Strategy for Technology Innovation in the U.S. Aluminum Industry

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ABSTRACT

Working through The Aluminum Association, the U.S. aluminum industry has teamed with the U.S. Department of Energy's Office of Industrial Technologies (DOE/OIT) to address issues of competitiveness, the environment, and energy use from a long-term perspective. One of the products of this partnership is a series of three "technology roadmaps" outlining the industry's strategy for achieving the energy efficiency, environmental performance, productivity, and market targets it has set for itself for the year 2020.

The first in this unique series is the overarching *Aluminum Industry Technology Roadmap*, which outlines the wide spectrum of research and development needs facing the aluminum industry and shows the industry's priorities. The *Inert Anode Roadmap* addresses the highest-priority R&D need identified in the *Technology Roadmap*, the development of viable inert anodes for use in advanced electrolytic cells. The third roadmap describes the research and development needed to improve the cost-effectiveness of fabricating and using aluminum components in automotive applications. This roadmap is complementary to R&D planning efforts conducted by the Partnership for a New Generation of Vehicles (PNGV).

The aluminum industry, with the help of DOE, has found ways to work together on precompetitive research towards the common goals of improved competitiveness, environmental performance, and energy efficiency. The technology roadmaps should help to reach those goals by aligning the financial and technical resources of aluminum companies, federal agencies, academia, and other research institutions, maximizing the impact of these resources on research critical to the aluminum industry.

Introduction

Leaders in the U.S. aluminum industry recognize both the opportunities and challenges they face as they head into the 21st century. As demand for more technologically complex and ecologically sustainable products increases, opportunities for aluminum will continue to grow. Aluminum's unique properties (e.g., light weight, high strength, and corrosion resistance) make it an ideal material for use in conventional and novel applications. However, while market opportunities are promising, aluminum continues to compete with materials that may offer even lower cost, higher strength, lighter weight, or some other competitive advantage. Aluminum companies must continually innovate to provide their customers with better enabling technologies and superior materials that offer unique properties. U.S. suppliers also face strong competition from international aluminum producers.

Dealing successfully with these challenges and opportunities in the changing dynamics of competitive global markets will require new business strategies that align technology investments across industry and government. The formation of R&D partnerships is becoming increasingly critical in working toward meeting tomorrow's technology and market challenges.

Working through The Aluminum Association, the aluminum industry has teamed with the Department of Energy's Office of Industrial Technologies (DOE/OIT) to address issues of competitiveness, the environment, and energy use from a long-term perspective. One of the products of this partnership is a series of three "technology roadmaps" outlining the industry's strategy for achieving the energy efficiency, environmental performance, productivity, and market targets it has set for itself for the year 2020. This paper will describe these roadmaps and provide insight into the overall strategy that the aluminum industry and the OIT have adopted for realizing the industry targets.

Partnerships for the Future

The aluminum industry/DOE partnership began in 1994, when the aluminum industry began examining its long-term technology needs by outlining a vision of its future market, business, energy, and environmental goals: "To maintain and grow the aluminum industry through the manufacture and sale of competitively priced, socially desirable, and ecologically sustainable products." By early 1996, the industry had converged on its major market and technology goals. Under the leadership of The Aluminum Association, and with help from the OIT, the industry published *Partnerships for the Future*, which set forth its long-term vision of how to maintain and build the competitive position of the U.S. aluminum industry.

Partnerships for the Future identifies and describes the forces, or drivers, that can be expected to create the scientific and technical challenges that the industry will face in enhancing its worldwide competitiveness over the next 20 years. The three main sectors of the aluminum industry – the *raw materials sector*, the *semifabricated sector*, and the *finished products sector* – each have distinct drivers that will guide research and technology development. In the *raw materials sector*, the existing Bayer and Hall-Heroult processes are well-established, and technology will likely be focused on reducing costs via improved operating, energy, and environmental efficiencies of these processes. The *semifabricated sector* will likely focus on lowering costs and improving performance, quality, and environmental acceptability via the development and application of advanced manufacturing processes and technologies. The *finished products sector* will work towards increasing integration of materials, enhancing existing processes, product design, and enabling technologies to create the end-products that 21st century consumers will demand.

The vision document also describes some history of the aluminum industry, highlighting trends that are apparent and may continue to drive the industry in the future. One such trend that has continued to strongly influence the industry is the drive for expanded use of aluminum in the automotive industry. Concern for the environment has stimulated a drive towards lightweight vehicles, and aluminum's high strength-to-weight ratio makes it a viable alternative to heavier steel. This growing market is the topic of the third and final roadmap in the aluminum industry series.

Increased recycling is another trend highlighted in the industry's vision that remains critical to the industry's future success. Recycling was instituted early in the aluminum industry both to save energy and because of the high value of recovered metal. More recently, it has also been encouraged by government regulations as a means of conserving resources and reducing waste. As a result, the quantity of aluminum recycled has increased from about 525,000 tons in 1960 to 4,850,000 tons in 1997. Recycling is an important component of the industry, accounting for over one-third of total metal supply. Throughout the series of roadmaps,

recycling reoccurs as an important theme.

Aluminum Industry Technology Roadmap

Soon after the aluminum industry's vision was published, the industry began work on a detailed technology roadmap. The Technical Advisory Committee of The Aluminum Association began the roadmapping process by translating the broad strategic goals contained in *Partnerships for the Future* into a set of specific performance targets. These performance targets helped to clarify the key technology requirements that reflect the major concerns of the industry: cost and productivity, development of new markets, environmental protection, energy efficiency, health and safety, and workforce.

This target-setting effort was followed by an Aluminum Technology Roadmap Workshop that was jointly sponsored by the DOE and The Aluminum Association in November 1996. Its purpose was to build an industry-wide consensus on the essential research needed to meet aluminum industry performance targets and goals. The workshop was attended by a cross-section of highly respected technology experts from aluminum producers, suppliers, and customers, the university research community, national laboratories, and government research programs (Table 1).

Table 1. Aluminum Technology Roadmap Workshop Participants

Aluminum Companies	**Associations**
Alcan Rolled Products Company	The Aluminum Association
Alumax, Inc.	
Aluminum Company of America	**National Laboratories**
ARCO Aluminum, Inc.	Argonne National Laboratory
Kaiser Aluminum and Chemical Company	Idaho National Engineering Laboratory
Reynolds Metals Company	Oak Ridge National Laboratory
Werner Company	
Customer Companies	**Federal Government**
Ford Motor Company	U.S. Department of Energy
Chrysler Corporation	Federal Highway Administration
Universities	**Industry Consultants**
Case Western Reserve University	John Mihelich
University of Kentucky	Nolan Richards
Rensselaer Polytechnic Institute	Elwin Rooy

The industry performance targets developed by the Technical Advisory Committee were used to identify more specific targets in four areas: primary products (including secondary production), casting, rolling and extrusion, and finished products (Table 2). Technology barriers that inhibit the achievement of the targets were identified, and research needs were generated based on their ability to overcome these barriers. Participants prioritized research needs and identified the time frame in which the research is expected to yield benefits – near-term (0-3 years), mid-term (3-10 years), or long-term (beyond 10 years). Workshop participants also assessed the appropriate roles for industry and government in supporting R&D investment in specific areas. Research projects may be funded through single companies, industry-industry collaborations, or industry-government partnerships.

In all, technology experts identified 86 priority research thrusts that should be pursued to meet performance targets. While each research area requires a more detailed R&D plan with specific projects, the priorities helped focus and integrate industry and government research activities. Six common research themes underlie all four industry segments studied in the

Table 2. Performance Targets for the Aluminum Industry

Primary Products Sector
- Improve the performance of the Hall-Heroult cell
  - Achieve an average cell efficiency of 97% on an annual basis
  - Reduce the energy intensity of aluminum production to 13 kWh/kg using retrofit technology (near to mid term)
  - Reduce the energy intensity of aluminum production to 11 kWh/kg (long term)
  - Reduce capital cost of aluminum production to $2,500 per annual metric ton of capacity
  - Cost-effectively minimize the generation of perfluorocarbons (PFCs)
- Improve Bayer process productivity by approximately 20%
- Reduce/eliminate CO2 emissions during smelting
  - Enhance aluminum recycling technologies
  - Increase education on existing technologies
- Minimize or eliminate formation/landfilling of dross and salt cake
  - Improve metal quality
  - Adapt to using alternative sources of carbon
- Reduce impurities in recycled alumina
- Develop new uses for wastes and byproducts form aluminum processes

Semifabricated Sector: Casting
- Increase reliability of manufacturer operations to 95%
- Improve process control
  - Better models of plant operations
  - Temperature sensors for rolling operations
  - Real-time measurement of molten metal composition
  - Pressure sensor for container/die
- Develop better understanding of strip casting
  - Models of materials properties

Semifabricated Sector: Rolling and Extrusion
- Reduce weight by 20%+ through non-conventional forming technologies
- Reduce cost of joining technologies (compared to steel)
- Increase reliability of manufacturer operations to 95%
- Reduce energy use and costs associated with extrusion 20-30%
  - Model extrusion metal flow process
  - Improve the efficiency of thermal processing
- Improve process control
  - Better models of plant operations
  - Temperature analysis sensors for rolling operations
  - Real-time measurement of molten metal composition
  - Pressure sensor for container/die
  - Improve systems design
- Improve productivity and quality of extrusions
  - Lower die cost
  - Thinner wall tolerances
  - Higher speed
  - Expand extrusion die technology

Finished Products Sector
- Reduce the costs associated with metal production by 25%
- Reduce the cost ratio of aluminum-to-steel to less than 3-to-1 for automotive applications
- Increase aluminum use in auto markets by 40% in 5 years
- Increase aluminum use in non-auto transportation markets
- Increase aluminum use in infrastructure markets by 50%
- Increase aluminum use in building and construction markets

workshop: fundamental understanding of properties and processes, enabling technologies, improved metal quality, system-level approaches, education, and improved economics. For example, the need to better characterize microstructure and its influence on mechanical properties and the resulting product performance is critical for technology advancement in several sectors. Table 3 shows how selected research needs of each aluminum industry segment correspond to the six themes.

An illustration of a proposed pathway for reducing the energy intensity of aluminum production to 11 kWh/kg (a key target) is given in Figure 1. The Figure shows the near-, mid-, and long-term research, including enabling technologies in modeling and materials, needed to achieve this target. The roadmap presents a broad scope of R&D that will need to be considered if the target is to be successfully achieved.

The highest-priority technology need identified in the roadmap is the development of inert anode technology, which could lead to significant energy savings and emissions reductions. However, this is a long-term activity requiring substantial research funding beyond the resources of most individual companies.

Pursuing inert anode technology provides a prime example of the power of roadmapping. It has been deemed a consensus priority by the industry at large, making the roadmap a good vehicle by which industrial consortia, with the help of academia and government laboratories, can leverage funds to work towards a common technological goal. Because of the strong opportunity for such partnering in inert anode R&D, a unique, separate roadmap entitled *Inert Anode Roadmap* has been developed.

Table 3. Common Aluminum Research Themes				
Themes	**Primary Production (Including Recycling)**	**Casting**	**Rolling, Extruding, and Other Semifabrication**	**Finished Products**
Fundamental Understanding	Physical and chemical phenomena in reduction	Solidification	Materials behavior and chemistry	Structural properties of aluminum and processing interrelationships
Enabling Technologies	Models, sensors, and controls for Bayer process and Hall-Heroult reduction process	Low-cost sensors and solidification models	Comprehensive process models, advanced sensors	Integrated models and better process controls
Improved Metal Quality	Develop new carbon sources; minimize impurities from reacted alumina in dry scrubbers	Develop technologies to remove certain impurities from the melt	Improve microstructure control	Minimize/eliminate surface defects in continuous cast sheet; overcome material property problems
System-Level Approach	Coordinate entire production process to improve quality and productivity	Use system-level thinking to solve problems and reduce costs	Better understand how aluminum competes with other materials	Integrate product design and processing
Education	Educate recyclers on available technologies	Share technical information among aluminum companies	Improve education infrastructure in the industry; improve customer education	Educate customers on performance characteristics of aluminum materials
Improved Economics	Develop low-cost extraction and purification technologies	Develop low-cost process for alloy/scrap purification/ upgrade; develop low-cost inclusion meter	Develop lower-cost alloys with competitive performance	Develop inexpensive, large-volume methods to improve surface hardness

Inert Anode Roadmap

Guided again by the Technical Advisory Committee of The Aluminum Association, leading North American aluminum producers have collaborated with academia and national laboratory representatives to establish a framework to guide the development of any new inert anode technology. In this framework, nine leading North American primary aluminum producers (Table 4) reached a consensus on the required performance characteristics and development requirements of the technology. The framework is a logical extension of the *Aluminum Industry Technology Roadmap* and is intended to provide the basis for guiding and judging new inert anode concepts. The industry anticipates that the framework will also serve to accelerate research efforts in this area by aligning the different segments of the research community toward a clearly defined goal.

Table 4. Aluminum Industry Inert Anode Workshop Participants
Alcan International Ltd.
Alumax, Inc.
Aluminum Company of America
ARCO Aluminum, Inc.
Century Aluminum
Goldendale Aluminum Company
Kaiser Aluminum & Chemical Company
Northwest Aluminum Company
Reynolds Metals Company

Rather than attempting to select a specific technology winner, the aluminum industry has taken the

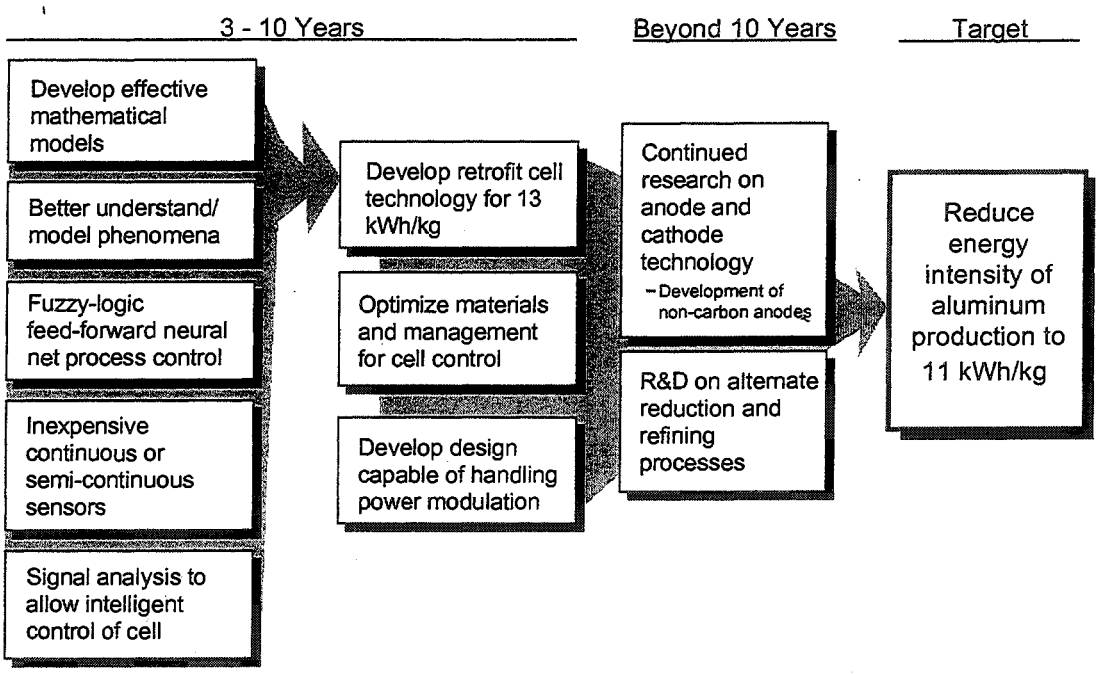

Figure 1. Research needed to meet performance target in primary aluminum production

unique approach of developing the framework by which inert anode development should proceed. This approach recognizes an important distinction: aluminum companies appear best able to identify their technology performance requirements, while the academic and research communities appear best able to generate innovative technology solutions. The framework has two main parts:

- the technical performance characteristics
- the technology development and scale-up pathway

With this framework, new inert anode concepts can be judged and the technology developed in a manner that meets the industry needs while not limiting potential technological innovation. The overall scale-up process has been broken down into four major steps: a comprehensive literature review and analysis, bench-top demonstration, laboratory pilot test, and full pilot test. At each stage of development, specific performance criteria have been defined by the industry to ensure that any inert anode technology that is developed will meet the specific operating needs of primary aluminum producers. Between each stage, technical and economic modeling is expected to further assess the potential for success for a given technology.

The benefits of viable inert anode technology to both the aluminum industry and the nation are shown in Table 5. Advantages over conventional carbon anodes include an expected energy efficiency increase of up to 25% when coupled with advanced wetted cathode technology. Considering the energy-intensive nature of the aluminum production process, that savings alone

Table 5. Potential Benefits of Inert Anodes	
Greatest Industry Benefit • Eliminate carbon plant • Increased flexibility in cell design • Potential for lower ACD when combined with wettable cathode **Greatest Global Benefit** • Reduce/eliminate CO_2 emissions • Reduce/eliminate PFC emissions	**Estimated Advantages over Conventional Technology** • Energy efficiency increases of up to 25% (when coupled with wetted cathode) • Operating cost reductions of up to 10% • Greenhouse gas emissions reductions of 7 million metric tons of carbon equivalent in the United States • Productivity increases of up to 5%

provides a strong incentive for the industry to pursue inert anode technology development.

Aluminum Industry Roadmap for the Automotive Market

The U.S. automotive industry is committed to creating a "next generation of vehicles" that have superior fuel economy yet do not compromise safety, performance, or comfort. The aluminum industry's intent is to help the automakers produce world-class quality, fuel-efficient, safe cars that people can afford to buy. Developmental work in aluminum will contribute greatly to the long-term cost-effectiveness of using this material in automobiles. Through a unique combination of physical properties, aluminum alloys and their manufacturing processes are able to contribute to both lower emissions and greater fuel economy by reducing total vehicle weight. Aluminum's light weight, strength, formability, corrosion resistance, and recyclability give it the potential to meet a wide range of design challenges.

The aluminum industry is preparing an *Aluminum Industry Roadmap for the Automotive Market* in order to fully capitalize on the significant opportunity for using aluminum in the automobiles. The goal of this final roadmap in the series is to outline and organize the R&D necessary to lower the cost of aluminum production and manufacture as it relates to automotive applications. Unlike its two predecessors, the automotive roadmap was drafted via a thorough literature review process rather than a workshop. The draft was then reviewed by both aluminum industry experts as well as experts from the automotive industry. This review process ensured that the roadmap addressed both the pressing technological needs that aluminum suppliers face in fully capitalizing on promising automotive markets, as well as the needs of the automotive manufacturers for lightweight, high-performance materials for a variety of applications.

The automotive roadmap systematically considers the main technological challenges and R&D needs for each major aluminum product – sheet, extrusions, and castings – and key issues related to joining and assembly, crashworthiness, and recycling. Recent trends and drivers for technology development in each area are discussed, setting the stage for considering technology advancement. This roadmap, while focusing on the specific actions that the aluminum industry needs to take to enhance the cost-effectiveness of aluminum in automotive applications, is meant to be supportive of the automotive industry's ongoing efforts

Table 6. PNGV Needs Addressed by Aluminum Industry	
PNGV Technology Need	**Addressed In:**
• Feedstock	• *Aluminum Industry Technology Roadmap*; Sheet and Extrusion Sections
• Casting	• Casting Section
• Forming	• Sheet and Extrusion Sections
• Joining	• Joining and Assembly Section
• Recycling	• Scrap Sorting and Recycling Section

through the PNGV program. Table 6 highlights the correspondence between PNGV needs and aluminum industry roadmapping efforts.

The goal of the research identified in the Automotive roadmap is to increase the efficiency with which aluminum is used and reduce the cost of converting it from ingot/sheet/extrusion product into a serviceable part or an integral component of the vehicle. Essentially every R&D effort proposed contributes directly or indirectly to lowering the cost of using aluminum in automobiles.

The technical topics addressed in the roadmap reflect the entire process chain of automotive manufacturing, from the production of semi-finished aluminum shapes through the assembly process and finally the recycling of automotive aluminum scrap. Research that focuses on improving the production of primary aluminum, which is germane to the goal of reducing the cost of aluminum components, already has been address adequately in the overarching *Technology Roadmap*.

Conclusions

The aluminum industry's series of roadmaps has helped the industry to enjoy a special working relationship with the DOE. The leveraging of industry and government research dollars is enabling rapid development of long-term technologies that otherwise would likely be inadequately addressed.

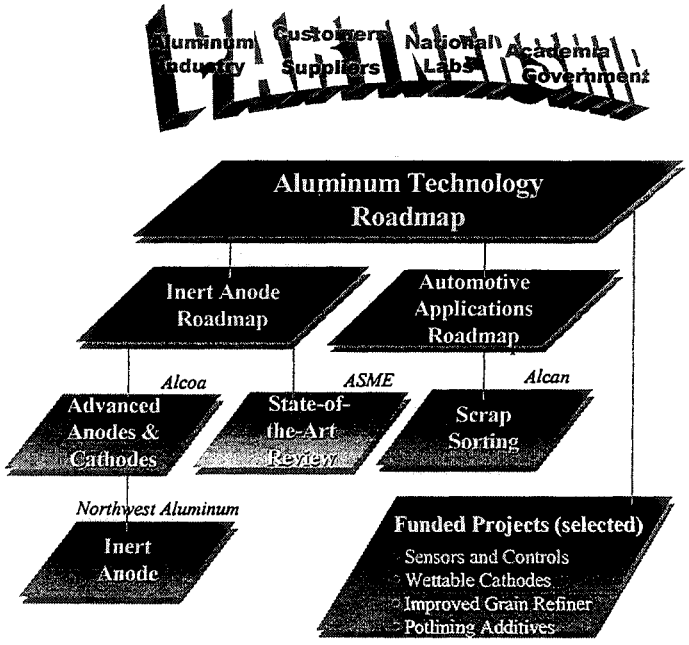

Figure 2. Overview of aluminum industry/DOE partnership and products

The partnership formed through the DOE and the aluminum industry has been a fruitful model for other U.S. industries to follow. The partnership has brought together the combined research capabilities of the aluminum industry, customers, suppliers, national laboratories, academia, and the government to systematically address the challenges and opportunities facing the aluminum industry in the 21st century. The series of roadmaps has led to a number of jointly funded research projects, as shown in Figure 2. These projects, and many others not shown, will allow the industry, with the help of government, to rise to the challenges of the next century and continue to provide the U.S. economy with advanced materials that can be used to provide the products of tomorrow.

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