



# Using Color to Enhance Optical Sorting of Aluminum Scrap for Recycling

## Project Overview

**Is there a fast and effective method to separate post-consumer mixed aluminum scrap by alloy so that it can be recycled at higher rates?**



Aluminum is a highly versatile metal, produced and sold as hundreds of different alloys (a combination of two or more metallic elements). It contains various amounts of elements, including copper, silicon, magnesium, manganese, and iron. When cars, airplanes, electronics, construction materials, and other goods come back for recycling, aluminum is separated from the other materials (like plastics, glass, and other metals), but separating post-consumer aluminum by alloy, which would then make the individual alloys more recyclable, is not currently economically feasible. As a result, the mixed aluminum scrap is not of sufficient quality to recycle into thin, valuable wrought alloys (alloys that have been processed into useful products by mechanical working).

In this project, a team led by MIT Professor Antoine Allanore (Materials Science and Engineering) and Research Scientist Katie Daehn, explores if there is a fast and effective method to color the surface of aluminum scrap, depending on the alloying elements present, to enhance optical sorting – an approach that is increasingly being used for sorting high volumes of municipal waste. The researchers chose to explore sulfur gas as the chemical reactant, as gas-solid reactions can be quick, and sulfur partial pressure may be controlled to selectively react with the alloying elements present. The sulfur compounds would impart color to the surface, depending on the concentration and type, allowing for the sorting of mixed scrap to individual alloys, as shown in Figure 1.

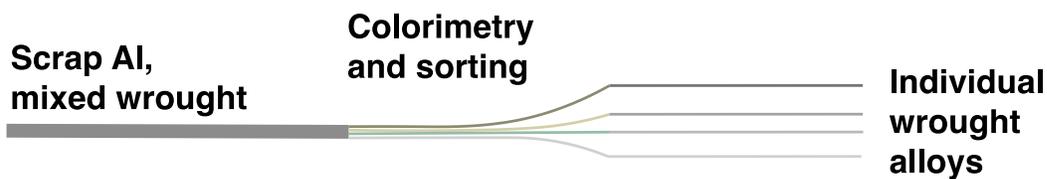


Figure 1: Simple schematic showing from left-to-right, the flow of mixed scrap aluminum, to the colorimetry and sorting step, allowing the differentiation of individual wrought alloys.



This project aligns closely with the MCSC’s Circularity pathway.

## Findings & Outcomes

**The team found that sulfur gas can be used to impart significant color changes between magnesium-containing alloys, thereby enabling increased recyclability.**

The team’s thermodynamic analysis and experiments show that sulfur gas can be used to impart significant color changes between magnesium-containing alloys. Aluminum alloy families 2xxx, 5xxx, 6xxx, and 7xxx have varying concentrations of magnesium, so this technique could be used to identify and sort by these alloy families (as shown in Figure 2), as well as differentiate between high-magnesium and low-magnesium alloys within the same family. This is relevant for sorting aircraft alloys (which contain both 2xxx and 7xxx series aluminum) as well as automotive scrap.

Temp., <i>T</i> / K ( <i>T</i> ' / °C)	Time, <i>t</i> / min	Type of wrought Al alloy sample					
		A1100	A2024	A3003	A5052	A6061	A7075
Initial (no heating)							
673 (400)	60 (No S)						
	0						
	30						
	60						
	120						
		5 mm	5 mm	10 mm	5 mm	5 mm	5 mm

Figure 2. Matrix showing the different aluminum alloys initially (top row), after heating with no sulfur present (row 1) and after heating with sulfur with increasing time (rows 2-5) within a sealed ampoule. The red boxes indicate observed changes in surface color.

Magnesium was found to be especially sensitive to this technique because it is not only more reactive to sulfur, but also more reactive to oxygen, compared to aluminum. All aluminum scrap has a very thin, but secure oxide layer on the surface, which may act as a barrier for the other alloying elements present to react with the sulfur gas. However, magnesium seems to migrate to the surface oxide, where it can react with sulfur to form magnesium sulfide (MgS).

The team conducted experiments within small-scale ampoules, as well as with sulfur gas flowing in a tube furnace (as shown in Figure 3) to demonstrate and identify the relevant conditions for a scaled-up process. A simple economic assessment of the process quantifying the cost of the operational inputs

(electricity, nitrogen gas, sulfur) shows there is a space for an economically competitive process if alloys, such as 6063, may be recovered from the mixed stream (as shown in Figure 4).

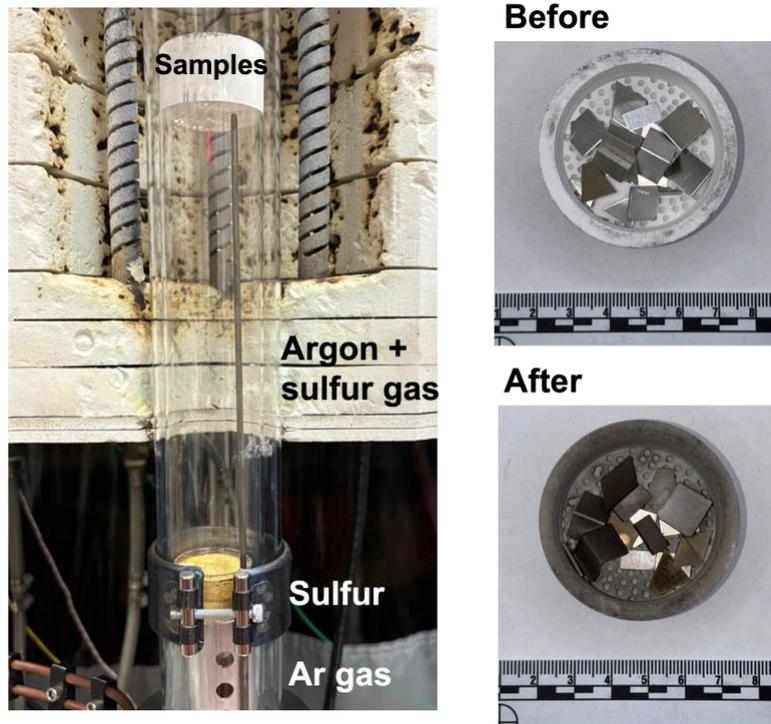


Figure 3. Sulfur-flowing experimental set-up showing the surrounding tube furnace, samples in the 'hot zone', and sulfur crucible (left). Aluminum alloy samples before and after treatment, with significant color differences, are shown on the right.

**Process Inputs**

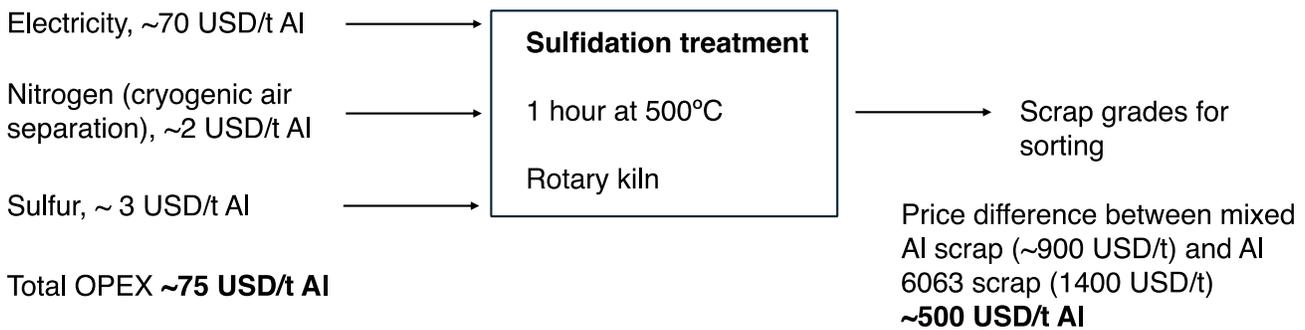


Figure 4. The operating cost (OPEX) of the main inputs in cost/metric ton of aluminum (USD/t Al), showing space for economic feasibility if individual high-value alloys can be recovered from the mixed scrap.

There is also an economic motivation to recover and retain the magnesium present. Alloy-to-alloy recycling would reduce the need for expensive magnesium additions, which is especially susceptible to supply disruptions and dramatic price increases.

The team is currently writing up this work as a research article for a materials processing journal.

## Opportunities for Implementation

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Coloring aluminum alloys using sulfur gas, followed by optical sorting, has the potential to promote closed-loop recycling of aluminum alloys, especially those containing magnesium.

For future work, the team is interested in testing any samples in the lab or connecting with relevant scrap processors and suppliers with insight into operational considerations and specific industrial needs. The researchers are particularly interested in understanding how this process may integrate with de-coating, and if paint pigments such as titania, may be effectively removed via sulfidation.

They are also interested in testing their samples within an optical sorting system. Existing optical sorting systems can perform some separation amongst aluminum alloys by shape, density and some inherent color differences, and we would be keen understand how this technique may complement this existing and evolving technology.