Atmospheric Processing Module for Mars Propellant Production

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Outline

- Introduction
- Project Goals
- Design and Construction
- Testing
- Current Status
- NASA Plans for Mars ISRU
- Other NASA ISRU Projects at KSC
Introduction – Major Milestones in NASA’s History

- First American Satellite – 1958
- NASA Established – 1958
- First American to Orbit Earth – 1962
- First American Spacewalk – 1965
- First Astronauts to Orbit the Moon – 1968
- First Manned Lunar Landings – 1969 to 1972
- First American Space Station – 1973-1974
- First Robotic Landing on Mars – 1976
- Space Shuttle Flights – 1981-2011
- First Robotic Rovers on Mars – 2003
- First Spacecraft to Leave the Solar System – 2013
- First Mars Sample Return – 2026?
- First Humans on Mars – 2030’s?
Introduction to ISRU

• What is ISRU? – In Situ Resource Utilization
  – “Living off the land”
  – Use Space Resources to reduce cost and risk for NASA missions
  – Already used with Solar Panels for power
• Chemistry and engineering enable even more resources to be used
• Key space resources:
  – Lunar regolith and polar water ice/volatiles
  – Asteroid regolith, metals, and volatiles
  – Martian atmosphere and water ice/hydrates
Martian Resources

- **Atmosphere of Mars**
  - 96% CO₂
  - 2% Ar, 1.9% N₂
  - <1% pressure of Earth’s atmosphere (~7 mbar)

- **Significant Amounts of Water in the Top 1-Meter of Regolith**
  - Water ice caps at the poles
  - ~2% at least everywhere else
  - ~10% even at equatorial regions
Utilizing Martian Water and CO₂/Advantages of ISRU

- **ISPP: In Situ Propellant Production**
  - Electrolysis: \(4 \text{H}_2\text{O} \rightarrow 4 \text{H}_2 + 2 \text{O}_2\)
  - Sabatier Reaction: \(\text{CO}_2 + 4 \text{H}_2 \rightarrow \text{CH}_4 + 2 \text{H}_2\text{O}\) (Ni or Ru catalyst, 300-600°C)
  - Net Reaction: \(\text{CO}_2 + 2 \text{H}_2\text{O} \rightarrow \text{CH}_4 + 2 \text{O}_2\) = Rocket Propellant! \(I_{sp} = 369\) s

- **Human Mars Mission Outline (DRA 5.0)**
  - Launch Surface Hab/Lander and Mars Ascent Vehicle in Year 1
  - MAV lands on Mars after 9 months
  - MAV produces ascent fuel for 11 months
  - Launch Transfer Vehicle and Crew (6) in Year 2
  - Crew lands on Mars after 6-9 months
  - Crew explores Mars for 1.5 years
  - Crew launches MAV to return to Transfer Vehicle
  - Crew returns to Earth in 6 months
  - Total Crew time away from Earth is \(~2.5\) years

- **ISPP saves >25 metric tons of mass**
- Also provides breathing oxygen for life support
- Eliminates two heavy lift launches!
MARCO POLO Project

• **ISPP: In Situ Propellant Production**
  – Demonstrate production of Mars Sample Return propellant
  – Reduce risk for human Mars missions

• **MARCO POLO - Mars Atmosphere and Regolith Collector/Processor for Lander Operations**

• The **Mars Atmospheric Processing Module (APM)**
  – Mars CO₂ Freezer Subsystem
  – Sabatier (Methanation) Subsystem

• Collect, purify, and pressurize CO₂

• Convert CO₂ into methane (CH₄) and water with H₂

• Other modules mine regolith, extract water from regolith, purify the water, electrolyze it to H₂ and O₂, send the H₂ to the Sabatier Subsystem, and liquefy/store the CH₄ and O₂
What is MARCO POLO?

- First generation integrated Mars soil and atmospheric processing system with mission relevant direct current power
  - 10 KW Fuel Cell for 14 hrs of daytime operations
  - 1KW Fuel Cell for 10 hrs of night time operations
- Demonstrates closed loop power production via the combination of a fuel cell and electrolyzer.
  - The water we make and electrolyze during the day provides the consumables for the 1KW Fuel Cell that night
- Planned for remote and autonomous operations
Lander Design Concept

Atmo Processing Module:
- CO2 capture from Mixed Mars atmosphere (KSC)
- Sabatier converts H2 and CO2 into Methane and water (KSC/JSC)

C&DH/PDU Module: (JSC)
- Central executive S/W
- Power distribution

Soil Processing Module:
- Soil Hopper handles 30kg (KSC)
- Soil dryer uses CO2 sweep gas and 500 deg C to extract water (JSC)

Water Cleanup Module: (KSC)
- Cleans water prior to electrolysis
- Provides clean water storage

Life Detection Drill: (ARC-Honeybee)
- Replaces excavator mockup
- Takes core samples
- Provides some feed to Soil Dryer

Liquefaction Module: (TBD)
- Common bulkhead tank for Methane and Oxygen liquid storage

Water Processing Module: (JSC)
- Currently can process 520g/hr of water (max 694 g/hr)

3m x 3m octagon lander deck

1KW Fuel Cell and consumable storage (JSC & GRC)
- Using metal hydride for H2 storage due to available
- 1KW No Flow Through FC (GRC)
- 10KW FC not shown (JSC)
APM Goals/Requirements

• Collect and purify 88 g CO₂/hr (>99%)
  – From simulated Martian atmosphere
  – 10 mbar; 95% CO₂, 3% N₂, 2% Ar

• Supply 88 g CO₂/hr at 50 psia to the Sabatier reactor
• Convert CO₂ to 32 g CH₄/hr and 71 g H₂O/hr
• Operate autonomously for up to 14 hr/day
• Minimize mass and power
• Fit within specified area and volume
  – 9,000 cm² hexagon
  – 44 inches tall (112 cm, same as Water Processing Module)

• Support MARCO POLO production goals of 444 g CH₄/day and 1.77 kg O₂/day (50% of O₂) for a total of 2.22 kg propellant/day
• Sufficient for a Mars Sample Return Mission
Atmospheric Processing Module

- Methane Dryer (Future)
- Sabatier Reactor
- Methane Separator
- Electro-chemical Methane Separator
- CO₂ ballast tanks not shown
- Chiller
- CO₂ Freezers
- Mixed Mars Gas Input
- Vacuum Pump

[Replaced by Recycle Pump and Membrane Module]
Atmospheric Processing Operations

- Ballast tank
- Ballast tank
- CO₂ freezer
- CO₂ freezer
- Mars Mix

88 g/hr CO₂ @ 50 PSI

2 g/hr H₂

16.2 g/hr H₂

71.3 g/hr H₂O
31.7 g/hr CH₄
2 g/hr H₂

CH₄/H₂ Separator

Condenser

Water Cleanup Module

Electrolysis Stacks

Water Processing Module

H₂O

CH₄

CH₄ Dryer

CH₄ storage

95% CO₂, 3% N₂, 2% Ar at 10.8 mbar
CO₂ Freezer – Final Design

Mars Atmosphere
95% CO₂, 3% N₂, 2% Ar
~700 psig max

15 psig
T, PI

Emergency Vent

FC

T, PI

CO₂ Freezer
Tank #1
< 1 mbar

CO₂ Freezer
Tank #2
< 1 mbar

Copper Cold Head

Cryocooler #1

Chiller

Pressure Equalizer Valves

CO₂ Ballast Tank

CO₂ Ballast Tank

Vacuum Pump

Vent to Atmosphere/Hood

10.8 mbar

2 - Cryocoolers with Freezing Chambers
11 - Magnetic Latching Solenoid Valves
1 - Chiller with 4-Way Dual Solenoid Valve
1 - Vacuum Pump
1 - CO₂ Pump
2 - CO₂ Ballast Tanks
2 - Vacuum Back Pressure Regulators
3 - Pressure Relief Valves
1 - Flow Controller
1 - Flow Meter
3 - Thermocouples and 2 RTDs
3 - Pressure Transducers, etc.
CO₂ Freezer

CO₂ Tanks

Copper Cold Head

Chiller

Cryocoolers

Avionics
Sabatier Subsystem Design
Sabatier Subsystem

JSC Sabatier Reactor

Recycle Pump

Membrane Module (Cut-Away View)
Atmospheric Processing Module
Water Cleanup Module (KSC)

- Tested with Water Processing Module at JSC
- Used to recycle fuel cell water from the MMSEV to $\text{H}_2$ and $\text{O}_2$
- MMSEV = Multi Mission Space Exploration Vehicle

Membrane separator not included in the final version
Lander and Soil Processing Module (KSC)

Van Townsend (KSC/ESC) with MARCO POLO lander and Soil Processing Module (under construction)

RASSOR (Regolith Advanced Surface Systems Operations Robot) will feed the hopper.
**CO$_2$ Freezer Testing**

- Avg. Capture Rate = 100.3 g/hr at 1.2 SLPM (1.4 hr test)
- Avg. Sublimation Rate = 93.8 g/hr (1.4 hr test)
- Avg. Capture Fraction = 76%
- Exceeds 88 g/hr requirement
- Better performance than test stand!

88 g/hr Requirement

![Graph](image)
JSC Sabatier Testing

- JSC Testing was successful (>99% conversion at 4.5:1 H₂/CO₂ ratio)
- First three KSC tests overheated
  - >600°C
- One test did not overheat (top) at 250 sccm CO₂ vs. 747 sccm desired (1000 sccm H₂)
  - Duplicate run did overheat (middle)
- Twelve tests at various flow rates overheated
- Two tests with simulated recycle gases (N₂/H₂/CO₂ = 6.0/3.35/0.75 SLPM) was slower to overheat, but still did so (bottom)
- Built a redesigned Sabatier reactor
Current Status

- **CO₂ Freezer Subsystem** essentially complete
  - Fully automated and fluid system functional
  - Need to test replacement CO₂ pump to reach 100 psi for overnight storage capability
- **Sabatier Subsystem**
  - Fluid system automated and functional
  - New reactor being installed
    - Based on proprietary design by Pioneer Astronautics
  - Testing needed to verify operation
- **Plan integrated MARCO POLO testing in Swamp Works “Big Bin” regolith bin**
  - Date TBD
- **Testing will support Mars ISRU design studies**
- **Long Term Goal** is to continue to refine the ISRU technologies for potential 2021 robotic Mars mission using a SpaceX ‘Red Dragon’ capsule as part of an Ames-led science effort
Mars 2020 Mission Science Definition Team Report (July 1, 2013):

- “The highest priority HEOMD payload is the demonstration of CO₂ capture and dust size characterization for atmospheric ISRU” p. 63
- “Collect atmospheric carbon dioxide. Analyze dust (size, shape, number) during CO₂ collection. Produce small quantities of oxygen and analyze its purity (option).” p. 61
- “Reduces risk for human missions and possible Mars sample return” p. 61

<table>
<thead>
<tr>
<th>Instrument/Demo</th>
<th>Purpose</th>
<th>SKG Addressed</th>
<th>P-SAG Priority</th>
<th>HAT Priority</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂ production from atmosphere</td>
<td>Collect atmospheric carbon dioxide. Analyze dust (size, shape, number) during CO₂ collection. Produce small quantities of oxygen and analyze its purity (option).</td>
<td>B6-1: Atm. ISRU</td>
<td>H</td>
<td>H</td>
<td>Reduces risk for human missions and possible Mars sample return</td>
</tr>
</tbody>
</table>

Table 5-4. Spacecraft resource requirements for candidate HEOMD Payloads

<table>
<thead>
<tr>
<th>Instrument/Demo</th>
<th>Mass (kg)</th>
<th>Power (W)</th>
<th>Operational Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEDLI+</td>
<td>15.1</td>
<td>10</td>
<td>Operates during EDL</td>
</tr>
<tr>
<td>Surface weather station</td>
<td>1.3</td>
<td>19</td>
<td>Sampling (approximately 24 times a day)</td>
</tr>
<tr>
<td>Atmospheric ISRU demo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- CO₂ capture + dust</td>
<td>10</td>
<td>30-50</td>
<td>Operate 7 to 8 hrs per sol. and as many sols as possible. Operate CO₂ capture and O₂ production on separate days to maximize production rate</td>
</tr>
<tr>
<td>- CO₂ capture + O₂ production</td>
<td>20</td>
<td>100-150</td>
<td></td>
</tr>
</tbody>
</table>
• Mars 2020 Mission Announcement of Opportunity (Sept. 24, 2013):
  • “A successful precursor mission is both prudent and required before incorporating ISRU into a mission-critical role for either crewed or robotic exploration missions. NASA’s Mars 2020 mission presents an ideal opportunity to validate critical ISRU technologies in an extraterrestrial environment.”

**NASA Plans for Mars ISRU**

| ISRU Plant Capabilities for Mars 2020 and Future Exploration Missions. |
|-------------------------------------------------|-----------------|-----------------|-----------------|
| Minimum Oxygen Production Rate                  | Mars 2020       | Subscale Validation Class Missions | Future Human Missions |
|                                                 | 0.02 kg/hr      | 0.44 kg/hr      | 2.2 kg/hr       |
| Minimum Operational Life                        | 50 sols         | 500 sols        | 1,200 sols      |

• Proposal selection in June 2014
**RESOLVE** is an internationally developed payload (NASA and CSA) that can perform two important missions for Science and Human Exploration of the Moon

**Prospecting Mission: (Polar site)**
- Verify the existence of and characterize the constituents and distribution of water and other volatiles in lunar polar surface materials
  - Map the surface distribution of hydrogen rich materials
  - Determine the mineral/chemical properties of polar regolith
  - Measure bulk properties & extract core sample from selected sites
    - To a depth of 1m with minimal loss of volatiles
  - Heat multiple samples from each core to drive off volatiles for analysis
    - From <100K to 423 K (150 C)
    - From 0 up to 100 psia (reliably seal in aggressively abrasive lunar environment)
  - Determine the constituents and quantities of the volatiles extracted
    - Quantify important volatiles: H₂, He, CO, CO₂, CH₄, H₂O, N₂, NH₃, H₂S, SO₂
    - Survive limited exposure to HF, HCl, and Hg

**ISRU Processing Demonstration Mission: (Equatorial and/or Polar Site)**
- Demonstrate the Hydrogen Reduction process to extract oxygen from lunar regolith
  - Heat sample to reaction temperature
    - From 423 K (150 C) to 1173 K (900 C)
  - Flow H₂ through regolith to extract oxygen in the form of water
  - Capture, quantify, and display the water generated
RESOLVE Analog Field Tests

**Nov. 2008**
- RESOLVE Gen II on Scarab Rover
- Power, avionics, and ground support equipment on separate trailer

**FEB. 2010**
- RESOLVE Gen II+ on CSA Juno Rover
- Power, avionics, and ground support equipment on separate Juno

**July 2012**
- RESOLVE Gen IIIA on CSA Artemis Jr. Rover
- Everything on single rover platform
RESOLVE Gen III

Purpose: Develop a flight-like unit that can fit on a rover and operate in the lunar environment

Sample Acquisition System
Auger Drill Subsystem
- Collect and transfer subsurface material down to 1 m below surface
- Maintain sample stratigraphy and volatiles (below 150 K)
- Meter samples for processing
- Auger material to surface for evaluation
- Measure geotechnical properties of regolith during drilling

Surface Mineral/Volatile Evaluation
Near Infrared Volatile Spectrometer Subsystem (NIRVSS) - ARC
- Measure surface bound OH/H\(_2\)O while traversing (at min. of 0.5% by mass)
- Detect form of water (ice/hydration) in auger tailings
- Detect water vapor in evolved gases
- Image surface and drill tailings

Resource Localization
Neutron Spectrometer Subsystem (NSS) - ARC
- Locate hydrogen and hydrogen bearing volatiles down to 1 meter below the surface while traversing (at min. of 0.5% by mass)

Volatile Content/Oxygen Extraction
Oxygen & Volatile Extraction Node (OVEN) - JSC
- Accept samples from Sample Acquisition System
- Heat samples from <150 K to 423K for volatile extraction
- Heat samples to 1173 K for oxygen extraction
- Transfer evolved gases to LAVA volatile analyzer

Volatile Content Evaluation
Lunar Advanced Volatile Analysis (LAVA) - KSC
- Accept evolved gas from OVEN; provide hydrogen for oxygen extraction
- Perform analysis in under 2 minutes
- Measure water content in evolved gas
- Characterize volatiles of interest (below 70 amu)
- Measure D/H and O\(^{16}/^{18}\) isotopes
- Capture & image water evolved

Operation Control Flight Avionics - KSC
- Space-rated microprocessor
- Control subsystems and manage data

Surface Mobility
- Traverse wide range of lunar surface/material conditions
- Tele-operation and autonomous traverse modes
- Carry RESOLVE payload; provide power, comm., and thermal management

RESOLVE Mission Requirements
- Nom. Mission Life = 5+ Cores; 14 Days
- Mass = 170 kg rover/80 kg payload
- Ave. Power: 200-300 W
Complete RESOLVE Mission Traverse on Mauna Kea

- 9 of 12 ‘hot spots’ found
- >1 km total traverse
- ~500 m between auger/cores
RESOLVE Mission Options – Potential South Pole Landing Sites

**LEND Results**

**Site Analysis**

<table>
<thead>
<tr>
<th>Site</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow “Frost Line”</td>
<td>&lt;0.1 m</td>
<td>&lt;0.2 m</td>
<td>&lt;0.1 m</td>
</tr>
<tr>
<td>Slopes</td>
<td>&lt;10</td>
<td>&lt;15</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Neutron Depletion</td>
<td>4.5 cps</td>
<td>4.7 cps</td>
<td>4.9 cps</td>
</tr>
<tr>
<td>Temporary Sun*</td>
<td>4 days</td>
<td>2-4 days</td>
<td>5-7 d</td>
</tr>
<tr>
<td>Comm Line of Sight*</td>
<td>8 days</td>
<td>17 days</td>
<td>17 days</td>
</tr>
</tbody>
</table>

* may not coincide

**Predicted Volatile Stability**

**Solar Power Potential**
RESOLVE Mission Options – Notional Traverse

- Major waypoint
- Discovery: traverse re-plan
- Excavation site
- Pre-planned traverse path
- Executed path

2 kilometers

100-m radius landing ellipse

RESOLVE: Regolith & Environment Science and Oxygen & Lunar Volatile Extraction
Other KSC ISRU Projects: Trash to Gas

- Logistics, Reduction and Repurposing (LRR) Project Overview
- TtSG overview and processes
TtSG Overview

Human Spaceflight Produces Trash!

Long term effects include:
- Pollution
- Wasteful spending
- Planetary protection
- Bad press

To maximize our resources, reduce trash volume, and minimize polluting in space habitats and long duration missions, we need to re-evaluate the trash produced and do something innovative and sustainable with it.

Presently the trash is brought back home to earth or burned during Earth atmospheric re-entry.

Human spaceflight trash includes:
- Food packaging (adhered/uneaten)
- Clothing
- Human waste products
- Paper products
- Etc.
Utilizing Spaceflight Trash!

Utilize technology to produce useful products from the trash.

- Activated Carbon
- Salt
- Wax
- Water
- Fuel Depots
- Aluminum
- In-Situ Manufacturing
- Plant Life Support
- Recycling Depot
- Fertilizer
- Basis of Chemical Production
- Reduce Trash Volume
- Rocket Fuel
- Breathing
- Fuel Cells
- Reduce Logistics
- Delivered from Earth

Maximizing our resources to reduce trash and pollution.
TtSG Overview

- Strayer et al. AIAA-2011-5126; Characterization of Volume F trash from four recent STS missions: weights, categorization, water content
TtSG Overview

- LOX Methane engines
- Resistojets
  - Electrothermal propulsion for station keeping, reboost and orbit maintenance
  - Detailed systems were designed for past space stations (Freedom)
  - Can use multiple fuels (CO₂, CH₄, H₂O, etc...) in same thruster
TtSG Overview

• Why TtSG?
  – Reduce volume of trash - Current human spaceflight missions either carry trash during the entire round-trip mission or discard trash inside a logistic module which is de-orbited into Earth’s atmosphere for destruction.
  – Cleans waste
  – Produce something useful from a waste product

KSC-01PP-0726: Workers in the Space Station Processing Facility are removing contents from the Multi-Purpose Logistics Module (MPLM) Leonardo to begin removing the contents after STS-102. The MPLM brought back nearly a ton of trash and excess equipment from the Space Station.
TtSG General System Analysis

- **Assumptions**
  - Crew of 4 for 360 days
  - Waste types: Human Waste, packaging, food, MAGs, tape, clothing, towels, washcloths, paper
  - Total waste: 1900 kg wet waste, 4200 kg from crew metabolism (CO$_2$, H$_2$O)

- **Production**
  - 800 – 1500 kg of methane/year
    - Carbon is limiting reagent, so if CO$_2$ is used you have to find a hydrogen source
    - Enough for 1 lunar ascent vehicle
  - ~800 kg of oxygen
  - ~900 kg of water
  - ~1100 kg of CO$_2$
TtSG General Systems Analysis

Solid Waste
4 Crew/360 Days
1917 KG (Wet)
(1145 KG (Dry))

1917 kg

Water Recovery System
(100% Condensate Recovery
85% Urine Recovery)

Water Electrolysis

Crew Metabolism
(1202 kg O₂ Required
3600 kg H₂O Required
1123 kg of water derived from food)

Sent to Propulsion
CH₄
1476 kg

O₂
2291 kg

Sent to Water Electrolysis

H₂O

H₂O
(from water supply)

H₂O
(water to brine)

Input H₂O

H₂O
(required to balance H₂ deficit)

O₂

H₂O

O₂

H₂O

H₂O

1440 kg

CO₂

CH₄

1476 kg

3600 kg

4609 kg

40
TtSG General Systems Analysis

Solid (Wet) Waste → Preparation → Incineration → Flue Gas (e.g., CO₂, H₂O) → Quench/Condensation → De-NOx → Sabatier Reactor → CH₄

- Water
- Heat
- Oxygen
- Ash
- CO₂
- Hydrogen
- Water
• KSC, GRC, ARC have hardware that they are testing
• All processes have a 3-4 TRL
  – Pyrolysis
    • Decomposition of waste materials with heat in the absence of oxygen
  – Gasification
    • Decomposition of waste materials with heat in the presence of oxygen and/or steam
  – Incineration
    • Decomposition of waste materials with combustion
  – Steam Reforming
    • Decomposition of waste materials with heat in the presence of steam
  – Catalytic Decomposition- Low Temperature Decomposition of waste materials in the presence of a catalyst
    • Wet air oxidation
    • Photocatalytic oxidation
  – Ozone Oxidation
    • Decomposition of waste materials with heat in the presence of ozone
KSC Processes

- **Pyrolysis:**
  - On-going effort at ARC as part of SBIR program
  - Thermal decomposition of waste material under inert environment or vacuum
  - Main products are a mixture of hydrocarbons (typically >C_4)
  - KSC will characterize this process as part of the Gasification effort; ARC has existing hardware from SBIR program

- **Gasification:**
  - Previous effort at KSC (CDDF 2009)
  - Thermal decomposition of waste material in the presence of oxygen
  - Main products: syn gas with mixture of carbon oxides, hydrogen, methane, hydrocarbons
  - Previous experience resulted in significant amount of wax material

- **Incineration:**
  - Combustion of waste material under the presence of oxygen
  - Main combustion products: mixture of carbon oxides and water
  - Trace products: other trace elements within waste
  - ARC has existing hardware from SBIR program

\[
\begin{align*}
\text{O}_2 \text{ ER} &= 0; \text{ Pyrolysis} \quad \text{Liquids and Char} \\
\text{O}_2 \text{ ER} &\sim 0.1-0.3; \text{ Gasification} \quad \text{Syn gas; CO, CO}_2, \text{ H}_2, \text{ CH}_4, \ldots \\
\text{O}_2 \text{ ER} &\sim 1; \text{ Incineration} \quad \text{CO}_2, \text{ H}_2\text{O}, \ldots \\
\end{align*}
\]

ER: Equivalence ratio equals 1 for stoichiometric oxygen
TtSG Schedule

- **FY12:**
  - Testing existing prototypes
  - Efficiency analysis
  - Waste characterization analysis

- **FY13:**
  - Mixed trash testing
  - Down-selection to two processes for breadboard design

- **FY14:**
  - Complete breadboard design testing
  - Upgrade analysis

- **FY15:**
  - Build upgraded prototype
  - Provide mission architecture recommendations

- **FY17:**
  - ISS flight project design complete
Future MARCO POLO Historic Marker?
Follow us on Facebook:
https://www.facebook.com/NASA.ISRU

Any Questions?
Ultimate Destination - Mars