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Achieving Carbon Neutrality in the Global Aluminum Industry

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In the 21st century, sustainability is widely regarded as the new corporate culture, and leading manufacturing companies (Toyota, GE, and Alcoa) and service companies (Google and Federal Express) are striving towards carbon neutrality. The current carbon footprint of the global aluminum industry is estimated at 500 million metric tonnes carbon dioxide equivalent (CO_{2eq}), representing about 1.7% of global emissions from all sources. For the global aluminum industry, carbon neutrality is defined as a state where the total "in-use" CO_{2eq} saved from all products in current use, including incremental process efficiency improvements, recycling, and urban mining activities, equals the CO_{2eq} expended to produce the global output of aluminum. This paper outlines an integrated and quantifiable plan for achieving "carbon neutrality" in the global aluminum industry by advocating five actionable steps: (1) increase use of "green" electrical energy grid by 8%, (2) reduce process energy needs by 16%, (3) deploy 35% of products in "in-use" energy saving applications, (4) divert 6.1 million metric tonnes/year from landfills, and (5) mine 4.5 million metric tonnes/year from aluminum-rich "urban mines." Since it takes 20 times more energy to make aluminum from bauxite ore than to recycle it from scrap, 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 metric tonnes for every tonne of incremental production via primary aluminum smelter capacity. Furthermore, the aluminum industry can and should take a global leadership position by actively developing internationally accepted and approved carbon footprint credit protocols.

INTRODUCTION

The industrial movement for safer operations began in 1930, followed by reforms in the mining industry of the 1950s. The pioneering practices led by Du Pont shattered the myth that accidents are the inevitable collateral damage of industrial work. Today, optimum efficiency and safety is the expected standard of the global industrial world. A similar paradigm shift occurred in the 1970s with the passage of the Clean Air Act. Subsequently, with the formation of the Environmental Protection Agency (EPA) in the USA, the zero-discharge (of solid, liquid, and gaseous pollutants) standard has become the industrial norm throughout the world. Japanese car manufacturers in the 1980s led the global movement of "zero-defect quality control," using Six Sigma and lean manufacturing methodologies. In the 21st century, sustainability is widely regarded as the new corporate culture, and leading manufacturing companies (Toyota, GE, and Alcoa) and service companies (Google and Federal Express) are striving towards carbon neutrality.

CARBON NEUTRALITY

Why should carbon neutrality become the new industry paradigm? Often, the ability to deliver "green," "carbon-neutral," or "sustainable" products and services can impact on long-term economic success in today's increasingly environmentally conscious global marketplace. Thus, the aluminum industry, by achieving carbon neutrality, can remain competitive with other materials alternatives. Striving for carbon neutrality now can help prepare the aluminum industry for the stricter government policies and social expectations on the horizon.

Many companies have launched advertising campaigns announcing that they have become—or

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are in the process of becoming—carbon neutral. Ball,[1] a columnist for *The Wall Street Journal*, observes this trend, noting Dell as an example, 'Dell said this summer that it has become "carbon neutral," the latest step in its quest to be "the greenest technology company on the planet".

To date, however, there is no international standard definition for what a company's "carbon footprint" entails. As Ball explains, "There is no universally accepted standard for what a footprint should include, and so every company calculates it differently." If carbon neutrality is ever to be achieved, we must first establish a standard of measurement, defining what qualifies as a company's carbon footprint.

The Australian Department of Climate Change and Energy Efficiency has already established a standard, the National Carbon Offset Standard (NCOS),[2] which "provides guidance on what is a genuine voluntary offset and sets minimum requirements for calculating, auditing and offsetting the carbon footprint of an organization or product to achieve 'carbon neutrality'." By adopting a similar carbon footprint standard on a global scale, it will finally be possible to legitimately determine an industry's carbon neutrality.

So what *is* carbon neutrality? For the purposes of this paper, carbon neutrality (for an integrated manufacturing industry in a "cradle-to-cradle" paradigm) is defined as an environmental carbon balance sheet with zero net CO_2 equivalent (CO_{2eq}) emissions. For the global aluminum industry, carbon neutrality is defined as a state where the total "in-use" CO_{2eq} saved from all products in current use, including incremental process efficiency improvements, recycling, and urban mining activities, exceeds the CO_{2eq} expended to produce the global output of aluminum.

Table I. Global metal industry carbon footprint (2008)

Metal	World Production (MMT*)	CO_{2eq}** (MT***/MT)	% Global GHG Emission
Iron and steel	1330	1.0	~4.4
Aluminum	38	12.7	~1.7
Copper	17	5.5	~0.3
Zinc	10	3	~0.1
Magnesium	1	> 18	~0.06
Titanium	0.1	> 20	~0.007

*Million metric tonnes; **carbon dioxide equivalent; ***metric tonnes.

CARBON FOOTPRINT

The metal industry contributes about 7% of total global carbon dioxide emissions from all sources, led by iron and steel (4.4%) and aluminum (1.7%). As shown in Table I, the aluminum industry worldwide produced 38 million tons of material in 2008, a mere 2.8% of the total volume produced by the iron and steel industry. Although the carbon footprint of the iron and steel industries is about three times larger than that of the aluminum industry, unit carbon emission for the aluminum industry (12.7 metric tonnes of CO_{2eq} per tonne) is about 13 times greater than that of iron and steel. This situation must be acknowledged and proactively addressed.

Table II illustrates the carbon footprint of the global aluminum industry at 500 million metric tonnes. The total global output (2008) of GHG measured in terms of global warming potential (GWP) and expressed as carbon dioxide equivalent (CO_{2eq}) is estimated at 29,888 million metric tonnes.[3]

METHODOLOGY

How, then, can the aluminum industry usher in this new paradigm of carbon neutrality? The concept was first articulated by the author in a previous paper and presentation using a qualitative framework.[4,5] This paper expands on that qualitative approach to a quantitative framework, outlining a methodology for designing and assigning a numerical value for each of the following five "cradle-to-cradle" strategies:

1. Increase use of "greener" sources of electrical energy by 15%
2. Reduce process energy requirements by 16%
3. Deploy 35% of products in "in-use" energy saving applications
4. Divert 6.1 MMT per year from incinerators/landfills
5. Recover 4.5 MMT per year from "urban mines"

Increase Use of "Greener" Source of Electrical Energy by 15%

The largest concentration of the aluminum industry's carbon footprint stems from the use of

Table II. Carbon footprint of the global aluminium industry (2008)

Items	Production (MMT)	Emission (CO_{2eq} MMT/ton)	Total Emission (MMT CO_{2eq})	Comments
Ore to metals production	38	12.7	482	World average
Recycling	37	0.5	18	~5% of primary

electrical energy in the smelting process. Table III documents the CO_{2eq} emissions from various electric generation sources at different global locations.

Aluminum producers are not able to use the best smelting electrical energy resources. For example, the electrical grid in the average aluminum production facility emits 12.7 kg of CO_2 for every kg of aluminum produced. Facilities that burn fossil fuels such as coal (as in China) often emit as much as 16 kg of CO_2 for every kg of material produced, a 26% carbon increase. Natural gas burning facilities, such as those in the Middle East, use only 13 kg of CO_2, an increase of only 2%. Aluminum producers should always strive to use clean, efficient power sources, such as nuclear (as in Western Europe) or hydro (as in Iceland, Canada, and Brazil). On average, facilities that use nuclear or hydroelectric power sources only emit about 6.2 kg of CO_{2eq} per kg of material produced, about half of the amount generated by the common electrical grid-powered facility.[6]

The trend toward use of "greener" electricity sources is fairly negative as most newer smelting plants are being built in China (with coal-fired power plants) and the Middle East (with natural gas-fired power plants). A reasonable goal in the long term should be to increase use of "greener" energy sources (hydro or nuclear from coal) by 15%, eliminating 27 million tons of CO_{2eq} emissions a year.

Reduce Process Energy Requirements by 16%

The aluminum smelting industry has made a significant reduction in its greenhouse gas (GHG) footprint over the past decade. This has been achieved almost entirely by a reduction in the anode effect contribution via perflourocarbon (PFC) gases, and to a lesser extent by the dilution of older, less efficient smelters, as new smelters are brought on stream.[7]

As shown in Table IV, the total carbon emissions of the aluminum industry (500 million metric tonnes) are distributed among its three largest components: electrical energy needed for electrochemical reduction of alumina into aluminum (236 million metric tonnes), release of 6500 times more potent greenhouse warming potential perflourocarbons (PFC) during anode effect (84 million metric tonnes), and the combustion of anode releasing carbon dioxide (46 million metric tonnes) during smelting.

Although Bayer–Hall–Heroult (H-H) processes, the only commercially viable routes employed globally to make alumina and aluminum, have gone through many innovations, there is still a potential for many evolutionary brownfield and revolutionary greenfield improvements.[8,9]

The following process improvements in the existing technologies, including the minimization of anode effect, and implementation of new technologies can assist in achieving the 16% goal:

Table III. Estimated global aluminum production and CO_{2eq} from electricity generating sources

Smelting Electrical Energy Source	Total GHG Emissions (kg CO_{2eq}/kg Al)	Base Change (%)	Estimated Global Production (%)	Source of Smelting Electrical Energy, Trend	Predominant Global Locations
Nuclear	6.2	−51	4	Decreasing	Western Europe
Hydro	6.2	−51	35	Decreasing	Canada, Iceland, Norway, Brazil
Average grid	12.7	0	NA		World
Natural gas	13.0	+2	16	Increasing	Middle East
Coal	16.0	+26	45	Increasing	China, India, Oceania, Europe

Table IV. Production steps emissions (kg CO_{2eq}/tonne aluminum)

Emissions	Mining	Refining	Anode	Smelting	Total
Fuel oil	120	790	10	380	1270
Natural gas		688	88	260	1036
Calcined coke			133		133
Pitch			301		301
Green coke			1199		1199
Electricity	100	152	59	6200	6511
PFC				2200*	2200
Total	220	1630	1790	9040	12,680

*GWP: 6500 CO_{2eq} per kg PFC.

Table V. Carbon footprint of aluminum production processes

Technology	Status	kg CO_{2eq}/tonne Al	Change from Base (%)
Hall–Heroult (H–H) at 4.5 cm anode–cathode distance (ACD)	Commercial	12.6	0
H–H center break prebake at 4.5 cm ACD (lower anode effect)	Commercial	10.0	−21
Wetted drained cathode at 2 cm ACD	Advanced Pilot	9.0	−28
Wetted cathode and inert anode at 2 cm ACD	Pilot	8.0	−44
Carbothermic electric furnace	Pilot	8.0	−44
Clay carbochlorination and chloride electrolysis	Pilot	8.0	−44

Process improvements for existing technologies:

- Replace rotary with fluid bed calciners
- Reduce electricity needed for smelting
- Lower anode effect
- Decrease carbon anode consumption

Development and adaption of new technologies:

- H-H center break prebake at 4.5 cm anode–cathode distance (ACD)
- Wetted drained cathode at 2 cm ACD
- Wetted cathode and inert anode at 2 cm ACD
- Carbothermic electric furnace
- Clay carbochlorination and chloride electrolysis

Table V documents the estimated carbon footprints (CO_{2eq}) for various new aluminum production processes under development (compared with the existing technology).[7–9] If the aluminum industry is able to reduce its energy needs by 16%, it will eliminate 79 million metric tonnes of annual carbon emissions.

Deploy 35% of Products in "In-Use" Energy Saving Applications

Most carbon footprint neutralizing uses of aluminum products are in the areas of transportation, as the use of lighter materials save energy "in-use" throughout the product lifetime. On the other hand, the least carbon neutralizing use of aluminum products are in the packaging and electronic applications with traditionally lower recycling rates due to suboptimal product design and unsustainable consumer behavior in the industrialized Western world. Additionally, the aluminum industry should also develop products for renewable energy such as hydro, solar, geothermal, and wind sources—a direct reduction of the carbon footprint.

Randall Scheps, chairman of the Aluminum Association's Aluminum Transportation Group[10] and marketing director at Alcoa Inc., observes, "We are fast-entering a transition stage to more holistic vehicle design approaches premised on greater use of lighter, stronger and more crash-absorbent aluminum alloys replacing less efficient iron and steel. Vehicles with their size maintained but down weighted with aluminum are inherently more efficient than heavier ones."

The integration of aluminum components into automobiles, especially in electric and hybrid vehicles, is on the rise. Based upon a survey by Ducker Worldwide, The Aluminum Association estimates that North American automakers will increase their use of aluminum from 327 pounds per vehicle in 2009 to 550 pounds per vehicle in 2025.

A good target for the global aluminum industry is to increase the usage in the ground transportation sector from current 28% to 35%. Based on the number of ground transportation vehicles active on world roads today, it is estimated that this action will cut the carbon footprint of the aluminum industry by 266 million metric tonnes of CO_{2eq} emissions per year. This calculation is based on the assumption that every metric tonne of additional aluminum in automotive application saves 20 metric tonnes of CO_{2eq} over the lifetime of the vehicle. With changing consumer habits in developing countries moving towards higher numbers of vehicles on world roads, the global aluminum industry should utilize the majority of new aluminum production for automotive applications. Table VI recommends the most prudent use of aluminum solely based upon carbon neutrality considerations.

Divert 6.1 MMT per Year from Incinerators/Landfills[11]

Recycling is one of the cheapest and most sustainable ways to lower the carbon footprint of the global aluminum industry. Recycled aluminum has 5% of the carbon footprint of primary aluminum. A recent paper presents a framework suggesting integration of somewhat disparate elements of the aluminum recycling landscape by focusing on improved: (1) engineering, (2) communication, (3) public policy, and (4) actionable sustainability strategies.[12]

Since it takes 20 times more energy to make aluminum from bauxite ore than to recycle it from scrap, 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 pound of incremental production via primary aluminum smelter capacity.

Table VI. Market share and recycling rates for aluminum products

Application Sector	Current Market Share (%)	Recycling Rate (%)	Comments	Suggested Market Share for Carbon Neutrality (%)
Transportation	28	~70	*Ground*—Higher recycling rate and medium collection cycle *Marine and aerospace*—Lower recycling rate and long collection cycle	35
Building and construction	22	~80	Long collection cycle	25
Electrical	16	~70	Long collection cycle	20
Renewable energy	<1	~		5
Packaging	14	~40	Negative consumer habits Educational issues *Foils*—difficult to recycle	5
Machinery/equipment	10	~40	Long collection cycle	5
Electronics/misc.	10	~20	Consumer habits/difficult to recycle	5
Overall	100	~59		100

Table VII. Carbon neutrality achieving steps

Action Item	CO_{2eq} (Million Metric Tonnes per Year)
World carbon footprint from all sources	29,888
1. World aluminum carbon footprint, current status	500 (~1.7% of world)
2. Increase use of "green" electrical energy grid by 15%	(27)
3. Reduce process energy needs by 16%	(79)
4. Deploy 35% of products in "in-use" energy saving applications	(266)
5. Divert 6.1 million metric tonnes/year from landfills	(74)
6. Mine 4.5 million metric tonnes/year from "urban mines"	(54)
7. Total credit from items 2-6	(500)
Carbon footprint balance (items 1–7)	Zero

The current global aluminum recycling rate is only 59%, which means nearly 16 million tons of unaccounted or "lost" aluminum is being incinerated or dumped into landfills every year.

The carbon footprint of the global aluminum industry can be lowered by 74 million metric tonnes per year by increasing the current recycling rate of 59% to 75%. This goal will divert over 6.1 million metric tonnes per year of aluminum from going to landfills or incinerators.

Recover 4.5 MMT per Year from "Urban Mines"[13,14]

It has been estimates that U.S. landfills alone contain more than 20 million tons to 30 million tons (~240 million tons of CO_{2eq} to 360 million tons of CO_{2eq}) of used beverage cans (UBC), valued at ~US $50 billion to US $75 billion at current prices. This rate is increasing at the annual rate of 1 million tons, valued at US$ 2.5 billion. In other words, new landfilled aluminum UBC in the USA is equivalent to running three primary aluminum smelters (~330,000 metric tonnes per year/smelter) full time for the purpose of producing buried products. Each landfilled aluminum is equivalent to ~200 g of CO_{2eq}. The global aluminum industry should actively investigate the feasibility of "urban mining" to recover this large, untapped resource and prevent further unintended carbon sequestration. Landfills in advanced Western societies constitute among the "richest bauxite deposits" in the world.

Some have already begun capitalizing on this largely untapped resource, such as John Sherigan, CEO of Electronic Recyclers International. Sherigan's company has recently partnered with Alcoa to advance its urban mining efforts. An editorial on the *Modern Metals* website notes[15] that "urban mining" represents both a future and present consistent feedstock for Alcoa.

By exploring urban mining, the aluminum industry can significantly reduce its carbon footprint, while simultaneously generating metric tonnes (literally) of raw materials. If the industry were able to divert 4.5 million tons of aluminum from landfills, it would reduce its carbon impact by 54 million tons annually.

CONCLUSIONS AND PATH FORWARD: CARBON SCORE CARD, STANDARD, AND PROTOCOLS

Table VII illustrates a suggested carbon scoreboard. The global aluminum industry can become "carbon neutral," reducing its current carbon print of 500 million metric tonnes per year to zero, by assigning a numerical value for each of the five "cradle-to-cradle" strategies.

As outlined in this paper, the aluminum industry can and should take a global leadership position by actively developing internationally accepted and approved carbon footprint credit protocols.

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