ALUMINUM RECYCLING
AN INTEGRATED INDUSTRY – WIDE APPROACH

Recycle – Friendly Alloys, Recycling Indices and Carbon Management

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PHINIX, LLC

- New company devoted to “Globally Responsible Resource Management“
- Assess, Develop and Commercialize low Carbon/Energy Footprint Processes and Products for the Minerals/Metals/Material Industries (MMMI)
- Provide Techno-Economic framework and forum for carbon management and trading for MMMI
OUTLINE

• Background
  – Aluminum Recycling  Driving Forces
  – Design Drivers

• Recycling Challenges by Market
  – Electrical & Packaging
  – Automotive
  – Building & Construction (B&C)
  – Aerospace

  ▪ New Paradigm
  ▪ Recycling Index
  ▪ Carbon Footprint, Carbon Management and Trading
Aluminum Industry emits 1% of Global GHG
500 Billion Tonnes per Year

• Recycling aluminum impacts energy needs and carbon footprint
  – Requires only 5% of energy
    • ~2.8 kWh/kg Al vs. ~45 kWh/kg Al
  – Produces only 5% of CO₂
    • ~0.6 kg/kg Al vs. 12 kg/kg Al
  – Alloying Elements Conservation (Mg, Mn, Cu, Zn, Si)
    • Have higher energy and carbon footprints than Al
Recycling Driving Alloy Development

• Previous approach to alloy development
  – Driven solely by desired performance
  – Limited considerations of end-of-product-life
  – Less considerations for cost, carbon footprint and availability of alloying elements

• Beginning to recognize impact of recycling
  – How will product be recovered for recycling?
  – How will composition impact cost & recyclability?
  – What will be it's carbon footprint?
Challenges in Recycling of Aluminum

Review by Market

• Electrical and beverage can markets have closed recycle loops requiring less attention

• Others are less complete requiring attention
  – Automotive
  – Building & Construction
  – Aircraft
Automotive Applications

Why Pre-Sorting is Highly Desirable?

- Bumper alloys have high Zn
- 2xxx body sheet alloys have high Cu
- Castings have high Si
- A356 wheels are high in purity for toughness
- 5xxx & 6xxx body panels provide compatible compositions
- Mixing alloy types not practical
- Segregated remelts could have directly reusable compositions
Laser Induced Breakdown Spectroscopy (LIBS) Technology
Maximize Value of Recycled Aluminum

• Consider dismantling, segregating parts prior to remelt
  – Wheels, often A356, with high-Si, high purity
  – Bumpers, 7xxx alloys, with high Zn content
  – Outers, usually 6xxx alloys, low in Cu and Zn
  – Inners, often 5xxx alloys, also low in Cu and Zn

• Evaluate remelted alloys for recycling into similar components

• Look for opportunities for new alloy modifications
  – Non-heat treatable sheet alloy (similar to 5754)
  – Heat treatable alloy for exterior / structural applications (6063 or 6111)
  – High quality structural castings (like 332)
## New Recycle-Friendly Automotive Alloys

<table>
<thead>
<tr>
<th>Source</th>
<th>Source Alloys</th>
<th>Si, %</th>
<th>Fe, %</th>
<th>Cu, %</th>
<th>Mn, %</th>
<th>Mg, %</th>
<th>Zn, %</th>
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<tbody>
<tr>
<td>panel alloys</td>
<td>2010, 5754, 6022, 6111</td>
<td>0.7</td>
<td>0.4</td>
<td>0.5</td>
<td>0.25</td>
<td>0.70</td>
<td>0.20max</td>
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<td>bumper alloys</td>
<td>7116, 7029, 7129</td>
<td>0.10max</td>
<td>0.15max</td>
<td>0.75</td>
<td>0.10max</td>
<td>1.35</td>
<td>4.7</td>
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<tr>
<td>castings, wheels,</td>
<td>A356.0, 360.0, A380.0</td>
<td>8.5</td>
<td>1.2</td>
<td>1.0</td>
<td>0.25max</td>
<td>0.35</td>
<td>1.0</td>
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</table>
Do “Unialloy(s)” Merit Further Attention?

• “Unialloy” approach has been proposed

• Difficult because
  • Body sheet inners require max formability
  • Body sheet outers require max strength, dent resistance
  • Bumpers require even higher strength

• One solution:
  – 6xxx-O for inners
  – 6xxx-T4 for outers.
  – 6xxx-T6 for bumpers and structural members

• Conclusion: yes, it does merit further attention
Building & Construction - Opportunities

• Building and construction applications include:
  – Skin and fascia of residential and commercial buildings
  – Structural components in buildings and towers
  – Highway structures:
    • Overhead and roadside signs,
    • Light poles
    • Bridge decks
• Aluminum alloys utilized are primarily:
  – 5xxx alloys for components of sheet or plate
  – 6xxx alloys for extruded shapes
• Active life may be 10 to 50 years
Recycling of Al From B&C Structures

• Maximize advantages of demolition process:
  – Use demolition company workings with new building contractor who will reuse undamaged parts
  – As demolition proceeds, segregate Al and steel components from remaining aggregate mix
  – Segregate aluminum components into two categories:
    • Flat rolled products (sheet & Plate)
    • Extruded shapes
  – Retain segregation through remelting operation to separate 5xxx and 6xxx alloys
Recycled Alloys for B&C Applications

<table>
<thead>
<tr>
<th>ALLOY TYPE &amp; SOURCE</th>
<th>Al, %</th>
<th>Si, %</th>
<th>Fe, %</th>
<th>Cu, %</th>
<th>Mn, %</th>
<th>Mg, %</th>
<th>Cr, %</th>
<th>Zn, %</th>
<th>Ti, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>5xxx Sheet &amp; Plate</td>
<td>~96</td>
<td>0.4</td>
<td>0.4</td>
<td>0.15</td>
<td>0.6</td>
<td>2.5</td>
<td>0.15</td>
<td>0.25</td>
<td>0.1</td>
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<tr>
<td>6xxx Extruded Shapes</td>
<td>~96</td>
<td>0.5</td>
<td>0.5</td>
<td>0.2</td>
<td>0.12</td>
<td>0.8</td>
<td>0.15</td>
<td>0.15</td>
<td>0.12</td>
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Why Recycle Aluminum Aircrafts?

• Thousands of obsolete aircraft stored in “graveyards” around the world

• “Graveyards” are large, located in dry / hot places, establishment of recycling center practical

• Older aircraft are 90%-plus aluminum recovery feasible
Aircraft Recycling
Why Has it Not been Done to Date?

• Aircraft are made largely of high-strength aluminum alloyed with large amounts of Cu and Zn

• Such alloys are more difficult to recycle than lesser-alloyed aluminum used in most other applications

• Special recycling practices will be needed to make aircraft recycling economic
Potential Remelt Compositions of Recycled Aircraft Components Assuming Pre-Sorting of 2xxx & 7xxx Alloys

<table>
<thead>
<tr>
<th></th>
<th>Al %</th>
<th>Cu %</th>
<th>Fe %</th>
<th>Mg %</th>
<th>Mn %</th>
<th>Si %</th>
<th>Zn %</th>
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</thead>
<tbody>
<tr>
<td>2xxx</td>
<td>~93</td>
<td>4.4</td>
<td>0.5</td>
<td>1.0</td>
<td>0.7</td>
<td>0.5</td>
<td>0.1</td>
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<tr>
<td>7xxx</td>
<td>~90</td>
<td>2.0</td>
<td>0.4</td>
<td>2.5</td>
<td>0.2</td>
<td>0.2</td>
<td>6.0</td>
</tr>
<tr>
<td>Mix</td>
<td>~92</td>
<td>3.0</td>
<td>0.4</td>
<td>1.8</td>
<td>0.4</td>
<td>0.4</td>
<td>3.0</td>
</tr>
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</table>
Opportunities for Direct Re-Use of 2xxx and 7xxx Compositions

• Non-fracture-critical, moderately stressed aircraft components
  • Stiffeners
  • Flaps

• Building and highway structural components

• Railroad and truck structural components

• Cast components as well as wrought
ALLOY RECYCLING INDEX (ARI)
RECYCLING PRODUCTION INDEX (RPI)

• ARI – Recyclability for recovering the maximum stored energy invested in the alloy, carbon footprint (Quantitative)

• RPI – Ease of producing from recycled remelts (Qualitative)
ALLOY RECYCLING INDEX (ARI)

• Nominal alloy content is sum of the nominal alloy additions (mid-range)
• Sum of the mid-range of the impurity limits
• Total of nominal alloying content plus nominal total impurity content subtracted from 100% = ARI.
RPI - Classification

• High (H) – Readily produced from recycled remelts in the same alloy

• Medium (M) – Readily produced from recycle remelts of scrap segregated at least by alloy series

• Low (L) – More difficult to recycle from recycle remelts

• Unlikely (U) – Composition doesn’t lend to production from recycled remelts (Ag, Be, or Li)
# ARI & RPI for Key Aerospace Alloys

<table>
<thead>
<tr>
<th>ALLOYS</th>
<th>ARI</th>
<th>RPI</th>
</tr>
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<tbody>
<tr>
<td>2XXX</td>
<td>94</td>
<td>M</td>
</tr>
<tr>
<td>7XXX</td>
<td>91</td>
<td>M/L</td>
</tr>
<tr>
<td>2XXX/7XXX</td>
<td>91</td>
<td>U</td>
</tr>
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</table>
Aerospace Alloys -- Conclusions

• Aging / obsolete aircraft = “urban aluminum mine”, reuse will lowering carbon footprints.

• **Alloy Recycling Index** and **Alloy Recycling Production Index** have been developed.

• Alloys with high Cu / Zn **difficult to recycle together**, pre-shred **segregations** into 2xxx and 7xxx groups for remelting.

• Manage alloying elements **Ag, Be, Bi, Pb, Li** and grain refiners **Cr, Zr, V**.
Alloy Design Drivers

• **Previously primary design drivers were:**
  • Performance, safety, fuel economy, primary & chemistry based tradition

• **Secondary design drivers were:**
  • Dismantling, recycling and end-of-life issues, multiple - materials, cost

• **Problem:** complicates eventual dismantling and recycling

• **Solution:** Combine primary and secondary design drivers
New Paradigm

• For both existing and new alloys --- Recycle to same product

• For existing alloys
  – Recognize relative value when recycled
    • How big are energy source and carbon footprint?
  – Group alloys for remelting to maximize value

• For designing new alloys
  – Consider how useful composition will be when remelted
    • Avoid adding elements that become contaminants
  – Consider possibility of direct production from recycle remelts
    • Avoid tight impurity limits unless required for performance
    • Consider compositions from automotive, B&C, packaging or aircraft recycling (new class of “elements” )
Challenge to Collaborate
Customers and Suppliers

• Working together to develop lowest carbon footprint multiple - material products!

  – Assess recycling index of multiple – material systems
  – Minimize multitude of alloys & excessive product differentiation
  – Consider logistics for recycling in advance
  – Consider mixing different multiple-material scrap
  – Design automotive alloys for safety, energy efficiency, consumer tastes, and RECYCLING
Promote Recycling as a Carbon Offset

Carbon Management

Production

End Use

Recycling
CARBON MANAGEMENT STRATEGY

1. Legislations Under Way

   European Union 2013
   United States 2009
   EPA : Clean Air Act
   Waxman and Markey : Cap and Trade

2. Protocol Development for “Recycling as a Carbon Offset or Credit”

3. Action Items