereas an important add-on project funded by the Energix programme, "Enzymes4Fuels" started in January 2018 (Post-doc Tine R Tuveng & PhD student Heidi Østby). Key activities in Bio4Fuels in 2017 were:

- Hiring a PhD student, Line Degn Hansen.
- Selecting and purchasing novel laboratory- and small pilot-scale processing equipment needed to implement to most recent insights in enzyme functionality and process optimization.
- Collection of relevant raw materials from industrial partners (Borregaard, St1, Novoyzmes) for laboratory-scale process optimization studies. These raw materials will be supplemented with materials produced "in-house" by NMBU and PFI.
- Regular discussions with partners Borregaard and Novozymes about their own ongoing saccharification studies; exchange of knowledge and identification of prioritized further joint studies.
- Identification of key enzyme samples supplied by Novozymes early 2018 for process optimization studies with the various industrially relevant raw materials listed above.

Process optimization studies will be the core activity in WP2.5 in 2018 and these studies will be aligned with the interests of the involved industrial partners. Initially we will use more or less standard enzyme cocktails, but eventually, this work will also lead to identification of limiting enzyme activities, which then may be compensated.

SP3: Secondary Conversion and Upgrading
- Energy efficiency and high yields - Fermentation for novel fuels
SP Leader: Vincent Eijsink …

WP3.1	Gas Conditioning (Edd Blekken, NTNU)
WP3.2	Thermochemical Upgrading (R. Tschentscher, SINTEF MK)
WP3.3	Chemo-catalytic conversion (D. Chen, NTNU)
WP3.4	Fermentation (A. Wentzel, SINTEF MK)
WP3.5	Anaerobic digestion and gas upgrading (T. Briseid, NIBIO)

BACKGROUND AND APPROACHES

The subproject on secondary conversion is targeted to upgrading intermediates from the primary conversion including the potential of production direct from biomass. With respect to thermochemical routes; a main hurdle for the gasification is the thermal efficiency of the overall process, making gas cleaning and conditioning an important factor to investigate. This includes, removing volatile inorganic species as well as tars and lighter hydrocarbons that are formed in the processing of the biomass. For the liquefaction routes, the focus is towards the challenges in the development of suitable catalysts for upgrading of bio-oils to fuels, aiming to selectively remove oxygen while keeping the hydrogen consumption low. The upgraded oils and fuel blends will be characterized with regards to their suitability for further conversion to fuels and basic chemicals.

Additional options of catalytic chemical conversion are also being investigated. This will focus on conversion of the targeted components of biomass feedstock, such as separated carbohydrates, cellulose, hemicellulose and lignin to valuable products. This will be based on approaches by integrating advanced synthesis, characterization of catalysts and kinetic studies.

With respect to biochemical approaches, fermentation will focus on processes for production of higher alcohols and esters, and the production of oils. This will include development of high productivity, robust microorganisms and process intensification by integration of fermentation processes and in-situ product removal. Anaerobic digestion and gas upgrading, will provide pathways for converting residue fractions from lignocellulosic liquid and solid waste streams to methane as a biofuel. In addition to more efficient production, alternative routes to upgrading to hydrogen will be investigated

THERMOCHEMICAL UPGRADING OF BIO OILS

Based on meetings with the stakeholders Statkraft and Johnson Matthey several points have been agreed. As reactor concept slurry reactors have been chosen operating in batch and CSTR mode, as they provide a good heat control, catalyst can be added and replaced and issues of maldistribution are absent. With regard to feedstock the focus will be on firewood, namely spruce, pine and birch. For liquid phase upgrading slurry reactors and catalyst powders will be used. The following types of commercial catalysts have been selected: 1. NiMo sulphide catalysts; 2. Supported Nickel catalysts; and 3. Supported noble metal catalysts. Catalyst samples in the scale of several grams will be sent to SINTEF and tested using batch autoclaves. Literature review have been focussed on additional catalyst formulations.

Experimental work has been limited to the production and analysis of crude oils. Pyrolysis oils from pine and spruce stem wood and bark have been produced. Both non-catalytic pyrolysis and ex-situ vapor upgrading have been applied. The oils have been sent to the analysis using the following techniques, which will give a detailed picture of the oil composition with regard to compounds, functional groups and bonds to heteroatoms:

Preparation of ex-situ catalytic pyrolysis test.
Joanna Pierchala, Researcher at Sintef Oslo.

- Liquid state NMR for quantitative analysis of functional groups
- GCxGC-MS/FID for quantification of the light and medium oil fraction
- High resolution FT-ICR-MS for quantification of the medium and heavy oil fraction
- ICP-MS-MS for analysis of heteroatoms, and traces of inorganics

Currently, within NorBioLab II a lab-scale autoclave is being built allowing to operate in batch and CSTR mode and to extend the regime of upgrading conditions to higher temperatures and pressures. In addition a high-throughput unit is being modified to allow feeding of viscous bio oils. A major challenge is to obtain samples of representative HTL crude oils in sufficient quantities, while Sintef Energy is upgrading their HTL rig. Institutes outside of Norway owning pilot scale HTL equipment have been contacted.

FERMENTATION

In 2017, work in Bio4Fuels work package **WP3.4-Fermentation** has focused on identifying sources and developing strategies to identify and characterize promising new biorefinery strains from both Bacteria and Fungi, respectively by SINTEF and NMBU. A literature study was performed by NMBU to identify potential oleaginous fungi for screening. As a result, one hundred Mucoromycota strains, belonging to three families and eight genera, i.e., *Mucor*, *Amylomyces*, *Rhizopus*, *Umbelopsis*, *Absidia*, *Cunninghamella*, *Lichtheimia* and *Mortierella* were selected for the screening study. A high-throughput microtiter plate system (MTPS) based on deep-well Duetz microtiter plates combined with Fourier transform infrared (FTIR) spectroscopy was used for the extensive high-throughput screening of the selected oleaginous filamentous fungi with respect to their lipid production capabilities. The screening of 100 oleaginous filamentous fungi grown on the standard glucose-based medium suitable for lipid accumulation was performed by using Fourier transform infrared (FTIR) spectroscopy and GC-FID chromatography. The FTIR spectroscopy was used to evaluate total biochemical composition of the biomass while GC-FID was used to obtain detailed information on the lipid profile of the fungal biomass. As a result, ten high lipid producers were identified

with the total lipid content up to 47%. Activities at SINTEF in WP3.4 started late in 2017 with specific planning of approaches to identify and characterize new bacterial strains for biorefining and bio-based product formation. Strain sources included existing comprehensive collections of isolates from previous projects at SINTEF, harboring thermophilic strains from locations worldwide, new enrichments from suitable natural or industrial samples, but also strains obtained or obtainable from strain collection with prospects for becoming important future platforms for the production of advanced biofuels, bio-based commodity and fine chemicals, as well as building blocks for bio-based polymers and materials from lignocellulosic or other biomass. Deriving thermophilic strains isolated from anaerobic digestions by NIBIO in WP3.5 has also been identified as a potentially valuable source of new thermophilic strains. Work in 2018 will be dedicated to putting the ambitious plans for new strain isolation and selection, and in-depth characterization and evaluation in action, targeting identification of the most promising microbial platforms for further development in Bio4Fuels.

ANAEROBIC DIGESTION AND GAS UPGRADING

The key research tasks in 2017 have been:

- Addition of H2 to biogas digesters to biologically upgrade biogas to CH4
- Link microbial communities and their dynamics to process performance and, eventually, control such communities
- Direct conversion of biogas to H2 and bio- CO2 using Sorption-Enhanced Reforming technology (SER): Process intensification and heat integration

Addition of H2 to biogas digesters to biologically upgrade biogas to CH4

Anaerobic digestion of biomass produces biogas with 50 to 70% methane (CH4) and 30 to 50% carbon dioxide (CO2). Upgraded biogas, containing more than 90% CH4, has higher heating value and can be used as a vehicle fuel or injection into natural gas grids. This study presents a biological method for upgrading biogas through addition of hydrogen (H2) into mesophilic lab-scale reactors fed with glucose. Hydrogenotrophic methanogens, which exist in anaerobic reactors, use H2 as reducing agent for conversion of CO2 into CH4. Results showed that addition of H2 based on 4:1 H2:CO2 ratio improved overall CH4 yield and increased CH4 content in the biogas from 67% to 94%. The CO2 level was reduced from 33% to 3% and the average residual H2 was around 3%. Approximately 97% of H2 added into the reactors were consumed. These findings illustrate the adaptability of methanogen population to H2 injection and positive implementation of biological methanation.

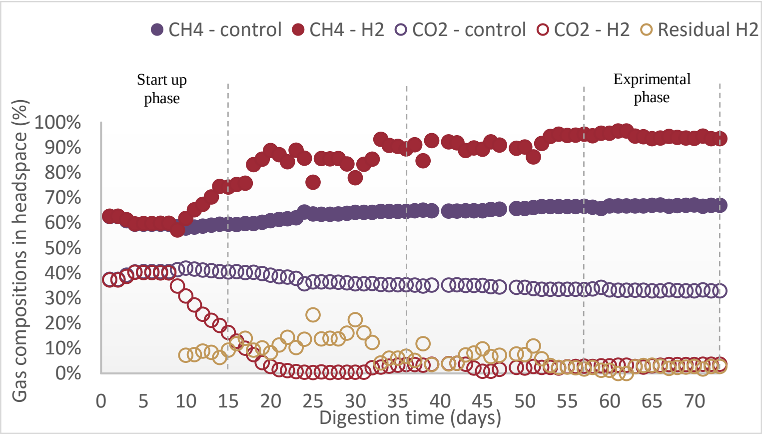


Figure 1 - Gas compositions in the headspace of control and H_2-supplemented reactor (C – control reactor, H_2 – H_2 supplemented reactor).

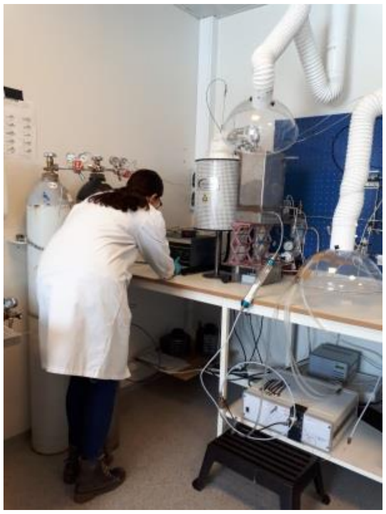
Radziah Wahid, Post. Doc. Student

Link microbial communities and their dynamics to process performance and, eventually, control such communities

The paper: Kine Svensson, Lisa Paruch, John Christian Gaby and Roar Linjordet: "Feeding Frequency influences methane yield and microbial community in anaerobic digesters treating food waste" has been worked out and submitted.

Direct conversion of biogas to H2 and bio- CO2 using Sorption-Enhanced Reforming technology (SER): Process intensification and heat integration

In the framework of WP3.5, IFE has focused its research on the development of the Sorption-Enhanced Reforming process (SER) for production of hydrogen from biogas or biomethane with integrated CO2 separation. SER is a modified reforming process and relies on the addition of a high temperature solid CO2 sorbent to the reforming catalyst for simultaneous CO2 separation. The modification brings process intensification and, if applied to biogas, allows to skip the upgrading step and to produce a valuable bio-CO2 rich stream. The produced renewable hydrogen can be used in bio-refinery processes or as a transportation fuel.



Laboratory scale Sorption-Enhanced Reforming (SER) FBR set-up at IFE

Small pilot scale Sorption-Enhanced Reforming (SER) FBR rig at IFE

The experimental work carried out includes SER tests in laboratory scale and small pilot scale fluidized bed reactors using biomethane and synthetic biogas containing methane and CO2 in different concentrations. Natural calcined dolomite and a novel synthetic sorbent developed by IFE, both calcium oxide based, have been used. Preliminary results show a very satisfactory SER performance with hydrogen and CO2 concentrations in the range of 92-98 vol% and 1-2 vol%, dry basis, respectively. The work will also focus on the optimisation of SER operating conditions, and on long-term material performance tests. In addition, IFE is planning, in collaboration with Oslo EGE, to run laboratory scale SER tests with real biogas at the Nes Romerike biogas production site.

SP4: Process design and End Use
- Identify most promising process configurations - Efficient and clean end use
SP Leader: Bernd Wittgens

WP4.1	Modelling Tool for Biorefineries (H. Preisig, NTNU)
WP4.2	Techno-Economic Eval. / Scale of Economy (B. Wittgens, SINTEF MK)
WP4.3	Preparing for Piloting and Up-scaling (K. Jens, HSN)
WP4.4	Product quality and End Use (T. Løvås, NTNU)

BACKGROUND AND APPROACHES

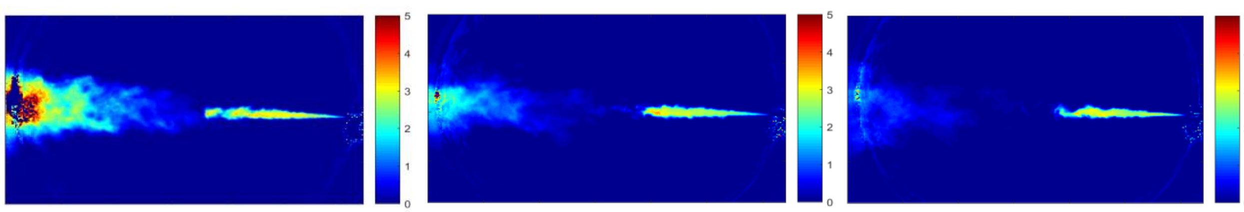
The viability of processes and the quality of the products will be addressed using high level modelling tools for Biorefineries with an approach that requires biology, process technology, control and material properties to generate the predictive capabilities of the process models required for design 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.

PRODUCT QUALITY AND END USE

Combustion in compression-ignition (CI) engines has been a subject to research for almost a century. However, issues relating to particulate matter and NOx emissions have not yet been resolved, resulting in advanced after-treatment systems being used in order to meet stringent emissions requirements set by the authorities. In recent years, there has been a large focus on alternative fuels derived from vegetable oils and solid biomass through processes like transesterification of bio-oils, hydro-treatment of bio-oils and gasification of solid biomass (e.g. Fischer-Tropsch fuels). The different fuels resulting from these processes have different chemical and physical properties which will affect the combustion and emissions characteristics in an engine. Developing an understanding of the in-cylinder combustion processes like soot formation and oxidation are still hot topics of research, since the underlying physical phenomena are not fully understood. Numerical simulations provide insight to complex processes that are hard to capture in real experiments, however, the models for predicting soot formation and oxidation in the engine still require validation from experiments. 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. In the Motorlab at NTNU, topics on soot and NOx are studied in detail in an optically accessible compression ignition chamber (OACIC). In the figure shown, optical measurements of in-flame soot concentrations with high accuracy are presented for three different fuels combusting under the same conditions in the OACIC, i.e. diesel, fatty acid methyl ester (FAME) and hydrogenated vegetable oil (HVO). In addition to detailed in-flame soot concentrations, particulate matter and gaseous exhaust emissions are studied. The aim is to characterize the combustion and emission properties of alternative fuels and find suitable models for understanding the complex combustion processes in detail.



Optical density of soot for Diesel, FAME and HVO combusting under the same conditions.

INTERNATIONAL COOPERATION

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

INTERNATIONAL 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)	NL	Biomass to liquid (btl) pyrolysis
Johnson Matthey (UK)	UK	Chemical and catalytic processing of bio-feedstocks
Novozymes (DK)	DK	Enzymes for forest based biorefineries
Pervatech (NL)	NL	Membrane and separation systems for organic substrates
Haldor Topsøe (DK)	DK	Chemical/catalytic processes for several bio feedstocks
Steeper ENERGY (DK)	DK	Hydrothermal liquefaction
Lund Combustion Engineering as (SE)	SE	Consultancy and software on combustion in motors
Preem (SE)	SE	Biofuels production and distribution in Sweden/Norway
Volvo Group Trucks Technology (SE)	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 together in the Centre, most of the research partners have an extensive network of international contacts and collaboration. These include coordinating input to Mission Innovation, 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

North Carolina University (USA)

Sandia National Laboratories (USA)

Pacific Norwest National La – PNNL (USA)

f3 fossil free fuels (SE)

DTU Chemical Engineering (DK)

University of York (UK)

Abendgoa Research (ES)

Gjennom samarbeid med forskningsmiljøene PNNL og Sandia i USA, har senteret etablert en dialog med miljøer som er involvert i det nasjonale "Co-optima" prosjektet, finansiert av DoE i USA. Senterets partnere, spesielt industri og andre stakeholders, er invitert til å delta på de faste, månedlige "Stakeholder" Web-møtene.

EU RESEARCH PROGRAMS

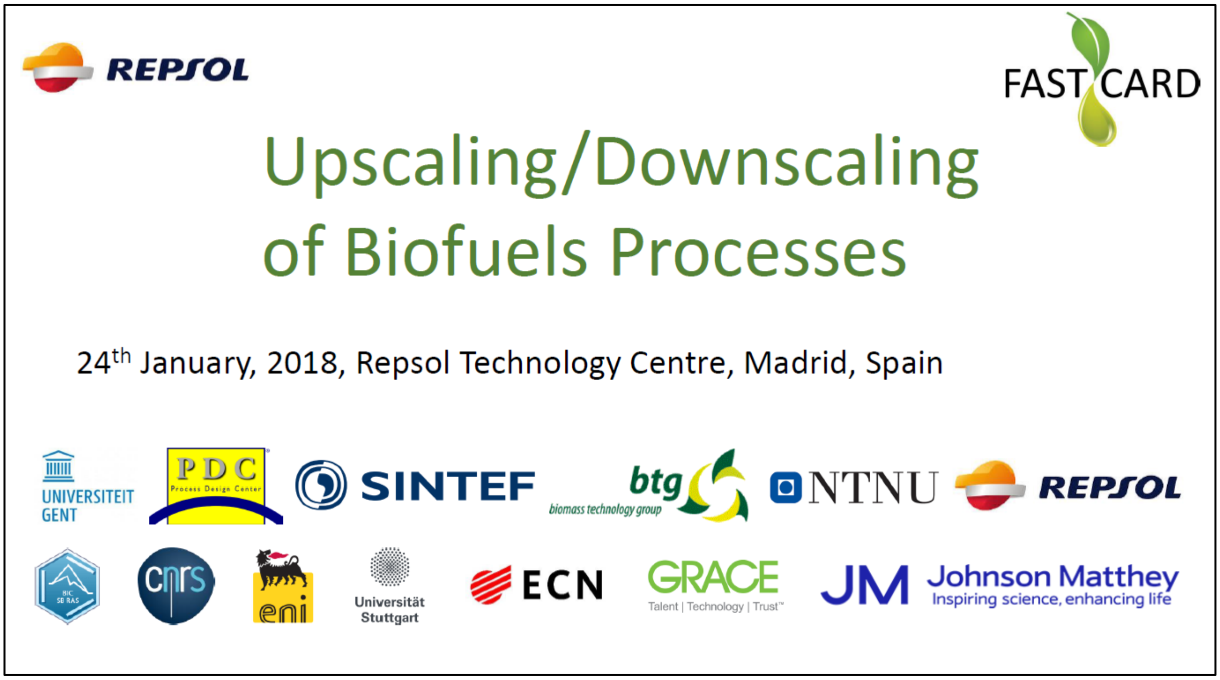
Many of the research partners involved in the Centre have established a significant porteforlio of European projects, both from FP7 and H2020. As shown in the table below, Bio4Fuels partners were involved in at least 13 active EU projects, with at least 9 projects within H2020. As shown in the table, the projects cover different stages of the Bio4Fuels value chain towards biofuels production, with a total project volume of nearly 500 MNOK. In addition to existing network of projects, the partners and management are actively involved in establishing new initiatives to the relevant calls in the NMBP and BBI programs. During 2017, a new project 4REREFINERY was successfully obtained, with SINTEF as coordinator (http://www.sintef.no/projectweb/4refinery/). This project focusses on the pyrolysis and Hydrothermal liquefaction value chains with respect to different scenarios for integration into existing (bio)refineries.

Overview of active EU research projects with involvement of Bio4Fuels research partners

Type	Name	Project owner	Financed by	Total budget [mNOK]	Bio4Fuels Platform addressed
Project	AMBITION	SINTEF	H2020-ECRIA	22,5	Biochem./Thermochem
Project	BioRaff	PFI	H2020/Interreg	8,1	Biochem./Thermochem
Project	ERC starting grant to P. Pope	NMBU	ERC	14	Biochemical - Biogas
Project	Prowood	INBIOTEC-	ERA-IB; RCN and others	17,5	Biochemical platform
Project	Thermofactories	SINTEF	ERA-MBT; RCN + abroad	22,3	Biochemical platform
Project	ERIFORE	VTT	H2020	50	Biorefinery
Project	FASTCARD	SINTEF	EU FP7	100	Thermochemical
Project	4Refinery	SINTEF	EU - H2020	60	Thermochemical, chemical
Project	DAFIA	Aimplas (Spain)	EU - H2020	58	Biochemical platform
Project	BRISKII	KTH	H2020-INFRAIA	86	Bio-, thermochemical
Project	BESTER	SINTEF	ERA-CoBioTech, H2020, RCN, and others	27,7	Biochemical platform
Project	C1pro	NTNU	ERA-CoBioTech, H2020, RCN, and others	17,2	Biochemical platform
Project	MetaFluidics	UAM (Spain)	EU - H2020	86	Biochemical platform
ITN	Oxytrain	Un Groningen	Marie Curie	29	Biochemical
	The Bioeconomy Region	Akershus energi + Region Värmland	H2020/Interreg	35	End use

Arrangements

As part of its international activities, Bio4Fuels and its partners plan to take the opportunity to contribute to the arrangement of relevant workshops, seminars and conferences. An example of this was through SINTEF's coordination of the FASTCARD FP7 EU project within Bio4Fuels. As shown below, SINTEF together with the Spanish oil company REPSOL, arranged a workshop on the key challenges of "Upscaling/Downscaling" of processes for the production of Biofuels. This is seen as a major barrier for the commercialisation of biofuel production and the workshop shared the experiences from several companies.



Mobility

Prof Svein Jarle Horn, deputy leader of Bio4Fuels centre has a 12 months sabbatical at the University of California, San Diego (UCSD). The research group «FF21» at UCSD is one of the leading algae research centres in the world, where it is possible to produce algae crop at a scale of up to 10000 liter. Prof Horn will be working with microalgae at UCSD, organisms that have the potential for use in food and animal feed, production of enzymes, oils and chemicals. During his sabbatical, Prof Horn will characterise LPMO-enzymes in microalgae and study the different applications of these. Farming of microalgae for production of biomass and industrial enzymes is also quite central.

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 Martina Cazzolaro (WP3.3), NTNU

This PhD project is a part of the work package *Catalysis for biomass conversion to chemicals* (WP3.3). Lignocellulosic biomass is not only abundant, inexpensive and renewable, but it also possess many desired chemical linkages, providing an excellent starting point for the production of fuels and chemicals. Pyrolysis is a thermochemical process assumed to become an avenue to petroleum-type products producing charcoal, condensable organic liquids (bio-oil) and non-condensable gases. Catalytic hydrodeoxygenation (HDO) is proposed as a strategy to enhance bio-oil properties incrementing the hydrogen-carbon ratio. The main challenge of HDO processes is the development of a highly active and selective catalyst, which can remove a high degree of oxygen with minimum hydrogen consumption. This project aims to develop a highly active, selective and stable catalyst towards the hydrogenation of hydroxyacetone to 1,2-propanediol. Hydroxyacetone is one of the many species contained in bio-oil and will be used as model species contained in the bio-oil. Martina Cazzolaro will prepare, characterize and the test the catalyst.

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 Nordic countries have abundant roundwood and harvest residual resources, which may be used as a raw material for producing second-generation biofuels. For this reason, second-generation biofuel may become important in the Nordic countries. Yet, technological development remains before second-generation biofuel become cost competitive to fossil fuel. Many parameters have an impact on the cost of producing biofuel. The production cost has to be equal or lower than the selling price for fossil fuel for biofuel to become cost competitive with fossil fuel. This is a huge challenge. The price development for fossil fuel and energy prices in general will be important parameters for the production of biofuel. Important parameters on the production cost are the prices of roundwood and forest residuals. Thus, theses prices are important for biofuel profitability and viability. The price development for roundwood and forest residuals will in general follow the price development for the rest of the forest sector. An increased production of biofuel may change the production of other forest products. For this reason, biofuel production in the Nordic countries may lead to increased uncertainty in the forest sector. The greatest uncertainty regarding biofuel production from biomass is that the technology has not yet been tested in full-scale plants, and hence, production costs are uncertain.

The aim of my PhD-project is to use economic models to find the most optimal technologies for production of biofuel from forest biomass in the Nordic regions and to assess the benefits of biofuel production against other bioenergy options such as heat and electricity. This may include further development of quantitative economic models for the forest and bioenergy sector as well as the larger energy system.

An important part of my PhD-project is to integrate a Nordic energy sector model (Balmorel), with a Nordic forest sector model (NFSM). This will give a model that include the entire Nordic energy sector, with electric power, heat and biofuel. The model will be capable to find connections between the heat and power sector, and harvest levels of biomass for production of biofuel.

PhD Student Simona Dzurendova (WP3.4), SINTEF/NMBU

This PhD project is a part of the work package *Fermentation* (WP3.4). In recent years, it has been shown that lignocellulose materials can potentially be used to produce Single Cell Oils by microbial fermentation. Single Cell Oils are rich in highly valuable polyunsaturated fatty acids (PUFAs) with a market value of up to 150 US $ per kg. Single Cell Oil PUFAs contain many essential fatty acids (EFAs), such as omega-3 and omega-6 fatty acids. EPAs are fatty acids that the human body requires, but does not produce itself. EFAs are abundant in nuts, seeds, fish, algae, leafy greens, and krill. The traditional source of PUFA in human nutrition is marine fish. Marine sources are limited due to short fishing seasons, geographical locations and declining fishing populations. Certain filamentous fungi referred to as oleaginous species, have the ability to accumulate up to 85% (w/w) lipid as a storage compound of the biomass using rest material as substrates, including whey and fat from wastewater. Fungi grow very fast, they do not need

CO_2 or sunlight for their growth, and they double their biomass within short time, thus representing a potentially very effective cell factory for the production of PUFA. In addition, fungi can utilize a broad spectrum of lignocellulose materials for growth, such as cheap carbon and energy sources.

During the last years, we have been working on the screening of oleaginous fungi for production of Single Cell Oils by using different cheap substrates (food and agricultural rest materials). Currently, we identified several promising oleaginous filamentous fungi (*Mucor circinelloides*, *Mortierella alpina* etc) producing high amounts of high-value lipids and which also can accumulate high-value polysaccharides (chitin, chitosan, glucans) and polyphosphate. Lipids are accumulated in lipid bodies while polysaccharides and polyphosphate are in the cell wall. We observed that the high lipid accumulation associated with the cell wall changes - increase in cell wall polyphosphate content as well as possible change in chitin and chitosan content. These changes have not been studied earlier. In order to obtain the highest possible value out of the oleaginous fungi biomass there is a need to study how the composition and the yield of cell wall components is changing versus composition and yield of lipids at different conditions:

1. Different lignocellulose sugars;
2. Different growth conditions (temperature, time);
3. Different C/N ratios;
4. Different nitrogen sources;

Further, there is a need to investigate the effect of inhibitors present in lignocellulose hydrolysates on the lipid production and cell wall formation.

The main tasks:

- Develop FTIR and Raman calibration models of the cell wall components for oleaginous fungi. The following cell wall components will be in focus: polyphosphate, glucans, chitin and chitosan.
- Investigate effect of phosphorus on the lipid accumulation and cell wall composition.
- Investigate the consumption rate and effect on lipid and cell wall productivity and profile when different lignocellulose relevant sugars are used as substrates.
- Investigate the effect of inhibitors from lignocellulose hydrolysates on the production of lipids and cell wall components.

PhD Student Vaibhav Sahu (WP1.2), NTNU

This PhD project is a part of the work package *Bio-Resources, Environment, Climate* (WP1.2). The first year will consist of an extensive review of the literature, examining biodiesel, 2nd generation fuels and chemical kinetic numerical techniques applied to internal combustion engine study. I will also spend this period learning how to use the software I intend to use during the research project. This will include (not exclusively) LOGEsoft, LOGEengine and Fluent. LOGEsoft and LOGEengine are a stoichiometric reactor model (SRM) currently being used and developed in the ComKin group at NTNU. I will start to use these tools to build models of the engine and optical combustion chamber, currently in use in the group. I will also work with the group to collect experimental data from the engine and chamber to fine tune and validate the models. **Milestone 1** will be to have a basic model of the optical combustion chamber using Diesel fuel and suitable surrogate based in either LOGEsoft or LOGEengine. Deliverables at this point will be attendance to an international conference with presentation and abstract delivery.

The second year of my PhD will focus on extending the model, with validation to include the use of a number of different low carbon biofuels. This will involve the implementation of suitable kinetic mechanisms for a number of possible biodiesel surrogates. Experimental data collection from the engine and the optical combustion chamber using these surrogates and real biofuels will also be carried out. **Milestone 2** will be the implementation of a functioning model for a range of low carbon biofuels and surrogates with validation data. Deliverable 1 at this point will be a paper to a peer-reviewed journal detailing the model and experimental data.

The third year of my PhD will be the fine tuning of the model to expand the simulation results to include increased details concerning emissions, focusing on soot, PM and NO_x. Specifically, the model and mechanisms used should be able to be adapt to changing biofuel and accurately simulate soot and NO_x emissions allowing fuel developers to tailor the fuel produced with emissions reduction in mind. **Milestone 3** will be the implementation of a working model in the SRM that accepts a range of biofuels as input (using suitable surrogate) and provides simulation results of soot and NOx emissions, along with validating data. Deliverable 2 will consist of a peer-reviewed article outlining the model used, along with validating data using emissions measurements from the optical combustion chamber and the instrumented engine. Deliverable 3 will consist of a peer-reviewed article detailing soot modelling based upon the SRM. Completion and submission of the thesis is planned to be done by autumn 2020.

Courses given by Bio4Fuels Researchers

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

Courses at NTNU

Energi- og prosessteknikk, fordypningsprosjekt, 15 sp
Termodynamikk 1, 7,5 sp
Termisk energi, fordypningsprosjekt, 15 sp
Industriell økologi, 15 sp
Klimavern, 7,5 sp
Nanoteknologi, fordypningsprosjekt, 15 sp
Katalyse og petrokjemi, fordypningsemne, 7,5 sp
Kjemisk prosessteknologi, fordypningsprosjekt, 7,5 sp

Courses at NMBU

Bioenergi, 10 sp
Anvendt biokatalyse og bioraffinering, 5 sp

PERSONNEL AND RECRUITMENT

PERSONNEL

Name leader	institution	Main research area
Rasmus Astrup (WP 1.1)	**NIBIO**	Resources and Ecosystem processes
Francesco Cherubini (WP 1.2)	**NTNU**	Bio-Resources, Environment, Climate
Torjus Bolkesjø (WP1.3)	**NMBU**	Energy, Fuels and Economics
Per Carlsson (WP 2.1)	**SINTEF**	Gasification
Kai Toven (WP 2.2)	**RISE PFI**	Pyrolysis
Judit Sandquist (WP 2.3)	**NTNU**	Hydrothermal Liquefaction
Øyvind Eriksen (WP 2.4)	**RISE PFI**	Pretreatment and Fractionation
Aniko Varnai (WP 2.5)	**NMBU**	Enzymatic Saccharification
Svein Jarle Horn (WP 2.5)	**NMBU**	Enzymatic Saccharification
Edd Blekkan (WP 3.1)	**NTNU**	Gas Conditioning
Roman Tschentscher (WP 3.2)	**SINTEF**	Thermochemical upgrading of bio oils
De Chen (WP 3.3)	**NTNU**	Chemo-catalytic conversion
Alexander Wentzel (WP 3.4)	**SINTEF**	Fermentation
Tormod Briseid (WP 3.5)	**NIBIO**	Anaerobic digestion and gas upgrading
Heinz Preisig (WP 4.1)	**NTNU**	Modelling Tool for Biorefineries
Bernd Wittgens (WP 4.2)	**SINTEF**	Techno-Economic Evaluation and Scale of Economy
Klaus Jens (WP 4.3)	**HSN**	Preparing for piloting and up-scale
Terese Løvås (WP 4.4)	**NTNU**	Product quality and End Use
Francesco Cherubini (SP1)	**NTNU**	Bio-resource, Environment and Climate
Berta Güell (SP2)	**SINTEF**	Primary Biomass Conversion
Vincent Eijsink (SP3)	**NMBU**	Secondary Conversion and Upgrading
Bernd Wittgens (SP4)	**SINTEF**	Process design and End Use
Duncan Apkoriaye	**SINTEF**	Centre Leader
Torjus Bolkesjø	**NMBU**	Vice Centre Leader
Odd Jarle Skjelhaugen	**NMBU**	Project Leader
Janne Beate Utåker	**NMBU**	Administrator

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
Eirik Ogner Jåstad	Norwegian	01.02.2017 – 31.12.2020	M	Models for Economic Assessments of Second Generation Biofuel Production
Martina Cazzolaro	Italian	01.08.2017 – 31.07.2020	F	Catalytic biomass conversion
Vaibhav Sahu	Indian	01.03.2017 – 30.04.2020	M	Combustion and emission characteristics of low carbon biofuels
Simona Dzurendova	Slovakia	14.09.2017 – 13.09.2020	F	Bioconversion of lignocellulose materials into lipid rich fungal biomass.

Postdoctoral Researchers with financial support from Bio4Fuels budget

Name	Nationality	Duration	Gender	Topic
Radziah Wahid	Malaysia	10 months 2017	M	Enzymatic Saccharification
Otávio Cavalett	Italian		M	LCA of biofuels in Norway

Other researchers

Name	Institution	Duration	WP
Gerdt Müller	NMBU	8 months 2017	2.5
Boris Zimmermann	NMBU	01.02.2017 – 31.12.2023	3.4
Per Kristian Rørstad	NIBIO	01.01.2017 – 31.12.2020	1.3
Volha Shapaval	NMBU	01.02.2017 – 31.12.2023	3.4
Achim Kohler	NMBU	01.02.2017 – 31.12.2023	3.4
Jia Yang	NTNU		3.3
Liang Wang	SINTEF Energy		3.2
Michaël Becidan	SINTEF Energy		3.2
Øyvind Skreiberg	SINTEF Energy		3.2
David Emberson	NTNU		
Roar Linjordet	NIBIO		1.3
Hege Bergheim	NBIO		1.3
Julien Meyer	IFE		

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-treatment, post-treatment and recirculation as strategy for improved biogas-yield in anaerobic digestion of food waste
Jianyu Ma	NRC "Chemical Looping Desulfurization"	Chinese	28.09.17-27.09.2020	M	Hot gas cleaning using solid sorbents, sorbent development, reactor development, kinetics and modelling.

MEDIA, PUBLICATIONS AND DISSEMINATION

COMMUNICATION AND OUTREACH

One important role of Bio4Fuels has been to contribute to the discussion and debate with respect to the role of biofuels in the energy mix for Norway. This has often been a theme that has been taken up in the media, particularly during 2017. With respect to this scientists and stakeholders from Bio4Fuels have on certain occasions aimed to provide fact-based information in various forms of the media. Below is an compilation of media articles that were made in relation to a debate in the media regarding the prospects of achieving the Norway's 20% target for 2020.

The articles are identified according to those written by scientists (*) and stakeholders (**) from Bio4fuels.

**	Dagbladet 10. mars Nett Anne Marit Melbye og Marius Holm, Zero: At biodrivstoff fører til økte utslipp er en feilaktig konklusjon
**	DN 16. mars Trykk Innlegg Erland Løkken, Bergene Holm as: Kan dekke norsk biodrivstoffbehov
*	DN 17. mars Trykk Debatt Ryan Bright og Rasmus Astrup, NIBIO: Deler av skogen kan gå til drivstoff 'Restmaterialene kan utgjøre over 60 % av biomassen tilgjengelig etter hogst'
*	Aftenposten 22. mars Trykk Debatt Thomas Hansen, St1 Norge: Produksjon av biodrivstoff må være bærekraftig
*	Aftenposten 23. mars Nett Viten Svein Horn, NMBU, Rasmus Astrup, NIBIO, Bernd Wittgens og Duncan Akporiaye, SINTEF Nærmere en løsning for biodrivstoff
*	Aftenposten 27. mars Nett Debatt Per Kr. Rørstad, Torjus F. Bolkesjø, Hans Fr. Hoen, Birger Solberg, Erik Trømborg, NMBU Trenger vi drivstoff – og må det være norsk?
*	Dagbladet 4. april Nett Meninger Duncan Akporiaye, Svein Jarle Horn, Bernd Wittgens, Bio4Fuels: Derfor forsker vi for morgendagens biodrivstoff
**	Skog (Tidsskriftet til Norges Skogeierforbund) 10.april Egne ansatte Erik Lahnstein og Erland Lunder: Feil om biodrivstoff

PUBLICATIONS

Type	Author(s)	Title	Journal/book/compendium/place	Pages	Issue/volume/year	ISSN/ISBN
Article	Birgen, Cansu; Markussen, Sidsel; Preisig, Heinz A.; Wittgens, Bernd; Wentzel, Alexander; Sarkar, Ujjaini; Saha, Sudeshna; Baksi, Sibashish	Understanding Effect of Sugar Composition on Growth Kinetics: Fermentation of Glucose and Xylose by Clostridium Acetobutylicum ATCC 824	25th European biomass conference and exhibition proceedings	1042-1046	2017	ISBN 978-88-89407-17-2
Article	Birgen, Cansu; Preisig, Heinz A.; Wentzel, Alexander; Markussen, Sidsel; Wittgens, Bernd	Attainable Region for Biobutanol Production	Computer-aided chemical engineering	2893-2898	40/2017	ISSN 1570-7946
Article	Bissaro, Bastien; Kjendseth Røhr, Åsmund; Müller, Gerdt; Chylenski, Piotr; Morten, Skaugen; Forsberg, Zarah; Horn, Svein Jarle; Vaaje-Kolstad, Gustav; Eijsink, Vincent	Oxidative cleavage of polysaccharides by monocopper enzymes depends on H2O2	Nature Chemical Biology	1123-1128	13/2017	ISSN 1552-4450
Article	Dayanand Chandrahas Kalyani, T Fakin, Svein Jarle Horn, Roman Tschentscher	Valorisation of woody biomass by combining enzymatic saccharification and pyrolysis	Green Chemistry	3302-3312	19/2017	1463-9262
Article	Gonzalo del Alamo Serrano, Rajesh Shivanahalli Kempegowda, Øyvind Skreiberg, Roger Antoine Khalil	Decentralized Production of Fischer-Tropsch Biocrude via Coprocessing of Woody Biomass and Wet Organic Waste in Entrained Flow Gasification.	Energy & Fuels	6089-6108	31/2017	0887-0624
Article	Jåstad, Eirik Ogner; Torheim, Turid K Gjerstad; Villeneuve, Kathleen; Kvaal, Knut; Hole, Eli Olaug; Sagstuen, Einar; Malinen, Eirik; Futsæther, Cecilia Marie	In Quest of the Alanine R3 Radical: Multivariate EPR Spectral Analyses of X?Irradiated Alanine in the Solid State	Journal of Physical Chemistry A	7139-7147	38/121/2017	ISSN 1089-5639
Article	Kalyani, Dayanand Chandrahas; Fakin, T; Horn, Svein Jarle; Tschentscher, Roman	Valorisation of woody biomass by combining enzymatic saccharification and pyrolysis	Green Chemistry	3302-3312	14/19/2017	ISSN 1463-9262
Article	Lausselet, Carine;	Norwegian	Resources, Conservation and Recycling	50-61	126/2017	ISSN 0921-3449

	Cherubini, Francesco; Oreggioni, Gabriel David; del Alamo Serrano, Gonzalo; Becidan, Michael; Hu, Xiangping; Rørstad, Per Kr.; Strømman, Anders Hammer	Waste-to-Energy: Climate change, circular economy and carbon capture and storage				
Article	Liang Wang, Eszter Barta-Rajnai, Øyvind Skreiberg, Roger Antoine Khalil, Zsuzsanna Czégény, Emma Jakab, Zsolt Barta, Morten Grønli	Effect of torrefaction on physiochemical characteristics and grindability of stem wood, stump and bark	Applied Energy	null-null	2017	0306-2619
Article	Margareth Øverland, Svein Jarle Horn, Vincentius Gerardus Henricus Eijsink	Kampen om det grønne karbonet	Dagens næringsliv	36-null	2017	0803-9372
Article	Mustapha, W.F., Bolkesjø, T. F., Martinsen, T., Trømborg, E.	Techno-economic comparison of promising biofuel conversion pathways in a Nordic context ? Effects of feedstock costs and technology learning.	Energy Conversion and Management	368-380	149/2017	ISSN 0196-8904
Article	Svein Jarle Horn	Skal forske på drivstoff fra skog	Skog	null-null	2016	1892-9990
Article	Svein Jarle Horn	Skal forske for miljøvenleg biodrivstoff	www.regjeringen.no	null-null	2016	
Article	Svein Jarle Horn, Rasmus Andreas Astrup, Bernd Wittgens, Duncan Akporiaye	Nærmere en løsning for biodrivstoff	Aftenposten Viten	null-null	2017	

CONFERENCES, LECTURES

Type	Author(s)	Title	Event
Lecture presentation	Aniko Varnai	Bioprocessing of lignocellulosic biomass.	Bio4Fuels Kick-off seminar. Ås.
Lecture presentation	Aniko Varnai	Application of enzymes for adding value to biomass.	Statssekretær Bjørn Haugstad- Kunnskapsdeparteme møter NMBU. NMBU.
Lecture presentation	Cherubini, Francesco; Strømman, Anders Hammer; Faaij, André; Krey, Volker; Valin, Hugo	Global Land Management and Climate Change	Workshop organized for Norwegian Environmental Agency and Ministries, Oslo, 20/9-17
Lecture presentation	Duncan Akporiaye	Fra skogrester til flytanken	Fremtidsfestivalen, Ås
Lecture presentation	Duncan Akproiaye, Svein Jarle Horn, Bernd Wittgens	Derfor forsker vi for morgendagens biodrivstoff	Dagbladet, debatt 4/4-2017
Lecture presentation	Francesco Cherubini	Unravelling the Knot of CO2 Emissions from Bioenergy and Climate Change	
Lecture presentation	Francesco Cherubini	Unravelling the Knot of CO2 Emissions from Bioenergy and Climate Change	Workshop "Understanding the Climate Effects of Bioenergy Systems", Gothenburg 16/5-17
Lecture presentation	Gerdt Müller, Piotr Chylenski, Bastien Bissaro, Aniko Varnai, Vincentius Gerardus Henricus Eijsink, Svein Jarle Horn	Optimization of process conditions for efficient saccharification of cellulose by LPMO-containing cellulose preparations	
Lecture presentation	John Christian Gaby, Espen Govasmark, Live Heldal Hagen, Lisa Paruch, Linn Solli, Magnus Øverlie Arntzen, Phillip Pope, Svein Jarle Horn	Multi-omic characterization of a commercial-scale, food-waste biogas reactor	2nd international metaproteomics symposium. Alghero.
Lecture presentation	Judit Sandquist	Kvister og topper skal bli til bio-drivstoff. Men det har ingen i verden fått til før.	Aftenposten 18/3-17
Lecture presentation	Judit Sandquist	Activities in Hydrothermal Liquefaction and Carbonisation in Norway	HTP Fachforum 2017 . Leipzig.
Lecture presentation	L.D Hansen, Aniko Varnai, Vincent Eijsink, Svein Jarle Horn	Optimization of enzyme cocktails and process conditions for efficient saccharification of Norway spruce	VLAG course ?Food and Biorefinery Enzymology. Wageningen.
Lecture presentation	Li, Yahao; Chen, De	Fe/N/P tridoped biomass derived carbon electrocatalyst for highly efficient ORR	Vitenskapelig foredrag på Carbon 2017, 23/6 - 28/6-17
Lecture presentation	Liang Wang, Øyvind Skreiberg, Roger Antoine Khalil, Michael Becidan	Ash fusion characteristics of spruce stem wood and blends with bark, forest residue and fermentation residues	2nd International Bioenergy (Shanghai)
Lecture presentation	Line Degn Hansen, Aniko Varnai, Vincent Eijsink, Svein Jarle Horn	Optimization of enzyme cocktails and process conditions for efficient saccharification of Norway spruce	Post-Graduate course Industrial Biotechnology for Lignocellulose Based processes. Gøteborg.

Lecture presentation	Morken, John; Briseid, Tormod; Hovland, Jon; Lyng, Kari-Anne Kallerud; Kvande, Ingvar	Veileder for biogassanlegg mulighetsstudie, planlegging og drift	Ås: NMBU 2017 56 s. IMT Rapport serie(56)
Lecture presentation	Odd Jarle Skjelhaugen	Biodrivstoff fra norsk skog	Nasjonalt råd for teknologisk utdanning, Ås, 17/11-16
Lecture presentation	Odd Jarle Skjelhaugen	Biodrivstoff fra norsk skog	Prosjektmøte Interreg-prosjektet "The bioeconomy region", Ås, 21/6-17
Lecture presentation	Odd Jarle Skjelhaugen	Biodrivstoff fra norsk skog	Planlegging av FoU-oppgaver i Statens Vegvesen, Oslo 17/8-17
Lecture presentation	Olaf Trygve Berglihn,Bernd Wittgens, Duncan Akporiaye	Muligheter basert på Norsk Skogressurser	Tekna, Oslo, 4.4.2017
Lecture presentation	Per Kristian Rørstad	Hvilke reelle muligheter er det for at bioenergi kan redusere transportutslippene ? og hvilke krav vil EU stille til klimavennlig biodrivstoff?	Foredrag på NTVA Teknologiforum, Tronheim 26. april 2017.
Lecture presentation	Radziah Wahid, Kine Svensson, Daniel Girma Mulat, Svein Jarle Horn	Biogas upgrading via hydrogenotrophic methanogenesis in mesophilic lab-scale bioreactors	IWA World Conference on Anaerobic Digestion. Beijing.
Lecture presentation	Ryan M Bright, Rasmus A Astrup	Deler av skogen bør går til drivstoff	Kronikk i Dagens næringsliv, mars 2017
Lecture presentation	Rørstad, P.K., Bolkesjø, T.F., Hoen, H.F., Solberg, B., & Trømborg, E.	Trenger vi biodrivstoff ? - og må det være norsk?	
Lecture presentation	Svein Jarle Horn	Norwegian Centre for Sustainable Bio-based Fuels and Energy (NorSusBio)	Ministerbesøk på NMBU med tildeling av FME. NMBU, Ås.
Lecture presentation	Svein Jarle Horn	Bio4Fuels - ny FME med fokus på biodrivstoff og bioraffinering	Ås Kommune. Ås.
Lecture presentation	Svein Jarle Horn	Bio4Fules - ny FME	NMBUs styre, Ås
Lecture presentation	Torjus F. Bolkesjø	Fremtidens etterspørsel etter biomasse	Foredrag på Bioenergidagene 2017. Gardermoen 26/11-2017
Lecture presentation	Torjus F. Bolkesjø	The role of bioenergy in the future energy system	Presentasjon for Nordisk Energiforskning, 22/5-2017
Lecture presentation	Torjus F. Bolkesjø	Hvordan legge til rette for biodrivstoff i transportsektoren?	NRK Nyhetsmorgen 6/9-2017
Lecture presentation	Vincent Eijsink	Lytic Polysaccharide Monooxygenases (LPMOs) and other redox enzymes in polysaccharide degradation – fundamelntal and applied aspects	Invitert foredrag ved Chalmers Universitet. Gøteborg.
Lecture presentation	Vincent Eijsink	New developments in enzyme research	Partnermøte I Bio4Fuels. Trondheim.
Lecture presentation	Vincent Eijsink	Recent insights into the role of LPMOs and other redox enzymes in fungal polysaccharide degradation	The 2nd symposium on plant biomass conversion by fungi. Utrecht.
Lecture presentation	Vincent Eijsink, Bastien Bissaro	Structure and function of lytic polysaccharide monooxygenases (LPMOs) and other redox enzymes involved in biomass processing	Enzyme Engineering XXIV. Toulouse.
Lecture presentation	Vincentius Gerardus Henricus Eijsink	Bioraffinering ? med enzymer og mikrober mot en grønnere framtid	Årsmøte i LabNorge. Sundvollen.
Lecture presentation	Vincentius Gerardus Henricus Eijsink	Examples of enzyme technology and biorefining at NMBU	lecture for a delegation from Szent-Istvan University, Hungary. NMBU. Ås.

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

Type	Name	Project owner	Financed by	Total budget [mNOK]	Platform addressed
Project	AMBITION	SINTEF MC	H2020-ECRIA	22,5	Biochem./Thermochem
Project	BioRaff	PFI	H2020/Interreg	8,1	Biochem./Thermochem
Project	ERC starting grant to P. Pope	NMBU	ERC	14	Biochemical - Biogas
Project	Prowood	INBIOTEC	ERA-IB; RCN and others	17,5	Biochemical platform
Project	Thermofactories	SINTEF MC	ERA-MBT; RCN + abroad	22,3	Biochemical platform
Project	4Refinery	SINTEF MC	EU - H2020	60	Thermochemical, chemical
Project	DAFIA	Aimplas (Spain)	EU - H2020	58	Biochemical platform
Project	BRISKII	KTH	H2020-INFRAIA	86	Bio-, thermochemical
Project	BESTER	SINTEF MC	ERA-CoBioTech, H2020, RCN, and others	27,7	Biochemical platform
Project	C1pro	NTNU	ERA-CoBioTech, H2020, RCN, and others	17,2	Biochemical platform
Project	MetaFluidics	UAM (Spain)	EU - H2020	86	Biochemical platform
ITN	Oxytrain	Un Groningen	Marie Curie	29	Biochemical
	The Bioeconomy Region	Akershus energi + Region Värmland	H2020/Interreg	35	End use

NATIONALLY FUNDED PROJECTS

Project	Project owner	Financed by	Total budget [mNOK]	Platform(s) addressed
Bio4Fuels	NMBU/SINTEF	RCN, FME	236,6	All platforms addressed
AMBITION	SINTEF MC	H2020-ECRIA	22,5	Biochem./thermochem. platform
BioRaff	PFI	H2020/Interreg	8,1	Biochem./thermochem. platform
Rubiosa	NIBIO	RCN - SANCOOP	3	Biogas - Fertilizer
Complete	Biokraft	RCN - Bionær	25	Biogas - Fertilizer
Hyperfermentan	Hyperthermics	RCN - EnergiX	7,5	Pretreatment - Biogas
BioGasFuel	NMBU	RCN, ENERGIX	19	Biochemical - Biogas
BioLiGas	NMBU	RCN. ENERGIX	14	Biochemical - Biogas
ERC starting grant to P. Pope	NMBU	ERC	14	Biochemical - Biogas
Prowood	INBIOTEC	ERA-IB; RCN and others	17,5	Biochemical platform
Promac	Møreforskning	RCN-BIONÆR	35	Biochemical platform
MIRA	NTNU	RCN-Havbruk/Biotek2021	13,3	Biochemical platform
EcoLodge	NTNU	RCN-EnergiX/IndNor	6,6	Biochemical platform
Thermofactories	SINTEF MC	ERA-MBT; RCN + abroad	22,3	Biochemical platform
DAFIA	Aimplas (Spain)	EU - H2020	58	Biochemical platform
Foods of Norway	NMBU	RCN, SFI	218	Biochemical - Sugar
NorZymeD	NMBU	RCN, Biotek 2021	55	Biochemical - Sugar
BioFeed	NMBU	RCN, Biotek & Havbruk	14	Biochemical - Sugar
WoodPrebiotics	NMBU	RCN, Bionær	20	Biochemical - Sugar
BioMim	Nibio	RCN, Bionær	28	Biochemical - Sugar

Value-added sugar platform	Borregaard	RCN, BIA	77	Biochemical - Sugar
Single Cell Oils	NMBU	RCN	7	Biochemical - Sugar
Cat. conv. of biomass to fuels	NTNU	NTNU (N5T)	3,3	Chemical
Cat. hydrogenolysis to chem. & fuels	NTNU	NTNU	3,3	Chemical
BioCoPro	PFI	RCN, SANCOOP	3	Biochemical platform
ReShip	PFI	RCN, ENERGIX	15	Thermochemical platform
PyroGas	Norske Skog	RCN, ENERGIX	4	Thermochemical platform
BIOGREEN	RFFINNL; Moelven	RCN	6	Thermochemical platform
Advanced Biofuels via Syngas	NTNU	RCN, ENERGIX	8,9	Thermochemical platform
H2BioOil	NTNU	RCN, ENERGIX	11,8	Thermochemical platform
GAFT	SINTEF ER	RCN, ENERGIX	20	Thermochemical platform
LipoFungi (NFR, Bionær, Project No. 268305)	NMBU	RCN, Bionær	10	Biochemical platform

ACCOUNTS 2017

A overview of the accounts for 2017 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.

Costs Specification	Costs / NOK
Payroll and indirect*	5 523 348
Procurement of R&D services**	12 596 875
Equipment	62 634
Other operating expenses	2 057 152
Total	20 240 009

* Host institute's (NMBU) costs

**Other research Partners Costs

Finance Specification	Finance / NOK
In-kind	1 616 227
Public	6 876 581
Private	1 970 270
International	585 562
Other	1 143 741
Research Council	8 047 628
Total	20 240 009

ACKNOWLEDGEMENTS

The authors of the annual report would like to acknowledge the help and input from all the contributors. This includes the Chair of the board, management group, Sub-project leaders, Workpackage leaders and all the involved students. We also acknowledge the support and input from the Stakeholders and in particular Biokraft for the cover photo. We also acknowledge the opportunity of establishing Bio4Fuels as financed by the Norwegian Research Council.

AUTHORS

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

Bio4Fuels Stakeholders