Star Forge: Space Mining With Plasma

A Design for a Plasma-Assisted Chemical Reactor to Reduce Infrastructure Needs for In-Situ Resource Utilization of Metals

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Introduction

- The ability to access raw materials in space has been identified as a necessary step in NASA's goals of establishing sustainable human presence in space.
- However, the processes used today to extract and refine these materials are far too heavy and complex to be transported directly into space.
- The present design solves this problem by providing a light-weight system capable of refining critical compounds without the use of chemical reactants sourced from Earth.

Problem Statement

- Space exploration is entering a new age of rapid growth.
- There is an urgent need to develop new technology to revolutionize supply chains to sustainably support this effort.

Market

- The space mining market reached $11.6 Billion in 2022 and is expected to grow to $27.4 Billion by 2030.
- NASA alone plans to spend $2.6 Billion on commercial lunar payload contracts, including funding for lunar resource extraction, by 2028
- The Biden administration announced in 2022 a $156 Million investment to develop a U.S. supply of Rare Earth Elements (REE) and Critical Minerals (CM) from unconventional sources.
- Investments in lunar resource extraction technologies and new sources of critical materials has opened commercial opportunities for advanced space mining technologies.

Design Description

- Previous concepts have proposed to exploit the function of a mass spectrometer, in which material is ionized into charged particles which can be manipulated with electromagnetic fields.
- Figure 1 shows this type of system and the mass spectrometer system from which it is derived.
- This concept is limited to low volumes and masses; nano grams processed each minute vs. kilograms or tones.
- The Star Forge design, whose block diagram is also shown in figure 1, introduces a new, plasma-based reactor and material flow system which can process and ionize material at an industrially viable scale.

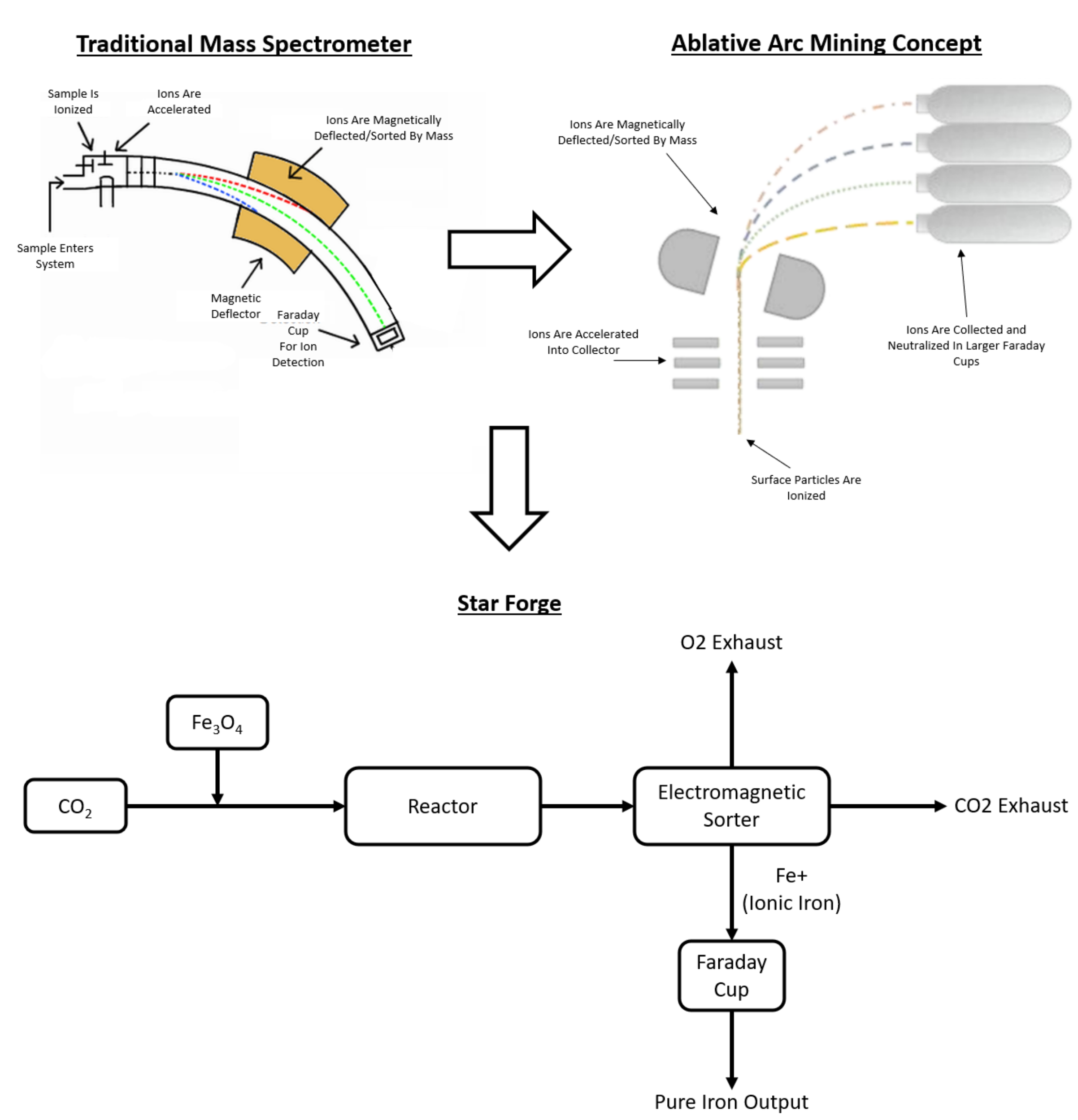

Figure 1: Mass Spectrometer vs. Ablative Arc Mining vs. Star Forge Process Diagrams

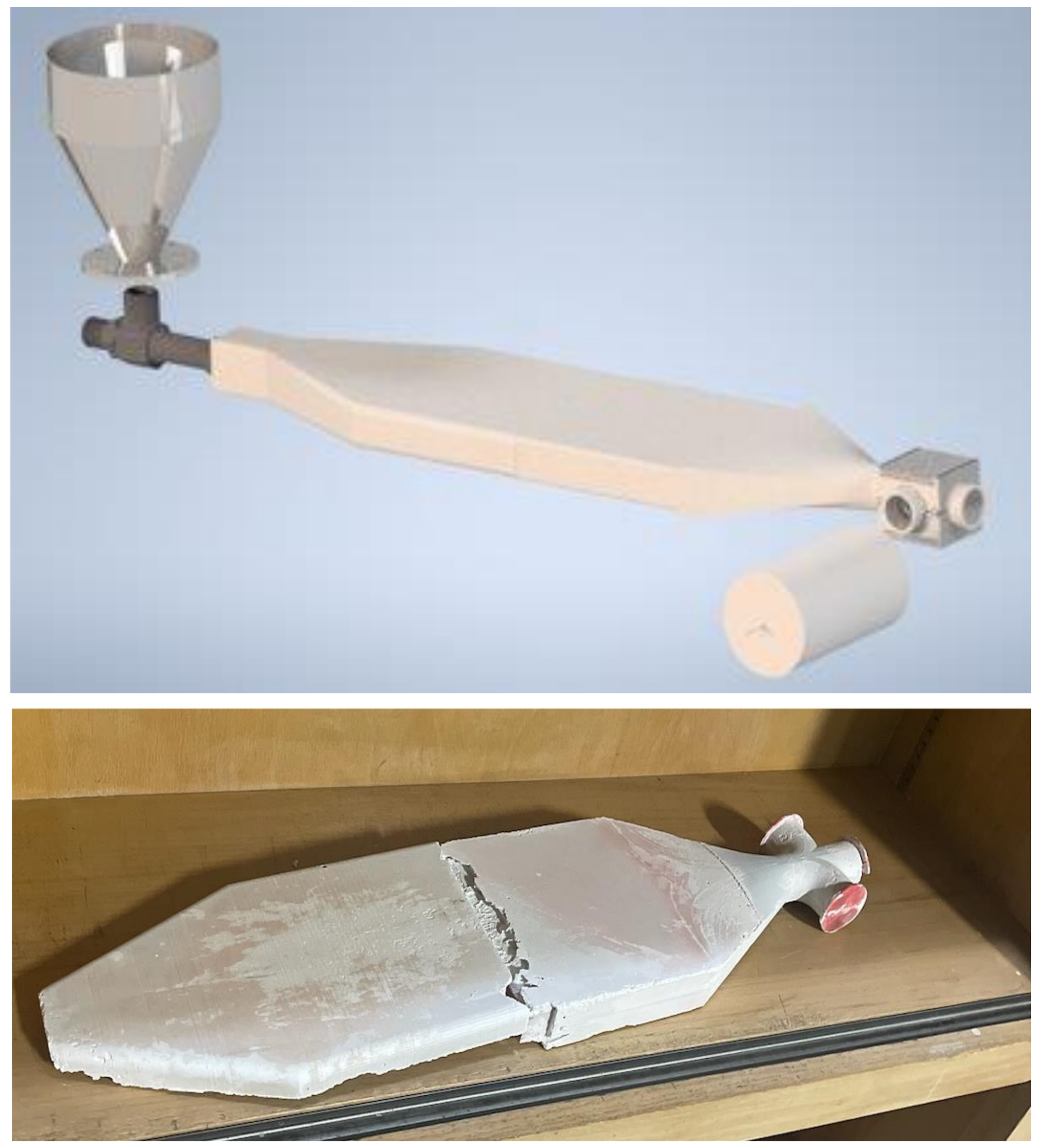

Figure 2: External CAD Assembly (Top) and Ceramic Components (Bottom)

- In the present implementation, metal oxide powder (such as rust, Fe_3O_4) is pulled into the system using a Venturi Pump with CO_2 as its working fluid.
- The pump propels the rust powder and CO_2 into the system's reactor, where the iron in the rust is freed from the oxygen in the compound.
- The iron leaves the reactor as positive ions; these ions are then accelerated by an electromagnetic field and diverted from the flow of gases by a permanent magnetic field.
- The iron ions are then received by a negatively-charged Faraday cup, where the ions are neutralized and stored as pure iron metal.
- This metal can then be used as construction or industrial material.
- Notably, this process will function with any ionically-bonded metal oxide compound, including rare earths.

Verification and Testing

- Using analytical models obtained through calculated curve fits and Computational Fluid Dynamics analysis, the testing will be done within iterations to optimize both the flow rate needed to drive proper material ratios for the intended reaction as well as power delivered to ensure proper refinement of the material yielded.
- To verify these tests, a mass spectrometry analysis will be used to evaluate the amount of material yielded as well as the efficiency of refinement.

Conclusion

- The development and manufacturing of this design is a functional proof of concept demonstrating the viability of this system in off-world resource processing and gathering applications.
- Continued research and investment is required to increase power delivery to the reactor of the system, more control of the flow of material into the system, and reactions involving other useful materials within the system to increase efficiency and yield.
- The project also has the potential for serving as a research test bed for the advancement of scientific and engineering fields such as plasma state chemistry enhanced combustion.

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