CLOSING THE LOOP FOR INDUSTRIAL BY-PRODUCTS, RESIDUALS AND WASTE: FROM WASTE TO RESOURCE

SYNTHESIS REPORT OF MISTRA CLOSING THE LOOP RESEARCH PROGRAM CARRIED OUT AND COMPLETED 2012 – 2015
It has become evident to date that the wasteful economic model in use since the start of the industrialization can no longer be supported by the ecological resources of the planet. Clearly, new models that make it possible to restore and regenerate natural capital have to be found. The Mistra Closing the Loop program makes its contribution to the development of a new economic model by leading the recycling of industrial by-products away from the mentality of single use and the need to mine ever more resources.

The program illustrates that the market often discourages production of secondary raw materials and their uptake by the industry. Environmental costs of production of primary resources are not properly taken into account in their pricing. This, together with the lack of measures for creating demand for recycled streams causes severe market conditions and intense competition from lower-priced virgin materials. Clear economic reflection of environmental costs in virgin materials’ prices should perhaps be seen as a key factor in creating the conditions for price stability and increasing demand for secondary resources.

Importance of taking effective policy measures to increase the circulation of secondary raw materials has now been recognized by both European governments and industry. This report provides examples of the impact from regulations encountered by participating projects and researchers’ insight into how policy measures could facilitate uptake of new technologies and more resource-efficient practices in their areas of research.

For building an efficient market of secondary raw materials today’s uncertainty associated with potentially unstable supply and quality of secondary raw materials should be eliminated. Secondary raw materials should become available in a safe stable quality and quantity. Essential aspects of building this market are discussed in the report based on the experience shared by the projects.

The report also includes brief descriptions of the projects included in Mistra Closing the Loop program and their achievements.
An interdisciplinary research program

Closing the Loop is an interdisciplinary research program initiated by Mistra, the Swedish Foundation for Strategic Environmental Research, that started in 2012 and in three years’ time created new knowledge about how industrial residues and by-products can be returned to society as valuable resources. The program united seven individual projects and involved 50 organizations including representatives from various industries, research institutes and universities.

The diverse disciplinary backgrounds of the researchers coupled with different approaches to the problem of industrial residues enabled the program, as a whole, to raise the issue of resource efficiency and use of secondary resources to a brand new level. The versatility of participating projects was a major strength of the program, but also a challenge.

The program has created extensive network of specialists and established arena for ongoing exchange of thoughts and ideas about resource-efficient solutions. Collaboration between complementary competences has led to generation of new project ideas, helped to improve the training of new professionals who will push the sustainability forward, and contributed to better understanding of the desired future development. These are just some examples illustrating interaction between the projects, but not covering the entire spectrum of cooperation.
Closing the Loop is driven by a philosophy of circular economy and zero waste. This concept, in which today’s goods become tomorrow’s resources, seems to be the only reasonable line of development for humanity in a world of finite resources. To date, both European governments and the industry recognized that only such system-wide perspective can help us make better decisions about resource use, resolve our waste problem, and advance towards sustainable and prosperous society.

Unfortunately, our today’s realities are far from the model to which we aspire. According to Global Footprint Network’s calculations, our demand for ecological resources and the services they provide is now equivalent to that of more than 1.5 Earths\(^1\). We are simply using more than what the planet can provide. In addition, this use is extremely inefficient. As a study carried out by Ellen MacArthur Foundation has shown, in 2012 European economy lost 95 percent of the material and energy value, while material recycling and waste-based energy recovery seized only 5 percent of the original raw material value\(^2\). In other words, Europe still uses materials only once.

It is obvious that such a wasteful economic model endangers the well-being of today’s society and also its very existence. We are in urgent need of a new economic model that makes it possible to restore and regenerate natural capital.

Closing the Loop program makes its contribution in the development of such economic model by leading the recycling of industrial by-products away from the mentality of single use and the need to mine ever more resources. Projects participating in the program are focused on various aspects of industrial waste problem trying to contribute to the construction of a joint working system.

\(^1\) http://www.overshootday.org/
Quick Flux

The Quick Flux project is developing a process route for the recovery and utilization of salt slag from the aluminum recycling industry. The suggested process is based on transforming salt slag into a valuable slag-former for the steel industry.

Salt slag is a residue formed during melting of aluminum scrap, which has so far had no use and had to be processed before landfilling. The Quick Flux new flash melting process closes the loop for salt slag from the Swedish aluminum industry by converting it into a customized pre-melted synthetic slag for steel industry. The product is a strategic consumable for production of high quality and high strength steel. Up until now all material is imported to Sweden. The amount of salt slag produced in Sweden is in balance with potential consumption of pre-melted slag in the country.

Several approaches to transforming salt slag into industrial products have recently been discussed within several research programs. In difference to these projects focus on “water-washed” slags as input material. The salt in these processes is collected in a water solution and has to be evaporated and dried before further use, which means that extra technological steps and additional energy is needed on top of the main process. Another unfavorable aspect is that the remaining metallic Al is partly lost by oxidation in the washing procedure. The washing procedure itself has also a risk to generate toxic gases.

The Quick Flux-route avoids these problems as the washing procedure of salt slag is not used. Metallic aluminum in the Quick Flux process is recovered by use of a new rapid cooling process for salt slag followed by conventional sorting systems using eddy current. The method is now planned to be implemented in industrial scale at Stena Aluminium. Salt and pre-melted slag are produced in a converter process were the pre-treated salt slag is melted together with burned lime and dolomite. The salt is vaporized during the operation and is collected in the off-gas stream. The extracted salt can be re-used in the aluminum scrap melting furnace.

An apparent and direct achievement of Quick Flux technology is preventing landfill of 20,000 tons salt slag and converting this waste into a new marketable product.

Presently imported pre-melted slag is mainly produced from virgin raw materials. In the Quick Flux route the most valuable primary product Al₂O₃ is recovered from currently unexploited secondary source, which helps to preserve natural resources, moderate environmental burden and safeguard future access to raw materials.

Use of the Quick Flux product offers a number of environmental benefits as well. Quick-melting slag produced by Quick Flux technology allows reducing CO₂-emissions and energy consumption in steel production by more efficient ladle metallurgy.

It can be estimated that the production of 16,000
tons of pre-melted slag in Sweden will cause net 
CO₂-reduction of about 8,000 tons annually.

Similar analysis for energy savings due to lower 
coke and coal consumption caused by replacing hot 
metal with steel scrap gives a potential reduction of 
about 31,000 MWh annually.

Overall, implementation of the Quick Flux 
technology will lead to environmental impact from 
aluminum recycling, treatment of salt slag, and 
production of steel as summarized in the following 
table:

<table>
<thead>
<tr>
<th>Environmental savings</th>
<th>GWh/year</th>
<th>Thousand ton CO₂/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al recovery</td>
<td>7.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Fe recovery</td>
<td>2.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Production of pre-melted slag</td>
<td>-5.8</td>
<td>-1.8</td>
</tr>
<tr>
<td>Transports</td>
<td></td>
<td>-0.4</td>
</tr>
<tr>
<td>Savings in steel production</td>
<td>28</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31.5</strong></td>
<td><strong>8.0</strong></td>
</tr>
</tbody>
</table>

Secondary and probably even more important 
effect of the increased availability of an environme-
tently and economically affordable pre-melted slag 
is that standard steel can be replaced by significant-
ly smaller amounts of high strength steel. This is an 
important step towards a more resource-efficient 
society.

The availability of a high quality slag former to 
a competitive price is an important condition for 
the development of high quality steels. The use of 
high strength steels offers many advantages and 
enhances resource efficiency of the processes in 
which they are used by reducing the weight of 
components and, therefore, energy consumption, 
by increasing their service life and offering the pos-
sibility of using superior process parameters. This 
makes processes more economical and businesses 
more competitive.

SSAB in Luleå currently use 5 kg of pre-melted 
slag per ton of high strength steel. The potential use 
of the product in Luleå with a crude steel produc-
tion of 2.5 Mton/year is, thus, about 12,500 tons 
annually. The potential figure for Sweden in total is 
25,000 tons.

The share of high strength steel is constantly in-
creasing and is expected to be dominating in the fu-
ture. Quick Flux can be considered as a demo-case 
that develops a product specially tailored for the 
SSAB ladle metallurgy processes. It is expected that 
other steel manufacturers will need the product to 
be optimized for their individual metallurgy. This 
is a completely new approach, which can only be 
implemented in cooperation between recyclers and 
the end user of the product and that can be a useful 
example for the market of secondary resources in 
general.
Slag 2 Cement

The Slag 2 Cement (S2C) project aims to increase the use of by-products and residues from the steel industry in cement production in order to partly replace limestone, marlstone and sand used traditionally. This will allow producing cement types with improved environmental footprints compared to today’s production, increasing lifetimes of present mineral reserves, and minimizing the amount of residues from iron and steel production put into landfill.

The chemical reaction of removing carbon dioxide from limestone-based raw material is highly energy-intensive. These calcareous materials lose the bound carbon dioxide (CO₂) to the atmosphere at temperatures above 1000°C. Residues from the steel industry originated from limestone have already been exposed to high temperatures and have already undergone the calcination reaction. By using these residues instead of virgin limestone large amount of energy required for calcination can be saved and unnecessary emission of CO₂ can be avoided.

Traditionally, blast furnace slag is used in so-called Ground Granulated Blast furnace Slag (GGBS). GGBS has been used in concrete projects as a direct additive for over 150 years. GGBS has required rapid cooling to be used in cement and has been added in large amounts, close to 100 % of used raw material, thus producing Blast Furnace Cement, a special cement grade with properties different from those of the most commonly used Ordinary Portland Cement (OPC). Efforts in S2C project have been focused on production of OPC cement of the highest quality using residues from steelmaking as raw material. The successful implementation of this ambitious task provides the basis for the production of other cement types if desired. Additionally, no rapid cooling of slag is required in the new S2C route, which leads to a substantial increase in volumes of suitable secondary raw materials that can be utilized in OPC production.

Depending on the limit for the content of “unwanted” elements other type of residues from steelmaking can also be used in OPC. Production of other type of cement for special purposes, such as Sulpho Aluminate Belite (SAB) or Calcium Aluminate Cement (CAC), can further widen the range of “acceptable” chemical compositions and increase amount of residue materials used in the cement production. Generally saying, more diversified production of different cement qualities designed for intended use can drastically increase usage of iron- and steelmaking residues for construction purposes making both steel production and cement manufacturing more sustainable.

The S2C project has successfully tested the addition of 5 % of blast furnace slag to the raw meal in industrial scale. Such addition results in decreased consumption of high quality limestone and sand in the cement production process. An addition of 5 % of blast furnace slag leads to the reduction of sand consumption by 30 % and limestone consumption by 4 %.

This, in turn, reduces excavation of limestone material in Sweden by 120,000 tons per year. The use of natural siliceous sand decreases by 60,000 tons annually with 5 % blast furnace slag replacement.

The use of 5 % of blast furnace slag results in significantly reduced energy consumption. Production
of 1 ton of clinker, a semi-product for cement manufacture, with 5% of blast furnace slag requires 6% (0.3 to 0.4 GJ) less energy than the conventional process.

These two components, decreased use of virgin raw materials and lower fuel consumption due to reduced energy consumption, contribute to the reduction of CO\textsubscript{2} emissions by 9%, which means 40 - 50 kg CO\textsubscript{2} per ton clinker.

Additionally, a reduction of NOX in the combustion gases has been achieved compared to the conventional process running conditions.

While the environmental performance of the project is very good, the economy in the developed environmentally friendly process is inferior to the traditional one because of higher logistics costs.

Production of OPC cement in Sweden takes place in Slite, Degerhamn and Skövde. Due to the consumption of large quantities of limestone and marlstone in cement production the plants are situated close to the quarries. Iron ore based steel production takes place at a considerable distance from cement production plants, in Oxelösund and Luleå, which significantly increases logistics costs compared to traditional, even despite the possibility of delivery of goods by sea.

The Slag2Cement process offers savings by reducing greenhouse gas emission allowances costs and lower amounts of natural sand needed as raw material. These savings, however, do not balance the increase in logistics costs at the moment. Emission allowances costs should be much higher than today (30 - 50 € per ton CO\textsubscript{2} instead of today’s 5 - 6 € per ton CO\textsubscript{2}) in order to balance the increase in logistics costs and make the new process economically viable.

The project’s results make the position of Swedish industry stronger in the context of developing circular economy, where environmental issues are high on the agenda.
Waste 2 Design

To assist the initiative of closing material loops in society, the Waste 2 Design (W2D) project brings together experts from Stena Recycling, Semcon and Chalmers University of Technology to investigate possibilities of using currently existing industrial wastes for new product development.

Massive material flows identified by Stena Recycling as currently not exploited are offered to design students as thesis subjects within the frame of a product development challenge. Project members from Stena, Semcon and Chalmers serve as dedicated supervisors for the students during their thesis projects, assisting them with technical knowledge about recycling systems, production processes and general product development stages.

Materials that today remain unexploited due to the absence of feasible solution cause substantial environmental impacts during their production, use and latter disposal. By trying to reincorporate these difficult materials into production processes Waste 2 Design got the opportunity to highlight the obstacles that society will face when closing material loops. The project aims to investigate how to better prepare future designers to work with secondary materials, while exploring what institutional limitations designing with residues currently has. This project is a first step into developing strategies and methods for helping designers use secondary material in new product development.

The project contributed to the understanding of differences between designing from secondary materials and from virgin ones and pointed out a few key issues that are important for success. Usually, design starts from specifying product requirements to be fulfilled or defining user(s) to be satisfied. In case of designing from secondary resources, the process takes off from a material fraction out of which a wide array of products could be developed. The understanding of the material properties, applicable processes and possible safe and effective uses become the cornerstone in this case. Another key issue stressed in the project is the ability of the designer to assess the real market demand for the final product.

The potential effects of the studies are great, although difficult to quantify. Product design is a unique point of leverage from which environmental problems can be addressed. Finding the way to use discarded materials instead of virgin ones in product development would greatly increase resource efficiency and help to close currently open material loops.
PhosRec

Phosphorus has a number of indispensable biochemical roles, but it does not have a rapid global cycle similar to the circulations of carbon or nitrogen. "Virgin" source of phosphorus is phosphate rock, a non-renewable resource that is distributed on the planet unevenly and that quickly becomes scarce. It is estimated that the demand for phosphorus may exceed supply already in 2035.

At the same time, most of the phosphorus used in society becomes spread into the environment and lost for reuse. In some areas this causes eutrophication and oxygen deficiency in natural waters. The society is facing both a diminishing supply of virgin phosphate minerals and environmental damage caused by discharges of phosphorus into the water.

In today’s high and ever increasing urbanization wastewater and municipal sewage water in particular is the largest phosphorus-rich flow that is to become an effective secondary source of phosphorus in the circular economy model. The PhosRec project gives valuable insights in the chemistry of phosphorus in wastewaters and in different ways to recover it to useful products. Highly alkaline wastewater from AkzoNobel is used as the PhosRec model case. A few-step method for converting phosphorus from this wastewater into magnesium-ammonium-phosphate product, also called struvite, has been developed in the project. Life Cycle Assessment of the developed process has confirmed that recovery of phosphorus from the wastewater results in significantly decreased emissions of substances contributing to eutrophication as well as in reduced depletion of element resources since less phosphorus will be extracted from nature. At the same time emissions of greenhouse gases increase since the recovery process requires significant amounts of magnesium chloride, the production of which causes formation of carbon dioxide as a side product. Additionally, natural gas is used by AkzoNobel at the moment to generate energy needed for phosphorus recovery. Further process improvements and use of renewable energy are needed to reduce the emission and improve environmental balance of the process.

3 Two thirds of the world’s resources are in China, Morocco, and Western Sahara.
4 Cordell, Dana; Drangert, Jan-Olof; White, Stuart (2009). "The story of phosphorus: Global food security and food for thought". Global Environmental Change 19 (2): 292–305. ISSN 0959-3780
Green Plastics

The Green Plastics project has generated practical knowledge on many aspects of recycling of bio-based plastics.

In a time of increasing scarcity of fossil raw materials and of global warming the use of renewable raw materials is an obvious solution that offers huge potential for increasing sustainability, reducing greenhouse emissions and for preserving natural resources. Benefits of using renewable raw materials are due to exploiting the advanced work of nature as carbon is extracted from the atmosphere in the form of CO₂ and is converted into energy-rich organic compounds through the process of photosynthesis. These organic compounds can then be used as energy sources or chemical raw materials, for example for the production of bioplastics.

In 2013 1.6 million metric tons of bioplastics were manufactured worldwide, which accounted for only about 0.5 % of the total plastics production. This share is, however, growing rapidly as these materials become an increasingly attractive choice for industry. The largest part of bioplastics manufactured until now was of biodegradable type, but it is expected for durable bioplastics to amount to 60 % of predicted global production, by 2015.

Recycling of “conventional” fossil plastics is complicated due to the large variety of available plastic types and compositions that require different processing to be reformulated and re-used. Introduction of bioplastics to the marked further increases the complexity of the problem. Today, bioplastics are seen as contaminants to the recycling system but, as plant-based plastics become more popular, the incentives to develop recycling processes for them increase. The research on the recycling of biopolymers is still on a primary stage and lacks deep studies of different factors affecting the performance and economy of recycled bioplastics as well as new strategies. The development of a comprehensive recycling infrastructure for durable bioplastics is timely as it is necessary to create preconditions for successful transition to renewable raw materials in plastics manufacturing.

Special attention was focused on bio-based engineering plastics like Polyamide (PA) which are similar to but not identical with their fossil counterparts. It has been found that bio-based and fossil-based PAs are not compatible and their mechanical properties deteriorate in blends. The situation is further complicated by the fact that it is often difficult to distinguish between different types of PA in products.

Study performed on biopolymers commonly used in the production of durable goods, such as...
Polylactic acid (PLA) and its blends and composites has given more positive results. The project has shown that PLA and its blends can be reprocessed several times, provided that the process parameters are right. Recycling of post-consumer PLA materials is, however, hampered due to materials degradation. Blends of PLA with fossil-based polymers like Polyethylene (PE) or Polycarbonate (PC) exhibit enhanced durability and mechanical properties, while maintaining a high content of carbon of plant origin.

Performed Life Cycle Assessment of the environmental performance of different plastics has confirmed that durable recyclable bio-based plastics are the most resource-efficient and environment-friendly option among all plastic types. Reduction of environmental impact throughout the lifecycle can mainly be achieved by (i) prolonged service life of the product, (ii) recyclability and use of secondary material sources, and (iii) use of bio-based materials instead of fossil ones.

Knowledge gained in the course of the project provides Swedish industry with reliable data on durability and recyclability of green plastics. This will help to confront apprehensions delaying the use of bioplastics at the moment.
The Realize project aims at finding strategies for more resource-efficient recycling of vehicles. More specifically, the goal is to increase the value of the recycled material in both environmental and economic terms.

Efficient recycling and reuse is the key to minimizing losses of material values in the vehicle chain. This is particularly relevant for securing availability of scarce and critical materials, but also for avoiding downgrading of recycled materials and for reducing residual flows. The potential large scale shift to electric vehicles over the next couple of decades adds the problem of not losing materials that currently are of low value but that may rise in value as the transition proceeds. In practice, not only is the development of new technological processes and practices for recycling necessary, but also that their use in the industry is made possible through innovation in business models and intelligent policy. Activities in Realize include therefore research on all these aspects: (i) extended dismantling for material recycling and its impact on the ELV (End of Life Vehicles) recycling chain, (ii) optimization of car shredding, (iii) recycling of scarce and critical metals in cars, (iv) non-technical barriers and possibilities for advancing Swedish ELV recycling.

While vehicle dismantling currently is focused on de-polluting and removing spare parts, Realize has initiated dismantling for material recycling. The dismantling trials of over 200 cars allowed accumulating knowledge, which has been used in large-scale industrial tests and also led to investments. Tested dismantling procedures can potentially save 150-250 kg of carbon dioxide equivalents per car if implemented. This corresponds to driving 1,500 km with an average new car in 2014. Additional labor required for such an extended car disassembly, however, causes serious negative impact on the economic feasibility of new methods.

Research on the shredding process has generated knowledge with benefit for the whole recycling chain from an environmental point of view, such as reducing energy demand in the processes. Improved material yields in shredding processes increase resource-efficiency and contribute to a secure supply of materials.

With few exceptions, scarce and critical metals in vehicles are not functionally recycled today and are thus lost for future use. For many of the scarce and critical metals present in vehicles, recycling is not possible due to missing infrastructure. A short-term strategy to functionally recycle some of these metals could be to dismantle automotive electric and electronic equipment for recycling in the existing WEEE recycling systems. Unfortunately, currently existing policy does not offer incentives for such activities.

Information on quantity of scarce and critical metals in discarded vehicles and their fate in the current recycling system is a necessary knowledge for industry and policy-related investments in recycling. Project results related to this issue were reported to a government study within the Sweden’s minerals strategy and will also be included in the European database of secondary raw materials currently under development.

Barriers and opportunities to move to circular business models were investigated in a case study involving automotive industry and suppliers. The hypothetical case of selling transport services instead of selling a vehicle has shown that material savings of 20 % can potentially be achieved through
the adoption of the new business model and that companies already have experience and capability in many aspects important for the implementation of product service system and circular business models.

The development of recycling is affected not only by technical and industrial solutions, but also by actors’ relations and business models, knowledge generation, existing regulations and practices and the functioning of markets for recycled materials. A fundamental challenge that has been observed in scientific publications over the past 30 years is the necessity to improve economic conditions for recycling. Promoting markets for recycled materials using political measures has commonly been suggested as a solution. The project also pointed out that coordination between actors along the value chain can play major role in enabling circular material flows. Projects such as Realize, involving actors throughout the recycling chain can, in this sense, contribute to increased communication and coordination between actors.
MEMIMAN

Each year, manufacturing companies generate and dispose billions tons of non-hazardous industrial solid waste. In light of rising raw material and disposal costs, existing and pending regulatory pressures and changing consumer preferences, companies in the manufacturing and industrial sector are seeking ways to minimize their waste streams and maximize their cost savings. Waste minimization strategies present companies with a true sustainability advantage in the form of economic, environmental and social benefits.

However, obstacles remain for companies seeking to minimize their waste streams – manufacturers’ supply chains are usually complex and often lacking in transparency; in difficult economic times, it can be a challenge to secure the necessary resources to redesign products and processes with the aim of minimizing wastes; difficulties in locating or securing alternative raw materials for the manufacturing process can hinder efforts to
reduce the toxicity of process wastes; and finally, inertia and the status quo can foil efforts at waste minimization. Due to all these reasons and a lack of systematic approach that focuses attention on resources throughout the value chain, manufacturers tend to think narrowly about what is actually a broad landscape of opportunity, which results in deficient systematic solutions.

The MEMIMAN project examines possibilities to modify current waste management practices in order to reach improved materials recycling in manufacturing industry. The project employs a few different approaches: (i) assessment of trends and current structure of incentives and regulations in waste management, (ii) analysis of existing obstacles against increased material recycling, (iii) assessment of possible modifications to be done for the development of more efficient waste management and optimization of material flows in the industry, and (iv) evaluation of the environmental impact of currently existing practices and the impact of potential improvements. Through its multidisciplinary approach the MEMIMAN project helps to analyze patterns in multiple-stakeholder waste flows.

According to the results of MEMIMAN sampling analysis successful waste separation can more than double the purity of material fractions. As the analysis has shown, only 43% of the content of “combustible” bins constitute of the materials that should be sorted as combustible and household waste according to standards. This means that 57% of the waste in “combustible” bins could have been recycled if they had been sorted correctly. This makes about 1 500 tons (57% of the total amount of 2,700 tons of combustible waste) for four tested plants, which corresponds 2 to 3 MSEK potential savings. On a national scale “steel and metal manufacturers” and “metal goods manufacturers” produce 65,600 tons of “mixed and non-differentiated materials” annually. Assuming the results of the MEMIMAN analysis are applicable on national scale, there is a potential to recycle an additional 37,000 tons of materials that currently are incinerated. Obviously, these numbers are indicative and further studies are needed to verify potential environmental and economic savings.

Main general observations made in the project are that (i) high potential of environmental and economic savings lies in reducing generation of waste and increasing sorting of plastics and biodegradable materials, (ii) insufficient knowledge of potential gains from the correct sorting often hinders development despite existence of right infrastructure for sorting, (iii) plastics should not only be sorted out from the combustible fraction but also collected separately as paper, for example. This greatly increases the probability of their correct further processing. For this, not only behavioral but also today’s economic barriers, such as lack of incentives to balance the costs of separate collection and logistics, as well as weak demand for small volumes should be overcome.
Unfortunately, at present market discourages production of secondary raw materials and their uptake by Europe’s industry. Lack of measures for creating demand for recycled streams in the EU causes severe market conditions with acute price volatility and intense competition from lower-priced virgin materials.

The market of secondary raw materials is currently very dependent on the prices for virgin materials, as secondary raw materials directly compete with the lower-priced virgin ones for the demand. Given the fact that the prices of virgin and secondary raw materials are formed under the influence of different sets of factors, such dependence puts the entire value chain for some secondary materials at risk. In such a way, current drop in oil prices has lowered the price of virgin plastics to below that for recovered ones. Similarly, for metals a market surplus of virgin material combined with weakening demand from China has also depressed prices, making secondary metals uncompetitive. Clear economic reflection of the environmental costs of production of primary resources should perhaps be seen as a key factor in increasing demand and creating the conditions for price stability.

Moreover, in today’s market conditions Europe is dependent on the export market to place the secondary materials it produces. Even at current recycling levels the EU exports about 25% of the secondary raw materials it generates. To improve the resource efficiency of the European industry and to ensure the availability of raw materials in the future it is essential for Europe to create domestic demand for secondary materials and close own material cycles, even though international trade should be retained at least as a safety valve. The importance of creating an integrated internal market through rationalizing the existing regulatory framework has been highlighted in the Communication from the Commission “A vision for the internal market for industrial products”.

According to the European Federation of Waste Management and Environmental Services (FEAD) EU’s re-industrialization strategy should be seen as an opportunity to boost markets for secondary raw materials within the EU. Importance of taking

---

5 "Commodity Markets Outlook" World Bank, April 2015
7 EUROSTAT 2015
8 Communication from the Commission to the European Parliament, the Council and the European Economic and Social Committee “A vision for the internal market for industrial products”, COM(2014) 25 /2
9 Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions “For a European Industrial Renaissance” COM/2014/014
The seven projects included in Mistra Closing the Loop are focused on various aspects of industrial waste problems trying to contribute to the construction of a joint working system.

Almost all the projects involved in the Closing the Loop program encountered the great impact from regulations that in many cases constitute barriers to new technologies or more resource-efficient practices.

In such a way the process developed by Slag 2 Cement offering significant reductions of greenhouse emission and savings in natural resources cannot compete economically with environmentally costly traditional cement production since the environmental costs of the traditional process are weakly reflected in the price of virgin product.

Effective political measures for increasing the circulation of secondary raw materials is emphasized in the FEAD Opinion Piece from June 2015. In particular, including measures for material resource efficiency to the Eco-design Directive, implementing lower rate of VAT on second-hand goods and products with recycled content, enforcing incentives for manufacturers for designing their products in a recyclable and non-hazardous way, and amending Eco-labeling rules to make it easier for consumers to choose recycled and resource efficient products are named as potentially credible and effective measures for building strong markets for secondary raw materials across Europe.

Almost all the projects involved in the Closing the Loop program encountered the great impact from regulations that in many cases constitute barriers to new technologies or more resource-efficient practices.

In such a way the process developed by Slag 2 Cement offering significant reductions of greenhouse emission and savings in natural resources cannot compete economically with environmentally costly traditional cement production since the environmental costs of the traditional process are weakly reflected in the price of virgin product.
In particular, emission allowances costs should be much higher than today in order to make the environmentally beneficial process also economically viable. Another example is the legislation requirement (2000/76/EG) which includes manganese in the list of elements, the concentration of which must be strictly limited as dangerous. This confines possibility of the replacement of limestone by slag, since manganese content in the blast furnace slag is higher than in limestone. The reason for the inclusion of manganese in this list is not clear, as the presence of manganese in the cement is not dangerous for the properties of the cement or for the environment.

The Green Plastics project notes that the legislations related to green plastics are lacking clear definitions, recycling standards and requirements as well as system and methods for traceability. Such terms as bioplastics and biodegradability are often misused, which makes it difficult to develop effective legislation and stimulate sustainable development of the branch as a whole. Even though strategic documents issued by the Commission promote the use of bio-based products and consumers are showing interest in the use of renewable resources, effective legislative mechanisms related to production and use of green plastics are needed to ensure a conscious movement towards sustainability and resource efficiency.

Realize points out that government efforts and structures related to the provision of material resources still do not receive same attention as for example the energy sector. While the development of the energy sector is controlled and operated by a government agency and the minister, corresponding functions related to supply of materials are scattered with significantly less resources allocated. The level of public funding for research, development and education also differs significantly between the two fields. This can lead to lack of capacity required to induce profound social change and movement toward a sustainable and circular economy in the near future.

Recycling policy for End of Life Vehicles (ELV) seems to be rather poorly designed and insufficiently funded. Mass-based recycling targets (such as in the ELV Directive) induce side effects that may
(i) limit the ability of the recycling system to retain small diffuse amounts of critical materials, and (ii) lock the system into certain technology set-ups that will not be suitable, and will impede the recycling of future vehicle materials.

Over time, the entire automotive recycling value chain has been optimized to reach the mass-based recycling targets. Changing the set-up of the recycling chain involves adopting new technologies and practices for dismantling, shredding and post shredder treatment (PST). Shredding and PST often require large investments, which few actors want to – or can – take. Extended dismantling, in turn, increases labor costs, which are borne by dismantlers. Potential economic cost and benefits from such changed operations will not be distributed evenly over the recycling chain. This justifies political measures such as introduction of external compensation to dismantlers.

Information provided by the vehicle manufacturers for dismantling in accordance with the ELV Directive is also designed to achieve mass-based recycling targets set out in the Directive. Very limited data on the recovery of rare and critical metals is included. There is a clear need for restructuring and detailed elaboration of requirements for information to be communicated.

The quality of vehicle dismantling and its compliance with legal requirements still vary considerably between the actors, as pointed out by the Swedish Environmental Protection Agency several years ago. Improved and enhanced supervision and the introduction of certification requirement for dismantlers are among the possible policy measures that can help to reduce unfair competition in the industry.

Current procedure for calculating the recycling rate for cars and reporting to the ELV Directive is not transparent. Lack of transparency makes it difficult to assess the effects of the extended dismantling and in general affects the methodology of research in this field.

According to MEMIMAN a system of policies, established end-of-waste criteria and standards that offer clear incentives for collection and recycling of scrap with high level of environmental consideration is set up only for metals. For many other materials, e.g. plastics, no such system exists and incentives remain low, despite the high environmental burden of their production. This leads to an inefficient collection and poor sorting of these materials, which in turn often makes further processing and production of marketable secondary materials impossible.

The need for regulation to ensure the effective circulation of phosphorus in the production system is an actively discussed topic. In 2014, phosphorus was added to the EU list of so-called “critical raw materials”, i.e. commodities of strategic importance, whose shortage can have severe consequences for the economy and/or political stability. The EU is dependent on imports of phosphate for production of fertilizers to 90 %, while 7 countries outside the EU control 85 % of world reserves of phosphates\(^{10}\). Sweden, in turn, imports 100 % phosphates. Thus, the recovery of phosphorus from various waste flows is not just a necessity to ensure the production of food for a growing population in the future, but also a question of political security.

The Circular Economy Package adopted by the Commission in July 2014\(^{11}\) once again highlighted the need to recirculate phosphorus between city and countryside. Current policies and legislation affecting recovery of phosphorus are, however, still insufficient if the goal is the greatest resource conservation. Sweden has only two legislative documents in the area, a Decree of 1994 which primarily regulates the amount of sludge that may be spread on arable land, as well as a Statutory of 1998 which regulates the maximum concentration of metals in the sludge to be used in agriculture. The situation at the EU level is similar and requires a comprehensive approach. The question of phosphorus conservation should probably get the same status as, for example, Climate Change. There should be a strategy and targets for the functioning of the phosphorus cycle both in Sweden and the EU. This would provide political support for technological development that would ensure safe supply of phosphorus to agricultural land.

\(^{10}\) The world phosphates market: What risk for the European Union? INRA, LERECO, 2014

\(^{11}\) COM (2014) 398 final
Secondary raw materials market

Efficient market of secondary raw materials should be adapted to the general market conditions of trade and industry. Today’s uncertainty associated with potentially unstable supply and quality of secondary raw materials as well as the demand for them should be eliminated and secondary raw materials should become available in a safe stable quality and quantity.

But what is needed to make this a reality?

Through collaboration between the projects and communication within the program a number of aspects essential for building a system solution and well-functioning market for secondary raw materials was stressed once again.

First of all, to create a market, it is important to know what is available. That is why a systematic description of the waste flows is of great importance. Currently existing waste statistics databases contain only description of the origin and form of waste streams. This information is insufficient for finding a new use for these resources and supporting the secondary raw materials market. More information is needed on the characteristics to create an understanding of the possible and the optimized use. Streams should also be evaluated in terms of sustainability of their origin, collection and sorting, that is, do they originate from and through sustainable processes, do these processes lead to the formation of toxic or unsustainable products, etc. This analysis could be helpful for sorting out flows that no closing-the-loop efforts should be concentrated on because they are not a part of a sustainable system.

The need for such material flows database has regularly been discussed for some time now, but the idea still remains unrealized. To go further, it is necessary to answer how the development and maintenance of the database should be organized in practice and who should be involved in order to obtain complete and useful information in the database. Manufacturing companies whose business generates these secondary material flows as by-products should probably be seen as key stakeholders and potential users of the database. These companies are certainly interested in the transformation of these “waste” flows into a profitable commodity, and therefore, in disseminating information about them. They would also appreciate an opportunity to find alternative raw materials for their own processes through the database. The problem is that their interest in the database is unorganized, they are too busy taking care of their core businesses, and their efforts, thus, remain scattered. But this very group of actors, apparently, can and should drive this database and populate it with information, provided that these activities are structured and sufficient economic incentives for these companies to prioritize activities related to secondary flows are created.

The fundamental knowledge of materials is of high importance for all research around recycling. Lack of materials knowledge can result in inability to identify recycling possibilities and choose the risk-free and most resource-efficient solutions. This statement may seem obvious, but it is the lack of materials knowledge that often is a stumbling block for the effective use of secondary resources. This is
between other projects also often focused on the exchange of materials knowledge.
With knowledge on available resources and coupled fundamental materials knowledge on hand, technical solutions for resource-efficient recycling can be developed. To ensure that we pursue sustainable development these technical solutions should be analyzed from an LCA perspective and in terms of their prospects for the circular metabolism of materials and materials conservation in the production cycle. Preservation of non-renewable resources in the cycle should have a high priority because it serves many important purposes of securing access to raw materials, supporting resource efficiency of the industry and reducing the negative impact on the environment12.

This means that the development of technologies returning end-of-life products to the state of raw materials, so-called feedstock recycling, is an issue of extreme importance as these technologies close the loops. At the same time, to reach greater resource-efficiency materials and products should be reused and recycled as many times as possible before they are returned to the state of raw material. Each new use is advantageous, even if it is less demanding than the previous one, as long as the possibility of feedstock recycling is maintained.

Another interesting criterion for assessing the sustainability of the processes is their dependence on virgin raw materials. How environmentally friendly are processes in which secondary raw materials can only be used in a mixture with virgin ones? Should these processes be developed as a first step towards decoupling economic growth from resource use and environmental impacts, or they lead to the construction of unsustainable system?

Technology is the decisive factor for development in the long run but its importance is often overestimated in the short term. Thoroughly selected technological solutions give answer to

---

12 Preservation of natural resources is one of priority objectives of the 7th Environment Action Programme established within the framework of a long-term vision of 2050.
the question what needs to be done to reach the goals. However, describing what needs to be done to change the system without answering questions who and how should implement the changes create a gap impeding market uptake of an innovation. Therefore, so-called "market pull" approach has to be used for enabling transition towards a more sustainable society and helping to overcome persistent problems in society. This means that the development of recycling market has to be evaluated in terms of the structures and processes that support or hamper it. Analytical instruments like Technology Innovation System Analysis are to be used to answer such important questions as (i) who is the customer for new products, (ii) does the transition require changes in policy and legislation and how these changes can affect the market, (iii) what business models can show reasonable Return on Investment level, (iv) what market shares old and new businesses can gain, etc. In such a way the developed innovations can be translated into policy suggestions offering guidance to policy makers and helping to ensure that new policies will create customer demand for the developed innovative solutions and thus a “market pull” for innovations. According to a study mandated by the European Commission, well-designed market pull instruments not only promote innovation and contribute to the sustainable development of the market, but also lead to greater innovation and to diffusion of eco-innovation into related product groups, and to other geographical markets.

Another key issue for supporting the market and the economy of new products and processes is quality assurance. Currently, there is no way to get better paid for any type of scrap because there is no way to demonstrate its “better” quality or its stable compliance with the requirements. Without it, it is impossible to achieve good financial results if quality assurance mechanisms are absent, i.e. there is no way to predict with certainty the quality of the material, which means that each material batch must be tested.

That is why a clear methodology for quality assurance is needed to provide a necessary instrument for communication between different actors along the value chain. Furthermore, as it has recently been noted at the Stakeholder Conference on Circular Economy, harmonized material quality standards are needed for secondary raw materials to increase their use. The development of such standards and the methodology is directly linked to another aspect of improving resource efficiency, namely to preventing the use of resources of a higher quality than required for a particular application, that is, using "the right" quality, not "better" ones. Presently, the market operates only with standards on virgin materials. These materials usually have high purity and quality that becomes the norm for the market. This forces the secondary materials suppliers to strive to meet these standards, which often requires high costs and hampers the progress of secondary resources in the market. At the same time there are many applications that do not require such a high purity/quality as that of virgin materials, and secondary materials could very well do the job there if "right" and uniform quality at a flow can be offered. The use of “better” materials in such applications is nothing but a waste of resources which should have no place in a sustainable society. None of our grandmothers wiped the floor with new textiles but used old clothes for this instead. This was a way to take care of a rational use of resources, something that we should learn again.

---

The importance of quality assurance mechanisms was demonstrated in many projects participated in the program. In such a manner, has Waste 2 Design observed that the development of new products from a waste material can only be possible if the composition and properties of this material are stable and reliable information on them has been made available. For the Quick Flux project a potential obstacle for gaining broad acceptance for their pre-melted synthetic slag-former is a traditional prejudice against the use of recycled materials for the production of high quality steel products. Common concerns that instability in the composition or impurities can affect the quality of the steel and the possibility to manufacture new products from the slag create obstacles for the QuickFlux product. According to The Swedish Steel Producers’ Association (Jernkontoret) it is imperative to guarantee a stable and chemically acceptable composition of the product. Transparent quality assurance methods that are acceptable to all stakeholders in the value chain are essential to eliminate the prejudices and concern that hinder the growth of high value recycling market.

The market of secondary raw materials cannot be based on a static solution, but should be a living system with embedded mechanisms for continuous improvement. The market should have the ability to respond to changes in demand due to changes in society, to the evolution of the composition of waste and material flows, induced by changes in consumer behavior, etc.

Thus, monitoring progress using reliable sustainability and resource efficiency indicators is necessary. Indicators perform many functions. They can help to measure and calibrate progress towards sustainable development goals. They can provide an early warning to prevent economic, social and environmental setbacks. They can lead to better decisions and more effective actions by simplifying, clarifying and making aggregated information available to policy makers. In other words: “What gets measured gets managed”. Good indicators alerts to a problem before it gets too bad and help to recognize what needs to be done to fix the problem.

A number of such indicators has been identified and assessed in terms of their effectiveness in tracking the progress of the EU in relation to the objectives of the Flagship Initiative for a Resource Efficient Europe\(^\text{15}\). These indicators can be used to measure resource productivity, environmental impact of the use of specific resources, and progress in reducing the ecological stress of resource use\(^\text{16}\). Sustainability indicators in turn point to areas where the links between the economy, environment and society are weak and help find a solution to the problem. When monitoring results are fed into the next development cycle the process of continuous improvement begins.

This monitoring will also provide feedback to the designers of industrial processes and product designers, which will contribute to the promotion of “green” design for waste prevention and better materials management. "Green” design meaning a design process, wherein the environmental attributes are regarded as design objectives and design possibilities, and not as constraints. A key point is that green design includes environmental goals with minimum loss of product performance, useful life, or functionality. Green design serves the purpose of waste prevention reducing the use of toxic materials, increasing energy efficiency, using less material to perform the same function, or designing products so that they have a longer service life. Green design promotes better materials management making products that can be reused and/or effectively recycled. The need for innovation and design for recyclability of materials and products was newly expressed as one of the key messages at the Stakeholder Conference on Circular Economy in Brussels\(^\text{14}\).

The system, which includes all of the elements that interact with each other, will help us to develop, select and apply resource-efficient solutions and maintain resource efficiency at the highest level.

### Green Plastics

**Full project name:** Sustainable Recycling of “Green” Plastics  
**Host institution:** SP Technical Research Institute of Sweden  
**Project leader:** Ignacy Jakubowicz  
**E-mail:** ignacy.jakubowicz@sp.se  
**Participants:**  
- Cefur  
- Chalmers University of Technology  
- Kreol  
- Lysmask  
- Orthex  
- Reflex  
- Safeman  
- Södra  
- Tarkett  
- University of Borås

### MEMIMAN

**Full project name:** Material Efficiency Management in Manufacturing  
**Host institution:** Mälardalen University  
**Project leader:** Marcus Bjelkemyr  
**E-mail:** marcus.bjelkemyr@mdh.se  
**Participants:**  
- Alfa Laval  
- DynaMate (nowadays Scania Industrial Maintenance)  
- Lund University  
- Miljögiraff  
- Stena Recycling  
- Swerea IVF  
- Volvo Group

### PhosRec

**Full project name:** Phosphorous Recovery from Industrial Waste Water  
**Host institution:** Chalmers University of Technology (Industrial Materials Recycling)  
**Project leader:** Britt-Marie Steenari  
**E-mail:** bms@chalmers.se  
**Participant:**  
- AkzoNobel

### Quick Flux

**Full project name:** Production of Calcium-Aluminate out of Aluminum Black Dross  
**Host institution:** Swerea Mefos  
**Project leader:** Sten Ångström  
**E-mail:** sten.angstrom@swerea.se  
**Participants:**  
- Chalmers University of Technology  
- SSAB Europe Luleå  
- Stena Aluminium AB  
- Stena Metall AB  
- Swerea IVF
Realize

Full project name: Realize – Realizing Resource-efficient Recycling of Vehicles
Host institution: Chalmers University of Technology
Project leader: Maria Ljunggren Söderman
E-mail: maria.ljunggren@chalmers.se
Participants:
BilRetur
Chalmers Industriteknik
Eklunds Bildelslager
IVL Swedish Environmental Research Institute
Kuusakoski Sverige
SKF
Stena Recycling
Thomassons
Walters Bildelar
Viktoria Swedish ICT
Volvo Group

Slag 2 Cement

Full project name: Increased Use of By-products and Wastes from Steel Industry in Cement Production
Host institution: Umeå University
Project leader: Bodil Hökfors, Rainer Backman
E-mail: bodil.hokfors@cementa.se
Participants:
Cementa AB
Luleå University of Technology
SSAB Merox AB

Waste 2 Design

Full project name: Industrial waste to product design
Host institution: Chalmers University of Technology
Project leader: Isabel Ordonez Pizarro, Daniel Gillblom
E-mail: isabel.ordonez@chalmers.se
Participants:
DIAB
Eklunds Bildelslager
Linköping University
Semcon

Synthesis Report

Full project name: Closing the Loop for Industrial By-products, Residuals and Waste: From Waste to Resource Synthesis Report of Mistra Closing the Loop Research Program
Carried out and Completed 2012 – 2015
Project leader: Lena Smuk, SP Technical Research Institute of Sweden
E-post: lena.smuk@sp.se
Jordens resurser klarar inte längre av den slösaktiga ekonomiska modell som varit förhärskande sedan början av industrialiseringen. Det behövs nya arbetssätt som gör det möjligt att återställa och återskapa naturens tillgångar.

Forskningsprogrammet Mistra Closing the Loop bidrar till utvecklingen av en ny ekonomisk modell genom att finna vägar bort från industrins engångsbruksmentalitet och behov av att bryta allt mer resurser.

Programmet visar att marknaden ofta hindrar användningen av sekundära råvaror. De miljömässiga kostnaderna för produktion av primära resurser tas inte med när priserna sätts. Detta tillsammans med bristen på åtgärder för att skapa efterfrågan på återvunnet material ger hård konkurrens från billigare jungfruliga råvaror. Att låta miljökostnaderna påverka priset på jungfruligt material kan vara en nyckelfaktor för att skapa prisstabilitet och ökad efterfrågan på sekundära resurser.

Vikten av effektiva politiska åtgärder för att öka spridningen av sekundära råvaror har uppmärksammat av både industrin och Europas regeringar. Denna rapport ger exempel på de deltagande projektens och forskarnas insikter om hur politiska åtgärder skulle kunna underlätta spridningen av ny teknik och mer resurseffektiva metoder.


Läs mer på www.closingtheloop.se