FROM WASTE TO VALUE

Synthesis report of Mistra Closing the Loop research program 2016 – 2019
Closing the Loop for industrial by-products, residuals and waste:

**From Waste to Value**

Synthesis report of Mistra Closing the Loop research program carried out and completed 2016 – 2019

**Mistra Closing the Loop**

www.closingtheloop.se

Stockholm, February 2020

Text: Lena Smuk and Evalena Blomqvist,
RISE Research Institutes of Sweden

Layout and graphics: Maria Ljung, RISE

Mistra Closing the Loop is an interdisciplinary research program initiated by Mistra, the Swedish Foundation for Strategic Environmental Research with RISE as the program host and the scientific leader.

The first phase of the research program lasted for three years between 2012 and 2014. This report presents results from the second phase which was conducted during four years between 2016 and 2019. Additional to the overall program research, the program consists of six individual projects and an international Mistra Fellow scholarship.

The program is funded by Mistra and participating organizations and involves 50 organizations including representatives from various industries, research institutes and universities. Discussions and meetings with important authorities for the research area has occurred ongoing during program period. More information about participating organizations and the program plan such as common program activities, results and goals is presented in Appendix 1.

The use of materials in society is unsustainable

Mistra Closing the Loop is an interdisciplinary research program consisting of six independent projects, each working to increase the use of recycled materials in various products and processes. The projects have also been involved in research activities at the program level where an analysis of international and national policy as well as an in-depth analysis of the driving forces and barriers to expanding the use of recycled material in the society was carried out.

The use of materials in modern society is unsustainable and involves large value and material losses. One step to move towards sustainable material use is to increase the use of recycled material. In order for the transition to be sustainable in the long term, it must result in reduced mining of virgin material. Therefore, Mistra Closing the Loop recommends setting clear targets to reduce the use of virgin materials at global, national, local and organizational levels in accordance with the Climate Action Plan.

**There are opportunities to be realized**

Mistra Closing the Loop shows that there are opportunities for both a wider and more valuable use of recycled material in many industries, from the automotive and construction industries to mining and battery recycling.

In order to realize these opportunities, the unique properties of recycled material and its availability both in time and place should be regarded as valuable qualities. Small gradual changes, such as replacing a few percent of virgin material with recycled, are not enough to achieve the global scale of change that the unsustainable use of materials requires. A new approach to recycling is required. Change from low quality material recycling to material property reuse.

**Important barriers for the use of recycled materials**

It is not yet a norm to use recycled material. It is instead both complicated and uncertain, which explains the low levels of circular high-quality materials today. The use of recycled material faces an overwhelming number of obstacles at all system levels. Mistra Closing the Loop suggest that barriers with ineffective risk assessment, fragmented market and lack of collaboration needs to be addressed in order to lead to increased usage of recycled materials.

**Innovation for high value material loops**

The absence of supporting and attractive solu-
tions for circular material usage is one of the reasons why a majority of the material stock disappears yearly in the society. In order to reduce the amount of material that is landfilled or incinerated, the development of processes that enable efficient and sustainable recycling of materials through components, functional material recycling and molecular recycling is needed. In parallel with this, development of supportive logistic system and a waste incineration processes optimized for materials that cannot be used elsewhere in society need to be prioritized.

Important next step – 12 messages from Mistra Closing the Loop

To solve the problem with inefficient and unsustainable material usage, transformation in many dimensions and roles within the society is required. The report suggests twelve necessary steps for the industry, municipality, authority and research community, to increase the level of use of recycled material.

Mistra Closing the Loop was launched to increase knowledge on waste treatment and resource recovery and has always been driven by a desire to contribute to a broader concept in which today’s products become tomorrow’s resources.

Thanks to the contribution of individual projects and the research carried out at program level, a significant amount of information about the problems associated with the development of this concept and the movement towards sustainable use of resources has been collected and processed during the seven years of the program’s work.

The results of this work on problematic aspects of such a transition, the possible and necessary steps to enable the transition and the motivation for these steps are discussed in this report.
Sustainable material usage requires recycling of material

The global annual use of materials has almost tripled since 1970 and the material throughout reach 100 billion tons for the first time ever in 2019, and the cycling rate of resources has gone into reverse. This strong and clear message is given in the third edition of The Circularity GAP report 2020. This means that despite the ever-increasing amount of information on tremendous risks associated with unsustainable use of resources that becomes available we are not heading in the right direction!

Only 5% of the material used in the world is recycled but mainly by inefficient processes that generate materials of low quality and value. Society’s ambition is to achieve significantly higher levels of recycling. The obvious problem is that despite decades of high ambition, the use of recycled materials still causes major difficulties. 60% of the materials enter the economy in the form of short-lived products and are lost during the first life cycle - either dispersed in the form of emissions or non-recyclable waste.

Material use and carbon dioxide emissions continue to grow and, according to the forecast, the use of materials will reach 180 billion tons by 2050. This intensification of resource consumption poses a serious threat and is clearly incompatible with the intention to build a sustainable society.

To satisfy societal needs, 50 billion tons of carbon dioxide equivalence (Gt CO2e) was emitted globally in 2017. About 50%, of the emissions were released during extraction (mining and processing) of virgin materials. Additional calculations have shown that 70% of the CO2e emissions in the society were due to inefficient use of materials. Numerous recent studies show that 70% of greenhouse gas emissions are caused by inefficient use of materials in the society. Therefore, efforts to reduce the use of materials and increase the use of recycled materials are essential for combating climate change.

Facts and numbers

- 100 billion tons of material throughout globally 2019
- 60% of the material is lost after first usage
- 5% of the material used in the world is recycled
- 70% of greenhouse gas emissions are caused by inefficient use of materials in the society
- 700 billion USD can be saved annually if efficient material usage is applied globally

References:

2 The circularity GAP report 2019
3 The circularity GAP report 2020
4 Completing the picture how the circular economy tackles climate change.
5 Industrial Transformation 2050
It's clear that we will gain both positive climate effects and money by using materials for a longer period of time.

Paying tribute to the potential of innovations, we consider it necessary to emphasize that, first and foremost, a holistic view of the material system and an assessment of its sustainability in a broader perspective are required. It should be recognized that there are fundamentally unsustainable material flows that are unwise to include in closed loops. These material flows should instead be stopped and terminated. Otherwise, we risk making sustainable production dependent on materials originated from unsustainable sources. For example, recycling business based on processing of never-used products, such as making beer from bread or furniture upholstery from unused clothing, are not a sustainable solution in the long term since the primary problem with unsustainable excessive production is not solved in this way.

It’s clear that we will gain both positive climate effects and money by using materials for longer and giving the materials the high value, and status they deserve. The pathway to a low-carbon future is via slow and prudent material use.

The unsolved problem is how to stop ever accelerating material consumption. It is time for an economy that meets social needs using less virgin resources.

Doing “more with less” requires innovation. One component of the solution is to increase the use of recycled material instead of using virgin material.
Circulation of materials can potentially replace environmentally stressful extraction of virgin materials, but it involves potential conflicts and risks. Recycled material bears the influence of previous uses, loses its equality and may contain higher, and most importantly difficult-to-predict, pollution levels compared to virgin material.

The environmental goal of a non-toxic environment is today the main guideline for Swedish authorities when it comes to material recycling. At the same time, other important sustainability goals have limited the impact on the recycling-related decision today. Decisions on whether a material can be recycled or not are often made by performing a local environmental risk analysis that is guided by a limit value for the selected substance. This narrow and local risk assessment contributes to low levels of material recycling. The local potential risk must be compared with the potential for sustainable benefits at a global level, since sustainability will always be a global problem and no local boundaries can control it. Some EU countries, such as Germany, Denmark, Spain, Finland, Spain and France, have used other principals and decision-making methods that have resulted in higher levels of recycled material being used by them compared to Sweden.

A recent study *Recycling of waste: Decision and risk assessment* illustrates that a strategy focusing solely on a non-toxic environment has no scientific basis or support. This decision can even be counterproductive and lead to higher levels of hazardous substances being spread due to the need to extract virgin material and process non-recycled material through energy recovery or landfill. While chemical safety represents a natural limitation and a necessary pre-condition for sustainable use of materials, risk analysis should always be carried from a system perspective and compared with risk analysis of alternative scenarios.

To give an adequate assessment, the potential risk must be considered in relation to the application in which the material will be used. An alternative and broader risk assessment method has recently been published, which includes three decision steps adapted to the complexity of material recycling and based on experiences from other areas, such as transport and health care. When a broader perspective on risk assessment and a holistic system approach

---

7 How can conflicts, complexities and uncertainties in a circular economy be handled?

8 *Återvinning av avfall: Beslut och riskbedömning*

9 *Återvinning av avfall: Beslut och riskbedömning*
is applied, all the environmental goals will be accounted for in the decision. In addition, a broader perspective will also show that no alternative is risk-free.

The main reason why the process of risk assessment and decision making applied to the recycling of materials is ineffective is that most of the available policy instruments are primarily designed to control and regulate waste and emission flows in society. Sustainable use of materials requires political tools that support increased circulation\(^\text{10}\). To design policy instruments that support a society operating within the planetary boundaries is difficult since the boundaries are global, long-run, uncertain and interconnected. It is clear, that both current and new instruments need to be analyzed together to avoid conflicts and take advantage of synergies\(^\text{11}\).

To manage the calculated potential risk, a mechanism to distribute the risk and allocate responsibility is essential. Otherwise, there is a great risk that the implementation of the solution will be suspended due to a lack of trust, and the alleged low security of the new solution. To perform a sustainable risk assessment all

\(^{10}\) Waste policies gone soft: An analysis of European and Swedish waste prevention plans
\(^{11}\) Policy design for the Anthropocene
three aspects, (people, planet, profit) on a global scale needs to be valued to be sustainable in the long run. To decide if a material should be recycled or not the consequences of both alternatives need to be evaluated, with respect to all relevant goals, such as the non-toxic environment target, the resource efficiency target and the climate target. Since today very low levels of material are reused or recycled, we are losing the opportunity to significantly reduce CO₂ emissions. The low levels of circular material are often caused by non-functional risk assessments and decision methods.

**Sustainable risk management need to**

- Account for at least the three environmental goals, Resource efficiency, Climate and Non-toxic environment
- Evaluate and compare risks of implementing the change vs continuing business as usual
- Suggest mechanism for risk sharing

→ None of the alternatives is risk-free!

### Innovation is needed to keep material value high

The way products are constructed, used and discarded today leads to very short material cycles. Proper waste management is currently associated with incineration as a way to prevent uncontrolled discharge and disposal, which continues to be the dominant “treatment” of used material worldwide. While there are many reasons for the dysfunctional use of materials today, they are based on one main problem – materials have a remarkably low value in our economy. This situation contradicts our current understanding of the relationship between maintaining high material value and contributing to achieving Sustainable Development Goals.¹²

We need a transition from a concept that focuses on collection, treatment and minimization of waste, to a strategy for sound material management as a valuable resource, which is also equipped with policy tools supporting high material values.¹³ ¹⁴

From the resource efficiency perspective, unnecessary excessive processing leads to loss of resources. All decomposition processes, even composting, cause energy loss. In light of this, the production of goods that should decompose after the first use does not always seem justified, just like modern processing methods aimed at immediately returning the material to virgin state after the first use. The approach in which the search for possible economic and environmental benefits from the unique properties of the recycled material prevails over attempts to make it “like new” seems more reasonable. Change from bulk material recycling to material reuse.

---

¹² Completing the picture how the circular economy tackles climate change

¹³ Retaining value in the Swedish materials system

¹⁴ Is this the end of end-of-waste? Uncovering the space between waste and products
The Material-wheel tool (Figure 1) is created to support this approach and facilitate product and process design that maintains high material value for a long time\(^\text{15}\). The model differs from the waste hierarchy, which mainly focuses on identifying end-of-life method to dispose a product. The material wheel connects product design, use and recycling by focusing on the usage of materials. It rewards high material value by keeping materials in use and retaining the bound energy and value in products and materials. There is no given hierarchy between the solutions. The sustainability of a solution depends on the material composition and quality of the product, as well as the plans for next area of use.

Efficient material usage in the “primary” and “multiple” section of the wheel is mostly related to the design and business model innovations, meanwhile the following three sections - “component”, “material” and “molecular” are depending on innovation based on the product composition, material quality and material treatment processes. The lack of efficient processes for component-, molecular- and functional material recycling, is a reason why materials are landfilled or incinerated prematurely in a life

\(^{15}\) [https://resource-sip.se/materialhjulet-kopplar-samman-design-anvandning-och-atervinning/](https://resource-sip.se/materialhjulet-kopplar-samman-design-anvandning-och-atervinning/)
cycle. Therefore, efficient and sustainable processes are needed that provide society with new solutions to extend the life cycle of the material and enable the material’s multiple use.

**This calls for innovation**

- that enables recycling of components, such as supporting supply chain management and logistic systems. Methods used today make it difficult for reused components to be an option in a production processes, for example at a construction site or production line,
- that turns from bulk material recycling generating material with low quality to high-quality functional material recycling that preserve original function and property of the material to the highest possible extent. Specific recycling processes designed for selected materials, such as critical raw materials, and products need to be developed. An adapted process for selected materials instead of fragmentation methods designed for a bulk flow has great potential to produce higher quality materials with less energy and material losses,
- that enable resource-efficient chemical, biological or thermal processes converting complex or contaminated material and product flows into valuable raw materials through molecular recycling,
- which transforms the waste incineration processes into a sustainable solution optimized for materials that cannot be used elsewhere in society, ie optimized for materials that are not necessarily easy to incinerate,
Attempts to make recycled materials "equal" to virgin materials are often associated with large energy and economic losses. In a sustainable material system, the unique properties of recycled materials must be accepted and taken into account in order to seek economic and environmental benefits. Benefits can also be derived from the fact that material stocks will be local and can be handled by the community. We need to change how we plan for material availability and learn how to use the way recycled materials are available in the market.

A transition matrix, describing different solutions and the effect on the market and technology within the society is presented in Figure 2. Solutions and changes in the blue corner have generally marginal effects and can be rather difficult as well as time and resource consuming since they are inhibited by the norm and organizational structure of the current system.

**Incremental improvements**

Partial replacement of virgin material being recycled in an existing process is classified as incremental improvement of existing product in the transition matrix (Figure 2). The recycled material will be controlled and used according to the current process criteria, defined by the properties of the virgin material. Thus, the recycled material is often classified as the "second best" material and the effects on reduced usage of virgin material will only be marginal.

Innovative solutions and actors focusing on transformative change for global sustainability rather than incremental improvement in existing systems, tend to ask for something more and will look for business based on the unique properties of the recycled material and its ability to meet a societal need. The new product/service will then rely mainly on recycled material and will depend entirely on the properties, such as quality, quantity and location, of the recycled material. This type of innovation is defined as a disruptive solution both at market and technology level, i.e the solution is moving into the purple and maybe even orange section of the Innovation matrix in Figure 2. This type of solutions has potential to transform the society and generate large impact. By going beyond studying the current system and by attracting new knowledge and new collaboration in the innovation process, the conditions for disruptive solutions can be created.
**BACKGROUND**

A paradigm shift is needed.
Disruptive changes with exponential effects are needed to change society and make life within planetary boundaries possible.

Our consumption of virgin material must decrease significantly!

Producer of recycled components and materials should play a key role to support the society with material. This calls for innovations and creative solutions.

Noticeable limitations in use of virgin resources should serve as a powerful driver for people’s creativity and transformational innovations.

*Figure 2 Innovation matrix for technology and market.*
Important next step – messages from Mistra Closing the Loop

To solve the problem with inefficient and unsustainable material use significant changes in many dimensions and roles within the society are required. To boost this transformation, we suggest 12 necessary steps for the industry, municipality, authorities and research community.

To industries and municipalities

Recycled material is a unique resource!
Recycled material will never be equal to virgin material. We can’t afford the loss of material and energy associated with attempts to convert recycled material into “virgin-like” state. The unique properties of recycled materials must be valued positive and seen as an advantage in a sustainable material system. Change from low quality material recycling to material property reuse.

Reduce your appetite for virgin resources!
Start controlling your annual use of material to satisfy the needs of your business. Set goals and make a roadmap to cut your consumption significantly. Think of materials, by-products and even emissions as possible products and profits. Stop focusing on avoiding and reducing costs for waste treatment. Make material plans instead of waste plans for your organization.

Think ahead! Take responsibility for clean and homogenous material flows.
Do not create non-recyclable material mixes in your products and services. The problem with non-recyclable material within the society is an issue that primarily should be addressed and solved by producers and not by the recycling industry.

Be prepared! Share data to achieve reliable material recycling loops.
We need to increase information sharing (material- and process-data) to create sensible recycling solutions and increased use of recycled material. Increased exchange of information will also improve the high-quality risk assessment. The opportunity offered by digitalization and artificial intelligence should be exploited to achieve transparent and reliable material loops.
MESSAGES FROM THE PROGRAM

To authorities

Stimulate material use within the planetary boundaries!
Companies have little incentives to reduce their use of virgin material by changing to a more material-efficient process and business model. The main reason to the overall unsustainable economy is that we act as if there were no limitations on virgin resources. Help the society to be creative and innovative by setting a sharp long-term goal to cut the use of virgin resources by half. The reduction time plan should be synchronized with the global climate strategy to 2050.

Proper risk-assessment gives courage to handle chemicals in our environment!
Risks associated with the use of recycled material should be evaluated at the system level. All important environmental goals and targets need to be addressed. The Swedish government need to give clear guidelines to the authorities on how to handle the conflict between the environmental goals. Implement risk-assessments and policy instruments that supports increased material circulations. The primary purpose of existing tools is to regulate the treatment and discharge of waste, which prevents the circulation of material.

Create a market for recycled materials!
Industry needs incentives to use recycled material in their production and to design products for future material recycling. Introduce distinct and long-term policy instruments to facilitate investments for increased use of recycled material. Introduce policy instruments that makes it economically more attractive to use recycled material as well as instruments that increase the demand of recycled material.

Move from bulk to sustainable reuse!
Introduce policy instruments that favor both the recycling of critical raw materials and a high-quality functional material recycling. Mass- and bulk-based recycling creates a loss of valuable material. Digitalization and sharing of information and data can play an important role to increase the efficient material reuse i.e. functional recycling.

Support disruptive changes!
Create possibilities for research to lead a system transformation towards sustainable material use. The innovation system should support and encourage researcher to lead system transformation based on disruptive changes rather than incremental changes in existing systems. Moreover, introduce policy instruments and stimulate sharing of process and material data.
To research society

Innovation for sustainable risk decisions!
Knowledge for risk assessment is needed. Risk assessment at the system level should be conducted to find sustainable solutions. Decisions based on a local risk analysis and considering one material at a time often lead to counterproductive decisions that are likely to result in higher levels of harmful emissions globally. A knowledge base and methodology for efficient risk analysis must be created.

Innovation for increased investment!
Knowledge is required to understand the level of risk and how to share business risk and profit when the recycled material is part of the transaction. Sustainable environment and materials should be valued high and emissions should cost to facilitate correct calculations of risks and profit for a business. Long-term solutions and investments are needed to increase the use of recycled materials in production. Lack of knowledge, data and decision-making methods make it difficult to make these decisions.

Innovation for selection of recycling method!
Knowledge is needed to choose sustainable recycling processes to transit to high value material recycling. There is a lack of possible solutions between mechanical recycling and combustion, which creates a need for innovation within chemical/thermochemical recycling of materials. Innovations to support the transition from traditional bulk material recycling towards functional material recycling are also required. Moreover, clear knowledge-based guidelines are needed for the selection of recycling method.
Challenges with use of recycled material

The lack of a functioning market and, as a result, the low demand for recycled materials as well as the lack of a mechanism for sharing the risks associated with the use of recycled material, can be considered as the main obstacles to their use. These obstacles and their central role for the development are actively discussed in many reports, reviews and articles in various contexts. The results of research conducted within the framework of the Mistra Closing the Loop program allow to illustrate the crucial role of these barriers and also make progress in discussing possible solutions using a number of examples from participating projects.

Methods and theories applied

To analyze barriers and driving forces for use of recycled material as an important part of circular transition, the projects – namely Cimmrec, Constructivate, EBaR, Explore and GLAD – were used as case studies. The analysis was aimed at answering the following questions:

1. What can be said about the drivers and barriers to material recycling and circular economy in Sweden, drawing on the participating projects’ experiences?
2. What barriers are worth focusing on in order to bring about the change?
3. What methods and tools can help answer the questions above?

The study was highly exploratory and action-based, with creation of methodology and barrier analysis as equally important results. Two frameworks were developed to analyze barriers from the system perspective. These frameworks were specifically tailored to suit the purposes of the study and served different functions – the first used for information gathering, and the second – for information analysis.

Table 1 provides a brief overview of the two. A detailed description of each framework and methodology for the study is provided in a separate report.

17 Exponential Roadmap
18 Is this the end of end-of-waste? Uncovering the space between waste and products
19 Barriers for industrial waste recycling in the context of circular transition: lessons from Mistra Closing the Loop
Industrial recycling as a part of a broader transition towards a more circular society faces a great number of obstacles on all system levels. Apart from being a source of frustration, long and unprioritized lists of barriers can lead to diffusion of efforts and resources while attempting to tackle them all at once. In addition, these barriers have traditionally been regarded as separate entities, and little is known about the relationships between them. Based on the conducted program research Mistra Closing the Loop argue for a shift in how the barriers to circular transition should be studied and acted upon. More specifically, our results draw attention to:

- a need to better understand the links, relationships and dynamics between different barriers and barrier groups,
- a need for methodological experimentation and more action-oriented research,
- a more targeted approach, where resources are pulled towards tackling a few barriers with a scientifically demonstrated potential to accelerate the change.

**Analyze and prioritize**

To analyze and prioritize the barriers, Leverage Point Analysis (LPA) has been used. Central to the LPA assessment is weighing of the barriers identified at the information collection stage according to several criteria. The following criteria served as the basis for
the weighing exercise in this work:
- **Importance**: perceived importance of the barrier for the projects
- **Instances**: prevalence of the barrier, number of projects experiencing the barrier
- **Interactions**: the degree to which solving the barrier can affect other barriers
- **Influence**: potential to act on the barrier within certain actor groups

The method applied for the LPA is inspired by systems theory, particularly the concept of leverage points and the cross-impact method of forecasting. Applying the systems theory allowed to grasp and visualise the complexity of relationships between different barriers and barrier groups. This, in turn, is a key step in identifying leverage points - barriers that, once solved, can have a positive effect on the whole system. These leverage points are central, as they mark the most impactful points of action.

The identified barriers

The main barriers faced by the analyzed research projects were grouped according to the barrier types: policy, market, behaviour, actors, technology and product properties. These types represented reoccurring themes in interviews with project participants. Figure 3 below features relative perceived importance of different barrier groups split by project and barrier type. When it comes to the detected policy barriers:
- lack of instruments
- inferior design of used instruments, and
- level of ambition of the existing instruments acted as barriers according to projects’ experience.

There exist a number of policies related to collection and recycling of waste generated from industry relevant to the Mistra Closing the Loop projects (e.g. packaging, batteries, cars, electronics, and on-going discussions on textiles), a summary of existing policy instruments found in the current EU laws is presented in Table 2.

**Figure 3** Overview of the barrier groups by project and significance

<table>
<thead>
<tr>
<th>Plastic film</th>
<th>Policy</th>
<th>Market</th>
<th>Behaviour</th>
<th>Actors</th>
<th>Tech</th>
<th>Product Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constructivate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mn, Zn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EBar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLAD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explore</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMMRec</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## CHALLENGES

Table 2 A summary of existing EU laws stipulating requirements relevant for closing the loop for waste/material flows considered by the Mistra Closing the Loop projects

<table>
<thead>
<tr>
<th>Product/waste streams</th>
<th>Collection/sorting requirements</th>
<th>Collection targets</th>
<th>Recycling targets</th>
<th>Separation of components containing hazardous substance</th>
<th>Landfill bans</th>
<th>End-of-waste and bi-product criteria</th>
<th>Substance restrictions*</th>
<th>Product design requirement related to closure of material loops</th>
<th>Law governing both upstream &amp; downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packaging</td>
<td>94/62/EC, Art. 7</td>
<td>94/62/EC, Art. 6</td>
<td>1999/31/EC, Art. 5(3)(f)</td>
<td>2008/98/EC, Art. 5, 6 Recital (22)</td>
<td>94/62/EC (Art. 9, 11, Annex II(1)), 94/62/EC, Art. 9, Annex II</td>
<td>Not at the EU level, but practiced by many MS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical &amp; electronic equipment</td>
<td>2012/19/EU, Art. 5</td>
<td>2012/19/EU, Art. 7</td>
<td>2012/19/EU, Art. 11, Annex V</td>
<td>1999/31/EC, Art. 5(3)(f)</td>
<td>2008/98/EC, Art. 5, 6 Recital (22)</td>
<td>2011/65/EU, Art. 6, Annex II, III</td>
<td>2009/125/EU, 2012/19/EU, Art. 4</td>
<td>2012/19/EU, Art 7, 8(3), 11, 12, 13, 15 Recital (6), (12), (22)</td>
<td></td>
</tr>
<tr>
<td>Textiles</td>
<td>2008/98/EC, Art. 11(1)</td>
<td>1999/31/EC, Art. 5(3)(f)</td>
<td>2008/98/EC, Art. 5, 6 Recital (22)</td>
<td>2008/98/EC, Art. 5, 6 Recital (22)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
To better understand the causes of identified policy barriers, a systematic analysis based on so-called reconstruction of theories of policy interventions has been carried out. An important function of reconstructing intervention theories is to make implicit assumptions explicit. Although all political interventions are based on certain assumptions, these assumptions may not be explicitly stated.

Making these assumptions explicit provides an opportunity to examine the validity of such assumptions. The reconstruction of theories also gives the opportunity to understand if there is something wrong with the theory based on which an intervention was developed (theory failure), or if something went wrong in the implementation process (implementation failure). This is particularly useful in cases where desired results did not occur.

**Figure 4** illustrates the overall, simplified intervention theories for measures aimed at increasing the use of recycled materials in production.

---

21 Policy measures to increase the use of recycled materials in production - Achievement and challenges of existing policy measures and analysis of selected potential policy innovation – [https://closingtheloop.se/slutrapporter/](https://closingtheloop.se/slutrapporter/)

---
The implicit assumption behind these policies seems to be that improved the sorting of specific waste stream would lead to the development of cleaner recycled material fraction, which in turn would increase the use of recycled material in production. However, after deeper analysis of the barriers identified by projects within Mistra Closing the Loop, we conclude that this chain of changes does not hold (theory failure) and/or is not actualised (implementation failure). This illustrates once again that the approach of using recycled materials as substitutes for virgin on existing market conditions does not work.

Potential customers see few reasons to use recycled material instead of conventional virgin material\(^{22}\). It is necessary to create demand for recycled material under the new market conditions, where the unique properties of the recycled material are taken into account and appreciated. Implementation failures related to this chain of changes can be illustrated by examples from projects where the level of ambition and the design of administrative instruments was often criticized. For instance, Constructivate pointed out that weight-based requirements and goals prevent recycling of low weight plastic, such as plastic film. Explore noted that the way recycling rate is calculated – through collected volumes, represents an important barrier. Low level of ambition in setting political goals for circular economy was picked up by both Constructivate and Cimmrec, while GLAD faced the issue of the definition of waste and end-of-waste criteria. Since GLS is classified as waste, there is both significant resistance to its use and stricter regulatory framework applied.

**Market related barriers**

A closely tied barrier is the level of ambition in the Swedish Extended Producer Responsibility system. One part of the issue is the scope – or the material streams – included in the system. Another is stringency of the goals for material recycling. Yet another is the fee modulation, where the classic weight / sales / type of material fee is applied. While it has achieved significant results, it is often not enough to create incentives to improve the resource efficiency of recycling.

Consistent with other studies on industrial waste streams, market related barriers were experienced by all the projects, albeit to a different extent and in different forms.

- Cost structure that differs fundamentally from that of virgin resources,
- the low value of the material in relation to the high labor value, and
- unfavorable competitive conditions in the market

represented reoccurring themes, where issues either resulted from the fragmentation – or absence – of the market, or necessity to compete with cheap primary resources. In such a way, low value of plastic was named as an obstacle in Constructivate, CimmREC and Explore. Also, low prices for virgin plastic made it near impossible to compete. In addition to this, Explore had to deal with high labor costs for dismantling of cars. In EBar, the high capital investment required was difficult to justify with the value of potentially recovered Zn and Mn. In case of Constructivate, the market for recycled construction products was largely inexistent. Likewise, for GLAD one of the central market elements - pricing mechanism - was missing. GLAD and Explore both pointed out prohibitively high transportation costs in the absence of an established infrastructure.

**An opposite situation**

Virgin materials have been establishing their value chain for many years, decades or sometimes centuries. With source materials highly

\(^{22}\) How can conflicts, complexities and uncertainties in a circular economy be handled?
Concentrated geographically, the production facilities evolved to accommodate for this large volumes and short distances, and the economy of scale was the result. Recycled materials are facing the opposite situation. The lack of scale comparable to the scale of virgin materials, the distributed infrastructure or its absence, as well as market fragmentation mean that costs are higher while the volumes are lower. The issue manifests, among other, in prohibitively high transportation costs and comparatively high investment needs.

The investment costs are an issue due to, not the least, undefined risk ownership and lack of risk sharing mechanisms, another issue picked up by the projects. In a prisoner’s dilemma with a circular twist, self-interest reflected in risk aversion leads to lack of any development, as no actor is willing to assume any additional risk.

The perceived conflict between resource efficiency and toxicity is currently being resolved on the basis of the precautionary principle taken to its extreme. As discussed earlier, although chemical safety is a natural constraint and a necessary precondition for a circular economy, prohibitions, complete restrictions and prohibitively high limits are not efficient measures if achieving sustainability goals are on the agenda. Alternative methods for holistic risk assessment are possible and necessary.

Some of the barriers referred to in the “Actors” section of the Figure 3 can also be attributed to risk management. These are the barriers linked to the risks of information exchange under the prevailing lack of trust, limited cooperation and silo mentality. Explore, GLAD, Cimmrec and Constructivate faced such barriers in their project.

The identified technology-related barriers can be grouped into the following categories:

- Low maturity levels for technologies and processes (Cimmrec, EBaR, GLAD)
- Absence of technology easily available in Sweden (soft plastic washing for Constructivate, plastic sorting facilities for Explore, black plastic unidentified by the dominating sorting systems for Cimmrec)
- Failed previous trials that affected the development in a negative way (GLAD)

In many cases, there is a fine line between a
technological and a market barrier: even if a technological barrier is named, it often relates to the infrastructural setup and the context. An example is soft plastic washing (Constructivate) – a technology that is readily available but represents a barrier in the Swedish context as no facilities are available that could shorten the distances and cut the costs.

In many cases product properties act as a root cause of many barriers. The barriers can be associated with (i) material and product complexity, (ii) current product design and/or (iii) service phase characteristics, such as time perspective or aggressive environment. Time perspective can be clearly illustrated using Constructivate and Explore as examples.

Both projects are dealing with long service life products (buildings for Constructivate and cars for Explore). Many of products from these industries that are currently in use were not developed with sustainability and recyclability in mind. They often consist of non-traceable and mixed materials and, due to their long service life, will continue setting limits and defining challenges for circular economy for many years to come.

**Leverage points for action**

*Figure 5* presents the results of the leverage point assessment. The barriers that appear to present the biggest potential for acting as lever-

ages are:

1. Lack of risk sharing mechanisms (and broadly, risk management for recycled materials)
2. Fragmented market
3. Lack of collaboration and exchange of information
CHALLENGES

1 What are the barriers?

Policy: missing economic policy instruments, quality assurance and standards, requirements and goals not stringent enough, EPR not stringent or advanced enough

Market: high transportation and/or labour costs, no established logistics, fragmented market, lack of risk sharing mechanisms

Actors and behaviour: low collection rate, lack of capacity among actors directly involved in collection, hindered information exchange, lack of trust, collaboration hindered by silos

Technology: low maturity levels for technologies and processes, absence of locally available technology, failed previous trials

Product properties: material properties, material and product complexity, product design, use characteristics and time perspective

2 Which of them should we focus on?

Lack of risk sharing mechanism

Fragmented markets

Lack of collaboration and exchange of information

3 How can we solve these barriers?

Risks mapping and clear risk distribution

Involving the financial institutions

Demand commitment

New intermediaries and value chain innovation

From digitalisation to digital transformation

Roadmaps for closing the material loops

Strategic network building

4 What tools do we use to answer the questions above?

Context and Critical Conditions (CCC) – identifying and providing an overview of the barriers across two dimensions – time and system level

Leverage Points for Action (LPA) – exploring the relationships between barriers and suggesting the barriers that have the biggest potential to bring about change

Figure 5 Barriers and leverage points
Risk sharing and risk management

Establishing risk sharing mechanisms and embedding risk management principles into circular economy has potential to improve both the demand and the supply of recycled materials. On the demand side, an established society-wide risk management system means easier introduction of recycled materials on the market, a better understanding and communication of their value and a potentially higher willingness to pay. On the supply side, risk sharing across and beyond the value chain can help secure funding of the circular economy initiatives and level the playing field. Additional benefits include improving information exchange and collaboration between the actors through discussing and negotiating risk sharing arrangements and contributing to the “defragmentation” of the market for recycled materials through establishing tangible links between the actors.

Risk sharing and risk management for circular initiatives is needed on both macro (societal) and micro (industry and value chain) levels. Here, macro level risks include societal acceptance, political landscape, environmental and health and safety risks. Micro level risks include the market (demand, competition), organisational (intermediary, missing link, actor roles), financial (lack of financing, default) and technological (integration into production processes) risks.

Crucial to identify ownership of risks

Different types of risks require different types of measures and different actor constellations to successfully manage them. But central to any risk management endeavour is a common understanding of all risks that might arise. A successful risk mapping exercise would include identification of the sources, aspects and types of risks throughout the value chain and beyond.

After the risks have been properly identified and valued comes the stage of risk distribution. It is crucial that ownership of every type of risk is clearly defined. The general principle is that industrial partners – or partners closest to the development - allocate as much as possible between themselves, followed by the financial institutions, the government and the society/consumers. Creation of joint ventures is one way of distributing the risks and profits across multiple actors benefiting from the development. But regardless of the arrangement, there is often need for additional external funding, justifying the inclusion of the financial institutions.

There are two main ways financial institutions can contribute to circular economy: through providing with financial structures, and through adjusting their own risk assessment frameworks to balance linear and circular risks. ING provides a similar but more detailed overview, written from the perspective of financial institutions themselves. Both studies conclude that significant adjustments need to be made in the ways the traditional financial institutions operate in order to effectively capture the circular economy potential. Indeed, circular models and projects are strikingly different from linear ones and cannot be evaluated in the same way the linear are evaluated. Differences vary from time distribution of operational costs and benefits, to potentially higher capital expenditure, to a complicated market assessment. The adjustments need to be made to make sure that circular initiatives do not pay discriminatory premiums that reflect the added risks but...

24 Sustainable Banking: Finance in the Circular Economy
25 The ING Group is a Dutch multinational banking and financial services corporation
26 Rethinking finance in a circular economy
fail to encompass the added benefits of circular alternatives.

It is worth pointing out that the scope of the adjustment will depend on the type of activity. There is a need for a variety of capital types to finance the circular transition, and thus, a broad range of financial institutions to engage. Initiatives for increasing the resource efficiency can be relatively easily financed, while other initiatives associated with completely changing the business model are riskier and less fit for low-risk funding. For these, there might be a need for creating new financing models and financial institutions, such as dedicated circular economy funds.

Two risk categories are directly related to the fact that the market for circular products is not fully established – namely, market reliability and financial risks. In such situation, it is hard to estimate the demand for the product, appropriately finance new infrastructure and estimate the capacities required. One potential arrangement is various forms of demand commitment from the buyer’s side, the most common form being an offtake agreement. Offtake agreement implies that the buyer of the material commits to purchasing a certain amount of this material in the future, often before the infrastructure is built. Thus, demand commitment secures the cash flow for the material and simplifies financing of the facility. Other, less binding forms include setting corporate goals. In our conversations with Explore, it was named that Volvo’s commitment to recycled materials acted as an important driver for the project. Other market players such as Ikea start to drive similar initiatives in other markets.

“Defragmentation” of the market

With traditional distribution and selling channels seemingly failing to accommodate for the distributed nature of circular material flows, new types of marketplaces and value chain arrangements need to be established. The role that was sought after the most in the participating projects is an intermediary that facilitates the transactions. Such a role would stretch across the areas of business development, logistics and purchasing, sustainability and quality.

Introducing a new role in the value chain can lead to a cost increase. Some of these costs can be cut through optimizing transportation and digitalizing the transactions, as well as through attracting a critical number of players.

Diversity of materials and volumes means that the possible losses from low volumes for some deliveries can be balanced out by other, bigger, deliveries. In cases where a platform is co-funded by several actors, the general financing of the initiative can be arranged through joint ventures, where risks and benefits are shared between the participating parties. Digitalization is another way to compensate for the negative cost effects of redesigned value chains. AI and digitalization can help manage the complexity embedded into the distributed circular value chains. In fact, the digital dimension should be seen as a natural part of the circular transition.

Collaboration and exchange of information

Both distributing the risks and building new value chains require collaboration and exchange of information to properly function. In a way, collaboration acts as a key enabler for all the solution groups named above.

One success factor for a collaborative network is, once again, the presence of a central node – an actor that coordinates and facilitates the collaboration. Identifying the actor that could
act as such a node for other circular economy industrial initiatives is the first step in the right direction.

However, establishing a collaboration node and a platform is not enough to build a successful network. Equally important is the presence of a common goal and the sense of the progress towards this goal. For this, facilitating a dialogue between industries that deal with similar raw materials, building strategic networks similar to Fossil Free Sweden and developing common roadmaps can be helpful. A collaboration of this type can bring about several benefits:

- Breaking the silo mentality – creating new communication channels and facilitating the dialogue between actors that otherwise do not collaborate
- Creating accountability and ownership over societal issues through transparent commitments and clear responsibility distribution
- Gathering the critical mass for the transition

Identified barriers are similar to those mentioned in the literature. It seems that we are approaching the point of saturation in our understanding of what obstacles are. It’s time for a shift from mapping the barriers to acting on them.
The research program Mistra Closing the loop consists of six individual research projects that aim to increase the use of recycled material in production.

Material flows from the pulp and paper industry (GLAD), the recycling industry (Fines), battery recycling (EBaR), the automotive industry (Explore), the construction industry (Constructivate) and the manufacturing industry as a whole (Cimmrec) that could potentially be reused were studied. Innovations in the molecular and functional processing segments of the material were studied in three projects, namely EBaR, GLAD and Fines. Meanwhile, innovations for functional material recycling and component reuse were in focus for Explore, Cimmrec and Constructive (Figure 6).

In addition to research projects, a cross-European study of specific examples of how to resolve conflicts, difficulties and uncertainties in a circular economy was carried out. Each project is briefly presented below.

Figure 6: Six research projects within Mistra Closing the Loop have generated results and knowledge that contribute to the effective molecular and functional recycling of materials, and recycling of components.
EBaR – efficient recovery of Zn and Mn in alkaline battery

The main focus of the EBaR has been to develop a pyrometallurgical concept for efficient recovery and reuse of Zn and Mn in the alkaline battery black mass (crushed batteries after removal steel cases) which contains about 25-30% Zn and almost the same of Mn. The existing processes of recycling of alkaline battery blackmass recover only Zn. Meanwhile Mn is lost in the slag which then requires additional processing for safe landfill due to the Mn content. The main route developed in the project is using a reactor to process the blackmass at about 1000-1100C. By doing that Zn in the material was recovered as a ZnO-dust fraction containing about 70%Zn that can be used by Boliden integrated in their Zn process. The remaining fraction contains mainly MnO that was found to be of such a high-quality that Eramet Norway can used it in their SiMn production.

Selected major achievements of the project:
• A zero-waste process concept for co-recovery of Zn and Mn from alkaline battery blackmass has been developed by thermodynamic modelling, lab-scale
• The developed process has been successfully demonstrated in pilot scale (1.2 ton/batch) in a two weeks long test campaign where 22 tons of blackmass has been processed.
• Samples from pilot testing have sent to the end-user industrial partners for characterization and evaluation. They found the generated EBaR products useful and suitable for their Zn respective Mn-alloy production.

Author:
Guozhu Ye, Swerim
For more information about the specific project and list of publications:
https://closingtheloop.se/aktuella-projekt/ebar/
One of today’s main challenges for the mining industry is the release of acid rock drainage with high concentration of trace elements, from mining waste deposits. At the same time, the paper and pulp industry produces large amounts of alkaline materials almost exclusively deposited. Each year, about 300 000 tonnes of green liquor dregs (GLD) is generated by the Swedish pulp and paper industry. There is no sustainable use for GLD today; the material is deposited at the mills own landfill or used to cap municipal waste landfills (a demand which decreases as most landfills are covered). Even if there are no taxes for GLD disposal, the mills have high costs to operate their own landfills. Meanwhile, the potential to use GLD to reduce the negative environmental impact of mining waste has been shown. The research focus on two strategies where the properties of GLD can be utilized: (i) used along with till in sealing layers to prevent oxidation of sulfides in the mining waste, and (ii) via injection to neutralize the acid and tie up metals in already oxidized tailings from the mining industry.

The project aims to fill the knowledge gap that remains on production and quality requirements, to establish the use of GLD for remediation of mine tailings and waste rock.

Selected findings by the project:
• GLD has been chemically and physically characterized from several mills during several years. There is a large variation in GLD quality between the different mills, but the quality variation with time within a single mill is fairly low. Through the establishment of an environmental GLD-database the use of the material has gained a higher degree of acceptance from the authorities becoming more transparent re-

GLAD – sustainable use of green liquor dregs
garding the content of the material, its leaching properties and environmental impact, etc.
• It has been shown that GLD is suitable for treatment of acid forming mining waste. Through large pilot tests different methods for mining waste reclamation has been shown to work through minimizing contact with oxygen (GLD in dry covers) or neutralizing already weathered waste (injection).
• There is a need for an independent mediator that guarantees the quality of GLD and accepts the risk in order to facilitate the deal between the mills and the mining companies.

Author: 
Mattias Bäckström, Örebro University
For more information about the specific project and list of publications: 
https://closingtheloop.se/aktuella-projekt/glad/
Many of our current recycling systems only valorise a fraction of the materials contained in the waste streams, while the remains are either downcycled to low quality resources or disposed of in landfills. Their operation therefore often generates significant amounts of heterogeneous residues, which are technically challenging and economically unappealing to recover. Beyond adding disposal costs to the recycling industry, such a practice leads to continuous losses of natural resources.

The project aims to contribute with knowledge and methods for facilitating valorisation of such heterogeneous residues in Sweden. In doing so, we study the resource potential and multifaceted challenges for valorisation of a specific and fine-grained residue in terms of shredder fines, which is generated from the recycling of end-of-life vehicles and other scrap. By synthesizing these results and by analysing which functions and conditions that are required to establish new markets for waste-based materials, guidance on how to initiate and further support valorisation of heterogeneous residues is provided.

**Selected main findings from the project is provided below.**

- Through an extensive characterisation study, the project concludes that shredder fines have a significant resource potential in terms of potentially recoverable metals, energy carriers and minerals. However, the realisation of this potential is currently hold back by several material constraints, readily available and low-cost disposal options that are classified as recovery, a low market demand for waste-derived resources and unclear regulations and playing rules for recycling.

- A generic methodological approach that facilitates a more strategic and systematic development of recycling processes for heterogeneous residues is presented. By applying this approach, the recycling industry can identify potential recycling options, specify which material constraints that need to be addressed to comply with regulatory and gate requirements and develop integrated upgrading and recycling process schemes for the recovery of multiple resources.

- Policy and market interventions is vital for facilitating valorisation of heterogeneous residues such as shredder fines, ashes and slags. Through such administrative and economic instruments, the incentives for the recycling industry to engage in the recovery of their residues can be increased, a market demand induced, development consent processes facilitated, and the
responsibilities and roles of waste producers and users clarified. When it comes to shredder fines, however, such policy measures first of all need to challenge the current low-cost disposal options and provide clear requirements and guidelines for recycling so that the shredding industry can foresee the outcome of such investments. The need for addressing the regulatory challenge of how to balance the conflict between resource recovery and a non-toxic environment is particularly profound in this respect.

Author:
Joakim Krook, Linköping University
For more information about the specific project and list of publications:
https://closingtheloop.se/aktuella-projekt/mistra-fines/
The main goal of the Explore project is to find ways to strengthen the Swedish automotive recycling industry’s role in a more circular economy and create close cooperation between manufacturing and recycling industries. To deliver on that goal, the research has focused on:

1. Analyzing future vehicle fleet’s material content and its implication for recycling system adaptation.
2. Adopt and adapt manufacturing planning and control theories and practices to develop a more efficient vehicle dismantling.
3. Analyze and propose solutions for more efficient reverse logistics in vehicle recycling.
4. Identify political and industrial action that can support the development of Swedish vehicle recycling.
5. Identify technical solutions for disassembly, sorting and recycling of future vehicles.

Selected main findings from the project are provided below:

- The current European vehicle fleet of about 260 million, loose substantial amounts of scarce metals every year due to inefficient recycling, among them about 20 tonnes of gold. The quantities of critical and scarce metals have increased in vehicles over time due to rising amounts of electronic components, and vehicles now contain many new metals. The increase will continue in the future, which implies that recycling technologies will have to adapt to keep these metals in use. Another type of materials that have increased in vehicles over time are plastics.

Plastic and elastomer content in 44 vehicle models produced between 2003 and 2018 has been mapped. A trend towards a use of more thermoplastic vulcanizate, thermoplastic elastomer (TPV, TPE) and acrylonitrile-butadiene-styrene (ABS) plastics in battery electric vehicles (BEVs) than in other powertrains was noticed. Ethylene-propylene-diene monomer (EPDM) appeared to be more common in gasoline and diesel cars. Polypropylene (PP) was very common in all cars, as was polyurethane (PUR). Other common plastics and elastomers were polyamide (PA), polyethylene (PE), polybutylene terphthalate; polyethylene terphthalate (PBT; PET). According to the analysis, the share of plastics and elastomers in Swedish cars is not likely to continue increasing but will remain constant around 20 per cent by weight until 2025.

- Today, precious metals (gold, palladium, silver) can be recycled from waste electrical and electronic equipment (WEEE). However, the recycling of precious metals from vehicle
electronics is currently hindered by the design of waste legislation, the material composition of ELV waste and current capabilities and business models in the recycling industry. Recycling of minor metals (gallium, tantalum) will likely remain a challenge also in the long term, unless metal-specific policies at national and supra-national levels are introduced that support the build-up of new recycling value chains. To increase the material recycling of plastics from vehicles will likely need a combination of increased dismantling and recycling of plastic components, advanced Post Shredder Technologies and future chemical recycling technologies. Based on mapping in Explore, a spin-off project has tested separate collection of bumper skins from repair workshops and dismantlers together with industry actors.

Author: 
Hanna Ljungkvist Nordin, IVL
For more information about the specific project and list of publications: 
https://closingtheloop.se/aktuella-projekt/explore/
The overall goal of the project is to help achieve increased material recycling rates of construction and demolition waste in Sweden. According to the EU waste directive, each member state should reach a recycling rate of 70% by weight by year 2020. To achieve this target innovations and improvements are needed. Constructivate aims to have a holistic approach where value chains that link to construction and demolition operations in Sweden are investigated. Various actors in such value chains have also been part of the project. The project operates at the construction and demolition sites, i.e. where the waste is generated. The focus here is on management and how the industry works with the waste generated at the site. The project also explores how digitalization, logistic and value chains methods, can assist the waste management and help achieve increased recycling rates. An integral part of the project is to show how materials in the waste streams, currently not being recycled, can be recycled. The identification of drivers and challenges as well as environmental analyses of solutions presented by the project indicate where there are hotspots to be found. And finally, the investigation of potential policy instruments, to help stimulate the recycling of construction and demolition waste, sends a clear signal to policy makers that much more can be done.

Selected findings from the project is provided below:
• An overall conclusion from the work done in the project is that especially developers must require sorting of waste at construction and demolition sites and recycling of the waste that is generated. Without that kind of demand from those ordering construction projects, there are not enough and strong enough incentives to sort the waste at the source in Sweden today. 
• Something that complicate things is that it was also found that clear incentives for developers to require a thorough sorting for a more successful recycling are also missing. This tends to leave the question about who’s responsible?
• Also, construction projects generally involve numerous actors and in order to achieve a high sorting rate of waste everybody must have knowledge about the correct way of doing things at the specific site. And at the next site things might look different which require a good understanding and quick adaptation.
• Through experiments the project showed how plastics and concrete found in the construction and demolition waste can be recycled and used in the production of new building components made of plastic and new concrete, respectively.

Author:
Max Björkman, Chalmers Industriteknik
For more information about the specific project and list of publications:
https://closingtheloop.se/aktuella-projekt/constructivate
Through studies in the manufacturing industry, CiMMRec has investigated recycling loops mainly for metals and plastics to develop models and tools to increase industry recycling. Material efficiency for systems were investigated and material efficiency performance measures were developed e.g. in the Ph.D thesis of Dr Sasha Shahbazi. During the course of the project, we have investigated a variety of sub-processes. The aim has been to study various cases in some recycling loops with the generalizable knowledge of recycling from the manufacturing industry.

Three main findings from the project is provided below:

- The product materials in the cases investigated (of different types of plastics, textiles and steel / iron) are often well defined. There are good opportunities to increase the proportion of recycled materials in the products if we ensure availability and quality over time. For steel / iron, there is a high proportion of recycled material already and nearly all wasted industrial iron/steel is sent to recycling. In the project we have shown opportunities to increase the proportion of recycled in plastic components and to improve collection of wasted industrial plastics. Process materials are less well defined than product materials. There are good opportunities to request better information on the proportion of recycled raw materials and to use recycled raw materials to a large extent, for example, packaging from both closed loop and open loop recycling. Quality demands may not need to be lower but adopted for use of recycled materials.
- There are good opportunities for efficient residual material handling to many pure material fractions for recycling from the manufacturing industry. In the manufacturing, consumed process material and product material spillage occur with high material purity. The project has provided tools and demonstrated how to maintain it in the recycling system. Effective residual material logistics is important for maintaining material quality. Digital technology can thus be a support to implement efficiency despite complex logistics with many different flows.
- Simple principles for environmental assessment and LCA are agreed upon in the scientific community. The project has followed the LCA development and investigated various conceptual ways of visualizing LCA and allocating environmental impact. We recommend following the international EPD-system (PEF standard). The ongoing change towards increased proportion of the use of recycled raw material in manufacturing industry will then have an impact on the environmental impact. Transparency in ma-
Material and process data is needed for both correct environmental assessment and quality assurance of the material. Certification of recycled material may thus be needed.

Author:
Martin Kurvde, RISE
For more information about the specific project and list of publications: https://closingtheloop.se/aktuella-projekt/cimmrec
How can conflicts, complexities and uncertainties in a circular economy be handled?

A CROSS EUROPEAN STUDY OF THE INSTITUTIONAL CONDITIONS FOR SEWAGE SLUDGE AND BOTTOM ASH UTILIZATION

How can conflicts, complexity and uncertainties in a circular economy be handled? The importance of this issue comes from the fact that the risks of increased circulation of waste are often at local level in the form of increased levels of undesirable substances such as heavy metals. While the benefits are more difficult to track and primarily found at global level, in the form of, for example, avoided carbon dioxide emissions as mining practices are replaced by recycling. There is thus an inherent complexity in a circular economy, where pros and cons relates to different environmental values such as climate change and substances of concern, as well as a conflict between increased circulation and a non-toxic environment. The purpose of the fellowship was to map the institutional challenges and possibility in a circular economy and to understand how waste in terms of both its resources and hazards could be handled in the best way. This was done by comparing the management of sewage sludge and bottom ashes in different European countries. The fellowship at ÖKA institute allowed me to conduct the study in the heart of central Europe; at ÖKO institute, Berlin, Germany.

Selected findings from the project is provided below:

- The challenges for increased circulation includes (1) missing trust in the regulation, (2) uncertainty about future policies, (3) lack of institutional capacity, (4) unbalanced resources policy, (5) lack of interest from the customer, and the (6) availability of better alternatives.

- Favorable institution conditions included (1) liberal guidelines, (2) strict guidelines, (3) differentiated guidelines, (4) political will and policy objectives, (5) neutral and coherent resource policy, (6) cooperation between government and business and (7) customer compensation.

- There are many different policy principles that could improve the balancing of non-toxic environment and circulation: (a) high limits – low limits; (b) abundance – net addition; (c) indicator – all elements; (d) concentration – total load; (e) total – leaching concentrations; (f) utility – mass; (g) single – differentiated; (h) origin – use; (i) national – local.

Author:
Nils Johansson, KTH

For more information about the specific project and list of publications: https://closingtheloop.se/rapport-om-konflikten-mellan-risk-och-resurs/
The European Parliament has now declared a planetary emergency. This calls for creativity to make the impossible possible, for dramatic action and the transformation of conventional frameworks such as economy, trade, politics and governance globally. We must pacify the intensive use of resources to bring our economy to sustainability. The use of virgin resources should be reduced by at least half to create a society that lives within planetary boundaries while meeting the needs of 10 billion people living on the planet by 2050. By continuing business as usual the global demand for industry will increase by two- to fourfold by 2050\textsuperscript{27}.

About 10 years ago, when discussions about initiating a research program Mistra Closing the Loops was started, the question mainly was driven by the recycling industry and very few actors were aware of the key role of the use of recycled resource for achieving a sustainable society. A shift of awareness and knowledge has occurred at many levels of the society since then. Today’s discussions have gone from waste management to unsustainable use of materials. The problems we face today are not just a matter of market or political failure but are a question of a broader system failure due to the fact that sustainable use of materials has never been a priority issue. We built our society as if material resources were endless. Now is the right time for a paradigm shift! This is recognized and presented in many recent publications, such as, for example, \textit{Exponential roadmap, scaling 36 solutions to halve emissions by 2030}\textsuperscript{28}, that motivates and mobilizes for a change by stating: “The next few years are probably the most important in our history”.

The \textit{Circular Economy Action Plan} adopted by the European Commission and green financial instruments such as the \textit{European Green Deal} and the \textit{EU Taxonomy} provide a window of opportunity to change the focus from waste management to material management. The European Green Deal is a clear demonstration of the EU’s readiness to lead the change. The EU is a powerful player with the world’s largest trade bloc, which has trade agreements with 80 countries, and is responsible for 16 percent of the world’s imports and exports\textsuperscript{29}. Thus, the EU has the potential to be a powerful leader in the transformation towards a sustainable economy.

\textsuperscript{27} Completing the picture how the circular economy tackles climate change.

\textsuperscript{28} \textit{Exponential roadmap}

\textsuperscript{29} An EU Green Deal for trade policy and the environment: Aligning trade with climate and sustainable development objectives
It is time for an economy that serve the societal needs with less virgin resources. We believe that the coming years will bring:
• An economy based on high material value where products are designed for material circularity.
• A new perception of recycled material as a material with unique properties that can be reused rather than raw material with inferior properties.
• Disruptive new solutions that significantly increase the use and value of recycled material.
• Changes within current systems that have considerable impact on our resource appetite.
• A new role in the value chain, so-called “material-valorizer”, that operates as an intermediate actor who assists in creating higher trust and transparency, reducing potential risks, and matchmaking between the material seller and buyer.
• Society that has effective risk assessment and risk sharing mechanisms to support sustainable decisions.
• Citizens who no longer accept unethical resource appetite or unsustainable production and consumption.

Awareness and understanding of the necessity for a transition to sustainable use of materials create demand for a change in all three dimensions of sustainability.

PEOPLE:
Humanity has realized that the current structure of resource consumption is unethical and requires change. Studies of transformation and major changes in society have shown that when humanity begins to realize unethical behavior, it leads to change.30 31

PLANET:
The environment/condition of the planet is changing, and a number of natural ecosystems are unbalanced. Climate and biodiversity are approaching a state where the risk of large-scale abrupt or irreversible environmental changes becomes unacceptably high.

PROFIT:
The financial sector avoids investing in a business that is unsustainable. New green financial instruments are in use, and sustainability is becoming an important factor in the business.

30 Det kan klimatrörelsen lära sig av kampen mot slaveriet
31 Sustainability Transformations – Agents and drivers across societies
References


Det kan klimatrörelsen lära sig av kampen mot slaveriet. B-O Linnér, Dagens Nyheter 2019-10-23


Is this the end of end-of-waste? Uncovering the space between waste and products, N. Johansson & C Forsgren (2020) Resources, Conservation & Recycling 155, 104656

Policy measures to increase the use of secondary materials in production – Achievement and challenges of existing policy measures and analysis of selected potential policy innovation, Naoko Tojo, IIIEE Lund University (2020) https://closingtheloop.se/slutrapporter


Mistra Closing the Loop is not only a transdisciplinary research program. It consists of six individual research projects, all of which are granted independently of each other and entirely on their own merit.

Additionally, to the research occurring within this research project Mistra Closing the Loop could perform complementary research that strengthening the overall research as well as the findings in the individual research programs. In order to create ONE strong research program, and to identify the complementary program research it was very important that common program goals and purpose with Mistra Closing the loop was developed by all program participants initially.

### Program activities

<table>
<thead>
<tr>
<th>Program activities</th>
<th>Program results</th>
<th>Program goal</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Program research</td>
<td>Facts and analyses of future material flows</td>
<td>1) The use of recycled material is closer to economically viable processes</td>
<td></td>
</tr>
<tr>
<td>Research by 6 industrial processes</td>
<td>Development of resource efficient processes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Program meetings</td>
<td>Facts and analyses of policy instruments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Program communication</td>
<td>Business and cocreation models for increased usage of recycled resource</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dialog with authorities</td>
<td>Demonstration on how to use recycled resource</td>
<td></td>
<td></td>
</tr>
<tr>
<td>International analyses</td>
<td>Successful communication of program results</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analyses of barriers and hinder</td>
<td>Scientific publication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Policy analyses</td>
<td>10 messages to actors for increased usage of recycled material</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 7 The strategic program planning of Mistra Closing the Loop (2016-2019)*
APPENDIX I

Participating actors in Mistra Closing the Loop

Academia and Institutes
Chalmers tekniska högskola, Linköpings universitet, Luleå tekniska universitet, Lunds universitet, Mälardalens högskola, Örebro universitet.
CIT Chalmers Industriteknik, IVL Svenska Miljöinstitutet, RISE- Research Institutes of Sweden, RISE (Swerea IVF), Swerim (Swerea Mefos), RISE (Viktoria), RISE (SP Processum).

Industry and Municipality
This is the synthesis report from Mistra Closing the Loop, an interdisciplinary research program initiated by Mistra, the Swedish Foundation for Strategic Environmental Research with RISE Research Institutes of Sweden as the program host and the scientific leader. The program was carried out and completed 2016 – 2019. Read more at closingtheloop.se.