Aluminum Recycling in a Carbon Constrained World: Observations and Opportunities

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With a global population approaching 7 billion, there simply is not enough primary aluminum available to indefinitely meet demand. Developing optimal effectiveness of aluminum recycling is critical to ensuring an adequate aluminum supply for future generations, while also contributing to a more sustainable world. This paper presents a framework for achieving substantial progress that integrates key elements of the aluminum recycling landscape: engineering, communication, public policy, and actionable sustainability strategies.

INTRODUCTION

Recycling is one of the cheapest and most sustainable ways to lower the carbon footprint of the global aluminum industry. However, the spectrum of aluminum manufacturing is at a crossroads in its ability to realize the fullest potential benefits of recycling, both from a business and an environmental impact perspective. Substantial progress from this point requires a better coordinated, more cohesive approach to developing and applying recycling technologies that also engages the sectors of society impacting recycling implementation. This paper presents a framework integrating these somewhat disparate elements of the aluminum recycling landscape by focusing on improved engineering, communication, public policy, and actionable sustainability strategies.

While the drive to reduce carbon emissions is rooted in the need to preserve the earth's fragile ecosystem, carbon management is also simply good business practice. Emission reduction can cut costs by enhancing process efficiency, lowering energy usage, and reducing consumption of scarce raw materials. This is illustrated by the significant production and economic gains recently achieved by the strategy adopted by DuPont:

> "In 1994, DuPont committed to cutting its gas emissions by 40% by 2000 from its 1990 levels. By 2000 the company had met its original target and set an even more ambitious one - a 65% reduction by 2010. But the gains have been so dramatic that DuPont has already hit that goaltoo. It also uses 7% less energy than it did in 1990, despite producing 30% more goods. This action has saved DuPont over $2 billion." [1,2]

The aluminum industry has likewise had its share of carbon reduction success stories. Table I identifies the estimated carbon emissions for the worldwide aluminum industry. This is expressed as carbon dioxide equivalent or CO_{2eq} which takes into account global warming potential (GWP) of different greenhouse gases (GHG).[3] As indicated in Table I, recycling generates about 5% of the GHG compared to smelting (456 vs. 18 CO_{2eq} million metric tons).

There is enormous opportunity to improve this performance, while maximizing energy and production savings and ensuring a supply of material that supports the most cost-effective manufacturing possible. Recognizing this, the aluminum industry is actively exploring approaches to increase its recycling rates, but a number of challenges remain. This paper explores paths to overcoming these barriers, in order to stimulate thinking, discussion, and action.

ENGINEERING PRODUCTS AND PROCESSES FOR RECYCLABILITY

It's All about the Alloys

The speed, efficiency, and cost of recycling can be significantly improved with materials and products engineered from the start to facilitate the process. Most of the alloying elements commonly used to produce aluminum alloys— including Mg, Cu, Si, Mn, and Zn—have even higher carbon footprints than aluminum, complicating subsequent recovery and recycling at the end of the useful product life. Excessive product differentiation to promote perceived competitive advantages also leads to more waste, higher costs, and larger carbon footprints.

It is estimated that more than 110 varieties of aluminum alloys are in commercial use today to serve all sectors. Table II offers some suggested recycle-friendly alloys for a variety of specific

Table I. Carbon Footprint of the Global Aluminium Industry (2008)

Items	Production (Million Metric Tons)	Unit Emission CO_{2eq} (Metric Ton/Metric Ton)	Total Emission (Million Metric Tons CO_{2eq})	Comments
Ore to Metals Production	38	12	456	World Average
Recycling	37	0.5	18	~5% of Primary
Total Emissions	—	—	474	>1% of Global 44,130 million metric tons CO_{2eq}

Table II. Suggested Recycle-Friendly Alloys

Industry/Field	Recycle-Friendly Alloy
Electrical	1350
Can Sheet	One " uni-alloy" 3104 (For body, lids, tabs)
Building and Construction	3105 (painted sheet); 606X (extrusion)
Automotive	5754, 6111-O (interior); 6111-T4 (exterior); 6061-T6 (bumpers/structural); A356, 380, 319
Aerospace	2X24, one 7 × 50 (plate, extrusion)
Marine	5052 (plate); 6063 (extrusion)
Guide Lines for Material/Metallurgical Engineers & Alloys Designers	Minimize use of Li, Ag, Be, Bi, Pb, Ti, Cr, Zr, V ("Entropy Enhancers/Recyclability Reducers"). All that's needed are Cu, Zn, Mg, Mn , Fe and Si

applications. As indicated, the global aluminum industry could serve the entire spectrum of applications with only 15 alloys, using alloying elements Cu, Zn, Mg, Mn, Fe, and Si. This minimizes use of entropy enhancing and recycle-limiting elements such as Li, Ag, Be, Bi, Pb, Ti, Cr, Zr, and V. Focusing on the development and production of a small, but powerful, cadre of recycle-friendly alloys will enable the widespread adoption of a "secondary aluminum dominated paradigm," with new products made primarily from cost-effective recycled materials.[4]

To fully realize the benefits of this manufacturing model, producers, consumers, and recyclers must work together to design multi-material systems, such as aluminum, steel, vinyl, composites and copper, for efficient disassembly. This will ensure maximum recyclability for all metals and materials contained in the end-products entering the marketplace.

Recycling /Melting/Sorting Technologies

Another innovation area that is key to improving the business and environmental advantages of aluminum recycling is the development of improved recycling technologies. The melting of aluminum is still highly inefficient, with only 25% (2,200 actual average vs. 510 BTU/pound-theoretical) thermal energy efficiency. A global average of 925 BTU/pound is possible within 3–5 years with retrofits for existing melters and implementation of more highly energy efficient technologies in newer facilities.[5-9] Another technology that can greatly improve recycling processes is sensor-based particle sorters capable of maximizing product yield in an economic and efficient manner.[10]

CONSISTENT RECYCLING METRICS AS A COMMUNICATION TOOL

Revalidate Recycling Energy Requirements

More than decade has passed since the methodology and results of a worldwide industrial survey were published to assert that recycling aluminum requires about 5% of the energy needed to smelt from bauxite ore.[5] Since that time, rapid advances have taken place throughout the world to develop and commercialize newer and more energy efficient smelters and retire obsolete smelters or curtail their production. The development and implementation of recycling, sorting, and remelting technologies has been less rapid. The "5% energy" claim needs to be reexamined and validated in light of dynamic changes in the industry with respect to geographic location and implementation of "greenfield' and retrofitted "brownfield" technologies.

Consolidate Methodologies for Recycling Rate Calculation [11,12]

Depending upon the respective interests of their stakeholders, different organizations use different approaches in devising their methodologies for calculating, reporting, and promoting recycling rates. The industry must resolve this disparity and adopt a common methodology with appropriate communication and compromise to report "one number" to the public, producers, consumers, and law makers.

While trade associations and interest groups are calculating and reporting national recycling rates, it is important to note that local municipalities and states should also adopt a consistent tool for calculating local recycling rates—especially for aluminum UBC—using "waste composition analysis." These calculations, as validated in Lexington, Kentucky, are useful in building local public support and developing policy.[13,14]

Introduction and Promotion of Universal Recycling Indices

Every material competing with aluminum for market share promotes itself as "green," "recyclable," and "eco-friendly." The definitions behind these buzzwords, however, vary from industry to industry, and often do not take into account the scope of environmental factors affiliated with the products. All of these industries share common challenges in ensuring that their businesses operate as effectively as possible amid growing global sensitivities to their environmental impacts. They are also often mutually independent on each other for formulating possible solutions to these issues. To promote better networking among these various industrial spheres, common standards and definitions need to be developed that can enable them to communicate in a mutually intelligible way. Because of its leadership in the recycling arena, the aluminum industry has the opportunity to forge a universal standard by which all trades associated with aluminum and its competing materials may evaluate and improve the recyclability of their materials.

Two recycling indices—Aluminum Recycling Index (ARI) and Recycling Processing Index (RPI)[15,16]—could be used as the basis for improving communications and recycling practices throughout the metals/materials industry. Both effectively illustrate relative value of alloys from the recycling standpoint in a way that is simple and convenient. The ARI is a measure of the ability to recover stored energy invested in an alloy by recycling, as well as an inverse measure of the carbon footprint of the alloy. The ARI measures alloys on a 100-point scale, where 100 is ideal. The RPI is a measure of the ease of producing the alloy in question from recycled remelts. Rather than measuring alloys quantitatively, the RPI uses

Table III. Recycling Indices for Aluminum Alloys

Aluminum Alloys	Aluminum Recycling Index (ARI)	Recycling Processing Index (RPI)	Applications
1XXX	99	H	Electrical
2XXX	94	M/U (if mixed)	Aerospace
3XXX	98	M/H	Packaging / B&C
5XXX	94	M/H	Transportation / Packaging
6XXX	98	M/H	Transportation
7XXX	91	M/U (if mixed)	Aerospace

a qualitative scale, ranging from high (H) to medium (M) to low (L) to unusable (U). Table III illustrates where popular aluminum alloys rank according to each index, compared with more recycle-friendly alloys.

Intertwined with the need for consistent recycling standards across industries is the lack of common life cycle analysis (LCA) methodologies for competing materials.[17,18] Since no one LCA methodology has been universally accepted and uniformly applied, each metal/material claims its own interpretation of "carbon footprint" and "life cycle analysis." Variations creep in from such diverse items as debits/credits from raw materials and by-products, mode of energy source, and unending debate on energy saved during the product service phase. For intelligent, informed discussion and decision-making, there needs to be an agreed upon methodology to guide information sharing, analysis, and dialogue. Filling this knowledge gap presents a rich opportunity for LCA academics and practitioners to make significant leaps in the advancement and impact of LCA.

PUBLIC POLICY SOLUTIONS

The environmental movement has long benefitted from the support of government legislation. Through regulations and incentives, the government also has the power to assist in the aluminum industry's quest for carbon neutrality. This section examines two specific policy approaches and their ramifications.

Bottle/Deposit Bills

In the United States in particular, recycling rates could potentially be improved with increased attention on the evaluation and implementation of "bottle bills" in all states. This approach essentially creates a financial incentive for consumers to recycle their glass bottles and aluminum cans. *BottleBill.org*, a leader in the bottle/deposit bill initiative based in Culver City, California, USA, explains how this mechanism works:

> "The term 'bottle bill' is actually another way of saying 'container deposit law'. . . When a retailer buys beverages from a distributor, a deposit is paid to the distributor for each can or bottle purchased. The consumer pays the deposit to the retailer when buying the beverage. When the consumer returns the empty beverage container to the retail store, to a redemption center, or to a reverse vending machine, the deposit is refunded. The retailer recoups the deposit from the distributor, plus an additional handling fee in most U.S. states".[19]

Presently, only 11 states in the United States have passed some sort of bottle or deposit bill into law. However, the evidence of this legislative approach's ability to bolster recycling rates is compelling: states operating under some type of deposit bill legislation have recycling rates over 70% compared with ~ 40% for non-bottle–bills states.[26]

Protocols for Qualifying Recycling as Carbon Credits/Offsets[20–22]

The concept of carbon offsets is a relatively new phenomenon. The World Resources Institute, an environmental think tank based in Washington, D.C., defines a carbon offset as, "a unit of carbon dioxide-equivalent (CO_{2eq}) that is reduced, avoided, or sequestered to compensate for emissions occurring elsewhere."[20] In many industries, carbon offsets are based on a company's investing in some form of renewable energy to compensate for the carbon dioxide emissions its business generates. By offsetting its carbon emissions in this manner, the company effectively becomes carbon neutral.

This same principle can be applied to recycling, since recycling aluminum saves 95% of the energy needed to produce new aluminum from raw materials. Within this context, the amount of carbon credits businesses could potentially acquire through aluminum recycling is tremendous, making it both an effective and profitable solution. However, policy makers must first develop and implement protocols for qualifying recycling as carbon offsets.

ENSURING SUPPLY THROUGH SUSTAINABILITY PRACTICES

With a global population approaching 7 billion, there simply is not enough primary aluminum available to indefinitely meet demand. This creates an imperative for the aluminum industry to produce alloys and products capable of meeting many needs, while also being highly recyclable, in order to ensure an adequate aluminum supply for future generations.

In addition to advancing design and engineering approaches intended to extend the useful life of aluminum, the industry also needs to focus on capturing aluminum lost in landfills and incineration.[12,23,24] This author estimates that U.S. landfills alone contain more than 20–30 million tonnes (~ 240–360 million tonnes of CO_{2eq}) of used beverage cans (UBC), valued at ~ US $50–75 billion at current prices. This rate is increasing at the annual rate of 1 million tonnes (~ 12 million tonnes CO_{2eq}), valued at US $2.5 billion. In other words, new landfilled aluminum UBC in the United States is equivalent to running three primary aluminum smelters (~30,000 tonnes per year/smelter) full time for the purpose of producing buried products, with each landfilled aluminum can being equivalent to ~200 grams of CO_{2eq}.[3] The global aluminum industry should actively investigate the feasibility of "urban mining" to recover this large untapped resource and prevent further unintended carbon sequestration. [4]

Table IV. Market Share and Recycling Rates for Aluminum Products

Application Sector	Market Share (%)	Recycling Rate (%)	Comments
Transportation	28	~70	Higher for ground, lower for marine and aerospace; Long collection cycle
Building & Construction	22	~80	Long collection cycle
Electrical	17	~70	Long collection cycle
Packaging	14	~40	Consumer habits / difficult to recycle
Machinery / Equipment	10	~40	Long collection cycle
Electronics /Misc.	10	~20	Consumer habits / difficult to recycle
Overall	~100	~60	—

CURRENT AND EMERGING OPPORTUNITIES

While aluminum recycling rates for different markets vary widely based upon application and geography, overall global recycling rates for post-consumer scrap is currently estimated at 60%. The recycling rates for select market sectors are presented in Table IV.[25]

It takes 20 times more energy to make aluminum from bauxite ores than to recycle it from scrap. Tremendous savings in energy, money, and resources can be realized by even modest improvements in the rates presented in Table IV. Through a coordinated exploration—actively involving every sector of aluminum manufacturing and application—of processes and alternatives offered in this paper and other sources[23], the global aluminum industry could set a reasonable, self-imposed energy/carbon neutrality goal to incrementally increase the supply of recycled aluminum by at least 1.05 pounds for every one pound of incremental production via primary aluminum smelter capacity.

An array of challenges still loom ahead within the aluminum industry and the social, economic, and political structures that impact on it for making recycling the most profitable investment that it can be. Because of the potential "ripple effect" that actions in one aspect of the aluminum recycling scenario can have on the others, addressing these issues cannot be done in isolation. Instead, an approach that incorporates all technological and implementation considerations is necessary for success. By taking a lead role in this effort, the aluminum industry cannot only achieve carbon neutrality, but also be able to translate that achievement into real and positive business results.

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