Norwegian Centre for Environmentfriendly Energy Research

Bio4Fuels

Norwegian Centre for Sustainable Bio-Based Fuel and Energy

HIGHLIGHTS FROM 2022

Enabling sustainable biofuels production in Norway

BIO4 FUELS

Contents

Front page photo: Pilot plant at Tofte, Norway. Photo: Silva Green Fuel

Illustration: The Research Council of Norway

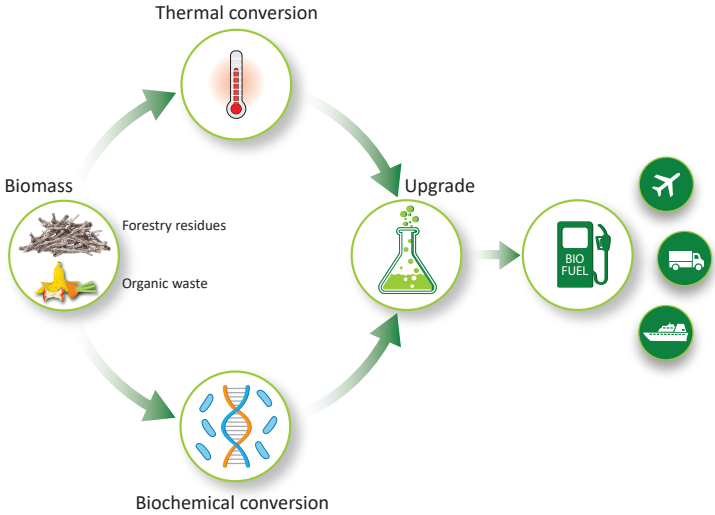
What is Bio4Fuels?

The goal of the FME Centre Bio4Fuels is to contribute to the reduction of climate gas emissions from the transport sector. We aim to enable a sustainable production of biofuels in Norway based on low-grade woody biomass, organic and agricultural waste.

Bio4Fuels also addresses issues regarding viable commercial production of advanced biofuels from sustainable biomass. The ambition is to improve the technologies and economics of processes for converting biomass to advanced biofuels, investigate the sustainability and impact of large-scale use of low-grade biomass, and to evaluate and design the process concepts and testing quality of the biofuels for the engines used today.

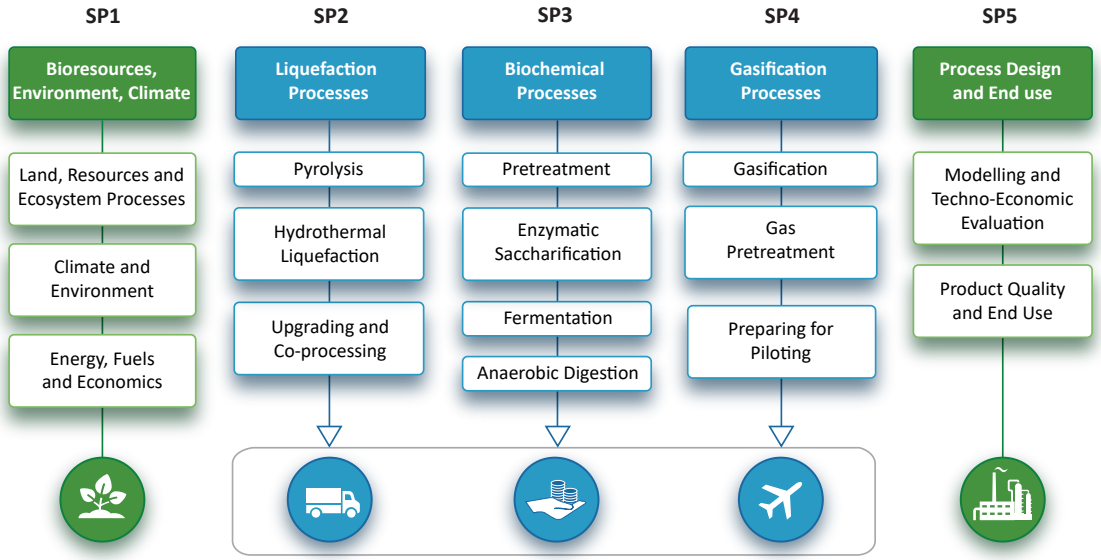
The prospects for advanced biofuel production in Norway have increased significantly through the activities of key stakeholders since the establishment of Bio4Fuels in 2017.

Centre start date: 1 January 2017
Centre end date: 15 October 2025



Value chains and research

From sustainable biomass resources to economic production of advanced biofuels



SP = sub-project

From the Centre Leader and Deputy Centre Leader

In 2022, the landscape for energy security, particularly in Europe, was severely impacted in by the conflict in Europe – underlining how the current complete dependency on fossil-based energy sources is problematic. This has catalysed and driven a mobilization for energy independence – with the US and Europe establishing major investment initiatives towards the green transition.

With respect to the operations of Bio4Fuels, this has given additional opportunities for some of our key stakeholders – those focused on investing in commercial scale production in Norway. In particular, the activities and stakeholders within biogas having the opportunity of responding to the EUs Biomethane Industrial Partnership of 35 bcm annual production by 2030.

With this as a backdrop, the timing of the Bio4Fuels Days meeting, hosted by Equinor at Mongstad, gave the opportunity for an update from the main industry partners of Biozin, Silva Green Fuels and Equinor. It was also a good opportunity for developing the concept and vision for an application for a new FME from 2025 – taking on the challenge of deploying technologies for sustainable transport fuels to meet the targets of the transport sector for 2030 and 2050.

In parallel with this, there is a continued high productivity of the research partners within the research fields of the centre, with publications in high impact journals as well as continued success in getting funding through major EU-projects.

We acknowledge again the continued support of the Bio4Fuels stakeholders, both industrial and public sector, and the dedication of the research partners.

Duncan Akporiaye, SINTEF
Centre Leader

Svein Jarle Horn, NMBU
Deputy Centre Leader

Some of our partners

St1

St1 is an energy company that researches and develops economically viable, environmentally sustainable energy solutions to become the leading producer and seller of CO_2-aware energy. Work in Bio4Fuels is towards the same goal to explore renewable solutions to replace fossil energy. The R&D laboratory forms a world-class entity with a Cellunolix® demonstration biorefinery in Kajaani, Finland.

St1 has a strong focus on lignocellulosic feedstock. The St1 research team is further developing the Cellunolix concept, producing advanced ethanol from sawdust, a processing residue from the sawmill industry, and the enzymes at enhanced capacity in the biorefining process. The research results and development work can immediately be taken seamlessly to production for testing on a demonstration scale, and the results can be returned to the development work. 100% of the feedstock of their advanced ethanol production is waste based. Renewable energy is used in production and energy efficiency has been one of their top priorities.

Advanced ethanol biorefineries produce other bioproducts in addition to ethanol. St1 is involved in several lignin application developments together with universities and private partners. Some of the promising applications are, for example, bitumen replacement in asphalt production, the replacement of fossil components in resins production, and biochar production for the steel industry. Through St1's R&D activities, as well as by participating in partnership-funded R&D projects, they continuously look for new potential sustainable feedstocks for producing advanced fuels. For example, recycled wood, bark, and waste streams from the chemical forest industry have proven to be great local feedstocks.

St1 Cellunolix® demonstration biorefinery in Kajaani, Finland. Photo: St1

Biozin project halted - considering alternatives

After extensive technology testing and new cost calculations, Shell decided in May 2023 to stop investment in the application of the IH2 technology that forms the basis of the Biozin project in Åmli. Biozin must now spend some time reassessing the plans and looking at what other possibilities they have.

Energy conversion projects that use completely new technology are often challenging and involve considerable risk. Despite promises of support totalling NOK 1.3 billion from Enova, the EU's innovation fund and Innovation Norway, Shell considers that the project's finances are too uncertain. Shell is clear that the company wants to look further into opportunities to create business in Åmli together with Biozin.

- We greatly appreciate the support that the project has received in Norway, including from Åmli municipality, Agder county and the Norwegian State through Enova and Innovation Norway. Biozin's concept and location still have great potential for utilizing residual raw material from forestry and side streams from the sawmill industry. We have had a fantastic partnership with Bergene Holm and Biozin - who have matured the project in an exemplary way. Biozin has excellently organized the necessary infrastructure and solutions to all matters related to logistics. With the background of all the good work that has been done on Biozin's part, we hope to find other opportunities together, says Andrew Murfin, head of Shell's global department new fuel types.

Preliminary 3D-model of the planned Biozin Åmli plant. Photo: Biozin

Innlandet county – Adventurous Opportunites

Inland county has long tradition as forest county no. 1 in Norway. About 40% of Norwegian forest harvest arise from Inland. The volume amounts to 4.2 - 4.6 million m³ annually. Of this, about 1.2 million m3 of pulpwood is exported to Sweden. Branches and tops remain in the forest, representing opportunities for new industry.

In 2023 the survey 'Inland Portfolio' will be completed. The involved actors are the County Municipality, the County Governor, and Innovation Norway. Here, the most important green innovation projects will be identified. The portfolio wil shows the most value-creating, innovative and circular innovation projects in Inland, and what it takes to realize them.

The company Glocal Green represents one such innovation project, with high potential for use of forest residues for producing biomethanol. The concept allows for the establishment of economically sustainable commodity flows for biological residual raw materials – from forests, agriculture, aquaculture, and other biological waste to produce biomethanol

Similar projects that take care of side streams and contribute to reduce climate changes are what Inland is looking for.

Sustainable raw material from the forest.
Photo: Mostafa Pourbayat

AVINOR

Avinor

Supporting development of Sustainable Aviation Fuel (SAF)

Innovation and technology development is important to Avinor. They work to develop more sustainable solutions for their own operations and act as a catalyst in the aviation industry's efforts towards fossil-free aviation in 2050.

Avinor has, in close cooperation with key players in Norwegian aviation, led and financed knowledge-development projects on sustainable aviation fuel. They have both looked at the potential for Norwegian production of sustainable fuel and possible measures for increased production and use.

Aviation is a typical hard-to-decarbonize sector with high abatement cost and few alternatives to fossil fuels compared to other sectors. Electrified aircraft can potentially play an important role, and a lot of resources are being invested in developing hydrogen-fueled aircrafts.

Sustainable aviation fuel (SAF) will play a key role in the green transition. It can be used in existing aircraft and infrastructure with no need for modifications, and it is the only technology that we know will work for long distances.

Norway was the first country worldwide to introduce an effective biofuel blend-in mandate for biofuel (2020). In 2021 the EU Commission proposed a European blend-in mandate starting at 2% in 2025, and increasing every 5 years, to 63% in 2050.

Norway is well positioned for large scale production of sustainable aviation fuel from forestry residues. The volume can make up more than 30% of the national jet fuel consumed.

A high renewable share and infrastructure for CCUS and bio-CO_2 are important assets for jet fuel. But large-scale investment decisions remain to be seen. Research and development to increase the maturity of feedstocks and production processes are of high importance.

BP Biojet. Photo: air bp

Equinor Mongstad refinery. Photo: Øyvind Hagen

Bio4Fuels relevant industrial activities in Norway

Reseach activities - Selected highlights

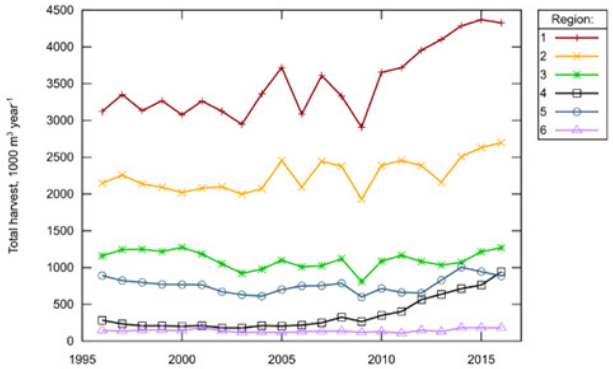
Regional differences in timber supply

We have good knowledge about available forest resources in Norway. It is, however, the more than 120,000 forest owners that ultimately decide how much timber will be harvested. In this study we have investigated the regional differences in Norway using regional data on harvests, prices, interest rates and standing stock.

Region 4 – along the western coast – appears to have a different dynamic compared to the other regions. Here the harvests have been monotonically increasing despite a negative trend in real timber prices. The short-term elasticities are positive. This implies that forest owners react to short term variation in prices in the way we expect, but that there are underlying long term changes not captured by our models.

We are quite certain that hurricanes and windthrow are not the reasons. For the models estimating the short-term reaction to changes in prices, a model with regional effects did not perform (statistically) better than one without.

Still, if we are interested in modelling the regional timber supply – as we usually are – using regionalized models would still be preferable even though we do not gain anything at the aggregate level. This work was published in Silva Fennica:



Rørstad P.K., E. Trømborg, B. Solberg (2022). **Can we detect regional differences in econometric analyses of the Norwegian timber supply?** Silva Fennica 56:1

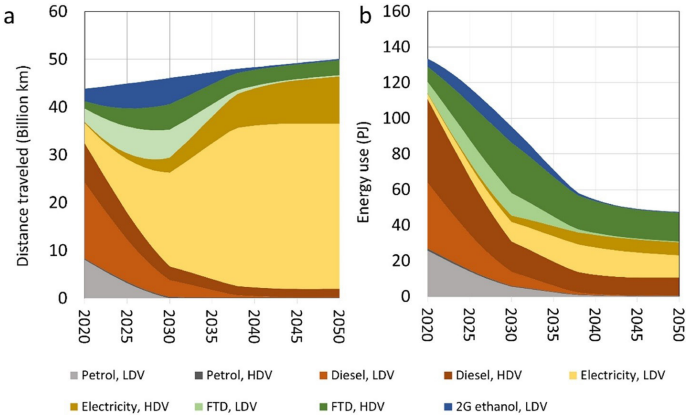
Read the full article here: https://doi.org/10.14214/sf.10326

Unraveling the role of biofuels in road transport under rapid electrification

Biofuels have been the predominant option for climate change mitigation in road transport for decades, but the recent expansion of electric vehicles may question this role. We model the energy use and life-cycle emissions of road transport activities until 2050 in Norway, a country with a rapid growth in vehicle electrification.

Mitigation from biofuels peaks in 2030 at 3.1 ± 0.45 $MtCO_2eq$/year (30% of today's road transport emissions) and impacts on human health decrease. The largest emission savings are achieved from biofuels in trucks, buses and vans. Integrated strategies combining high electrification rates of the vehicle fleet with targeted applications of biofuels can increase the mitigation of road transport emissions.

This work was published in Biofuels, Bioproducts and Biorefining (Biofpr).



Cavalett, O., & Cherubini, F. (2022). **Unraveling the role of biofuels in road transport under rapid electrification.** Biofuels, Bioproducts and Biorefining, 16(6), 1495-1510.

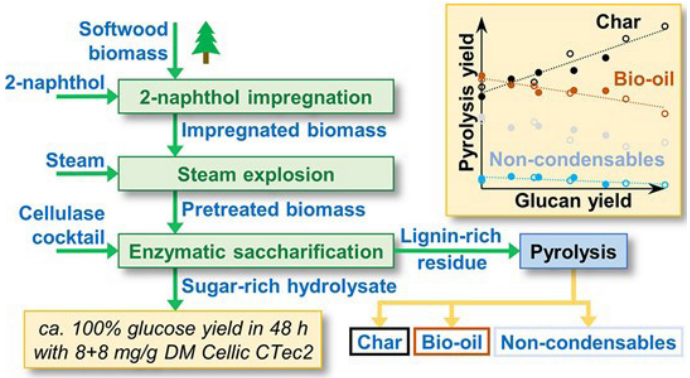
Read the full article here: https://doi.org/10.1002/bbb.2395

Regional differences in timber supply

A combined biochemical and thermochemical conversion route generating high-quality pyrolysis fractions.

In 2022, a combined biochemical and thermochemical conversion route was established, based on Biomass pretreatment (WP3.1), Enzymatic saccharification (WP3.2), and Thermochemical Upgrading (WP2.3). The process was based on a modification of steam explosion, a biomass pretreatment used by St1, with carbocation scavengers to improve lignin reactivity in the pretreated feedstock. The modified lignin promotes oxidative cellulose depolymerization by lytic polysaccharide monooxygenases (LPMOs), one of the key components in the state-of-the-art cellulase cocktails of Novozymes and enables efficient separation of the spruce feedstock into a sugar-rich hydrolysate and a highly pure lignin fraction.

The process achieved close to 100% saccharification with the LPMO-containing enzyme cocktail Cellic CTec2 over 48 h incubation time, using process parameters that are close to being industrially realistic: 10% (w/v) DM feedstock loading and 8-16 mg/g DM Cellic CTec2. The generated lignin-rich saccharification residue could be upgraded into high-quality pyrolysis fractions. The study was published in ACS Sustainable Chemistry & Engineering.



Hansen, L. D., Østensen, M., Arstad, B., Tschentscher, R., Eijsink, V. G., Horn, S. J., & Várnai, A. (2022). **2-Naphthol Impregnation Prior to Steam Explosion Promotes LPMO-Assisted Enzymatic Saccharification of Spruce and Yields High-Purity Lignin**. ACS Sustainable Chemistry & Engineering. 10 (16) 5233–5242.

Read the full article here:
https://doi.org/10.1021/acssuschemeng.2c00286

Line Degn Hansen

Prajin Joseph

PhD degree

Converting Norwegian spruce into fuel and bio-chemiclas

Line Degn Hansen

14 June 2022 Line Degn Hansen successfully defended her thesis "Leveraging H_2O_2-fuelled activity of lytic polysaccharide monooxygenases in cellulase cocktails for improved bioprocessing of lignocellulosic biomass". The work was performed at the Faculty of Chemistry, Biotechnology and Food Sciences, NMBU, as a part of Bio4Fuels work package 3.2, Enzymatic Saccharification.

Line has written her thesis about how the production of biofuels from woody biomass can be improved using enzyme technology. By using steam explosion as a pretreatment and boosting powerful oxidative enzymes called LPMOs with H_2O_2 she has been able to enhance yields of platform sugars that can be used for production of a variety of bio-fuels and -chemicals.

Prajin Joseph

16 December 2022 Prajin Joseph successfully defended his thesis "Organosolv pretreatment of Norway Spruce: Ethanol pretreatment for Biorefinery applications". The work was performed at both The Institute for chemical process technology (NTNU) and RISE PFI, as a part of Bio4Fuels work package 3.1, Pretreatment and Fractionation.

The main objective of the PhD work was to develop and demonstrate in lab-scale an efficient organosolv based fractionation process of Norway spruce to increase the accessibility of cellulose to enzymes and produce high value biopolymers. High purity and low molecular mass organosolv lignin are desirable properties for high value chemicals and products based on organosolv lignin. The results were included in four journal publications and two posters presented at international conferences.

Bio4Fuels days 2022

Bio4Fuels' partners meet once per year during the Bio4Fuels Days. In 2022 we met at Lindås, north of Bergen, Norway. Here is Equinor's refinery "Mongstad" which we planned to visit. Due to security restrictions all over Europe we were unfortunately not allowed to come inside. An informative bus ride in beautiful weather was a good replacement thanks to a brilliant guide from Equinor.

The energy situation in Europe after Russia's invasion in Ukraine was the backdrop for Bio4Fuels Days 2022. The transition to a net-zero energy system, and the importance of biofuel in this transition, was emphasized during the meeting.

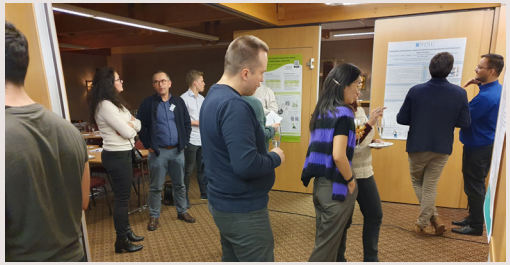
Due to Mongstad's remote location we offered a hybrid conference with online presentations from both international and national speakers: IEA Bioenergy, European Biogas association, Johnson Matthey, Biozin and Silva Green Fuel.

Equinor's people, who were physically present at the meeting, gave a broad insight into their activities at Mongstad refinery, including their biofuel commitments.

In this year's poster session we arranged a competition in which the professors Patricia Thornley (Aston Univ.) and Svein Horn (NMBU) selected the best poster. The winner was PhD student Cristian Bolaño Losada from NMBU!

Day two of Bio4Fuels Days is an internal meeting for the partners in the Centre and always includes research highlights, group discussions, and plans for the final two years of the Bio4Fuels Centre.

Full program for Bio4Fuels Days 2022: https://www.nmbu.no/en/services/centers/bio4fuels/events/node/45947



EU Projects

Bio4Fuels is associated with many EU projects, both completed and ongoing. Here is a brief introduction to two of them. More information about our associated projects can be found on our web site.

PYROCO$_2$

Demonstrating sustainable value creation from industrial CO_2 by its thermophilic microbial conversion into acetone.

The project's main objective is to demonstrate the scalability and economic viability of carbon capture and utilization (CCU) using innovative biotechnology to make climate-positive platform chemicals for the chemicals, fuel additives, and materials markets.

If successful, the project will show that it is possible to close the industrial carbon cycle to combat climate change through industrial scale (TRL7) technology demonstration at Herøya Industripark.

www.pyroco2.eu

REFOLUTION

Demonstration of aviation and marine biofuels production in refineries.

The project's challenge is to unlock the full potential of advanced biofuels production in Europe from European Refineries.

The aim is to increase cost-effectiveness of the production of advanced aviation and marine biofuels, while enhancing sustainability in a circularity approach, and preparing market up-take in EU.

www.refolution.eu

Funded by the European Union

Organisation 2023

Management and leaders

Biochemical Processes — SP3

Aniko Varnai, NMBU
Mihaela Tanase Opedal, RISE PFI
Alexander Wentzel, SINTEF
Lu Feng, NIBIO

SP2 — **Liquefaction Processes**

Judit Sandquist, SINTEF
Kai Toven, RISE PFI
Roman Tschentscher, SINTEF

Gasification Processes — SP4

Morten Seljeskog, SINTEF
Edd Blekkan, NTNU
Klaus Jens, USN

SP1 — **Bio-resources, Environment and Climate**

Francesco Cherubini, NTNU
Rasmus Astrup, NIBIO
Per Kristian Rørstad, NMBU

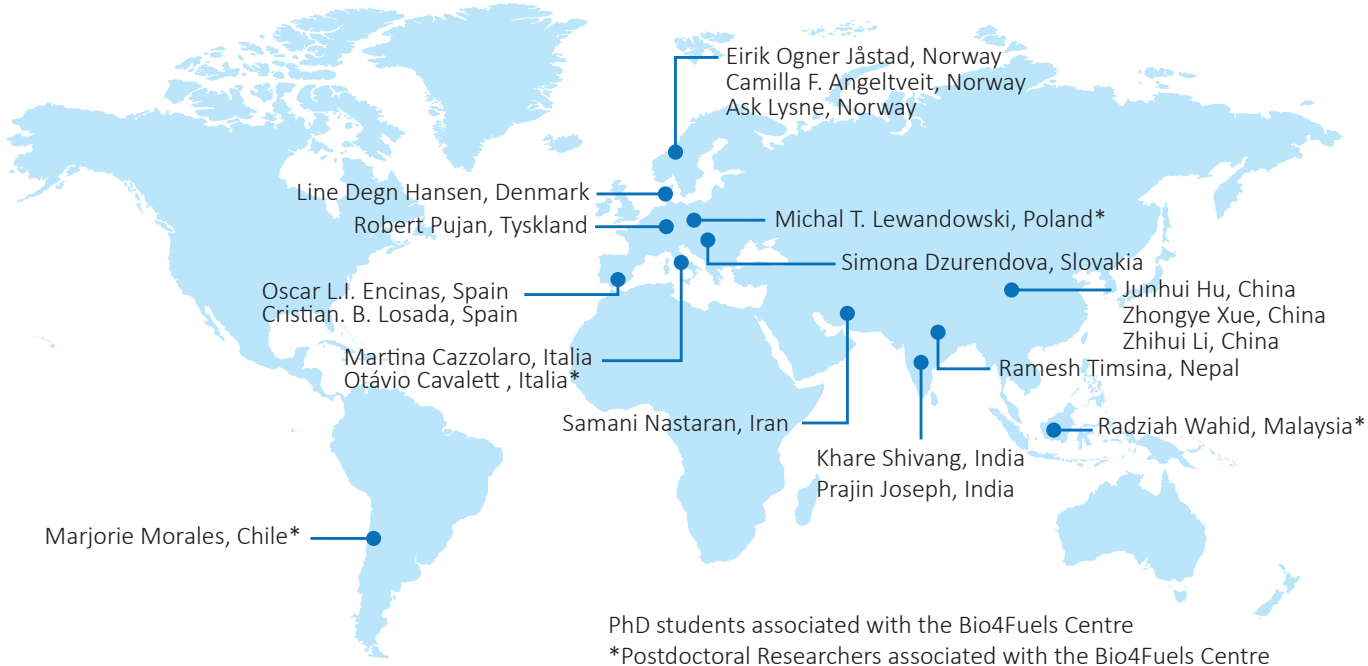
Process Design and End Use — SP5

Bernd Wittgens, SINTEF
Terese Løvås, NTNU

Management and Staff

Duncan Akporiaye, SINTEF
Svein Jarle Horn, NMBU
Odd Jarle Skjelhaugen, NMBU
Janne Beate Utåker, NMBU
Jon Hovland, SINTEF
Ann-Solveig Hofseth, NMBU
Camilla Fløien Angeltveit, NMBU
Haldis Bjerva Watson, SINTEF

PhD students and Post Docs in Bio4Fuels and their country of origin



PhD students associated with the Bio4Fuels Centre
*Postdoctoral Researchers associated with the Bio4Fuels Centre

Bio4Fuels Industrial and public stakeholders

BIORESOURCE OWNERS

BIOFUEL AND BIOCHEMICAL PRODUCERS

TECH./KNOWLEDGE PROVIDERS, NORWEGIAN

TECH./KNOWLEDGE PROVIDERS, INTERNATIONAL

BIOFUEL DISTRIBUTERS AND END USERS

TRADE ORGANISATIONS

GOVERNMENT AND STATE PARTNERS

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