System Modeling of a Lunar Molten Regolith Electrolysis Plant

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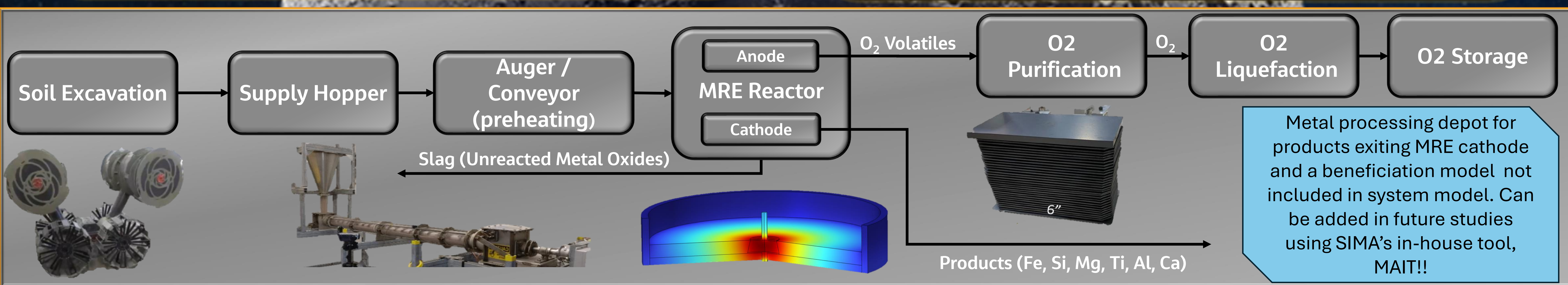
System Engineering & Integration (SE&I)
In-Situ Resource Utilization (ISRU)
Modeling and Analysis (SIMA)

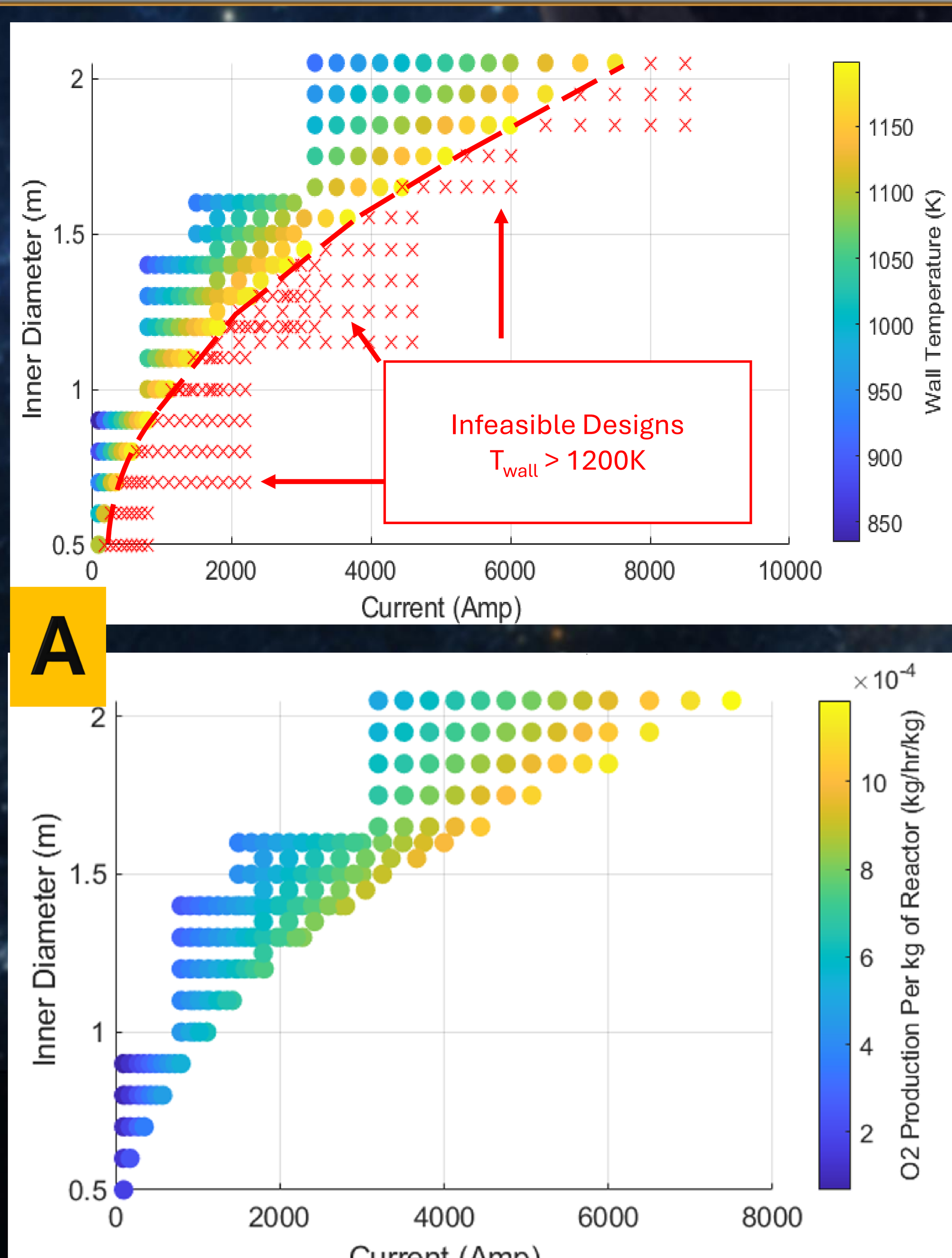
Study Goals

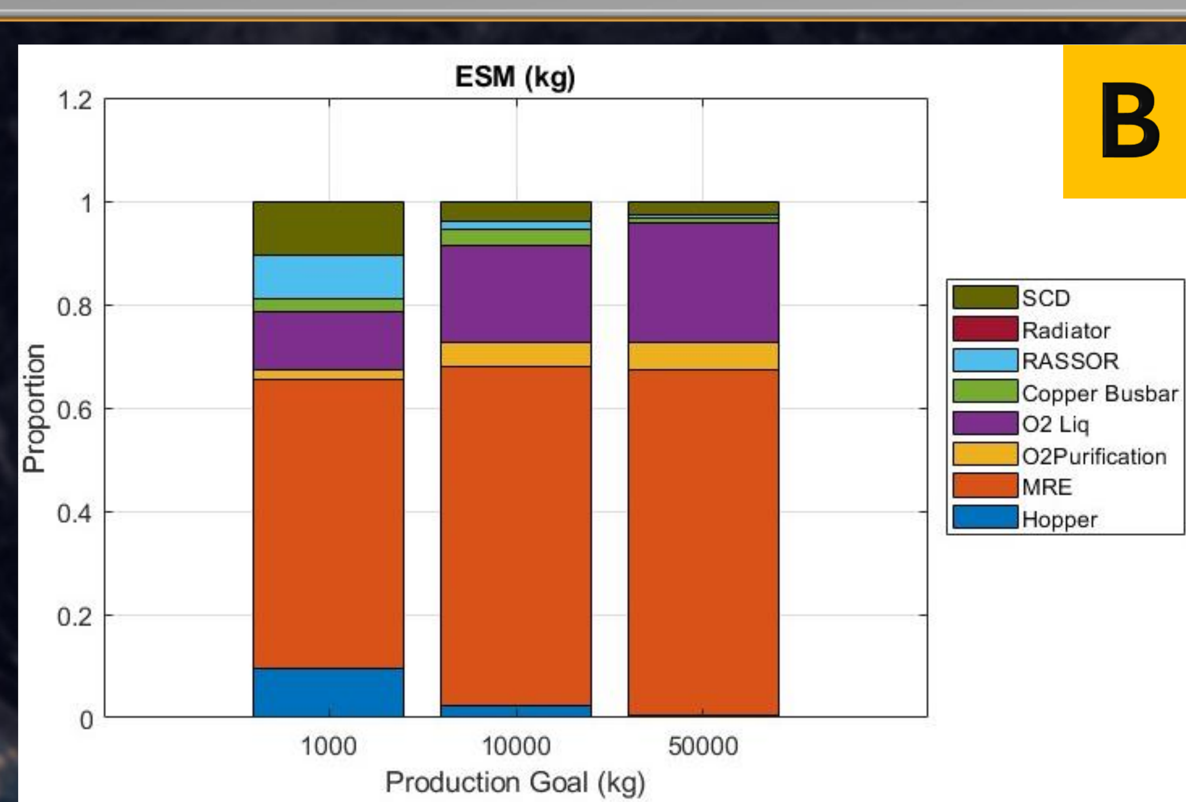
- **Determine feasibility of a Molten Regolith Electrolysis (MRE) ISRU Plant.**
  - Use the Mission Analysis and Integration Tool (MAIT) to determine the power, mass, volume, and equivalent system mass (ESM) of an ISRU plant capable of producing 1, 10, and 50 mT of liquid O_2 per year.
  - Identify subsystems or system interactions that require further development for feasibility.
- **Determine the critical parameters and models to optimize an MRE ISRU plant.**
  - Run parametric sweeps on design parameters to identify the sensitivity of the model to the parameters.
  - Identify the subsystems that are most mass, power, and volume intensive.
- **Identify future work studies or gaps in understanding to address future development of ISRU.**

System Model Description

- **Regolith is excavated, preheated, and transferred to the MRE reactor using KSC's 'Regolith Advanced Surface Systems Operations Robot' - RASSOR, a hopper, and a screw conveyer (SCD).**
- **Oxides in lunar regolith are broken down within MRE reactor to produce gaseous oxygen and molten metals.**
  - High current is passed through solid core of regolith to melt it and break down oxides (e.g. FeO, SiO_2)
  - Multiphysics COMSOL model is used to determine molten mass, temperature, and design feasibility (see below)
- **Volatiles are removed from Oxygen stream via Yttrium-Stabilized Zirconium cells**
- **Oxygen is liquified and stored in cylindrical aluminum tanks.**

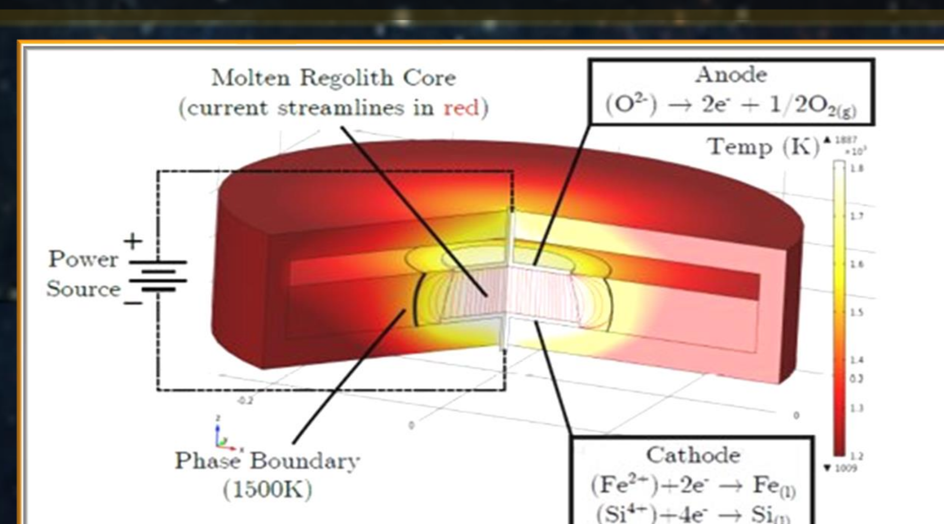


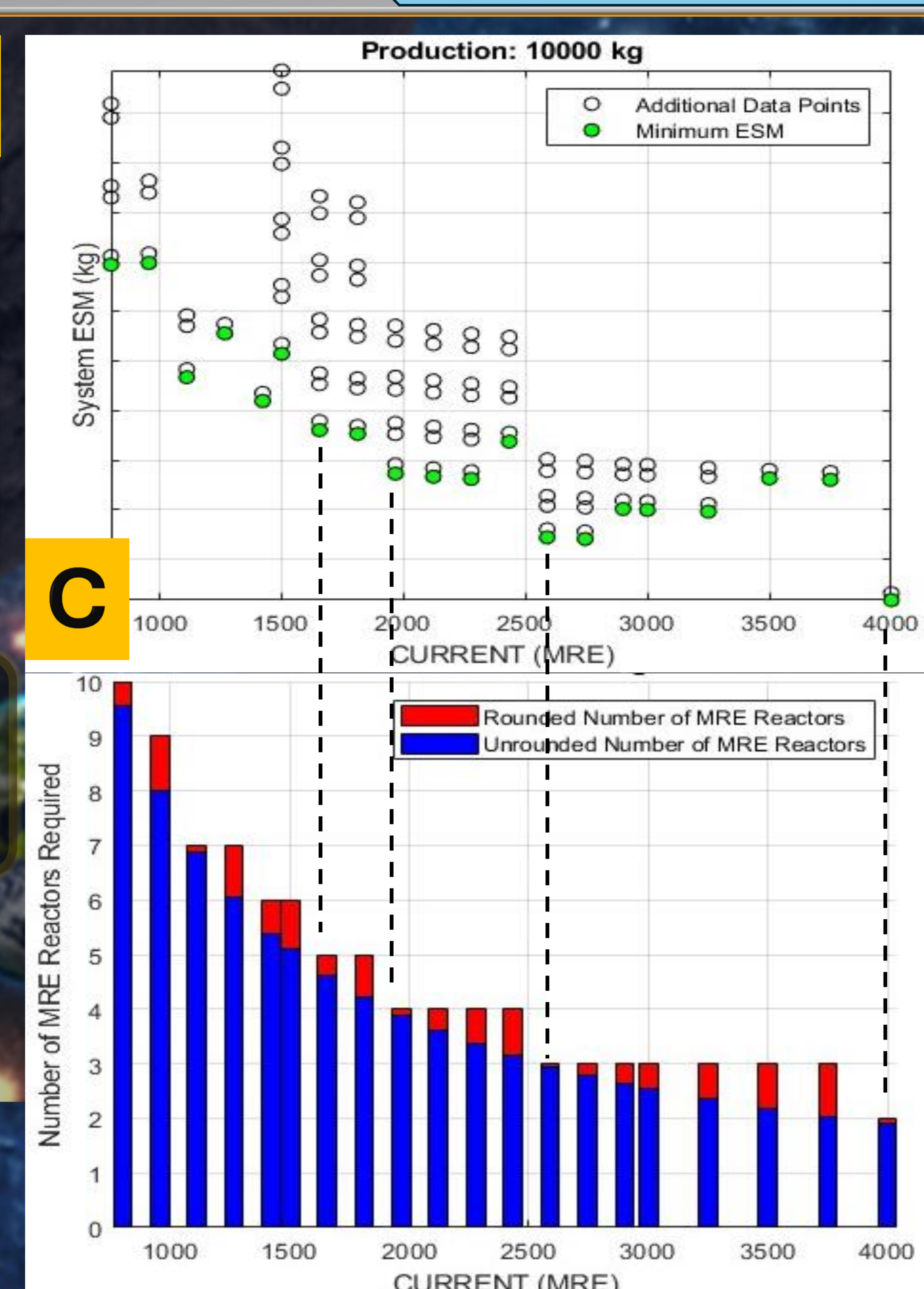




B The proportion of ESM for each subsystem in reference to the total system ESM for all three production targets.

The MRE reactor is the most mass intensive subsystem, following by oxygen liquefaction, in all three cases.





A At higher operating currents, the MRE reactor is more efficient and has a higher rate of oxygen production (bottom graph), but a larger inner diameter of the reactor is required to avoid wall melting (top graph).

To optimize the design, the MRE reactor should follow the Pareto Frontier (red line) as closely as possible.

C Operating current is correlated with MRE geometry. Optimal ESM occurs where current is maximized to ensure full utilization of reaction volume within reactor, thereby reducing the heaviest material in the reactor.

The minimum system ESM for each 'cluster' of currents ran for a parametric sweep corresponds to when the reactors are operating near maximum capacity.

Takeaway One

- **Optimization of the MRE subsystem is most critical in reducing ESM mass.**
- **At lower production targets, the RASSOR, hopper, and SCD have a larger impact on system ESM than at higher production targets.**

Takeaway Two

- **MRE is more efficient at higher currents.**
  - Smaller reactors have lower permissible currents, therefore inherently less efficient.
  - ISRU plant efficiency therefore scales better at higher production due to higher permissible currents in large reactors.

Takeaway Three

- **MRE reactor is most efficient when the ratio of molten mass to solid regolith inside the reactor core is maximized.**
- **This corresponds to designs bordering the "line of feasibility" - dependent on material properties of wall.**

Takeaway Four

- **Design efficiency could be further improved by increasing wall temperature limit and maximum current**
  - Increasing permissible wall temperature would allow for larger molten mass
  - Increasing current limits would increase efficiency.