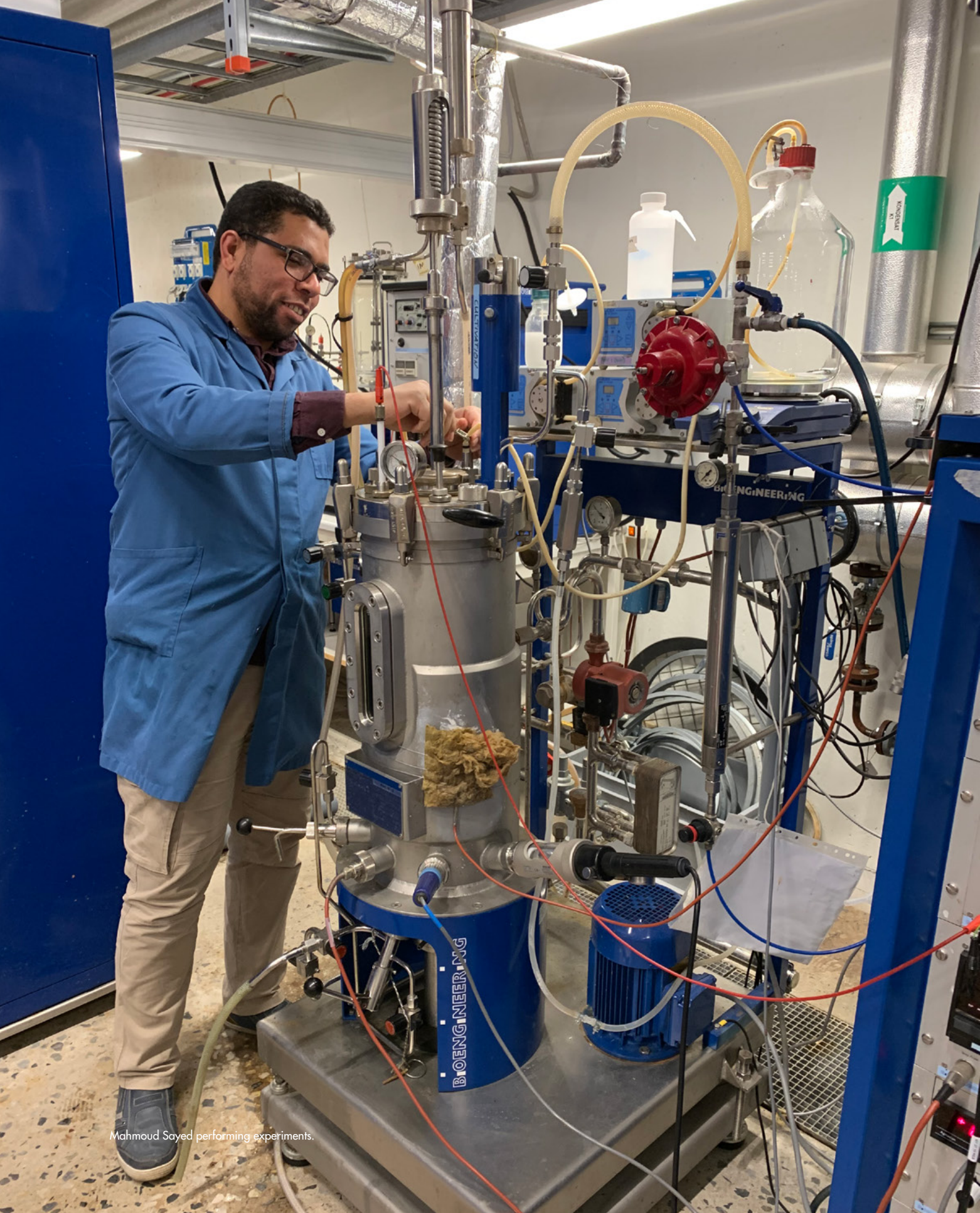
STEPS

Sustainable Plastics
and Transition Pathways

ANNUAL REPORT 2023

Illustration: Catrin Bengtsson



Mahmoud Sayed performing experiments.

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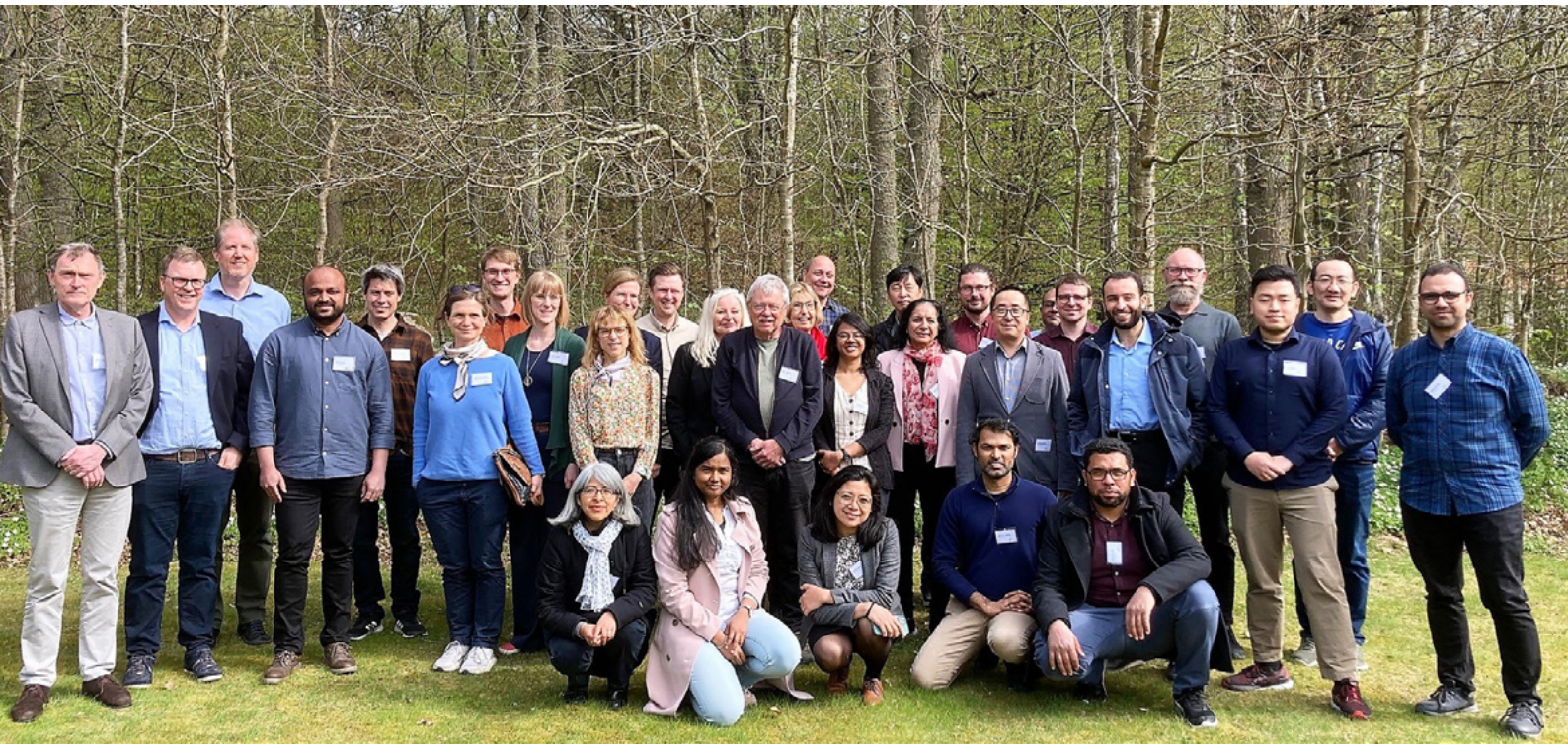
Cover illustration: Catrin Jakobsson



STEPS programme meeting in Backaskog in May.

STEPS programme

STEPS research programme was initiated in 2016 with the vision of a future society in which plastics are sustainably developed, produced, used and recycled in a circular economy.

STEPS is based on a close collaboration between academic and industry partners. The consortium includes Lund University, University of Copenhagen, RISE, IVL Swedish Environmental Research Institute, 21 industrial partners and the County Council of Scania.

Our work on transition to sustainable plastics is divided into three research work packages: green building blocks, bio-based polymers, and plastic governance.

During our existence as a programme, we have:

- Designed novel biobased monomers that have been made into polymers.
- Produced two plastic demonstrators: a floor coating and textile fibres with superior qualities and low climate impact.
- Suggested transition pathways towards a sustainable plastic system.

"We believe in strong collaboration between academia and industry at an early stage through which we can ensure that our research corresponds to real societal needs and questions", says Professor Rajni Hatti-Kaul, STEPS Programme Director.

Illustration: Frida Nilsson

Message from the Board

Now that STEPS is drawing to a close after almost eight years, it is easy to get nostalgic. It is important to look at all the achievements made during these years. And it is even more important to think about the impact and legacy of STEPS.

At the kickoff meeting in 2016 there was a lot of enthusiasm and ideas. As the years have passed, the focus on plastics from a political perspective has increased dramatically, showing the urgency and forward-thinking in creating STEPS as a multi-disciplinary programme. The three work packages bring different perspectives and fields of research together and thus provide a more holistic view. It is like in standardisation or many other fields – the more stakeholders you have around the table, the more well-rounded the results and the smaller the risk of serious mistakes because you missed an important perspective. Is that the easiest way to do things? No, but it is a fact that everyone involved in STEPS has learned a lot that they would never have if they just stayed within their field.

This of course also brings challenges, the scientists in work package three have had to tackle a whole new field and a complex one at that. But they have gradually found their place in STEPS and have generated a lot of interest and attention over the years through deliverables such as policy briefs, a survey on consumer attitudes towards plastics and not least the critical investigation of the petrochemical industry, including their creation of lock-ins and defense of status quo.

But enough nostalgia – let's focus on what will happen next, after the final conference and when STEPS is officially ended. What will the legacy be? What difference will STEPS have made?

It is a well-known fact that there is often a vacuum when any type of project ends. You normally do some outreach in the beginning, but at some point, the results have to "fly on their own". It does not matter how good the research results are, it is when they are used that they make a difference. The use might not be what was originally intended though. A medicine developed for one purpose might be much more useful for something else. Or a standard developed to be widely used by industry is developed slower than certification schemes but instead becomes a benchmark in international negotiations and research on the topic.

The key message here is – it is important to make sure that the scientific results when it comes to new materials and methods are upscaled, used by industry and built upon in research whenever possible. But we also need to think about how to upscale and build on the results from work package three. The findings there can (and in some cases already do) have a huge influence on the policy landscape as well as the public perceptions.

We should also look at the ripple effects, some of which might not have been possible to foresee, when evaluating the impact a few years from now. Has the knowledge gained by researchers and company representatives been put to good use? Have the presentations held and the articles written informed key people on important topics and thus changed the decisions they take? Can the experiences from this multi-perspective programme be used as a model and knowledge-base for others wishing to do the same on other topics? Have connections and networks been built that continue to work together on finding ways to make the world a better place? And, maybe most important of all, what are all the brilliant PhD students that have been educated through STEPS doing?

Let us all take a minute and think about – what do I want the legacy of STEPS to be? What can I do during 2024 to make it happen? Are there any ripple effects that I can set into motion? And how can I use all that I have learnt in the best way?

Maria Gustafsson

Message from Management

As we enter the final year of the STEPS programme, it is both timely and relevant to reflect not only on the past year, but on the entire programme period to get a perspective on our achievements and what is left to do. The past years have seen EU implementing a set of policies to support transition to a circular plastics economy. Besides banning single use plastics, enhanced recycling of plastics has been the main focus in contrast to decoupling of plastic production from fossil feedstock. There are also ongoing Global Plastics Treaty negotiations among 160 UN member countries, which are supposed to be finalised around the same time as the STEPS programme. These negotiations are being closely monitored by STEPS researchers attending the different sessions during 2023 in person.

For STEPS, the year started with three of our PhD students from each one of the three work packages successfully defending their theses. We are also proud of the two students from work package two in STEPS who have moved on to do their postdoctoral studies at the prestigious universities Stanford and MIT in the United States.

External communication has been a strong feature of STEPS. We participated in a Mistra organised event in Almedalen to discuss the importance of packaging irrespective of the future of the food systems, presented at Naturvårdsverket's annual Plastbubbel in Stockholm, and organised two events during Sustainability Week in Lund on textiles and plastic recycling. We also organised a summer school on sustainable plastics with help of some STEPS researchers, board members and industry partners, and even guest speakers from academia and industry. We will continue our focus on education in 2024, with a school on sustainable plastics aimed at municipalities, regions and companies.

STEPS researchers continued to be a strong voice in the societal discussions on plastics, featuring in several media articles and interviews on topics such as the Plastics Treaty, large-scale investment in plastic production, and the plastic bag levy which will be abolished from November 2024. We also submitted a grant application with several partners to extend our work on communications related to design, architecture and art, which will allow us to further communicate our work on plastic pathways for a circular plastics economy in new and interactive ways, should it be successful.

Some of the important research activities during 2023 in work package one and two have been scaling up the processes for production of building blocks, polymers, and chemical and enzymatic recycling of plastic including mixed plastic waste. Here, the close interaction with our industrial partners has been extremely fruitful and necessary. Work package three has continued its work on the global plastics treaty process as well as issues around, e.g., the sourcing of green carbon, PET recycling and standardisation, and plastics and financing.

Finally, our collaboration in STEPS has formed the basis for new and fruitful collaboration, something we are very proud and happy about. We secured 10 million SEK in funding for a new project from the Swedish Energy Agency for continuing work on scale up of furan production from lignocellulosic components together with Alfa Laval, Bona, Nordic Sugar and Perstorp. Additionally, we got a smaller fund of 0.5 million SEK from Re-Source for producing and evaluating two furan derivatives in wood coatings; the project is included as a new mission in STEPS.

This annual report will provide you with more insights on our activities as well as reflections from some researchers and industry representatives.

Rajni Hatti-Kaul
Photo: Kennet Ruona

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Three work packages

Work Package One

This work package has focus on production of polyester building blocks from surplus renewable feedstocks using clean and cost-effective process technologies.

In 2023, research on building blocks from sugar, lignin and recycled plastic was continued and Oliver Englund Örn defended his thesis on microbial production of aromatic and aliphatic building blocks. Among the sugar-based products, focus was on furan derivatives. An alternative catalytic route was used for efficient carboligation of 5-HMF (5-hydroxymethylfurfural) to form a C-12 aromatic triol, which was further oxidized to C12-diol. Evaluation of these chemicals as monomers and crosslinkers in polyurethane coatings is continuing in a Re-Source funded project "Networking with Nature". Development of biocatalytic process for oxidation of 5-HMF to FDCA (2,5-furandicarboxylic acid) using a novel microbial platform was intensified. Further funding for upscaling of 5-HMF and FDCA production was obtained from the Swedish Energy Agency.

With respect to lignin, the work with creating monomers that can be used in polymer production is ongoing. The focus has switched from kraft lignin to more specialised lignins, such as lignosulfonates and soda lignins. These have interesting properties, and are to some extent, more suitable for depolymerisation with oxidative cleaving. The oxidative depolymerisation is milder than base catalysis, and the preservation of the resulting monomers are high. The yields of monomers have reached beyond the current state-of-the-art commercial processes, and, after suitable separation, can be turned into renewable based polymers. Separation of the monomers was further investigated in a EU-funded spin-off project together with the University of Porto, with successful outcome.

A number of novel chimeric polyester hydrolysing enzyme variants generated in a combinatorial library were screened for their activities against amorphous, semi-crystalline and crystalline forms of PET. A few enzyme candidates with promising activity profiles were also tested against other polyesters and mixed plastic waste. The latter was scaled up to process 100 g/L waste and terephthalic acid product was recovered in a pure form.

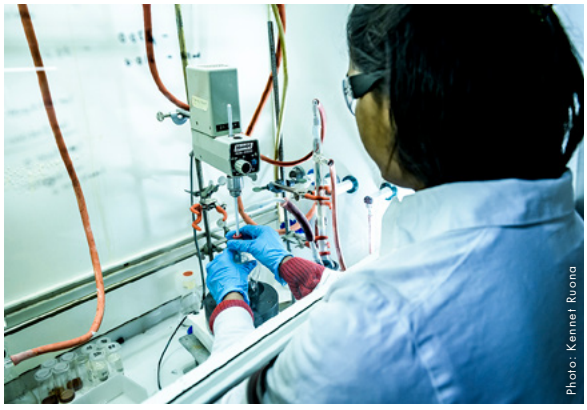


Photo: Kennet Ruona

Work Package Two

This work package investigates polymerisation, processing and characterisation of bio-based plastics using potentially the building blocks from work package one and other sources toward applications such as fibers, coatings, foams, packaging, and oral hygiene products. Particular attention was paid to enhance the recyclability of the designed polymers and materials.

In 2023, we continued our investigations on the development of new biobased recyclable polyesters and polyurethanes in lab scale. Various new polyesters with acetal structures have been designed and synthesized, and their chemical recyclability was explored. Two PhD students, Smita Mankar and Nitin Valsange, have defended their theses. Upscaling investigations on the polymerization of a methyl paraben-based monomer have been successful at Clariant using the catalysts developed by Clariant as well as other commercial catalysts. Further upscaling polymerization was initiated at Sumitomo. This investigation will be relevant for Mission three as well as Mission two.

Work Package Three

Work package three has the main task to assess potential transition pathways to develop research-based advice on policy and industrial strategies for sustainability in the longer term. Governance and policy implications for a circular plastics economy are addressed, including social dimensions and the roles and responsibilities of key actors.

In 2023, research articles were concerned with topics such as (1) examining various lock-ins around the petrochemical industry that are central to the continuing increase in production and consumption of plastics, (2) demonstrating the substantial public support in the Swedish population for ambitious policies targeting the environmental consequences of plastics, and (3) the challenges of implementing and upscaling zero-waste supermarkets. In addition, a letter on plastics and finance was published in Science. Finally, many WP3 researchers are active in the Scientists' Coalition for an Effective Plastics Treaty (SCEPT), formed by scientists to coordinate the scientific efforts around the treaty-making process.

A MSc thesis on the sourcing of green carbon, in collaboration with IKEM, was completed and one thesis on PET standardization for recycling was finalized. Stine Madsen defended her this on Pursuing a circular economy in the Danish Waste Sector. Preparations and final writing was done for Ellen Palm´s PhD thesis to be defended on April 5, 2024 (Decarbonising plastics: On the technologies and framings of carbon capture and utilization). Planning and preparations were also made for the workshop on The Future EU Governance of Plastics co-organized by the EEA (Copenhagen 2024-01-25).

Stine Madsen is nailing her thesis at the Social Science Faculty in Lund.

Missions

STEPS missions aim at intensifying the collaboration between industrial, regional and research partners by co-developing and evaluating carbon-neutral plastic products for specific target applications. Missions are formed for developing better products, identifying challenges for transition, and to suggest potential pathways for circular economy and reduced plastics pollution.

Mission 1: Biobased plastics for packaging applications

Mission leader: Tetra Pak. Other STEPS stakeholders involved: GPS, Lund University, Nordic Sugar, Orkla Foods.

The mission was ended during the year, and communicated through dissemination of two scientific articles; **Exploring the industrial perspective on biobased plastics in food packaging applications–Insights from Sweden** (K Molina-Besch, H Keszleri, Sustainable Production and Consumption, 2023) and **Use phase and end-of-life modeling of biobased biodegradable plastics in life cycle assessment: A review** (K Molina-Besch, Clean Technologies and Environmental Policy, 2022).

Mission 2: Biobased textile fiber

Mission leader: RISE, IKEA. Other STEPS stakeholders involved: Clariant, GPS, Ludvig Svensson, Lund University.

Research work continued on the synthesis of Polyester polytrimethylene furandicarboxylate) (PTF) from biobased 2,5-furandicarboxylic acid (FDCA) and 1,3-propanediol. The main aim this year was to improve the flexibility of PTF as a suitable material for fiber application. In addition, inducing of the third monomer into a PTF chain in order to increase its flexibility and processability was tried. The attempt of using low molecular weight of bio-PTF was also discussed with IKEA. One possible application of such low molecular weight of PTF is to produce nonwoven fabric by melt blowing. In addition, the inducing of the third bio-monomer into PTF chain in order to increase its flexibility and processability was tried. During 2023, research on the synthesis of FDCA based polyesters was continued. The incorporation of third biobased monomer succinic acid could improve the flexibility of the synthesized polyesters. Changing the diol from 1,3-propanediol to 1,4-butandiol can improve the processability of the polymer. In addition, biodegradation tests show that FDCA-based polymers have higher biodegradability than terephthalic acid-based polymers. However, the scalability of polymerization of FDCA monomer with diols is difficult. The optimization of the polymerization of FDCA monomer with diols is ongoing.

Mission 3: Biobased toothpick

Mission leader: TePe. Other STEPS stakeholders involved: Clariant, Lund University, Nordic Sugar.

A series of AB-type polyesters have been synthesized in lab scale in work package two, which showed desirable thermal properties and promising potential for further optimization and upscaling investigations toward TePe's toothpick applications. A selected monomer based on methyl paraben was polymerized at Clariant AB, and the preliminary result was encouraging. The monomer was then delivered to Sumitomo for kg scale polymerization attempts. Purification of the polymers synthesized at Clariant toward fibre spinning (Mission 2) was also investigated.

Mission 4: 3D printed foam

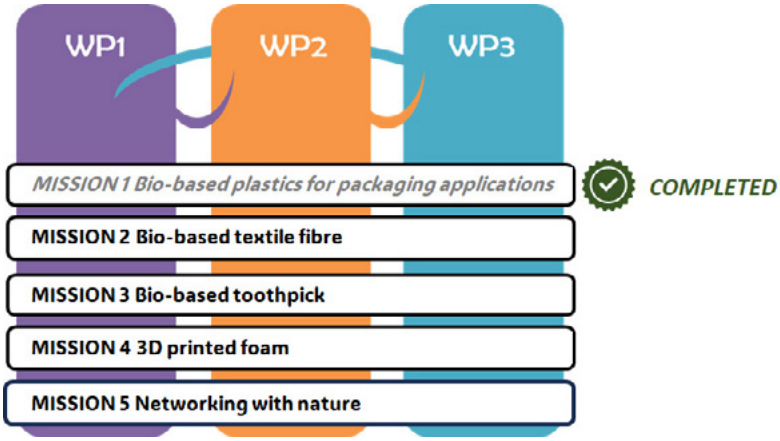
Mission leader: Jonas Ihreborn AB. Other STEPS stakeholders involved: Lund University, Nordic Sugar.

In 2023, we have presented results on numerical modeling of the compressive strength of 3D-printed structures at the ICED conference. Satabdee Dash has successfully defended her licentiate thesis on flexible 3D-printed lattice structures and we have begun work on creating a demonstrator upholstery product. We have also evaluated the suitability of more biobased plastics for extrusion based printing.

Mission 5: Networking with Nature

Mission leader: Bona. Other STEPS stakeholders involved: Lund University, Nordic Sugar, Perstorp

Mission 5 started in 2023 as a result of funding from Re-Source for the project "Networking with Nature" based on our work on making C12-furan based functional monomers with potential to crosslink polyurethanes for floor coatings in a new energy-efficient and environmentally benign way. The project involves Nordzucker, Perstorp and Bona as stakeholders, which form a value chain from raw material to product application. The work has been initiated and one of the two monomers has already been provided to Bona for evaluation, while efforts to make the second monomer are in progress.



Left image: Zengwei Guo (RISE) is collecting PBF fibers during a large scale experiment in Mission 2. Top right image: PBF filaments and pellets. Lower right image: Miniature model of 3D-printed foam produced in Mission 4.

A chat with our researchers and industry partners

A new aliphatic monomer can improve the recyclability of hard plastic applications

Sudhir Kamani finds his research in STEPS to be a fitting continuation of his career in plastic recycling. Originally from India, he did his PhD in organic chemistry in Taiwan, where he also worked in a similar consortium focusing on green energy transitions. Now, he is a postdoc in work package two, focusing on bio-based polyester synthesis, from monomer production to polymerization and recycling.

– Moving into polymers was a natural progression for me since the chemistry is very similar to organic chemistry. As a child, I saw clean environments, but as I grew I saw plastic pollution so often. I always have a thought why the life forms on earth have to suffer for the favor of humans.

– After my PhD, I joined a consortium that is working on green energy transitions in plastic research, which was my entry to sustainable plastic research. I wanted to work on something that can give second life to waste plastics, more often the waste plastics are not that old, which means up to 95% of their original properties are still intact. Either we can directly reprocess them or through chemistry tools we can upcycle them to a new product. One other way to build degradable polymers is by using bio-based raw materials, says Sudhir Kamani.

He thinks the Swedish pulp industry can provide raw material very effectively, as their by-product lignin is the source for a variety of monomers to be used in bio-based plastics. Within STEPS, he has therefore focused on developing new bio-based polyesters with improved thermal and recyclability properties. Since he arrived in Sweden, he has, together with Baozhong Zhang, Patric Jannasch and other researchers in STEPS, produced a series of completely new rigid aliphatic polyesters, with very promising results. The monomer has a rigid bicyclic structure which in combination with different bio-based diols produced very high glass transition temperature (range 60 – 103 °C) polyesters, which means the material would not soften at this temperature, making it suitable for the production of hard plastic for hot fill applications. Moreover, this polyester is chemically degradable to its monomeric constituents.

– It is rare for a linear polyester with fully aliphatic functional groups to have such high glass transition temperature, and also good recycling capacity. This is very exciting and opens up avenues for new biobased products made out of aliphatic polyesters, which are also recyclable again and again, says Sudhir Kamani.

Sudhir Kamani

Sudhir Kamani and his colleagues´ results are so far unique and not mirrored in any other academic literature. As a next step, they are aiming to develop a patent for the polymer.

– With a patent, we will have the chance to display our work to industries. If they are looking to use this type of polyester, then we can offer them the patent for business purposes.

Sudhir Kamani is glad that there are many industrial partners in STEPS, since this collaboration gives further value to his research in terms of input and opportunities to discuss results. It is also challenging and rewarding to know that his work would get a chance to solve some of the real industry challenges.

In the future, he hopes his research can help change the current plastic system. He is a firm believer in the three R's: Reduce, Reuse and Recycle.

– It is inevitable that there is plastic everywhere in our society. But we also have many ways to reduce, for example, regulate the volumes produced, effective reuse, and recycle efficiently over many cycles. This is also where my research comes in to play, and where I want to contribute.

Improved enzymatic degrading process shows a way forward to recycle postconsumer PET

For Mohamed Ismail, the STEPS programme – with its interesting research, close collaboration with partners, and sustainable direction – is the perfect fit. The way of life in Sweden brought him back to Lund as a postdoc in STEPS work package one after doing a PhD in Germany, and a postdoc in the UK.

– I first came to Lund for my master's, on a scholarship from Egypt, where I'm from. In Egypt, my training was in Microbiology and Mycology, however, during my master's I got increasingly interested in enzymes since they work as catalysts and make all life possible. I am passionate about trying to understand their structure and function, and to see how one can manipulate them in different ways.

– What I especially like with STEPS is that its different work packages are trying to close the loop, and that there is this mentality of joining the spots together. When you work in the lab, like I do, it is important to connect what you do to society. This is what drives me in my work, to produce something that is also good for the environment.

Within STEPS, Mohamed Ismail is active in work package one, where he works with different enzymes and with synthetic biology, which focuses on connecting different enzymes together to create new circuits, or pathways for the production of certain building blocks and high value chemicals. Currently, he is working with enzyme development to break down certain polyesters, as well as creating different building blocks with the help of enzymes, via so called metabolic engineering, where one introduces new genes or removes present genes in the organism to be able to do its function. The work has so far yielded very good results, and he and his colleagues can now degrade up to 100 grams of mixed plastic waste per liter using minimal concentration of the enzymes. They can also fully degrade different types of polymers.

– We are very happy with what we have done. Degradation is a good option once the plastics cannot be recycled anymore. We degrade the plastics into monomers (building blocks), and recover the monomers in pure form. This means that we can reuse the material again to make the same product, or to produce other high value chemicals and materials.

The results of work package one not only mirror similar results found in academic literature, but also show improved degradation results for PET. Mohamed Ismail and his colleagues now hope to publish their results, and also file a patent application for their enzymatic process.

Mohamed Ismail

Does he think that the use of enzymatic degradation will grow over time?

– I definitely think we need to develop this area since it has many uses, not least for material that cannot be recycled, like PET when reaching its End-of-Life. Already a company in France (Carbios) is developing enzymes for plastic degradation and recycling and is in the process of constructing an industrial plant for enzymatic degradation.

After STEPS is finished, Mohamed Ismail hopes to stay in Sweden, and build his own research group over time.

– Rajni Hatti-Kaul is an amazing colleague and supervisor. I have learnt a lot in her group, and I hope to be able to pass on my knowledge to my own students in the future.

"The focus of increased sustainability must be the concern for all the links in the value chain"

Clariant has been part of STEPS since its inception in 2016. As the program is nearing its end, in December 2024, Sales Manager Carina Stjernman, has many reflections. According to her, the knowledge exchange and research production, are the areas where STEPS have come the furthest. In STEPS's final months, she hopes that Clariant will also have the opportunity to characterize STEPS' own monomers.

– To get the chance to be a part of such a sustainability consortium as STEPS is very valuable. The focus of increased sustainability must be the concern for all links in the value chain.

– In hindsight, I think we should have been much more proactive in bringing in an actor who can actually scale up polymers. Now we miss this perspective in the program. We could also have brought in companies that are used to producing bio-based polymers in order to learn from them.

Carina Stjernman also believes that more motivation is needed in the entire plastic system if there is to be a change towards more sustainable, biobased plastics – because there is biomass available on the market, even if competition from biofuels is great.

– It takes a long time to get a new biobased polymer out to companies. One party has to produce it, another has to scale it up, and a third party make products from it. The industry often uses the same molds for injection molding for at least ten years. A lot needs to be done for them to change their forms and invest in handling a new polymer, biobased or not.

– If we are to bring about a change, there must be a will. The way I see it, biobased polymer companies should push to get companies to choose them over companies that produce fossil-based plastics.

Carina Stjernman

– I also believe that it is important that academia makes efforts to find relevant areas of use in connection with the development of a new monomer. Will the price be reasonable? Is it sustainable? Can it be scaled up? This is partly what we have done within STEPS, which has been an important part, even if we have lacked someone who can take it further.

Carina Stjernman further believes that the STEPS program has been valuable for creating contacts and networks. The program itself is a way to drive sustainable change. By collaborating with academia and industry, new ideas and working methods can take shape. She hopes that the work to produce monomers in larger quantities will have time to bear fruit before STEPS ends.

– We would like to see this particular work continue! Here, we from Clariant can contribute in a constructive way. In the future. I also hope that we can jointly share everything we have learnt within STEPS as a way to inspire transition towards more sustainable plastics.

"It is an exciting time to work with plastics"

Anette Munch Elmér is Development Manager at Polykemi. She is certain that the market for recycled plastics will grow substantially in the coming years and is positive about the future for sustainable plastics.

Polykemi joined STEPS in 2020 and works with both post-industrial plastics and recycled consumer plastics. Their aim is to increase their assortment, but securing large quantities of raw material with the desired quality can be a challenge. This is because the plastics can come from many different sources, for example from various smaller injection molding businesses, says Anette Munch Elmér. All plastic that Polykemi buys must be quality assured and characterized before it is made into different types of granules that they then sell on to injection moulders. These producers, in turn, produce different components for the automotive industry.

– We have an increasing demand for recycled plastic, but also face challenges to meet this need. To create a better supply, it has to become easier to trade in recycled plastic raw material.

Post-consumer plastics are becoming more interesting

– Our customers are also becoming more interested in post-consumer household plastics. In the long term, this is something we want to work with more, not least because there are ongoing discussions at EU level that post-industrial plastics should not be defined as recycled.

A legal requirement that 25-30 percent of all plastic parts in cars must consist of recycled plastic is also imminent – through the so-called "End-of-life Vehicle" directive. Pending a decision at EU-level, the regulation will probably come into force by 2030. These different proposals are set to increase the demand for post-consumer plastic even more. Anette Munch Elmér is positive to this development but highlights the need for e.g. Swedish laundries that are able to clean the dirty plastics. Because currently Polykemi is not able to work with the household plastic handled at the sorting facility, Site Zero, in Motala because it is dirty and therefore unsellable. Today it has to be sent abroad to be washed.

– We need to create more value chains for both recycled consumer plastics and post-industrial plastics in order to bring down the price and increase availability on the Swedish market – for example establishing actors who can take care of household waste, reusing the plastic when dismantling cars, and setting up flat-bed laundries here in Sweden.

She is optimistic about the future because she believes that these new legal requirements, combined with changing customer expectations, can drive speedy change. In time, she also believes that more and more plastic will become biobased. Today, (non-degradable) high-volume plastics such as polypropylene and polyamide are already manufactured from biobased raw materials. Yet, implementing completely new types of biobased plastics in the automotive industry will take time in a conservative industry with high safety requirements for construction, she notes.

Anette Munch Elmér

– The recycled content will grow significantly within the next ten years. Next step is to look at effective ways of working with both recycled and biobased. I also believe that chemical recycling will become increasingly important to reduce our use of fossil raw materials. She adds:

– It is an exciting time to work with plastics. It is a fantastic material that has every chance of being sustainable. Just think of how much has happened in the field in such a short time.

Regarding Polykemi's participation in STEPS, Anette Munch Elmer hopes that they will have the opportunity to characterise and test the monomers that have been produced within the programme. For that, at least one kg of a monomer is needed.

– It would be rewarding to be able to contribute with knowledge to improve the monomers. We have great experience and many contacts.

For Polykemi, it is also important to maintain the network after the programme ends. She highlights that they now have more knowledge about biobased materials, and a deeper understanding of the legislation concerning plastics.

– Being able to pick up the phone and call if you have a question. I hope that we can continue to do that even after STEPS is over.

Highlights in 2023

Students show the way forward for plastic industrial waste.

Artificial rattan, cutlery bowls, bumpers and a combined computer and storage unit. These are just some of the uses that industrial design students at Lund University identified for plastic waste in polyethylene.

– It was very exciting to follow their design and idea process. Imagine if you could do that at a company to bring in new ways of thinking about waste and other materials that we burn today, says Peter Andersson, CEO of General Plastics Scandinavia.

It was he who contributed the material to the students, within the framework of a collaboration between General Plastics Scandinavia, Polykemi, Clariant and teachers in the industrial design programme. The aim was for the students to learn more about the material and together identify new products for it.

The process was divided into two stages, where the first included lectures and brainstorming about potential products. From a long list of suggestions, such as bumpers, school cutlery and car interior buttons, the students then narrowed down three ideas: cutlery baskets, a combined computer and storage table and artificial rattan. Divided into three groups, they produced mechanical sketches and conducted a design analysis. They also made cost calculations to be able to compare their product with equivalent products on the market to see if it landed at a reasonable cost level. When this work was finished, they presented their projects to classmates, teachers, General Plastics Scandinavia, Polykemi and Clariant.

– I was very impressed by all three products and by the students' presentations. The group working on the computer table had even printed a miniature table in 3D, which was cool to see! All suggestions were also well thought out.

Although all the proposals could work in theory, both Peter Andersson and representatives from the other companies believed that the artificial rattan was the product with the greatest potential – partly because it is already an established product, and partly because many customers like to buy sustainably. At the same time, the majority of all artificial rattan is manufactured in Asia, which means that the students would either have to find a manufacturer in e.g. China or try to sell the idea to a Swedish company.

– It is refreshing to see how new and innovative the students think. In just a couple of weeks, we came up with a great many different proposals for a material that is difficult to get onto the market, one of which could actually become a viable product. To me it shows how important it is to take advantage of these young talents, and make sure they get into the industry. Otherwise, we will continue to throw away plastic we can actually use, just because we are stuck in the same rut, says Peter Andersson.

He believes that the students got a lot out of the project, not least because they didn't have that much material knowledge beforehand. The fact that the companies were involved in assessing the proposals was also valuable, he believes.

– The fact that we can work so closely with the university is one of the things that I have appreciated about the STEPS programme. For us as a company, being able to lecture at different courses gives us the opportunity to share our knowledge at an important stage for the students.

The collaboration regarding the plastic waste will not continue in its current form. But in the long term, Peter Andersson hopes to be able to bring in master's students from LTH's various courses in different projects at his own company.

– The contacts we have built up between us companies, teachers and researchers within STEPS will last!

Peter Andersson

Towards a global plastics treaty: Mopping up the water without turning off the faucet?

In the international realm, dominated by sovereign states, negotiation is the predominant mode of reaching joint decisions. Growing global concern about the impact of plastics has led to negotiations towards a global plastics treaty. These were initiated at the fifth session of the United Nations Environmental Assembly in March 2022. The formal aim of the negotiations is to agree on an international, legally binding instrument to end plastics pollution, with a specific mandate to consider the "full life cycle" of plastics, from material extraction to waste management. The first round of negotiations, INC-1, took place in November and December 2022 in Punta del Este, Uruguay. Two more rounds were held in 2023 – INC-2 in June (hosted by France) and INC-3 in November (hosted by Kenya). Two final rounds are set to take place in 2024, INC-4 in April (hosted by Canada) and INC-5 (hosted by South Korea), with the aim of reaching a final agreement by the end of 2024.

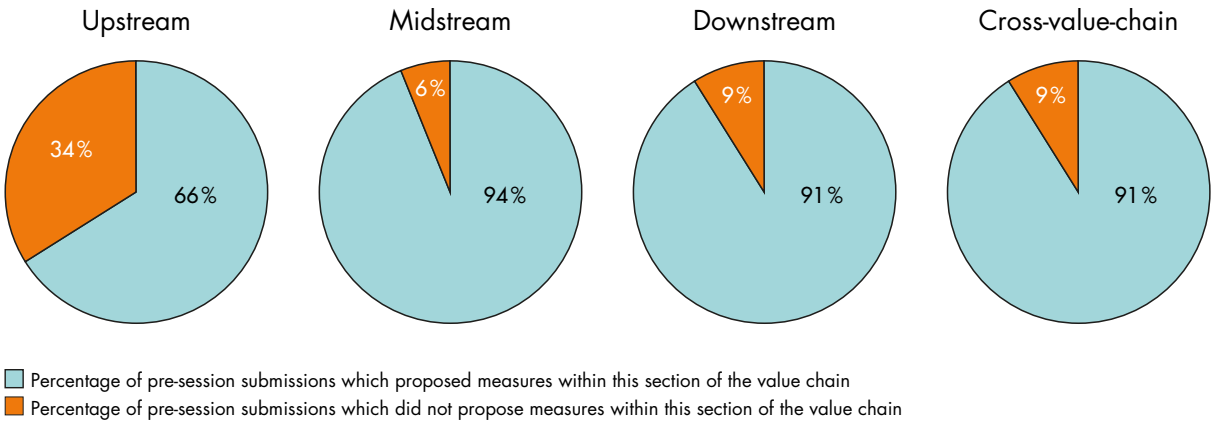
In late 2023 and early 2024, STEPS researchers Elin Dreyer, Teis Hansen, Karl Holmberg, Tara Olsen, and Johannes Stripple wrote a report about the treaty making process called "Towards a Global Plastics Treaty: Tracing the UN negotiations". Our research examines the pre-session submissions by states and coalitions for the second (INC-2) and third (INC-3) rounds of negotiations, held in 2023. In all international negotiations there are both cooperation and conflicts among states in the world. Fred Iklé sums up this condition in his well-known book How Nations Negotiate (1964) with the phrase 'Without common interest there is nothing to negotiate for, without conflict nothing to negotiate about' (Iklé, 1964: 2). Keep in mind that negotiations at international conferences under the United Nations is primarily textual. It's about deciding on the particular concepts and words to be adopted by consensus at the conference. During the negotiating process, states (and coalitions of states) submit proposals for how they wish the final treaty should look like. This is of key importance, as the conference can only agree on something that has been proposed.

Our aim was to capture both the variety of policies that was proposed to be included in the plastic treaty, and the degree of consensus that could be discerned among the states in the world. We conducted a qualitative coding of all submissions made in the negotiation process. The categories that emerged from the coding process cover the proposed objectives for the treaty, the types and range of measures proposed, and where along the value chain these measures fall. We find that: (1) the pre-session submissions give considerable attention to improving waste management and extending recycling infrastructure, while scant attention is given to upstream (production-related) measures; (2) relatively few economic measures have been proposed thus far, with pre-session submissions focusing on regulatory and soft measures instead; (3) this uneven distribution of proposed measure types could weaken the overall effectiveness of the instrument by impeding its ability to address the issue of plastic pollution in all its complexity; (4) if current trends continue, we can expect a treaty focused on waste management and recycling, instead of one addressing the full life cycle of plastics; (5) and finally the sheer quantity of plastics being produced each year undermines any efforts either to `end' plastic pollution or to reach any net-zero carbon emission targets.

If the pre-INC-2 and pre-INC-3 submissions analysed in this report can be taken as broadly indicative of the interests of states, then the prospects are not good. A robust, implementable plastics treaty that is ambitious in scope, and has the broad mix of policy that will be needed to tackle this complex challenge, is not going to be agreed upon at the end of the negotiation process.

The photo is taken outside the third negotiations meeting in Nairobi. Photo: Tara Olsen.

As the treaty-making process continues, oil- and gas-producing countries can be expected to defend their economic interests. Big oil-producing countries like Kuwait and Saudi Arabia emphasised in their pre-INC-3 submissions that it is their sovereign right to exploit their own resources. During INC-3, the organisation of these interests seemed to solidify. Iran spoke on behalf of a new coalition, offering the clear message that the treaty should be limited to downstream measures around waste management. If such interests come to define the scope of the treaty, it will mean that the core aim of 'ending' plastic pollution remains unattainable. If we accept the premise that the root cause of the plastics crises is the endlessly increasing volumes of production, then we can foresee a global plastics treaty that tries to mop up the water without turning off the faucet.



Note: Reproduced figure from: "Dreyer, E., Hansen, T., Holmberg, K., Olsen, T., Stripple, J., 2024. Towards a Global Plastics Treaty: Tracing the UN Negotiations. Lund University. Lund, Sweden."

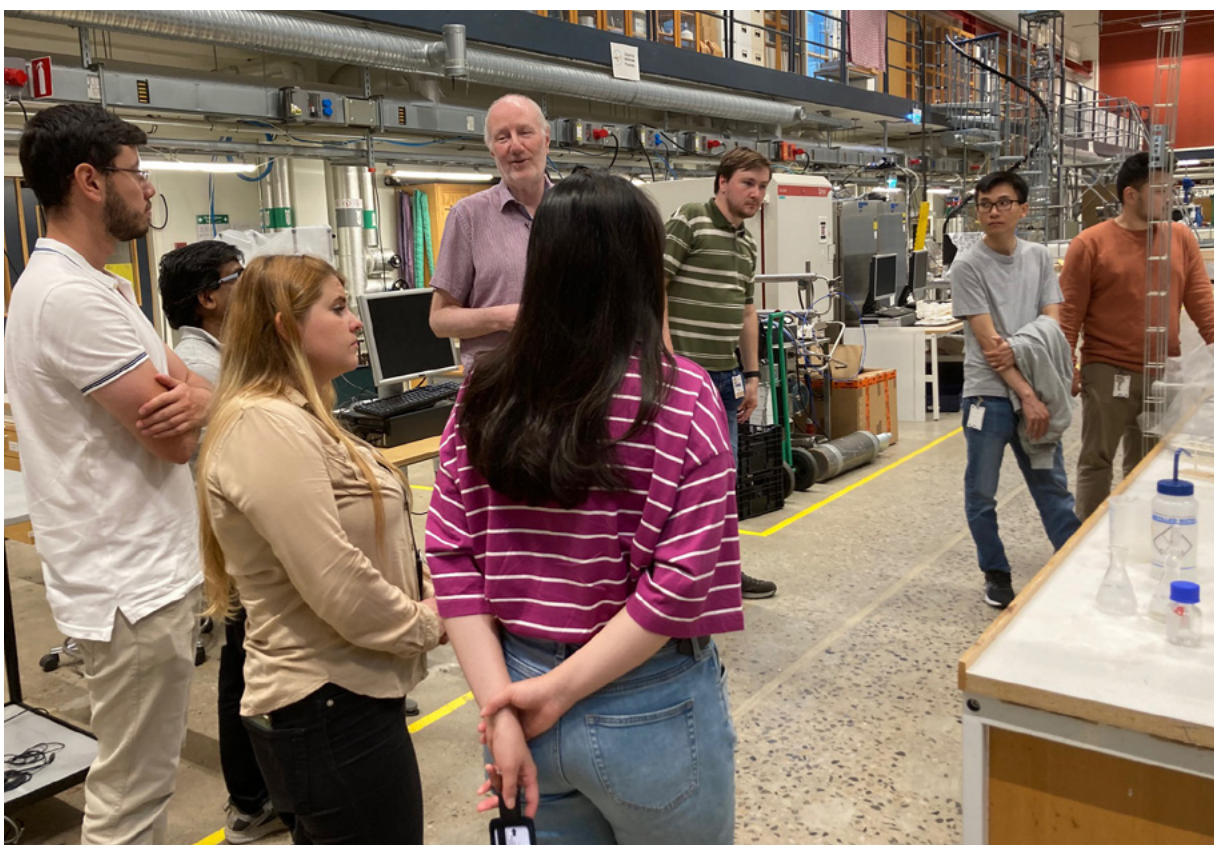
STEPS School on Sustainable Plastics gave new insights and made students reassess their views on plastics

A great overview of the plastic system, an interesting inclusion of industry perspectives, and incredibly well planned! These are just some of the positive comments on the summer school on sustainable plastics organised by the research programme STEPS. It gathered around 30 participants – Master and PhD students with different backgrounds from different departments at Lund University, and even other universities as well as engineers and specialists from different companies.

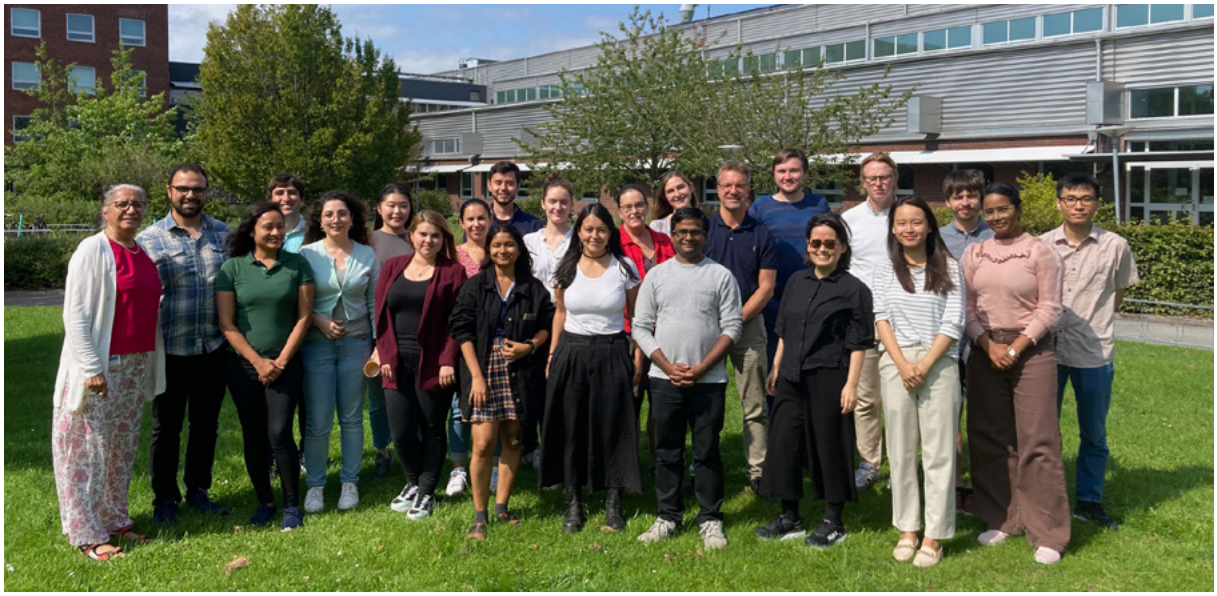
The course ran in August 2023 and aimed to provide understanding of the current plastic system and its challenges, pathways to a sustainable plastic system, biobased and biodegradable plastics, recycling solutions, policies, and standards for sustainable plastic.

– We wanted to remove some of the misunderstandings about plastics by presenting an overview of the whole plastic system. We do not advocate a ban on plastics, but instead to find ways how to produce and use it sustainably, says Rajni Hatti-Kaul, STEPS programme director, and professor in Biotechnology at Lund University.

– Involving industry partners in the course was important to connect the course to real life. They have first-hand knowledge and experience of how the plastic system functions and its limitations and can also give perspectives on how one could move away from fossil-based plastics. They provided added value to the course and for the participants, and made the course stand out from other theoretical seminars.



Some participants of the STEPS Summer School photographed during a tour of the pilot hall at Kemicentrum used for biomass pretreatment.



Group photo of teachers and students during STEPS Summer School.

Great feedback from students

A majority of the participants were very happy with the course, especially the opportunity to listen to people from industry was highlighted by many. Another positive aspect was the diverse mix of both lecturers and students, which helped to create dynamic conversations and facilitated new perspectives

Matilda Johansson is a PhD student in Applied Microbiology at Lund University.
– I know a lot about biotechnology but not so much about plastics. I was amazed at the diverse lectures, which covered so many aspects of plastics. I was happy that people came from different backgrounds. They asked questions I would never ask! All in all, it felt more like a conference than a course!

Micaela Mafla Endara is a PhD student in Microbial Ecology at Lund University:
– The political and social aspects of plastic production were interesting to learn about, as well as the new techniques developed to produce more sustainable plastics, to recycle more efficiently and to improve the degradation of complex materials. I also liked that people in the course were very aware of the problems and want to do something about it.

Arvind Kumar Gupta is a researcher at the Centre for Analysis and Synthesis, Lund University.
– My view used to be that plastic was a bad material, but the course has changed my mind. It has been interesting to learn about how to make plastics useful in your daily life. It is a good initiative since it gives an opportunity to learn together.

Chia-Wen Yang is doing a Masters in Environmental Studies and Sustainability Science at Lund University.
– I am from Taiwan where plastic is a serious problem. My aim has been to learn about how you do things here in Sweden. Learning about recycling has given me inspiration and ideas for what can be done at home. It surprised me that you don't have to wash the products before recycling as this practice helps in conserving water rather than wasting it.

Freya Dastoor has just finished a master's in Middle Eastern Studies at Lund University.
– I took the course because I wanted to learn more about plastics, and what contribution -positive or negative- the material has to environmental change. It has been great to learn about the properties of plastics, as well as recycling and packaging: there are so many hidden details about our use of plastics which need to be included in conversations about conservation and sustainability!

Oskar Boström is a PhD student in Polymer Technology.
– My research is very focused on how to develop properties and functions of new polymers. By taking the course, I got to learn some basic insights about the issues of recycling plastics.

Renan Melhado works at Tetra Pak, which is one of STEPS partners.
– I work with injection moulding at Tetra Pak. I am impressed with the course presenting a more human and social and historical view on plastics. It gave me new perspectives on my own work. I will bring this with me when we brainstorm around new ideas at work.

Communication and impact

Making societal, policy and environmental impacts beyond academia are important aspects of the research and work performed in the STEPS programme. Our researchers are engaged in different activities to highlight our research, including an increasing number of presentations for various target groups, panel debates, and media appearances.

In 2023, we continued to influence and shape the societal and media landscape connected to plastics with contributions to niche publications, press releases, and education aimed at disseminating our research to the plastics industry, students, and interested members of the general public.

Some examples of our outreach work are STEPS participation in the yearly Sustainability Week, an annual collaboration between Lund University and Lund municipality, with events focusing on sustainable development. We organised two events, featuring participation of our researchers and board members, Lars J Nilsson, Karl Holmberg, Joachim Tilsted, Mattias Andersson and Lars Fogh Mortensen. The first event focused on sustainable plastic textile production, highlighting ways forward for society and industry, whereas the other focused on recycling, with a panel discussing ways to improve recycling, and what other measures are needed to change the plastic system towards more sustainable practices.

STEPS researchers also participated in The Environmental Protection Agency's Plastbubbel, a yearly event gathering the Swedish plastics industry, as well as representatives from county councils and municipalities, with an aim to highlight ongoing plastics research and initiatives.

During Almedalen in July in Visby, Gotland, STEPS joined forces with three other Mistra programmes to discuss the future of food systems based on four different potential scenarios. Director Rajni-Hatti Kaul and board member Leif Nilsson highlighted and discussed how changed food consumption and production patterns could impact the plastic system.

During the year, many STEPS researchers contributed with expertise towards the UN Global Plastics Treaty negotiations, which aims to develop a legally binding agreement on plastic pollution. Examples include Teis Hansen, Fredric Bauer and Ellen Palm's participation in the Scientists' Coalition for an Effective Plastics Treaty, including workshops and policy briefs ahead of the different negotiating sessions, in particular two policy briefs: "Climate change impacts of plastics" and "Global Aggregate Reduction Target and Levers to reduce plastic production, a baseline for the UN's international legally binding instrument on plastic pollution".

Another major effort was STEPS Summer School on Sustainable Plastics which was very well received by the participants including both students and STEPS partners.

Selected articles in the press and popular science journals

- Extrakt, 15/5: Skatten på påsar behöver breddas.
- Aktuell Hållbarhet, 19/5: Statsvetare tror inte på helt slopad plastskatt
- Radio Ekot, 24/5: Så blir mer plast ”räddningen” för oljeindustrin
- Aktuell Hållbarhet, 31/5: Därför är plastavtalet som förhandlas fram i Paris avgörande
- Svenska Dagbladet, 2/6 Fossila intressen kan försvaga avtal om plast
- Plastforum, 25/6: Sommarskola om plast redde ut missförstånd och gav nya insikter
- Polymervärlden, nr 2: Plastavhandling ifrågasätter på vilken nivå systemförändring bör ske
- Polymervärlden, nr 3: STEPS på Plastteknik Nordic
- Polymervärlden, nr 3: Tre sätt att göra plasten hållbar
- Polymervärlden, nr 6: Skola om hållbar plast skingrade myter och redde ut missförstånd
- Polymervärlden, nr 8: Hållbarhet viktigt i den polymertekniska utbildningen

Participation in Conferences

[1] **N. Valsange et al.** (2023) Lignocellulose-based dicarboxylate monomers for aromatic polyesters: synthesis, characterization, and properties, Nordic Polymer Days – IDA Conference, Copenhagen, Denmark, 8–10 May 2023

[2] **B. Zhang** (2023) Design for recycling: Synthesis of new biobased polymers, Nordic Polymer Days – IDA Conference, Copenhagen, Denmark, 8–10 May 2023

[3] **S.** Mankar et al. (2023) Polyesters with a spiroacetal unit toward tailored properties and recyclability, Division: POLY, Indiana Convention Center, ACS Spring meeting Indianapolis, 23–30 March 2023.

[4] **Å. Romson, T. Hansen & S. Madsen** (2023) Sustainability transitions research and legal analysis. Exploring the extended producer responsibility on packaging in Denmark and Sweden. Utrecht, The Netherlands: 14th International Conference on Sustainability Transitions, August 2023.

[5] **E. Palm, J.P. Tilsted, V. Vogl & A. Nikoleris** (2023) Imagining Circular Carbon: A mitigation (deterrence) strategy for the petrochemical industry. Energy Future in Industry Conference, Gothenburg, Sweden, May 2023.

[6] **S. Dash & A. Nordin** (2023). Towards realistic numerical modelling of thin strut-based 3D-printed structures. 24th International Conference on Engineering Design, Bordeaux, France, 24–28 July 2023.

[7] **R. Hatti-Kaul, M. Ismail, M. Sayed, A. Abouhmad, S-H. Pyo** (2023) Closing the plastic loop: Biobased building blocks, degradation and upcycling. 4th International Conference on Bioresource Technology for Bioenergy, Bioproducts & Environmental Sustainability, Riva del Garda, 14–17 May 2023.

[8] **O.Y. Abdelaziz, E. Capanema, O. Ajao, T. Kristensen, O. Hosseinaei, M. Benali & C. Hulteberg** (2023). A Rapid and Tunable Approach for the Fractionation of Technical Kraft Lignin, The 16th International Conference on Chemical and Process Engineering (ICheaP), Naples, Italy, 21–24 May 2023.

[9] **J. Liu** (2023) Biodegradability evaluation in organic solid waste using a novel volumetric respirometer, International Conference on Solid Waste, Hong Kong 31 May – 3 June 2023

Published Scientific Articles

[1] **O. Abdelaziz, E. Capanema, O. Ajao, T. Kristensen, O. Hosseinaei, M. Benali, C. Hulteberga**, A Rapid and Tunable Approach for the Fractionation of Technical Kraft Lignin, Chemical Engineering Transactions 99 (2023) 67–72.

[2] **O. Abdelaziz, I. Clemmensen, S. Meier, S. Bjelić, C.P. Hulteberg, A. Riisager**, Oxidative Depolymerization of Kraft Lignin to Aromatics Over Bimetallic V–Cu/ZrO2 Catalysts, Topics in Catalysis (2023) 1–12.

PHOTO: PEXELS

[3] **D.D. Argyropoulos, C. Crestini, C. Dahlstrand, E. Furusjö, C. Gioia, K. Jedvert, G. Henriksson, C. Hulteberg, M. Lawoko, C. Pierrou**, Kraft Lignin: A Valuable, Sustainable Resource, Opportunities and Challenges, ChemSusChem 16(23) (2023) e202300492.

[4] **A. Aristi Capetillo, F. Bauer, C. Chaminade**, Emerging Technologies Supporting the Transition to a Circular Economy in the Plastic Materials Value Chain, Circular Economy and Sustainability 3(2) (2023) 953-982.

[5] **E. Chertkovskaya, J. Hasselbalch, J. Stripple**, Plastic Turbulence: Illusions of Containment, Clean-up, and Control, and the Emergent Promise of Diverse Economies, Global Environmental Politics in a Turbulent Era (2023) 25.

[6] **E. Chertkovskaya, J.A. Hasselbalch, J. Stripple**, Assembling a Zero-Waste World: From Situated to Distributed Prefiguration, Organization Studies (2023) 01708406231200726.

[7] **S.U. Din, Kalsoom, S.M. Satti, S. Uddin, S.V. Mankar, E. Ceylan, F. Hasan, S. Khan, M. Badshah, A.O. Beldüz**, The Purification and Characterization of a Cutinase-like Enzyme with Activity on Polyethylene Terephthalate (PET) from a Newly Isolated Bacterium *Stenotrophomonas maltophilia* PRS8 at a Mesophilic Temperature, Applied Sciences 13(6) (2023) 3686.

[8] **K. Holmberg, S. Persson**, Keep Plastics on a Tight Leash: Swedish Public Opinion on Plastic Policies, Environmental Science & Policy 141 (2023) 109–116.

[9] **S.V. Mankar, J. Wahlberg, N. Warlin, N.G. Valsange, N. Rehnberg, S. Lundmark, P. Jannasch, B. Zhang**, Short-Loop Chemical Recycling via Telechelic Polymers for Biobased Polyesters with Spiroacetal Units, ACS Sustainable Chemistry & Engineering 11(13) (2023) 5135-5146.

[10] **K. Molina-Besch, H. Keszleri**, Exploring the Industrial Perspective on Biobased Plastics in Food Packaging Applications–Insights from Sweden, Sustainable Production and Consumption 35 (2023) 72-84.

[11] **T.T. Thuy Vu, S. Liu, M. Jonušis, S. Jonušienė, J. Choi, R. Kawano, N. Rehnberg, R. Hatti-Kaul, S.-H. Pyo**, Sustainable One-Pot Synthesis of 5-(Hydroxymethyl) furfural from C6-Sugars by Enhanced H+ Exchange Heterogeneous Catalysis, ACS Sustainable Chemistry & Engineering 11(48) (2023) 17130-17141.

[12] **J.P. Tilsted, F. Bauer, C.D. Birkbeck, J. Skovgaard, J. Rootzén**, Ending Fossil-based Growth: Confronting the Political Economy of Petrochemical Plastics, One Earth (2023).

[13] **J.P. Tilsted, E. Palm, A. Bjørn, J.F. Lund**, Corporate Climate Futures in the Making: Why We Need Research on the Politics of Science-Based Targets, Energy Research & Social Science 103 (2023) 103229.

[14] **P. Wagner-Egea, L. Aristizábal-Lanza, C.** Tullberg, P. Wang, K. Bernfur, C. Grey, B. Zhang, J.A. Linares-Pastén, Marine PET Hydrolase (PET2): Assessment of Terephthalate-and Indole-Based Polyester Depolymerization, Catalysts 13(9) (2023) 1234.

[15] **M. Wang, F. Bauer, K. Syberg, T. Gammage**, Finance Plastics Reuse, Redesign, and Reduction, Science 382(6670) (2023) 526-526.

PhD theses

[1] **S. Mankar,** Toward Biomass-Derived Recyclable Polyesters. 2023.

[2] **O. Englund Örn**, Towards Sustainable Plastics: Microbial Production of Aromatic and Aliphatic Building Blocks from Biobased Feedstock and Plastic Hydrolysate. 2023.

[3] **S. Madsen**, Pursuing a Circular Economy in the Danish Waste Sector: Scale and Transition Dynamics in Transformative Innovation Policy. 2023.

Master thesis

[1] **S. Vesterbacka**, Investigation of Acidic Chemical Recycling of Poly(acetal-ester)s

[2] **S. Bengtsson**, Hardware Design and Evaluation of Non-planar Fused Deposition Modeling on a 3-axis printer

[3] **R. Kawano**, Identification and Characterization of Novel Oxidoreductases from *Gluconobacter oxydans*

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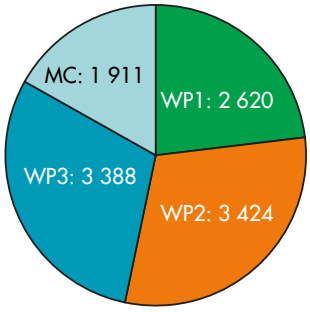
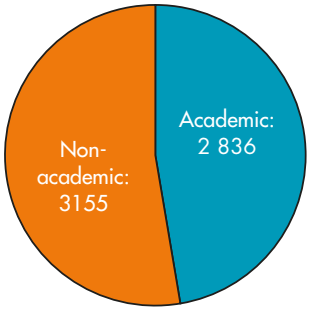
STEPS in Numbers

Total financial outcome 2023



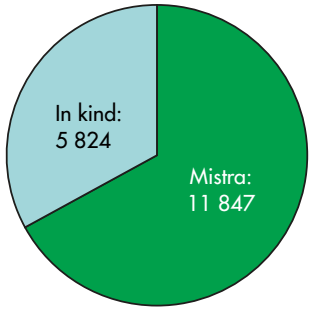
WP1 – Renewable feedstock to polymer building blocks
WP2 – Drop-in and new plastic formulation
WP3 – Governance towards plastic transition
MC – Board, management and communication

Total In kind contribution 2023



Academic partners
Non-academic partners

Total budget 2023



MISTRA
In kind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Bona


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IKEA


IKEM
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JONAS IHREBORN


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Member of Nordzucker Group


Orkla


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