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- Intermediate: Document is approximately 50% complete – review checkpoint
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SuPLight Consortium

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BOL	Beginning-of-life
MOL	Middle-of-life
EOL	End-of-life
KPI	Key performance indicator

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1 Publishable summary

The work presented in this report is part of the European joint project *Sustainable and efficient Production of Light weight solutions* (SuPLight), EU FP7 project 263302. The aim of this project is, among other things, development of new industrial models for light weight solutions in transportation and identification of methods for more sustainable material (aluminium) production.

Aluminium scrap has a high intrinsic value. That has always been the main reason for recycling. Aluminium is not actually consumed during a lifetime, it is simply used. Therefore the lifecyle of an aluminium product is not the traditional "cradle-to-grave" sequens, but rather a renewable lifcycle from "cradle-to-cradle". These factors have contributed to the good-for-the-environment image that the material has compared to other materials.

When it comes to high end aluminium the cradle-to-cradle thinking is still a faraway dream. In reality we recycle high end aluminium products, such as suspension arms and aeronautic parts into door handles or coat hangers.

GARC (2009) points out that end-of-life recycling performance and recycled metal content are often misunderstood. There is no problem, from a technical point of view, to produce new aluminium part from the same used product. There is no difference in quality between a product made entirely from primary metal or recycled metal. The limited amount of material available for recycling leads though to a situation where aluminium scrap is recycled where it is deemed most efficient. Any attempt of increasing the recycled content in one particular product would lead to a decrease in another product. It would also certainly result in inefficiency in the global optimization of the scrap market, as well as wasting transportation energy. Finally GARC makes clear that if there is aluminium scrap available it will be recycled, not stockpiled, due to the high market value of the scrap.

With this in mind we realize that some factors must change in order to increase the interest of recycling high end aluminium in a more efficient way. At the same time it is known that customer demand for more sustainable products, the changing price of aluminium, transportation and other related factors together with demands of reducing the environmental impact of humanity in general the factors setting the conditions in today's market will change in a nearby future.

This report identifies some of the issues in the different phases of a products lifecycle that must be taken into consideration in developing a more sustainable aluminium industry for the future.

2 Introduction

Lightweight components and solutions are increasingly important for a more sustainable world. Wrought aluminium alloys have the potential of replacing many of the traditional, heavier materials such as steel and high strength steel. Due to the high energy consumption in the manufacturing process of virgin aluminium it is crucial to increase the post-consumer recycling of wrought alloys aluminium to make this a truly sustainable alternative.

2.1 Role of this deliverable

Deliverable D4.1 is the initial deliverable in WP 4, Holistic life cycle approach in the SuPLight-project (Sustainable and efficient Production of Light weight solutions). The deliverable will form the base for the other activities in WP4.

2.2 Relationship to other SuPLight deliverables

Deliverable 4.1 founds the base and draws the map for the rest of the activities in WP 4, Holistic life cycle approach. In addition it is closely connected to task 3.1, Requirement, system and test specification for multi-objective parameter optimisation of lightweight solutions in WP 3, Simulation based optimisation of lightweight solutions. WP 2 has contributed greatly with competence and input to the product lifecycle of an aluminium part in the automotive industry.

2.3 Work progress and achievements before this deliverable

Some tasks in SuPLight demands major contribution from different scientific fields, Task 4.1 is one of them. Therefore two creative workshops were arranged in order to get a wide perspective on the task.

In the initial study Diliverable D1.3 came to the folloving conclusions:

"Report D1.3 investigates possible aluminium scrap sources relevant for wrought-to-wrought recycling. The production of the aluminium alloy AA 6082 is used as a case in this study, and potential suitable scraps as input to this production is identified. Scrap flows that are investigated are end-of-life (EOL) vehicles, construction and demolition waste and packaging waste, with the main focus on EOL vehicles.

There are suitable aluminium scraps fractions present in each of these scrap flows, but the level of detail in knowledge on chemical composition, volumes and availability varies greatly. As there is a significant gap in information about the composition of post-consumer aluminium scrap, composition is estimated here from the alloys used in a selection of applications rather than from measurements on scrap flows. Results are presented with the original resolution in the source literature, to allow investigation of different flow compositions depending on life-cycle scenarios modelled for the end-of-life treatment of aluminium wastes.

The study concludes that the most suited scrap flow would be window frames from demolished buildings, and that alloy separation from EOL vehicles would require adjustments of the current recycling systems for these. Composition of aluminium packaging scrap is known only on a rather crude level. Hence, the information is too scarce to make any recommendations regarding this type of scrap. An exception is the fraction of beverage cans, but the recycling system for these is already organized in a “closed loop“.

The authors of report D1.3 has also contributed to this report. We have merged knowledge from other parts of SuPLight and looked closer on alloy separation for EOL vehicles before this report was written.

2.4 Structure of this document

A model of the lifecycle of aluminium in automotive/aviation industry forms the base of the document. To describe the different phases in the lifecycle the four stages; Before beginning of life, Beginning of life (BOL), Middle of life (MOL) and End of life (EOL) is described in connected models.

3 Background

Aluminium is a rather new material used in high end products compared to steel and other "old school" but well proven materials. Aluminium suffers from a deficit in the value chain, i.e. all available aluminium on the market is recycled after use, and in addition there will be a need for "new" aluminium (virgin aluminium) in many years to come, also to supply production of lower end products. Figure 1 shows the global flow of aluminium in 2007.

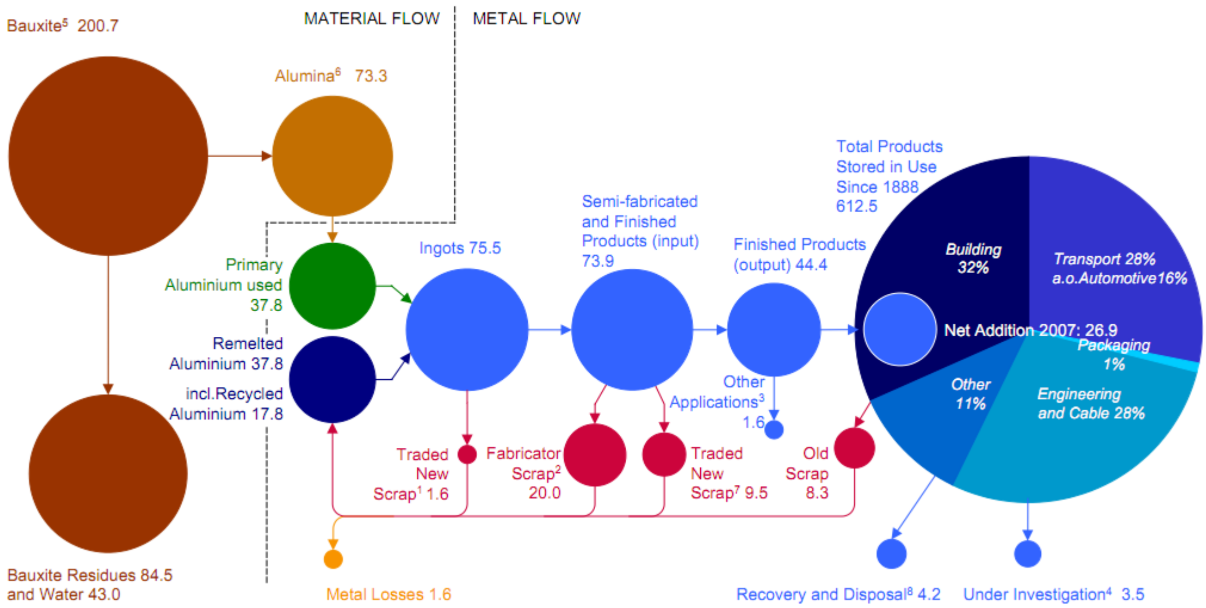

Figure 1: Global Aluminium Flow in 2007 [millions of metric tons] (GARC 2009)

In order not to waste all the energy that is needed to produce alloys for high end aluminium products, such as automotive or aviation parts, and to make more recycled material available for this kind of products the recycle chain has to be divided into a "high end"- and a "low end"-loop. Today we literarily recycle suspension arms into door handles or coat hangers. There are many factors that need to be changed before the two recycling loops for aluminium is a profitable business for the recycling industry. This report outlines some of the issues.

The forecast for use of aluminium in light vehicles indicates that there will be a major increase of the use of aluminium. Ducker (2011) estimates 155 kg (343 pounds) of finished aluminium per vehicle in 2012, an increase from 148 kg (327 pounds) in 2009 in a report by The Aluminium Association (2011). Aluminium is expected to double its share of the average light vehicle material mix to 16 % by 2025 compared to 2008 (the Environmental Protection Agency (EPA) base year).

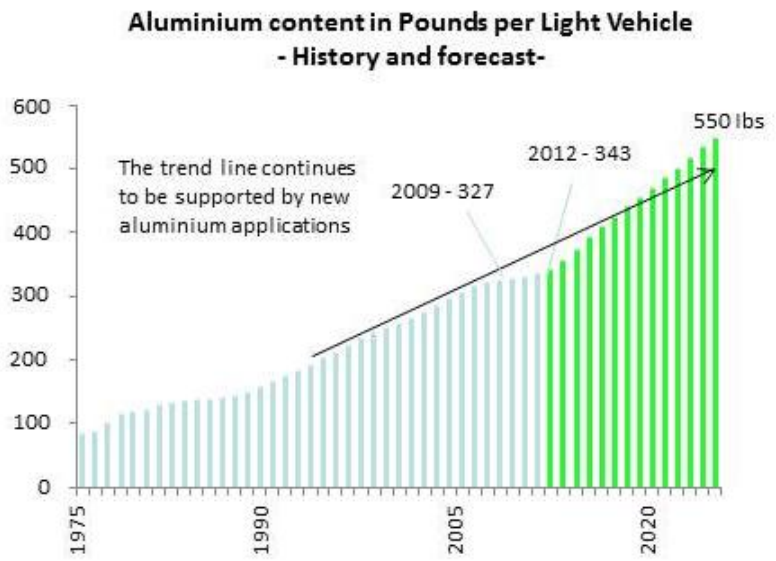

Figure 2: Aluminium content in pounds per light vehicle (Ducker 2011)

Aluminium is currently the dominant material for powertrain, heat exchangers and road wheels and Ducker (2011) reveals it is rapidly gaining masked share for hoods, trunk lids, bumpers, steering knuckles and suspension arms. The average vehicle weight will be reduced by 10% or 185 kg by 2025 compared to 2008. Aluminium is gaining market shares from both traditional and high strength steel. Ducker also predicts that direct cost of the materials upgrade is estimated to less than €400, before any cost savings from downsized components are taken into account. Before the end of this decade, high volume of aluminium-bodied vehicles will be on the road.

As an example Audi A8 contains 520 kg of aluminum according to Aluminium in cars (2007).

Figure 3: Audi A8 contains 520 kg of aluminium, picture from audi.no

Somewhere down this road there is a breakeven point where recycled aluminium for high end products as well as the knowledge about how to use it becomes big business.

There exist plenty of tools, methods and methodologies for sustainable product development and manufacturing. Today, the main barriers to sustainable product development are not the lack of strategies, models and tools, but how to implement and introduce them into existing practices whilst ideally improving competitiveness (Baldwina, Allenb et al. 2005)

4 Performance characteristics

In order to define performance characteristics there must be an agreement of what is the SuPLight definition of the reality in this specific case. With extensive knowledge about the production of high end aluminium products on one hand and the existing global recycling loop of aluminium on the other hand a wide range of participants in SuPLight have agreed on the map of reality shown below. For a more detailed view, see appendix A.

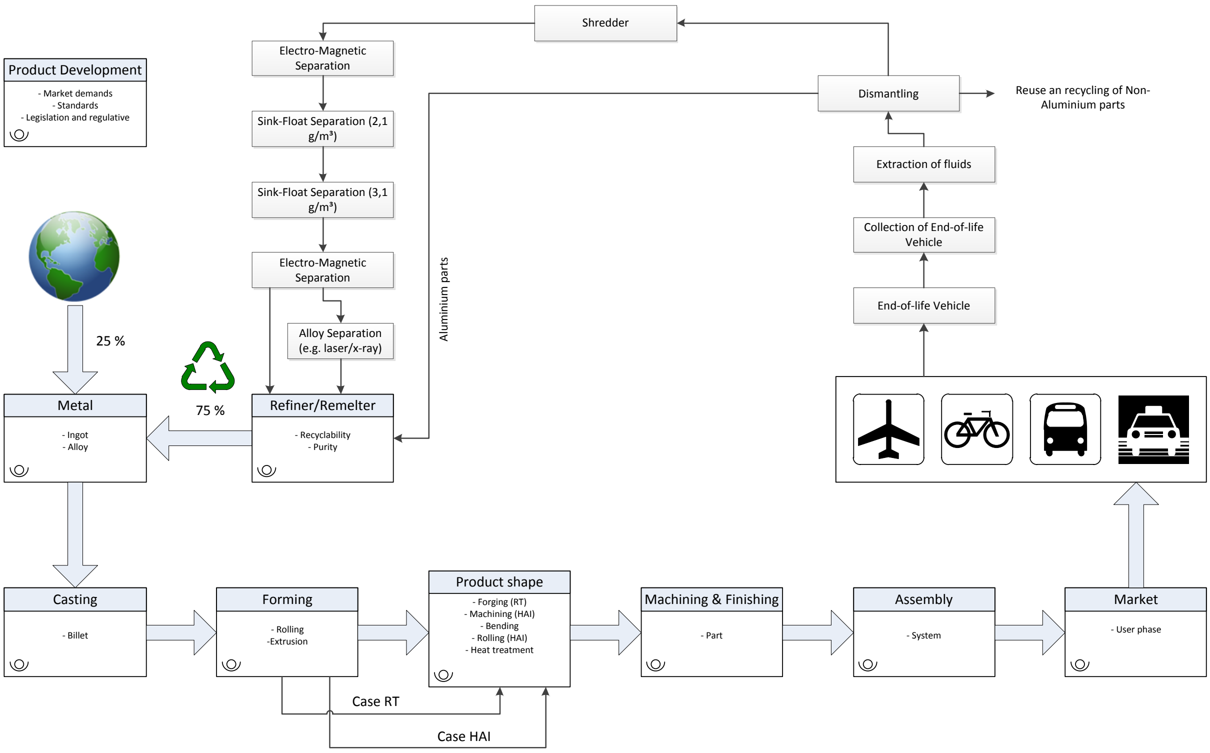

Figure 4: Value chain - Wrought aluminium alloys in transportation

4.1 Before beginning of life (Before BOL)

There are several factors that need to be considered before beginning of life of a product in order to increase the amount of recycled material in high end, light weight products. This is visualized in a decision tree below.

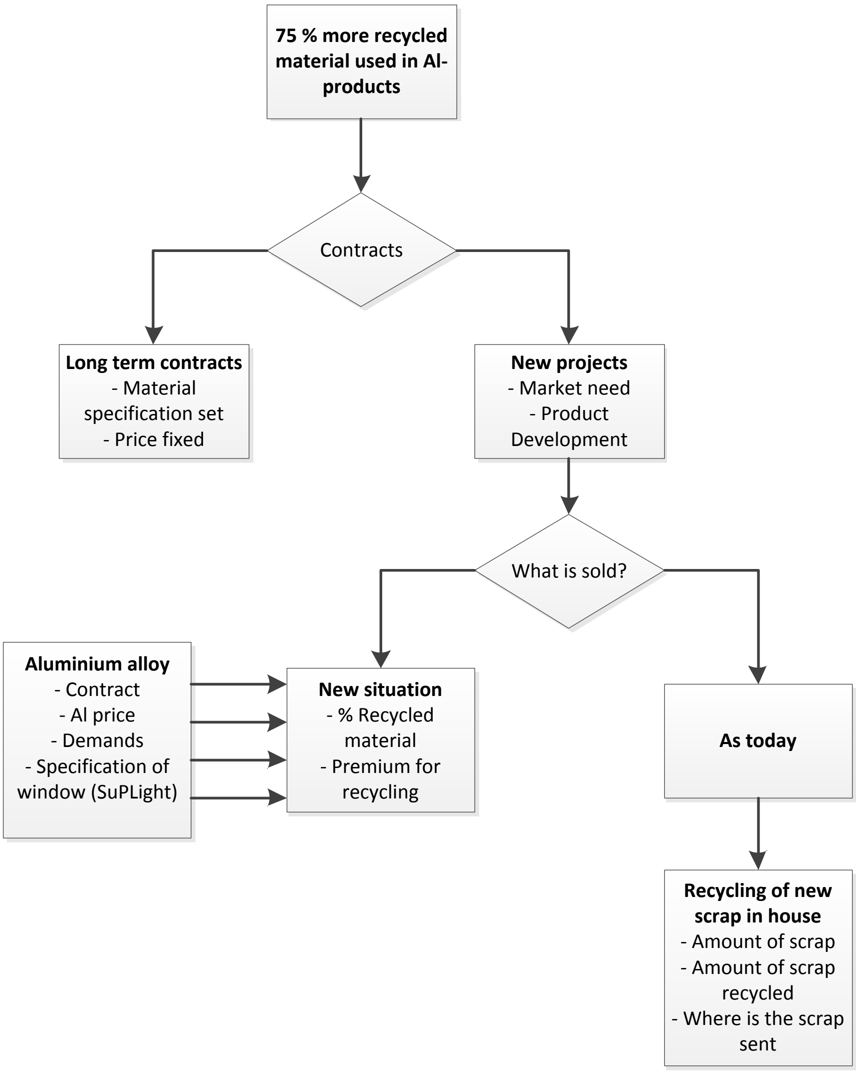

Figure 5: Decision tree Before Beginning of Life

4.2 Beginning of life (BOL)

The two industrial partners of SuPLight recycle new scrap from their own production.

Case HAI: HAI produces approximately 500 tones (metric) per year, mainly chips and defect parts. All scrap is sent for recycling, HAI does not have any processes of elaborating scrap in-house. The scrap is collected by local metal traders and later handed over to recycling companies and Greek aluminium producers.

Case RT: Depending on what product that is produced (variation in process and material utilisation) 20-35 % is classified as scrap. 100 % of the scrap is recycled by an internal rough sorting process in-house in order to take out impurities generated by the manufacturing process. The scrap that is pure enough is sent directly to the billet producer for casting of new billets and the rest is rent to a refiner for further purification before new billets are casted.

The objective of the SuPLight project is to realize the beginning of life (BOL) process below.

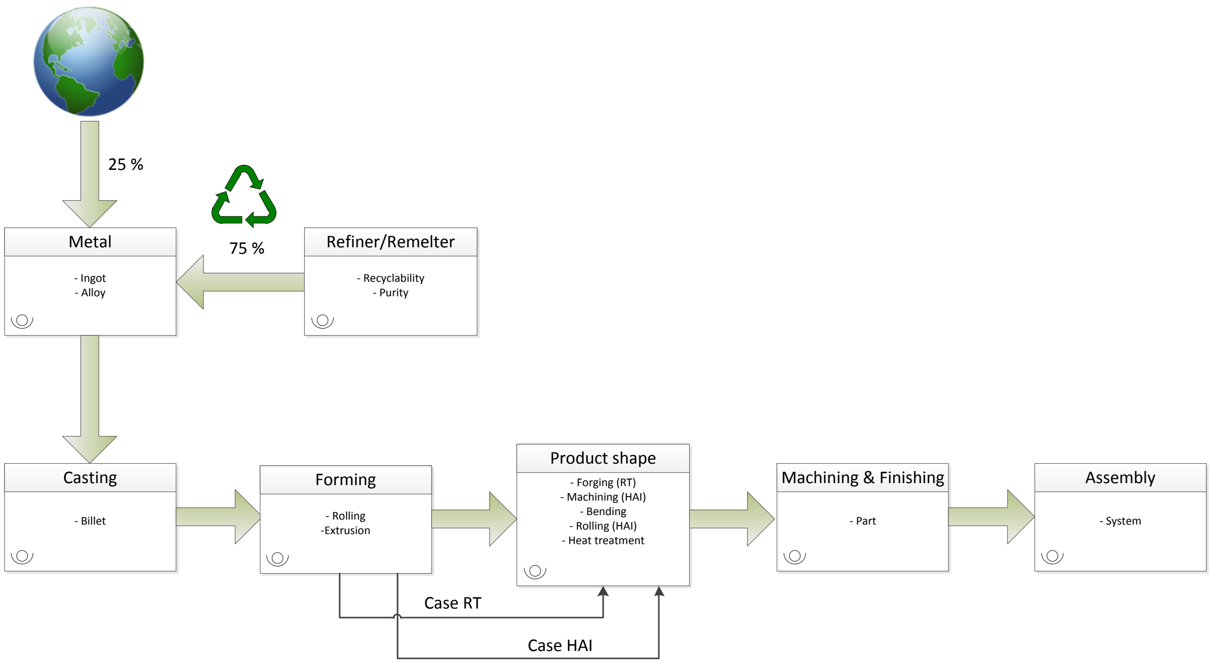

Figure 6: Beginning of Life (BOL)

4.3 Middle of life (MOL)

While in use the situation is in status quo. Aluminium is not actually consumed during a lifetime, it is simply used. When it comes to maintenance and replacement of high end parts containing high tech aluminium, the vehicle service centres keeps the replaced parts for further collection by a recycling company in the area. Obviously, there should be a better way to recycle it than merely into ordinary metal scrap. This would require an easy way to identify the material and that again requires a marking system in the BOL-phase. A stamp identifying the alloy content of the part would be a non-expensive and easy way of solving the problem.

4.4 End of life (EOL)

The recycle loop for aluminium is well established and well-functioning for aluminium but it is mainly aluminium used in products in a lower end than those regarded in SuPLight. There is no established recycling loop for wrought aluminium, high end products. There are ways to come around this decrease in material quality in the recycling loop, but most of them require a more specified and complex dismantling operation than what seems efficient in the current market. A study tour to the nearby recycling company Oppland Metall AS shows that there is an emerging market for an extra loop in the recycling process for some scrap. The company owns an advanced production line that sorts scarp by x-ray technology.

It would be possible to make an effort developing this technology further in order to investigate cost/benefit impacts of such technologies.

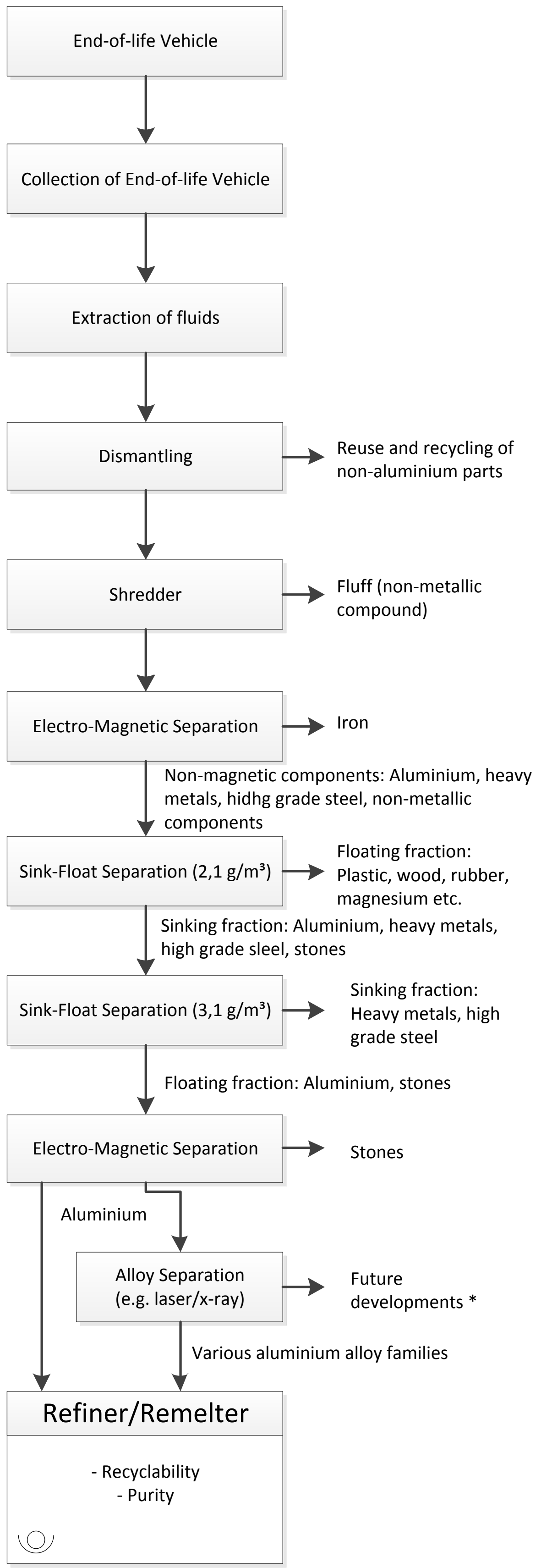

Figure 7: End of Life (EOL)

5 Key Performance Indicators

A performance indicator or key performance indicator (KPI) is an industry jargon for a type of performance measurement (Fitz-Gibbon 1990). KPIs are commonly used by an organization to evaluate its success or the success of a particular activity in which it is engaged. Sometimes success is defined in terms of making progress toward strategic goals but often success is simply the repeated achievement of some level of operational goal (for example, zero defects, 10/10 customer satisfaction, etc.).

Key performance indicators define a set of values used to measure against. These raw sets of values, which are fed to systems in charge of summarizing the information, are called indicators. Indicators identifiable as possible candidates for KPIs can be summarized into the following sub-categories:

- Quantitative indicators, which can be presented as a number.
- Practical indicators, that interface with existing company processes.
- Directional indicators, specifying whether an organization is getting better or not.
- Actionable indicators are sufficiently in an organization's control to effect change.
- Financial indicators, used in performance measurement and when looking at an operating index.

Regarding SuPLight, the critical factors to be collected or computed in real time during the manufacturing process (BOL) for the current market, are mainly productivity and quality. In addition, factors related to the use of energy and emissions are increasingly relevant due to more exigent requirements and regulations concerning environmental impacts.

Table 1: Over all KPIs

KPI	
Productivity	Measured by production time
Quality	Control by samples or 100 % control
Use of energy in production	When the alloy or the process (itself or the parameters) changes, this may help to justify the change.
Use of energy in use phase	An estimated 80% of the total energy consumption comes from the use phase.
Use of chemicals/ Emission	LCA tool may give some quantitative feedback about this.

For each step of the production process the performance of the material must be monitored.

Table 2: Process specific KPIs

KPI	**What to measure?**
Castability	Depending on the production process
Forgability	
Rollability	

For the finished product the mechanical and chemical properties must be controlled with regard to strength, ductility and corrosion.

Table 3: Product specific KPIs

Property	**What to measure?**
Mechanical	Strength
	Ductility
Chemical	Corrosion

22 key performance indicators (environmental, economic and social indicators) were defined to determine the Aluminum Industry's progress along the sustainable development path by *"The Global Aluminium Sustainable Development Initiative"* (2002). Among the defined indicators, environmental indicators below may be applicable to SuPLight:

1. PFC&GHG emissions from production (From LCA tool)
2. Amount of recycled aluminum used in production (From the suppliers)
3. Amount of parts reached to the EOL
4. Fresh water consumption for production
5. Use of energy (renewable/non-renewable) in production

6 Methodology

Since Task 4.1 requires a wide range of competences from the different contributors in SuPLight, the task was solved in two workshops hosted by SINTEF RM in April 2012. The first workshop was based on the competences from the different departments of SINTEF RM e.g. Materials technology, Optimisation/calculation, Production technology and Product and production development. For the second workshop also the competences of EPFL and Misa was included.

The method used in the workshops was a structured brainstorming on characteristics and KPI for the different phases of a product lifecycle. The product lifecycle was based on the two industrial cases in SuPLight and the Aluminium recycling process described in the Global Aluminium Recycling report (2009) developed by the International Aluminium Institute.

It can be assumed that the recycling industry might have a lack of competence and understanding about the possibilities, both economic and environmental, they have within their business.

Questions about the handling of recycling metal e.g. replaced vehicle parts has been addressed to a local vehicle service centre (Fyksen servicesenter AS) and a local waste and recycling company (Glør AS) in addition to the recycling company Oppland Metall AS.

7 Results

Future more sustainable products such as automotive- and aviation parts will face higher demands from its stakeholders and the market. Producing more sustainable products needs to be economically driven in addition to the environmental benefits.

The new, more sustainable products will face demands on productivity in order to satisfy the production company and demands on quality/performance to satisfy their customers. Sustainability must be taken into account in all phases of the product lifecycle in order to make this possible.

A key factor is the phase before Beginning of life (BOL). The business of automotive- and aviation parts are customised production where the customer creates a market pull to initiate development and production of new parts. Therefore, 80 % of the decisions affecting the whole lifecycle of the product are taken in the process preceding the BOL of a product.

In the BOL-phase it is important to monitor sustainable KPIs such as emissions and energy consumption in addition to productivity and quality, to make sure that the total of the production is truly sustainable.

Middle of life (MOL) is when the product is in use during its lifetime. Weight is crucial in order to decrease the environmental impact from vehicles and aircrafts. Light weight products will have a natural advantage in the MOL-phase compared to heavier alternatives.

The End of life (EOL) of aluminium plays a key role in order to be able to use an increased amount of recycled material in high end aluminium structural parts. The current recycling loop for aluminium wastes much of the energy needed to produce virgin aluminium. The production of virgin aluminium requires ten times more energy than using recycled aluminium. In addition the existing recycling loop decreases the quality of the material by mixing high end and low end aluminium, which results in low end aluminium.

The results of this report show what lifecycle phases have the biggest potential for increasing the degree of sustainability, i.e. before BOL and EOL. Looking further into the possibility of making more high-end aluminium available for recycling might be the most interesting conclusion form deliverable 4.1 in the SuPLight project.

8 Future Work

During a study tour to the local scrap dealer we visited a plant containing a sorting process using x-ray technology. Today the plant is mainly used for sorting E-waste in order so separate plastic containing bromine from material with no bromine content. The technology can also be used to separate aluminium alloys of different kinds from one another.

To establish a differentiated recycle loop for high end aluminium it would be very interesting for the SuPLight project to make trials with the x-ray technology or other similar technologies in order to separate high end and low end aluminium alloys.

9 References

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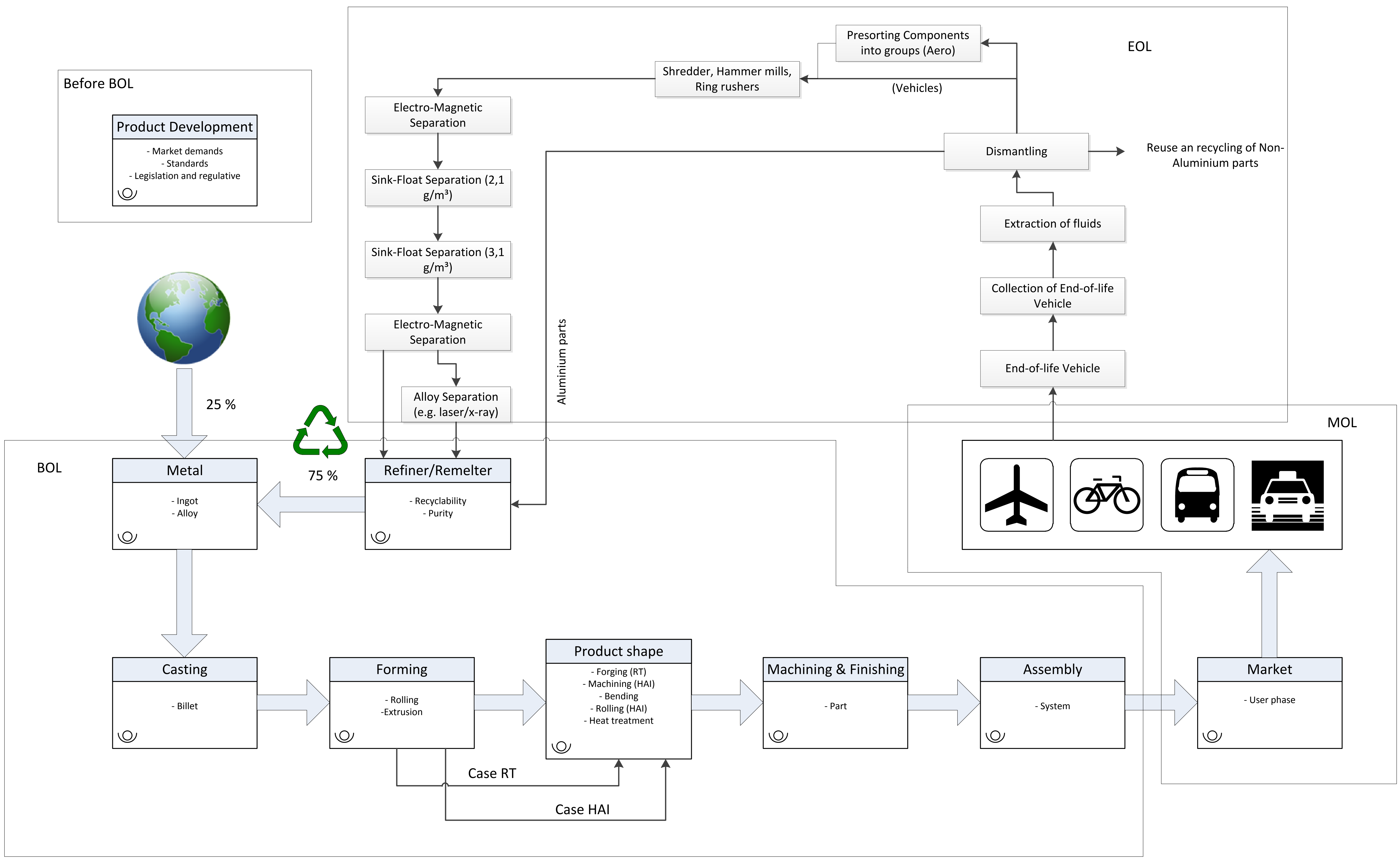
APPENDIX A: Map of wrought Aluminium value chain


Before BOL
Product Development
- Market demands
- Standards
- Legislation and regulative
EOL
Presorting Components into groups (Aero)
Shredder, Hammer mills, Ring rushers
(Vehicles)
Electro-Magnetic Separation
Sink-Float Separation (2,1 g/m³)
Sink-Float Separation (3,1 g/m³)
Electro-Magnetic Separation
Alloy Separation (e.g. laser/x-ray)
Aluminium parts
Dismantling
Reuse an recycling of Non-Aluminium parts
Extraction of fluids
Collection of End-of-life Vehicle
End-of-life Vehicle
MOL
25 %
75 %
BOL
Metal
- Ingot
- Alloy
Refiner/Remelter
- Recyclability
- Purity
Casting
- Billet
Forming
- Rolling
-Extrusion
Product shape
- Forging (RT)
- Machining (HAI)
- Bending
- Rolling (HAI)
- Heat treatment
Machining & Finishing
- Part
Assembly
- System
Market
- User phase
Case RT
Case HAI