Maturing Aluminum Production from Lunar Regolith: Status of the MAGMA Project

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Introduction

Previous work on high-temperature regolith processing focused on oxygen as the main product or looked at iron and titanium that would be extracted from mare regolith at equatorial landing sites.

With the current goal of building up infrastructure at the lunar south pole in highlands terrains, **aluminum is a much more viable metal** and has diverse applications in **power transmission, radiators, and structures like towers**.

The MAGMA project (Molten Aluminum Generation for Manufacturing Additively) is a LuSTR23 selection to mature technology for extracting aluminum from regolith at the lunar south pole and turning it into an additive manufacturing feedstock. Here, we provide an update on the current project status and future plans.

MAGMA Overview

MAGMA is being led by Colorado School of Mines with Lunar Resources as the sole industry partner. The team has expertise in lunar geology, ISRU hardware, metallurgy, materials science, and additive manufacturing.

The main technology being pursued is **Molten Regolith Electrolysis (MRE),** which operates directly on raw regolith of any composition **without the need for an electrolyte or other consumables** shipped from Earth. The overall goal of the project is to work toward an integrated test in vacuum that produces pure aluminum from highlands regolith simulant and casts it into a wire that would be appropriate for additive manufacturing applications. Progress from different areas of the project is described below.

Taps & Launders

We are developing several taps and launders that will interface with the LR MRE reactors. These include: (1) empty Fe-Si metal from extractor reactor, (2) transfer Al-rich slag from extractor reactor to aluminum reactor, (3) tap Al metal, and (4) empty remaining slag. Work to date has taken in CAD models from LR reactors to work out tap geometries; canvassed design concepts from industry; and designed and built a room-temperature apparatus to rapidly iterate on tap concepts using fluids with the same viscosity as the reactor liquids (Fig. 1).

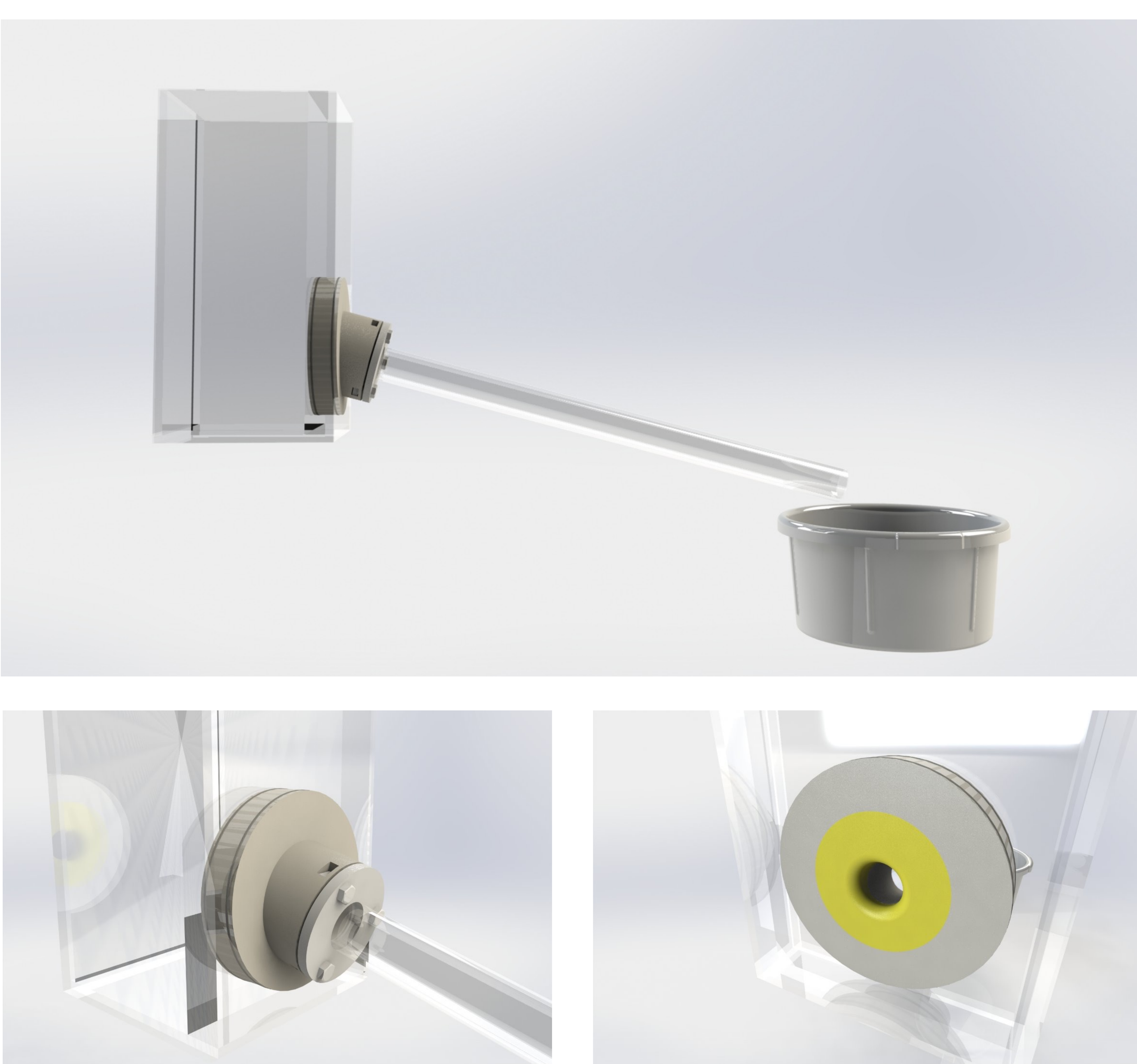

Figure 1. Design of room-temperature test apparatus for iterating tap design concepts.

Aluminum Wire Characterization

We are in the process of obtaining aluminum wire AM feedstock from an industry partner that will be characterized as a baseline for the wires to be produced during the project.

Materials Compatibility

We are testing reactivity and wetting angles of MRE melts and slags with candidate refractory materials (to be used in the taps/launders) including alumina, boron nitride, zirconia, graphite, and SiAlONs. Initial reactivity tests of Al_2O_3 and BN are shown in Figs. 2–4, with Al_2O_3 forming a strong reaction boundary and BN forming almost none.

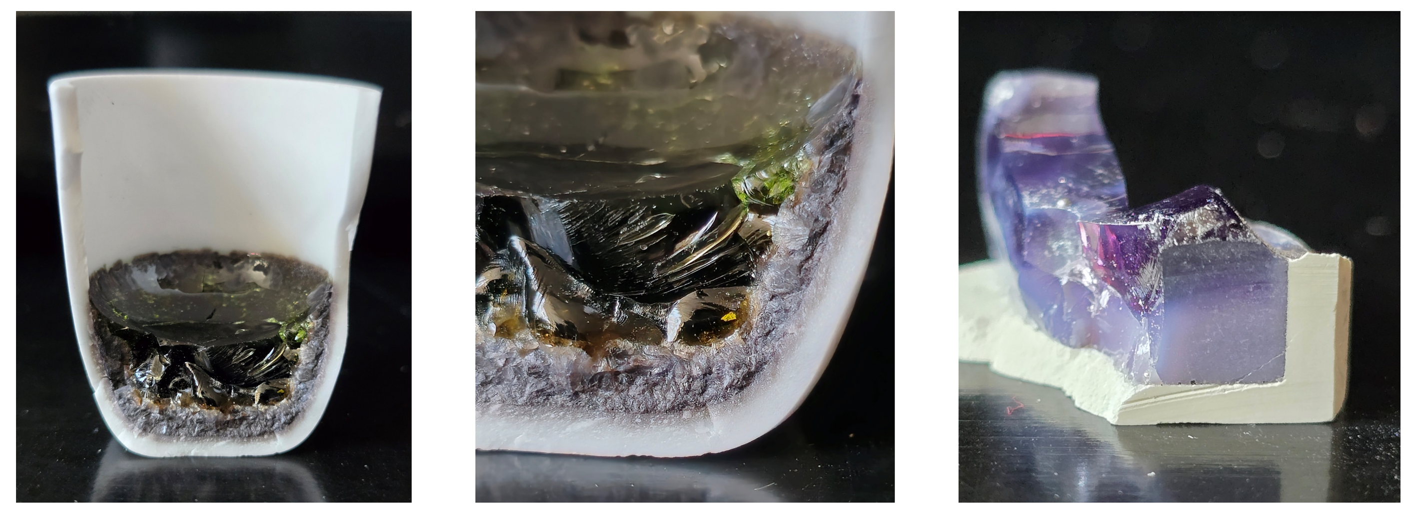

Figure 2. Photographs of reactivity tests between refractory crucibles and bulk highlands melt after 1 hour (alumina; left) and 25 hours (boron nitride; right) at 1600 °C.

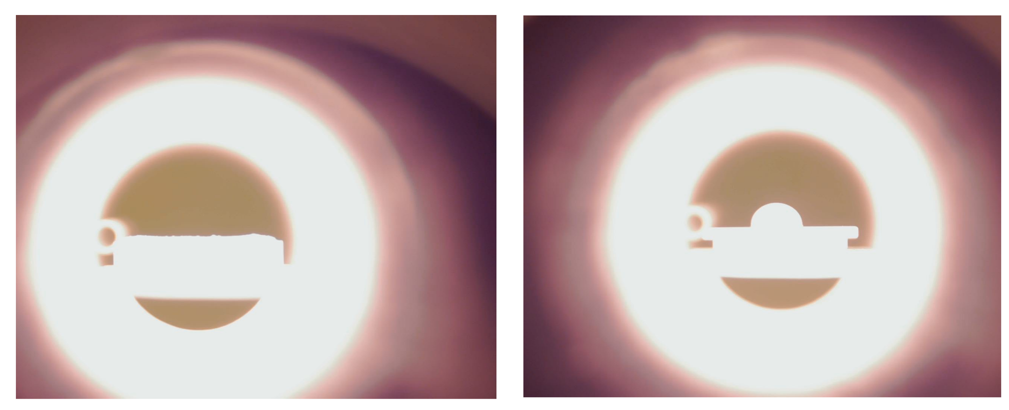

Figure 3. Wetting angle tests with the bulk highlands melt on alumina (left) and boron nitride (right), showing a marked difference in wettability between the two refractories.

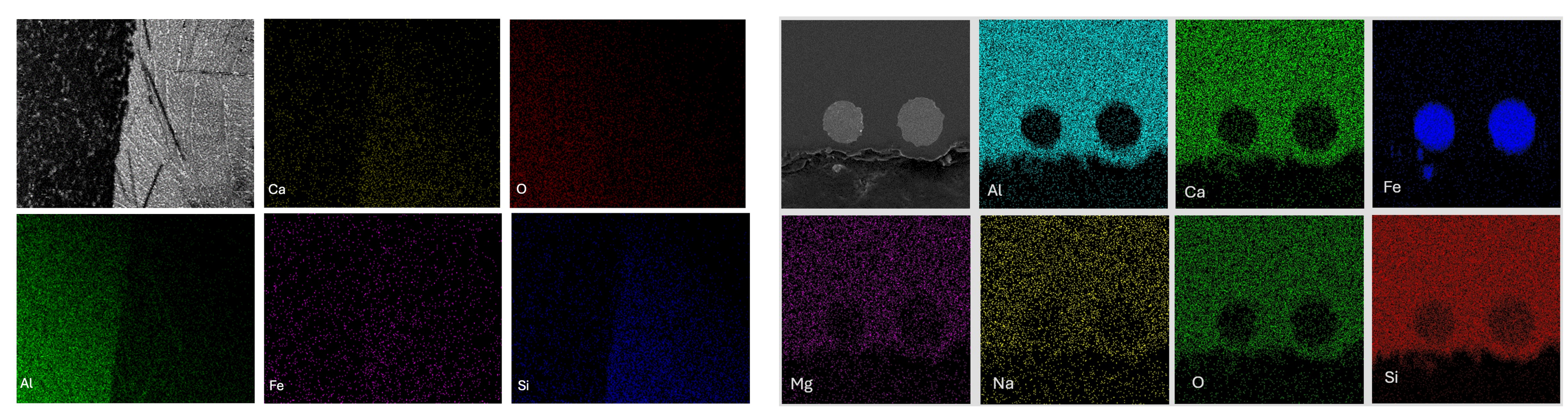

Figure 4. EDS maps of the interface between crucible walls and bulk highlands melt. Left: alumina (melt on right). Right: boron nitride (melt at top).

Thermodynamic Modeling

FactSage is being used to predict equilibrium phase assemblages and phase compositions at different stages of the MRE process as elements are progressively reduced. Initial "dynamic Ellingham diagrams" and predicted slag compositions are shown in Figs. 5–7. Early results suggest the first reaction step will produce 3 immiscible liquids, plus a gas phase in addition to evolved oxygen.

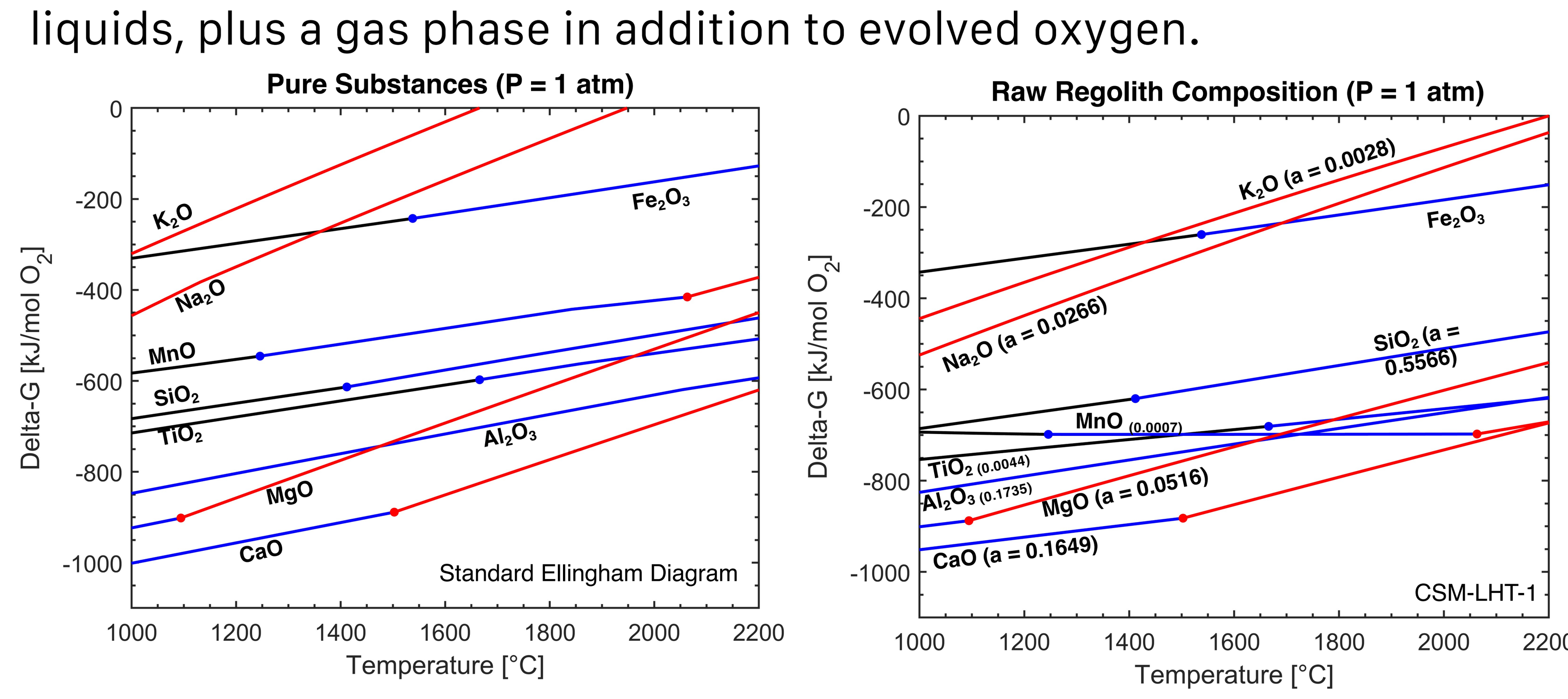

Figure 5. Effect of composition on free energy of reduction reaction.

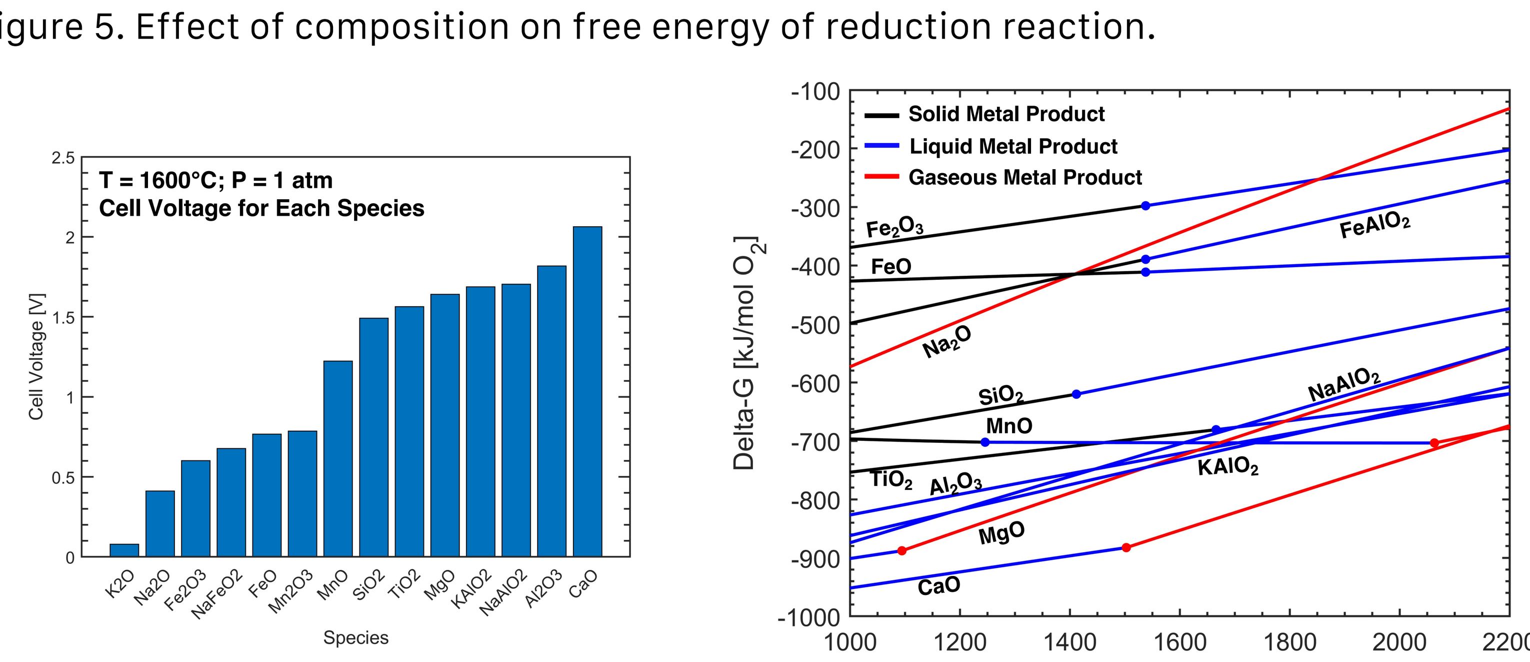

Figure 6. At equilibrium a custom Ellingham diagram is produced, and the cell potential is calculated for each oxide species.

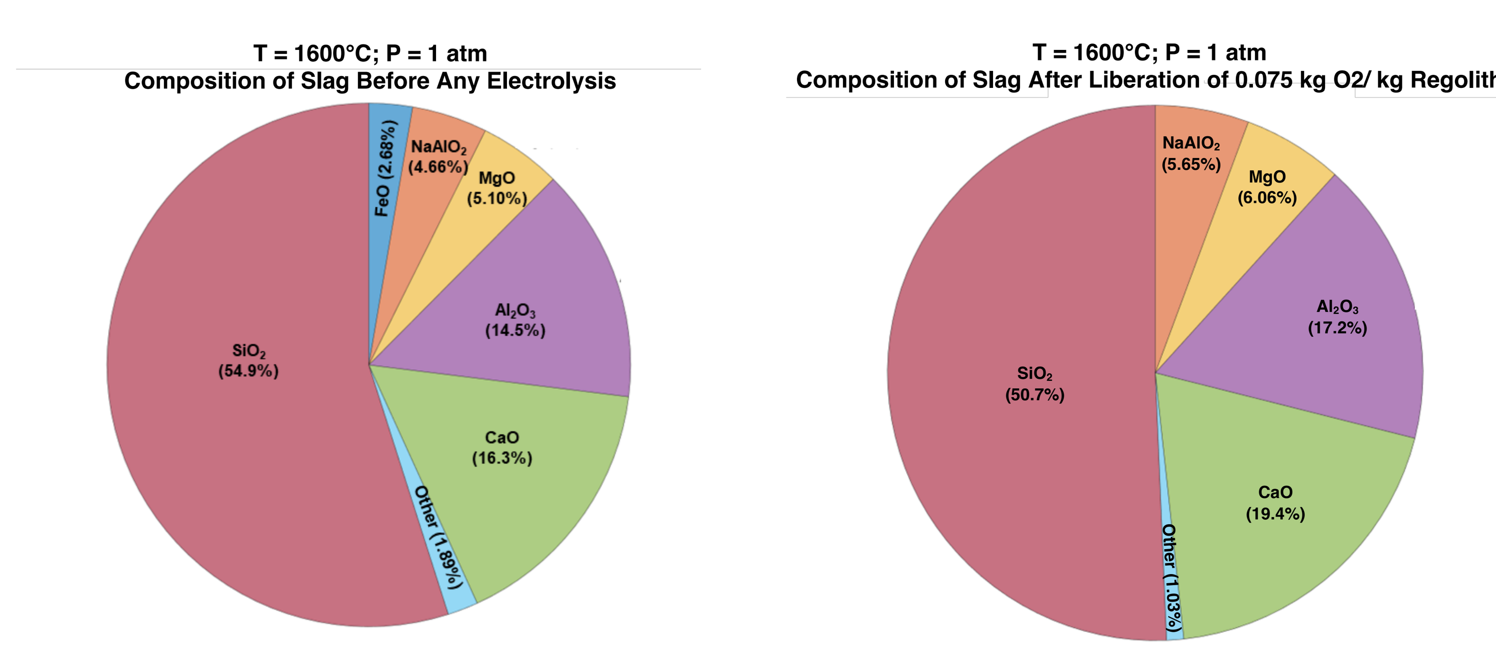

Figure 7. Evolution of slag composition with electrolysis reaction.