STEPS

Sustainable Plastics
and Transition Pathways

ANNUAL REPORT
2016–17

STEPS programme

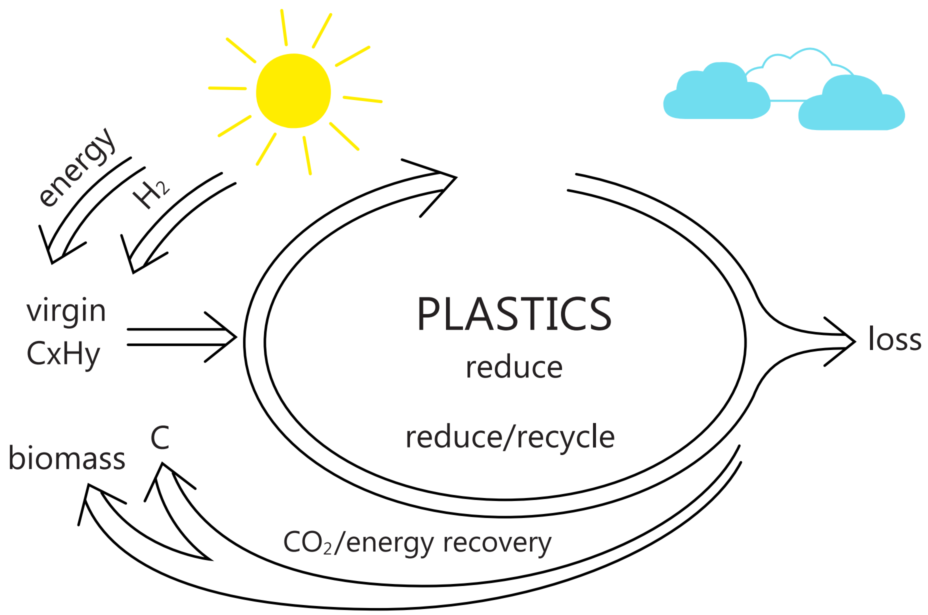
The Mistra financed programme STEPS – Sustainable Plastics and Transition Pathways – is a research program with a vision of a future society where plastics are sustainably produced, used and recycled. The goal is to facilitate this transition by sharing innovation, knowledge and findings between academia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

STEPS partners include Lund University, Swedish Agricultural University, Swerea IVF, along with 18 industrial partners and county council of Skåne county representing the entire value chains 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 material 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 sizable 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.



Cover photo: First demo product – StepOn, a fructose-based floor varnish developed by Lund University and Bona in 2017

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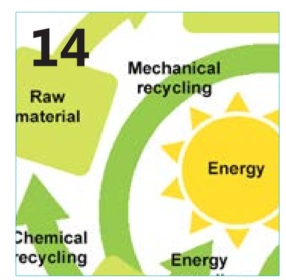

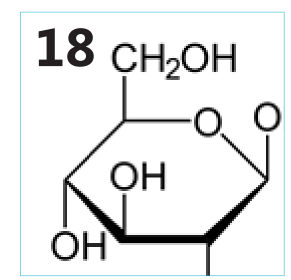

A few words from the Board

Britt Marie Bertilsson, Chair of STEPS Board

The Mistra programme STEPS is driven by a vision of sustainable plastics, materials that will comply with the requirements of a circular society – plastics made from non-fossil carbon, recyclable, and with a better environmental performance.

Plastics constitute a fairly young group of materials, very versatile and much appreciated, with a rapid development during the last several decades, now ubiquitous. It could be argued that we live in the Age of Plastic. More than 100 years ago Bakelite was invented, the first fully synthetic plastic. Nylon and many others came in the 30´ies. The plastic materials have entered the market due to inherent properties like low weight, low cost, moldability, insulation properties etc. However, we have to further develop the plastics to fit into the circular economy and to eliminate the waste problems epitomized by i. a. plastic garbage patches in the Pacific. We want the plastics to be bio-based, not made from fossil sources. That is STEPS´ ultimate goal.

STEPS has currently 22 partners, among them 18 companies and one Swedish county council, together they cover the whole value chain. Naturally, some companies are more active than others, the engagement might change over time due to changing priorities and resources. However, all partners will learn a lot, meet each other and contribute to the success of the programme. The 2-day programme meeting last year was actively attended by representatives of most industrial partners.

The STEPS organization of the research efforts is straightforward with 3 interlinked work packages (WP). More unusual is that each WP is managed by a combined group of academic and industrial researchers. This has proven very fruitful. The communication and the idea generation between partners are facilitated and encouraged by almost daily contacts. The interface between different academic disciplines and various end users provide an excellent breeding ground for new solutions.

Less than a year into the programme, the demonstrator StepOn was produced by Bona AB - a bio-based floor varnish applied on a wooden floor in a conference room at Lund University. The varnish is based on a chemical building block made from sugar at the university and then converted into a polymer and eventually formulated to a varnish by the company. It is such a great asset to have a demonstrator already early on in a programme.

STEPS is addressing the very complex system of plastics in the society and will contribute new knowledge and suggest pathways to a circular society. We are confident that the coming years will be exciting.

Britt Marie Bertilsson,
Chair of STEPS Board

Riding the wave of interest in sustainable plastics system

STEPS management group

There could not have been a better timing for the STEPS research program! Plastics are in focus – the ecological impact of the enormous amounts of plastics litter on land and in oceans is coming to the fore, and urgent solutions for a more sustainable plastics system are needed. Solutions for plastics are also seen as a part of several of the 2030 Sustainable Development Goals such as sustainable cities and communities, responsible consumption and production, climate action, and life below water. The plastics challenges are thus high on the political agenda, and at the time of preparation of this report, the European strategy for plastics in a circular economy has just been announced.

Formulated in close dialog with important stakeholders, the STEPS program reflects the need for the new plastics economy. The program targets the plastics challenges from different angles and explores solutions, e.g., through shifting the raw material base to renewable feedstock to reduce the carbon footprint, designing the plastics to improve durability and recyclability or biodegradability, and analyzing the institutional and policy implications of potential transition pathways. These objectives are being met through three interlinked work packages led by individuals from both academia and industry, who also constitute the management group of the STEPS program.

Activities in STEPS began already before the official start of the program in September 2016. The Board, comprising members with varying backgrounds of great significance to STEPS, was in place at the time of the kick-off. Besides recruitment of doctoral students and other personnel, a very important part of the first year of the program was to meet all of the industry partners to understand their interests and needs with respect to sustainability and desired properties of plastics, and about suitable biomass streams available for valorisation in Sweden. This led us to choose the target applications including films, rigid packaging, textiles and coatings. The 19 stakeholders, representing the entire value chain from raw material providers to those handling plastic waste, are of utmost value to STEPS not only in sharing their passion, creativity and knowledge, but also in having a collective ability to drive the transition towards better, more circular and sustainable system for plastics.

An important challenge in a large multidisciplinary program like STEPS is the communication within as well as into and out of the program, which has been handled very well by our efficient communicators. STEPS has received good coverage in the press during the first year. We have also been presenting STEPS at different conferences like Plastics & Textiles, Packbridge Research Forum, and in our respective organisations. The close collaboration and communication in the management group formed a key driver for innovation from STEPS, which have already resulted in a successful demonstration of the sugar based coating product "StepOn" within the first year of the program.

During the coming year, we will continue to engage with other national and international organisations, and research networks with similar goals as STEPS, as well as to follow the effects of the EU Plastics Strategy. We are, of course, also working with technical innovation with the goal of performing demonstrations of more products developed under the STEPS brand.

STEPS management group: Rajni Hatti-Kaul (Programme Director, Lund University), Johanna Generosi (Programme Coordinator, Lund University), Baozhong Zhang (WP2 Leader, Lund University), Christian Hulteberg (WP1 Leader, Lund University), Ellen Lindblad (WP3 Leader, Sysav Utveckling AB), Ellen Palm (WP3 Leader, Lund University), Johan Bruck (WP1 Leader, Ikea), Katarina Elner-Haglund (Programme External Communicator, Elner Communication), Lars J Nilsson (WP3 Leader, Lund University), Linda Zellner (WP2 Leader, Perstorp), Nicola Rehnberg (WP1 Leader, Bona), Sanel Peric (Programme Financial Officer, Lund University), Åsa Hallden Björklund (WP2 Leader, Perstorp)

Recycled plastics, biodegradable plastics or both?

Linda Zellner and Åsa Halldén Björklund, Perstorp AB

One type of plastic does not have to exclude the other as long as there is knowledge and sufficient waste management infrastructure in place to handle them.

Lately we are fed with pictures and stories about the environmental problems plastics contribute to. Terrible pictures of plastic debris in huge amounts floating around in our oceans and covering large coastlines affecting the wildlife, hurting animals and in the end ourselves negatively. Although the pictures do not lie, the message is unfortunately one-sided and none of the benefits with the material is even mentioned most of the time.

Biodegradable plastics

Thanks to plastics we can protect and preserve food, save lives in the medical sector and transport more with less fuel since plastic is lightweight compared to other materials, thereby reducing the climate impact from CO_2 emissions. The material can be designed in ways we never thought of but yes it is a problem when it ends up in nature since many types of polymers will never degrade. However, there are ways around this. Polymers that are biodegradable do exist and are perfect candidates for food packaging, wrappers, and catering products that are used once and then discarded. If these materials are combined in the right way and sorted in the organic waste it will not only make it easier to sort the food residues, greasy cutlery, plates and films it will also enhance the biogas value since more organic waste will actually be sorted out.

Often it is pointed out that the more sustainable and biodegradable polymers are lacking in performance. That is mostly true but in this case different types of biodegradable polymers can be combined to achieve the targeted properties without trading away sustainability. In packaging solutions either used in regions where waste management is very limited or when there is a high risk of these materials slipping through the grid and out in the environment, biodegradable alternatives are suitable especially since then the accumulation of plastics can be controlled. Also, in areas where landfilling is still applied certain biodegradable formulations can be used and over time biodegrade limiting the amount of plastics that will remain in the landfills and hence in the environment.

Many countries have infrastructures to collect and handle organic waste streams where biodegradable plastics can fit in those streams. The challenge is rather that the waste management facilities have difficulties in handling the bioplastic materials over paper based options since they are not modernized or adapted for that type of materials. From that perspective it is not the biodegradable alternatives that are the problem, the focus needs to be on upgrading our waste management facilities. From a study made in Sweden by Waste Refinery several benefits where identified by using biobags for food waste and one of the biggest was that the volume of organic waste collected increased since it was easier to handle, less leakage and odors thanks to the biobag[1].

To avoid contamination of plastics in the organic waste but also biodegradable plastics being sorted among plastics going into recycling streams an improved labelling is of importance. In many cases the labels used are different depending on the certification systems and they are quite small and easily missed or misunderstood. If this could be streamlined and a clearer marking on the final article is implemented that could make a big difference for the consumer when making choices on what products to buy but also when sorting the plastic waste. A dream scenario would be only two labels – one for recyclable and one for biodegradable plastics resulting in two streams where the organic waste units are adapted to handle the biodegradable plastics that ends up there and for the recycled alternatives these are sorted at a unit equipped with IR/sensors or a combination of established methods that ensures the sorting is correctly done avoiding contaminations and at the same time even more types of plastics can be collected and sorted removing them from the environment but also leading to a more efficient use of the materials.

Recycling of polymers

Recycling is an important key factor to get plastics into a circular economy. There are two kinds of recycling methods. Mechanical recycling where the plastics are sorted, grinded, washed and then reused in the production to partly or fully replace virgin polymers. Chemical recycling which is much less developed to industrial scale and where the polymers are degraded back to monomers to be used as raw material to produce new polymers.

Key requirements for successful mechanical recycling are large, homogenous streams with constant and even quality. To achieve this, the design of the packaging is very important for recycling and waste management with collection of sorted waste at the households to avoid contamination.

Analysis has shown that 84% of the plastic packaging waste originates from polyolefins and polyethylene terephthalate (PET)[1]. The polyolefin group comprises polyethylene (PE) and polypropylene (PP) polymers.

PET is the most recycled plastic packaging material in Europe and today the PET bottle recycling is the only true circular stream in large scale where post-consumer packaging becomes packaging again in bottle-to-bottle or bottle-to-sheet applications. However, the major end-market-use for recycled PET is still textile fibres[2]. The PET bottle stream is very homogenous and clean especially when there is a deposit system to ensure that only the right bottles enter the stream of material. Deposits also seem to be the most effective way of achieving high collection rates both in quality and quantity aspects as shown by the high collection rate in Germany[3].

A challenge for new polymers is to fit into the established recycling streams by being compatible and having properties similar to the material in the stream. That is needed for a material to be truly sustainable if it is not degradable.

Tetra Pak shows examples where local initiatives can make recycling happen also in countries without developed waste management, such as Tetra Pak packages made from carton board, PE and aluminum foil, when a long shelf life in ambient conditions of the product is required, like UHT milk and juice. When recycling those packages the paper fibers are separated from the plastics and Al-foil and then the fibers can be used in new paper or board applications. The rest, PE and Al, is called

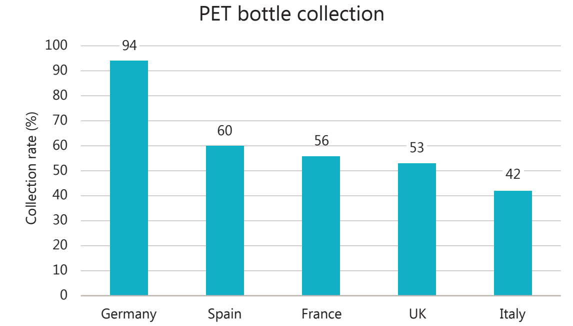

Figure 1. Collection rates of PET bottles for top 5 plastic consuming countries in EU[3]

PolyAl which is PE with varying concentrations of aluminum depending on the ratio of long shelf life vs. chilled packaging in the region. Tetra Pak has initiated many recycling projects in developing countries where large quantities of board packages have been collected and economically recycled into many applications such as: roof tiles, roof felt, furniture, industrial pallets, boxes and carpets with dissipative static effect, groundcover cloth, piping, Bahco tool handles and much more[4].

The Perstorp team in STEPS. From left:
Åsa Halldén Björklund, Technical Market Development Manager
Stefan Lundmark, Principal Scientist
Linda Zellner, Director of Innovation – Materials, Feed & Food.

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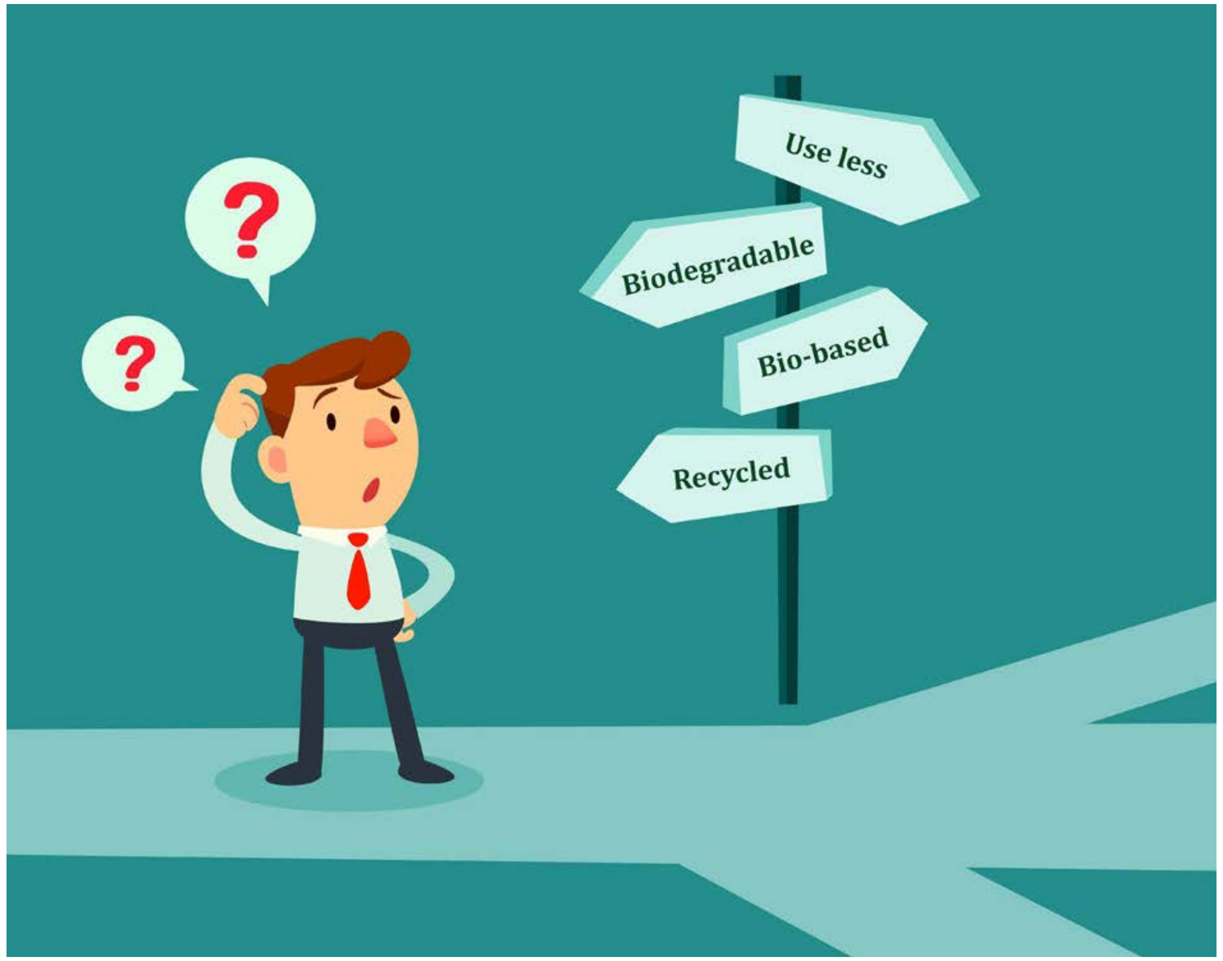

Sustainable plastics step by step

Teis Hansen, Stine Madsen, Tobias Nielsen and Lars J. Nilsson, Lund University

Plastics are ubiquitous in society and increasingly so in nature. Frequent reports describe remote beaches littered with plastics and government attempts to ban plastic products. Meanwhile, plastics are an integral and important part of a modern and more sustainable society. They protect food and help reduce food waste, enable the design of lighter vehicles, and facilitate efficient transmission of electricity as an insulator in cables. Plastics offer many solutions but also generate problems. It is hard to think of another material that evokes such strong feelings.

The production of plastics is strongly locked-in to petrochemistry and fossil feedstock. Global demand and production capacity is increasing with new investments being made, not least in the U.S. and Middle East. The current global production of bio-based plastics is only about 2 million tons per year (European Bioplastics, 2017). This is less than one percent of the total production of plastics of about 300 million tons.

Mobilisation for change

The problems associated with plastics are not new, e.g., feedstock issues and climate change, littering, and malfunctioning waste management, but awareness has increased in recent years. This is not least thanks to the Ellen MacArthur Foundation who, for example, has pointed out that there will be more plastics than fish in our oceans by 2050 unless we do something. In response to the mounting problems, the European Commission published its Plastics Strategy in January 2018 in order to lay the foundation for a new and more sustainable plastics economy. Similarly, the Swedish Government in September 2017 launched an official inquiry on reducing the negative environmental effects of plastics.

The feedstock issue

Increased recycling will reduce the need for fossil feedstock but due to downgrading of plastics in the use and recycling phases there will be a continued need for virgin material. In addition, global production is expected to increase. The Strategy says very little about the problems of using fossil feedstock, e.g., carbon dioxide emissions, but is highly concerned about the potential negative effects of bio-based plastics. Nonetheless, fossil feedstock is unsustainable and bio-based plastics, as researched in STEPS, are an important part of the solution. Bio-based plastics can be sustainably produced and in combination with renewable electricity and CO_2 as feedstock be a cornerstone in a more sustainable plastics system. Electrification and chemical recycling are key options to break the fossil feedstock lock-in.

The elephant in the room

The option of using less plastics is only briefly mentioned in the Strategy and in the context of single-use items and over-packaging. However, in response to the growing critique of what many see as unnecessary consumption of certain plastic objects, there needs to be an informed discussion on where, and how, plastic consumption can be reduced. It may be through lighter designs, avoiding "over-packaging", substitution, reuse of "single use" plastic products, etc. In this complex and diverse system, and since plastics often have clear sustainability benefits, it may be a challenge to design policies for using less plastics but it is nevertheless an option. At a minimum, fossil feedstock should be subject to taxes (i.e., carbon pricing) to create a more level playing field with renewable feedstock. If this is difficult due to international trade, consumption taxes should be considered.

Several pathways towards more sustainable plastics are possible, including bio-based, biodegradable, and recycled plastics, as well as fewer types and reduced use of plastics. In STEPS workpackage 3 we analyse these pathways, how they can be realised, and the role of a sustainable plastics system in a fossil-free future.

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Stine Madsen, Doctoral student, Department of Human Geography and CIRCLE, Lund University

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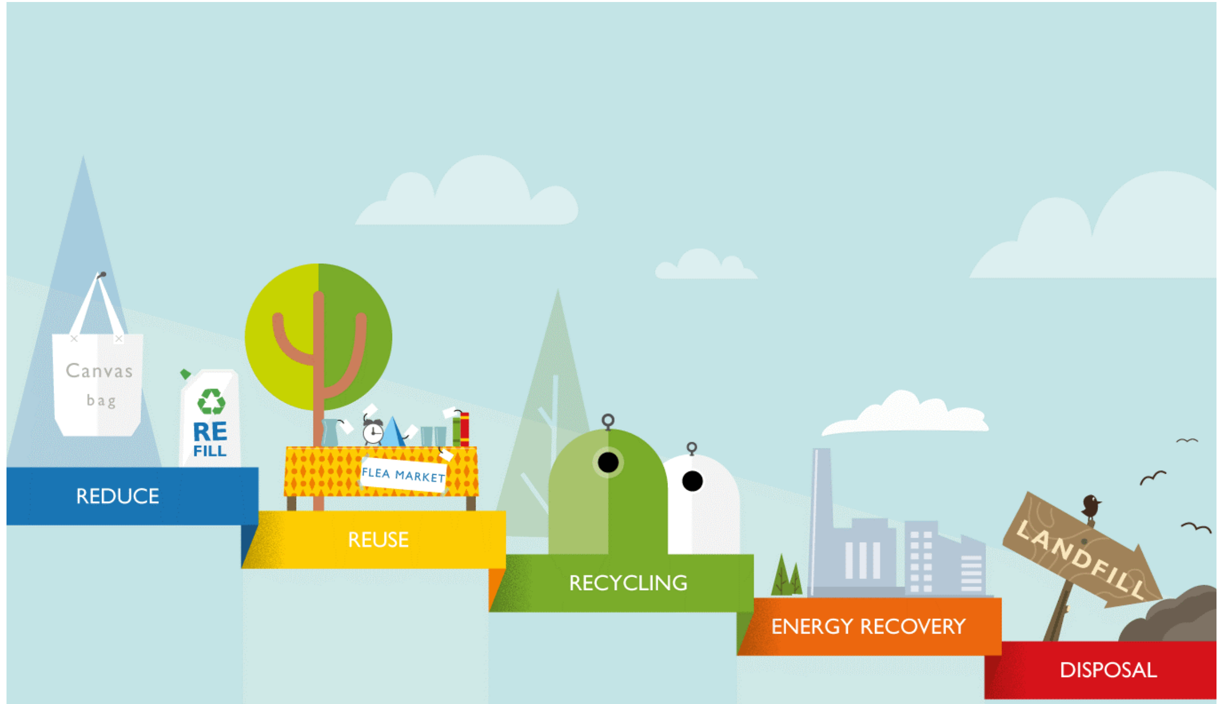
Lars J. Nilsson, Professor, Environmental and Energy Systems Studies, Lund University

Plastic waste – A Challenge for the entire value chain

Ellen Lindblad, Sysav Utveckling AB



The EU waste hierarchy (Sysav, 2018)

Today, only 16 % of the 600 000 tons of plastic that falls out of use in Sweden every year, is recycled into new material . This is well below the potential recycling rates and indicates that the road to a fully circular plastic system is a long and winding one. It is also a road that the waste management sector can´t walk alone since the challenges (and opportunities) ranges along the entire value chain, from design, manufacturing and use to collection, market and even development of new materials.

Fossil free vision

In Sweden it is not allowed to landfill combustible waste, which in practice means that plastic waste is redirected to waste-to-energy plants. Here the plastic acts as fuel in the production of district heat and electricity but since most plastic is made of fossil feedstock it also generates CO_2 emissions. Incinerating plastic is therefore not in line with the waste business vision of waste incineration being a fossil free energy source. The obvious alternative to incineration of plastics, and one step up in the EU waste hierarchy, is recycling. This is also highly prioritized in the EU plastic strategy as a means to increase the sustainability of the plastics system.

Starting at the beginning

If we want to recycle our way to a more sustainable plastic economy we need to start at the beginning: by designing products that are actually recyclable. The problem is that there is little or no incentive for plastic producers to design products this way and that designing only for recycling is not always the best option. In practice this means designers send the recycling challenge on for others (often waste managers) to handle. Because of this, there is a need to better integrate waste policies with production, consumption, and design related policies as well as increase cooperation throughout the entire value chain; from designers and manufacturers to waste handlers and recyclers.

A complex material

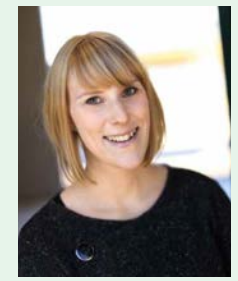
The wide range of different plastics with different properties and applications makes the collection and sorting of plastics much more complex than for most other basic materials such as metals, paper or glass. In some cases, it can work reasonably well, e.g. in the collection and recycling of PET bottles. In other cases, there are no set systems (e.g. PS and PVC from construction) or the existing system is simply not working well enough. For example, there is a system for collection of household plastic packaging, but still 60% of the plastic packaging ends up in the residual waste , destined for incineration. To further add to the complexity of the plastic system there is also a steady stream of new and potentially more sustainable plastic materials, such as bio-based and biodegradable plastics, entering the market. These plastics pose new possibilities, e.g. to reduce CO_2 from waste incineration, but when developed the recycling system should be kept in mind so that the quality and market value of recycled plastic is not put at risk.

Catch-22

According to the European Commission the demand for recycled plastics only accounts for around 6% of the plastic market in the EU and there seems to be a case of catch-22: manufacturers claim to have trouble finding enough volumes of recycled plastics of the right quality, while at the same time recyclers claim there is a lack in demand and thereby not profitable to make investments to increase the supply. However, volumes and qualities are not the only reasons for recycled plastics having a hard time at the market, there is also resistance among the product manufacturers to change their processes and a continuously low price on virgin feedstock. To boost the market of recycled plastics there is there for a need for quality standards for sorting and recycling, as well as economic incentives to both increase the price of (fossil) virgin feedstock and reward the use of recycled feedstock.

A challenge for the entire value chain

To summarize, plastic waste is not only a challenge for the waste management sector, but for the entire value chain: Products must be redesigned, collection systems need to be set up and optimized, the market for recycled plastic requires a boost and new technologies and materials need to be developed. However, all these challenges also present opportunities and though it might seem a daunting task, with cross-sectoral and holistic thinking there is no reason why a fully circular plastic system should not be possible in the future!



Ellen Lindblad, Project leader, Sysav Utveckling AB

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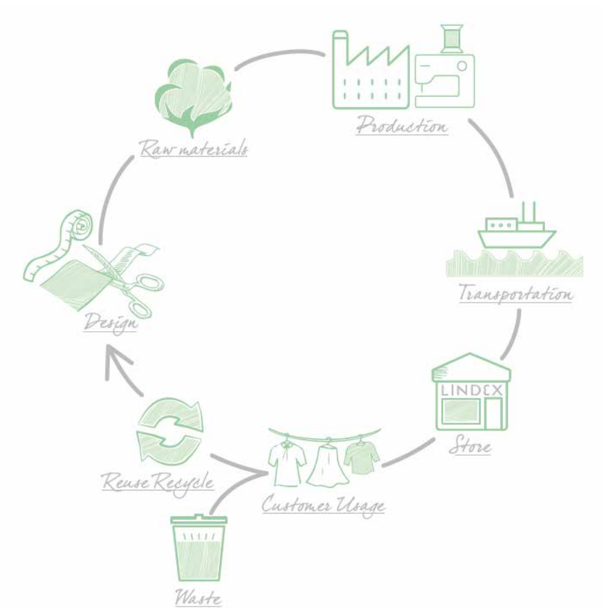
More sustainable fiber and raw material – an important part of a product's lifecycle

Annette Tenstam and Ingela Lind, Lindex

At Lindex we work with sustainability from a lifecycle perspective. Our ambition is to minimize the environmental impact in all parts of a product's lifecycle from design, fiber and production to reuse and recycle.



The production of fibers and raw materials is resource intensive and can have a significant effect on people and the environment. To minimize the impact we are continuously working towards increasing our use of more sustainable materials. We are committed to making 80 percent of our garments from more sustainable fibers by 2020. In 2017 we reached 55 percent.

Cotton is the most commonly used fiber for Lindex garments; in 2017, 49 percent of our garments were made from cotton. We want to contribute to a more sustainable cotton production by choosing more sustainable alternatives such as better cotton, organic cotton and recycled cotton. Organic cotton and Better cotton are grown with consideration for the cotton farmers and for the environment, and require less water, energy and chemicals. Whereas Organic cotton is certified according to a strict standard and also includes for example regulations regarding the use of genetically modified seeds, Better Cotton Initiative takes a more holistic approach on worldwide transformation of conventionally

grown cotton. In 2017 our share of more sustainable cotton was 95 percent, with organic cotton being the biggest part. We are one of the top ten users of organic cotton worldwide.

Today global production growth is intrinsically linked to a decline of utilization per item leading to an incredible amount of waste. Lindex cooperates with partners and suppliers to find new ways of re-using and recycling fibers in order to be more resource efficient. Today at Lindex we use recycled cotton, polyester and polyamide. During spring 2017 we launched Re:Design, a collection of exclusive upcycled products redesigned and remade in Borås, Sweden.

The need for textile fibers is constantly growing. The production of petroleum-based textile fibers and cotton fibers has already peaked and impacts the environment in various ways. Apart from using and creating demand for the more sustainable fiber options available on the market, we are also engaged in development projects that work to find new and resource-efficient ways to produce textile fibers. Lindex is participating in the STEPS project in the development of a new synthetic fiber based on renewable feedstock.

Annette Tenstam and **Ingela Lind**, Environmental Sustainability, Lindex

Örtofta Sugar factory: an agro-based biorefinery in Southern Sweden

John J Jensen, Nordic Sugar

Örtofta Sugar – the biggest bio-refinery in Sweden – is producing >300.000 ton sugar plus co-products beet pulp and molasses. Basically all incoming raw material is handled as valuable one way or other - one example is the sugar lost in wash water which is converted to methane in biogas reactor and replace part of natural gas for energy production.

Our ambition is to increase the overall value of sugar beet production to secure also in the future Swedish sugar production. From 1.10.2017 the internal EU sugar market is without production quotas and minimum prices for the beets bought from farmers. This liberalization will put even more focus on ways to increase the overall profitability of the whole value chain.

We participate in several projects to find the best new value additions – we think STEPS is very important project in this context to identify candidates/processes for production of bio-building blocks or bio-products like plastic.

The broad STEPS consortium enables also networking and identification of new collaborations and ideas for new products.

In another project we investigate the composition of beet top – which is around 25 % of dry matter of the beet and today left on field. In that project saponin and protein are well known components but we will look also for other functional components.

Sugar beet with top

Örtofta Sugar factory view

The valorization in a future cluster, where several raw materials can be processes in same plant or partly integrated plants but based on same infrastructure and utility systems will enable an overall better feasibility for new ideas, new raw materials and boost of existing raw materials.

Could such new raw materials be grown in rotation with sugar beet – would enable overall more secure supply situation for the sugar production.

Raw materials could also be sourced from existing food, feed, wood based industries.

John J Jensen, Senior Group Advisor Technology & Innovation, Nordic Sugar

STEPS for the future, Swedish research leads the way

Nils Hannerz, Innovation and Chemical Industries in Sweden (IKEM) and Ylwa Alwarsdotter, SEKAB Biofuels & Chemicals AB

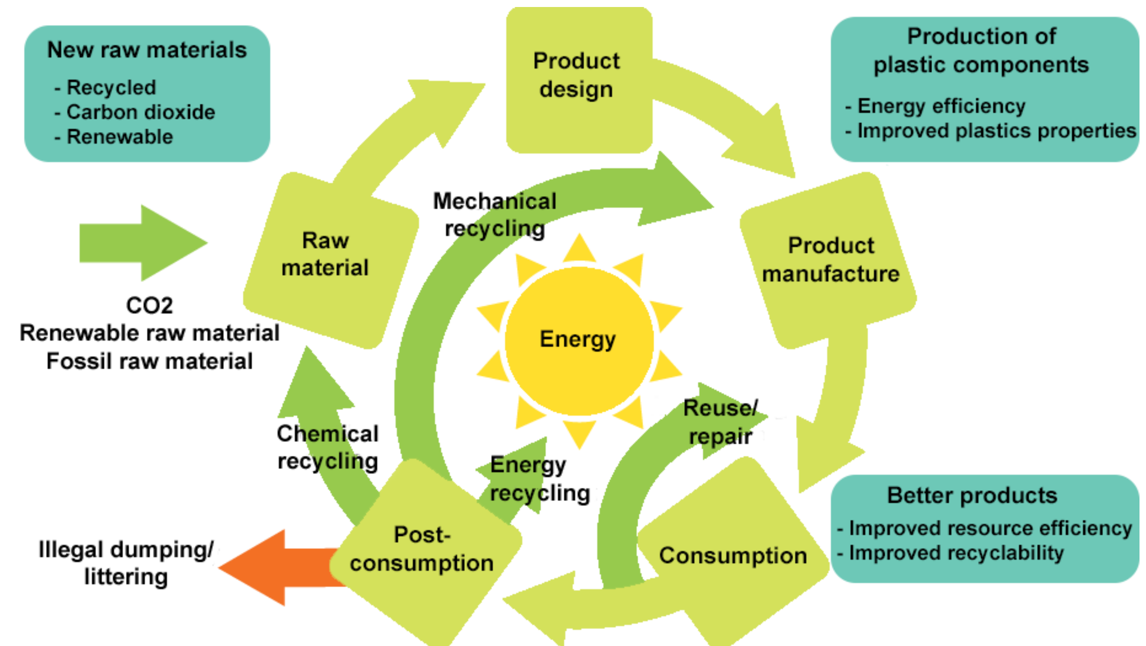
The adventure has just begun, materials for the future are being developed now!

Plastic is light, strong and resource-efficient. But the plastic cycle is not yet closed. Humanity needs plastics that are recyclable and renewable (see figure). That is why we in STEPS will develop such plastics for the future – a work that is equally interesting as important to do!

In STEPS, we will find means to produce plastics from renewable resources and find smart ways to recycle the plastic products. A complex task! Since plastics are a diverse group of materials, we have chosen to focus on a small group, polyesters, but this group can have a large impact on humans and environment.

Plastics are all around us, a large part is incinerated or much of its value is lost once a plastic object has been used just once. That is sheer waste. Today the plastics are produced from fossil based chemicals that are put together into long fibers, molecular chains. To be able to use renewable chemicals instead, one can both use existing techniques but we also need to develop totally new technologies. This is what our clever engineers and chemists are currently doing, they use their creativity and their knowledge to convert sawdust into a plastic bottle. This is an adventure that can be compared to the technical revolutions of Elon Musk. To go into a lab and try to do something that no one else has done before. Plastic bottles are perhaps not as exciting as Elon´s electric cars and space rockets, but there are many, many more plastic bottles and we use them every day. This is also quite exciting since it affects so many, in fact everyone. Plastics reduce food waste and provide a cheap and efficient packaging solution.

During 2017, we have tried to find new ways to produce raw materials for polyester in STEPS. We have for example started to develop new smart yeasts and processes for producing aliphatic and aromatic monomers for the polyesters. For example, the road from straw or saw dust to a bottle actually goes via producing alcohol by fermentation, and then use the alcohol as the raw material. It is important to find the right yeast strain for the fermentation, just like a brewmaster likes to find the right yeast for producing beer. Sweden can take the lead in new sustainable ways for production of bioplastics.



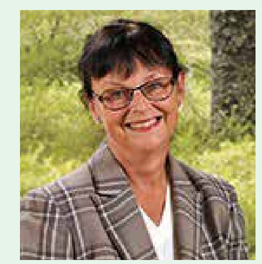
Recycling and reuse of plastics in a circular economy

The next step is to find funds for building factories. That means that one needs to count what everything costs, how much funds one can obtain, and the number of personnel needed. One needs also to consider where the feedstock will come from – forestry residues are available, where the factories can be built and how the transport can be made eco-friendly. All this needs to be evaluated and reported so that a bank or a venture capitalist is willing to invest money.

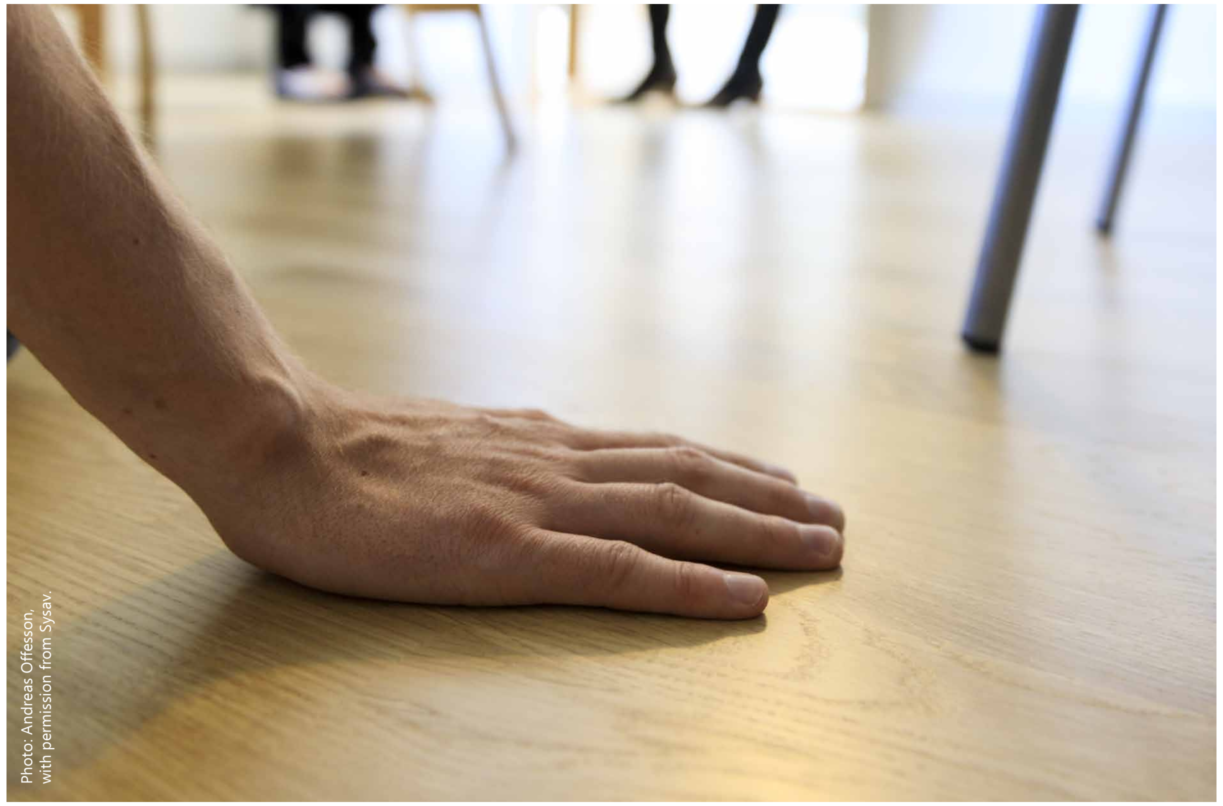
In the transition to a sustainable society, many different types of jobs will be needed that can give Sweden both economic growth and new job opportunities. In Sweden, we have no oil to sell but we do have a lot of residues from both forestry and agriculture that we can use instead so that we contribute towards sustainability as well as create products that Sweden can sell.

Earn money, create jobs, contribute towards sustainability, and at the same time participate in an adventure – that is STEPS. Now we look forward to a new and interesting year.

Nils Hannerz, Head of Research and Innovation, Innovation and Chemical Industries in Sweden (IKEM)



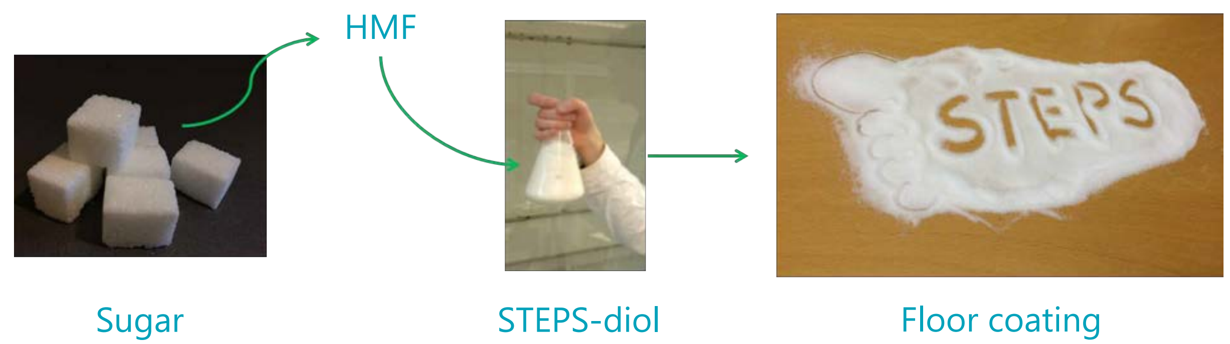
Ylwa Alwarsdotter, Excecutive Vice President, Market Development, SEKAB Biofuels & Chemicals AB



StepOn – how to protect a surface with a sugar

Nicola Rehnberg, Bona AB, Smita Mankar, Baozhong Zhang, Niklas Warlin, Lund University

The protection and modification of surfaces is seemingly a timeless human activity. The oldest rock paintings are believed to be 40 000 years old and, besides being decorative, may have put humans in contact with the spiritual world. Body painting is known from most tribalist cultures and has seen no decline in popularity over the millennia's. Microbial degradation of wood has for long been prevented using pine tar and was essential for the European naval exploration of the world starting in the middle of the 15:th century. Linseed oil and shellac are other examples of naturally derived coatings known for centuries or in the case of shellac, millennia. However, with the advent of the modern chemical industry in the late 19:th century, new materials, such as alkyds and phenolic resins became available for surface protection. During the 20:th century, coatings and other polymeric materials became very diversified and almost totally dependent on fossil raw materials. With a new look at resource availability, responsible consumption, and environmental impact, there is a renaissance for biologically derived materials. One of the most challenged coating types is floor coating. By spill, they are exposed to chemicals like water, alcoholic beverages, and fats and oils. Being the only surface that is walked on, they are subjected to excessive mechanical wear and in the case of wooden floors that move with changes in humidity, they must have a well-balanced hardness and flexibility profile. Coatings for the most heavily exposed floors are in many cases based on polyurethanes as these provide many of the desired properties. By weight, polyols constitute the most important raw material group for polyurethanes. These may be low molecular



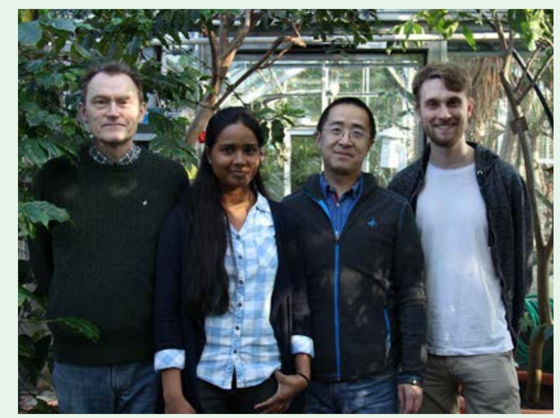
weight, such as neopentyl glycol or trimethylolpropane, or of higher molecular weight like polyesters or polyethers. Today, waterborne coating system dominates over solventborne and the compatibility and stability in an aqueous environment is accomplished by a diolcarboxylic acid.

Scratches and good scratch protection is important to all coating chemists. An object is considered new by many consumers until it gets its first scratch. Scratch resistance is important not only from an esthetical point of view but very much from functional aspects. A scratch is an opening in the surface where water can enter and corrode the substrate.

Nature provides innumerable chemicals but very few natural resources are realistic to utilise for large scale polymer production. Industry is not impressed by number but purity. A natural material that is available at high purity and large volumes is fructose (fruit sugar). It is widespread in all sweet fruits, as such or chemically united with glucose (grape sugar) as sucrose. Fructose is most commonly produced from corn, sugar cane or beet. In a principally simple, but technically challenging, reaction fructose is heated until it loses water. Besides steam, 5-hydroxymethylfurfural (HMF) is formed. It is also formed when a sweet beverage such as fruit juice is heated or when sugar is spilt on a hot stove. HMF is a product well suited for further chemical transformations. It is a rather rigid molecule and by reaction with other rigid molecules, the rigidity can be enhanced and very inflexible polymer building blocks result.

By reacting HMF with a biobased polyol we made a di-functional alcohol ("STEPS-diol"), an example of a rigid product.

Afterward, the produced "STEPS-diol" was added to a regular urethane polymerisation process and the polymer was mixed with water to give a dispersion that was used for the formulation of a floor finish, "StepOn". Preliminary testing revealed coated surfaces to be of good scratch resistance, a very appreciated property of a floor coating. A larger lot of "STEPS-diol" was synthesised and used for the preparation of floor finish at Bona in an amount enough to coat the meeting room Berzelius at the Chemical Center at Lund University. The scale-up went well and the coating took place as a public demonstration. The aging of the coated floor will be monitored to provide valuable input to the optimisation and development of new coatings based on sustainable raw materials.



Nicola Rehnberg, Manager of Innovative Partnership, Bona AB (extreme left) together with **Smita Mankar**, Doctoral student, **Baozhong Zhang**, Associate professor, and **Niklas Warlin**, Doctoral student, Centre for Analysis and Synthesis, Department of Chemistry, Lund University.

Carbon-neutral building blocks for sustainable plastics

Stefan Lundmark, Perstorp AB, Nicola Rehnberg, Bona AB and Rajni Hatti Kaul, Lund University

For a chemical company, the environmental, social and economic impacts arise mostly from up-stream raw material sources, production facilities and the downstream markets into which the products are applied. The impacts on the wellbeing and economic prosperity of employees, associated partners and the communities in which the company operates are also significant factors in measuring the success as a corporate steward. The heart of a sustainability strategy is a strong set of links between the company vision, the markets to serve and the United Nations Sustainable Development Goals. With this roadmap, we know that we must push ourselves and our value chains into the circular economy by using more "wastes" as raw materials and fuels, while developing the renewable resources needed to support our present and future platforms. The focused Innovation continues with selected efforts to commercialize new products driven by major market needs and transformations in society. More sustainable new solutions is the common trend why customers are turning to these products. Novel polyesters as alternatives to polystyrene in rigid packaging, and to polycarbonate are examples of plastic applications. Customers are substituting these driven by end-user demand on safer and more sustainable plastics.

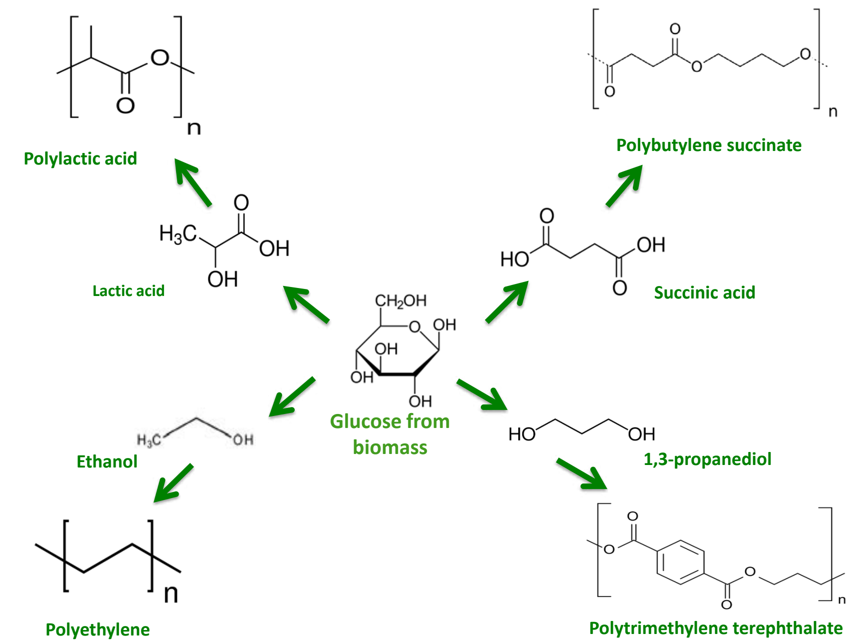
While the first plastics (Parkesine and celluloid) made over 150 years back had their origins in bio-based feedstock (cellulose), the advent of fossil based plastics in the early twentieth century and the rapid growth of petro-chemistry transformed the society by making available an amazing variety of plastics with a range of properties suited for a range of simple and advanced applications that touch every aspect of our lives. In this course, however our planet has taken a beating – we are depleting our resources and also creating and accumulating wastes at a very fast rate. There is now a growing awareness of greenhouse gas emissions, climate change, of the fact that petroleum is a limited resource, an increased market interest for renewable raw materials, for potential opportunities and long-term survival of innovative businesses.

In order to be fossil-free, the chemical and polymer industry is in need of carbon-neutral building blocks from renewable resources that could replace the fossil based olefins and aro-

matics used to make the current plastics. This gives room for innovative chemistry both for manufacturing the building blocks of choice and for making the plastics having not only the material properties and functionalities that we have come to depend upon, but also with better durability and end-of-life solutions. The approaches being pursued are both "drop-ins" and new products made from renewable raw materials.

Renewable products have multiple starting points, primarily biomass streams from agriculture and forestry and related industries such as paper and pulp, but also synthesis gas, methane and carbon dioxide, which can be processed by alternative technologies based on thermal, chemical and biological methods and their combinations. Unlike fossil feedstock, biomass is more complex and oxygenated that provides challenges of separation and new chemistry but also opportunities for achieving new, diverse functionalities through its various components. Plant oils and fats, being closer in structure to the fossil hydrocarbons, are already used widely in chemical industry, while carbohydrates and lignin, being the most abundant in nature, are being explored as raw materials for diverse aliphatic and aromatic building blocks. Bioethanol (with 2 carbons, C2), produced by fermentation of sugars primarily for use as biofuel, is now attracting attention as a building block for polyethylene and polypropylene.

In STEPS research program, the focus is on making biobased polyesters that are recyclable or biodegradable. Polyesters have a wide scope of applications in packaging, films, textiles, durable plastics, etc. They are made basically by polymerization of diol and diacid, or hydroxyacid building blocks, the nature of which determines the material properties as well as recyclability or biodegradability of the polymers. Examples of the building blocks available commercially are lactic acid (C3) e.g. for polylactic acid, succinic acid (C4) for polybutylene succinate (PBS), and 1,3-propanediol (C3) for PTT (polytrimethylene terephthalate)(see Figure 1). Interestingly, all three are produced from sugar through biotechnology routes making use of



Biobased building blocks produced currently in industry

microbial cells that produce these chemicals naturally or are engineered by altering and adjusting the metabolic pathways to produce the product of interest in large amounts.

Demand for longer carbon chain and aromatic building blocks is still to be met and there are ongoing efforts including STEPS for developing production routes for these. FDCA (furan dicarboxylic acid) – the emerging building block for making PEF (polyethylene furanoate) as an alternative to PET (polyethylene terephthalate) in bottles, coatings, and fibers, was included already in the 2004 Department of Energy's list of basic building blocks derivable from sugar. The industrial production of the starting compound for FDCA, i.e. 5-hydroxymethyl furfural (5-HMF) by dehydration of C6 sugars has been hampered by difficulties associated with finding both an economically viable process and a sound way to store this rather unstable compound. The novel approaches to the preparation of 5-HMF open the way not only to the large-scale production of FDCA but also other interesting molecules as potential building blocks for novel polymers that have found interest in STEPS.

This visionary integration of renewable raw materials will be achieved by applying and combining strong knowledge of all aspects of chemistry, chemical engineering and biotechnology into processing of bio-based raw materials, in order to produce and market chemicals, and polymers of non-fossil origin.

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Nicola Rehnberg,
Manager of Innovative Partnership,
Bona AB

Rajni Hatti Kaul,
Professor in Biotechnology,
Lund University

Events 2016–17

Kick-off meeting

The start of the STEPS programme was formally set by a kick-off meeting at Gamla Biskopshuset in Lund on 12 September 2016, attended by the majority of academic and industrial partners.

During these first sixteen months the programme has advanced by combining the research activities with several meetings within the work packages, among the work package leaders, between industrial and research partners and with external actors.

The main topics of discussion have been the choice of suitable raw materials, the value chains and the application areas of the biobased plastics. In addition, specific meetings were dedicated to the understanding of the end user perspective, crucial throughout the design process of bioplastics.

Participants at STEPS kick-off meeting at Gamla Biskopshuset, Lund, 12 September 2016

Programme meeting

STEPS programme meeting took place on 30-31 May 2017 in the nice surroundings of Örenäs Castle, Glumslöv, and was attended by academic partners, industrial representatives, board members and invited speakers from Sweden and the rest of Europe.

Panel discussion at STEPS Program meeting at Örenäs Castle, Glumslöv, 31 May 2017

Lectures and invited speakers:

Dr. Teis Hansen, Lund University, Sweden
Investing in biorefineries

Dr. Stephen Hall, Lund University, Sweden
Characterising polymer structure and mechanics from the molecular to the bulk material scale

Eva Myrin Svensson, Milav
Waste management of plastics – an overview

Dr. Zengwei Guo, Swerea IVF
Polyester textile recycling

Dr. Etienne Bouyer, CEA – New technologies for Energy Program Directorate, France
Mapping of the most promising fully biodegradable & fully biobased plastics

Prof. Lovisa Björnsson, Lund University, Sweden
Sustainable biomass supply

Marc Lankveld, Corbion
Creating biopolymers with biotechnology

Anna Fråne, IVL Swedish Environmental Research Institute
Collection – a key to increased recycling

Workshops

December 2016

"*Introduction to bio-based plastics*" by Rajni Hatti-Kaul;

"*Bio-based plastics - industrial perspective*" by Stefan Lundmark (Perstorp)

"*Bioplastics in Europe: market development and regulation – past, present, potential future*" by Board member Kristy-Barbara Lange;

"*Standardisation, innovation and standards for bioplastics and the bioeconomy*", by Board member Maria Gustafsson

May 2017

Workshop on sustainable plastics, 9 May 2017, Lund University. Organised by Work Package 3 using "Open Space" method. The workshop was attended by academic and some industrial partners.

Seminars

August 2017

"*Introduction to plastics*" by Åsa Halldén Björklund, 24 August 2017, Lund University

Acting hosts for important guests

MEP Federley visited Lund (21 April 2017) and had a meeting with STEPS researchers and some of the industrial partners (Perstorp, Region Skåne and Sysav).

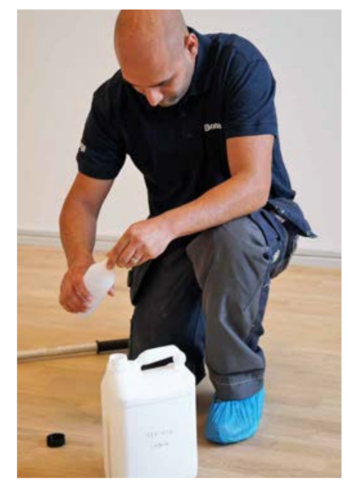
STEPS work package leaders and industrial partners meet MEP Fredrick Federley in Biskopshuset, Lund

Presenting STEPS for Mistra board and staff one year after the programme start.

Exactly after one year from the kick-off, in the very same building – Gamla Biskopshuset in Lund – STEPS work package leaders presented the programme's results, challenges and future development for Mistra's staff and Board.

First demo product

On the 28th of June 2017, STEPS fulfilled an important milestone – demonstration of the first product, the fructose-based floor coating StepOn. After only 10 months since the launch of STEPS, Bona and LU developed a coating with durability and chemical resistance similar, if not better, than the conventional fossil-based products on the market.



Ellen Palm and Rajni Hatti Kaul, Lund University with Peter Andersson, General Plastics Scandinavia AB at the demonstration of StepOn

StepOn floor coating being applied on the floor of a meeting room in the Chemical Center, Lund University

Study visits

Study visit to the waste management company Sysav in Malmö on 3 April, 2017

Left: Study visit at Nordis Sugar's sugar-production facility in Örtofta on 31 October, 2016

Study visit at Swerec plastics recycling facility in Lanna on 30 November, 2017

Study visit at Borealis Cracker and Polyethylene plants on 19 April, 2017

Invited presentations

Rajni Hatti-Kaul

"*Towards a circular plastics economy*", KILU Day (Annual day of the Department of Chemistry), 13 October 2016.

"*Bioplastics - ideal for circular economy*" at a lunch debate "*Time to rethink plastics? Going biobased is the new black!*", European Parliament, 18 October 2016, Brussels.

"*STEPS. Sustainable Plastics and Transition Pathways*", Plastics and Textiles Conference 2016, 15-16 November 2016, Göteborg.

"*STEPS towards a sustainable future of plastics*", Packbridge Research Forum 2017, 23 May 2017, Malmö.

"*Towards a circular economy: transforming wastes into plastics and other valuable products*", LUBIRC seminar, 1 September 2017, Chemical Center, Lund University.

Josefin Ahlqvist

"*STEPS – Sustainable Plastics and Transition Pathways*", *Bioplast – ett hållbar alternativ i en cirkulär ekonomi*, 20 September 2016, Gothenburg.

"*STEPS – Sustainable Palstics and Transition Pathways*", PlantLink Day 2016, 6 October 2016, LTH, Lund.

"*Grön Kemi Mistra Steps och Cirkulär biobaserad ekonomi*", LU Business council, 16 November 2016, IKDC, LTH, Lund.

"*How to obtain both commercial and scientific results in sustainability - from my experience*", 25 November 2016, Gamla Biskopshuset, Lund.

"*STEPS towards a low carbon future for plastics*", 17 January 2017, SEI, Stockholm.

Ellen Palm

"*En värld av plast – är det hållbart?*", Lär dig något nytt på 15 minuter! Akademiska lunchkvartar i bibliotekets atriumgård, 28 September 2016, City Library, Lund.

Åsa Halldén Björklund

Shared presentation with R. Hatti-Kaul, "*STEPS towards a sustainable future of plastics*", Packbridge Research Forum 2017, 23 May 2017, Malmö.

Lars J Nilsson

Tetra Pak Science and Innovation 23 May 2017. Earth System Governance conference, October 2017, Lund.
COP23 and side-events, 10 November 2017, Bonn.

Katarina Elner-Haglund

Material Depot event at Form /Design Center, 11 October 2017, Malmö.
Raw Materials University Day 2017 at Vattenhallen Science Center, 13 October 2017, Lund.

Niklas Warlin

Raw Materials University Day 2017 at Vattenhallen, 13 October 2017, Lund.

Invited to Roundtable discussion

On 15 December 2017 STEPS was invited to participate in the roundtable discussion at the Swedish Parliament, dealing with "Plastics – a driving force in the circular economy". **Ellen Palm** represented STEPS in the meeting.

Publications

Master theses

David Gustavsson, **Therese Stark**. *Production of 5-hydroxylmethyl furfural from hexose sugars using acid catalysts*. Biotechnology, Faculty of Engineering, Lund University, February 2017.

Dick Kuan, **Timothy O'Brya**n. *Investigation of rigid building block made from bio based material*. Center of Analysis and Synthesis, Center for Chemistry and Chemical Engineering, Lund University, June 2017.

Åsa Halldén Björklund and Rajni Hatti-Kaul presenting STEPS at Packbridge Research Forum 2017 in Malmö

Niklas Warlin at Raw Materials University Day 2017 at Vattenhallen, Lund.

STEPS in media

STEPS has drawn attention in media, resulting in the following publications:

Date	Title	Magazine/Journal	Link
160922	Tema plast: På jakt efter miljövänlig, hållbar plast	Lund University Research Magazine	www.fokusforskning.lu.se/2016/09/22/pa-jakt-efter-miljovanlig-hallbar-plast/
160922	Kan du tänka dig en värld utan plast?	Lund University Research Magazine	www.fokusforskning.lu.se/2016/09/22/kan-du-tanka-dig-en-varld-utan-plast/
160922	Hur skapar vi ett hållbart kretslopp för plast?	Lund University Research Magazine	www.fokusforskning.lu.se/2016/09/22/hur-skapar-vi-ett-hallbart-kretslopp-for-plast/
160922	Att använda bioplaster för 3D-utskrift – tre frågor till Olaf Diegel.	Lund University Research Magazine	www.fokusforskning.lu.se/2016/09/23/att-anvanda-bioplaster-for-3d-utskrift-tre-fragor-till-olaf-diegel/
160922	Stora möjligheter med bioplaster.	Lund University Research Magazine	www.fokusforskning.lu.se/2016/09/22/stora-mojligheter-med-bioplaster/
161013	Kampen mot en ohållbar plastvärld	Lunds universitets magasin (LUM)	www.lum.lu.se/wp-content/uploads/2016/10/LUM-6-2016.pdf
161208	Robusta biobaserade plaster	Plastforum	www.plastnet.se/article/view/526683/robusta_biobaserade_plaster
170118	Framtidens plast kan tillverkas av koldioxid	LTH-Nytt	www.lth.se/fileadmin/lth/omlth/kommunikation/lthnytt/LTHnytt_nr2_2016.pdf
170123	Kraftfullt svenskt bioplast projekt	Plastforum	www.plastnet.se/alla/kraftfullt-svenskt-bioplastprojekt/
170124	STEPS mot biobaserad plast-produktion	Nordisk bioplastförening	www.nordiskbioplastforening.se/2017/01/24/steps-tar-stora-steg-mot-svensk-biobaserad-och-hallbar-plastproduktion/
170305	Bioplasters roll i framtidens samhälle	Polymervärlden	sustainable-steps.se/wp-content/uploads/2017/01/Polymerv%C3%A4rlden-2-17.pdf
170322	Bioplasters roll i framtidens cirkulära samhälle	Nordemballage	www.n-e.nu
170327	Svensk forskarsatsning för bio-plastsamhälle	Packmarknaden	sustainable-steps.se/wp-content/uploads/2017/01/Packnet-27-mars-17.odt
170630	StepOn - the future floor varnish is made of sugar	News, Bona	news.cision.com/bona-ab/r/environmentally-friendly-and-renewable--stepon---the-future-floor-varnish-is-made-of-sugar,c2300548
170703	Hon provade ett mindre plastigt liv i en månad	Sydsvenskan	www.sydsvenskan.se/2017-06-29/inte-latt-att-leva-utan-plast
170711	Framtidens plast kan tillverkas av koldioxid	LTH-Nytt	www.lth.se/nyheter-och-press/nyheter/visa-nyhet/article/framtidens-plast-kan-tillverkas-av-koldioxid/
170719	Framtidens plast kan göras av koldioxid	Extrakt	www.extrakt.se/innovation-och-gron-tillvaxt/framtidens-plast-kan-goras-av-koldioxid/
170810	Plast av Olja kommer att fasas ut	ETC	www.etc.se/klimat/plast-av-olja-kommer-att-fasas-ut
170921	Drömmen är plast av koldioxid	Mistra	www.mistra.org/aktuellt/nyhetsarkiv/2017-09-21-drommen-ar-plast-av-koldioxid.html
171017	Nya steg på golv av socker	Retur (Sysav)	www.sysav.se/globalassets/retur-nr-2-2017.pdf
171022	Hon är med i jakten på ny klimat-räddare	Sydsvenskan	www.sydsvenskan.se/2017-10-22/infor-arets-klimatmote-den-som-forvandlar-koldioxid-till-nagot-nyttigt-vinner-stora-priset

STEPS Members

The Board

Top row, from left: Kristy-Barbara Lange (Board member, Deputy Managing Director / Regulatory Affairs at European Bioplastics), Christopher Folkeson Welch (Programme administrator at Mistra), Britt Marie Bertilsson (Chair), Søren Hvilsted (Board member, Hvilsted Consult), Maria Gustafsson (Board member, Project Manager at SIS - Swedish Standards Institute). Bottom row, from left: Josefin Ahlqvist (Former Programme Coordinator, Project Manager at Research, Collaboration and Innovation, LU), Rajni Hatti-Kaul (Programme Director, Professor at Biotechnology, Department of Chemistry, LU).

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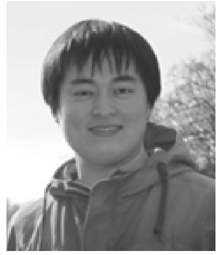
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MISTRA
The Swedish Foundation for Strategic Environmental Research

The Swedish Foundation for Strategic Environmental Research (MISTRA) **supports research of strategic importance for a good living environment ans sustainable development**.

Mistra, invests in various research initiatives to build bridges among academic disciplines, as well as between research, on the one hand, and companies, public agencies and other stakeholders on the other.

Mistra is an active research funder that monitors its own contributions to ensure that they are conferring benefits on society in the form of a good living environment, and that various users are developing new products, services and working methods to meet the environmental challenges facing us.

The purposes of Mistra´s investments are to create strong, world-class research environments with the ultimate goal to solve key environmental problems, strengthen Swedish competitiveness, and be valuable to users.

Further information can be found on www.mistra.org

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STEPS
Sustainable Plastics and Transition Pathways

ANNUAL REPORT 2016–17

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Cover photo: First demo product – StepOn, a fructose-based floor varnish developed by Lund University and Bona in 2017

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