Aluminium from Cans to Cars: Closing the ELV Recycling Loop

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Innoval Technology and BCAST, Brunel University
Zhongyun Fan
BCAST, Brunel University

Innoval Technology is an independent technology provider serving aluminium companies and end-users of aluminium. 27 engineers and materials specialists based in Banbury, Oxfordshire.
Aluminium and CO$_2$ Emission Burden

Average emissions are 9.7kg CO$_2$e/kg Al
5.4kg from electricity + 4.3kg from mining, refining etc
Emissions can be much higher especially for old pot lines
and where electricity generation is coal based
(20.8kg CO2e/kg Al just for electricity production)
Glenn T Seaborg’s Vision

“the present materials situation is literally reversed; all waste and scrap - what are now called secondary metals - become our major resources, and our natural, untapped resources become our back-up supplies”

“Aluminum, the Magic Metal”, Thomas Y Canby, National Geographic, August 1978
Full Metal Circulation
Vision

- **Solidification science**: Effective microstructural control can be achieved by control of nucleation during solidification through better understanding of liquid metal engineering.

- **Technological development**: High performance metallic components and feed stock materials can be manufactured by innovative solidification processing through liquid metal engineering with little requirement for solid state processing.

- **Sustainable metallurgical industry**: The demand for metallic materials can be met by an efficient circulation of existing metallic materials with limited additions of primary metal to sustain the circulation loop.
Academic team

Oxford
Professor P. Grant
Dr K. O'Reilly

Brunel
Professor Z. Fan
Professor G. Scamans
Professor D. Eskin
Dr N. Hari-Babu
Dr B. McKay
Dr I. Stone
Dr Y Huang

Birmingham
Professor N. Green
Dr W. Griffiths
Industrial partners

Materials suppliers
MEL, Sapa, LSM, Norton

Materials processors
JVM, Meridian, NewPro, Aeromet, Granger & Worrel, Sandvic

End users
JLR, RR, DSTL, QinetiQ

Equipment suppliers
Foseco, Rautomead

Research organisations
NPL, Innoval, Namtec

Promoters
CMF, AlFed, ICME, Materials KTN
Liquid metal engineering

MCAST = Melt Conditioning by Advanced Shear Technology
Fluid flow characteristics

Twin screw mechanism

Rotor-stator mechanism
Oxide in LM24 alloy

Without shear

With shear
Nucleation on oxides

Mg/MgO interface in AZ91

Al/MgAl$_2$O$_4$ interface in LM24
DC casting - AA7075

Direct chill casting
High shear degassing

LM25

AA7032
New grain refiners

CP Al, No GR
CP Al, MgAl$_2$O$_4$ GR
CP Al, Al$_2$O$_3$ GR
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Novelis: Latchford Used Beverage Can Recycling

- **Incoming Al Scrap**
- **Surge Hopper 12MT**
- **Melters 1 & 2**
  - Capacity 90MT
- **Decoater**
- **Off-site Al Recovery**
- **Cold Extraction System**
- **Belt Conveyor**
- **Class Scrap and UBCs**
- **Cold Fines Screen**
- **Magnetic Separator**
- **Off-site Al Recovery**
- **DC Casting Centre**
  - 3 ingots per cast
- **21-26MT Slab, 8300mm long**
- **Two point Grab**
  - 32MT Max. Load
- **Sheet ingot to Alunorf**

Only dedicated aluminium can recycling plant in the EU
– 120KT production capacity, UK market 90KT (5 billion cans)

**Andy Doran**, Novelis Recycling

Aluminium in Automotive Conference 2011, 28-29 September 2011, Thinktank, Birmingham, UK
Relative price of UBC scrap compared to the average monthly LME aluminium price. On average it is 56% of the metal price.
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Global Aluminium Beverage Can Collection Rates (2009)

<table>
<thead>
<tr>
<th>Country</th>
<th>Collection Rate</th>
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<tbody>
<tr>
<td>World</td>
<td>69.1%</td>
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<tr>
<td>Europe*</td>
<td>70.0%</td>
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<tr>
<td>USA</td>
<td>54.2%</td>
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<tr>
<td>Turkey</td>
<td>52.0%</td>
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<tr>
<td>Switzerland</td>
<td>75.0%</td>
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<tr>
<td>Sweden</td>
<td>90.0%</td>
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<tr>
<td>Spain</td>
<td>91.0%</td>
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<tr>
<td>Russia</td>
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<tr>
<td>Portugal</td>
<td>67.0%</td>
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<tr>
<td>Poland</td>
<td>92.0%</td>
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<tr>
<td>Norway/Iceland</td>
<td>92.7%</td>
</tr>
<tr>
<td>Netherlands</td>
<td>85.0%</td>
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<tr>
<td>Japan</td>
<td>92.7%</td>
</tr>
<tr>
<td>Italy</td>
<td>91.0%</td>
</tr>
<tr>
<td>Ireland</td>
<td>42.0%</td>
</tr>
<tr>
<td>Hungary</td>
<td>50.0%</td>
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<tr>
<td>Greece</td>
<td>36.0%</td>
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<tr>
<td>Germany</td>
<td>53.0%</td>
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<tr>
<td>France</td>
<td>91.0%</td>
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<tr>
<td>Finland</td>
<td>89.0%</td>
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<tr>
<td>Estonia</td>
<td>87.0%</td>
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<tr>
<td>Denmark</td>
<td>65.0%</td>
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<tr>
<td>China*</td>
<td>99.5%</td>
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<tr>
<td>Quebec (Canada)</td>
<td>67.9%</td>
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<tr>
<td>Brazil</td>
<td>96.5%</td>
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<tr>
<td>Belgium/Luxembourg</td>
<td>91.0%</td>
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<tr>
<td>Austria</td>
<td>91.0%</td>
</tr>
<tr>
<td>Australia</td>
<td>70.0%</td>
</tr>
<tr>
<td>Argentina</td>
<td>90.5%</td>
</tr>
</tbody>
</table>

* Includes unregistered collection
Cans are shredded before being de-inked and melted

In UK alone 45kt of aluminium cans are lost (landfilled??) every year (90kt of cans sold)
UK wastes 3 billion, Spain 1.9 billion and Italy 1 billion cans/year (2002 figures)
30kt/year are recycled into canstock (15kt/year castings or export??)
At Latchford each kg of recycled Al carries the low environmental burden of 0.68kg CO$_2$e/kg from decoating, melting and casting

Aluminium is cast into ingots, each large enough to make 1.5 million new cans
Chemical Composition of Cans

<table>
<thead>
<tr>
<th>Major alloying elements (wt.%)</th>
<th>Fe</th>
<th>Si</th>
<th>Mg</th>
<th>Mn</th>
<th>Cu</th>
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</thead>
<tbody>
<tr>
<td>AA3104 Can Body</td>
<td>0.4</td>
<td>0.2</td>
<td>1.2</td>
<td>0.9</td>
<td>0.2</td>
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<tr>
<td>AA5182 Can End &amp; Tab</td>
<td>0.2</td>
<td>0.1</td>
<td>4.7</td>
<td>0.3</td>
<td>&lt; 0.1</td>
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<tr>
<td>Remelted UBC's</td>
<td>0.35</td>
<td>0.17</td>
<td>1.6</td>
<td>0.7</td>
<td>0.15</td>
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<tr>
<td>AA5754 Structural alloy</td>
<td>0.2</td>
<td>0.1</td>
<td>3.0</td>
<td>0.3</td>
<td>&lt; 0.1</td>
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<tr>
<td>AA6016 skin alloy</td>
<td>0.2</td>
<td>1.2</td>
<td>0.5</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
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<tr>
<td>AA6111 skin alloy</td>
<td>0.2</td>
<td>0.7</td>
<td>0.7</td>
<td>0.3</td>
<td>0.7</td>
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</tbody>
</table>

Recycled cans that are presently lost to landfill are a potential low cost source of automotive sheet. Aluminium loose can scrap recently peaked at £1040 ($1634) /tonne in Jun 2011 just after the LME price peaked at $2760.
Automotive Sheet Recycling

- Recycle
  - Chemistry
  - Scrap Value

- Sheet Process
  - Blending
  - Chemistry Control
  - Cold Rolling
  - Annealing
  - Finishing

- Scrap
  - Segregation
  - Collection
  - Handling
  - Tier 2s

- Coating
  - Slitting
  - Cut-to-length
  - Laser Blanking

- Stamping
  - Stamping
  - Trim

- Old Scrap
  - Transport scrap
  - Building scrap
  - Can scrap

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Aluminium in Automotive Conference 2011, 28-29 September 2011, Thinktank, Birmingham, UK
EU Aluminium Automotive Sheet Market Development
(includes the two new aluminium intensive Land Rovers from 2013 at 60kt/year)
EU Aluminium Automotive Sheet Manufacturing Capacity Development
(Based on the capacity in kt of the six known heat treatment and finishing lines)
Jaguar Land Rover closed loop recycling plan and future end of life vehicle recycling
Remelting of AA5754 sheet with SPRs
Aluminized Rivet from Re-melted AA5754 sheet

Steel

Fe₂Al₅

Aluminium

3 mm
Rivet from Vehicle Melt Dross

Steel rivet

Intermetallic phases at rivet edges
SEM images of Aluminized Rivet from Vehicle Melt
Separation of Wrought and Cast Alloy Scrap (Alcan)

- Brazing sheet
- Core alloy AA3003
- Clad alloy AA4045

Fluidized bed process offers highest potential for close control of metal temperature.

Temperature range to melt and remove cladding alloy:

- AA3003: ~630°C
- AA4045: 610 - 620°C

After FB processing:

<table>
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<tr>
<th>Element</th>
<th>Original</th>
<th>After FB</th>
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<tbody>
<tr>
<td>Si</td>
<td>0.058</td>
<td>0.392</td>
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<tr>
<td>Mn</td>
<td>0.187</td>
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<tr>
<td>Mg</td>
<td>1.469</td>
<td>1.443</td>
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<tr>
<td>Fe</td>
<td>0.512</td>
<td>0.476</td>
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<tr>
<td>Cu</td>
<td>1.098</td>
<td>0.158</td>
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Fluidized Bed

Porous Plug
Separation of Wrought and Cast Alloy Scrap

- The "hot crush" method of thermomechanical separation was developed about 25 years ago by the U.S. Bureau of Mines, now the DOE Albany Research Center. The hot crush system consists of a series of heating, crushing, and screening steps.
- Mixed cast and wrought scrap is heated to a point that is slightly below the melt temperature of the cast alloys. The heated cast alloys then undergo mechanical crushing or grinding, by hammer mill or flail mill, causing the cast alloy pieces to fracture along the weakened grain boundaries. Wrought alloys remain solid during the heating stage and do not fracture.
- Heating the mix has a side benefit, because it also cleans the scrap, removing paints and coatings from the surface of the material. This eliminates the need for delacquering, normally a required step for all aluminium scrap processing.
- Following the mechanical crushing stage, the mix goes through a size separation process, such as a rotary trommel, which separates smaller cast fragments from the wrought alloys. The wrought alloy pieces are then ready for further separation into their alloy families.
- The hot crush method is quite effective for separating wrought aluminum from castings, giving better than 96% separation. Although the hot crush technology has been demonstrated only with small quantities it can be readily scaled up as all of the equipment used in it is known in the minerals and materials processing industries.
Separation of Wrought Alloy Scrap

- Alcoa rotary furnace process process for separating can end alloy (AA5182) from can body alloy (AA3004) (US 4491473 1985)
- Colour sorting has been evaluated to separate different wrought aluminium alloys into individual alloy families. Using etching processes patented by Alcoa, wrought aluminium alloys are coloured by selectively etching in three different solutions. Each solution promotes a unique colour change.
- Laser-Induced Breakdown Spectroscopy (LIBS) is able to separate both cast and wrought aluminium scrap into their individual alloys. This unique technique was first developed at the Los Alamos National Laboratory, and has grown into the most comprehensive method for sorting aluminium scrap. A pulse laser is used to produce a spectrum that corresponds to its chemical composition. The chemical composition is what determines into which bin the piece of scrap is directed. The end result is that the cast and wrought products are separated into their individual alloys.
- The first industrial plant to sort secondary wrought alloys from aluminium shred using LIBS analysis has been in operation since 2004.
- The SILAS project in the EU is aiming to improve on this technology for wide commercial implementation.
Increasing Alloy Tolerance to Impurities (Iron)
Melt Conditioned Twin Roll Casting Process (MC-TRC)

Vertical TRC

Horizontal TRC

Production of aluminium alloy sheet made using a high proportion of wrought product scrap with properties to match AA5754 and AA6111 for lightweight automotive BIW construction
High speed TRC of Aluminium Strip

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High speed TRC of AA6111 sheet

Tensile test results AA6111-T4

Tensile test results AA6111-T6

AA6111 Strip microstructure after cold rolling (a) 0.13%Fe, (b) 0.43%Fe, (c) 0.62%Fe, (d) 0.81%Fe, (e) 1.02%Fe

180° bend test results AA6111-T4

150 million scrap cars
Shredding or Disassembly?

ELVs  Shredding  Metal  Fluff

Automotive disassembly line
Research Vision and Ambition

2011

- Primary input materials
- Vehicle manufacturing
- Vehicle use
- ELVs

- CO2 emission
- Recovered metals (downgraded)
- Waste for land filling

2030

- Limited input of primary materials
- Low-carbon input lightweight materials
- Low-carbon manufacturing technologies
- Reuse & remanufacture
- Mass-optimised design for low-carbon usage
- ELVs (end of life vehicles)

- Significantly reduced CO2
- Minimal waste for land filling

- Dismantling of ELVs
- Closed-loop recycling
What are our ideas?

- Closed loop recycling of light metals
- Use of recyclable PMCs
- Low carbon manufacturing technologies
- Recycling LEVs without shredding
- Holistic vehicle design
TARF-LCV aims to lay down a solid scientific and technological foundation for future LCV development in the strategic areas of advanced materials, low carbon manufacturing technologies, holistic mass-optimised vehicle structure design and closed-loop recycling of ELVs.
Project Objectives

- To develop closed-loop recyclable Al-alloys and self-corrosion-resistant Mg-alloys
- To develop advanced PMCs using recyclable rGFs, rCFs and recoverable rNFs
- To develop novel technologies for liquid metal treatment to enable closed-loop recycling
- To develop advanced technologies for LC manufacturing and effective disassembly of ELVs
- To develop mass-optimised vehicle design principles
- To develop specific LCA methodology for future LCV development
Research programme

TARF-LCV Programme

- Manufacturing Technology
- Mass-Optimised Design
- LCA (Life Cycle Analysis)

- Aluminium Alloys
- Magnesium Alloys
- Polymer composites
## Resources

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<tr>
<th>Partner</th>
<th>Investigator</th>
<th>PDRA (funded)</th>
<th>PDRA (leveraged)</th>
<th>PhD (funded)</th>
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<td><strong>9</strong></td>
<td><strong>3</strong></td>
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**Grand total: 47 Researchers**