STEPS

Sustainable Plastics
and Transition Pathways

ANNUAL REPORT 2021

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STEPS programme

The Mistra financed programme STEPS – Sustainable Plastics and Transition Pathways – is a research programme with a vision of a future society where plastics are sustainably produced, used and recycled. The goal is to facilitate this transition by sharing innovation, knowledge and findings between academia and stakeholders.

STEPS partners include Lund University, University of Copenhagen, RISE and IVL, 21 industrial partners and Skåne county council – representing the entire value chain in a sustainable plastics system: renewable raw materials providers, producers of chemicals and plastic materials, users of plastics and plastic waste handlers.

STEPS is looking for sustainable solutions throughout the value chain from the choice of renewable feedstock, conversion and design of plastic products to post-consumer plastic waste handling.

The concept is to design sustainable plastics with desired materials properties and life cycle by matching suitable carbon-neutral building blocks from agriculture and forestry side-streams, and even carbon dioxide. Transformation of feedstock to building blocks is based on green chemistry and biotechnology processes to achieve resource-efficiency and low environmental impact, and the bioplastics are designed for efficient recycling or biodegradation.

STEPS main focus is on polyesters – a plastics group with varying properties for a wide range of applications and a sizeable global market. Target applications for plastics developed in STEPS are packaging, textiles, coatings and durable products.

STEPS goal is also 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.

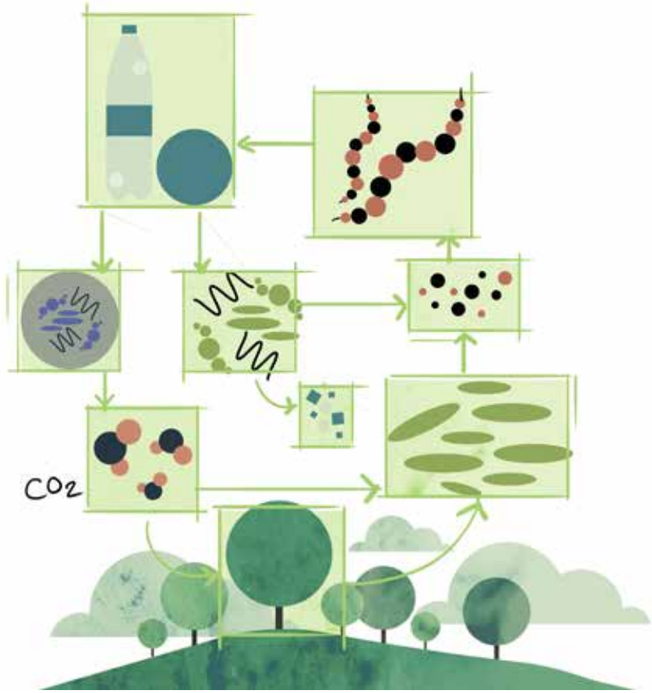

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Illustration: Catrin Jacobsson, Lund University

Message from the Board

The climate change appears to be one of the most urgent challenge for man-kind since it will impact us all negatively. World-wide, united efforts at all levels are needed to limit the average temperature rise in coming years in order to prevent foreseeable disasters like forest fires and flooding among others. One of the most efficient – but at the same time difficult – solutions will be to limit CO2 and other gas emissions stemming from transportation, heating/cooling as well as industrial and agricultural productions.

STEPS has by now been running for more than five years and seems both even more necessary and timely. With the ultimate goal to enable production of novel plastic items from renewable resources and thereby replacing fossil-based polymers STEPS can be seen as one solution to limit increasing CO2 emission. Also, the STEPS initiatives on governance and societal behavior with plastic circularity and carbon capture are pertinent. This latter is very important given the fact that only a minor amount of the plastic waste, especially the household generated, is actually recycled and reused into new products.

The STEPS research has over the years progressively matured with excellent collaboration between the University researchers and the strong involvement of the industrial partners. Here it is also important to mention the numerous master and doctoral students that have graduated are long lasting results of the STEPS activities.

In short, several novel routes to preparation of monomers and other polymer building blocks considered to be the most important chemicals based on renewable feedstock have been developed. Based on the building blocks prepared in STEPS also novel, intriguing bio-based polymers have already been designed and characterized.

From a Board perspective a key challenge will be the implementation of the results achieved so far into industrial design and production. For this to happen procedures to scale-up the preparation of the most interesting building blocks and polymers will be necessary. A scale-up scenario most likely will be a multi-step procedure where initially a thoughtful selection of the most promising candidates must be performed. Then a production scale-up to sufficient amounts where the industrial partners can evaluate and test the new polymers is needed. Finally, a real pilot-plant production would secure the legacy of STEPS. Involvement of some of the industrial partners in the entire scale-up chain would without doubt be both desirable and very beneficial to reach the final goal: realistic novel bio-based polymers that can replace some of the fossil-based polymers used today.

Søren Hvilsted
for STEPS board

A message from the Management Group

The year 2021 will be remembered in history as a period when the world was in the grip of Covid-19 pandemic for the second year, resulting in the loss of many precious lives, but also in the development of the vaccines made available at an extraordinary pace. A proof of human ingenuity and resilience! One would have thought that the plastic pollution issue, although having been discussed for several years, would end up in the back seat, but the European Commission followed up on the Single-Use Plastics Directive passed in 2019, to ban several commonly found plastic items in the European coastal areas. And earlier this year, a legally binding global treaty to end plastic pollution was agreed upon by 175 nations.

The pandemic did affect STEPS activities, which to a large extent had to be conducted in a digital mode. The researchers and students performing laboratory work have braved through the restrictions and managed to continue their experiments although at a somewhat reduced level. However, the results are evident in several high-quality scientific publications from STEPS during the year. The research that caught the most public interest was the study on the public opinion in Sweden on the plastic policies and the one on how the global oil companies plough money into fossil-fueled plastics production.

Considering the risk of losing momentum and interest among the STEPS members due to lack of physical meetings, we organised a number of online workshops on themes related to plastics in different sectors, such as flame retardants, standardisation, and sustainable increase of biomass supply. Most of these events were led by our partners and also our board member Maria Gustafsson, and involved even external speakers. Our programme meetings during spring and autumn were also well received and included some very interesting invited talks by Kim Ragaert, professor at Ghent University, on the state of plastics recycling in the EU, and by Lars Mortensen from European Environmental Agency, who joined the STEPS board during the spring and for which we are very happy. You can read interview with Lars in this report!

Together with IVA, the Royal Swedish Academy of Engineering Sciences, and KTH Royal Institute of Technology, and with financial support from Mistra and its CEO Anna Jöborn, STEPS organised a French-Nordic Conference on Plastic Recyclability and Circular Economy (conducted in a hybrid mode). The conference was an opportunity to strengthen collaboration between France and the Nordic countries and included speakers from several Mistra programmes, Swedish funding agencies, the Swedish EPA and a number of universities and institutes from the Nordic countries and France.

The four Missions established from the start of STEPS Phase 2, have advanced in their applied research, aiming for solutions for a circular plastics economy and reduced plastics pollution. In this report you can read more about the challenges two of the industrial leaders, Tetra Pak and TePe, are facing and how they strive for solutions through STEPS. This also brings to the fore our challenge for scaling up the production of samples for evaluation. We have already initiated discussions with some of our industrial partners and also our Board member Sören Hvilsted, to find ways forward.

Three interlinked workpackages


Photo: Unsplash

WP1 has focus on production of polyester building blocks from surplus renewable feedstocks using clean and cost-effective process technologies.

During 2021, work on the production of bio-based furan and aromatic building blocks, was continued. A novel bacterial aryl alcohol oxidase oxidizing 5-hydroxymethyl furfural (5-HMF) was identified, and the 5-formyl-2-furancarboxylic acid (FFCA) product was used for making a novel monomer with WP2, and alternatively oxidized to 2,5-furandicarboxylic acid (FDCA) using microbial cells. Moreover, a facile process for the production of alkyl levulinate at high yield from C6 sugars was developed. Recovery of aromatic monomers, including vanillin, vanillic acid, and acetovanillone from oxidatively depolymerized lignin was demonstrated; assessment of these monomers as bisphenol-A replacements is ongoing with WP2. Studies on thermal recycling of plastics to novel polymers and its integration into existing industrial frameworks have progressed, and discussions with relevant stakeholders initiated. Development of enzymes for the depolymerization of polyesters was started, and some enzymes with improved activity for PET hydrolysis were obtained.


Photo: Kenneth Ruona

WP2 investigates polymerisation, processing and characterisation of bio-based plastics using potentially the building blocks from WP1 and other sources toward applications such as fibers, coatings, packaging and oral hygiene products. Particular attention was paid to replace non-recyclable thermosets with potentially recyclable thermoplastics.

In 2021, biobased 2,5-furandicarboxylic acid was applied as a building block for synthesis of biobased PET-like polyester for fiber application. Lignin-based building blocks were investigated for the preparation of new PBT-like polyesters that can potentially replace the fossil-based PBT used in toothpicks. Various biobased spiroacetal monomers derived from 5-hydroxymethyl furfural, levulinic acid, and vanillin have been investigated to prepare copolyesters with enhanced chemical recyclability. Thermoplastic polyamide foams produced by 3D printing technology were mechanically characterized and other biobased thermoplastics were evaluated toward potential furniture use.


Photo: iStock

WP3 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.

During 2021, WP3 contributions included an analysis showing how the investments of plastic manufactures continue to favour fossil feedstocks, which is central to maintaining the current unsustainable plastic system. Another paper highlighted how waste policies in Denmark have changed over the last decade, most recently by taking away significant power from the municipal level. WP3 has also conducted a survey around attitudes towards plastic initiatives and policy suggestions by Swedish citizens, which demonstrated significant support for increased regulation of plastics.

Four missions

STEPS Missions aim at intensifying the collaboration between industrial, regional and research partners by co-developing and evaluating carbon-neutral plastics 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. Four Missions were initiated from the start of Phase 2, each having an industrial partner as leader. In the following articles you can read more about two of them.

	WP1	WP2	WP3
MISSION 1	Bio-based plastics for packaging applications: Level of food protection vs ease to recycle		
MISSION 2	Bio-based textile fibre		
MISSION 3	Bio-based toothpick		
MISSION 4	3D printed foam		


Photo: iStock

Bio-based plastics for packaging applications

Tetra Pak has a vision to provide packages that are produced fully from renewable materials, with low carbon emissions, and are 100% recyclable. In the process, it is important to consider the full value chain from material sourcing to end-of-life of the package.

In Tetra Pak´s processes it is a challenge to switch to new polymers in the existing production line. There are strict requirements on what characteristics they need to have to withstand the processes in our large-scale machines and high-speed production, explains Anna Skanse, Project manager in Innovation and Sustainability, at Tetra Pak.

Figuring out new methods and testing new materials, such as using bio-based plastics, in-depth knowledge about polymers is an advantage. Jan Wahlberg, Technology specialist at Tetra Pak is working on measuring qualities of the polymers produced in STEPS work package 2, led by Baozhong Zhang, Lund University.

– I have been looking at polyesters provided by the research group, based on lignin. Among other things I have checked the oxygen barriers and other qualities that are important for our food packages, says Jan Wahlberg.

Real testing in the machines at Tetra Pak would require several kilograms, even tons of the new materials that the teams in STEPS now have managed to produce a few grams of in the labs. Still, it is an interesting step and both Anna Skanse and Jan Wahlberg underline the value of being involved already at early stages:

– It will be a long time before these materials can be used commercially, but we are gaining a lot of valuable knowledge along the way, says Jan Wahlberg. Part of the value for us to take part in the STEPS program is the cross-disciplinary exchange. We get insights into the challenges of other stakeholders and those across disciplines in academic institutions.

– Today we are actors on a global market, continues Anna Skanse. Regulations and standards are very important. Therefore, the work carried out in work package 3, led by Katrin Molina-Besch, on these issues is very interesting. In many markets the recycling set-up is different from each other, furthermore the regulations differ. These challenges make it difficult to establish a real circular economy.

There are many aspects to consider in packaging applications. Food safety is always top priority for Tetra Pak and must be regarded along with the environmental considerations. There are also new consumer trends to monitor and shell life expectations to be met.

– Producing packages that secure high food quality over time is the fundament of our business. Today we can store milk in beverage cartons for up to twelve months. This is an enormous progress from the days when milk was sold in loose weight, says Anna Skanse.

Anna Skanse
Project manager
in Innovation and
Sustainability at Tetra Pak

Jan Wahlberg
Technology specialist
at Tetra Pak

For the industry it is important to find what is both financially viable, durable, and sustainable – and recyclable so that we do not produce new bio-based polymers that create waste along the value chain.

– We need to stay open-minded and innovative. There have even been discussions on potentially using carbon dioxide as a material to produce plastics from. If we come up with a great bio-based material that will not fulfill requirements regarding food safety and product protection, we will still not be able to use it. Now lignin looks very promising, concludes Jan Wahlberg.

"Part of the value for us to take part in the STEPS program is the cross-disciplinary exchange. We get insights into the challenges of other stakeholders and those across disciplines in academic institutions. lastics chain."

Jan Wahlberg
Technology specialist at Tetra Pak

Courtesy of Tetra Pak

Bio-based toothpick

TePe develops various products and solutions for good oral health as well as educating and raising awareness about the connection of oral health and general health. The innovation process to achieve this well-being and better quality of life implies a responsibility for people and the environment. Plastics is a material with good qualities for TePe´s products but the end of life is a major challenge.

– STEPS is an exciting programme for us as it targets directly our challenges with plastics. Still, plastic has so many advantages as a material since it is hygienic, smooth, and easy to clean. It works well in the mouth and in close contact with mucous membranes. Finding a raw material with low carbon footprint is one thing but the most difficult part is how to address the end of life of the product. This we cannot do on our own, and therefore STEPS is a great way to collaborate to find solutions.

– In our production line, TePe has replaced the materials we use from fossil-based to renewables, almost to one hundred percent. We are also using green energy sources in the production. The main thing to change now is to close the loops and create a circular flow of the materials.

– We have converted our products and there are principally two paths to choose from. (Drop- in solutions?). Find bio-based materials or recycled material to generate the least negative impact in production and at end of life. Plastic is a valuable asset and should be used wisely, says Karl Johan.

STEPS Mission three is focused on finding solutions for a Bio-based toothpick. The TePe toothpick is a two-component product which makes it more difficult to recycle and reuse. Thus, the material needs to have as low footprint as possible both at production and at end of life but at the same time meet high requirements on properties such as strength, elasticity, and heat resistance.

– The experiments by researchers at Lund University and RISE have provided promising results in building polymers from lignin based vanillin. The next step is to figure out how to scale these grams into kilograms for real life testing. We need to verify its properties by testing to be able to secure the whole value chain in production.

Helena Ossmer Thedius
Marketing & Innovation Director at TePe

The main markets for TePe are the Nordics and Europe including the UK, but sales are worldwide to sixty countries. To follow developments, especially in Europe they have a plastics expert who stays up to date with EU policies and regulations.

– Collaborations to work towards a circular system for plastics is very important and there are several challenges to solve. We struggle to get clear answers and guarantees related to production and transportation from some suppliers. And on the level of regulations, these need to be harmonised between all regions and countries. Today it is too fragmented, and it makes it harder for us producers.

– Some of the challenges with plastics and its lifecycle can be addressed with raised awareness and more emphasis on communication. To a great extent, it is a matter of how we behave – how we handle the plastics and what we do with it – not the material in itself.

Photo courtesy of TePe

Meet two of STEPS young researchers

With love for the complex lignin molecule

A curiosity for working on renewable energy sources was a driver for Omar Abdelaziz when he had the chance to work with this during his studies in his home country Egypt. Although Egypt is an oil-driven society, relying mostly on fossil energy sources, there are initiatives to find more sustainable solutions. He looked for positions as a PhD focusing on biorefineries and moved to Lund in 2015.

– Six years later I am in love with this lignin molecule that I have spent so much time with, says Omar Abdelaziz and laughs.

He finished his PhD in 2021 in Chemical Engineering on the topic of lignin conversion to value-added small-molecule chemicals: towards integrated forest biorefineries.

– Sweden has a long tradition and strong position in forestry and the pulp and paper industry. For many years, and in many ways, researchers and industries have tried to make use of lignin, and there is an old adage that: "one can make anything out of lignin except money."

Currently, there is a renewed interest in lignin, as its qualities and potential use areas are broad, and it is easy to access.

– In the woody biomass from trees, lignin is the component that constitutes up to 30 percent of the mass. As society is driving towards a transition to bio-based economies, we must utilise the whole tree, all the components of the wood.

Lignin is one of the most abundant aromatic resources in nature, an enormous natural resource that can be used. But it often cannot be used as it is, it must be modified. Lignin is rather easy to extract, but not easy to work with – it is a complex molecule. To date, lignin does not have a well-defined structure or sequence. About 50–60 percent of its structure has been discovered so far, and numerous researchers are now working to put all the pieces together.

– It is a challenge when you cannot work in the way you can with a single compound that you can convert to a higher, value-added compound. Lignin is heterogeneous and typically results in a mixture.

Omar Abdelaziz
Chemical Engineering, Lund University

Omar Abdelaziz started to work in the STEPS programme just as lignin was added to the various matters for the research on building blocks for sustainable plastics in work package 1.

– We are providing the chemical intermediates that are useful for further polymerisation for plastics, handled by work package 2. I work specifically on the depolymerisation of lignin extracted from industrial sources, breaking it down into smaller pieces, low-molecular-weight aromatics, which are good candidates for bioplastics, e.g., as replacements for bisphenol A.

– Since I have a chemical engineering background and have worked with evaluating the feasibility of various biorefinery systems, I am also involved in technical and economical assessments on scaling the lab demos for real world testing and use.

Joining STEPS during the pandemic meant that Omar did not meet many others in person. However, the online meetings, especially STEPS Informs were useful for knowledge exchange and networking. The ongoing collaboration with work package 2 was established based on a STEPS Informs session and a joint meeting between the two work packages.

– STEPS is an interesting research programme, as it connects so many actors from both academia and industry. We are also active internationally, in a pan-European network on the sustainable valorisation of lignin, called LignoCOST, supported by the EU framework programme Horizon 2020.

– I also think that a great approach in phase 2 of the STEPS Programme is the Missions, led by industrial partners. I have some ideas that could contribute to at least two of the four missions included in STEPS and I hope to get a chance to explore them. The material we are working with has an immense potential and can bring value to society – and it provides rewarding research as well!

Meet two of STEPS young researchers

I hope to see my ideas and work for sustainable solutions considered in the real world

Tam Nguyen has a strong motivation in his work, coming from Vietnam –a country that is producing a lot of plastic waste and being part of the young generation that understands the need to find new solutions. He looked for opportunities in a developed country and the choice happened to be Sweden, first Stockholm and KTH for his Masters in Macromolecular materialsand then Lund University for his PhD.

Tam Nguyen
Centre for Analysis and Synthesis, Lund University

– Plastic is polluting our waters and our land. But is the best man-made material and is also very versatile. When covid emerged, plastic was a reliable barrier protecting us in the fight with the virus as most the equipment for doctors and caregivers were made of plastic.Thus, while reducing plastic impact on environment, we still need to leverage this amazing material.

For Tam Nguyen it is interesting to work with solutions for a new generation of plastics and use the ideas about the circular economy, about closing the loop instead of producing more waste. By considering the products' end of life already from the start with chemistry, newly synthesized plastic could be not only endowed desired mechanical properties but also designed deliberately with degradability or recyclability.

– In the Mistra STEPS programme, I am trying to use the lignin-based building blocks that could be readily made from WP1 to find solutions for a bio-based toothpick within the Mission 3. We have clear goals on how the bio-based polymers should mimic polybutylene terephthalate (PBT). We are in the first stages of preparing new lignin-based polyesters; we will choose our best polymers and send them to test at Tepe.

The experience of working in collaboration between academia and industry is rewarding and new to Tam Nguyen. As many researchers dream about, to bridge the "valley of death", where research findings can be used to solve real industrial problem, is interesting. Good for researchers to understand the difficulties in the production as well as the application of material.

– I enjoy working in the lab, it gives me more freedom for my ideas and curiosity. Currently, I am working on lignin-based polyesters. Lignin is of interest for replacing several kinds of materials, which provides good research opportunities and interesting challenges for a PhD.

– My ambition is to be a bridge between academia and industry, close the gap, make the knowledge come closer to the core. I want to have the chance to speak out my ideas and have them considered in the real world.

A chat with a STEPS board member

Important to link plastic to climate change

I was very honoured to join the board of STEPS in 2021. I have followed the programme for some time and think it is a leading research project in the EU on sustainable and circular plastics.

With my background as an economist and working at the European Environmental Agency, EEA, the policy relevant pathways aspects of the programme are closest to me. In this area, I can help with advice and EU and global perspectives on the plastics agenda. I also value a lot the parts of the programme that I know in less detail and learn a lot from – mainly the chemical and technical aspects of plastics and its lifecycle.

STEPS pathways very influential

STEPS is being very influential in the work on the pathways. It is really making a difference. The EEA has picked up on the findings and are using it in our assessments, briefings and interactions with the other EU Institutions and Member States. Linking plastics with climate change is very important as pointed to by STEPS researchers and should be highlighted more in research and policy agendas across Europe. Citizens are very interested in the plastics challenges and policies are developed. In late 2022, we expect EU initiatives on bio-based and biodegradable plastics and on reducing microplastics from various sources.

I find the plastics pathways developed by STEPS to be an easy and understandable way to communicate about options for the future, about what could be done, as it can be strategic and detailed at the same time. In an EEA project that I lead about pathways to circular plastics, we are identifying good examples across Europe. The three pathways we have identified, based on research done by STEPS, is communicated by us to the European Commission, the EU Parliament and Member States and we hope and trust that they will take it on board. Hopefully, in this way, I contribute making the distance shorter and bridge the gap between research findings and policymakers in the EU.

Using and producing more plastic

I think that I can provide valuable inputs to STEPS on what I see is happening and in the plastics horizon in EU and on a global level. Now there are activities to reduce plastics pollution on all levels, regional, national, international and STEPS research and findings could and should be taken further in the future, One example of important STEPS research findings is on how the petrochemical industry is increasing its investment in the production of plastics – shocking and revealing to many.

The trend that we are producing – and using – more plastics now than ever, causing huge impacts on the environment and climate change, needs to be discussed and continuously challenged. My role is to feed this kind of information and knowledge to the European Commission, the EU Parliament and other bodies that can work on both a shift to other materials, more circular plastics and also to see how we can use less plastics overall. We also need to find ways of harmonizing policies better, at least throughout Europe, and hopefully also worldwide through a global plastics agreement.

Lars Fogh Mortensen, European Environment Agency (EEA)

STEPS excellent research should continue

There are a number of other projects in the EU that are focused on plastics, but I find STEPS to be on the forefront with top notch and innovative research and approaches. Therefore, I think it is important to secure that there will be some form of continuation and I will try to contribute to ensuring this. The plastics challenges are very far from being solved across Europe and the world.

I look forward to being part of the programme in the years ahead and hope to see more outreach activities to share the knowledge and create even more awareness on the challenges and opportunities of plastics. UN member states have recently agreed on the adoption of a mandate for an International Negotiating Committee (INC) to develop a legally binding UN Treaty on plastic pollution. This is an unprecedented milestone and important opportunity for STEPS research.

The Future of plastics?

STEPS researchers have conducted a survey on how Swedes view various regulations of plastic. The interviewees had to take a stand on 18 proposals – ranging from "soft" encouraging measures, and instruments based on financial incentives to more regulatory and far-reaching measures.

This report is the result of a cumulative work on behaviour, attitudes, and practices in connection to plastics conducted between 2019 and 2021. In the report, the authors, Karl Holmberg, Sara Persson and Johannes Stripple, examined the Swedish public's opinions on plastic policies using panel survey data. The data was collected and administered by the Laboratory of Opinion Research, affiliated with the SOM institute, at the University of Gothenburg. The fieldwork was carried out in February and March, 2021.

The survey consisted of 13 questions and covered five main areas of opinion on plastics: general attitudes towards plastic and views on various actors' responsibility in connection to plastic;

- opinions on the newly implemented plastic bag tax
- attitudes toward future current and future plastic policy proposals
- opinions on textile-related policy proposals
- evaluation of effectiveness of policy instruments to regulate plastic (packaging).

Based on the results, the main takeaways for policymakers are:

– Do not be afraid to regulate plastics – there is generally broad support for addressing the challenges that arise with the use of this material.

– Practise incrementalism and learn from best practice examples – begin with soft policies with very high support but do also communicate a vision of more sustainable plastic use in the near future.

– There is clear support for an expansion of the deposit-refund scheme. The deposit-refund principle is promising as it indirectly preserves the value of the packaging after its use – Hence an expansion of the scheme could be an effective step forward.

– Swedes support a tariff on imported fossil-based plastic – the inclusion of petrochemical products in the Carbon Border Adjustment Mechanism (CBAM) would likely have the public's support.

– Ultimately, plastic use is connected to a larger problem with unsustainable consumption practices – efforts to shift consumer habits toward reuse, borrowing and lending consumer items, sharing, and, in some instances, reducing consumption should be embraced with time. Narratives about the future sustainable material use could play an important part in this shift.

Photo: Pixabay

Plastic dinosaurs

The largest international plastics and chemicals companies are struggling as the rest of the industry shifts. Instead of green investments in recycling or bio-based plastics, new investments are being made and fossil-based activities are being expanded. This is highlighted in STEPS research, which has mapped the companies' rate of expansion over the past decade.

A new survey shows that the world's 12 largest companies in the plastics industry started a total of 88 new projects between 2012 and 2019 – and that all of them were based on fossil resources. Not a single project was based on "green" raw materials such as biomass or captured carbon dioxide.

– This sector flies under the radar and does not have the eyes of politicians in quite the same way as, for example, the energy sector, where the pressure to convert is much higher," says Fredric Bauer, researcher in work package 3, who wrote the article together with Germain Fontenit.

Large investments due to shale gas and crude oil becoming chemicals

Large investments have also been made to increase the production rate of plastics in North America as the availability of shale gas has increased. The trend has also spread to Europe, China and India as imports of shale gas increase. The study also points to another wave of investment – where crude oil is being converted into chemicals rather than fuel. Many plastics and chemicals companies are also wholly or partly owned by oil companies.

– The companies' strategy locks society into continued fossil fuel dependence. It is not just about new production, but an active resistance to the commitments of the Paris Agreement. Recycling efforts are limited, and in the US there are several lawsuits in which companies have sued states and cities to impose a tax on plastic bags or other types of requirements for increased recycling.

Plastics and chemicals industry under the radar

There are several reasons why the plastics and chemicals industries have managed to come under the radar when it comes to the transition, according to Fredric Bauer. One is that consumers do not have a strong relationship with plastic production, but rather with plastic in the oceans.

Another is that many oil companies, which own many plastics and chemical companies, are themselves indirectly or directly owned by nation states. This poses greater challenges in terms of bringing about change and political pressure.

Many companies do communicate a desire to become more sustainable outwardly. But if you scratch the surface, there is little practical substance to their objectives, argues Fredric Bauer. He says money should follow – and new investments and factory expansions speak for themselves.

– Studies have shown that oil, chemical and plastics companies such as ExxonMobil have for many years been spreading misinformation about the science of climate change and arguing that more fossil fuels are needed. Shell has even been taken to court for having inadequate climate change plans.

Small Swedish industry – part of an international market

So what is the situation in Europe and Sweden, where the green transition is a hot topic? Fredric Bauer replies that in the EU, the emission-intensive plastics and chemicals industries have so far received more free emission allowances in the European Trading Scheme (EU ETS) than they needed, which has reduced the pressure for a transition. Some reforms have recently been proposed to address this, but even there the plastics and chemicals industry and several other industries have been critical. The links between the Swedish chemicals and plastics industry and the international arena are many and complex.

– Companies operating in Sweden are part of larger groups, and are highly integrated in international markets. They may therefore find it difficult to pursue transition projects despite local ambitions, as we have shown in a previous study. As a researcher, I lack concrete information and roadmaps on how they want to convert. What do they actually want to do, and how do they intend to go about it? Industry cannot continue to shy away from the transition, he concludes.

The article 'Plastic dinosaurs – Digging deep into the accelerating carbon lock-in of plastics' is published in Energy Policy. Download the article at sciencedirect.com

A longer popular science text discussing the issue has been published in The Conversation: https://theconversation.com/oil-companies-are-ploughing-money-into-fossil-fuelled-plastics-production-at-a-record-rate-new-research-169690

Photo: Pixabay

Communication and outreach

Selected activities

Sustainability Week, 3–8 May 2021

STEPS participated in Lund University Sustainability Week with two activities. One activity was the photo exhibition of Materiality & Aggregation, which was shown in Botaniska trädgården in Lund for five days. The other activity was targeted talks on arts and plastics aimed at high school art students. Participating from STEPS was Karl Holmberg (Department of political science), together with Moa Petersén (Department of Arts and Cultural Sciences).

Almedalen 2021

Together with industrial partners, TePe, Jonas Ihreborn and Polykemi, STEPS organised a digital panel debate at Almedalen 2021. The purpose was to discuss how companies could become more proactive and use plastics sustainably. The debate was filmed and shared via the partners' networks and via STEPS and Lund University's social media channels. Video on lu.se: https://www.lu.se/evenemang/almedalen-2021-plasten-klimatet-och-framtiden-hur-kan-europas-plastsystem-bli-hallbart

Release party Plastutmaningen at Chamber of Commerce and Industry of Southern Sweden

STEPS was invited to contribute with an article in the report Plastutmaningen, issued by the Chamber of Commerce and Industry of Southern Sweden. Johanna Generosi, programme coordinator, participated at the release party of the report at Form/Design Center in Malmö on 21 October 2021, and presented STEPS research project for other companies from Southern Sweden.

Theme seminars

Theme seminars on different topics were organised during 2021. STEPS partners were engaged as speakers in most of them: in January, partners Bona and Clariant, together with an external speaker from Paxymer, gave an introduction to flame retardants, from basic chemistry to the latest trends.
In March, IKEM gave a general presentation on chemical recycling, followed by an example of fibre chemical recycling done at RISE, and pyrolysis of mixed plastics upscaling and deployment done at Quantafuel.
In May, board member Maria Gustafsson and her colleague from SiS – Swedish Institute for Standards, took us on a journey to explore the processes of standardisation and the current work with standards related to STEPS research.
In November STEPS organised an open seminar on sustainable increase of biomass supply. The event brought together three experts and STEPS industrial stakeholder Mats Wallin from Södra, to highlight sustainable production and use of biomass for energy and material production. Besides the environmental considerations, the debate included supporting policies and business strategies from Swedish and EU perspectives.

Selected interviews and media coverage

Targeted article for Polymervärlden

STEPS also contributed with a targeted article for the niche publication Polymervärlden. This article focused on highlighting recent research within WP1, in particular the research by Mahmoud Ali Sayed and Oliver Englund Örn. This article was published in autumn 2021.

Other selected media coverage

https://www.lu.se/artikel/tre-vagar-framat-plasten-enligt-ny-eu-rapport
https://www.dn.se/varlden/eu-rapport-tre-vagar-for-att-skapa-en-hallbar-plastanvandning/
https://www.extrakt.se/plastens-klimatpaverkan-lyfts-fram-i-eu-rapport/
https://www.lu.se/artikel/manga-plast-och-kemibolag-storsatsar-pa-fossil-plast-visar-ny-kartlaggning
https://theconversation.com/with-demand-for-oil-dropping-the-fossil-fuels-industry-is-ploughing-its-money-into-cheap-plastics-new-research-169690
https://www.dn.se/sverige/kartlaggning-plast-och-kemibolag-storsatsar-fossilt/
https://www.aftonbladet.se/debatt/a/nWv3wn/svenska-folket-vill-se-atgarder-mot-plasten
https://www.extrakt.se/nedskrapning-dominerar-konstens-skildringar-av-plast/
https://www.livsmedelifokus.se/det-ar-mojligt-att-stalla-om-kottindustrin-till-2050/
https://www.nordiskaprojekt.se/2021/03/04/sa-ska-stal-papper-och-plastindustrin-stalla-om/

Photo: Pixabay

Conferences

S Madsen. Mind the trap! Geographical perspectives on scale in transformative innovation policy. EU-SPRI, 9th June 2021, Oslo (virtual).

G Tilsted, **F Bauer**. Networks in global socio-technical regimes: Addressing petrochemicals, ESG conference, 7–9 September 2021, Bratislava (virtual).

G Tilsted, **F Bauer**. Networks in global socio-technical regimes: Ownership interlocks in the petrochemical industry. IST conference, 5–8 October 2021, Karlsruhe (virtual).

R Hatti Kaul. Biobased polyemrs and their building blocks for packaging materials. Livsmedelsakademin VD-nätverket, 9 March 2021 (virtual).

R Hatti Kaul. Catalysing transition to a sustainable plastic system. French-Nordic Conference "Plastic recyclability and circular economy, 4–5 October 2021, IVA and KTH, Stockholm.

S V Mankar, **M N G Gonzalez**, **E Nilsson**, **Z Guo**, **J Wahlberg**, **P Jannasch**, **B Zhang**. Polyesters with vanillin-based rigid spirocyclic structures. Poster presentation at European Polymer Federation meeting "Polymers and Circular Economy", 17–19 May 2021 (virtual).

N Valsange, **N G Gonzalez**, **N Warlin**, **S Mankar**, **N Rehnberg**, **S Lundmark**, **B Zhang**, **P Jannasch**. Synthesis and properties of biobased aliphatic polyesters containing a spirocyclic dicarboxylate derived from levulinic acid, poster presentation at European Polymer Federation meeting "Polymers and Circular Economy" on 17–19 May 2021 (virtual).

N Warlin, **E Nilsson**, **Z Guo**, **S V Mankar**, **N Valsange**, **S Lundmark**, **N Rehnberg**, **P Jannasch**, **B Zhang**. Sugar-based rigid monomer, polyurethanes, and polyesters for textile and coating applications, European Polymer Federation meeting "Polymers and Circular Economy", 17–19 May 2021 (virtual)

N Valsange. Preparation and investigation of biobased aliphatic polyesters based on a rigid spirocyclic dicarboxylate derived from levulinic acid, Nordic Polymer Days, 18–20 August 2021 (virtual).

S Mankar. Synthesis and LCA of vanillin-based spirocyclic diol toward fiber and packaging applications, "Nordic Polymer Days", 18–20 August 2021 (virtual)

Publications

Scientific papers

K Li, **H Almqvist**, **C Hulteberg**. 2021. Three-step conversion of Indulin AT to muconic acid under mild conditions. Biomass and Bioenergy 153, 106232.

H Almqvist, **H Veras**, **K Li**, **J Garcia Hidalgo**, **C Hulteberg**, **M Gorwa-Grauslund**, **N Skorupa Parachin**, **M Carlquist**. 2021. Muconic acid production using engineered Pseudomonas putida KT2440 and a guaiacol-rich fraction derived from Kraft lignin. ACS Sustainable Chemistry & Engineering 9(24), 8097-8106.

F Walch, OY **Abdelaziz**, **S Meier**, **S Bjelić**, **CP Hulteberg**, **A Riisager**. 2021. Oxidative depolymerization of Kraft lignin to high-value aromatics using a homogeneous vanadium–copper catalyst. Catalysis Science & Technology 11(5), 1843-1853.

P Wang, **B Zhang**. 2021. Sustainable aromatic polyesters with 1,5-disubstituted indole units. RSC Advances 11, 16480 –16489.

X Li, **S İlk**, **JA Linares-Pastén**, **Y Liu**, **DB Raina**, **D Demircan** and **B Zhang**. 2021. Synthesis, enzymatic degradation, and polymer-miscibility evaluation of nonionic antimicrobial hyperbranched polyesters with indole or isatin functionalities. Biomacromolecules 22, 5, 2256–2271.

N Valsange, **M N Garcia Gonzalez**, **N Warlin**, **S V Mankar**, **N Rehnberg**, **S Lundmark**, **B Zhang** and **P Jannasch**. 2021. Biobased aliphatic polyesters from a spirocyclic dicarboxylate monomer derived from levulinic acid. Green Chemistry 23, 5706-5723.

N Warlin, **E Nilsson**, **Z Guo**, **S V Mankar**, **N G Valsange**, **N Rehnberg**, **S Lundmark**, **P Jannasch** and **B Zhang**. 2021. Synthesis and melt-spinning of partly bio-based thermoplastic poly(cycloacetal-urethane)s toward sustainable textiles. Polymer Chemistry 12, 4942–4953.

F Bauer, **G Fontenit**. 2021. Plastic dinosaurs – Digging deep into the accelerating carbon lock-in of plastics. Energy Policy 156, 112418.

A Kawde, **M Sayed**, **Q Shi**, **J Uhlig**, **T Pullerits** and **R Hatti-Kaul**. 2021. Photoelectrochemical oxidation in ambient conditions using earth-abundant hematite anode: A green route for the synthesis of biobased polymer building blocks. Catalysts 11(8), 969.

Z Guo, **M Eriksson**, **H de la Motte**, **E Adolfsson**. 2021. Circular recycling of polyester textile waste using a sustainable catalyst. Journal of Cleaner Production 283, 124579.

O Englund Örn, **S Sacchetto**, **E W J van Niel** and **R Hatti-Kaul**. 2021. Enhanced protocatechuic acid production from glucose using Pseudomonas putida 3-dehydroshikimate dehydratase expressed in a phenylalanine-overproducing mutant of Escherichia coli. Frontiers in Bioengineering and Biotechnology 9, 695704.

E Palm, **J Hasselbalch**, **K Holmberg** and **TD Nielsen**. 2021. Narrating plastics governance: policy narratives in the European plastics strategy. Environmental Politics.

Report

K Holmberg, **S Persson**, **J Stripple**. 2021. The future of plastics? Swedish public opinion on plastics policies. Report. ISBN 978-91-8039-022-4.

Master and PhD Theses

A Isacsson. Klimatstrategier i kemiindustrin – Analys av 6 företags utsläppsstrategier kopplat till länders åtagande. 2021.

F de Agostini. The relation between food shelf-life and environmental impact of different plastic packaging alternatives. 2021.

D Sukumaran Nair. Integration of food shelf-life in life cycle assessment of polymers. 2021.

M F Njoman. Packaging and E-Commerce: An exploration of needs and potential innovations. 2021.

R Saravana Kumar. Packaging for plant-based protein diets – Exploring the requirements from the consumer and industry perspective. 2021.

M A Ruiz Meija, **M M Pelitser**. Assessment of 1,3-propanediol production using L. reuteri, and its downstream processing. 2021.

M Mao, **Y Fan**. Mutagenesis of the lipolytic enzyme Lysin B-D29 to enhance its activity and thermostability. 2021.

E Olsson. Homovanillic Acid: a novel building block for lignin-based polyester. 2021.

F Sinclair. Exploring flexible structures in 3D-printed bio-based materials to closely mimic the properties of foam. 2021.

Photo: Unsplash

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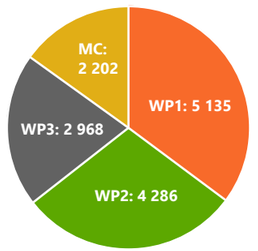
Photo: Anette Andersson)

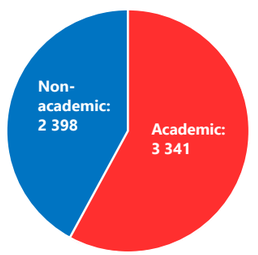
STEPS in Numbers

Total financial outcome
2020–2021*



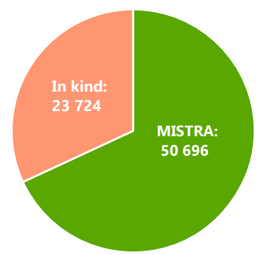
WP1 – Renewable feedstock to polymer building blocks
WP2 – Drop-in and new plastic formulation
WP3 – Governance towards plastic transition
MC – Board, management and commnunication

Total In kind contribution
2020–2021*



Academic partners
Non-academic partners

Total budget
2020–2024*



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In kind

*Total amount expressed in ksek. Numbers refer to Year 1 of Phase 2, September 2020–December 2021.

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