A UNIVERSAL ISRU ANALYSIS ENGINE AND PROPELLANT-METAL PRODUCTION CASE STUDY TO OPTIMIZE SYMBIOTIC ISRU PROCESSES AND IDENTIFY TECHNOLOGY GAPS.

Aiden O'Leary[1], Connor Geiman, Zach Burkhardt, James Bultitude, and Daniel Faber. [1]Orbit Fab Inc., 1460 Overlook Drive Lafayette, CO, 80026, [1]aiden@orbitfab.com.

Introduction: As the space ambitions of numerous commercial, public, and military segments grow towards the Moon and beyond, In-Situ Resource Utilization (ISRU) is an increasingly pressing topic. The problem is, while numerous technologies and potential solutions exist for the extraction, processing, and production of different compounds, actually understanding and coordinating how and what scales they fit into the ISRU frameworks is much harder. This can leave waste several would-be useful by-products if not examined and analyzed within a larger symbiotic architecture scope.

For this reason Orbit Fab is developing a Universal ISRU Analysis Engine which can optimize ISRU process segments into a cohesive scaling architecture from inputs on the industry's state of the art. Additionally, this allows it to find and examine ISRU technology gaps. This is done utilizing two layers of maximum flow networks (akin to a neural network), a Stoichimetry Engine layer and a Systems Engineering Process layer. Together these create a powerful tool which with sufficient user and industry inputs can provide a deep understanding of ISRU architecture needs and their required components/scale for any celestial body of interest in the solar system, promoting symbiosis and new markets. To put that to the test, this presentation will use the Systems Engineering Process layer to explore a case study of efficient High-Test Peroxide propellant, titanium, iron, and oxygen production from available lunar water and ilmenite.

Methodology: Figures 1 and 2 below provide a high level overview of the inputs and outputs of each of the analysis layer.

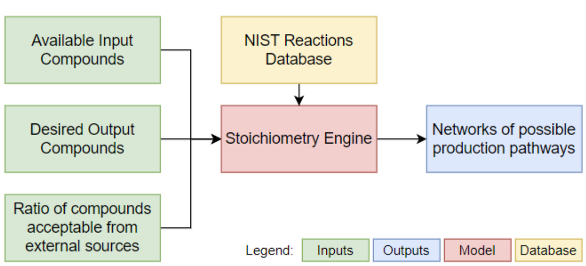

Fig. 1. Layer 1 - Conceptual Stoichiometry Engine

Layer 1 takes the model inputs listed above against the desired output and constructs maximum flow networks via chemical reaction databases to show all possible production pathways for the desired output elements and compounds, within the scoped compound input parameters. While Layer 1 is still a work in progress, it will eventually interact with Layer 2 by providing a database of would-be process pathways which can help identify areas of interest for further research, tech development, or architecture gaps as well as their breakeven points of usefulness within each of the potential solutions.

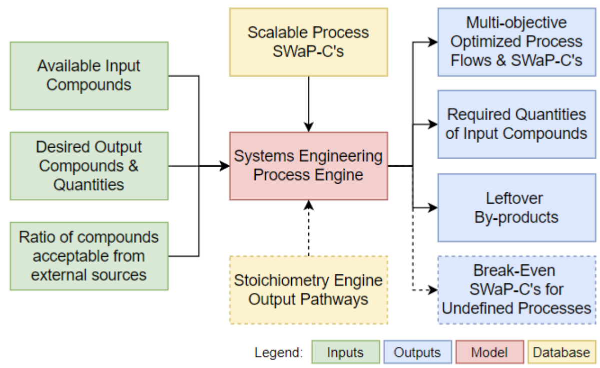

Fig. 2. Layer 2 - Systems Engineering Process Engine

Layer 2 works through a similar process of constructing maximum flow networks, but rather than trading chemical equations, it trades different production processes in a Systems Engineering context. It still is matching the input and output elements/compounds to get the desired final products, but the goal here is to create a multi-objective trade space that allows the user to understand the scope of their desired production yields, providing a valuable tool for combined ISRU architectures. The problem is that each of the processes needs inputs on the Size, Weight, Power, and Cost (SWaP-C), requiring much research and discussion with external parties to fill out. When this layer is combined with Layer 1, the break-even SWaP-C's of undefined processes (which were identified from the possible chemical reactions) can be identified to help direct this research and scope new potential breakthrough solutions.

A Lunar Case Study – HTP and Ilmenite Processing: With water appearing readily available for extraction at the lunar poles, some of the first production case studies of interest are propellants and consumables. While electrolyzing water to produce oxygen and hydrogen for short-term propellant needs and consumables; the complexity of systems required to store liquid hydrogen make it infeasible for any spacecraft missions requiring long term operations or small SWaP-C. This creates a demand for storable mono and bi-propellants that can be produced from lunar materials, for which only High-Test Perxoide (HTP) fits the bill. HTP is composed of 10% water and 90% H2O2, which means it can be easily produced from lunar materials utilizing electrolyzed oxygen, with the waste product of precious hydrogen [1]. With hydrogen's comparative rarity on the moon, and it being a by-product of both propellant and consumable production, finding near term sustainable use cases for it is extremely valuable. As surface needs scale on the Moon, second waves of demand will begin for processes like metal production. Because most lunar metals are found in the form of metals-oxides [2], there has been increasing research interest in ISRU-hydrogen reduction of these metal oxides. This could fit incredibly well with HTP production.

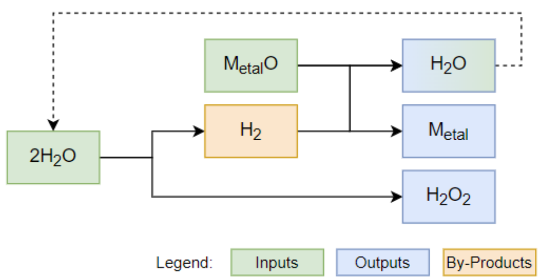

Fig. 3. HTP/Metal Production via Hydrogen Reduction

In the simplified stoichiometric sketch above, HTP production is symbitiocally combined with metal production to utilize the would-be waste hydrogen to generate free metal and water. This water can then be recycled back into the HTP production process, or depending on scale, utilized for other means. Finding symbotic processes such as this is exactly the intention of Layer 1, with Layer 2 being designed to understand from an engineering and architecture perspective the scales at which these processes could be beneficial. This presentation explores a more complicated metal reduction process with a lunar compound of interest, ilmenite, which has the chemical formula of FeTiO3. As ilmenite contains two important industrial metals, iron and titanium, finding ways to at scale reduce ilmenite efficiently without the standard carbon and chlorine (which are rare on the Moon) could eventually be of great importance [3,4]. This presentation will show the outputs from Layer 2 for this ilmenite case at varying demand scales to show how symbiotic processes such as this might benefit each other.

Conclusion: The goal of this Universal ISRU Analysis Engine and case study is to promote and discover the symbiotic benefits of different reactants, products, and by-products while optimizing the processes involved for maximum yield at minimum SWaP-C. The ask from the industry is that data sharing on the SWaP-C and capabilities of these different production systems becomes more common place so that a symbiotic web of coordinated efforts and markets emerge. By realizing this goal and promoting minimum-waste ISRU architectures, a bustling in-Space economy and market can be created sustainably on the Moon and beyond faster than ever before.

References: [1] C. Geiman et al (2021) High-Test Peroxide Production System for In-Situ Propellant Manufacture From Extraterrestrially Mined Water. [2] S. Taylor (1975) Lunar Science: a Post-Apollo View. [3] H. Sekimoto et al (2007) Reduction of Titanium Oxide to Titanium Alloy by Hydrogen. [4] G. Zhou and A. A. Mardon (2010) Lunar Oxygen Production Through Hydrogen Reduction at High Temperatures.