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Explore - Exploring the opportunities for advancing vehicle recycling industrialization

Summary report

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mistra closing the loop

IVL Swedish Environmental Research Institute In cooperation with Chalmers Environmental Systems Analysis, Chalmers Product and Production development, Chalmers Industriteknik, Volvo Personvagnar, AB Volvo, Stena Recycling, Walters Bildelar, Eklunds Bildelslager, Sveriges Bilåtervinnares Riksförbund, BilRetur, Motorbranschens Riksförbund.

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Preface

After almost four years of research, it is time to summarise the findings of the Explore project. Involving actors from across the vehicle value chain, it has aimed to increase dialogue and communication, built knowledge regarding the composition of vehicles and pinpointed barriers and opportunities to improve circular flows of vehicle materials in the future.

I would like to thank everyone who has participated in or contributed to the project over the years. Without your support and enthusiasm, the work would have been very difficult. I hope we have the possibility to work together in future projects, advancing vehicle circularity even further.

Gothenburg, February 2020.
Hanna Ljungkvist Nordin

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Project goals and structure

The project's goal is to find ways to strengthen Swedish automotive recycling industry's role in a more circular economy and create close cooperation between manufacturing and recycling industries. Against this background, the project has the following objectives:

PROJECT OBJECTIVES:

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

The project was carried out through six individual work packages related to different parts of the vehicle value chain, as illustrated in Figure 1:

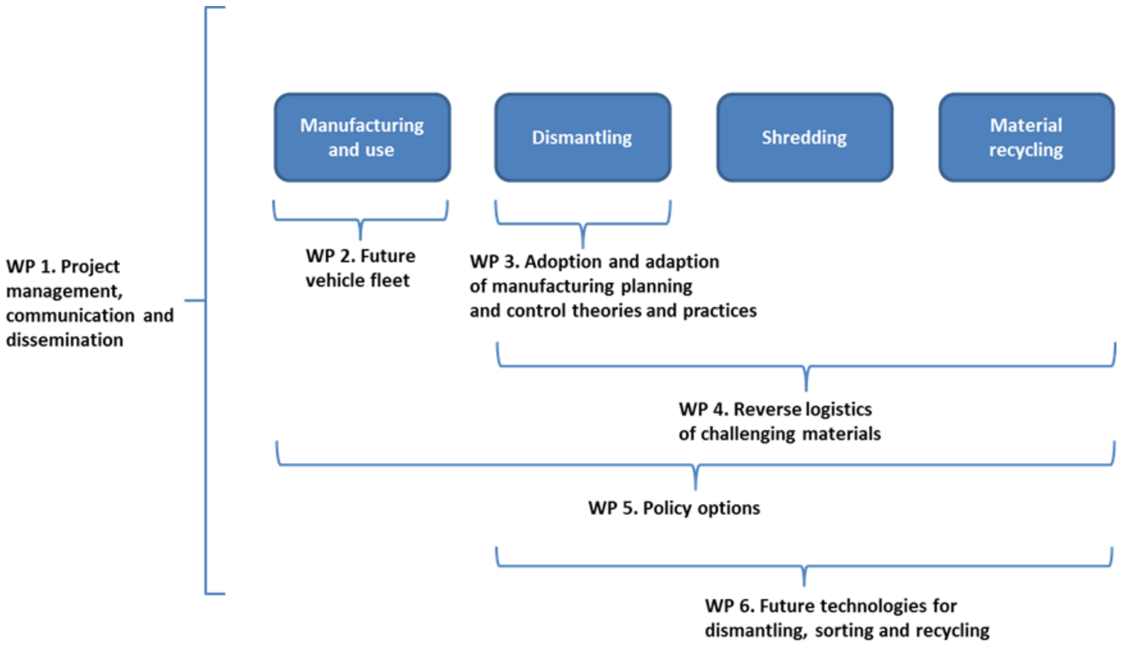

Figure 1: Structure and logic of the six work packages.

The following chapters summarize main findings and lists the deliverables produced in each work package.

WP 1 Project management, communication and dissemination

OBJECTIVES:

- To manage the project within the set timeframe and budget and coordinate various work packages and their mutual dependencies of information and results.
- To communicate and disseminate the results and insights obtained from the project to target groups such as policymakers, researchers and recycling- and automotive industry.

The project was led by IVL, with the manager role being shared between Hanna Ljungkvist Nordin and Carl Jensen through the project.

Meetings

Seven project meetings with all partners were held through the project:

1. Kick-off meeting April 28th -29th 2016 (lunch to lunch). Ekocentrum, Gothenburg
2. Meeting and workshop February 9th, 2017. Chalmers Lindholmen, Gothenburg
3. Meeting and workshop September 21st, 2017. Volvo Cars, Gothenburg
4. Meeting and study visit April 13th, 2018. Eklunds Bildelslager, Skövde
5. Meeting October 2nd, 2018. Volvo Cars, Gothenburg
6. Meeting and workshop May 23rd, 2019. IVL, Gothenburg
7. Final meeting November 26th, 2019. Chalmers, Gothenburg

Regular research meetings were also held between IVL, Chalmers and CIT to follow up on progress in the different work packages and prepare upcoming project meetings.

General project communication

Most of the project communication has been channelled through the different work packages. In addition, IVL has published four press releases and presentations related to Explore and Mistra Closing the loop on their website ivl.se.

IVL has also represented the project at the joint research activities and program meetings of Mistra closing the loop, communicating ongoing work and results to the other projects of the program.

Figure 2: Kick-off meeting in Ekocentrum, Gothenburg, April 29th, 2016.

Figure 3: Taking a look at the Volvo concept car with over 20% recycled plastics at the project meeting in October 2018.

WP2 Materials in the present and future vehicle fleet

RESEARCH QUESTIONS:

- How might the material flows entering and exiting the vehicle fleet evolve over the next decades considering various trends in e.g. technology and vehicle intensity?
- In what ways does the vehicle recycling system need to be adapted to recover future material flows?

Result summary

Efficient recycling of vehicles is a cornerstone of any circular economy strategy. The main policy - the ELV directive - specifies that as of 2015, 95 percent of the weight of ELVs must be recovered, of which at least 85 percent must be reused, or material recycled. Longer-term circular economy strategies go beyond mass recovery and aim at 'maintaining the value of the materials and energy used' such as reuse and functional recycling. These aims are complicated by the observable trends towards hybridized and electric drivetrains, light weight chassis design, and increased application of vehicle electronics. The trends are being driven by the automotive industry's efforts to improve vehicle performance and efficiency and also to comply with targets concerning greenhouse gas emissions and are thus likely to continue in the future. The implication for the vehicle recycling industry is changes in quantities and compositions of waste flows reaching recycling, which can change the economic as well as the technological context in which they operate. Due to the long lifetime of vehicles, it is however possible to predict these changes with some certainty. A stock and flow modelling approach, which distinguishes between vehicles of more than 60 different types and uses statistics on vehicles sales, fleet, recycling and imports and exports of used vehicles, was used to compare historic and current quantities and compositions of waste flows reaching recycling with those over the next 15 years. The following main observations from the analysis can be done:

- The quantities of waste to recycle will increase due to both the constantly increasing number of vehicles and their increasing individual curb weights.

- As opposed to historic trends, a continued distinct increase in the share of plastics in the material composition of vehicles can no longer be observed. But due to the increasing number of vehicles and increasing curb weights, the absolute mass of plastics to recycling is indicated to still increase, although at a lower rate than historically.

- Similar to the observations regarding plastics, no significant increase in the share of light-weight materials such as magnesium and carbon fibre reinforced plastic composites could be identified.

- The content of scarce or critical metals in vehicles change over time, with most metals increasing but some decreasing. Specific changes caused by electrification of drivetrains is introduction of batteries, electric motors, high voltage electronics and more wire harnessing, as well as reduction (or removal) of catalytic converters and engine blocks. A general increase of automotive electronics and high strength alloys can be noted for all vehicle types. More than 25 scarce or critical metal elements are involved in the changed quantities reaching recycling.

- Some scarce or critical metals are concentrated to a few components, but the same metals are also dispersively used in low concentrations in numerous components of which the quantities can be of similar orders of magnitude. For example, neodymium reaching recycling will mainly be found in numerous small magnets until a more significant share of electrified vehicles reaches recycling. Palladium and platinum decrease due to decreased use of catalytic converters but at a lower rate for palladium since it remains in vehicle electronics. This emphasizes the risk of underestimating the quantities if dispersive applications are overlooked.

Since vehicles is one of few products groups in society which is monitored both at sales, during its use and end of life, information on its fate is more accessible than compared to many other product groups. This means that material resources in vehicles could in principle be monitored enabling foresight for adapting recycling value chains in time. However, such analyses are hampered by the low access to data on vehicle content in combination with low resolution of publicly available vehicle fleet data. Furthermore, even if data was abundant and future projections could be made with high degree of detail and certainty, the variation in vehicle designs in and over time, would still require high flexibility in introducing technology and practices to ensure very high rates of functional recycling of individual materials and elements. The various barriers to adapting recycling value chains as identified in the studies in WP5 indicates that this a challenging prospect.

Scientific publications and technical reports

Emilsson, E., Dahllöf, L., Ljunggren Söderman, M. (2019) Plastics in passenger cars. A comparison over type and time, report C454, IVL Swedish Environmental Research Institute, Gothenburg, Sweden.

Hamza, M., and Trinh, L. (2017) Material trends in passenger cars, Thesis for Master of Science, School of Industrial Engineering and Management, KTH Royal Institute of Technology, Stockholm.

Ljunggren Söderman, M., Løvik, A. N., Kushnir, D., Restrepo, E., Wäger, P. (2020) Present and future stock and flows of critical raw materials in Europe's vehicle fleet, manuscript.

Industry conferences and popular science activities

1. ”Värdefulla metaller för klimatet slängs på tippen” (“Valuable metals for the climate are discarded in landfills”), interview with Maria Ljunggren Söderman in ETC, December 19, 2019.
2. Jordartsmetaller återvinns och återanvänds inte idag” (”Rare earth metals are not recycled or reused today”), interview with Maria Ljunggren Söderman in Swedish national radio news, Ekot, September 20, 2019.”
3. “What metals propel the European vehicle fleet – now and in the future?”, Maria Ljunggren Söderman, Initiative Seminar 2019, Transportation in the Age of Digitalisation, September 26, 2019, Chalmers.
4. Roundtable about PEF and environmental challenges for li-ion batteries for vehicles, Maria Ljunggren Söderman, at IVL Swedish Environmental Research Institute, May 22, 2018, Gothenburg.
5. “The impact of technology trends on materials in passenger car fleets”, Maria Ljunggren Söderman, keynote presentation, IEA Experts’ Dialogue on Material Trends in Transport, International Energy Agency, March 8, 2018, Paris, France.
6. ”Europas bilflotta är en rullande guldgruva – som ingen vill ha” (”Europe’s vehicle fleet is a gold mine on wheels – which no one wants”, interview with Maria Ljunggren Söderman in Ny Teknik March 7, 2018.
7. “Guldgruva går till spillo när bilar tjänat ut” and “Untapped gold mine is lost from end-of-life vehicles”, press releases from Chalmers with Maria Ljunggren Söderman resulting in 42 national and international news items, March 5, 2018.
8. ”Bilar och elektronik bygger upp den urbana gruvan” (”Cars and electronics build the urban mine”), interview with Maria Ljunggren Söderman in Swedish national radio’s Vetenskapsradion (The Science radio) January 22, 2018.
9. ”Litiumet i batterierna går förlorat” (”Lithium in batteries are lost”), interview with Maria Ljunggren Söderman in Ny Teknik, February 13, 2017.
10. ”Tydliga miljöfördelar” (”Clear environmental benefits”), interview with Maria Ljunggren Söderman in information leaflet from SBR – Swedish car recyclers’ association, 2017.
11. Expert seminar on energy storage, Maria Ljunggren Söderman, Swedish Energy Commission, September 28, 2016, Stockholm.
12. Podcast on vehicle recycling with Maria Ljunggren Söderman, OMEV (Omvärldsanalys energieffektiva fordon) (”Intelligence on energy-efficient vehicles”), August 29, 2016.
13. “Managing material resources – the challenge of complex products”, keynote lecture, Maria Ljunggren Söderman, Life Cycle Assessment and other Assessment Tools for Waste Management and Resource Optimization, June 5-10, 2016, Cetraro, Italy.
14. ”Hon forskar fram nya vägar för bilarna efter skrotningen” (”She researches new ways for vehicles after scrapping”), interview with Maria Ljunggren Söderman in Göteborgsposten, the main daily newspaper of the Gothenburg region, May 15, 2016.
15. “Realizing resource-efficient recycling of vehicles”, Maria Ljunggren Söderman, Circular Materials Conference, May 11-12, 2016, Gothenburg.

WP3 Adoption and adaptation of manufacturing Planning and control theories and practices

RESEARCH QUESTIONS:

- How can manufacturing planning and control theories and practices developed by and for the vehicle manufacturing industry be adapted to the vehicle dismantling industry and SME's in the recycling industry in general?
- What are the benefits of adopting manufacturing planning and control theories and practices and what are the barriers?
- In what areas does the adoption and adaption of manufacturing planning and control theories have the greatest potential for improvement?

Result summary

Within manufacturing a wide array of tools and technologies are used to identify the current state of production as well as to find possible improvement areas. Within this project two approaches; discrete event simulation and some aspects of Lean production were applied, one at each dismantler. By using simulation, the production flow was investigated, and the dismantling process was found to be the bottleneck. Several scenarios for altering the process could be evaluated. Lean production was applied to analyze operator work and inventory levels for spare parts. A waste reduction technique was used to analyze operator work and it was found that placement of tool and carts could reduce unnecessary movement. An experiment was performed deploying two operators at a station instead of the current single operator.

The barriers to implement Lean techniques, such as pull based production, were related to characteristics of the dismantling business and the business models often used in dismantling companies, i.e. make-to-stock. Characteristics making a full Lean implementation somewhat difficult were: 1. Uncertainties in both supply and demand to and from the dismantling process, 2. A fluctuating demand for spare parts, 3. Uncertain quality of parts not dismantled, and 4. Variance in dismantling times. Further, the current cognitive support tools directed to the operators were few. There is also a gap in research on cognitive support tools in dismantling industry. Overall few case studies from the dismantling business have been reported over the last 10 years, whereof very few have treated the approaches deployed within this research project.

There is a wide variety of tools applied in manufacturing and a couple of these were applied in dismantling enterprises with positive results.

Figure 4: Example of advanced material handling of ELV:s, available only at a few large dismantlers in Sweden today.

Scientific publications and presentations

Islam M. H., Bergqvist G., Tarrar M. (2018) Adoption of lean philosophy in car dismantling companies in Sweden – a case study. Procedia Manufacturing, vol 25. P 620 – 627. https://www.sciencedirect.com/science/article/pii/S2351978918306218 , Presented at Swedish Production Symposium (SPS). May 2018 Stockholm.

Standardisation and process thinking drives car disassembly forward. Poster presentation at American Association for the Advancement of Science (AAAS) yearly meeting. February 2017 Boston.

Tarrar M., Despeisse M., Johansson B. (Submitted) Driving vehicle dismantling forward - A combined literature and empirical study. Journal of Cleaner Production

Master theses

Mansour, M. O., Moreira, M. P. (2017) Improving car dismantling via discrete event simulation. Master thesis. Chalmers University of Technology, Gothenburg Sweden. https://odr.chalmers.se/bitstream/20.500.12380/251787/1/251787.pdf

Bergqvist G., Islam M. H. Adoption of lean philosophy in car dismantling industry. Master thesis. Chalmers University of Technology, Gothenburg Sweden

Popular scientific article

Explore – Projekt för att förenkla bildemonterarnas vardag. NBÅ number 2, 2017. http://www.sbrservice.se/wp-content/uploads/NBA-17-No2.pdf

Workshops

Workshop with 30 SMEs from the Norwegian car recycling industry together with Swerea IVF. Autmun 2017.

Workshop and presentations of main findings from the work package at both Eklunds Bildelslager and Walters Bildelar.

Explore

Projekt för att förenkla bildemonterarnas vardag

Hur kan fordonsåtervinningen bli effektivare samtidigt som vardagen för demonterarna blir enklare? Det är en del av vad man hoppas få svar på i ett av arbetspaketen i forskningsprojektet Explore.

– Demonterarna gör sitt jobb väldigt bra i dag, men vi försöker se hur det här kan göras ännu bättre, säger Kristoffer Gramnaes, projektledare vid Chalmers Industriteknik.

Figure 5: Popular scientific article in NBÅ number 2, 2017.

WP4 Reverse logistics of challenging materials

RESEARCH QUESTIONS:

- What are the main logistical challenges related to a national collection and recycling system for light, bulky and small volume parts and materials from vehicles?
- What are the current best practices for increasing filling rates of light and bulky materials and how can these be adapted to suit the needs of both small and large companies in the vehicle recycling industry?
- What other relevant waste flows exists and how can the vehicle waste flows potentially be coordinated with these?
- What are the key enabling elements for a successful implementation of a nationwide collection of light, bulky and small volume parts and materials from vehicles?

Result summary

The work package mainly focused on plastic components, since these are challenging to material recycle today. Based on recycling tests and market demand studies in the Realize project, bumper skins were identified as the most promising light and bulky materials to dismantle for separate recycling. The PP/EPDM material from bumper skins could be injection molded with good quality results. Based on this, the work package studied the possibilities to build up a national collection system for bumper plastics from both dismantlers and repair workshops. A good option for improving transport efficiency would be to use the existing network of material collection and storage hubs operated by Stena Recycling. At these hubs, bumper material could be inspected, baled and stored until sufficient volumes are reached to fill up trucks for further transport to buyers. Transport distances between dismantlers and material hubs were investigated, and rough estimates of transport costs were made.

A survey among dismantlers showed that the most common current practice was to leave the bumpers on the chassis that are compressed and sent to shredding. A few dismantlers had separate plastic collection. In order to dismantle more bumpers for material recycling, economic incentives were the most important for dismantlers. A similar survey among repair workshops showed that bumpers that could not be repaired were currently mainly sent to energy recovery. However, workshops stated that they were willing to change their handling to reduce environmental impacts and improve their economy. The findings from the surveys and investigations resulted in the wish to test collection of bumpers from dismantlers and workshops in practice.

At a workshop with selected stakeholders, the plan for a follow-up pilot project was drawn up. The project, called "Cirkulär fordonsplast" (circular vehicle plastics), was granted funding by the Swedish Environmental Protection Agency and was carried out during the later half of 2019 (Ljungkvist Nordin et. al. 2020).

Popular scientific article

Plasten i bilarna är nyckeln till en högre återvinningsgrad. NBÅ number 1, 2018.
http://www.sbrservice.se/wp-content/uploads/NBA%CC%8A-nr-1-2018-lr.pdf

ALLA KAN BLI VINNARE

Plasten är nyckeln till högre återvinning

Att återvinna plasten i bilarna är nyckeln till en högre återvinningsgrad och en bättre miljö. I projektet Explore, tittar forskarna på hur man kan stärka den svenska fordonsåtervinningens roll mot en mer cirkulär ekonomi.

MÄNGDEN PLAST i bilar ökar och plaståtervinning är därför viktig för att branschen ska klara EU:s återvinningsmål för uttjänta bilar, det så kallade ELV-direktivet. En modern bil innehåller cirka 200 kilo plast. I dag följer plasten ofta med karossen till fragmenteringsanläggningen, där den mals sönder och hamnar i den så kallade fluff-fraktionen, alltså restavfallet. Det mesta av fluffen går till energiåtervinning, men en del hamnar också på deponi.

För att öka materialåtervinningen skulle man antingen behöva återvinna fluff-fraktionen eller plocka ut plastdelar för materialåtervinning innan fragmenteringen. Från miljö- och kvalitetssynpunkt brukar man argumentera för att det är bättre att sortera plasten redan vid källan, alltså hos bildemonteraren i det här fallet. Men det är ofta svårt att motivera källsortering från en ekonomisk synvinkel.

EXPLORE ÄR UPPDELAT i sex olika arbetspaket. Ett av arbetspaketen handlar om att analysera och föreslå lösningar för en effektiv logistik av plastdetaljer från demonteringen av skrotade bilar. I arbetspaketet ingår Chalmers Industriteknik, Stena Recycling, Eklunds Bildelslager AB, Walters Bildelar, och IVL Svenska Miljöinstitutet. Övriga deltagare i projektet är Chalmers, Volvo Lastvagnar, Volvo Personvagnar, Sveriges Bilåtervinnares Riksförbund (SBR), och BilRetur.

När det gäller möjligheter att öka materialåtervinning av plast har tidigare studier tittat på hur man kan sortera ut plasten ur fluff-fraktionen. Det finns dock lite forskning som tittar på möjligheter för att demontera plastdetaljer direkt för återvinning, vilket är fokus i arbetspaketet.

– Vi har identifierat ett antal plastdelar som är lätta att demontera, som endast består av en plastsort samt har en stor effekt på återvinningsgraden, berättar projektledaren Linea Kjellsdotter Ivert. Produkterna har samlats in och skickats till ett antal potentiella kunder, bland annat Veolia, Axjo, Rondo Plast och Polyplank. Resultat visar att det finns en potentiell marknad för plast från uttjänta bilar.

SÅ HÄR LÅNGT kan studien sammanfattas i tre punkter:

Plast som återanvänds från stötfångare, hasplåt och innerskärmar kan användas för att tillverka standardformsprutningskvalitet av återvunnen polypropen.

Ett potentiellt område för återanvändning av expansionskärl och spolarvätskebehållare är tillverkning av extruderingskvalitet av polyeten.

Grundämneshalter för samtliga plastdelar ligger under aktuella gränsvärden. Priset varierar mellan 1,5 kr/kg och 16 kr/kg beroende på förädlingsgrad av materialet.

En ökad förädlingsgrad av materialet innebär ytterligare steg i materialåtervinningsprocessen, vilket i sin tur betyder ökade kostnader och högre krav på kompetens hos den aktör som ska stå för förädlingen.

DEN SORTERADE PLASTEN måste delas upp i mindre bitar i en så kallad shredder. Därefter måste den tvättas för att få bort fett och damm från plastytan. När plasten har

OM EXPLORE
Explore bygger vidare på det tidigare forskningsprojektet Realize och ska vara klart i slutet av 2018.
I projektet deltar IVL Svenska Miljöinstitutet, Chalmers Industriteknik, Chalmers Miljösystemanalys, Chalmers Industri- och Materialvetenskap, Volvo Lastvagnar, Volvo Personvagnar, Walters Bildelar, Eklunds Bildelslager, SBR, BilRetur och Stena Recycling. Projektet finansieras av Mistra.
Målet med projektet är att stärka den svenska fordonsåtervinningens roll mot en mer cirkulär ekonomi och få nya kunskaper om materialåtervinning av fordon och ett ännu bättre samarbete mellan fordonstillverkare, demonterare och återvinnare.

Linea Kjellsdotter Ivert är projektledare för arbetspaketet som handlar om plaståtervinning i projektet Explore.

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Figure 6: Popular article in Nordisk Bilåtervinning number 1, 2018.

Master thesis

Designing an efficient reverse logistics system for dismantlers: Increasing recycling rate of plastics from end-of-life vehicles. Lousie Fängström, Sahanda Yari.
http://publications.lib.chalmers.se/records/fulltext/256360/256360.pdf

Conference presentations

1. Presentation: Yearly conference of "Produktionsklustret" (the Production cluster). Katrineholm, May 2018.
2. Presentation: Testbed for plastics recycling at Swerea. Autumn 2018.

Figure 7: Bumper skins collected in the follow up project "Cirkulär fordonsplast".

WP5 Policy measures for functional recycling of scarce metals in cars and electronics

RESEARCH QUESTIONS:

- What development dynamics characterize effective and defective recycling systems, respectively?
- What measures for enabling the transition to highly functional recycling of scarce metals in vehicles can be identified?

Result summary

Cars and electronic equipment have come to depend on materially complex designs and are drawing attention to issues around sustainable materials management. The dependence of these products and other applications on metals that can be considered scarce, has been brought into political and scientific focus. This is largely because of potential regional scarce metal supply constraints and the crucial roles the metals may play in current society and in diffusing a variety of 'green' technologies. If the societal dependence on scarce metals continues, the demand for these metals may become larger still. It is therefore increasingly relevant to manage scarce metals sustainably. Ultimately, the metals need to be recycled if such sustainable management is to be achieved.

However, recycling industries are not well-adjusted to recovering all scarce metals, and concurrently policy makers and the research community are only in early stages of finding ways to approach challenges associated with managing scarce metal resources. As a result, instead of being recycled, many scarce metals risk being irreversibly lost. Thus, there is need for knowledge in multiple domains if recycling rates of scarce metals are to increase. The research in this work package aims to contribute with such knowledge by studying recycling of scarce metals from end-of-life cars (ELVs) and waste electrical and electronic equipment (WEEE). First, by quantifying scarce metals entering Swedish ELV recycling, tracking the metals through recycling, and identifying where metals end up. Second, by identifying factors that impact on developing industry abilities for recycling scarce metals from ELVs and WEEE. Third, by identifying and discussing research approaches used in waste management, WEEE and ELV related research. Fourth, by suggesting measures that may raise recycling rates of scarce metals. Methodologically, the research is based on material flow analysis (MFA), the technological innovation system (TIS) framework and bibliometric analysis.

Results indicate that 2,000-3,000 tonnes of scarce metals annually enter Swedish ELV recycling. Only 8 of 25 studied metals are estimated to have any potential for being recycled in such a way that metal properties are reutilised. Salient factors that impact on developing industry recycling abilities include: The material composition of ELVs and WEEE and the current value of contained metals; long-term metal price trends; access by industry actors to metal markets, an experienced work force, waste treatment technology and financial capital; business models and long-term goals within recycling industries; and EU and Swedish policy. These factors create socio-technical system challenges that need to be addressed by industry actors, policy makers and researchers if recycling is to develop. Furthermore, some environmental system analysis methods and most socio-technical change approaches have only marginally been adopted in WM, WEEE and ELV related research. Hence, valuable scientific tools are left unutilised.

Overall, results highlight that industry actors, policy makers and researchers need to engage in long-term, high impact and metal specific measures that target build-up of entire value chains, if individual scarce metals are to be recycled.

The research contributes theoretically to TIS literature by adapting the TIS framework to a new empirical field, and to using it for studying industry developments where multiple and potentially conflicting goals are salient features. Empirically it increases the resolution of knowledge about metal and material flows, and industry conditions, in Swedish ELV and WEEE recycling.

NB the text is drawn from the doctoral thesis of Magnus Andersson which was defended September 21, 2018 at Chalmers University of Technology (Andersson 2018).

Scientific publications

Andersson, M., Ljunggren Söderman, M., Sandén, B. (2019) Challenges of recycling multiple scarce metals: the case of Swedish ELV and WEEE recycling, Resources Policy, 63:101403.

Andersson, M., Ljunggren Söderman, M., Sandén, B. (2019) Adoption of systemic and socio-technical perspectives in waste management, WEEE and ELV research, Sustainability 2019, 11(6), 1677.

Andersson, M. (2018). Towards recycling of scarce metals from complex products. Chalmers University of Technology.

Andersson, M., Ljunggren Söderman, M., Sandén, B., (2017) Lessons from a century of innovating car recycling value chains, Environmental Innovation and Societal Transitions, 25:142-157.

Andersson, M., Ljunggren Söderman, M., Sandén, B. (2017) Are scarce metals in vehicles functionally recycled? Waste Management, 60:407-416.

Andersson, M., Ljunggren Söderman, M., Sandén, B (2017) Refining policies aimed at recycling of complex products, 8th International Sustainability Transitions Conference, June 18-21, 2017, Gothenburg.

Andersson, M., Ljunggren Söderman, M., Sandén, B. (2016) Mapping the content and fates of scarce metals in discarded cars, Life Cycle Assessment and Other Assessment Tools for Waste Management and Resource Optimization, June 5 -10, 2016, Cetraro.

Industry conferences and popular science activities

1. IT-prylar och bilar. Utmanande men viktiga att återvinna för en cirkulär ekonomi! – populärvetenskaplig föreläsning, Magnus Andersson, Popular science talks at Ekocentrum, August 13, 2018, Gothenburg.

2. Lärdomar från ett sekel av materialåtervinning i bilens värdekedja. Magnus Andersson, Avfall i nytt fokus. Från teknik till styrmedel, 29 mars 2017, Malmö.

WP6 Future technologies

RESEARCH QUESTIONS:

- What possible technologies are available for efficient dismantling, sorting and recycling of future vehicle waste stream in a 10-20-year perspective?
- Which are the most important barriers and opportunities for realization of these dismantling, sorting and recycling technologies?
- What impact will the identified technologies have on the recycling chain and it´s actors?

Result summary

Current vehicle recycling in Sweden is heavily dependent on shredding. To improve material quality and increase recycling levels further, the future may see more of a balance between dismantling and advanced sorting, separation and material recycling methods. While increased dismantling helps to keep high material purity in contrast to shredding output fractions, it has downsides in terms of costly manual work and logistic challenges. Implementing lean production principles (in line with findings in WP3) and using excavators (see Figure 4) and robots (see Figure 8) for material handling could be solutions for more efficient dismantling. In order to make such investments, the profitability of dismantlers would need to improve substantially.

Most plastic material recycling methods, with mechanical recycling being the most common one, demand a fairly homogenous feed of plastics. At the moment the sorting of different plastic types has to be done on the shredder light fraction (SLF), as very few plastic components are dismantled before the ELV is sent to a shredder. For this to be successful, advanced separation and sorting technologies are needed. Table 1 lists an overview of technologies. At the Stena Nordic Recycling Center in Halmstad, investments have been made into more advanced Post Shredding Technology (PST) for separation of the SLF fraction. Technologies include Eddie current, magnets, sifting and wet sorting. This has resulted in higher yields of valuable metals and better fuel fractions from the SLF, and efforts are made to also prepare the plastic fractions for material recycling in the future (Gyllenhammar 2019).

Other operators running PST facilities in Europe include Stena Recycling in Grenå (Denmark), Sicon (Germany), ARN (Netherlands), Gallo (France) and EMR in the UK. The EMR facility includes pyrolysis treatment with energy recovery and recovery of metals from the ashes (Gyllenhammar 2019).

Table 1: Overview of sorting and separation technologies Based on Al-Salem (2009), Dodiba (2004), Ragaert (2017) and the Plasort project (2017-2018).

Technique	Description	Advantages	Challenges
Flotation	Density based	Well-known technology Cost-effective	Not efficient when density of plastics overlap
Froth flotation	Density based	Densities can overlap	Need further development
(FT)-NIR	Spectroscopic	Well-known, Fast Post-drying not required	Not useable on black plastics
Raman Spectroscopy	Spectroscopic	Good detection coverage	Until now slow
Tribo-electric separation	Electrostatic separation	Efficient for various plastics	Need pre-treatment
LIBS	Spectroscopic	Fast Good detection coverage	Need further development
Spark OES	Spectroscopic	Good detection coverage	Close to sample Need further development

Chemical recycling could offer an opportunity for recycling of ELV plastics that for different reasons cannot or should not be mechanically recycled. There are several different techniques for chemical recycling based on physical (dissolution), chemical (solvolysis) or thermal (thermolysis, pyrolysis and gasification) properties. Chemical recycling capacity is currently increasing both in Europe and worldwide and may provide a complement to traditional mechanical recycling. An overview of current capacity and facilities is available from Waldheim (2019). However, many processes are tailored to specific inputs, and not all are robust enough to deal with a mix of plastics from SLF and similar fractions.

Connected to findings in WP4 & 5, achieving increased functional recycling of materials from cars is a complex matter that requires a combination of clear policy targets, efficient logistic systems and new business models that provide economic incentives for actors in the value chain. Material specific recycling targets in policy, new price models between dismantlers and recyclers and increased cooperation between dismantlers and repair workshops are examples of possible measures that could increase functional material recycling and improve profitability. The current trend of fewer dismantlers is also likely to continue, since profitability is connected to number of treated cars and dismantlers report a weakening market for spare parts, at least among private persons.

Work package report

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Figure 8: Picture from the Swedish innovation project ELV-robot, in which dismantling of glass details in cars were automated (source: Chalmers Industriteknik).

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