Energy Implications of the Changing World of Aluminum Metal Supply

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Driven primarily by energy considerations, there has been a major change in the geographical distribution of primary aluminum production over the past few decades, even as the energy efficiency of the process has been improved. Meanwhile, in the United States, production of aluminum from secondary sources increased nearly ten-fold. This paper discusses past and projected future trends, emphasizing the changes in energy savings potential as the industry comes to rely more on remelting and less on primary production.

INTRODUCTION

It has been said that the only thing that is constant is change. This adage certainly applies to the worldwide aluminum industry. Steadily increasing demand for aluminum has been met not only by production of primary metal but also by the recycling of metal from both in-process manufacturing and post-consumer sources. Over time the geographic distribution of production has shifted, driven by energy and raw-materials factors, and this transformation will likely continue. However, changes in the relative proportions of primary vs. secondary metal sources have strong implications for energy consumption patterns and opportunities for improved energy efficiency. A scenario for the U.S. aluminum industry is presented in this article that illustrates the increasing impact of remelting as compared to primary production by smelting of aluminum in the next few decades, with an emphasis on the magnitude of the opportunity for energy savings.

METAL SUPPLY— PAST AND PRESENT

The primary metal production process for aluminum is still fundamentally the same one invented independently by Hall and Héroult nearly 120 years ago, although the engineering manifestation of the process has changed enormously. While the smelting process itself remains relatively unchanged, what has changed is the location where aluminum smelting occurs, dictated both by energy and raw materials drivers. In the 1880s, the Pittsburgh Reduction Company utilized electricity produced from steam turbines to produce primary aluminum. With the advent of more inexpensive hydropower, smelting shifted from the Pittsburgh area to Massena, New York. This early transition was a harbinger of the future, evidenced by the modern-day trend of construction of new primary production capacity in countries with low electrical power costs in preference to regions with higher costs. Idling and closures of U.S. primary capacity in the Pacific Northwest and recent announcements of new capacity development in Iceland, Trinidad, and elsewhere[1] are evidence that the energy cost driver is still strong.

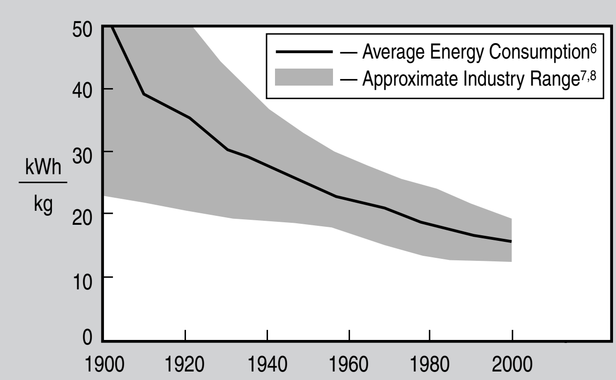

Figure 1. Historical energy efficiency improvements for aluminum smelting.

Looking at the statistics for a moment and concentrating on the last decade, the world primary aluminum production grew from 19.5 million tonnes in 1992 to 25.9 million tonnes in 2002, an average growth rate of 3.1%.[2] From the Aluminum Association reporting of U.S. Geological Survey data, it is apparent that this growth has not occurred uniformly throughout the world. Primary production in the United States has decreased by 33%, from slightly over 4 million tonnes in 1992 to 2.7 million tonnes in 2002, while the growth in primary production has occurred primarily in Canada, Russia, and China.

While primary production in the United States has decreased, shipments of aluminum in the form of both wrought and cast products have increased from 8 million tonnes in 1992 to 10 million tonnes in 2002.[2] If U.S. primary production is shrinking, where is the aluminum coming from to feed the hungry casting machines, rolling mills, and extrusion presses? The answer again can be found in the Aluminum Association data[2] and indicates that imports of ingot and mill products as well as

Table I. Energy Required Smelting vs. Remelting

	Smelting*	Remelting*
Theoretical minimum	10,200	510
Current average	26,000	2,200
Practically achievable	20,000	925
Energy-efficiency savings opportunity	6,000	1,275

* BTU per pound

secondary recovery (i.e., recycling) comprise substantial components of the metal supply to the U.S. aluminum industry today. In 2002, imports provided 40.8% of the total while secondary recovery accounted for 30.7%, with domestic primary production providing the remainder at 28.5%. From 1992 to 2002, imports grew at an annual rate of 6.1%, secondary recovery at 0.9%, and primary production declined at a rate of 2.3% per year. In effect, the United States has increasingly been importing energy in the form of aluminum ingot. Aluminum has been referred to as an "energy bank," in that once the energy has been "invested" in it through the smelting process it can be effectively drawn upon again and again through recycling.

Recycling and secondary metal production have become increasingly important components of metal supply, also driven by energy considerations. A well-quoted figure is that remelting of aluminum consumes roughly 5% of the energy required for production of primary metal from ore. To provide historical perspective, in 1960, 401,000 tonnes of aluminum were supplied by recycling. In 2000, 68 secondary processing plants in the United States were producing 3,450,000 tonnes. This constitutes a 760% growth in production of aluminum from secondary sources.[3] Choate and Green note that "the growth of secondary aluminum production represents the greatest change in the structure of the industry and in the energy consumption associated with aluminum manufacturing,"[3] which is clearly supported by the data.

LOOKING TO THE FUTURE

The trends in metal supply sources have significant future ramifications. The U.S. aluminum industry's recognition of these trends is captured in the Aluminum Industry Vision, published in 2001, and the Aluminum Industry Technology Roadmap that followed in 2003. Specifically, the vision notes "production of recycled or secondary ingot will play an increasingly significant role in the growth of the North American aluminum industry."[4] One prediction is that recovery rates of aluminum will increase with improved technologies, specifically referring to advanced technologies in scrap sorting. An industry-wide performance target in the area of sustainability identified in the technology roadmap is to "recycle 100% of aluminum by 2020."[5] Such an aggressive target will require technology developments to ensure metal quality and enable use of recycled metal in downstream products, which is the focus of a number of R&D priorities identified in the roadmap. See the Research in Recycling and Remelting sidebar for R&D priority details.

With the expected continued growth in aluminum demand, the Aluminum Industry Vision projects that increased imports will be needed since there will not be enough available scrap or domestic primary production capacity. Certainly a projection of past trends into the future must be tempered with alternative scenarios that can influence the outcome. One possibility is a technical breakthrough in the aluminum reduction process that could change the assumptions regarding energy, and hence open new options. Although research to date has not yielded a significant, commercially viable quantum change in process energy savings, the industry will likely continue to pursue inert-anode and wetted-cathode technologies as well as alternative reduction processes such as the carbothermic process. However, these are high-risk R&D efforts with no near-term assurance of success.

ENERGY IMPLICATIONS

In addition to economic and supply effects of a changing distribution of aluminum metal supply sources, there are also substantial energy implications. Energy efficiency has improved greatly during the first century of aluminum production, as shown in Figure 1.[3] Ongoing research seeks to further reduce the energy intensity of the smelting process, which is only operating at roughly 35% energy efficiency.[9]

Recent analyses[3] have identified the theoretical minimum energy for smelting, current practice, and practical minimum values. Table I summarizes these results and indicates the potential benefit of further process improvements.

An alternative to metal from a smelter is remelted primary ingot and recycled aluminum. Table I compares the energy requirement for remelting with theoretical and practical minimum values. While the potential energy savings are less for

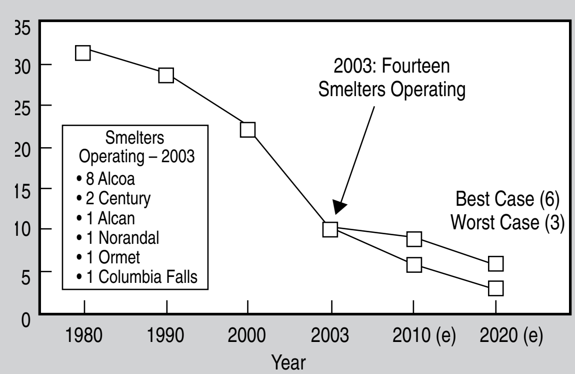

Figure 2. The number of primary smelting plants in the United States.

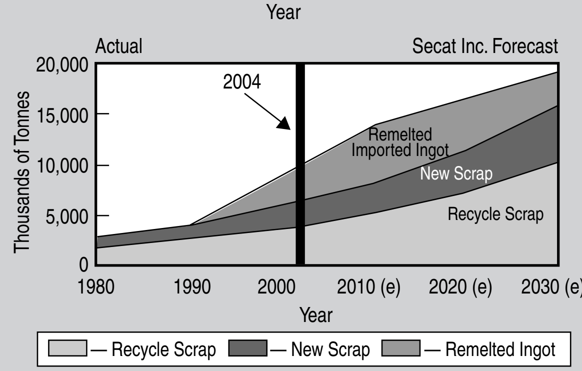

Figure 3. The U.S growth in remelting.

RESEARCH IN RECYCLING AND REMELTING

Achieving the Aluminum Industry Technology Roadmap goal of 100% recycling of aluminum by 2020 will require advancements in technology. R&D priorities identified in the roadmap[5] include:

- Develop and design aluminum remelting furnaces for the future that minimize melt loss, improve cost effectiveness, increase safety, improve fuel/energy efficiency, improve melt rates, and reduce emissions.
- Develop a low-cost process for metal purification to enable production of primary alloys from recycled scrap. This includes methods to remove specific impurities such as Mg, Fe, Pb, Li, Si, and Ti to produce high-quality metal from mixed scrap.
- Develop new secondary alloys that better match scrap to specifications for increased utilization. Coupled with this is a goal to develop manufacturing processes for scrap-tolerant alloys, such as spray rolling and other rapid solidification processes.
- Minimize the loss of aluminum to oxidation and dross formation during remelting. Priorities include developing a more complete understanding of oxidation mechanisms and developing processes that more effectively separate metal from dross or salt cake.

Achieving enhanced recyclability and energy efficiency are key building blocks in realizing the Aluminum Industry Vision that "(b)y 2020, the North American aluminum industry will be universally recognized as a world leader in providing innovative, materials-based solutions that build on aluminum's intrinsic sustainability and deliver superior value to users."[4]

remelting, as the proportion of metal supplied to manufacturing from remelting of ingot and recycled aluminum increases in comparison to that from primary production, energy-efficiency improvements for remelting will become more important.

Changing proportions of metal supply to downstream manufacturing processes from primary production and other sources can have dramatic effects on the energy requirement as well as opportunities for improved energy efficiency. Since primary production relies heavily on electricity while remelting of primary ingot or recycling traditionally employs natural gas, a shift from primary production affects the nature of energy resources required. See the sidebar, Predictions of U.S. Energy Industry Demands, for a perspective on overall energy trends.

A POSSIBLE ENERGY FUTURE FOR THE U.S. ALUMINUM INDUSTRY

Secat, Inc., a technical and business resource for the aluminum industry located in Lexington, Kentucky and dedicated to providing intellectual resources to the aluminum industry, has developed a scenario for the future based on a set of assumptions relevant to the U.S. aluminum industry that provides interesting strategic insights into future energy consumption dynamics.

In the primary production area, there are currently 14 operating smelters (down from 32 in 1980), with seven at full capacity and seven operating at approximately 63% combined capacity.[10] The Secat scenario assumes that by 2020, 80% of the smelting capacity operating in 1980 will be shuttered and only three to six primary facilities will be operating (Figure 2). This scenario assumes that large multinational companies will emphasize primary production outside the United States at lower-cost energy sites.

In contrast, the Secat forecast projects significant growth in the volume of aluminum that will be melted over the next 20–30 years. This growth is driven by the continued growth of the U.S. aluminum market along historical trends of 2.5% per year, with slightly faster growth in the automotive area and slower growth in packaging as well as building and construction. The volume of metal to be melted is made of recycled, post-consumer scrap, new scrap generated in manufacturing operations, and remelted primary ingot, as illustrated in Figure 3. The scenario assumes a growth rate of recycled scrap of 3.6%, driven by the increasing return of aluminum from end-of-life vehicles as the impact of increased aluminum usage in automobiles in particular makes its way into the scrap stream.[11] In addition, the rate of generation of new scrap is assumed to be 22% of shipped product. Finally, it is assumed that 75% of imported ingot will be remelted through 2010, 50% from 2010 to 2020, and 25% thereafter, based on the assumption that an increasing proportion of ready-to-fabricate ingot for rolling and extrusion will be provided with continued improvements in metal

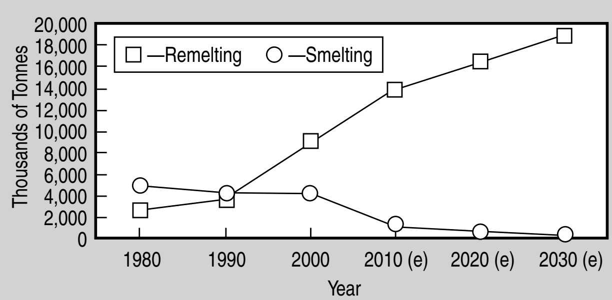

Figure 4. The U.S. trends of remelting vs. smelting.

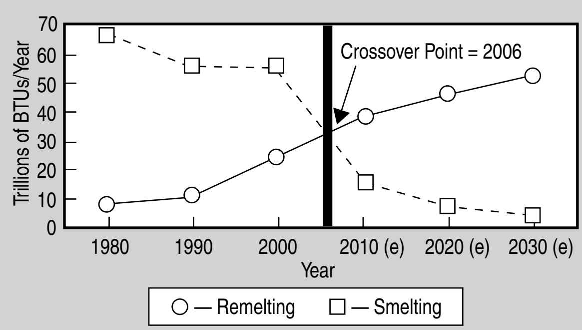

Figure 5. The U.S. energy-efficiency savings opportunities remelting vs. smelting.

PREDICTIONS OF U.S. INDUSTRIAL ENERGY DEMANDS

Recognizing that predictions are difficult, it is interesting to take a look at the "Annual Energy Outlook 2004 with Projections to 2025" prepared by the U.S. Energy Information Agency. While this document addresses energy use and supply very broadly, some highlights include:

- Primary energy use in the industrial sector is projected to increase by 1.2% per year.
- Industrial purchased electricity use is projected to increase 43% from 2002 to 2025, while that for natural gas is expected to rise 41% over the same time period.
- Prices for natural gas delivered to the end-use sectors are expected to fall in the early years of the forecast as wellhead prices decline. After 2006, wellhead prices are projected to start increasing, and delivered natural gas prices begin to increase in 2012. The average end-use price of natural gas is expected to increase 54 cents per thousand cubic feet from 2006 to 2025 (in 2002 dollars).
- Average U.S. electricity prices, in real 2002 dollars, are expected to decline by 8 percent, from 7.2 cents per kilowatt-hour in 2002 to 6.6 cents in 2008, and to remain relatively stable until 2011. From 2011 they are projected to increase gradually, by 0.3 percent per year, to 6.9 cents per kilowatt-hour in 2025.
- Industrial energy intensity (consumption per unit of output) will decrease due to a combination of slower growth of energy-intensive industries and their respective proportional energy use (labeled "Structural" in Figure A) and improved industrial energy efficiency.

The full report is available at *www.eia.doe.gov/oiaf/aeo/index.html.*

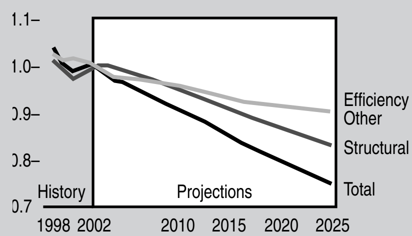

Figure A. The components of improvement in industrial delivered energy intensity (index—2002 = 1).

treatment, alloying, and ingot-casting technologies.

Figure 4 summarizes the projected impacts of a continued decline in primary production and an increase in aluminum that would be remelted in the United States based on the assumptions of the Secat scenario.

Coupled with the changes in the volume of aluminum provided by smelting and remelting processes are changes in the amount of energy used in the respective processes. While the smelting process requires 20 times the energy of remelting, the increasing proportion of metal that will be melted vs. smelted will shift the energy expenditure balance toward remelting. But perhaps more important is the opportunity for energy savings through process and technology improvements in the respective processes and the resultant impact on potential future energy usage. Considering the growth of remelting vs. smelting and the opportunities for energy-efficiency improvement described in Table I, it is obvious that there will be a point where the magnitude of the potential energy savings from improved remelting processes will outweigh the potential benefit from savings realized for the increasingly smaller primary production base. Using the projected volumes for smelting and re-melting for the scenario represented in Figure 5, the crossover point is in 2006. While this point would vary with equally plausible assumptions that could be selected for alternative scenarios, it is apparent that the crossover will likely occur in the not-so-distant future. The key outcome from this, at least from a U.S. perspective, is that efforts to realize the potential energy-efficiency savings for remelting estimated in Table I will have an increasingly valuable payoff in the decades to come.

CONCLUSION

Energy considerations will continue to be a significant factor in the industrial processing of aluminum worldwide. Certainly other components, such as the cost of capital and labor, tariffs, environmental regulations, and the price and availability of scrap and raw materials will also have important influences. In the United States, consumption will continue to grow while primary production will continue to shrink. Thus, the supply of metal to downstream fabrication processes will need to be increasingly met from remelted ingot and scrap sources. As a result, energy-efficient technologies for remelting and fabrication will play a more pivotal role in reducing energy consumption, environmental impacts, and imports.

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References

1. P. Glader, "Alcoa to Build $1 Billion Smelter on Trinidad," *Wall Street Journal* (May 24, 2004).
2. *Aluminum Statistical Review for 2002* (Washington, D.C.: The Aluminum Association, Inc., 2003).
3. W.T. Choate and J.A.S. Green, "U.S. Energy Requirements for Aluminum Production: Historical Perspective, Theoretical Limits, and New Opportunities" (full report), *www.oit.doe.gov/aluminum/pdfs/al_theoretical.pdf.*
4. *Aluminum Industry Vision: Sustainable Solutions for a Dynamic World* (Washington, D.C.: The Aluminum Association, Inc., 2001).
5. *Aluminum Industry Technology Roadmap* (Washington D.C.: The Aluminum Association Inc., 2003)
6. *"Electrical Power Used in Primary Aluminium Production,"* International Aluminium Institute, *www.world-aluminium.org.*
7. W. Haupin, "History of Electrochemical Energy Consumption by Hall-Heroult Cells, *Hall-Heroult Centennial: First Century of Aluminum Process Technology 1886–1986* (Warrendale, PA: TMS, 1986) pp.106–113.
8. A.R. Burkin, *Production of Aluminum and Alumina (Critical Reports on Applied Chemistry, Vol. 20)*, (Hoboken, NJ : John Wiley & Sons, 1987).
9. W.T. Choate and J.A.S. Green, "U.S. Energy Requirements for Aluminum Production: Historical Perspective, Theoretical Limits, and New Opportunities," *Energy Efficient Manufacturing Processes*, ed. I.E. Anderson, T. Grobstein Maréchaux, and C. Cockrill (Warrendale, PA: TMS, 2003), pp. 99–113.
10. R.P. Pawlek, "Primary Smelters of the World," *Light Metals Age* (April 2004), p. 6.
11. A. Gesing, "Assuring the Continued Recycability of Light Metals in End-of-Life Vehicles: A Global Perspective," in this issue.

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