PROJECT IMPACT SHEET

REIMAGINING ALUMINUM MANUFACTURING

UPDATED: FEBRUARY 6, 2017

PROJECT TITLE: Energy Efficient, High Productivity Aluminum Electrolytic Cell
PROGRAM: Modern Electro/Thermochemical Advances in Light Metals Systems (METALS)
AWARD: $5,809,354
PROJECT TEAM: Alcoa, Inc.
PROJECT TERM: March 2014 – May 2018
PRINCIPAL INVESTIGATOR (PI): Mark Ripepi

TECHNICAL CHALLENGE

Reducing automobiles' weight by using more aluminum (Al) and other light metals in their construction is one of the most effective ways to improve fuel efficiency. Therefore, the automotive sector is moving towards the adoption of light metals in their vehicle designs to meet the stringent 2020 and 2025 U.S. fuel economy standards. A prominent example of this being Ford's decision to make extensive use of aluminum in their F-150. However, America's effort to make vehicles that reduce oil imports and increase energy security brings a risk of increasing aluminum imports, because there are few aluminum smelters remaining in America. Due to the high cost of building new plants (>$2B), and the current low price of aluminum (~$1,700/ton as of late 2016), retrofitting existing U.S. smelters has the least barriers to increasing U.S. production. Aluminum production is currently performed using the electrolytic Hall-Heroult process, which has seen only incremental improvement since the 19th century in making a commodity material. Significant innovation is needed to create a retrofit option for plants using the Hall-Heroult process that reduces cost and energy use, and improves Al production efficiency.

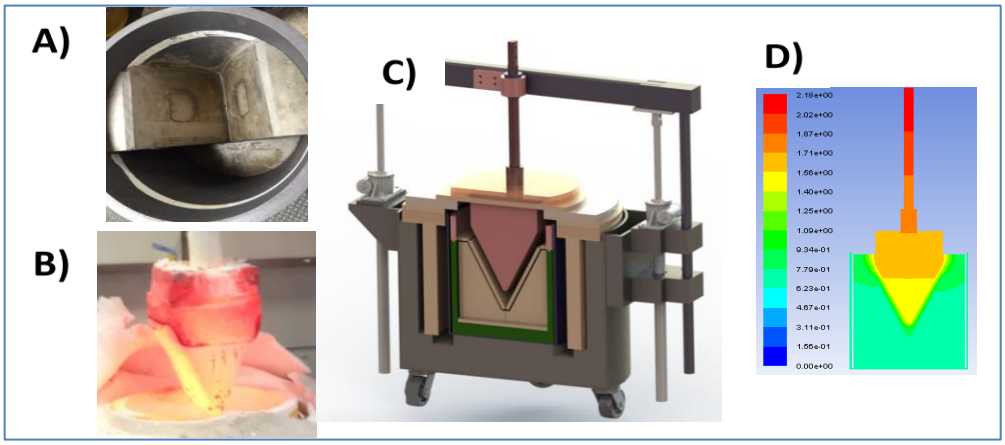
TECHNICAL OPPORTUNITY

Opportunities to use technical innovation to increase domestic Al production arise from technical advances in other fields. For example, numerous advances have been made in high-temperature materials, especially in the field of electrically conductive ceramics. Likewise, computer modelling techniques developed over the last decade have made it possible to quantitatively evaluate unconventional new cathode designs. Such new designs could enable a retrofit into existing smelting pots, lowering production and energy costs, and potentially making American Al cost-competitive with foreign imports.

INNOVATION DEMONSTRATION

Globally, the dominant technology employed to make Al is through the Hall-Heroult cell, which electrochemically reduces aluminum oxide dissolved in a molten salt solution at about 950ºC. In this cell, the carbon anode is consumed as aluminum metal is formed, creating an ever-changing anode shape with complex changes in salt "crust" formations within the cell as temperatures and current densities change dynamically. In order to maintain production efficiency and prevent electrical shorting, it is important to maintain uniform and close distance between the carbon anode and the molten aluminum that resides on the graphite cathode.

Figure 1: Aspects of Alcoa's original laboratory proof-of-concept 900 Amp cell, including A) bonded cathode plates, B) spent Anode Post-electrolysis extraction, C) design and D) modelling.



The goal of the Alcoa project is to develop a new technology that allows Hall-Heroult cells to operate with greater reactive surface area within each cell, and to maintain closer and more constant anode-cathode distances without shorting. Alcoa proposed that this could be accomplished by sloping the cathode, and making the cathode surface with TiB_2 plates. This construction material assures greater aluminum wetting than today's cells, and enables a significantly reduced anode-cathode distance. Alcoa's models show that these

changes would reduce energy consumption by more than 20% for a greenfield design using the optimum side angle illustrated in Fig. 1c. This greenfield cell design enables a lower anode-cathode distance within the cell and subsequently a reduced energy consumption.

The initial phase of the project focused on the adhesion, corrosion resistance, and wettability of the TiB_2 plates to carbonaceous support materials. High temperature electrolysis was conducted on materials that had passed a pre-test of high temperature cycling. The electrolysis tests demonstrated the aluminum wettability of the cathode as well as the bonding between the TiB_2 and support structures. A prototype cell was built and multiple tests were performed at 900 A followed by tests at 6,000 A. The 6,000 A cell demonstrated stable operation with an anode-cathode distance, a critical determinant of the energy efficiency, a factor of two to three lower than a standard Hall-Heroult cell. With this performance, modeling showed that an energy consumption of 11.2 kWh/kg can be achieved in a scaled-up, self-heated cell. In addition, the 6,000 A cell demonstrated approximately twice as much output per unit of cell floor area as a conventional cell by operating at a comparable electrode current density but packing in significantly more electrode area due to the sloped design.

To build on this work, Alcoa is proceeding with scale-up to a 65kA self-heated pilot cell to demonstrate the technology at the lowest cost and smallest scale possible that still has direct industrial relevance. This new project phase includes scale-up of the TiB_2 bonding process, developing a process to pre-heat the self-heating cell, and modeling to ensure that a full-sized 200+ kA cell retrofit into a legacy aluminum plant will have improved energy savings using sloped cathode technology. As of November 2016, Alcoa is evaluating the most economical angle of a retrofitted cathode to be used in legacy facilities, and will begin construction of its 65 kA pilot cell early in 2018. Extended operation (30-60 days) is planned to test the self-heated cell including the current efficiency, operation protocols and stability, and energy efficiency.

PATHWAY TO ECONOMIC IMPACT

Given a successful demonstration of the pilot cell, Alcoa plans to initiate pilot-scale testing and scale-up, drawing on existing infrastructure, to make the technology ready either for internal deployment or for licensing. The commercialization roadmap will require about five years of extensive corporate development following the end of the ARPA-E project.

There are two potential paths to market for this technology, greenfield and retrofit applications. Based on Alcoa's techno-economic models, using the sloped cathode design in a greenfield facility would allow for a 5% savings per ton of aluminum produced, comprised of 2/3 in energy consumption and 1/3 savings in increased metal production. This is critical to remain competitive in today's down market for light metals. The capital intensity of this greenfield sloped cathode smelter is estimated to be ~25% less than a greenfield facility of the present best design.

In addition to the benefits of greenfield production, retrofit opportunities represent a significant shorter-term opportunity for commercial impact as well. Alcoa's present total primary aluminum production in the United States is ~360k metric tons per year with average energy consumption of 14.5 kWh/kg of aluminum. By retrofitting the sloped cathode technology into Alcoa's existing U.S. smelters, Alcoa primary aluminum production could increase to ~645k metric tons per year with reduced energy use and cost. A retrofit technology developed in the plus-up phase of this sloped cathode project could result in the retention of more than 1,000 direct jobs in the United States and many more jobs in the local communities when indirect jobs are considered.

LONG-TERM IMPACTS

The total global market for aluminum is currently 57.9 million metric tons/year (2015 figures), of which 4.5 million is produced in North America[1]. Over the past year, demand for aluminum has leveled off[2], but there has been consistent year-over-year growth in production (~5.6%) since 2006. Should this trend resume, it would represent an increasing global market size of approximately 3.3 million metric tons of new production per year. A scenario in which Alcoa's sloped cathode technology is utilized in the United States to meet even one year's worth of this growing global demand would save 11k GWh per year in energy. This, in combination with switching from coal powered energy sources such as those used in China, would translate to a savings of ~51 million tons of CO_2 per year if hydroelectric energy is used to power the process, or ~27 million tons of CO_2 per year if natural gas were used as the primary electricity generation source. Either scenario would retain existing jobs and create new aluminum production jobs within the U.S. borders.

[1] http://www.world-aluminium.org/statistics
[2] ibid