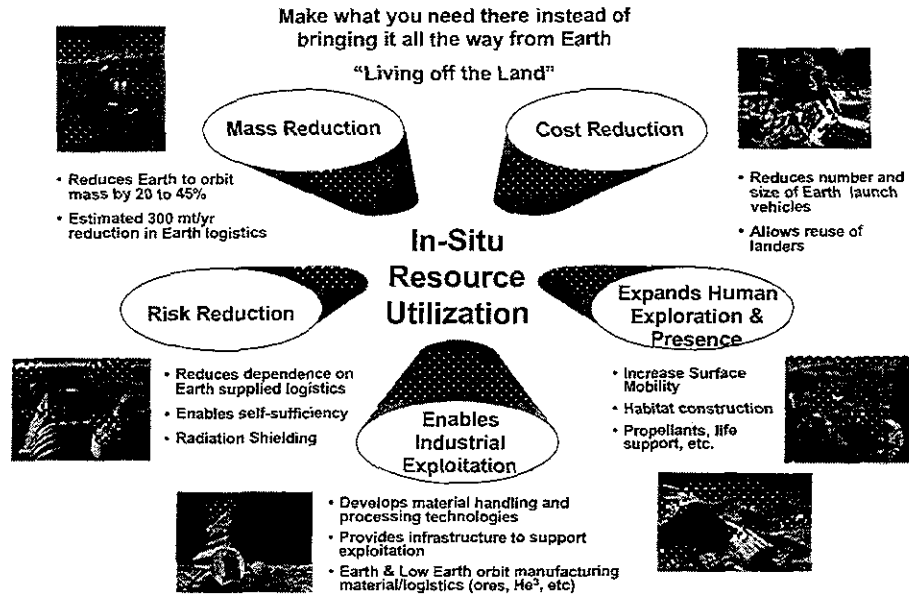


# IN-SITU RESOURCE UTILIZATION (ISRU) DEVELOPMENT PROGRAM

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## Why In-Situ Resource Utilization (ISRU)?



## Resources and ISRU Products

<p><b>Regolith</b></p> <ul style="list-style-type: none"> <li>Oxygen (45%)</li> <li>Silicon (21%)</li> <li>Aluminum (13%)</li> <li>Calcium (10%)</li> <li>Iron (6%)</li> <li>Magnesium (4%)</li> <li>Other (1%)</li> </ul>	<p><b>Regolith</b> <b>Solar Wind</b></p>	<p><b>Water</b></p> <p>0.5 to 1% at poles?</p> <p><b>Solar Wind</b></p> <ul style="list-style-type: none"> <li>Hydrogen (50 - 100 ppm)</li> <li>Helium (3 - 50 ppm)</li> <li>He<sup>3</sup> (4 - 20 ppb)</li> </ul>	<p><b>Soil*</b></p> <ul style="list-style-type: none"> <li>Silicon Dioxide (43.5%)</li> <li>Iron Oxide (18.2%)</li> <li>Sulfur Trioxide (7.3%)</li> <li>Aluminum Oxide (7.3%)</li> <li>Magnesium Oxide (6.0%)</li> <li>Calcium Oxide (5.8%)</li> <li>Other (11.9)</li> <li>Water (?)</li> </ul> <p><small>*Based on Viking Data</small></p>	<p><b>Atm. CO<sub>2</sub></b> <b>Soil</b></p>	<p><b>Atmosphere</b></p> <ul style="list-style-type: none"> <li>Carbon Dioxide (95.5%)</li> <li>Nitrogen (2.7%)</li> <li>Argon (1.6%)</li> <li>Oxygen (0.1%)</li> <li>Water (parts per million)</li> </ul>
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### Lunar Resources & Products

- Lunar regolith contains 45% oxygen by mass that can be used for propulsion, power generation, and crew breathing
- Lunar soil could be used for crew radiation protection
- H<sub>2</sub> and He (including He<sup>3</sup>) from the solar wind are available at very low concentrations (parts per million) for fuel production and fusion reactors on Earth
- Aluminum, iron, and magnesium can be used in construction
- Silicon can be used to produce solar cells for power generation
- Ice in the lunar regolith can be used for life support or to make propellants for propulsion and power generation

### Mars Resources & Products

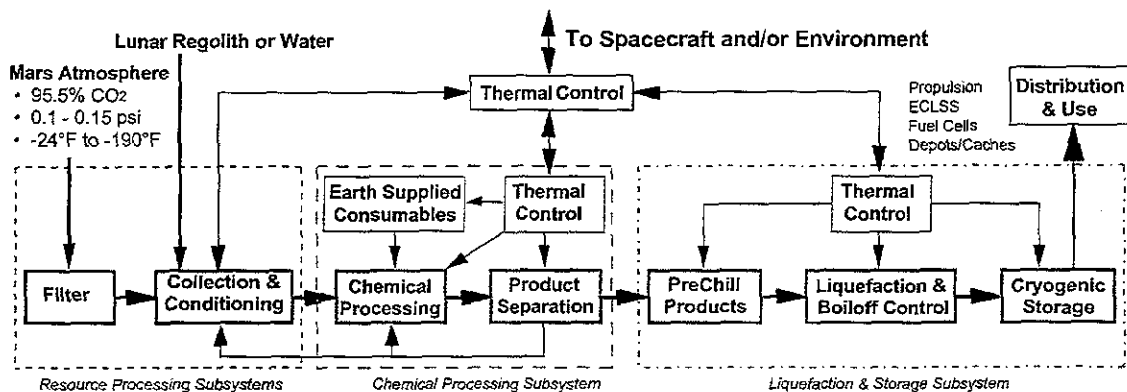
- The atmosphere contains >95% carbon dioxide that can be used to make oxygen and fuels
- Atmospheric nitrogen (N<sub>2</sub>) and argon (Ar) can be used for life support, experiment carrier gases, inflating structures, purging dust from hardware, etc.
- Water in the atmosphere and in the soil (if available) could be extracted for use in life support, propulsion, and power generation
- Further information is required to determine how best to extract and use Mars soil based resources, especially water content

## ISRU Term Definitions

- **In-Situ Resource Utilization (ISRU)**
  - Covers all aspects of using or processing local resources for the benefit of robotic and or human exploration. Examples:
    - > Using dirt/regolith for radiation shielding
    - > Making structures/habitats and solar cells from processed resources
    - > Making propellants or other consumables
- **In-Situ Consumables Production (ISCP)**
  - Is a subset of ISRU that covers all aspects of producing consumables from local resources
  - Consumable products/needs include:
    - > Propellant for ascent, hoppers, or Earth return
    - > Reagents for fuel cells
    - > O<sub>2</sub>, H<sub>2</sub>O, and N<sub>2</sub> for Environmental Control & Life Support System (ECLSS) backup
    - > Gases for purging or inflating habitats/structures
    - > Heat for spacecraft/habitat thermal control
- **In-Situ Propellant Production (ISPP)**
  - Is a subset of ISCP that covers all aspects of producing propellants from local resources for the benefit of robotic and or human exploration
  - ISPP requires the least amount of infrastructure to support and provides immediate benefits to mission plans

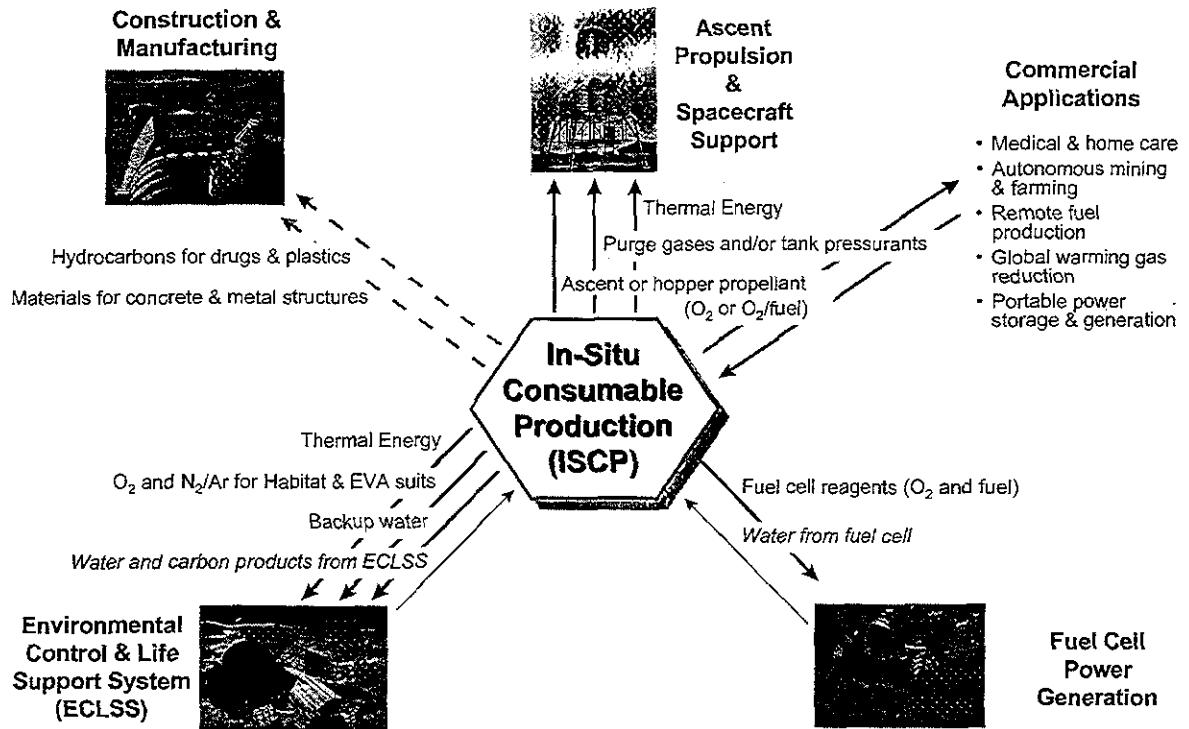
Note: Most work performed to date is specific to ISPP at this time

## ISCP Process Diagram



- **Resource Processing Subsystems:** Collects and prepares in-situ resources for use in process subsystem
  - Filtration, and collection & conditioning using adsorption beds or compressors for gas resources
  - Shoveling, mining, sorting, sifting, and grinding for solid resources
- **Chemical Processing Subsystems:** One or more chemical reactions and reactant/product separations to change the collected resource into usable products.
  - The Chemical Processing Subsystem defines the ISCP products, Earth consumable needs, and the system complexity and power characteristics for the ISCP plant
- **Liquefaction & Storage Subsystems:** Many in-situ products are gases. To efficiently store large quantities of these in-situ products, liquefaction and storage as a cryogenic liquid is required

## Possible Consumable Interaction



## ISCP Development Challenges



- **Chemical Process Development**

- Chemical/separation conversion efficiency
  - > Earth supplied consumable limitations
- Thermal integration and management
- Complexity

- **Operational Environment/Survivability**

- Autonomous control & failure recovery
  - > No crew for maintenance
  - > Non-continuous monitoring
- Environmental compatibility [dust, temperature]
- Long-life operation [months to years]



- **Support System Development**

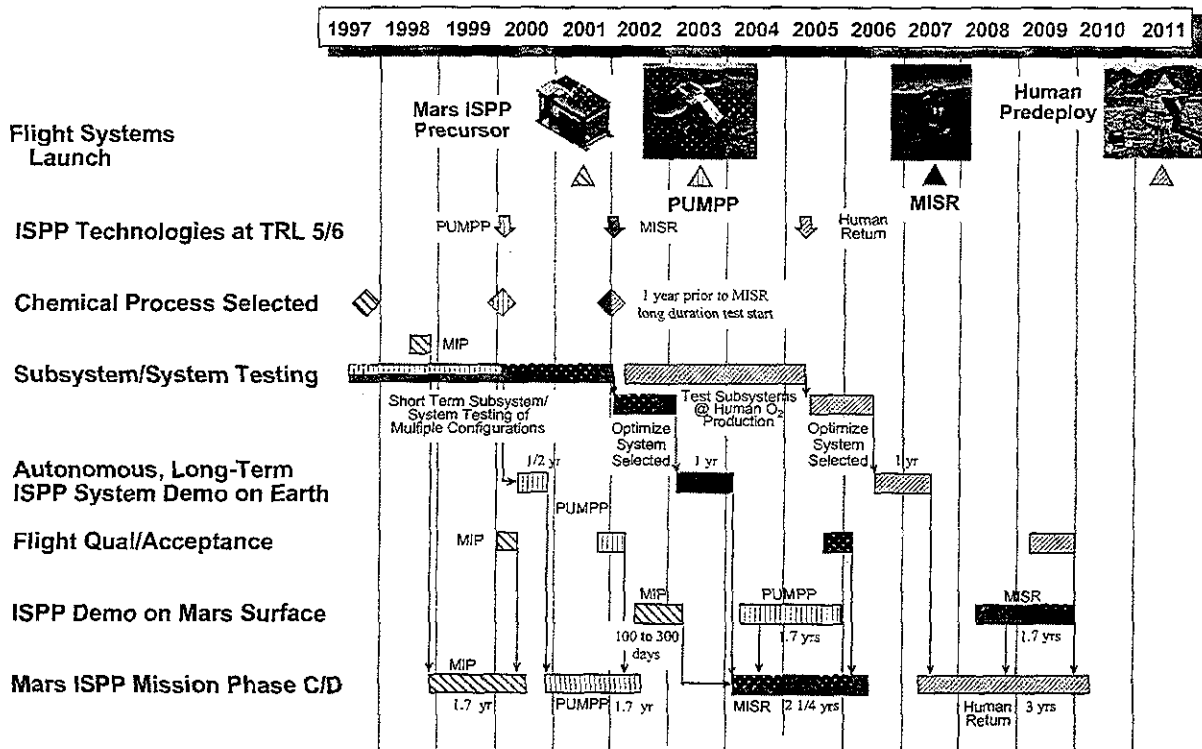
- Power
  - > Advanced solar cells or RTG's for robotic
  - > Nuclear power for human
- Product liquefaction and cryogenic storage [months to years]
  - > Earth supplied Hydrogen



- **Cost**

- Technology/system synergism between Moon and Mars
- Technology/system synergism with other systems [ECLSS, fuel cells]
- Commercial viability of technology

## Top-Level Mars ISPP Development Plan

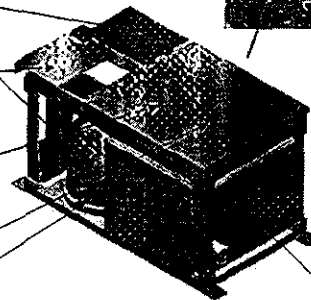
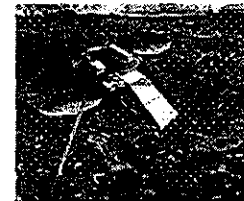


## Mars ISPP Precursor (MIP) Flight Experiment

MIP will incorporate five experiments from three NASA institutions; Johnson Space Center (JSC), Lewis Research Center (LeRC), and the Jet Propulsion Laboratory (JPL). JSC is also responsible for integrating the experiments into the MIP flight demonstration unit

The five MIP experiments are:

- **MAAC - Mars Atmosphere Acquisition and Compression (JPL)**  
Demonstrate the ability to collect and compress Mars atmospheric carbon dioxide
- **MTERC - Mars Thermal Environment and Radiator Characterization (JPL)** Provide data to determine the effective sky temperature and the long term effect of the Mars environment on radiator performance
- **MATE - Mars solar Array Technology Experiment (LeRC)**  
Characterize advanced solar cell performance and obtain data on Mars surface environments that can impact future solar cell designs
- **DART - Dust Accumulation and Repulsion Test (LeRC)**  
Demonstrate techniques to mitigate dust accumulation on solar cells (tilting and electrostatic repulsion) and characterize dust properties and deposition rates
- **OGS - Oxygen Generator Subsystem (JSC)**  
Demonstrate the production of oxygen from Mars atmospheric gases in the Mars environment

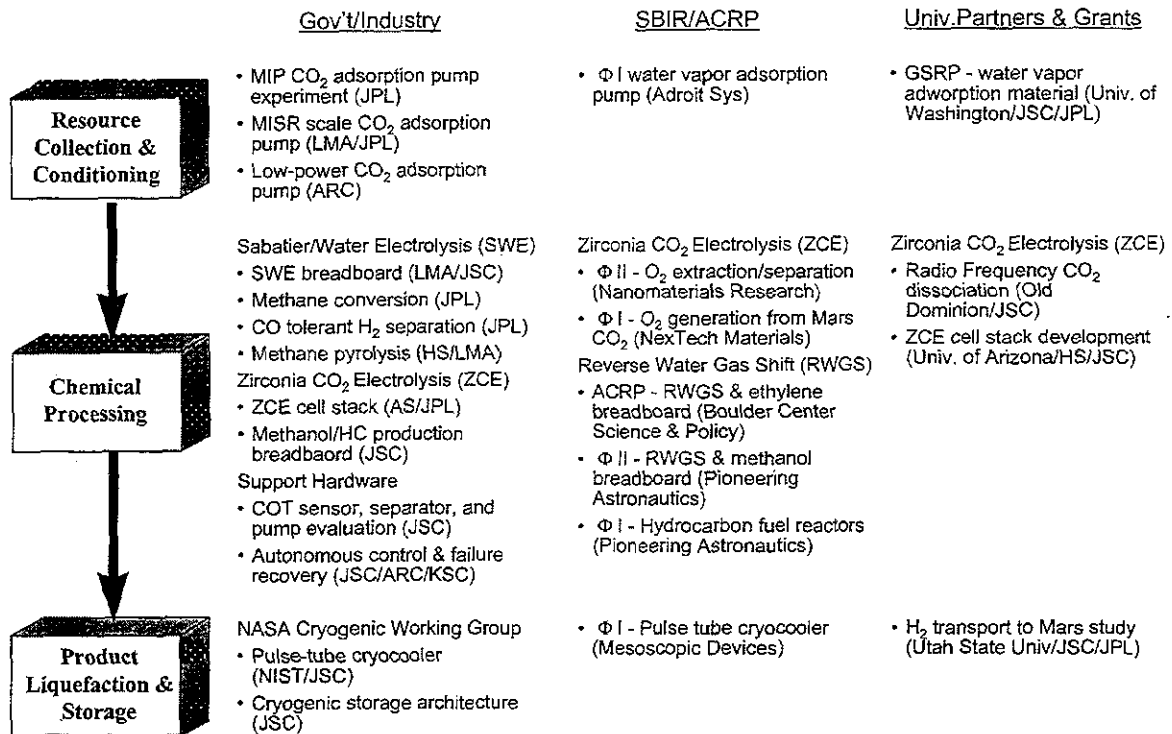


Warm Electronics Box

### MIP Design Characteristics

- Mission Design Life = 300 Mars days (sols)
- Mass = 7.5 kg
- Dimensions = 40 cm L x 24 cm W x 25cm H
- Average Power; Day = 15 Watts\*, Night = 3 Watts
- \* When producing oxygen; 9 Watts average without oxygen production

## Mars ISCP Technology Development Coordination

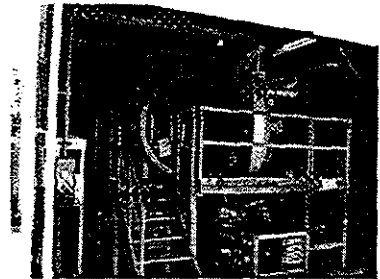
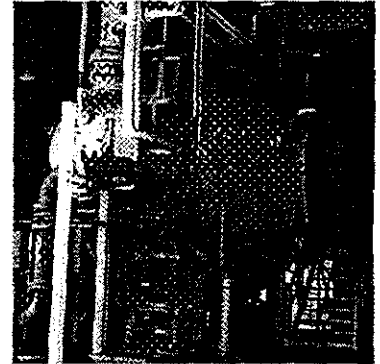


## Mars ISRU System Technology (MIST) Objectives

- Characterize technology and subsystem performance for mission modeling and technology funding planning
  - Advance multiple ISRU process options to same TRL for design flexibility
  - Verify performance/benefits/risks associated with different process options
- Raise individual subsystem/component TRL by:
  - Providing low-cost testing for industry/university partnerships
  - Funding key technology development efforts
  - Work w/ industry, universities, and other government organizations to focus ISRU development and testing
- Reduce risk/concerns for sample return and human missions utilizing ISRU
  - Development and demonstration of autonomous control and failure recovery hardware, operations, and logic
  - System level testing to understand subsystem interaction
  - System level testing to optimize processes
  - Long term testing to verify component/system operation robustness
- Demonstrate environmental suitability of ISRU components/processes/systems
  - Mars pressure, temperature, and atmospheric composition
  - Continuous versus day/night production cycles
  - Loads & vibration
  - Life cycles and contamination sensitivity

## MIST Facility Overview

- Building 353
  - Ambient test cells for subsystem and system testing
  - 20 ft dia chamber for Full Mars environment testing
    - > Atmosphere (CO<sub>2</sub>, N<sub>2</sub>, or Mars mixture), pressure, & temperature
    - > Designed for hazardous operation testing (explosion and fire hazards)
    - > Solar flux & dust conditions
  - Office area for hardware providers while at JSC
  
- Building 356
  - 5 ft dia. chamber for Partial Mars environment testing
    - > Atmosphere, pressure, & temperature
      - » -300 to +300F
      - » Vacuum to 10<sup>-6</sup> torr
      - » Atmosphere at 6.5 torr & 100% CO<sub>2</sub> or N<sub>2</sub>, or Mars mixture
    - > Night sky temperature simulation
  - Facility will be used for Mars ISPP Precursor development, qualification, and flight unit testing



## Stage 1 Proof-of-Concept Demonstration Schedule

