Roadmap
From Europe and North America

Workshop on Aluminium Recycling

13th-15th June, 2010
Trondheim, Norway

Collection of scrap

Sorting of aluminium scrap

Decoating and melting

Refining of melted recycled aluminium

Treatment dross & salt cake

Using recycled Al scrap

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Introduction

This Aluminium Recycling Roadmap represents the combined efforts of 35 invited aluminium experts from Europe and North America who met in Trondheim, Norway, organised by SINTEF/NTNU and chaired by Anne Kvithyld of SINTEF, during 13th-15th June, 2010. The Research Council of Norway, NTNU and SINTEF sponsored the meeting. The Roadmap is intended to focus the interests of all key stakeholders, especially industrial and academic researchers, regarding the current status and technology needs of the recycling of aluminium.

With the emphasis of industry and many national governments on increasing energy efficiency and decreasing emission of green house gases, the topic of aluminium sustainability has received much deserved attention recently. For example, the International Aluminium Institute (www.world-aluminium. org) currently monitors a series of sustainability goals on a global basis. In its Technology Roadmap (publ. Feb. 2003), [The aluminium association, 2003] in the United States, the Aluminium Association has set a goal of 100% recycling by 2020. The European Aluminium Association is also active in increasing the overall aluminium recycling rates and awareness. Recycling represents a critical component in the sustainability of aluminium. Recycling can be repeated with a very low loss of metal quantity and quality.

Recycling of aluminium is vital because it saves ~95% of the energy and associated emissions compared to producing the metal from the ore. Also it provides metal, saves capital expenditures (melters are much less costly than primary smelters), and reduces landfill space requirements and fees.

This Roadmap is timely for at least three reasons:

- With fuel costs rising, transportation-manufacturing companies are seeking economic ways to improve the gas mileage of their products, in response to mandates from national governments. This has resulted in the increasing use of light metals, especially aluminium. To increase the range for electric cars between charging, aluminium is essential since range is inversely proportional to vehicle weight.

- A second reason is governmental policies demanding recycling. The EU Government has mandated that all vehicles must be 95% recyclable by the year 2015. [Waste Watch, 2011] As aluminium recycling is a well-established process, this will encourage aluminium use and the adoption of recycling also of other metals and materials. The use of aluminium has greatly increased in recent years, and now the aluminium recycled from automobiles well exceeds that from packaging.

This Roadmap has given a "birds-eye view" of aluminium recycling covering important details. We hope that the Roadmap will serve as a guide for future solutions in aluminium recycling.

- Thirdly, a higher recycling rate of aluminium will enhance the sustainability and public image of the global aluminium industry. The use of aluminium is essential to support environmentally friendly solutions. In the production of renewable energy, aluminium is used as support systems for solar panels.

For all these reasons, this latest international roadmap is timely. The roadmap is organized to address all major aspects of the recycling process chain: Scrap Collection, Automated Sorting Technology, Decoating of Scrap, Melting and Refining Technology, Use of Recycled Aluminium, and Dross Handling and Minimization.

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1. Collection of scrap

Current state- of- the- art

Immense quantities of scrap flow through the global aluminium economy. Using the numbers from International Aluminium Institute (IAI) on the global aluminium flow from 2007 and categorising scrap after it has been to an end consumer:

New scrap:

30.4 million tonnes (MT) of new Al scrap were produced in 2008 [International Aluminium Institute, 2009] as:

- Metal in skimmings, white and black dross
- Ingots, scalping chips
- Edge and end trim
- Casting mould and die trim
- Stamping edge and skeleton trim
- Borings and turnings

Most of this was maintained as segregated alloys, the majority of which (20 MT) was internally remelted by semi-producers without reaching the scrap market.

Post-consumer scrap:

There is no such thing as a dedicated post-consumer Al scrap collection and processing system. Discarded end-of-life assemblies are collected in a number of recyclable collection systems that vary significantly. Post-consumer scrap/waste streams are: garbage, solid waste/recycling deposits, curbside collected recyclables, returns-for-deposit, end-of-life vehicles, scrap yards, building demolition residue and waste electrical and electronic equipment. Millions of households in hundreds of thousands villages and municipalities collect recyclables and feed tens of thousands of junk/scrap yards, de-pollution and recycling depots and transfer stations. These, in turn, deliver to thousands of material recovery facilities that group the recyclables and sell the grouped products either directly to scrap processors or to shredders.

In 2008 around 9.9 MT of post-consumer scrap was recycled. By far the largest sources are transportation (3 MT) and packaging (2 MT) (see Figure 1).

However 4.1 MT were either incinerated with/without energy recovery or were landfilled in municipal garbage. Some of this loss is accounted for by uncollected beverage cans and foil containers missed by the curbside or by depot collection systems; but a larger fraction are the aluminium components of consumer durable products that are not accepted in the current curbside collection systems.

Also 2.7 MT aluminium scrap could not be accounted for either due to the uncertainty in the lifetimes of durable products, or due to metal losses in the landfilled scrap processing residue. [IAI, 2009]

The IAI model numbers also imply that the losses in the collection portion of the recycling cycle of 4.1 (+2.7?) MT are significantly higher than the metal losses in scrap processing remelting and refining which total 1.7 MT. Clearly focus on improved collection is important for the overall efficiency of the aluminium recycling system.

Recycling rates of the post consumed scrap vary considerably by product, and location as discussed below:

Packaging
- In the US, and many Western European countries, the recycling rate for aluminium cans is around 50% or less. [International Aluminium Institute, 2009] p.23
- Developing countries (such as Brazil, India and China) along with Scandinavian countries (such as Norway), Switzerland, Europe and Japan have higher recycling rates of aluminium cans exceeding 90%. The higher recycling rate in the developing countries such as Brazil is due to the economic incentive of collectioning "cash cows", whereas the higher recycling rates in Norway, Sweden , Switzerland and Japan are due to high sustainability consciousness and an abundance of convenient recycling infrastructure.

Transportation
- The collection rate for aluminium from automobiles is >90% [Green, 2008]

- Used and abandoned airplanes are stockpiled in the desert such as in Tucson, Arizona, USA. There are few dedicated recyclers, and contamination is an issue especially with non-mixable aluminium alloys.
- Newer aircraft have more composites and titanium contents. Dismantling and separation is difficult at the end of useful life. However, reuse of parts and recycling is possible and can be profitable.

Construction and Demolition
- The collection rates of aluminium in this sector were found to vary between 92% and 98% [Udo Boin, 2004]. There is a clear division between northern and southern Europe probably due to climate differences. Southern Europe has more Al in residential areas 600 g/ton in southern, 35 g/ton in northern.
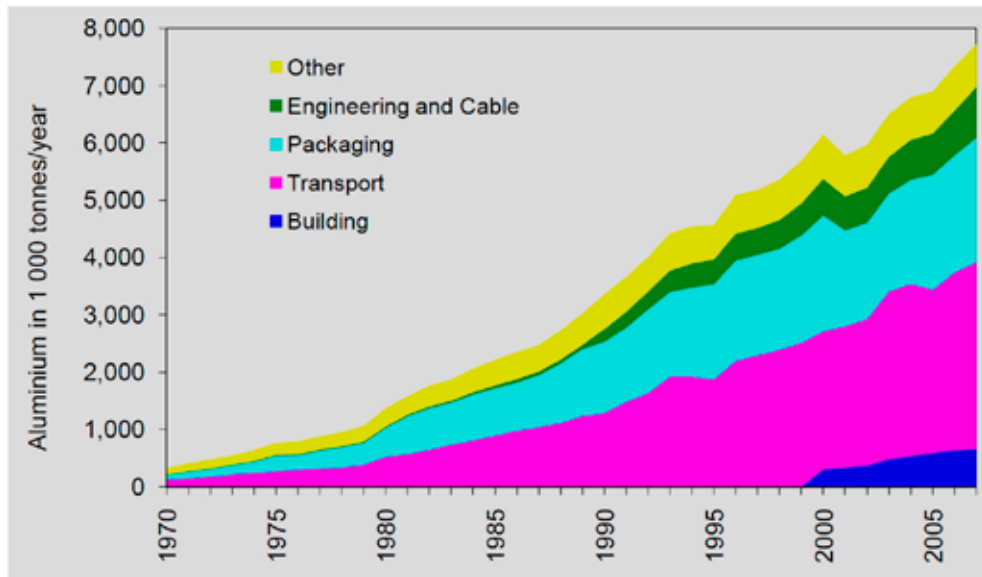
Figure 1: Global sources of recycled old aluminium scrap

In the building and construction category minimal new efforts are required. Separate sheet products (mostly 5XXX) from extruded (6XXX) products. Aluminium separation should take place before dismantling and before mixing scrapped building materials with other materials, as the aluminium is a small part of the scrap and can easily get lost.

- Give guidelines and regulations for dismantling buildings to ease recovery.
- Develop and implement a fast sorting process during demolition. Encourage architects to regard Al as green and viable. Develop concepts that encourage recycling.

Bottlenecks

- Convenience and social awareness is the largest factor influencing aluminium collection for recycling. The lack of convenience, especially away from home and lack of dedicated office and public places, creates a significant impediment.
- It is harder for smaller communities to recycle, larger cities have available funds.
- Deposits are shown to work, but, historically, there are vested interests that have resisted the institution of deposits.

Goals for collection of scrap:

1. Increased collection of aluminium packaging including used bev. can and aluminium components of consumer durables: in 5 years >75%+ (ultimate goal >90% +) collected worldwide.
2. Improved collection infrastructure
3. Closing gap on unknown losses
4. Recycling education for consumers

5. Address problem of stockpiled aircrafts
6. Learn from high recycling rate countries (Brazil, Norway , Sweden, Switzerland and Japan) and implement these best practices in low recycling areas such as North America and Western Europe.
7. Make sure regulatory metrics support recycling
8. Develop methods for identification and separation of Al-Cu, Al-Zn, and Al-Li alloys from end-of-life Al aircraft alloy scrap.

Collection infrastructure
Develop infrastructure for collection. Make it easier and convenient.
- Charitable organizations collecting
- Collection near homes, offices and commercial buildings
- Assess incentive methods
- Government regulations
    Regulation -deposit laws, mandatory recycling.
    Regulations should be the last step, as they can sometimes inhibit, rather than help.

Closing gap on unknown losses
The goal is to expand the existing IAI global Al flow model to better account for recycling loops and the interrelation with the recycling system for the non-Al components of the end-of-life assemblies. The goal is to develop an accurate research, technical and economic material flow model. Cooperate with industry in development and financing.
Validate data, quantify impact of life cycle, and differences by country, and include losses of unrecoverable Al.

Some data are confidential. A good way to update the model would be to sample input to landfills and incinerators to find out what is thrown away. Include data for unrecoverable aluminium.
- Define, consolidate and agree on one universally accepted recycling rate . There are over 5 different ways to calculate the recycling rate now (from EAO Organisation of European Aluminium Refiners and Remelters).

Recycling education for costumers
- Convince the public that recycling is a meaningful and sustainable action.
- Convey that each discarded aluminium can means the addition of 300 grams of carbon dioxide, leading towards climate change and global warming.
- Provide specific information of recycling actions required of the consumer: what can be recycled, where and how.

Development of recycle–friendly aluminium alloys
Prime based alloys with low alloying element content have more use options than recycled secondary alloys. Prime based binary alloys with high content of one alloying element, can be used to add that element into a variety of alloys. In this sense prime based alloys are more recyclable than secondary alloys since, in addition to closed-loop recycling they can be used to batch a wide variety of secondary alloys. Secondary alloy post consumer scrap has limited alloy options.

Alloys should not be designed to accept most post-consumer scrap. They should be designed as much as possible within the existing alloy families, for optimum forming and mechanical and functional properties. In this way the component weight can be minimized which in proper product lifecycle accounting is the dominant consideration. We will use less energy to produce the component, consume less energy using it and will have in the end less metal to recycle - a win-win-win proposition.

Design for recycling
- Keep the number of alloys to a minimum.
- Design assemblies for easy liberation of compatible alloy parts on shredding.
- Focus on processing and product properties instead of alloy chemistry; this is a strategy to avoid limitations by very tight chemical composition windows which is the situation today.

In permanently bonded structures where mono-material particle liberation is not possible, alloy compatibility considerations are important. In welded assembles, one of the joined alloys should be able to accept both the weld alloy and the other alloy. Co-cast or roll bonded sheet average composition needs to be composition compatible with one of the bonded sheet alloys. A uni-alloy could be useful for beverage can recycle business.

General actions
- Consider "urban mining" of rich landfills with high concentrations of aluminium and other metals.

2. Sorting of aluminium scrap

Current state-of-the-art

Sorting of scrap is all about making judiciously selected separations. Table I lists the separation types key to recycling of aluminium and the methods used to accomplish these separations.

Table I: Key separations and methods for recycling of aluminium

Desired separation	Separation method [**]
Metal - non-metal	
Steel from non-metal + non-magnetic metal	Drum magnet, overbelt magnet
Nonmagnetic metal from non-metal	Screen, air elutriator, eddy current rotor, eddy current coil sensor
Metal from non-metal fines (<9mm)	Jig, eddy current rotor
Non-metal or other metal contaminants from A1	Magnetic headpulley, eddy current rotor, hand sort
Al - other metal	
Light from dense NF metals	Sink-float (wet or dry), eddy current rotor
Mg from Al	hand sorting, colour sensor, XRT sensor
Other metal contaminants from Al	
Al - A1	
Al with attachments from liberated Al	Hand sorting, XRT sensor
Bare from painted or dirty Al	Hand sorting, colour sensor
Alloy grouping & Al by alloy	LIBS sensor, XRF sensor
Particle-by-particle target alloy batching	LIBS sensor, XRF sensor
Average particle stream elemental composition measurement	LIBS sensor, XRF sensor, PGNAA sensor

[**] LIBS = Laser–Induced Breakdown Spectroscopy; XRF = X-Ray Fluorescence; XRT = X-Ray Transmission; PGNAA = Prompt Gamma Neutron Activation Analysis

Bulk separations

In bulk separations, the method itself provides the force that separates the particles based on a physical characteristic such as density, shape, magnetic susceptibility, electrical conductivity, etc.

- Water slurries or air particle suspensions provide dense media for sink-float separations.

- Partial fluidization of a water-filled (or a heavy media) particle bed drives density separation of small particles in a jig.

- Air streams entrain high–aspect ratio, low–density particles in air knives or in elutriators.

- Screens, cyclone separators and bag-houses separate and collect fines and dust.

- Magnets separate the ferromagnetic particles, both steel and rust.

- Eddy current rotors generate repulsive forces in electrically conducting non-magnetic particles.

These bulk separation technologies are low cost, mature, and can separate light metals from mixed shredded scrap.

Particle sorting
People-based visual inspection and hand sorting is used to group recyclables during post-consumer waste collection in most material recovery facilities In Asia, it is used to sort particles of post-consumer Zorba (trade jargon for shredded nonmagnetic metals) and Twitch (trade jargon for shredded mix-alloy Al). Particles are separated by shape, surface coating or texture, attachments, colour and heft. Inspectors can separate old scrap by each parent metal, and, in the case of Al, can group sheet, extrusions, castings, wire and radiators. These Al groupings may give certain flexibility to batching of secondary alloys. However, the typical alloy mixtures in these hand sorted categories still confine their use to foundry alloy compositions, hence the value added by the sort is small.

Mechanized, sensor-based sorters expand the particle identification capability, and enable profitable particle-by-particle separation in the higher wage economies of North America and the European Union. Particle sorters equipped with eddy current coil, colour or XRT sensors have their applications in finding residual metals, separating parent metals and eliminating particles with attachments at shredders and downstream at the nonmagnetic scrap metal processors.

To better manage the alloying elements among the light metal alloys, an elemental concentration sensor combined with a mechanized particle sorter is necessary. LIBS and XRF sensors are competing for the elemental concentration sensor market. For light-metal alloy applications, LIBS has the edge since it can detect light element signals (including Li, Mg, Al and Si) from a distance, whereas XRF is dependent on signals from transition and higher atomic number elements. These elemental concentration sensors have a capability of sorting simple mixtures of fabrication scrap by alloy and/or particle-by-particle, batching target alloy composition from complex mixture of alloys found in post consumer scrap.

Problems, challenges and opportunities

- Residual Fe and other metals
- Paint removal
- Incomplete aluminium recovery
- Mg alloy contamination and Al losses in old Al scrap
- Mainly human sorting
- Improper and insufficient sorting and separation of scrap, can significantly reduce metal recovery rate and downgrade the product alloy.

Goals for sorting of scrap

1. Sort out components, metals and alloys while dismantling cars
2. Implement globally mechanical separation of Al from non-magnetic steel and other metals
3. Improve removal of iron, other metal attachments, and non-metallic contaminants
4. Produce clean Al product cost effectively with high productivity and recovery rate
5. Recover Mg rich stream
6. Replace hand sorting of non-ferrous metal scrap with sensor based particle sorters
7. Separate mixed-alloy Al scrap to batch higher value alloys

General actions

- Al industry should participate in the development and implementation of the scrap sorting technology and processes, by investing in scrap sorting plants that allow them to purchase lower cost scrap early in the recycling loop and to separate and up-cycle this low-grade scrap to the Al alloy specifications of their own products.
- Al industry should specify low Mg-based alloy content for shredded post consumer scrap (Twitch) to encourage removal of Mg alloy particles from the scrap Al shred. This would promote recycling of Mg and would reduce costs and losses in the Al recycling system associated with chlorination of Mg out of the Al melt.

3. Decoating and melting

Current state-of-the-art
Scrap pre-cleaning and decoating is the key determinant of the metal loss, impurity pickup and the product melt quality. Melting is essential in aluminium recycling. Remelting is the most energy intensive operation in the Al recycling process. The theoretical energy requirement to heat and melt solid Al from 20°C - 720°C is 316 kWh/t.

Refiners and remelters
Two major production chains are noted in the aluminium recycling; refiners and remelters. A refiner is a producer of casting alloys and aluminium for deoxidation of steel from scrap of various composition. Refiners are able to add alloying elements and remove some unwanted elements after the melting process. A remelter is a producer of wrought alloys, usually in the form of extrusion billets and rolling ingots from mainly clean and sorted wrought alloy scrap. Especially in the US, but also in Europe, both remelters and refiners, transfer molten metal to outside customers rather than create a finished product. There is also a large market in recycled secondary ingot which is sold to the end users.

Melting technologies
In refiners to protect the surface of aluminium against attack of the furnace atmosphere, the batch charged to the furnace is covered by salt. The additive also collects the non organic contaminations charged to the furnace. The salt slag discharged from the furnace requires further treatment (please refer to Section 5) Within the U.S. recovery of slag is not econonomical.

Energy is provided to the furnaces by combustion of gas or oil or in the case of induction furnaces by electrical energy. If economical oxy-fuel burners are used, particularly with reverberatory or multichambered furnaces, the heat of waste gases normally released to the atmosphere is recovered

Modern re-melting plants have the following furnace equipment:
- Reverberatory furnaces as casting furnaces and melting furnaces for clean scrap with small specific surface area.
- Rotary drum salt furnaces for salt application to process contaminated scrap with large specific surface area.
- Twin chamber furnace for scrap contaminated with organics only.

The stationary rotary drum furnace is gradually being replaced by the tiltable rotary drum furnace due to the more favorable operating parameters of this type of furnace. For some applications dry hearth furnaces and induction furnace are also in operation.

Some data are listed in the Table II below.

Table II: Furnace types:

| | Rotary furnaces | | Reverb Furnaces | Reverb Furnaces with side bay | Reverb Furnaces with dry hearths | Multi-chamber furnace |
	Salt Process Stationary Rotary Drum Furnace	Salt Process Tiltable Rotary Drum Furnace				
Organics	< 10%	<10%	<3%	<3%	<1%	<5 %
Non Al content	up to 60%	up to 60%	<3%	<3%	<25%	<3%
Salt factor*	1-2	<0.5				
Metal Yield**	75-95%	80 - 95%	85 – 95%	85-98%***	50 - 80%	80-98
Capacity	10-60 t/cycle	10-25 t/cycle	30-135t	2-5t/h 30-135t	2-5 t/h 5-100t	2-5t/h 30-100t
Energy required****	600-1400 kWh/t	450-800kWh/t	850-1750		850-1750	750-1000

*The salt factor shown in the table gives the ratio between the non-aluminium content of the scrap and the quantity of salt required.
** Metal yield, is the ratio of metal recovered to metal charged. The recovery is the ratio of metal obtained to scrap charged. One usually does not know the metal content of the scrap processed. The metal yield numbers will therefore be estimates
** * for submerged melted scrap, e.g. chips, metal yield is up to 100 %
**** The energy consumption listed in the table is the required input of the total furnace load. Relating this figure to the aluminium melted may give a very different value depending on the quantity of contamination of the scrap that needs to be heated to the melting temperature of aluminium as well.

Collected scrap is contaminated by various materials. The scrap contains oxides, tramp metal, built in parts of iron or other non aluminium alloys such as bolts, piston rings, bushings etc., sand, plastic and also water. Together with aluminium these additions consume energy and may also lead to some additional metal loss and environmental problems. It is an advantage for the melting plant to remove the unwanted components of the scrap prior to melting. This is referred to in section 2. A special case is dross. Even at a comparatively low content of aluminium, processing is mostly economical since dross contains valuable metal especially if supplied by primary smelters. However, dross results in metal loss, and its generation should be kept as low as possible. Please refer also to section 5.

Part of the aluminium scrap is often wet, oily, chemically surface treated, anodized, coated, laminated or adhesively bonded.

Delaquering/decoating

To address the challenge of organic coatings, some re-melting plants have invested in delaquering / decoating units. The types of delaquering systems can be divided into rotary kiln and belt conveyors, with various flow systems, direct or indirect fired. Some of the problems industry has experienced with the existing units are: variable scrap quality, sensitivity to scrap feeding rates, sensitivity to varying moisture content, non selective retention time, high oxidation losses, process emissions problems, fires in exit gas and complexity to operate. The additional processing cost has to be paid for by the cost and recovery difference between clean and coated scrap.

Dedicated cleaning for most scrap is favourable as surface contaminants may also cause oxidation on melting, produce dross, contaminate the melt, and may prevent accurate sensor identification when sorting. The best decoating, pre-cleaning and submergence melting practices give additional metal recoveries even for thin wall, heavily painted scrap like UBC. Thermal decoating also improves safety, has lower emissions and improves energy efficiency. Thermal decoating in a closed system allows for suitable cleaning of the evolved gases and reuse of the paint combustion energy.

Problems , challenges and opportunities

- How many stages are required to handle decoating and melting: accept contaminated scrap, burn off organics, use no salt. A two stage process will allow control of the exothermic reaction between coatings and air.
- The market is the driver in global scrap flow. The number of alloys is increasing, so scrap quality is a problem. The recyclers are limited in the use of contaminated scrap by technology as well as by legal constraints. Beneficiation of scrap before melting should be considered. (Refer to Section 2).
- Predict metal quality based on scrap quality using mass balance and kinetic models.

Goals for decoating and melting

1. Remove contamination and clean the aluminium scrap, for instance remove iron containing components and decoated materials.
2. Reduce energy losses (and thereby CO_2 emissions). Achieve better than 50% energy efficient when compared with the theoretical value to melt aluminium.
3. Preheat the aluminium. Utilize the energy in the organics.
4. Replace burners with better ones, optimise between oxidation and melting capacity .
5. Improve oxy-fuel burners and design furnaces with dual heating systems (electric and fuel heating). Monitor temperature and off-gases.
6. Improve furnace design with regard to heat exchange and environmental protection.

7. Develop and apply better monitoring and control systems. Measure the temperature etc. in-line, and adjust while processing.

8. Implement best practices for charging and the operation of the furnace.

9. Develop a robust pre-processing step

10. Process scrap of higher organic content

11. Lower dross formation. Monitor and avoid "break-away" oxidation. Oxidation increases over time, and in particular for Mg alloys.

12. Improve and standardise skimming routines.

13. Reclaim aluminium trapped in the dross that is skimmed off by cooling down in closed units. (section 5)

General actions

- Develop cost models.
- Develop and apply mass and temperature models to give higher efficiencies.
- Analyze decoupled system vs. connected process, also regarding flexibility.
- Communicate research results and industrial problems to find best furnace solutions. Cooperation should be easier to attain in problems regarding the environment.
- Study possibilities of processing more types of scrap

4. Refining of melted recycled aluminium

Current state-of-the-art

The treatment (refining) of molten aluminium is currently restricted to the removal of alkali/alkaline earths, hydrogen and non-metallic inclusions. Techniques for removing these are industrially mature and further developments should address efficiency, cost and environmental impact. On the other hand, refining in the sense of the removal of other undesirable/tramp elements such as iron, copper, silicon or zinc from molten aluminium present a considerable technical challenge and is unlikely to be economically viable unless the price differential between prime metal and secondary alloys widens significantly.

Current technologies for alkali/alkaline earth removal involve treatment with reactive halides either in gaseous form (e.g. chlorine) or as salts ($MgCl_2$, AlF_3, K_2SiF_6 etc.). In addition to removing the targeted elements (Li, Na, Ca or Mg) these treatments also generally promote the removal of non-metallic inclusions by dewetting/flotation. There are also a number of processes for the removal of inclusions including decantation/settling, filtration and flotation. Processes based on centrifugal or MHD forces have also been proposed but are not yet fully developed. Some of the widely used technologies are listed below.

- Deep Bed Filters(DBF) are used for removal of solid and liquid inclusions. DBF have shown to remove more than 95% of all particles larger than 20μm, and practically all larger than 50 – 60μm. The standard filter works satisfactorily for metal volumes exceeding 2000 metric tonnes. The disadvantage is the large metal volume in the filter box, and the long time it takes to change in the alloy.
- Ceramic Foam Filters (CFF) are much smaller filter units which have to be replaced for every cast. The filtration efficiency can be very high, and even better than for the DBF, although even small amounts of inclusions will block the filter.
- Porous Tube Filters (PTF) are also used for the removal of solid and liquid inclusions and generally offer superior performance to DBF's albeit at the cost of significantly reduced throughput.
- Flotation reactors are used for removal of hydrogen. In combination with salt or chlorine they can also remove inclusions. The inclusions are transported by the bubbles to the top surface, walls, or bottom.
- Treatment in the casting furnace (or introduction of treatment gas) using either lances with and without rotor or porous plugs in the furnace bottom.

Reliable measurement techniques are of course essential for both process control and development. Optical emission spectrometry is universally used as an off-line technique to measure the composition of the various elements present in the melt.

There are on-going attempts to adapt the technique for on-line analysis. Techniques for hydrogen analysis both on-line (Alscan, ALSPEK- H) and off-line (LECO, Reduced Pressure Test (RPT)) exist. There are several techniques to monitor inclusions including LiMCA, PoDFA/Prefil Footprinter /Lais. The actual volume of molten metal examined in each of these techniques is relatively small (16 grams in the case of a LiMCA reading, ~2 grams (effective) in the case of PoDFA/Prefil/Lais. A technique that would allow the examination of a large volume of molten metal would be a welcome development.

Priority should be directed towards the development of technologies that reduce the environmental impact (e.g. chlorine-free metal treatment or reduced landfill). Although improved methods of separation by metal/alloy family prior to melting are likely to be more cost effective than liquid metal refining for the foreseeable future, long term investigations into methods of selectively removing contaminants such as Fe, Cu, Si etc. from molten aluminium should be undertaken. Efforts to either remove or neutralize the effects of specific contaminants should be developed. A better knowledge of the impact of trace metals would be of benefit. Elements of current concern include selenium, phosphorous, bismuth, as well as the more widely recognized toxic metals (Hg, As, Cd) These elements pose significant health risks to employees or end product users, and are extremely detrimental in general use.

Problems, challenges and opportunities
- The possible presence of large inclusions (approximately ≥ 50µm) is a problem. Too much emphasis has been placed on removing inclusions smaller than the intermetallic phases present in most alloys.
- There is not a clear correlation between measurement techniques (LiMCA/PoDFA) and product performance.
- The use of chlorine should be discouraged. It is toxic in the plant environment and is a problem in transport to the plant.
- Entrapped oxide films are a problem.
- There is limited knowledge of the effects and fate of many trace elements in Aluminium; Pb, Se, Cd, Bi, Sb, RE etc.

Goals for refining of melted recycled aluminium
1. Implement chlorine-free melt treatment
2. Reduce harmful impurities in solid waste
3. Reduce energy consumption
4. Improve filtration focused on the removal of large harmful particles
5. Improve (larger sample volume) test to measure entrapped oxides inclusions
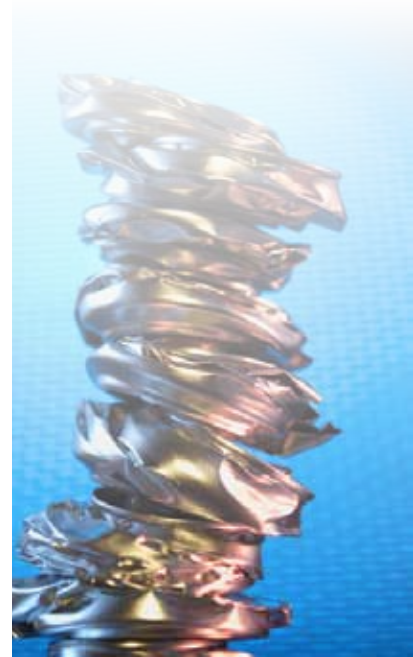
6. Develop better knowledge of trace elements effects
7. Remove harmful elements

General actions

Environmental considerations are going to dominate developments in the near term with the focus being on reducing landfill disposal and the use of hazardous substances.

The group recommends a special focused thinking on chlorine-free metal treatment and a rethinking of filtration in terms of reducing solid waste. A better understanding of the effects of impurity elements should be developed along with a longer term effort to develop methods for their selective removal.

5. Treatment of dross & salt cake

Current state of the art

Dross is a mixture of aluminium and it oxides and Non Metallic Components (NMC). Dross is generated on the surface of molten aluminium by contact with oxygen during melting, holding, refining and transfer. Salt cake is a by-product of aluminium recycling; such as from dross processing. The composition is dependent on the source materials and recycling practice. It consists of aluminium metal (4-8%), salt (25-45%) and NMC (50-70%).

Submergence melting dry decoated scrap in the industry gives high melt recovery, while melting of scrap bales without any preparation often leads to lower melt recoveries.

Procedures:

Dross processing

Prior to being remelted in rotary furnaces with the addition of salt, the Al metal content of dross is often up-graded. This is achieved by crushing and screening the dross and/or by eddy current separation. The product is a metal concentrate and a dust-like residue, which contains metal inclusions and oxides too small to be separated by affordable means. There are no reliable figures on the quantity of metal lost in dross. Model calculations of the European recycling aluminium industry carried out in 2006 indicate that about 8-9 % of the total recycling metal production is generated as dross. This number refers to the combined production of refiners and remelters, at that time about 6.7 million t/y. US geological survey data for 2006 reports over 600 kt of metal recovered from dross and skimmings. It is estimated that the US residue consists of more than 1,500 kt of non-metallics per year containing up to 30 kt of metal from slag processing.

Aluminium scrap with high contents of oxide/NMC is usually melted in rotary furnaces (with fixed axle or tiltable) under a liquid layer of fluxes (NaCl + KCl + fluorides), which provide a highly efficient separation of metal and NMC. NMC are completely absorbed by the liquid flux and forms after tapping and cooling the so-called salt slag or salt cake. In Europe about 1.4 MT of salt slag might be generated every year and the predominant part is processed in salt slag recycling plants. There the salt content and the metal inclusions are recovered and returned to the refiners for re-use. The NMC-content of the slag is separated and sold as an additive to the cement or ceramic industry. In Europe salt slag is categorized as hazardous waste and therefore largely processed. By the combination of scrap melting with dross and salt slag processing the aluminium cycle is closed. Meanwhile in the US salt cake is not considered a hazardous waste. Most salt cake is processed for the removal of entrapped aluminium. The remaining material is then sent to landfill.

Problems, challenges and opportunities

- Entrapment of liquid metal in dross skimmings (> 70 % metal content) is a problem.
  Hot dross is often not cooled in closed containers, resulting in metal oxidation (irreversible metal loss) In the US regulations: salt slag is not considered hazardous, therefore there is currently no closed loop processing, just metal recovery by dry screening. In the EU regulations salt slag is considered hazardous. It is wet processed.

- Recover salt

- Develop market for NMC

- Environmental hazards of salt cake are:

  - It is reactive in the presence of water or even moisture

  - Noxious gases can be produced such as PH3, H2S and NH3

  - Also there may be inflammable gases like H2 and CH4. Chloride and fluoride may leach from landfill.

Goals for treatment of dross & salt cake

1. Minimize the generation of dross through adoption of best available scrap preparation and melting methods.

2. Protect all hot skim and dross against air

3. In the US: All salt slags are dry processed to recover Al metal content. Encourage responsible landfill of resulting residue.

4. In the EU: Decrease salt input to minimize slag volume in EU.

5. Design and commercialize recycle-friendly lean aluminium alloys to minimize dross formation. Use less magnesium in packaging alloys and minimize lithium, copper and zinc usage in aerospace alloys.

6. Commercialize globally an adaptable version of European dross processing technology to minimize landfill disposal and the attendant problems.

General actions

Hot dross must be protected against oxidation of its valuable metal content. Efficient protection can be achieved by using sealed dross boxes for hot skims or through other techniques. Oxidiced aluminium is irreversibly lost from recycling.

The specific input of salt has to be reduced, as processing of the resulting salt slag is a sizeable cost burden for refiners. Since liquid salt/flux is just a packaging material for NMC, new furnace designs/techniques are required to increase the efficiency of salt use. Even recycling of liquid salt inside refiners has to be considered.

It is very important that the global aluminium industry design and implement a sustainable solution to landfill minimization and processing of dross and salt cake to lower cost and enhance the public image.

6. Using recycled Al scrap

Current state-of-the-art

Post-consumed scrap
New aluminium scrap generated internally at semi-fabrication rolling and extrusion plants is remelted and generally batched into compatible rolling or extrusion alloys. Prompt Al casting scrap is also closed-loop recycled in the foundry or back at a secondary smelter. However, new manufacturing scrap is often traded on the international scrap market and comes to a remelt plant or a secondary smelter with a less reliable pedigree. It is usually batched together with post-consumer scrap into secondary alloys, as shown in Table III.

Table III: Markets consuming post-consumer Al scrap

Market	Secondary alloy	Compatible scrap sources
Al packaging	3X04 can body sheet	• Old cans, can manufacturing scrap • Non-can wrought manufacturing scrap • Al- and Mg-based scrap mix from 2-t/m3 float fraction of a dense-media sink-float plant
Building Al	3105 painted sheet	• Old Al siding • Al siding and extrusion construction scrap • Mixed wrought manufacturing Al scrap with low Cu content • Old wrought scrap
Automotive Al	38X.x casting alloys	Some 38X alloys can accept a mixture of the most common old scrap varieties without dilution, as long as the Mg concentration is controlled by chlorination
	319.x casting	Tighter concentration limits on 319 increase the dilution requirement and limit the types of old scrap that can be added to a 319 alloy batch
Steel deoxidants	95% Al	This specification can be met by several mixtures of old wrought alloy scrap as well as limited quantities of old cast scrap.

In short supply
Currently the market consumes all the available post-consumer Al scrap. To satisfy product demand, remelts and secondary smelters have to supplement the old scrap feed by purchasing new manufacturing scrap and even prime-metal-based ingot. As long as primary Al and hardeners have to be purchased to satisfy these markets, the value of these products is set by reference to the primary Al price, and there is little price margin between secondary- and primary-sourced alloys. In this case, there is no economic justification to additionally upgrade scrap and divert it to other markets.

Growing market
In the current expanding market for light metals, there is a continuous need for primary Al production to supply a large portion of the demand. Given the rapid industrialization of the developing world, which is adding billions of additional consumers, the demand for light metals and for light-metal scrap is likely to grow for the foreseeable future.

Impurities

Impurity elements are picked up during the entire supply chain in various concentrations depending on raw material sources, cold metal/scrap source, master alloy, processing conditions etc. The effect of these impurities on product properties depends upon the form they appear in particles, dipersoids, precipitates and solid solutio. For instance, a small concentration of a given element can have a significant effect on the surface appearance of the product.

Product specifications

Historically the specification of an aluminium product is on chemical composition. However, processing of Al processing parameters (temperatures, time deformation and chemical treatments) is important to attain a certain level of properties.

Problems, challenges and opportunities

- Lack of methods to remove undesirable/tramp elements like; Fe, Zn and Cu, that are picked up in the supply chain.
- A clear understanding is still missing in industry of the effect that processing has on the properties of the final products.

Goals for using recycled Al scrap

1. Aim to recycle 100% of all new and old Al scrap
2. Find alternative applications for casting alloys
3. Develop melt purification techniques for unwanted alloying and trace elements, such as Fe, but also elements like Zn and Cu. Removal of these from molten aluminium represents considerable technical challenges (see chapter 4)
4. Develop an increased understanding of the effect of trace element concentrations on processing and properties of the existing secondary alloys (3X04, 3X05, 38X.x, and 31X.x)
5. Develop an improved understanding for the strong effect that processing has on the properties of the final products
6. Continue to translate customer requirements into composition and processing specifications
7. Mix wrought and cast alloys into new alloys. Develop methods for casting, plastic forming and heat treatment
8. Qualify use of post-consumer sorted extrusion scrap in 6000 series extrusion alloys
9. Keep the number of alloys to a minimum
10. Qualify use of post-consumer sorted sheet scrap in 3000 and 5000 series sheet alloys

11. Articulate clear distinction between alloys for, structures and sidings building
12. Develop new applications for aluminium using recycled aluminium such as in renewable energy developments
13. Design recycling indices taking into account carbon & energy footprints and ease and cost of recycling
14. Develop mathematical models linking market, chemistry, processing, physical metallurgy and product attributes

Conclusion

The Roadmap aims to present the current status and technology challenges in aluminium recycling. In this Roadmap the goals are not broken down into smaller tasks nor have priorities between the various goals been set. The main obstacle is that collected scrap is contaminated and mixed with various materials that increase aluminium loss and lower metal quality. It is a wish from the group that we continue with this Roadmap work in three years time; that is in June 2013.

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Abbreviations

CFF	Ceramic Foam Filters
DBF	Deep Bed Filters
EAO	Organisation of European Aluminium Refiners and Remelters
EU	European Union
IAI	International Aluminium Institute
LIBS	Laser-Induced Breakdown Spectroscopy
LiMCA	Liquid Metal Cleanliness Analysis
MHD	Magneto Hydro Dynamics
NMP	Non-Metallic Products
NTNU	Norwegian University of Science and Technology
PGNAA	Prompt Gamma Neutron Activation Analysis
PTF	Porous Tube Filters
RE	Rear Earth
UBC	Used Beverage Cans
XRF	X-Ray Fluorescence
XRT	X-Ray Transmission

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