ALUMINUM RECYCLING AND PROCESSING FOR ENERGY CONSERVATION AND SUSTAINABILITY

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ALUMINUM AND ENERGY—energy and aluminum—the two have been intimately linked since the industry started in 1886. That was when both Charles Martin Hall, in the United States, and Paul Heroult, in France, working independently, almost simultaneously discovered an economical process to produce aluminum from a fused salt using electrolysis. From this relatively recent discovery, the use of aluminum has grown rapidly and overtaken other older metals, such as copper, tin, and lead. It is now the second most widely used metal after steel.

Although the actual chemistry of the winning of aluminum from its oxide, alumina, has not changed greatly since 1886, the growth of the industry has brought about huge changes in production scale and sophistication. Also, there have been considerable reductions in the amount of energy used per unit of production. However, the production of aluminum is still energy-intensive, and the smelting process requires approximately 15 MWh per metric ton of aluminum production. For the United States, aluminum production consumes approximately 2% of the total industrial energy used.

For most of the 120 years of aluminum production, the growth of aluminum and energy production from hydroelectric sources were essentially symbiotic in nature. Aluminum production requires large quantities of stable and low-cost power, while hydroelectric projects need steady baseline users to ensure the viability of a hydroelectric project. Nowhere was this linkage between the aluminum industry and hydroelectric power producers better demonstrated than in the Pacific Northwest of the United States. There is now a concentration of both smelters and hydroelectric dams in the Columbia River basin. Although this mutually beneficial relationship was tested on occasion by market recession, drought, or lack of sufficient snowpack, the linkage persisted for several decades. It was not until 2000 and 2001 that the severe economic recession, coupled with the extreme energy crisis in California, caused the linkage between the industry and hydroelectric power producers to finally rupture. At this time, several aluminum smelters “mothballed” their operations, and power producers discontinued their supply arrangements with the aluminum smelters. About this same time, the importance of recycled secondary aluminum grew, and, in fact, in 2002, the percentage of recycled metal exceeded the primary smelted metal in the total U.S. metal supply for the first time.

Recycling of aluminum is vitally important to the sustainability of the aluminum industry. When the metal has been separated from its oxide in the smelting process, it can be remelted and recycled into new products numerous times, with only minimal metal losses each time. In fact, as the lifecycle and sustainability studies discussed in Chapters 3, 4, and 5 indicate, the recycling of aluminum saves ~95% of the energy used as compared to making the metal from the original bauxite ore. This enormous energy savings has accounted for the continuing growth of the secondary industry and has led to the concept that aluminum products can be considered as a sort of “energy bank.” The energy embedded in aluminum at the time of smelting remains in an aluminum product at the end of its useful life and effectively can be recovered through the recycling process. Probably the best example of this is the ubiquitous aluminum beverage can that, on average, is recovered, recycled, and fabricated into new cans that are put back on the supermarket shelves in approximately 60 days!

With an increasing awareness of environmental and climate-change issues in the public arena, it is considered that the publication of this sourcebook will be most timely. The purpose of this book is to provide a comprehensive source for all aspects of the sustainability of the aluminum industry. It is
anticipated that issues of sustainability will become increasingly important in the next couple of decades as individuals, companies, various agencies, governments, and societies in general strive to seek a responsible balance between using materials to maintain and improve living standards while not depleting the planet of its limited mineral and material resources for future generations.

This publication is a collection of basic factual information on the modeling of material flow in the aluminum industry, the life-cycle materials and energy inputs, and the products, emissions, and wastes. The energy savings involved with recycling, various scrap-sorting technologies, and future energy-saving opportunities in aluminum processing are outlined. Finally, the positive impact of the growing use of lightweight aluminum in several segments of the transportation infrastructure and its benefit on greenhouse gas production is also highlighted. This book should provide much-needed basic information and data to reduce speculation and enable fundamental analysis of complex sustainability issues associated with the aluminum industry.

Regarding the specific contents of this book, Chapter 1 is a brief introduction to the concept of life-cycle analysis by Hans Portisch and coworkers. Portisch has pioneered in the field of life-cycle studies and has helped to establish many of the life-cycle protocols developed by the European Union and International Standardization Organization (ISO) for working groups. Chapter 1, entitled “Life-Cycle Engineering and Design,” is an opportunity for the reader to become familiar with the concept of life-cycle analysis and its terminology that will be important in appreciating several of the subsequent chapters.

Chapter 2, entitled “Sustainability—The Materials Role,” by Lyle Schwartz, is probably the real introduction to the complex subject of sustainability. This chapter was first presented by the author as the Distinguished Lecture in Materials and Society in 1998. The chapter sets out the case for sustainability and life-cycle analysis and is introductory in nature. The huge worldwide growth of the automobile is used to illustrate the enormity of the materials and sustainability issues facing the technical community and society in general. The chapter traces some recent history and proposes several paths for future direction, such as:

- Cleaner processing
- The development of alternative materials
- Dematerialization, or the use of less material per capita to accomplish the necessary material requirements
- Reuse and recycling

The latter, recycling, is of course one of the key attributes of aluminum. This chapter also contrasts other materials, such as magnesium, advanced steels, and polymer composites, with aluminum in the context of reducing the weight of automobiles to enhance fuel efficiency. The chapter ends with a call to action by the professional societies and the individual materials scientists. It is indeed a rallying call for materials responsibility!

The Life-Cycle Inventory for the North American Aluminum Industry, discussed in Chapter 3, represents the original (year of 1995) study of the industry and is probably still the most comprehensive. It has since become the basis for future studies by the International Aluminum Institute (IAI). The study was conducted in response to a request from Chrysler, Ford Motor Company, and General Motors under the United States Automotive Materials Partnership. This automotive materials partnership was enabled by the PNGV program established by the U.S. Government. Recently, the PNGV activities have transitioned to FreedomCAR and its emphasis has been expanded to include other light materials, e.g. Mg, Ti and composites, as well as aluminum. The purpose of this study was to provide the participating companies with detailed life-cycle inventories of the various processes within the aluminum product life cycle. This information provides a benchmark for improvements in the management of energy, raw material use, waste elimination, and the reduction of air and water emissions. Although this is titled a North American study, it was in fact global in reach due to the international operations of the 13 companies taking part. The study incorporated data from 15 separate unit processes located in 213 plants throughout North and South America, Africa, Australia, Europe, and the Caribbean. The results were tabulated by an independent contractor (Roy F. Weston, Inc.) and were peer reviewed by a distinguished panel of experts prior to publication in accord with ISO methodologies. One excellent feature of this chapter is the graphical presentation of the results. For example, for any particular process, such as aluminum extrusion or cold rolling, it is possible to see at
a glance what the materials and energy inputs are and what are the products, air emissions, and wastes generated to that stage in the fabrication process.

Following the publication of the comprehensive life-cycle study discussed in Chapter 3, the leaders of the aluminum industry vested in the IAI, based in London, the responsibility of maintaining and extending the database to include significant areas of aluminum production that were not included in the initial study, namely Russia and China. Also, the IAI was requested to develop several global performance indicators and to track these indicators toward key sustainability goals agreed upon by the international industry. The global performance indicators chosen include such items as primary production; electrical energy used for production; emissions of greenhouse gases during electrolysis; specific emissions of perfluorocarbon gases, which are potent global-warming gases; consumption of fluoride materials; as well as injury rates and loss time severity rates. The considerable progress that the industry has made toward achieving many of these voluntary objectives is described in Chapter 5. The addendum report, updated to the end of 2005, illustrates quantitatively the industry’s progress toward the 12 voluntary objectives. Significant progress has been achieved and documented.

The sixth chapter, entitled “Material Flow Modeling of Aluminum for Sustainability,” by Kenneth Martchek of Alcoa, describes the development of a global materials flow model. Annual statistical data since 1950 from all the significant market segments have been combined with the most recent life-cycle information from the IAI to develop this global model. The model has demonstrated good agreement between estimated and reported worldwide primary production over the past three decades. Probably one of the most interesting features of the chapter is the table citing the worldwide collection rates and recycle rates for each market segment. The model also demonstrates that approximately 73% of all aluminum that has ever been produced is contained in products that are currently in service—surely a good testament to the recyclability and versatility of the metal!

Chapter 7 is devoted to a detailed discussion of the recycling of aluminum. As noted previously, recycling is a critical component of the sustainability of aluminum because of the considerable energy savings and the equivalent reduction in emissions from both energy and metal production. The chapter starts with a discussion of the recycling process and reviews the steps to remelt, purify the molten metal, and fabricate new products. The chapter also contains a discussion of the life-cycle trends in each major market area and how these factors impact recyclability. For example, one significant development that is discussed is the growing importance of automotive scrap. It is now estimated from modeling approaches that automotive scrap became more dominant than the traditional recycling of beverage containers at some stage during the 2005 to 2006 time period. This transition has occurred because of the marked increases of aluminum being used in automotives to enhance fuel efficiency, the fact that auto shredders are now commonly used, and shredder scrap can be economically sorted on an industrial scale. The transition has also occurred because the rates for the collection of can scrap have recently declined from the peak values of 1997, when ~67% of all cans were bought back by the industry, to the time of writing, when the recycling rates are hovering around 50%.

One dominant issue in the recycling of automotive scrap is the control of impurities, especially iron and silicon, that inevitably build up during the recycling process. Cast aluminum alloys, with their higher silicon content, are better able to tolerate this increase of impurity content than wrought alloys. Future trends, potential solutions, and research directions to resolve this issue of impurity control are outlined in this chapter. Also, the chapter mentions the potential impact of government regulations in European Union countries that now mandate that vehicles be 95% recyclable by the year 2015. Chapter 7 concludes with a brief discussion of the safety issues related to melting and casting aluminum.

Aluminum products are formed from an extremely wide array of alloys. These range from the soft alloys used in foil and packaging material, to the intermediate alloys used in the construction of boats and trains, to the hard alloys used in aircraft and aerospace applications. It is inevitable that some amount of all these alloys will end up in the products from the industrial shredder. Accordingly, to achieve the optimum recycling, it is most economical to identify and separate scrap and to reuse the specific alloying elements in the most advantageous manner. This is why the recent advances in scrap sorting by Adam Gesing and his coworkers at Huron Valley Steel Corporation are so significant. These developments are detailed in Chapter 8. This chapter is a comprehensive discussion of the complexities of automotive alloys and recycling issues. The chapter provides a state-of-the-art description of
sorting technologies and demonstrates alloy sorting by color, x-ray absorption, and laser-induced breakdown spectroscopy technology. Color sorting of cast material from wrought alloys is now fully established on a commercial scale, and LIBS sorting has become commercially viable in the past couple of years.

The next chapter, Chapter 9, explores some of the emerging trends in municipal recycling from the perspective of the operation of a municipal recycling facility. More importantly, the chapter discusses at length the issue of impurities and alloy content and how best to assimilate the recycled material stream into the existing suite of aluminum alloys. At present, sorted material can contain a wide range of elemental content, and this can modify and impact the physical, chemical, and mechanical properties of recycled alloys. This chapter, contributed by Secat and the University of Kentucky with partial support of the Sloan Foundation, suggests several routes to optimize the economical and property benefits achieved through recycling. It also explores the development of aluminum alloys that are more tolerant of recycling content, that is, recycling friendly alloys.

The final chapter of the sourcebook, Chapter 10, was originally prepared by BCS, Inc. for the U.S. Department of Energy in Washington, D.C., in February 2003 but has since been updated with the latest available data as of early 2007. This chapter looks at the whole production system for aluminum, from the original bauxite ore, through refining of alumina and smelting of aluminum, to various rolling, extrusion, and casting technologies. From an historical perspective, the chapter explores the energy requirements for aluminum production. The theoretical energy limits for each process step are compared to the actual current industry practice, and new opportunities for saving energy are highlighted. The original report was commissioned as the baseline study of the industry by the Department of Energy and contains extensive discussions of potential advances in aluminum processing and fabrication. For example, the potential of wettable cathodes, inert anode technology, carbothermic reduction, and various melting and fabrication technologies are discussed at length. Finally, the chapter is most valuable because it is supported by numerous appendices with almost 50 years of industry data and statistics. Much of the energy data used for the energy calculations evaluating competing technologies is drawn from the industry life-cycle outlined in Chapter 3.

It is hoped that this compilation of published material can be a contribution to the sustainability debate and, specifically, can help to increase the understanding about the sustainability and recyclability of aluminum. The availability of credible information can only help sustain rational debate and the development of optimal actions and policies for the future.

Much progress has been made in recent years, although a lot still remains to be achieved. At the time of writing, the *Baltimore Sun* newspaper (dated January 24, 2007), in an article entitled “Plane Trash,” refers to a report by the National Resources Defense Council that says that the aviation industry is pitching enough aluminum cans each year to build 58 Boeing 747s! This is blamed on a lack of understanding and on a mishmash of conflicting regulations and procedures at various airports around the country. While many airports are in fact recycling much of their trash and thereby reducing operating costs and landfill fees, many airlines and airports are not doing so. Under the present conditions and with the potential gains of energy and environmental emissions that are available through recycling of beverage cans, this situation seems remarkably shortsighted, especially when all cans are collected before the termination of a flight! On the other hand, enormous progress has been made in recycling and sustainability. Especially, it is noteworthy that computer models now indicate that the aluminum industry will become “greenhouse gas neutral” by the year 2020. This is indicated by the fact that the potential savings in emissions of greenhouse gases from the transportation use of aluminum for lightweighting of vehicles and increased fuel efficiency is growing at a faster rate than the emissions from the production of the aluminum itself. For all of us with children and grandchildren, this is indeed a hopeful sign.

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