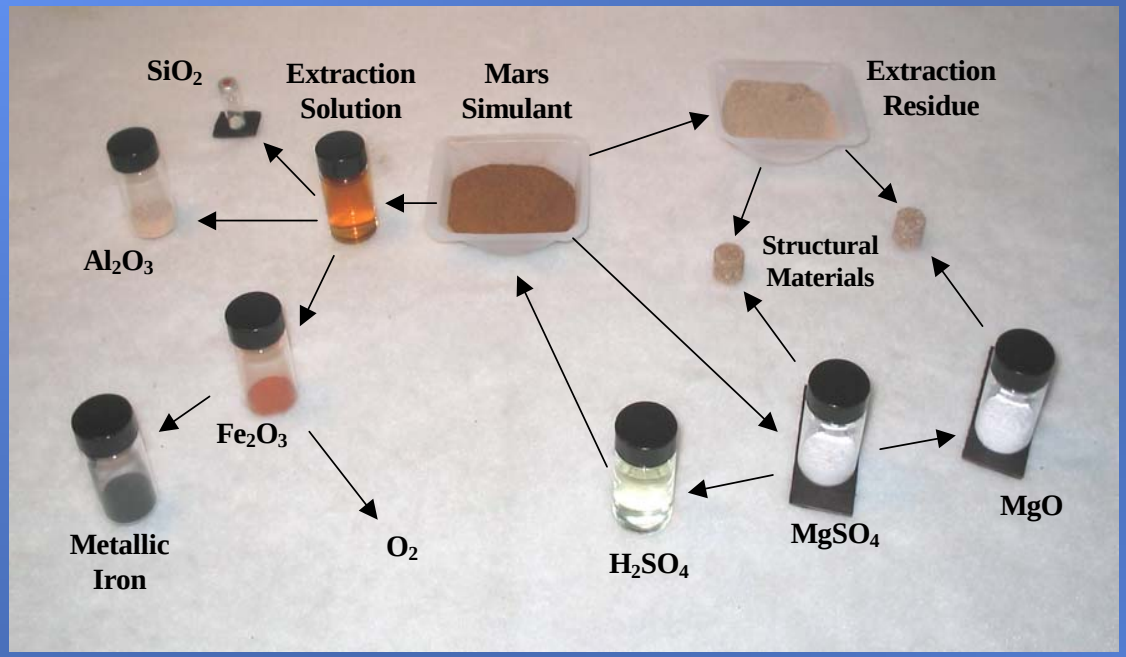
Mars Aqueous Processing System (MAPS)



Work Performed by:

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NASA Johnson Space Center

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Mars Aqueous Processing System
Project Team

- Mark Berggren - Principal Investigator
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- Kris Romig - NASA JSC COTR

Mars Aqueous Processing System

- A closed-loop H_2SO_4 extraction system for production of oxygen, metals, and metal oxides.
  - Originally conceived for application on Mars
    - Water and reagents are derived from indigenous resources.
    - Acids and bases are used to extract and selectively recover materials to make products such as metallic iron, alumina, silica, magnesia, calcia, and oxygen.
    - Spent solids are formed into concrete-like structural components using excess process reagents and water.

Mars Aqueous Processing System

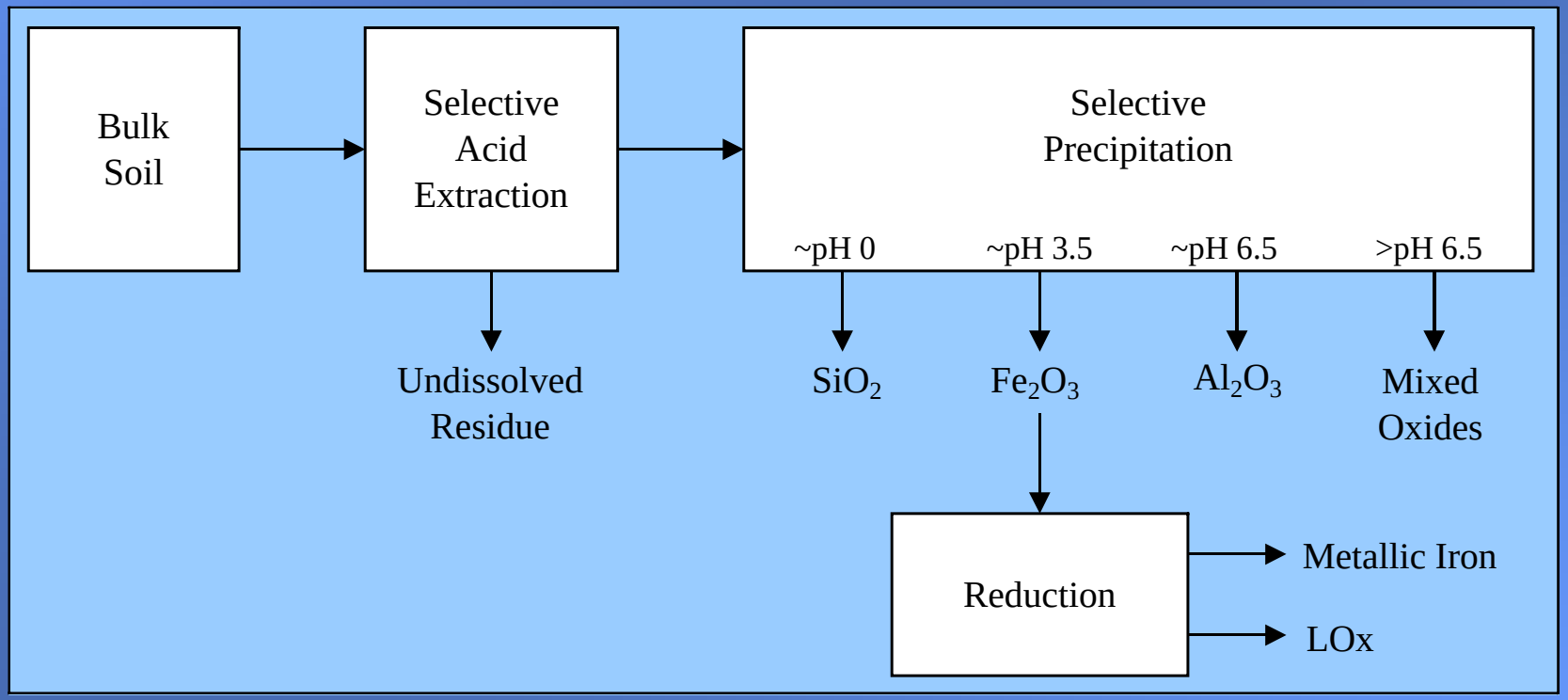
- A closed-loop H_2SO_4 extraction system for production of oxygen, metals, and metal oxides.
  - A subset of the technology is applicable to the Moon
    - Reagents need to be delivered from Earth and recycled.
    - Produces an iron oxide concentrate.
      - Generates metallic iron product plus oxygen.
      - Generate an equivalent amount of oxygen from $1/5^{th}$ the mass of bulk soil.
      - Can perform hydrogen reduction at 750°C instead of 1000°C+.
      - Reduces heating power by an order of magnitude compared to bulk soil.
    - The process can be expanded to produce oxide byproducts.
    - Water-based building materials cannot be made.

Mars Aqueous Processing System

- Example products to enable or sustain exploration and colonization
  - Iron and its alloys for manufacturing or repair applications
  - Oxygen for propellant and breathing gas
  - Alumina for metal production or ceramics manufacture
  - Calcium and magnesium oxides for ceramics, construction materials, or chemical process reagents
  - Silica for semiconductor manufacture, photovoltaics, and glass
  - Alkali metal oxides for glass manufacture and chemical process reagents
  - Fused or water-bonded components from spent soils

Mars Aqueous Processing System

- Acid selectively dissolves soil constituents.
- Bases sequentially precipitate valuable products.



Mars Aqueous Processing System

- Sulfuric Acid Advantages
  - Sulfur is the most available element for make up of reagent loss (sulfuric acid) on both the Moon and Mars.
  - Sulfuric acid provides extraction selectivity with good reactivity under moderate conditions.
  - Sulfate salts produced by aqueous extraction can be recovered as oxides or hydroxides with concurrent regeneration of acid.

Mars Aqueous Processing System
Process Advantages

- MAPS provides a greater range of products at higher grade and better recovery than physical separation or thermal treatment methods.
- Soil pretreatment consists largely of excavation and rough sizing - no power intensive crushing is required.
- No beneficiation required – however, beneficiated materials or naturally concentrated minerals can be refined using MAPS technologies.
- In-process soil handling and agitation power is minimized by using a column for all extraction, washing, and residue drying procedures. Solutions are pumped to obtain the needed mixing and circulation.
- Most MAPS process conditions are moderate with respect to materials of construction and materials handling.

Mars Aqueous Processing System
Process Implementation

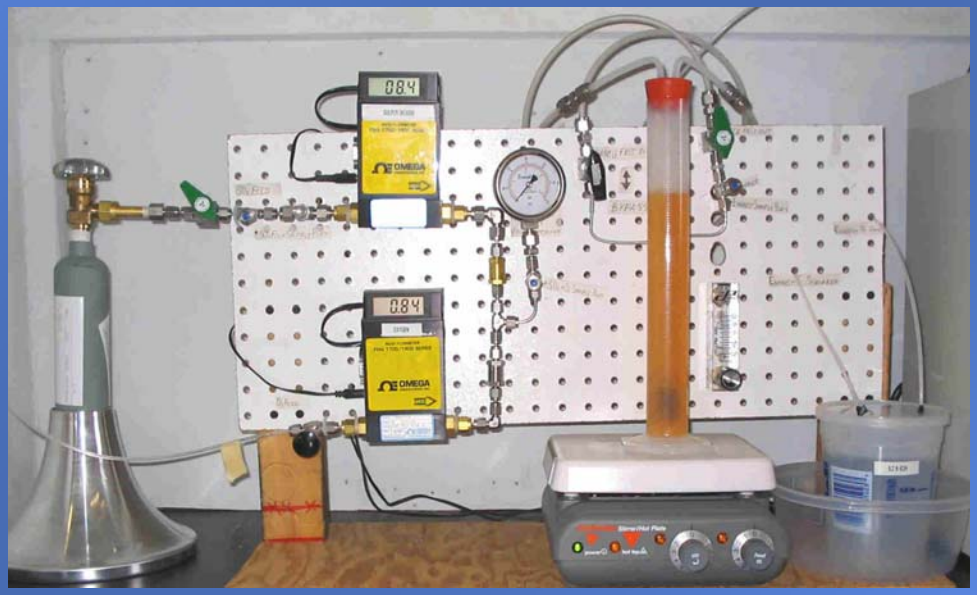
- MAPS is significant because it can be co-developed for lunar and Martian applications, resulting in reduced risks and costs.
  - Initial application is lunar iron and oxygen production
  - Next application is lunar materials production plus oxygen
  - Full implementation is for Mars materials plus oxygen production

Mars Aqueous Processing System
Accomplishments

- Magnesium Sulfate Extraction
  - Achieved 98% extraction from simulated Mars duricrust.
  - Used multiple water-soil contacts to build solution strength.
- Magnesium Sulfate Recovery
  - Recovered $MgSO_4 \cdot 7H_2O$ crystals from saturated solutions.
  - Produced anhydrous $MgSO_4$ from hydrated crystals.
  - Recycled residual solution to extraction step to maximize recovery.
- Magnesium Sulfate Decomposition
  - Produced MgO by thermal decomposition for use as base or refractory.
  - Concurrently made SO_2 and O_2 for acid production.

Mars Aqueous Processing System
Accomplishments (continued)

- Sulfuric Acid Production
  - Made 16 wt % H_2SO_4 from SO_2 and O_2 gases at 30-50°C.
  - Used low grams-per-liter Fe or Mn liquid-phase sulfate catalysts.
  - Method is suitable for salt-derived gases into acid.



Mars Aqueous Processing System
Accomplishments (continued)

- Iron and Metals Dissolution
  - Used MAPS-derived H_2SO_4 solution at 70°C.
  - Extracted iron oxide, alumina, silica, and other oxides.

Mars Aqueous Processing System
Accomplishments (continued)

- Iron and Metals Dissolution
  - Up to 45% Fe extraction in single-step extraction; up to 60% Fe extraction in two-step extraction in non-optimized tests.
  - Nearly complete Fe extraction expected with optimization.

JSC Mars-1 Feed and Residues

JSC-1 Lunar Simulant and Residue

Mars Aqueous Processing System
Accomplishments (continued)

- Iron Oxide Recovery
  - Recovered over 90 percent of extracted iron in the form of a concentrate containing 80 percent Fe_2O_3.

Mars Aqueous Processing System
Accomplishments (continued)

- Iron Oxide Reduction
  - A MAPS iron oxide precipitate was reduced with hydrogen to produce metallic iron and water vapor at a temperature of 730°C.

Mars Aqueous Processing System
Accomplishments (continued)

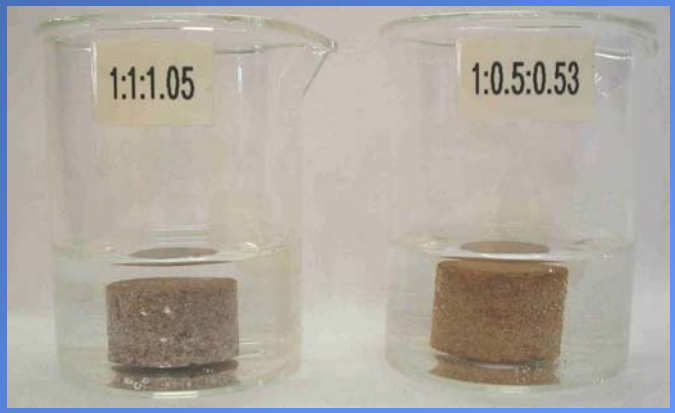
- Recovery of Other Metal Oxides.
  - Alumina recovered at 80% grade
  - Other extracted soil constituents include oxides of manganese, sodium, potassium, calcium, magnesium, phosphorus, and silicon.
  - Each can be further refined into useful products while regenerating acid and bases.

Mars Aqueous Processing System
Accomplishments (continued)

- Structural Materials Fabrication
  - A magnesium sulfate based cylindrical structural component was formed with spent simulant solids and water. One test cylinder of this material exhibited compressive strength of greater than 800 psi.

Mars Aqueous Processing System
Accomplishments (continued)

- Structural Materials Fabrication
  - A magnesium oxide based cylindrical structural component was also formed with spent simulant solids and water.
    - Formulations exhibiting compressive strengths of 600 to over 800 psi were obtained.
    - Improved strength and utilization of residue were obtained by tailoring particle size distribution.
    - These formulations retained strength after submersing in water.



Mars Aqueous Processing System
Recent Work

- Multi-Cycle Extraction and Recovery Experiments
  - Demonstrated recovery of metal sulfate salts by crystallization.
  - Demonstrated re-use of extraction solutions after acid regeneration.
  - Demonstrated thermal decomposition of crystals to recover water and acid precursors.
- Preliminary material balance preparation

Mars Aqueous Processing System
Conclusions

- MAPS can selectively extract and recover a high-grade iron oxide concentrate (80% iron oxide) from bulk soils. Iron and oxygen are coproduced.
- MAPS can be developed in tandem for Moon and Mars applications.
- MAPS aqueous processing steps can be conducted at low to moderate temperatures using mostly plastic vessels and piping, thereby reducing the mass of process equipment required.
- Thermal treatments are conducted only on limited masses of upgraded materials.

Mars Aqueous Processing System
Conclusions (continued)

- MAPS operates in a closed loop for lunar applications with recovery and recycle of process reagents. Sulfur from lunar regolith is available in the approximate quantities needed to make up for losses to solids residues.
- MAPS also operates in a closed loop for Mars applications, but the key process reagents can be derived from water and salts in the Martian soil. Excess reagent such as MgO or $MgSO_4$ can be used to form structural components.
- MAPS can recover materials of higher quality than can be produced by physical or thermal methods alone. MAPS provides the basic components needed to support lunar and Martian manufacturing.
- The near-term applications of MAPS are important. The long-term applications are extensive.

Mars Aqueous Processing System
Review