METALS AND OXYGEN MINING FROM METEORITES, ASTEROIDS AND PLANETS USING REUSABLE IONIC LIQUIDS

L. J. Karr, M. S. Paley, M. J. Marone,
W. F. Kaukler and P. A. Curreri
NASA/Marshall Space Flight Center

Metals and Oxygen Mining from Meteorites, Asteroids and Planets using Reusable Ionic Liquids

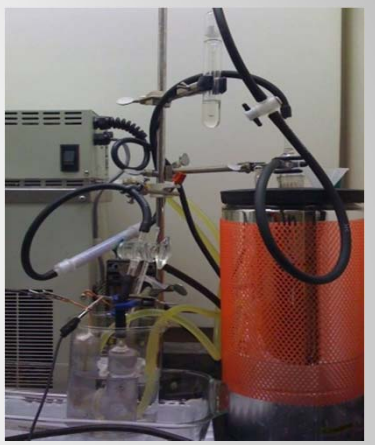
Ionic Liquids (ILs) are organic salts that are liquid at or near room temperature

- Low Volatility
- Low Flammability
- Chemical Versatility
- More Environmentally Friendly (green technology)
- Stable in Extreme Environments (low T, high vacuum)

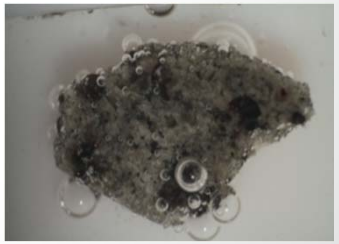
Extraction of Oxygen and Metals from Lunar, Martian, or Asteroidal Regoliths

- Acidic IL can be used to dissolve regolith, and extract as water, up to 80% of the oxygen available in metal oxides (at temperatures below 200°C).
- Method applies to any extraterrestrial regolith with metal oxides: Have Solvent - Will Travel.
- Water is electrolysized to hydrogen and oxygen, with the oxygen used for breathing or propellant and the hydrogen used to regenerate IL acid (through reprotonation).
- IL Acid regenerated at anode. Free metals are deposited at cathode.

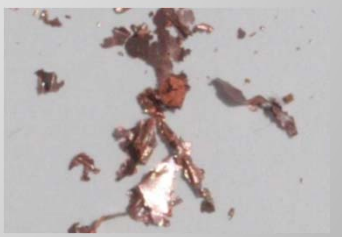
Water extraction from dissolving regolith simulant in acidic IL



Electrolysis and O_2 capture



Martian Meteorite (L) and Lunar Meteorite (R) dissolving in IL



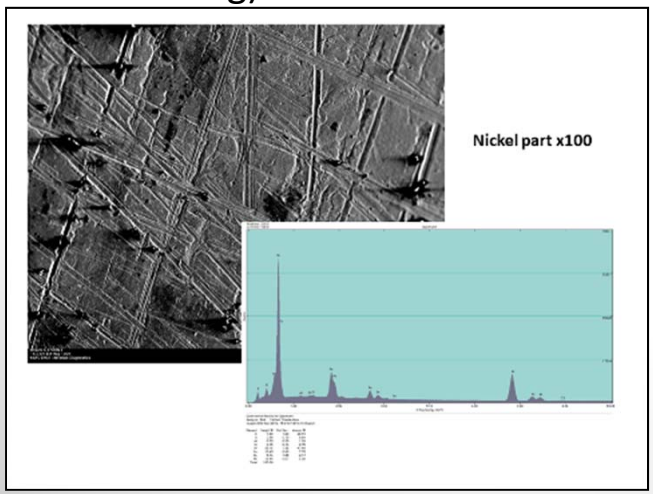
Micrographs of copper electrode and copper flakes recovered from electrode.

MSFC Point of Contact: Dr. Laurel Karr/EM10 256-544-7817

Metals and Oxygen Mining from Meteorites, Asteroids and Planets using Reusable Ionic Liquids

Metals from meteorites dissolved in ILs are plated onto cathode while IL is regenerated at the hydrogen electrode (anode).

- Campo del Cielo is an iron/nickel meteorite
- pH of acidic IL system after dissolution was about 6
- pH after regeneration was about 1
- High voltage applied – nickel and iron are plated out together
- Low voltage applied – nickel is plated out first, then raising voltage causes iron to be plated out (electro-winning).



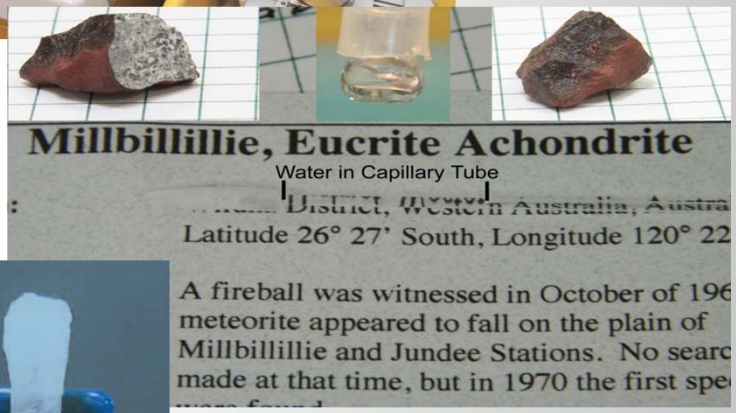
SEM analysis of Nickel Plating

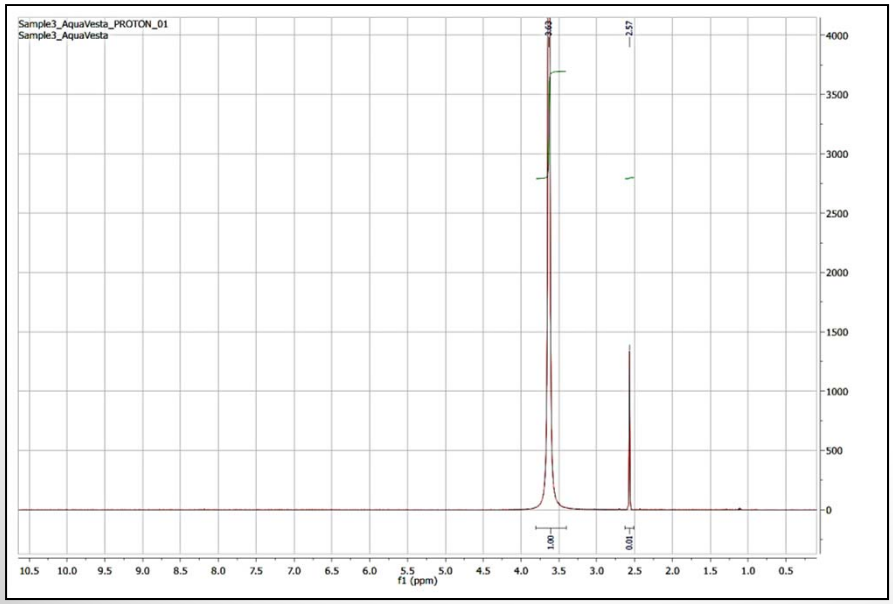
MSFC Point of Contact: Dr. Laurel Karr/EM10 256-544-7817

Metals and Oxygen Mining from Meteorites, Asteroids and Planets using Reusable Ionic Liquids

Hybrid Extraterrestrial/Earth Water was extracted from meteorite originating from Asteroid Vesta.

- Micro-distillation apparatus was developed - allows us to capture water from a small amount of meteorite material
- *This is the first extraction of oxygen from an extraterrestrial source*





NMR Analysis of Hybrid Extraterrestrial Water

MSFC Point of Contact: Dr. Laurel Karr/EM10 256-544-7817

Metals and Oxygen Mining from Meteorites, Asteroids and Planets using Reusable Ionic Liquids

Ionic Liquid Chemical Drill for Analysis of Regolith

- Acidic Ionic Liquid (IL), same as for extraction of oxygen and metals, is used for sampling, installing sensors or anchoring a structure
- Mechanical drilling enhanced by injecting IL to break up regolith ahead of it
  - Lower power consumption
  - Fewer drill replacements
- Purely chemical drill to dissolve soil and remove in solution/suspension
  - Advantages for analytical instrument design
  - New wet chemical techniques for compound analysis

Proposed Mars CO_2 Capture and electrolysis with H_20 for Methane and Oxygen Production (with KSC – A. Muscatello)

- 3rd Generation Task-Specific IL to efficiently capture CO_2 and serve as electrolyte for co-electrolysis with H_20 in single vessel
- Reduction of cost, complexity and risk of Mars sample return

Laboratory Demonstration of Chemical Drill

Single-Pot Chemical Reactions to Launch Samples or Crews from Mars

IL = Ionic Liquid

$CO_2(gas) + IL \rightarrow CO_2\text{-}IL(liquid)$

$CO_2 + 2\,H_2O \rightarrow CH_4 + 2\,O_2$ *(electrolysis, ~25°C)*

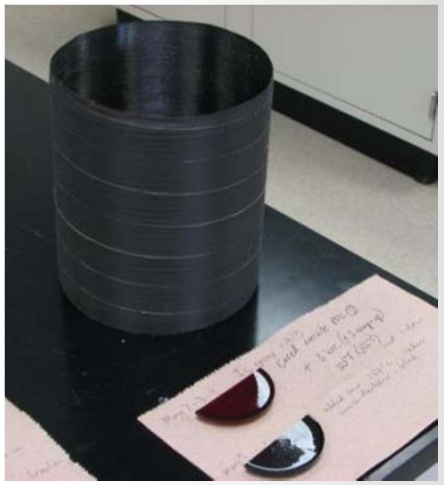
MSFC Point of Contact: Dr. Laurel Karr/EM10 256-544-7817

Metals and Oxygen Mining from Meteorites, Asteroids and Planets using Reusable Ionic Liquids

Ionic Liquids – Based Structural Applications

Composite Cryotanks

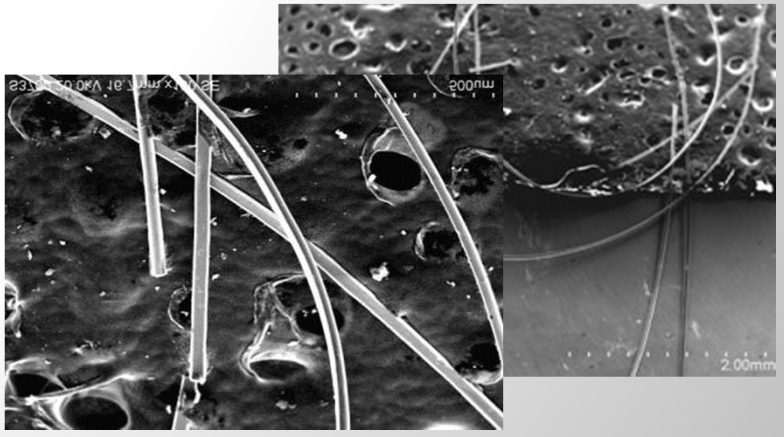
- Unique patented Ionic Liquid Epoxy was developed at MSFC – used as a matrix for lightweight carbon composite
- Shows superior toughness at cryogenic temperatures over commercially available composite material
- No microcracking after repeated thermal cycling
- Expect high resistance to chemical attack (liquid methane, nitrous oxide)



Wound and cured IL epoxy/carbon composite

Ionic Liquid Process for Cellulosic Based Carbon Fiber

- Carbon Fiber is critical material for carbon-carbon Solid Rocket Motors, and re-entry heat shields, TPS, and insulation (US Gov't Critical Technology Need)
- Viscose rayon processing method ceased in US due to EPA restrictions in 1997 (>$20M spent to find replacement)
- IL process is direct replacement for Viscose rayon
- Ultimate goal is for ecologically green, domestic cellulose-based carbon fiber needed by aerospace industry



SEM of carbon fibers made in the laboratory from IL-processed rayon precursor

MSFC Point of Contact: Dr. Laurel Karr/EM10 256-544-7817

Metals and Oxygen Mining from Meteorites, Asteroids and Planets using Reusable Ionic Liquids

Future Research Efforts

- Ground-based and flight technologies such as (oxygen compatible) adhesives, lubricants, solvents and green cleaning agents for hardware and components
- Environmental uses such as CO_2 absorbents, life support, heat transfer fluids, radiation shielding, and sensors.
- Structural components such as composites for cryogenic tanks, foams, and carbon fiber components
- Power sources, such as regenerative fuel cells, solar power systems
- Electro-deposition Processes
- Biological Processes (enzymatic reactions, crystal growth)
- Propellants
- Liquid Mirror Telescopes

Artist Concept, NASA's Space Launch System (NASA/MSFC)

MSFC Point of Contact: Dr. Laurel Karr/EM10 256-544-7817