

INERT ANODE ROADMAP



The Aluminum Association, Inc.
FEBRUARY 1998



Inert Anode Roadmap

A Framework for Technology Development

February 1998

The Aluminum Association

In conjunction with

The U.S. Department of Energy

Prepared by

Nancy Margolis
Jack Eisenhauer

ENERGETICS, INCORPORATED
Columbia, Maryland

Table of Contents

	<i>Page</i>
1 Introduction	1
2 Potential Benefits	5
3 Performance Targets	9
4 Technical Barriers	15
5 Technology Development Steps	21
6 Next Steps	27
Appendix A: Roadmapping Participants	29



Introduction

Aluminum is one of the most versatile materials available today that can meet the demanding requirements of tomorrow's products. Its light weight, high strength, and corrosion resistance make it ideal for applications in automobiles and trucks, rail, aerospace, containers, construction, electric transmission, and infrastructure. When used in transportation vehicles, it can greatly increase the energy efficiency of our Nation's transportation sector. Aluminum's success in recycling has also made it a model for sustainable materials. However, the production of primary aluminum continues to be quite energy intensive. Furthermore, the use of carbon anodes in the smelting process generates undesirable carbon dioxide and perfluorocarbons.

While past technology improvements have greatly increased the current efficiency of aluminum cells up to 96%, the industry continues to pursue research to increase energy efficiency, improve productivity, and reduce emissions in primary aluminum production. In particular, the international aluminum community has pursued the development of non-consumable, or inert, anode technology for many years. If successful, this technology would have clear advantages over conventional carbon anode technology, including the following "best estimates":

- energy efficiency increases of up to 25% (when coupled with a stable, 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%

This technology is particularly relevant today as nations around the world look for technologies that can help reduce emissions of greenhouse gases without compromising economic growth and product quality.

Although not absolutely required, retrofit capability is highly desirable of any new inert anode technology. The technology holds great promise for brownfield capacity additions and retrofit applications in North America. However, the largest impact may ultimately be realized in the application of inert anode technology to greenfield aluminum smelting projects throughout the world. Undoubtedly, the latest, most advanced technology will be adopted for any greenfield smelter project.

Why Inert Anodes?

One of the largest opportunities to lower the energy requirements and costs of primary aluminum production is through the use of advanced electrolytic cell designs. Advanced cell technology has been one of the top research priorities among aluminum companies for several decades. The industry affirmed the need for this technology during the *Aluminum Industry Technology Roadmap Workshop* held in November, 1996. Leading industry experts selected the development of advanced anode and cathode technology as its highest-priority R&D objective for primary production over the next 20 years. Research activities in this area should focus on the development of new materials for inert anodes and wetted cathodes, processing methods for these materials, and experimental design for materials selection.

The electrolytic production of aluminum is very energy intensive. In fact, electricity accounts for about one-third of the cost of production and is one of the key factors behind product affordability. The largest technical challenge to improving the energy efficiency of electrolysis is the development of a non-consumable, or inert, anode. Inert anode technology, coupled with that of stable, wetted cathodes, offers the greatest opportunity to improve cell energy efficiency and lower primary aluminum production costs. The technology also has significant environmental benefits because it eliminates the emissions of carbon dioxide and perfluorocarbons (particularly carbon tetrafluoride) associated with consumption of the carbon anode. In addition, improving cell energy efficiency will lower overall energy requirements, thereby reducing the emissions of greenhouse gases that may have resulted from primary electricity generation.

However, with inert or non-consumable anodes, the electrode reactions differ from those with carbon anodes. On carbon anodes the oxygen of alumina is discharged but reacts with the carbon and forms carbon dioxide, which decreases the decomposition potential by about a volt. Such depolarization does not occur on inert anodes. Oxygen is evolved at the standard decomposition voltage. There is some evidence that the anode overpotential is somewhat less with oxygen formation but not enough to fully compensate for the one volt depolarization.

If successfully developed and applied, inert anode technology could have significant energy, cost, productivity, and environmental benefits for the aluminum industry worldwide. When combined with other advances in electrolytic cell design, such as wettable cathodes, the technology should achieve even greater benefits. These benefits include an expected 25% reduction in the energy required for reduction of alumina to aluminum and, most importantly, elimination of the carbon anode plant. Although inert anodes will require a production facility, the industry's best guess is that the facility will be offsite and not require aluminum industry capital. The inert anode production facilities are expected to be less polluting than carbon anode plants.

The ability of inert anode technology to reduce emissions of greenhouse gases is also of great interest to the industry. In the United States alone (using the 1996 primary aluminum production rate of 3,577 thousand metric tons), the application of inert anodes could potentially eliminate 5 million metric tons of carbon dioxide emissions and more than 2,500 metric tons of perfluorocarbon emissions. When converted to carbon equivalent, the total reduction in greenhouse gases would be nearly 7 million metric tons. Worldwide, this potential translates to a

reduction of greenhouse gas emissions by nearly 40 million metric tons (carbon equivalent). Additional reductions in emissions would result from the improved operation of the cell itself.

A Framework for Technology Development

Guided by the Technical Advisory Committee of The Aluminum Association, leading North American aluminum producers have collaborated to establish a framework to guide the development of any new inert anode technology. In this framework, the industry has developed a consensus on the required performance characteristics and development requirements of the technology. These characteristics and requirements represent a unique consensus by nine leading North American primary aluminum producers (see Appendix A). 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.

The initiative being taken by the aluminum industry is very timely considering the increased interest in advanced industrial technologies that can reduce greenhouse gas emissions. Recently, the Clinton Administration proposed additional funds for research and development and tax initiatives to encourage the development of new technologies to spur energy efficiency and reduce emissions of carbon dioxide and other greenhouse gases. Additional incentives are promised for industries that take early action.

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

Key technical performance characteristics for successful operation of an electrolytic cell using inert anode technology are quantified and discussed. The sequence of generic development steps for any new inert anode technology are identified, and their critical components explained. In addition, the document includes in-depth discussions of the potential benefits of inert anode technology and the key technical challenges that it must overcome.



Potential Benefits

If successful, non-consumable, or inert, anode technology could yield significant energy, environmental, and cost benefits. As shown in Exhibit 2-1, the benefits are expected to fall into the following categories:

- Cost/Productivity
- Process Simplification/Control
- Energy Reduction
- Elimination of Greenhouse Gases
- Other Environmental Benefits

The benefits shown in Exhibit 2-1 are actually the *requirements* that the aluminum industry has developed for non-consumable anodes. While no single new technology must meet all of these requirements in order to be considered successful, the degree of success may be measured by how many of the requirements are indeed fulfilled.

To measure the benefits of the new anode technology (used in combination with wettable cathode technology), a comparison will have to be made not just against current technology but also against a cell operating with conventional anode technology and potential wettable cathode technology. This will yield the relative benefits and costs of technology improvement.

All of the projected benefits are discussed below in turn, although they will become somewhat less important if the government imposes restrictions that *require* reductions in CO₂ emissions because the economics of the proposed technology will become less important. Nevertheless, the industry has determined that an aggressive effort should be made to develop non-consumable anode technology aimed at achieving a number of important benefits such as energy reduction, as well as the reduction of greenhouse gas emissions.

Cost/Productivity

An important requirement is to lower the overall cost of a new anode below that of conventional carbon anodes, which is usually \$110 to \$120 per tonne. Other potential benefits include increases in space utilization and production per unit volume (consistent with the constraints of the heat balance of the cell). The new anodes should reduce labor requirements during operations as well as overall operating costs.

