Materials – Resources

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1 Resources

1.1 Resources of aluminium materials for cars

Why care for aluminium resources?

- Aluminium is having a growing potential for mass produced cars.
- The materials decisions are taken well in advance of the actual production runs.
- Car models are produced over a period of many years.
- Wrought and cast aluminium alloys rely on different raw materials resources.

Therefore, the criteria for materials selection, availability and supply must include the assured continuity of resources.

Sources of aluminium

At about 7.5% of the earth's crust aluminium is the most abundant metal and the third most abundant element in the earth's crust.

Since the development of the Hall-Héroult process in 1886, aluminium has enjoyed a rapid growth. Approximately 22 million tonnes of "primary" aluminium were produced worldwide in 1998, and another 5 million tonnes of "secondary" (recycled) aluminium. Approximately 30% of the consumption of aluminium goes to transportation applications - a rapidly growing market and a significant source for recycled aluminium (s. ELV Recycling).

Sustainability

Beyond the question of reliable raw materials resources the sustainability of the industrial production processes of materials and the deposition of industrial wastes are further criteria in materials selection.

This chapter, therefore, addresses not only the current aluminium production processes and the abundance of the raw material resources, but also describes relevant factors from an environmental point of view.
1.2 Primary aluminium

1.2.1 Brief history

Compounds of aluminium were known many, many years ago. Egyptians used alumen as a medicine and a dye fixative. The alumen of the Egyptians we know as alum, that is, aluminium sulphate.

The oxide of the metal, alumina, was isolated in its pure form very early in the nineteenth century, by Sir Humphrey Davy, in London. He named it alumina and assumed it had a metallic base which he called first alumium and later aluminium.

The first aluminium metal was prepared by a Dane, H. C. Oersted, in 1825. This he did by heating a potassium mercury amalgam with aluminium chloride and then distilling the mercury from the resultant aluminium amalgam.

For much of the nineteenth century, aluminium remained an expensive, and therefore relatively rare, metal. It is only with the development of a process based on electrolysis of alumina dissolved in a naturally occurring mineral (cryolite) that aluminium metal production started to grow rapidly.

Paul Hérault (left) and Charles Martin Hall (right) - the inventors of the aluminium electrolysis (1886)

The electrolytical reduction process was developed and patented in 1886 simultaneously and independently by Paul Héroult in France and Charles Martin Hall in the US. The Hall-Héroult process has formed the backbone of the aluminium industry for over 100 years.
1.2.2 The Bayer process

Production of Al₂O₃

With a few rare exceptions, all of the pure alumina (Al₂O₃) used by the industry to produce aluminium is manufactured by the Bayer process, the essential features of which remain as they were when the process was invented by Karl Josef Bayer in Austria in 1888 (see figure below).

Schematic of the Bayer Process

Bauxite Strip Mining in Jamaica

Characteristics of the Bayer process:
- mineral bauxite (above) is dissolved in caustic soda,
- seeding of the alumina-rich solution precipitates aluminium hydroxide (Al(OH)₃)
- calcination of Al(OH)₃ to Al₂O₃ (Fig.).

Bauxite, the almost exclusive source today for the production of approx. 38 million tonnes a year of alumina, takes its name from the town of Les Baux in the South of France, where the mineral was first identified in 1821.
Bauxite is essentially hydrated aluminium oxide with various other elements present - ferric oxides, silica, titania, and other elements in small quantities.

Bauxite occurs primarily in tropical countries where warmth and high rainfall have produced weathering.

It takes 2 - 3 tonnes of bauxite to produce 1 tonne of calcined alumina. Approximately 90% of world bauxite production is used to manufacture alumina to produce aluminium metal via the Hall-Héroult Process (described later).

Bauxites generally contain between 40 and 60% alumina (s. Table) and it is this high concentration, combined with the simplicity of dissolving the alumina, that leads to the relative economies of the bauxite/Bayer process combination compared with other ways of producing alumina.

In a Bayer plant, bauxite mineralogy has an impact on the efficiency of the process by driving the chemical reactions occurring throughout the Bayer process. The content and morphology of the alumina-bearing minerals as well as of other impurities with varying solubilities in caustic soda are critical factors in determining aluminium extraction, end-product purity, caustic soda losses and energy consumption.

**Typical Mineralogical Composition of Tropical Bauxites: Major Constituents**

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Percent present (as metallic oxide)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₂O₃ (gibbsite)</td>
<td>30 - 60</td>
</tr>
<tr>
<td>Al₂O₅ (boehmitic)</td>
<td>&lt; 0.2 - 20</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>1.0 - 30</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.3 - 10</td>
</tr>
<tr>
<td>SiO₂ (as clay)</td>
<td>0.3 - 6</td>
</tr>
<tr>
<td>SiO₂ (as quartz)</td>
<td>0.2 - 10</td>
</tr>
</tbody>
</table>

The bauxite is first digested with caustic soda solution, usually under pressure. The alumina, present mostly as gibbsite and boehmite, is extracted in the form of soluble sodium aluminate, which leaves behind most of the impurities, predominantly iron oxide, titania and silica, as an insoluble residue. The clear, filtered sodium aluminate solution is diluted and cooled, and a 'seed' of alumina trihydrate is added. The sodium aluminate solution hydrolyses on the
surface of the seed to form crystalline alumina trihydrate. The trihydrate is finally filtered off and calcined to anhydrous alumina.

The complete process may thus be represented by the following three reaction equations:

\[
\begin{align*}
\text{Extraction} & : \quad \text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O} + 2\text{NaOH} & \rightarrow & \quad 2\text{NaAlO}_2 + 4\text{H}_2\text{O} \quad \text{(1)} \\
\text{Crystallisation} & : \quad 2\text{NaAlO}_2 + 4\text{H}_2\text{O} & \rightarrow & \quad \text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O} + 2\text{NaOH} \quad \text{(2)} \\
\text{Calcination} & : \quad \text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O} & \rightarrow & \quad \text{Al}_2\text{O}_3 + 3\text{H}_2\text{O} \quad \text{(3)}
\end{align*}
\]

A typical Bayer plant (see figure) with an output of about 1,000 tons calcined alumina per week will use roughly 2,500 tons of bauxite and will have 3,500,000 gallons liquor in circulation, containing 2,000 tons of caustic soda and 1,000 tons of Al\text{2}O\text{3} in solution. The precipitators may contain 4,500 tons of trihydrate.

The process as worked today is essentially identical with that originally invented by Bayer, and as long as there is an adequate supply of good quality bauxite with less than about 7 per cent silica, it is unlikely that any other process will supersede it. Numerous detailed improvements have considerably increased the efficiency of the process. In modern practice the extraction efficiency (based on the theoretically extractable alumina in the bauxite) is typically 97 per cent.
1.2.3 The reduction plant (Smelter)

Aluminium metal is obtained from alumina by electrolytic reduction, using the Hall-Héroult process. Calcined $\text{Al}_2\text{O}_3$ is reduced to aluminium metal in electrolytic cells, or "pots", connected in series to a DC power source. The cells are rectangular steel pots lined with refractory bricks and carbon.

![400,000 tpy aluminium smelter at Alma, Canada](image1)

Modern smelters (figures below) contain typically several hundreds cells (432 for the smelter pictured), operating at currents of 150,000 to 300,000 amperes. New technology is coming on-line that operates at 500,000 amperes.

![Pot line at Grande-Baie Smelter, Québec, Canada](image2)
1.2.4 The reduction process

The cells contain a molten electrolyte at operating temperatures of approx. 950-970°C, from which aluminium is produced (see figure). The electrolyte is a mixture of cryolite (Na$_3$AlF$_6$) and certain additives to give an appropriate density, conductivity and viscosity.

Rectangular carbon anode blocks, which are suspended in the electrolyte, act as electrical conductors. These anodes are a mixture of baked petroleum coke and pitch.

Electrical current passing from the anode through the electrolyte to the cathode, formed by the thick carbon or graphite lining of the pot, reduces alumina into aluminium and oxygen. The oxygen is deposited on the carbon anode, where it combines with the carbon to form carbon dioxide (CO$_2$). The carbon anodes are changed frequently, as they are consumed by the reaction with oxygen. The aluminium, being denser than the electrolyte, settles to the bottom of the cell.

At regular intervals, the molten aluminium is siphoned from the bottom of the pot into large crucibles and transferred to holding furnaces where alloying of the metal takes place; the liquid metal is sometimes transported to a remote casthouse (see figure).
It takes approx. 2 tonnes of alumina to produce 1 tonne of aluminium metal.

Typical purity of the metal produced is 99.7%, with iron and silicon as principal impurities.

The smelting process is continuous. A smelter cannot easily be stopped and restarted. If production is interrupted by a power supply failure of more than four hours, the metal in the cells will solidify, often requiring an expensive rebuilding process.

From time to time individual pot linings reach the end of their useful life and the pots are then taken out of service and relined.

Considerable electrical energy is consumed in the process. It takes, on average, 15.7 kWh to produce 1 kg aluminium. The theoretical limit is 6.34 kWh/kg at 977 °C, so the energy efficiency of the process is less than 50%. The remaining energy is lost in the form of heat given off to the surroundings.

Primary aluminium smelters are concentrated in energy-rich environments, in particular where hydro-electricity is available. Historically, over 50% of the power used to produce aluminium has been hydroelectric power and it is expected that this trend will continue into the foreseeable future (s. figures below).
1.2.5 The reduction process – Environmental Issues

There are a number of environmental challenges related to the production of aluminium metal: emission of fluoride and polycyclic aromatic hydrocarbons (PAHs) compounds, particulates (dust), the generation of greenhouses gases (CO$_2$, PFCs) and the treatment of cathode waste (spent potlining).

A number of new technologies exist or are under development to face these challenges and maintain the competitive position of aluminium in Life Cycle Analyses. The generation of fluorides, PAHs and dust has been significantly reduced by the introduction of recent pre-bake anode technologies; what is left is controlled by efficient dry scrubbers, with recycling of the captured material into the process. Recent smelters are therefore fumeless, smokeless and odourless.

Across all aluminium smelting technologies, producers have reduced PFC emissions, which are generated when “anode effects” (alumina starvation) occur, by an average of 47% from 1990 to 1997 (see figure), through the use of improved alumina feeding and dynamic control of the electrolysis operations.

![PFC Emission Reductions in the Aluminum Industry](image)

Finally, new materials and technologies (Inert anodes, wettable and/or drained cathodes) are being developed that will significantly reduce energy and carbon consumption and CO$_2$ emissions in the future, while minimising, neutralising and treating cathode waste.
1.2.6 Casting

See also:
- AAM – Materials – 2 Alloy constitution
- AAM – Materials – 3 Designation system

While aluminium is sometimes used in its commercially pure form, most applications involve the addition of small quantities of other metals to create alloys with special properties. Certain alloying elements will increase strength or corrosion resistance, while others enhance such properties as machinability, ductility, weldability and strength at high temperatures.

Alloying elements include manganese (strength and formability), magnesium and silicon (strength and corrosion resistance), copper and zinc (higher strength), titanium and chromium (grain size control), etc.

DC Casting Pit at Arvida Smelter, Québec, Canada
1.2.7 Casting of "Sows" and Ingots

Molten aluminium is cast into ingots of various shapes depending upon the type of equipment that will be used to process the metal. For example, ingots for rolling into plate, sheet and foil are typically rectangular and can weigh up to 30 tonnes or more. Aluminium ingots for extrusion are usually cylindrical, while those for rolling into rod/wire are square.

Aluminium for remelting can be cast into large blocks called sows, as well as tri-lock shapes or T-ingots designed for efficient and secure handling.

A large proportion of aluminium ingots (in particular for sheet and extrusion applications) are cast by the semi-continuous, vertical direct-chill casting process (DC Casting), where water is directly sprayed onto a solidifying ingot installed on a descending platten.

Overview of Metal Processing in a Smelter Casthouse
1.2.8 Continuous Casting and Shape Casting

See also:
- AAM – Manufacturing – 1 Casting methods

Continuous Casting (Strip Casting)
In continuous casting, molten metal is fed (usually horizontally) directly between rotating belts or rolls or in a rotating wheel to produce a continuous strip or bar of metal suitable for coiling or immediate rolling. This has the advantage of circumventing the need for large, expensive hot mill installations while reducing the number of processing steps. While these processes are well-established for the production of low-alloyed materials such as foil, heat exchanger material and electrical wire and cable, metallurgical issues with internal microstructure and surface quality have until now limited the application of these processes for more highly alloyed products such as automotive sheet. This is due in part to faster cooling rates during solidification (thinner cross-sections) and its impact on microstructure development through the extended "freezing range" (difference between liquidus and solidus) of highly alloyed products (see table).

Shape casting (Mould Casting)
Aluminium may also be cast into various shapes by pouring molten metal into moulds. This is usually performed directly at the automotive parts manufacturer.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Liquidus Temperature (°C)</th>
<th>Solidus Temperature (°C)</th>
<th>Freezing Range ( T_{\text{liquidus}} - T_{\text{solidus}} ) (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure Al</td>
<td>660</td>
<td>660</td>
<td>—</td>
</tr>
<tr>
<td>1050</td>
<td>659</td>
<td>638</td>
<td>21</td>
</tr>
<tr>
<td>3003</td>
<td>655</td>
<td>634</td>
<td>21</td>
</tr>
<tr>
<td>3004</td>
<td>652</td>
<td>583</td>
<td>69</td>
</tr>
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<td>5005</td>
<td>653</td>
<td>575</td>
<td>78</td>
</tr>
<tr>
<td>5182</td>
<td>632</td>
<td>470</td>
<td>162</td>
</tr>
<tr>
<td>6063</td>
<td>655</td>
<td>576</td>
<td>79</td>
</tr>
<tr>
<td>7075</td>
<td>630</td>
<td>470</td>
<td>160</td>
</tr>
</tbody>
</table>

Freezing / solidification temperature Range for Some Important Commercial Aluminium Alloys
1.2.9 Casting Process – Melt treatment

See also: AAM – Materials – 1 Resources > Secondary aluminium

Before the metal is cast, the appropriate alloying elements must be added. In primary smelters, this is normally done in a holding furnace in the casthouse. For many applications, the metal must also be treated ("cleaned") to remove a number of contaminants. These include:

- alkali metals (Na, Ca, Li) which can cause problems in hot rolling (edge cracking), or with surface discoloration ("blue corrosion"-Li)
- dissolved hydrogen, which will be released upon metal solidification and can cause porosities or blisters
- non-metallic inclusions (oxides, carbides, borides) which can lead to mechanical damage such as tear-offs in cans or marks on rolls.

While Na, Li and carbide contamination are typical of primary smelter environments, the processes used to clean and cast aluminium alloys are very similar in primary and secondary smelters. Furnace designs and scrap handling specific to the remelt/recycling environments are described in the next section ("Secondary").

Techniques used to remove unwanted contaminants include chemical reaction with chlorine-containing gases or salts injected into the liquid metal, floatation of non-wetted species with gas mixtures and filtration.

In a smelter, cleaning may start while the metal is en route for the pots to the holding furnace. Solid or gaseous fluxes can be injected with rotors in the transport crucible to start removing Na, Li and carbides coming from the reduction process. Inside the holding furnace, a gas mixture containing chlorine (Cl₂) and argon or nitrogen is typically injected with graphite lance to further remove alkali elements and start the floatation of non-metallic inclusions. Further processing is performed in-line with multi-stage rotor-based degassers (the figure shows a single stage unit), where most of the hydrogen removal is performed. Finally, a cartridge or deep-bed filter completes the removal of non-metallic inclusions.

This multi-prong approach is necessary as quality criteria for many critical products now require overall removal efficiencies exceeding 98%, with final concentrations of alkali elements, hydrogen and inclusions measured in fractions of parts-per-million.

Diagram of a Single Rotor In-Line Degasser / Metal Treatment Unit
1.3 Secondary aluminium

1.3.1 Scrap sources

Aluminium scrap can generally be divided into two main categories:

1. Old scrap. This is scrap from products that have reached the end of their useful life, e.g. ELV (end of life vehicles).
   This group can again be divided into two main categories.
   a) Immediate return products: products with an estimated lifetime <1 year, e.g. packaging and lithographic plate.
   b) Installed base: products with a longer lifetime than 1 year, e.g. passenger cars.

2. New scrap. This is scrap generated in the process steps from semi-finished product to the end-product fabrication, e.g. scrap from automotive part manufacturers.
   New scrap is normally recycled within the aluminium industry (1st scrap loop, s. fig.) or may enter into the open scrap market (2nd scrap loop).

Aluminium product and scrap flows
1.3.2 Refiners and Remelters

Refiners

Refiners take a broad variety of scrap in their furnaces and are the main recycler of post-consumer scrap and other scrap which may have contamination or uncertain composition. Consequently they need some purity tools or sweeteners\(^1\) and use a minor amount of primary ingot for cost reasons.

Due to the technology used and the scrap input mix, they also have higher metal loss rates. They produce SFA\(^2\), specification remelt ingots\(^3\) master alloys\(^4\) and deoxidisation products\(^5\). Aluminium scrap from End of Life Vehicles is mainly recycled at these locations today.

Remelters

Remelters use primary aluminium (remelt ingot or liquid metal) and scrap to produce ingot\(^6\) for wrought aluminium production. While historically using only their own process scrap, today some large scale remelters exist, which use a mix of scrap types in order to produce ingot for wrought metal at lowest possible cost.

Explanatory notes

\(^1\) Metal units which are mixed into the remelting process in order to decrease iron content or any other relevant element.

\(^2\) Secondary Foundry Alloys.

\(^3\) Scrap analysed by refiners and cast in ingot form with a specified chemistry, for further remelting.

\(^4\) Alloys for direct use in aluminium remelting, in order to adjust the chemical composition.

\(^5\) Used for deoxidation of steel; these products exit the recycling loop of aluminium.

\(^6\) Billet for extrusion, slab for sheet production.
1.3.3 Special recycling issues: Laquered / painted scrap – Skimmings and dross

Delaquering
In view of metal quality and for environmental reasons it is recommended to remove lacquer/paint before melting. Several methods exist or have been suggested for this purpose:
- Mechanical pre-treatment (shears, shredding, shot-blast)
- Chemical treatment (salt baths, solvents etc.)
- Biological pre-treatment (bacterial cultures)
- Thermal treatment

Recycling skimmings and dross
Melting aluminium may produce residues such as skimmings and dross. The amount generated varies largely with operating conditions; main drivers are the technology used and purity of the metal being remelted. The following are indicative weight estimates for skimmings/dross generated from aluminium remelting: primary smelters 1-2 %, remelters 3-4%, refiners 5-10% (very dependent from the input scrap quality) of total aluminium ingot output.
Skimmings and dross are always recycled for recovery of the aluminium contained, through a range of techniques. The metal content of skimmings is typically around 50%, while it stands lower in dross. Typical recovery of metallic Al from skimmings / dross is 50–70%. Most of the Al balance is recovered as aluminium oxide, which is re-used in ceramic or other applications.

Definition for skimmings and dross (from EN 12258-3)
Skimmings: material composed of intimately mixed aluminium and aluminium oxides which have been removed from the surface of the molten metal or from the bottom and walls of liquid metal containers, e.g. furnaces, transport ladles or transfer channels. According to OEA (the European secondary aluminium smelters organisation), the metal content of skimmings is 45% or more.
Dross: same material with lower metal content
1.3.4 Applications in automotive components

Today most shape cast products such as engine block, transmission parts and some non-load carrying high pressure die cast components are produced from secondary aluminium.

Production of wrought aluminium alloys for automotive parts from secondary aluminium is currently limited however, due to alloy compatibility issues with post-consumer scrap.

There is a potential for expanded use of secondary aluminium in the production of sheet alloys of the 3xxx-series (lid stock and tubes for heat exchangers, heat shields, panels).

For age hardenable alloys of the 6xxx-series, it is possible to use a minor amount in alloys used today (6009, 6016, 6060, 6062).

For both the 5xxx-series and the 7xxx-series, Si from post-consumer scrap put strong limitations on the use of secondary metal.

Increased use of secondary aluminium in wrought aluminium production will result from several actions:

- The development of economical processes for separating aluminium alloys in post-shredded scrap.
- Increased dismantling of specific aluminium parts from ELVs.
- Expand specification limits for alloy elements that are not affecting the properties of the end product and accept more composition dependent fabrication processes.
1.3.5 Use of secondary aluminium for wrought automotive products – compatibility issues

Production of wrought aluminium for automotive parts from secondary aluminium / Compatibility issues with post-consumer scrap

Sources for alloy compatibility issues with post consumer scrap:

- **Fe**: from attachment on aluminium and from stainless (non-magnetic) steel not removed in post-shredder processes.

- **Zn**: castings (incl. brass) and sheet not removed in post-shredder processes and from galvanised/clad aluminium.

- **Cu**: mainly tube and cable not removed in post-shredder processes.

- **Pb**, **Cr**, **Sn**, **Ni**: most important trace elements in ELV scrap that may exceed acceptance limits (0.05 wt% for most alloys).

It should be mentioned that actually the scrap mix of different aluminium alloys (incl. mix of different wrought alloys, castings and foreign metal impurities) is the current feedstock for the production of secondary casting alloys. In order to utilise part of this scrap for wrought alloy production, economical processes are being developed for alloy separation and foreign metal removal.
1.3.6 Benefits from aluminium recycling

Secondary aluminium has important characteristics related to recycling:

1. The inherent quality of aluminium is not affected by recycling and remains high irrespective of the number of recycling cycles.

2. Energy savings through recycling can amount to 95%, depending on the type of aluminium scrap, the respective recycling technology and particular fuel sources used.

3. There are a number of other environmental benefits from secondary Al production. The graph compares the raw material consumption, air emissions and solid waste generation for ingots produced from primary or secondary aluminium (corresponding values shown on 100% reference scale). For example, CO$_2$ equiv. savings of 94% can be made with secondary aluminium compared with primary metal production. Nevertheless, the production of aluminium from bauxite or from scrap via recycling should not be regarded as competing processes. They are both essential and integrated parts of the aluminium material cycle.
1.4 ELV recycling

1.4.1 End of Life Vehicles (ELV) – resource for automotive aluminium

See also:
- AAM – Design – Environment, Health and Safety > Recycling
- AAM – Design – Environment, Health and Safety > Recycling > Current contribution of recycling to aluminium supply
- AAM – Design – Environment, Health and Safety > Recycling > Future outlook for aluminium recycling

Resource:
The present European car fleet contains approx. **10 mio. tons of aluminium**, which are reclaimed at the vehicles' end of life with a recovery rate of up to **95%**.

Economy:
Aluminium in current ELV's represents only a small percentage of the total car weight, about **5%**, yet it **accounts for 35 to 50% of the scrap value of the ELV**.

Aluminium's high value and its ease of recycling are the reasons for its successful recovery from ELV's.

Perspectives:
Currently, ELV-recycled aluminium is only partially filling the demand for automotive aluminium.

The expected growth of recycled ELV material calls for optimised sorting techniques in recycling, for limitations in range of alloy and product varieties and for recycling-friendly design of future cars.

Reference scenarios
- Current contribution of recycling to aluminium supply.
- Future outlook for aluminium recycling.
1.4.2 Aluminium usage and recycled content in automotives

Literature:
- European Aluminium Association: Automotive Aluminium Recycling (Brochure)

Source: The Aluminium Association, Ducker

Source: EAA brochure 'Automotive Aluminium Recycling'
Automotive aluminium enjoys a well-deserved reputation for recyclability. Around 110 kg of aluminium is used on current North American and European vehicles. Today, virtually all of the aluminium in ELVs is recycled by an efficient and dedicated industry. The foundation for this success is twofold:

- The intrinsic value for aluminium recycling requires just 5% of the energy necessary to make primary metal.
- An established recovery and recycling infrastructure, based on sound economics, that continues to strive for improvement in metal recovery and cost efficiency.

The importance of recycling will continue to grow with growth in use of aluminium in automotive applications.
1.4.3 Recovery of aluminium – Car shredders

Literature:

The process by which aluminium is recovered begins with the scrap collection and dismantling yards. There are over 6000 in North America and over 16000 in Europe. Their main function is reuse of spare parts, although some aluminium is usually recovered for recycling in the form of powertrain components, wheels and radiators etc. The vehicle hulks are sold to car shredders (of which there are 200 in North America and over 200 in Europe) where the real process of materials separation begins.

Car shredders employ a series of processes to recover the various materials fractions from ELVs.

Figure: ELV car shredders reduce the vehicle to small pieces that can be separated using magnets, screens and air classifiers into various concentrates for subsequent processing.

Vehicle recovery system: car shredding

The vehicle hulk is fed into a shredder, a powerful hammer mill capable of breaking the vehicle hulk into pieces small enough to liberate individual materials. The co-mingled stream of metallic and non-metallic materials exiting the shredder is then separated into groups. Air classifiers are routinely used to separate the lighter fraction of the non-metallics such as paper plastic, foil and foam. Magnets are used to separate the iron and steel from the heavier non-magnetics which include non-metals and non-ferrous metals.

The non-magnetic product of magnetic separation is further processed using screening and eddy current separation to concentrate the metallic content.
**Figure:** Powerful magnets, usually installed in conveyor rotors, are used for high speed bulk separation of ferrous from non-magnetic materials

Magnetic separation of ferrous from non-ferrous materials
1.4.4 Separation and enrichment of aluminium scrap stream

Literature:

The next phase in aluminium recovery involves passing the nonmagnetic concentrate through a series of fluids of controlled density. The materials fractions lighter than each fluid float out and are separated from the heavier fraction. The majority of the aluminium is concentrated in a fraction also containing rocks and insulated wire, which will be separated further in the next processing stage.

Figure: Density separation of non-ferrous concentrates using heavy media or sink/float separation.

The final stage in the separation of aluminium utilises an eddy current separator to isolate aluminium from the rock and insulated wire. The separator functions on the principle that eddy currents are induced in an electrically conductive material passing through an alternating magnetic field. The eddy currents in turn generate repulsive forces that are related to the conductivity, density, shape and size of the material and can be used for separation. The magnetic fields are generated by electromagnets or strong permanent magnets in an array on the fast spinning rotor inside head pulley of a conveyor belt. The aluminium is forced away from the rotor, follows a different trajectory from the other materials, and is separated from the other materials by an adjustable knife.
Figure: Eddy current separator works by inducing eddy currents and hence repulsive forces in materials according to their density and conductivity.
1.4.5 ELV recycling – Future trends and use of recovered automotive aluminium

See also:
AAM – Design – 3 Environment, Health and Safety > Recycling > Future ELVs scrap supply and demand for standard grade casting alloys

Mixed scrap from current ELVs is currently used to make secondary foundry alloys for cast applications. The secondary alloys, particularly A380 (EN AC-46000 and -46200) which is used to make cast products for automotive and many other applications, are chemically compatible with most aluminium alloys, and magnesium levels in wrought alloy scrap can be removed relatively easily in the melting process. However, recycling scrap into the wrought alloys is much more difficult as they are governed by stricter chemical composition limits. The use of mixed aluminium alloy scrap into secondary foundry alloys is an acceptable practice as long as the demand for castings using these alloys exceeds the supply of scrap alloys.

Figure: Significant wrought alloy growth is forecast in both North America and European markets. While the ELV scrap arising from this may be used into secondary castings applications, it poses an opportunity for scrap separation or melt purification of alloys.

Trends in growth of wrought and cast aluminium in European automotive applications.

With the expected growth of aluminium applications in cars, also the amount of aluminium scrap recovered from ELV will grow significantly. Studies in Europe have indicated that in 2015 only under a conservative scenario where all aluminium from ELVs would be recycled in Europe, the total amount of recovered aluminium would rise to 1.6 million tons. This is still below the needs of the total secondary aluminium production, but already in the range of the aluminium casting applications in newly produced automobiles. Some scrap could then possibly be in excess of the scrap need for recycling in automotive standard casting applications. A similar scenario is forecast for North America. This situation would lead to an opportunity for the development of scrap alloy separation or melt purification.
Figure: Significant wrought alloy growth is forecast in both North America and European markets. While the ELV scrap arising from this may be used into secondary castings applications, it poses an opportunity for scrap separation or melt purification of alloys.

Trends in growth rates for wrought and cast aluminium in North American automotive applications
1.4.6 Alloy sorting options for ELVs

Literature:

- Shultz, P. B., Wyss, R. K.: Chemical treatment of aluminum alloys to enable alloy separation: US patent 6100487, August 8 2000, assigned to Aluminum company of America

There are several potential solutions for dealing with the separation or purification of mixed automotive alloy scrap. Melt refining is one option that is being considered but a simpler approach is to physically separate the various aluminium alloys during the recovery process. This may be accomplished by ELV dismantling or post shredder sorting. Dismantling has potential for recovery of a percentage of the alloys, but is labour intensive and not considered to be commercially viable for smaller, difficult to remove parts. Sorting offers a more comprehensive capability but until recently the technology has not been available. A practical solution would take advantage of both approaches as shown in the figure.

Figure: A concept for recovering aluminium by alloy type from ELVs using a combination of dismantling and alloy sorting.

Analysis of recycling of ELV aluminium

The US Aluminium Association in North America is collaborating with the North American automakers and Huron Valley Steel Corporation (HVSC), a leading North American and international non-ferrous materials processor, to demonstrate HVSC technology for automated bulk sorting aluminium of alloys from shredded ELVs. Two techniques are being evaluated, one based on colour sorting following a chemical etch, a concept developed by Alcoa, the other based on optical emission spectroscopy using lasers. A concept that has been worked on by several companies, notably Metallgesellschaft and Alcan, but more recently has been developed into a commercially viable opportunity by HVSC. Both
Techniques rely on HVSC proprietary sorting equipment that is linked to the identification process.

**Figure**: Automated sorting comprises an identification/analysis station where the colour or chemistry of the scrap is determined. This is coupled with proprietary technology for accomplishing the physical sorting by alloy type.
1.4.7 Laser induced breakdown spectroscopy for alloy sorting

Literature:

Whereas the colour sorting technique is capable of differentiating alloy families (as the colour is a direct consequence of the alloying ingredients), the laser spectroscopic technique produces a full elemental spectrum of the composition allowing identification of individual alloys (see figure). Furthermore, the technique is compatible with a sorting algorithm that allows a target composition to be developed by blending many different alloys. The automated sorting techniques identified have already demonstrated capability on a pilot scale, and are compatible with commercial equipment installations in Europe as well as North America. Thus the prospects are excellent for a near term practical solution for sorting mixed alloys into usable wrought alloy products.
Tramp element pick-up, particularly of iron and silicon, will need to be controlled by the separation processes. Design of alloys with increased tolerance to these and other elements will help to optimize the recycle loop.