BIO4ENERGY

Annual report 2022

www.bio4energy.se

Introduction – overview of 2022

The Bio4Energy year of 2022 started with the long-awaited launch of a new webpage – come visit it at www.bio4energy.se !

With the new website, we have tried to make our research and operations more visible for the visitor. A few examples are a new research platform overview, one entire section dedicated to the projects supported by Bio4Energy's Strategic Funds, a presentation of our Advisory Board, a searchable list of scientific publications, and a section that highlights the context and challenges that motivate our day-to-day business.

After the pandemic "exile years", we are happy to be back to the "old usual". In 2022, we had two researchers' meetings – one in Umeå in June, and one in Luleå in November – each with almost 70 participants, including many of our active PhD students.

In relation to our PhD students – during 2022 we celebrated Bio4Energy's 100th graduated PhD, when Mojtaba Nobandegani from the platform Bio4Energy Chemical Catalysis and Separation Technologies successfully defended his thesis. Education is a central mission for Bio4Energy, and we are happy to be able to continue contributing to the competence supply within the biorefinery arena!

The year in numbers

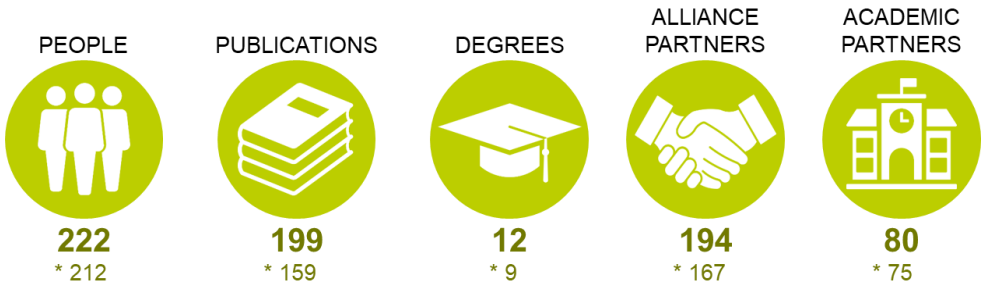
The figure below summarises a few of Bio4Energy's achievements of 2022 in numbers.

People are our most valuable assets! During the last decade, the number of researchers involved in Bio4Energy has been relatively stable at a bit over 200 persons.

PhD degrees are one way we contribute directly to society and industry – through providing competence for the future. The 13 defended PhD theses of 2022 mark one of our highest since the start of Bio4Energy.

Publications is how most our research is disseminated. Of the 199 published peer-reviewed journal papers in 2022, over 20 are a direct result of cross-platform collaboration, involving researchers from two or more of the seven Bio4Energy research platforms.

Alliance partners and *academic partners* represent national and international collaborations, a central part of Bio4Energy's operations. After a few slower years during the pandemic, our number of collaborations has now bounced back up and is touching on all-time high scores. The front page of this report shows a potpourri of alliance partners within ongoing collaborative projects and programs.



*Key numbers for Bio4Energy 2022. Numbers marked with * are average values for the period 2016-2022. 'Degrees' here represents PhD degrees. 'Alliance partners' represents our external collaboration partners from industry, society and institutes, and 'Academic partners' our external collaborations with academic departments outside Bio4Energy.*

News from the research platforms

Our research is conducted within seven research platforms, each with its own special focus in the biorefinery value chain. This is illustrated in the figure to the right.

The following pages are dedicated to highlights from the platforms from the previous year. Each platform is also described briefly.

Particular focus is here placed on new scientific results and achievements – or in short, we here give to you the quick flyover and a selection of insights from the almost 200 scientific publications of 2022!

New platform leaders

Environment and Nutrient Recycling
Nils Skoglund, Umeå University, took over the P7 platform leadership from Stina Jansson in March 2022. The platform today mainly focusses on areas such as; flows and recovery of nutrients, effluent treatment with algae, as well as reduction of air- and water pollutants.

In his new role, Nils wants to work to provide such scientific information that politicians could use to make decisions:
"I want us not only to develop facts and figures, but also to put them together in such a way that they can serve as a basis for decision-making."

Feedstock Pre-processing
Mikael Thyrel, Swedish University of Agricultural Sciences (SLU), took over the P3 platform leadership from Sylvia Larsson in September 2022, as she went from academia to become Senior Research Coordinator at MoRe Research.

Mikael shares some views on the FeedPro platform: "Our platform serves the rest of Bio4Energy by designing different types of fractionated biomass. It is mostly about applied research in the area of pre-treatment."

Left: Nils Skoglund taking over the P7 leadership from Stina Jansson. Right: New P3 platform leader Mikael Thyrel. Photos by Anna Strom, Bio4Energy Communications

P1 Systems Analysis and Bioeconomy

- Uncertain policy support is often claimed to be a major cause of the slower than expected deployment of advanced biofuel production. The economic rationale of this claim was investigated through a real options approach, incorporating various uncertainties. The results did not support the claim that policy uncertainty is a major source for the lack of commercial deployment of advanced forest-based biorefinery technologies. Instead, the uncertainties surrounding investment costs combined with future energy prices play a larger role in that investment in these technologies cannot be justified from an economically rational point of view.
- The techno-economic feasibility of combining biofuel production with CCS and CCU was examined. We found that applying BECCU to produce more biofuels from captured carbon may be economically competitive, and can offer a viable solution for a biomass-constrained future. Conversely, sequestering CO_2 through BECCS generates biofuels with very good climate performance, but at higher cost.
- Utilisation of surplus CO_2 from ethanol production in Brazil can, through combination with renewable H_2 for methanol synthesis, increase the fuel output of existing facilities by almost 50% without using additional land. This is sufficient to cover projected growth in Brazilian biofuel demand in 2030. A trade-off between renewable energy technologies was identified, with wind power needing the least amount of land whereas a mix of wind and solar costs the least.
- Leakage effect has been estimated between 24-27% for timber and 4-53% for pulp wood given a reduced wood harvesting in Sweden. That is, for each m^3 reduced domestic harvest in Sweden, the harvesting levels will increase in other countries by 0.24 and 0.53 m^3. As a consequence, unilateral polices related to climate and forestry will be undermined by high leakage effects.
- Life cycle assessment on a fuel produced using organosolv lignin was performed. It was shown that this is an interesting low sulphur biofuel for the marine sector.
- A positive relationship between blending mandates and domestic biofuel production has been identified. A more stringent blending mandate does not only increase the use of biofuels, but also domestic production. However, government R&D has not induced domestic biofuel industrialisation processes. A negative interaction effect between government R&D and blending mandates is also identified. The blending mandates tend to primarily favour commercialized first-generation biofuels, while government support to biofuel R&D has instead been focused on advanced biofuel technology.
- New collaboration within CEForestry, where the objective is to develop new and innovative practices (circular economy concepts) in forestry and novel solutions to utilise forestry side streams in the Baltic Sea region. This will be achieved through innovative means of collaboration across sectors (researchers, SMEs, large companies and other relevant actors) and demonstrated in pilot facilities. Cooperation with partners in Latvia, Estonia, Lithuania, Finland and Poland.

The SysAnaBio platform

Biorefineries are inherently interconnected with existing industrial infrastructures and other sectors of the economy, and the related scientific-technological challenges are multifaceted and require a multi-disciplinary perspective.
In this platform, holistic and comprehensive methodological systems analysis approaches are used to address technological, economic, and social challenges and opportunities related to the development of biorefineries.

P2 Forest-Based Feedstocks

- Sweden was shown to have good possibilities for large-scale plantations of poplar and other fast-growing trees species as raw material for biofuel and bioenergy. In total, there is approximately 478 kha of agricultural land (excluding land used for food production) and 1.1 Mha forested agricultural land that could be used for plantations of fast-growing trees. It was estimated that poplar plantations in only a small part of this land, i.e. 25% of the agricultural land and 5% of the fertile forest land, would produce bioenergy corresponding to 8 TWh on a yearly basis.
- A 20-year-old controversy was resolved, about the biosynthetic pathway of starch; one of the most important pathways in photosynthetic metabolism. In the model system *Arabidopsis thaliana*, sucrose synthase, previously considered central in starch synthesis, was shown to actually make no significant contribution to transitory starch synthesis in the leaves.
- Another long-term dogma in plant biology was challenged in research on aspen trees. Tree growth was shown to not be carbon limited under benign conditions, which implies that trees employ a passive strategy to save carbon for future needs. This information is important for full understanding of the role of terrestrial carbon sinks and for future climate modelling.
- The platform was instrumental in a study concerning metatranscriptomic analysis of Norway spruce roots and more than 350 root-associated fungal species from the boreal forests. Notably, an exchange was observed in prevalence and host-coordination of specialist ectomycorrhizal species critical for enzymatic cycling of recalcitrant carbon, to metabolically versatile species. This research unites kingdom-spanning taxonomic and functional details of the boreal root microbiome, contributing a missing perspective toward modelling global carbon cycling.
- Novel technologies were developed in research on aspen trees to understand how cambial activity and xylem differentiation influences wood properties and tree functioning. The technologies included measurement of stem hydraulic conductivity and drought resistance in trees grown under controlled soil humidity in an automated phenotyping platform. These technologies can be used to device breeding strategies for trees having better climate resistance in the future.
- We also estimated the adaptive capacity to drought stress in Scots pine seedlings for natural and managed origin.
- We discovered that low-intensity stem flexing greatly improves tree growth, changes hormonal levels in developing wood, and alters wood chemistry, making lignocellulose easier to convert to sugars.
- Characterization of the natural variation in tree growth and wood properties in a population of Swedish aspen trees revealed a few genetic markers as well as the simple volumetric growth traits of tree height and diameter as good predictors of the overall biorefining potential of the trees. We also initiated experiments to study how biorefining yields as well as wood chemical and morphological features are influenced by nitrogen fertilization of aspen both in greenhouse-grown trees and in trees grown on the field.

The ForFeed platform

Feedstock is the basis of all other platforms, and optimised feedstock will influence the whole value chain. Research on feedstock production systems contributes to increased wood yield and allows engineering of wood characteristics. Within this platform, genetic and molecular control of properties that are important for feedstock biorefining are investigated, as well as how these properties are governed by environment and management practices.

P3 Feedstock Pre-Processing

- A facile one-pot synthesis using Norway spruce bark as raw material gave activated biochars with a highly mesoporous structure containing ordered graphite sheets with a high degree of surface functionality which improved the electrochemical response. The biochars was tested as anode material for lithium and sodium batteries and yielded excellent rate capability and capacity retention during cycling.
- The regulatory roles of nitrogen and bark addition in mushroom-growing substrates was studied for *Lentinula edodes* (shiitake) production and the subsequent cellulose saccharification of the spent substrates. Carefully designed substrates resulted in 19–35% of glucan mass loss after fungal pretreatment, less than half of the previously reported values, thus improving bioconversion efficiency.
- The carbocation scavenger (2-naphthol) was studied to mitigate lignin self-condensation during steam explosion pre-processing of softwood bark destined for enzymatic conversion. The main factors affecting saccharide conversions were reactor temperature and enzyme loading, while acetic acid addition and bark pre-drying had no or little effect. In general, carbocation scavenger addition in the form of 2-naphthol was detrimental to sugar hydrolysis yields, contradicting earlier literature findings.
- Wood powder from green milling with the multi-blade shaft mill (MBSM) was characterized using two-dimensional image analysis and surface area analysis for particle size distribution (PSD) and shape properties. Compared to conventional techniques, MSBM powders were finer and more spherical with enhanced bulk densities. Mill settings permit tailor-made powders according to the desired PSD.
- The use of individual spruce tree components (i.e., stem wood, bark, branches) as feedstocks during O_2-blown gasification proved more efficient than using mixtures of components. Cold gas efficiency based on CO and H_2 (CGE_{fuel}) differed markedly between the different tree components, and co-gasification of mixtures, reduced the CGE_{fuel} by 1.3–6.2%, compared to optimal gasification of single feedstocks.
- Preparing sustainable and efficient biomass-based carbon materials (BBPM) as adsorbents remains a challenge for organic pollutants. Different single-step pyrolysis chemical methods using a Norway spruce bark was employed in BBPM adsorbent production. The produced carbons were characterized for BET, XPS, RAMAN and hydrophobic-hydrophilic balance and later evaluated as adsorbents for the drug acetaminophen. All carbons showed good properties regarding adsorption equilibrium times. Studying the adsorption process suggested that pore-filling mechanisms dominated the acetaminophen removal.
- New electrochemistry lab is being set up, as well as a dedicated mushroom lab equipped with state-of-the-art cultivation capabilities including several autonomous features and sensors.
- Green battery (Interreg Aurora, new project with RISE and University of Oulo) aims to develop more sustainable batteries for grid storage application. SLU takes the lead on biochar-based anodes.

The FeedPro platform

Forest-based lignocelluloses are characterised by their structural and chemical diversity. Expertise in advanced feedstock characterisation and design and evaluation of tailored pre-processing technologies is critical for accelerating the development of biorefinery processes and products. This platform addresses challenges and opportunities caused by biomass heterogeneity, through research on characterisation, separation, and modification of bio-based materials.

P4 Thermochemical Conversion Technologies

- The precise control of bio-based combustion is challenging due to the varying composition and moisture content of the fuels, difficulties in achieving stable fuel feeding, and complex underlying thermochemical processes. A fast online tool that simultaneous measures two combustion parameters, (equivalence ratio and fuel moisture content) was developed and tested, in a pilot-scale environment. The parameters were evaluated by analysing the H_2O and CO_2 concentrations.
- An SEM/STEM (Apreo 2 High Vacuum) system has been installed at RISE in Piteå. The microscope has an MEMS chip based microreactor which allow in situ experiments under reactive high temperature conditions.
- Collaboration established resulting in the project "Oxygen and hydrogen in TSR kilns (O2H2)" (Swedish Energy Agency). The aim is to construct a validated CFD model with enough predictive capacity to efficiently support necessary decision making for full-scale implementation of O_2 and H_2 enriched combustion conditions in quicklime production. The extensive process modifications targeted will enable reduced CO_2 emissions and increased resource (fuel) efficiency in lime kilns, here primarily by flame stabilization and improved fuel flexibility, but enrichment can also target oxy-fuel combustion which increases energy efficiency and concentrates the CO_2 to assist future carbon capture technologies.
- Several published scientific papers that focus on ash transformation and ash properties when co-processing sewage sludge with residual biomass feedstocks, in particular agricultural residues, in thermochemical conversion processes. Promising results were achieved regarding the opportunity to recover nutrients from sewage sludge, with decreased ash-related operational issues.
- By combining optical methods using high-speed imaging with sampling methods, important findings on the effect of acoustic forcing and the interaction with the particle in an entrained flow reactor (EFR) were presented. The application of acoustic forcing in the biomass particle-laden flow and a swirling co-flow in a lab-scale EFR burner generated significant changes in the multiphase flow, by increasing particle dispersion. Shadowgraph image analysis applied to non-reacting conditions with acoustic forcing showed the presence of regions with high particle concentration, identified as particle clusters in the near-burner region. The dispersion angle, quantified from time-averaged contour maps of particle distribution, presented nearly linear behaviour to the pressure amplitude. In reacting conditions, the flame morphology analysis indicated a lower lift-off distance for acoustically forced flows, suggesting enhanced air-fuel mixing, especially for the small particles in high-swirling flow. Analysis of the particulate emissions identified a lower amount of unburned char and soot for excited conditions. The results are promising regarding opportunities for reduced soot emissions from EFR applications for direct combustion and gasification of pulverized biomass.

The ThermoChem platform

Through thermochemical conversion processes, widely different types of biomass can be converted into advanced fuels and chemicals. The overall challenge for this platform involves generating the fundamental understanding needed to support the technical development of thermochemical conversion of forest-based biomass, side streams, recycled fibres, underutilised fractions, and to make the corresponding technologies competitive to those for fossil fuels.

P5 Biopolymers and Biochemical Conversion Technologies

- In collaboration with Boliden Mineral we have demonstrated the impact of using biobased flotation reagents, i.e. lignin-based micro-and nanoparticles, as a strategy to increase metal recovery and at the same time reduce the environmental impact of the mining sector and enhance its potential to mitigate climate change. During the project LIGNOFLOT, conducted in close collaboration with Boliden within the strategic innovation program Swedish Mining Innovation (joint venture by Vinnova, Formas and the Swedish Energy Agency), a scale-up study, conducted at the Boliden pilot plant, showed that our in-house produced lignin particles had the potential to increase the revenue significantly, while at the same time contributing to the development of more eco-friendly mining sector and a synergy with the forest industry supplying the feedstock for the production of the OLPs. Core in this achievement is the use of the pilot scale organosolv pretreatment/fractionation reactor at LTU that allows the fractionation of lignocellulosic biomass into distinct streams of cellulose, hemicellulose and lignin, where the obtained lignin stream is of high lignin purity (>90%). This system is used to produce lignin-based micro-and nanoparticles with a negative zeta-potential to be used in a green flotation concept where the selectivity of the new reagents system is significantly higher compared to the traditional one. The recovery of the flotation process improved by 4-6% when the OLP system was used, compared to the conventional used xanthate.
- Within the EU project BIOMAC, we are upgrading our pilot organosolv pretreatment/fractionation rector to a continuous organosolv reactor, which is the first of its kind globally. Moreover, LTU is part of an open innovation test bed ecosystem for upscaling the market-readiness and production of nano structure bio-based materials. This network is placing Bio4Energy and LTU in an advantageous position within the European biorefinery research and is bringing increased attention to our research activities.
- Research on cellulose properties and cellulose derivatives resulted in new findings. The substitution of C-2 in cellulose was found to be slightly less dependent on water accessibility than the other carbons. A novel type of cellulose ether was synthesized using a lignin degradation product as substituent.
- Several new projects were approved that involve researchers from the platform, as well as other academic partners and companies. These include one project on mushroom-based processes for enhanced agriculture sustainability (financed by NordForsk, Sustainable Agriculture program), one project on developing valorization alternatives for spent mushroom substrate (financed by the Research Council of Norway, RFF program), and one project on production of fungal protein and lipids from lignocellulose (financed by the Formas program *Hållbar livsmedelsförsörjning i osäkra tider*).

The BioPolChem platform

This platform focuses on bio-based polymers for advanced and sustainable materials, and conversion processes that involve microorganisms and enzymes. Both conventional forest-industrial processes and products, e.g. cellulose and cellulose derivatives, and novel polymeric bio-based materials are included. Exploitation of the inherent characteristics of the raw materials is central, incorporating the sustainability aspect to reduce, recycle, and reuse.

P6 Chemical Catalysis and Separation Technologies

- Successful collaboration with industrial partners and universities has been undertaken for the commercialisation CHA membranes for biogas and natural gas upgrading.
- Highly permeable and selective DDR membranes for CO_2/CH_4 separation have been developed, that displayed the highest CO_2 permeance compared to the results in the literature.
- ZSM-5 catalyst with a size as small as 5 nm for methanol to distillate has been developed. The size is one of the smallest ZSM-5 catalysts. The small size could significantly reduce the mass transfer in the crystals.
- The development of a new method for CO_2 separation, where the merits of liquid (ionic liquids) and solid (ZIF-8) materials will be combined to form porous liquid to achieve optimal performance has been initialised.
- The development of a new method to convert lignin to bio-chemicals via electrochemical conversion together with H_2 production has also been commenced.
- A new collaboration was initiated with the "Kebnekaise" computing cluster for molecular modelling of PVDF modifications and derivatization, involving researchers from the platform as well as from Åbo Akademi.
- Electro-chemical pyrolysis of spruce needles project is advancing.
- The project around "Porous Liquids" is advancing.
- A new set up for desalination/water purification was purchased, at Chemical Technology at LTU, for use in research within the platform. This setup can be operated for direct contact membrane distillation and vacuum membrane distillation. In particularly, this setup can be used for long-term stability tests.
- The renewable GVL project (ECO-OIL) has advanced to PCT process at EPO. Within the ECO-OIL, letters of intent have been signed with a few companies to advance the commercialization of several different processes. The gasoline pilot plant was transported to Halmstad in the summer to be showcased for investors. The response was very positive; we produced the fuel for several hours and demonstrated it in rented lawn-mowers. The endeavor is now to scale-up the process to the intended sea container scale.
- The collaborative project with the University of Oulu (funded by Academy of Finland) to develop novel "mechanical energy to electricity" –devices (e.g. wearable electronics and sensors) is almost completed, and publications are forthcoming.

The CatSep platform

In order to make biorefineries successful, it is essential to develop suitable catalysts and energy lean separation technologies. The focus of this platform is fundamental research on novel integrated catalysis and separation processes designed for application in forest and other lignocellulosic-based biorefineries, encompassing both thermochemical and biochemical routes to fuels and chemicals.

P7 Environment and Nutrient Recycling

- The Bio4Energy strategic project ReAsh showed that P-rich ash particles perform similar to the commercial fertiliser triple superphosphate in plant pot trials with no nitrogen deficiency. The valorisation of such ash particles will however mainly depend on the economic value from the energy conversion – if existing CHP plants are utilised, the integration of resource recovery is a highly interesting route.
- Successful stimulation of algal growth through wood ash fertilization in the Åkerberg pit lake was performed. The fertilisation of microcosms with two P-rich wood ashes lead to an increase in chlorophyll-a and an algal element uptake of many elements, e.g., Ni, Zn, and Cd. These results suggest that fertilising pit lakes with wood ash can potentially be used as a remediation method for improving pit lake water quality.
- In another Bio4Energy-supported project, ANA-CONTA, novel venues of valorising thermally treated forest industry biosludge as adsorbents in environmental applications, was explored by a team of P7 researchers. Biosludge was transformed into hydrochar (via HTC), and pyrolyzed or activated, to assess the influence of pretreatment conditions on the adsorptive properties, focusing on PFAS substances. Steam activated hydrochars showed good capacity for PFAS removal in general, while pyrolyzed hydrochars showed lower removal efficiencies.
- Synchrotron-based experiments were conducted at a variety of synchrotron sources including Max IV, Soleil, and DESY by P7 researchers granted beam time in international competition. These infrastructures enable research at the forefront using a variety of techniques including X-ray diffraction, fluorescence, absorption and microtomography. The main scope has been the chemical speciation and morphology of P-rich ash particles and biochars to gain further knowledge on how they could be used in recovery, either directly or by post-processing into chemical products.
- A portable Scanning Mobility Particle Sizer was acquired (funded by the Faculty of Science and Technology, UmU), for semi time-resolved measurements of aerosol particle size and concentration in different indoor air environments, e.g. emissions from combustion sources.
- A portable 5-wavelength (UV-IR, 375-880 nm) aethalometer was acquired (UmU, funded by Kempe Foundation) for real-time measuring concentration of carbonaceous suspended particulates in for example diesel exhaust, woodsmoke, and other biomass burning emissions.
- Three P7 researchers were part of the UTRI lead application for UmU's Profile Areas with the proposal "Advancing Sustainable Transformations: Facilitating the green industrial transformation in northern Sweden". The application was selected as one of the five strongest, though not finally reaching the top three appointed by the university management. Bio4Energy is one very important research constellation, collaboration platform, and industrial network within this multidisciplinary initiative.

The EnviroNut platform

One of the key challenges when introducing new biorefinery concepts is to develop sustainable and resource-efficient utilisation routes of forestry biomass, industrial residues and organic waste streams, including closing the loops of nutrients and minerals, as well as minimising the potential environmental and health impacts. This platform aims at advancing the understanding related to critical research questions on the environmental aspects of sustainable forestry, bioenergy and biorefinery processes.

New strategic projects

Twenty percent of all funding to Bio4Energy is set aside as **Strategic Funds** used to create synergies and explore and address new and important avenues of research.

Our strategic projects:

- Concern high-quality research dedicated to the biorefinery field;
- Involve collaboration between research and development platforms and research groups;
- Are targeted at finding solutions to global problems and strengthening the development and competitiveness of Sweden and Swedish industry and;
- Support young Bio4Energy researchers in a critical phase of their academic career.

In the 2022 call for **free strategic funds (2023-2024)**, six 2-year projects were granted, each at a total budget of 2.1 MSEK, according to below.

Expansion of biorefinery feedstock supply by mobilization of woody residues from multi-functional silviculture treatments and marginal land operations – From Trash To Cash
Dan Bergström (SLU, P1), Åsa Lindman (LTU, P1), Elisabeth Wetterlund (LTU, P1), Charilaos Xiros (Processum), Marcus Öhman (LTU, P4)

Circular and sustainable production of bioplastics with the help of photo-synthetic microorganisms – Proof of concept
Francesco Gentili (SLU, P7), Christiane Funk (UmU, P5), Carmen Cristescu (SLU, P1), Lalie Kossatz (Processum), Gunnar Westin (Processum)

Green H_2 and bio-based aromatic chemicals from lignin
Xiaoyan Ji (LTU, P6), Leif Jönsson (UmU, P5), Tomas Gustafsson (Processum)

Novel environmentally friendly hydrophobic zeolite membranes and coatings
Jonas Hedlund (LTU, P6), Nils Skoglund (UmU, P7), Linn Berglund (LTU, P5)

Trade-off between wood quantity and quality in response to nitrogen fertilization - Is there a breaking point for beneficial nitrogen level in boreal forests?
Hannele Tuominen (SLU, P2), Sandra Jämtgård (SLU, P7), Zakiya Yassin (RISE, P2)

Design of biochar from residual streams – influence of fuel and process parameters on biochar properties for water and soil applications
Anna Strandberg (UmU, P3), Christoffer Boman (UmU, P7), Magnus Rudolfsson (SLU, P3), Fredrik Forsberg (LTU, P4), Mirva Niinipuu (RISE, P4)

Photos by Anders Kroon, Francesco Gentili, Anna Strandberg.

Bio4Energy graduate school

From the end of 2022, the **Bio4Energy Graduate School** has a new coordinator, Dimitris Athanassiadis of the Swedish University of Agricultural Sciences (SLU). The graduate comprises two (soon three) courses for PhD students and early career scientists. In 2022, the graduate school's popular course "Biorefinery Pilot Research", was "restarted" after the pandemic years.

During 2022, Bio4Energy had 70 active PhD students. Twelve PhD students defended their doctoral theses in 2022, and five their licentiate theses. Big congratulations to you all – and an extra congrats to **Mojtaba Nobandegani** who became Bio4Energy's 100th doctor!

PhD theses

Sonja Viljamaa, SLU, Dept. of Forest Genetics and Plant Physiology (P2)
"Carbon allocation in aspen trees "
Main supervisor: Totte Niittylä

Feng Chen, SLU, Dept. of Forest Biomaterials and Technology (P3, P5)
"Combined production of edible mushroom and biofuel from lignocellulosic residues"
Main supervisor: Shaojun Xiong

Marjan Bozaghian Bäckman, SLU, Dept. of Forest Biomaterials and Technology (P3)
"Lignocellulosic residues for bioenergy: effects of storage, fuel design, and combustion characteristics"
Main supervisor: Sylvia Larsson

Ali Hedayati, LTU, Dept. of Engineering Sciences and Mathematics (P4, P7)
"Ash transformation in thermochemical conversion of different biomass resources with special focus on phosphorus"
Main supervisor: Marcus Öhman

Gustav Häggström, LTU, Dept. of Engineering Sciences and Mathematics (P4, P7)
"Studies of ash transformation processes in thermochemical co-conversion of phosphorus-rich manure and sludge with biomass residues"
Main supervisor: Marcus Öhman

Joel Falk, LTU, Dept. of Engineering Sciences and Mathematics (P4, P7)
"The fate and ash transformations of phosphorus in combustion of biomass and sewage sludge"
Main supervisor: Marcus Öhman

Thamali Rajika Jayawickrama, LTU, Dept. of Engineering Sciences and Mathematics (P4)
"Particle-fluid interactions under heterogeneous reactions"
Main supervisor: Kentaro Umeki

Ángel David García Llamas, LTU, Dept. of Engineering Sciences and Mathematics (P4)
"Particle dynamics during biomass devolatilization: Momentum exchange and particle dispersion"
Main supervisor: Kentaro Umeki

Mitul Kumar Patel, LTU, Dept. of Engineering Sciences and Mathematics (P5)
"Improving properties of poly(lactic acid) biopolymer for use in food packaging"
Main supervisor: Kristiina Oksman

Bony Thomas, LTU, Dept. of Engineering Sciences and Mathematics (P5)
"Trees to supercapacitors: green energy storage for sustainable future"
Main supervisor: Kristiina Oksman

Mojtaba S. Nobandegani, LTU, Dept. of Civil, Environmental and Natural Resources Engineering (P6)
"Adsorption and Mass Transport in Zeolite Membranes"
Main supervisor: Jonas Hedlund

Jingjing Chen, LTU, Dept. of Engineering Sciences and Mathematics (P6)
"Heat-transfer Enhancement for Slurries from Biogas Plants --- Properties, processes, and thermal systems"
Main supervisor: Xiaoyan Ji

Licentiate thesis

Marzieh Bagheri, LTU, Dept. of Engineering Sciences and Mathematics (P1, P4)
"Integrated sewage sludge treatment scenarios – techno-economic analysis on energy and phosphorus recovery"
Main supervisor: Elisabeth Wetterlund

Nikolaos Papafilippou, LTU, Dept. of Engineering Sciences and Mathematics (P4)
"*Modelling of Biomass Syngas Combustion with CFD"*
Main supervisor: Rikard Gebart

Marcelo Dal Bello Takehara, LTU, Dept. of Engineering Sciences and Mathematics (P4)
"Experimental analysis of a pulverized biomass-fired entrained flow reactor under imposed acoustic oscillations"
Main supervisor: Rikard Gebart

Ali Valizadeh, LTU, Dept. of Engineering Sciences and Mathematics (P4, P7)
"The effect of surface morphology on bed particle layer characteristics in fluidized bed combustion and gasification of woody biomass"
Main supervisor: Marcus Öhman

Fangfang Li, LTU, Dept. of Engineering Sciences and Mathematics (P6)
"CO_2 electrochemical reduction: Techno-economic evaluation and experimental research for producing methanol"
Main supervisor: Xiaoyan Ji

Media and communications

In 2022, much work was put into building a new website for Bio4Energy. It has a new design and is substantially scaled down compared with the previous site. New features include a section for collaboration projects supported through Bio4Energy's Strategic Funds, a section displaying the Bio4Energy Advisory Board, and a searchable publications section, showcasing our (to date) 1500+ peer-reviewed scientific journal papers.

Bio4Energy news have been addressed by both specialist press within our sector and general media. A few examples are ATL, Bioenergitidningen, Land, Västerbottenskuriren, Svenska Yle, SVT Västernorrland, Affärer i Norr, Energipress, Processnet, SVT Nyheter and Forskning.se.

Topics that received notable attention in news and media during the year include:

- A fundamental research breakthrough on the way in which plants adapt their lignin content, using enzymes.
- A large new study to assist Sweden's iron and steel industries in phasing out fossil fuels.
- A new step in Bio4Energy's large and long-running quinoa collaboration project with Bolivian partners, that should enable the identification of product lines.
- A new project to create a biorefinery for organic waste materials.
- On-site off-gas sampling of biogenic CO_2 from SunPine, followed by enzyme assisted CO_2 purification and enrichment, for processing into chemicals.

Other outreach activities

Bio4Energy also communicates research findings through other outreach activities. A few examples from 2022 are:

- A number of Bio4Energy researchers were among the approximately 500 scientists signing the "Scientist Letter regarding the need for climate smart forest management" which was sent to the presidents of the European Commission, the European Parliament, and the European Council in October 2022.
- Outreach via GVMs Instagram channel on activities around the microcosm experiment as well as the ongoing climate chamber experiments.
- Christoffer Boman (EnviroNut) was co-author/expert writer for a special topic report Air and Environment (Tema Rapport Luft och Miljö) on particulate air pollution, on commission by the Swedish EPA.
- Popular scientific lectures and presentations in various contexts, of which a few examples during 2022 were during "Våga fråga" at Curiosum in Umeå and "Pint of Science" at Gröna Älgen in Umeå.

Awards and commissions of trust

Rainer Backman, Matias Eriksson and Markus Broström (all ThermoChem) were awarded UmU's Faculty of Science and Technology's collaboration award 2022. The prize motivation emphasised their work in creating a competence centre for the sustainable production of cement and quicklime.

Shaojun Xiong (FeedPro) made it to IVA's "100 list" (top 100 innovative research projects with potential for industrial implementation) for the second year in a row, this time together with Carlos Martín and Feng Chen (both BioPolChem) with the project "Cultivation of mushroom for non-meat protein and renewable energy".

Kristiina Oksman (BioPolChem) was LTU's most cited researcher of 2022, as well as the 11th most cited researcher in Sweden within materials sciences.

Luisa Völtz (BioPolChem), placed third in the MWP (Marcus Wallenberg Prize) Young Researchers pitch presentation.

Rosario García-Gil (ForFeed) received the Gold Medal for Distinguished Service from SLU- The medal rewards exemplary, exceptional efforts of lasting value that benefit SLU or the sector in which the university is active.

Jonas Hedlund (CatSep) received the Innovator of the year award from LTU for his long-time research on zeolite membranes that may e.g. be used for purification of biogas to vehicle gas, to save energy and reduce CO_2 emissions.

Nils Skoglund (EnviroNut) was appointed member of the advisory board for FlashPhos, a €15 million Horizon 2020 industrial demonstration project hosted in Germany for the recovery of elemental phosphorus as P_4.

Johannes Hanson (ForFeed) was selected as the head of the department of Plant Physiology (UmU), and Totte Niittylä (ForFeed) started as the head of the department of Forest Genetics and Plant Physiology (SLU).

Bio4Energy's researchers also hold a large number of commissions of trust, and act as members on various boards and committees. Examples include the Scientific Council of Centre for Business and Policy Studies (SNS), the European Federation of Chemical Engineering (EFCE), IEA Bioenergy, the MWP Selection Committee, the MAX IV reference group, the EFCE, the EU COST action EUAlgae, Treesearch, and several of the program counsels and boards for the Swedish Energy Agency's research programs

Bio4Energy Advisory Board

During 2022, we would finally welcome Bio4Energy's external Advisory Board to a physical meeting in Umeå. The theme of the meeting was **"Biocarbon – material, energy carrier and carbon sink".** In addition to presentations from several Bio4Energy researchers from three different platforms and from two Advisory Board members, the meeting also gave the opportunity to show our activities at Biomass Technology Centre (BTC).

Peter Axegård
C-Green Technology AB
Senior Advisor

Charlotte Bengtsson
Skogforsk
CEO

Erik Dotzauer
Stockholm Exergi
Policy expert

Ann-Britt Edfast
Edfast & Wallén
konsult

Björn Fredriksson-Möller
St1 Biogas
Senior specialist

Anna Karlberg
Stora Enso
VP Forest R&D

Johanna Mossberg
RISE
VP Biorefinery & Energy

Torgny Persson
Swedish Forest Industries
R&I director

Linda Werner
St1
Head of Future Upstream

Martin Wimby
Valmet Recovery Business Unit
Technology Director

At the end of 2022, long-time collaborator Björn Sundberg, Stora Enso, announced his retirement. Björn has been with Bio4Energy since the very beginning – originally as professor at Department of Forest Genetics and Plant Physiology at SLU in Umeå., and now during the last couple of years as a member of the external Advisory Board.

We wish Björn a happy retirement and welcome Anna Karlberg as his replacement in our Advisory Board!