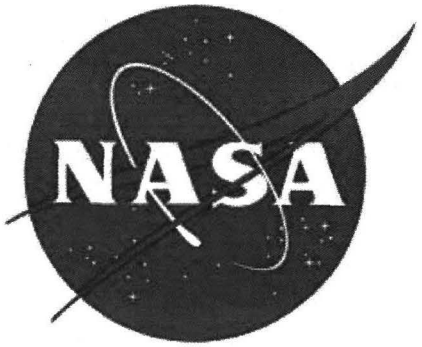




# Atmospheric Processing Module for Mars Propellant Production

Anthony Muscatello, NASA – KSC

Tracy Gibson, James Captain, Robert Athman, Matthew Nugent, Steven Parks, and Robert Devor, ESC – KSC

**The 16th Annual Mars Society Convention**

The University of Colorado, Boulder

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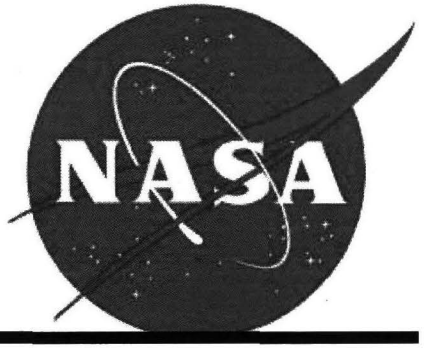
# Outline

- Introduction
- Project Goals
- Design and Construction
- Testing
- Current Status
- NASA Plans for Mars ISRU


# Introduction

- **ISRU** – In Situ Resource Utilization
  - **ISPP:** In Situ Propellant Production
  - Produce Mars Sample Return launch propellant
  - Demonstrate to reduce risk for human Mars missions
- **MARCO POLO - M**ars **A**tmosphere and **R**egolith **CO**llector/**PrO**cessor for **L**ander **O**perations
- The **M**ars **A**tmospheric **P**rocessing **M**odule (**APM**)
  - Mars $CO_2$ Freezer Subsystem
  - Sabatier (Methanation) Subsystem
- Collect, purify, and pressurize $CO_2$
- Convert $CO_2$ into methane ($CH_4$) and water with $H_2$
- Other modules mine regolith, extract water from regolith, purify the water, electrolyze it to $H_2$ and $O_2$, send the $H_2$ to the Sabatier Subsystem, and liquefy/store the $CH_4$ and $O_2$


# What is MARCO POLO?



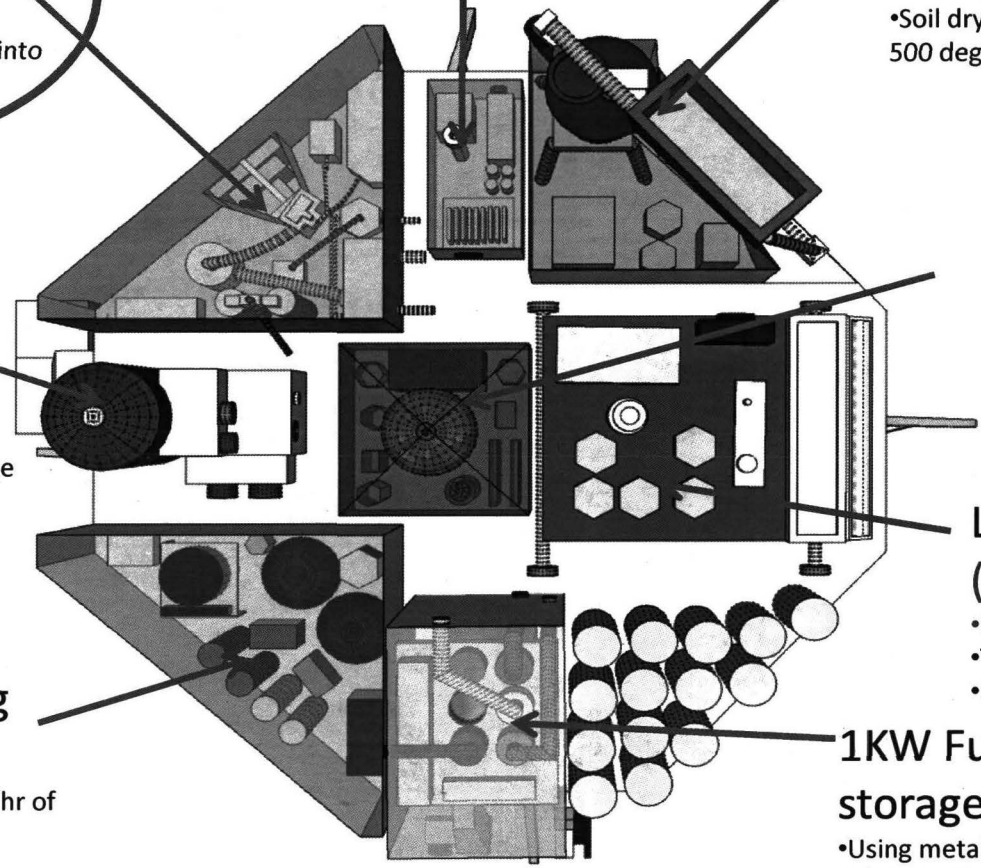

- **M**ars **A**tmosphere and **R**egolith **CO**llector/**Pr**O**cessor for **L**ander **O**perations
- First generation integrated Mars soil and atmospheric processing system with mission relevant direct current power
  - 10 KW Fuel Cell for 14 hrs of daytime operations
  - 1KW Fuel Cell for 10 hrs 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 at Critical Design Review

## Atmo Processing Module:
- $CO_2$ capture from Mixed Mars atmosphere (KSC)
- Sabatier converts $H_2$ and $CO_2$ into Methane and water (JSC)

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

## Soil Processing Module:
- Soil Hopper handles 30kg (KSC)
- Soil dryer uses $CO_2$ sweep gas and 500 deg C to extract water (JSC)



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

## 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

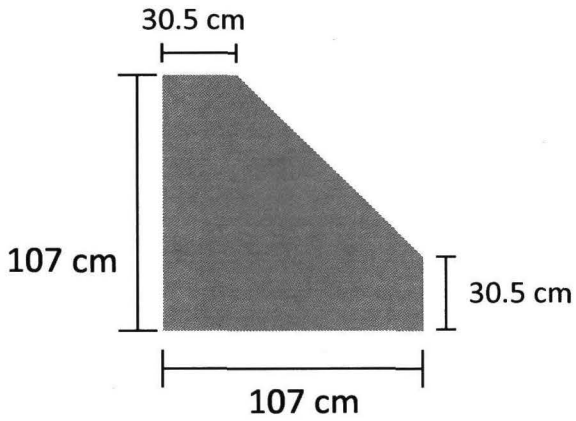
## Water Processing Module: (JSC)
- Currently can process 520g/hr of water (max 694 g/hr)

## 1KW Fuel Cell and consumable storage (JSC & GRC)
- Using metal hydride for $H_2$ storage due to available
- 1KW No Flow Through FC (GRC)
- 10KW FC not shown (JSC)

3m x 3m octagon lander deck

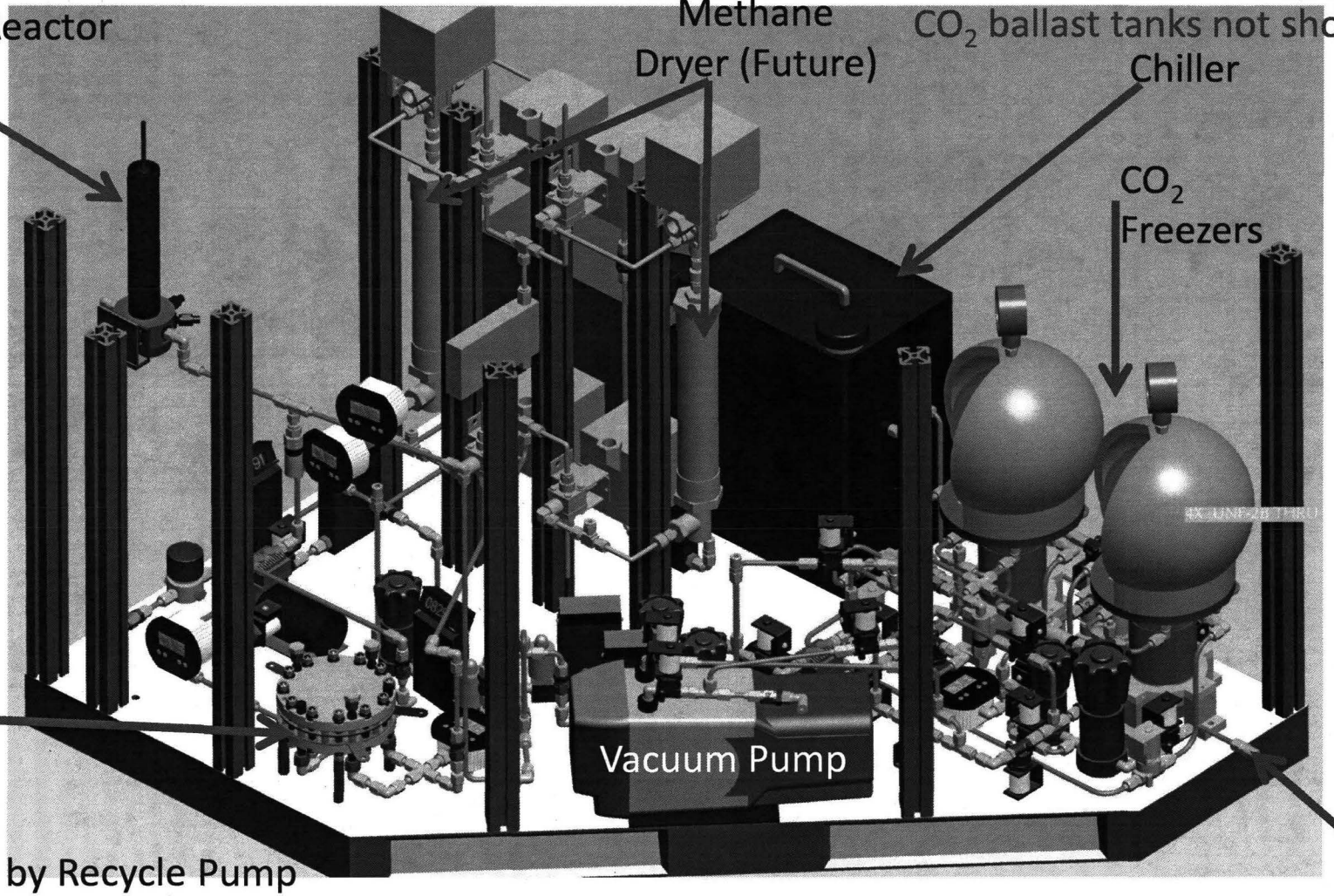
# APM Goals/Requirements

- Collect and purify 88 g $CO_2$/hr (>99%)
  - From simulated Martian atmosphere
  - 10 mbar; 95% $CO_2$, 3% $N_2$, 2% Ar
- Supply 88 g $CO_2$/hr at 50 psia to the Sabatier reactor
- Convert $CO_2$ to 31.7 g $CH_4$/hr and 71.3 g $H_2O$/hr
- Operate autonomously for up to 14 hr/day
- Minimize mass and power
- Fit within specified area and volume
  - 9,000 $cm^2$ hexagon
  - 44 inches tall (112 cm, same as Water Processing Module)

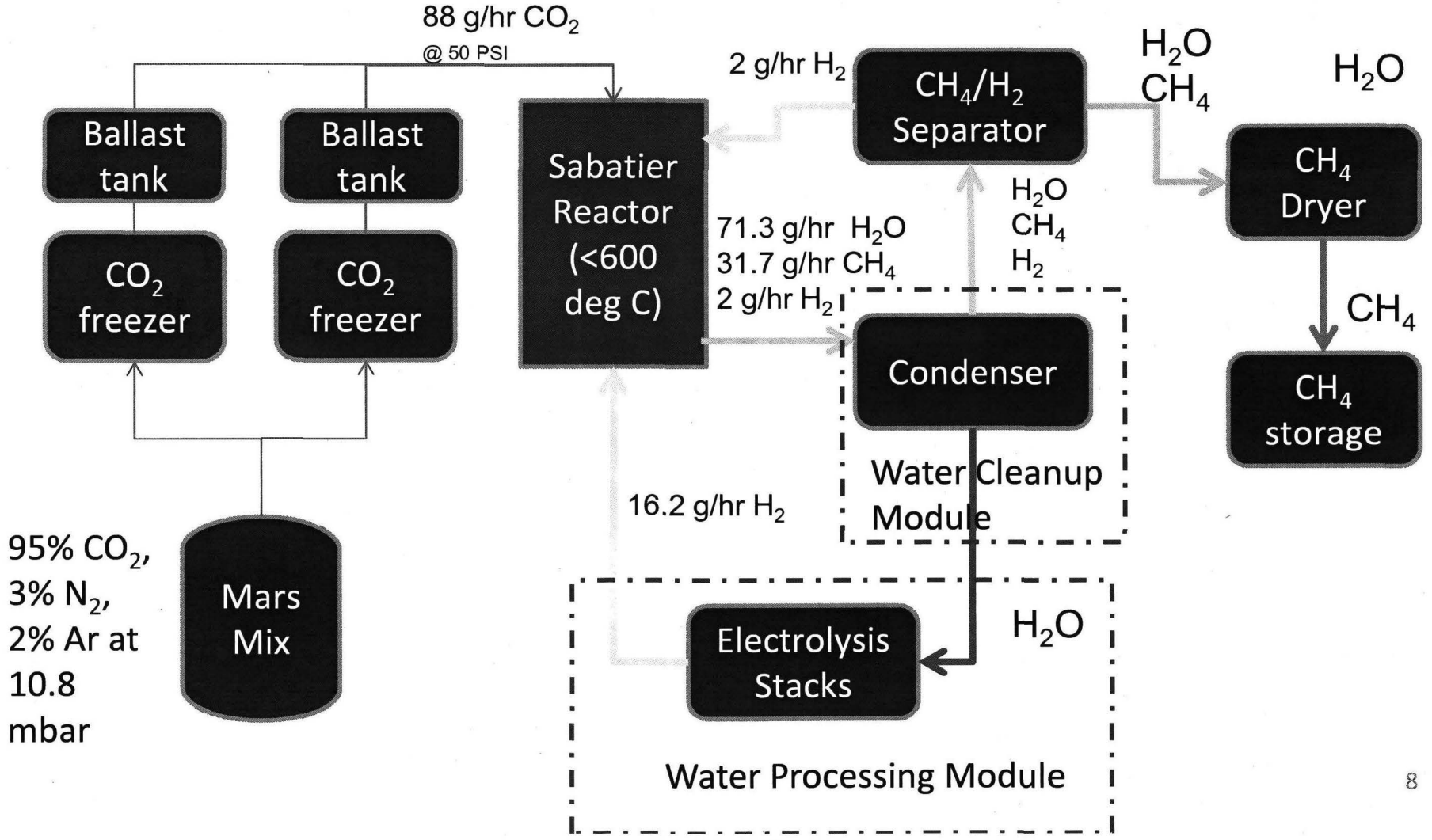



- Support MARCO POLO production goals of 444 g $CH_4$/day and 1.77 kg $O_2$/day (50% of $O_2$) for a total of 2.22 kg propellant/day
- Sufficient for a Mars Sample Return Mission

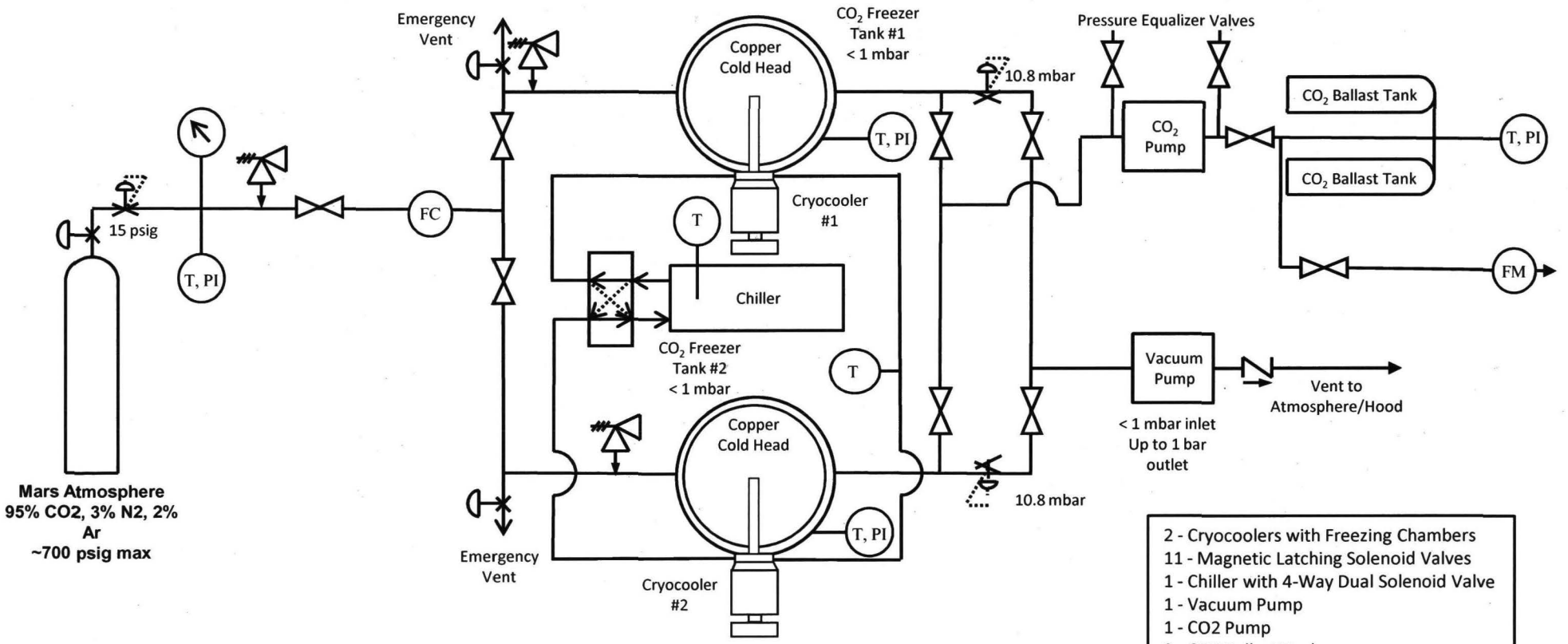
# Atmospheric Processing Module



# Atmospheric Processing Operations

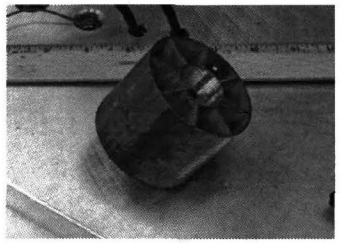


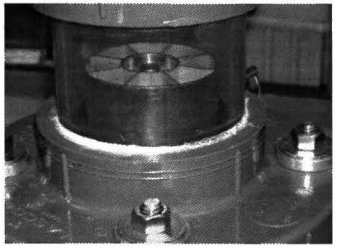
# $CO_2$ Freezer – Final Design



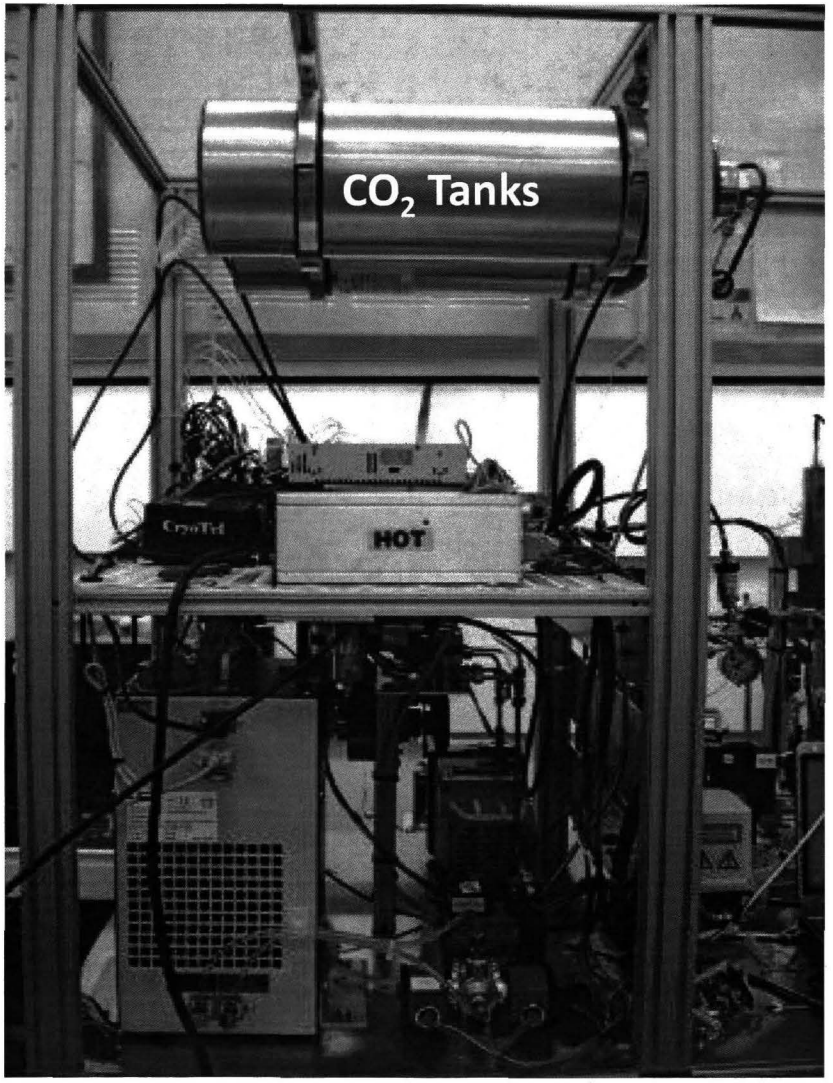

- 2 - Cryocoolers with Freezing Chambers
- 11 - Magnetic Latching Solenoid Valves
- 1 - Chiller with 4-Way Dual Solenoid Valve
- 1 - Vacuum Pump
- 1 - CO2 Pump
- 2 - CO2 Ballast Tanks
- 2 - Vacuum Back Pressure Regulators
- 3 - Pressure Relief Valves
- 1 - Flow Controller
- 1 - Flow Meter
- 3 - Thermocouples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

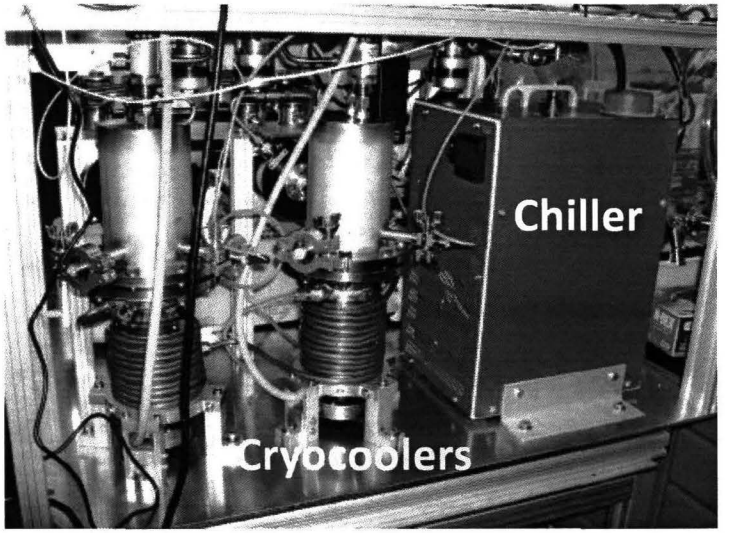
# $CO_2$ Freezer

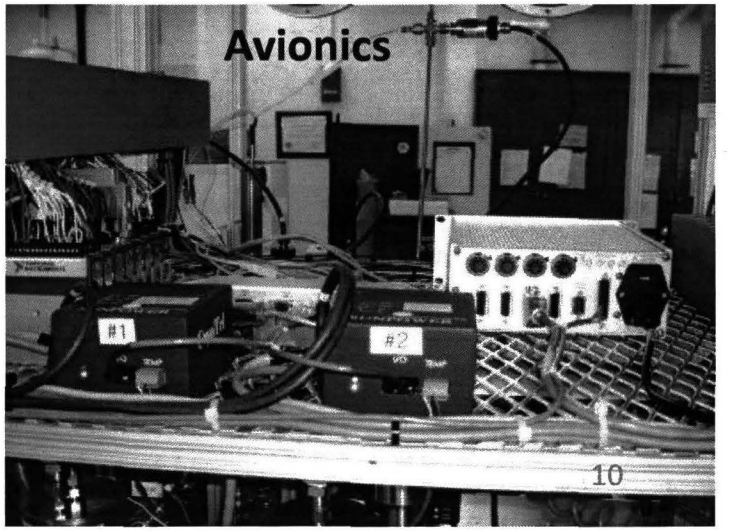




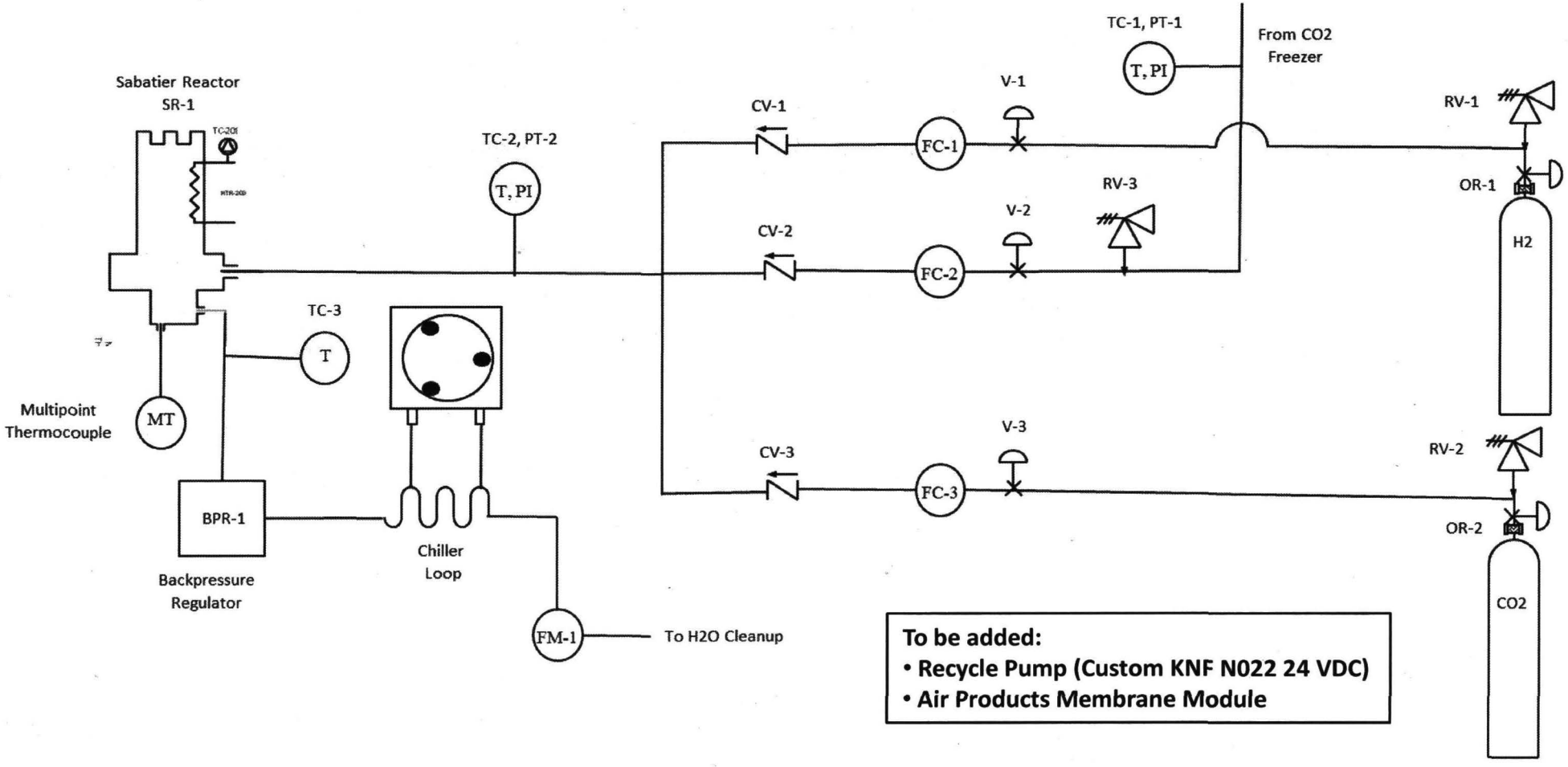
Copper Cold Head



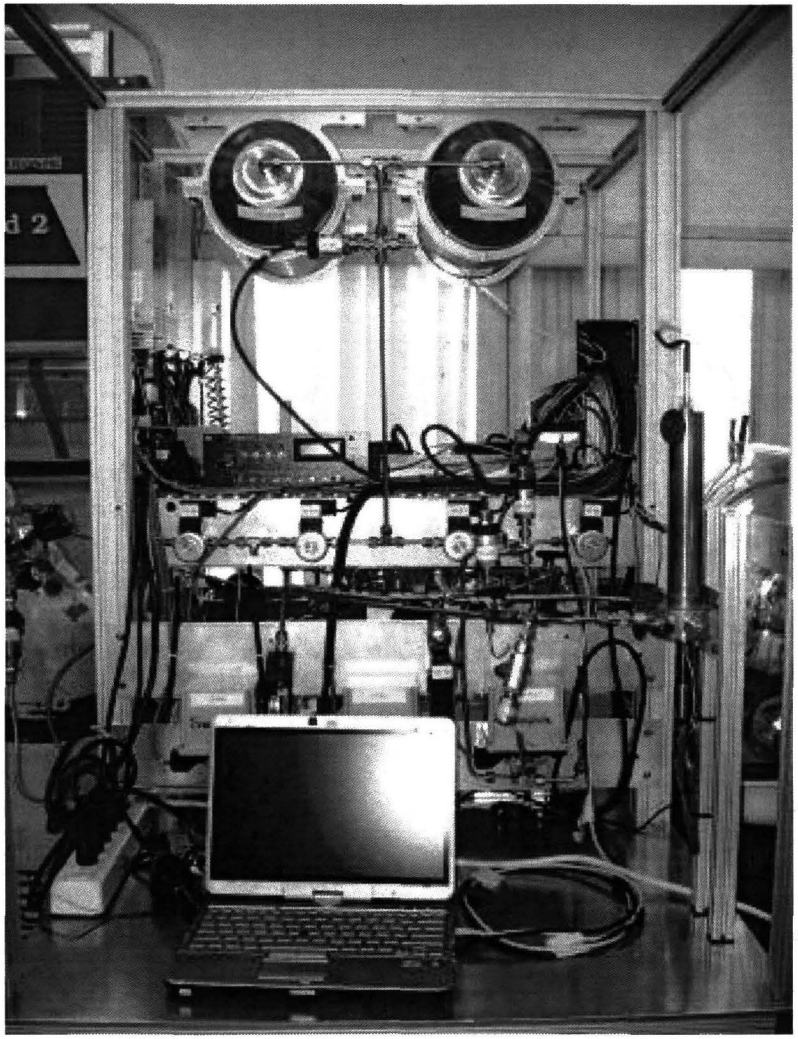



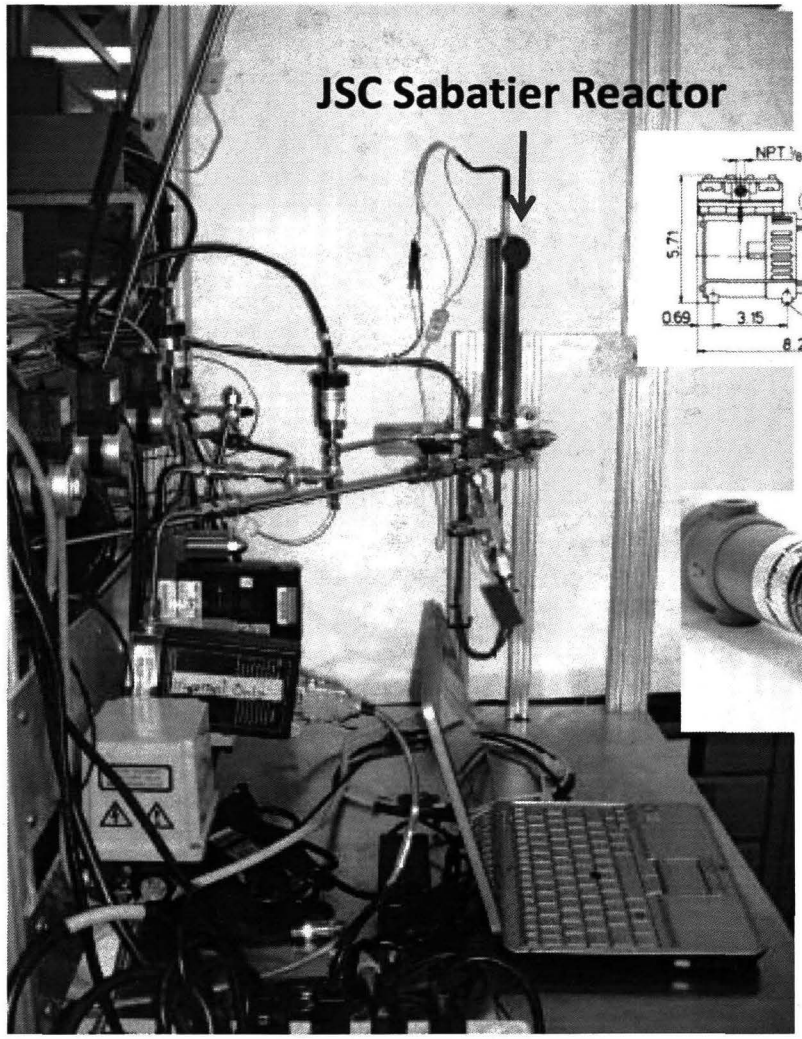
# Sabatier Subsystem Design

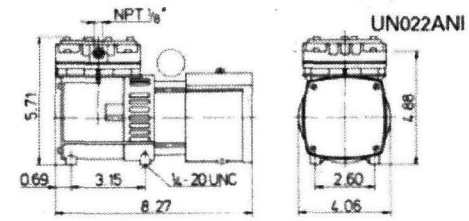



**To be added:**
- **Recycle Pump (Custom KNF N022 24 VDC)**
- **Air Products Membrane Module**

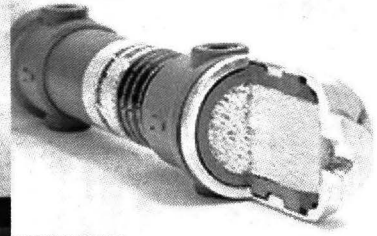
# Sabatier Subsystem





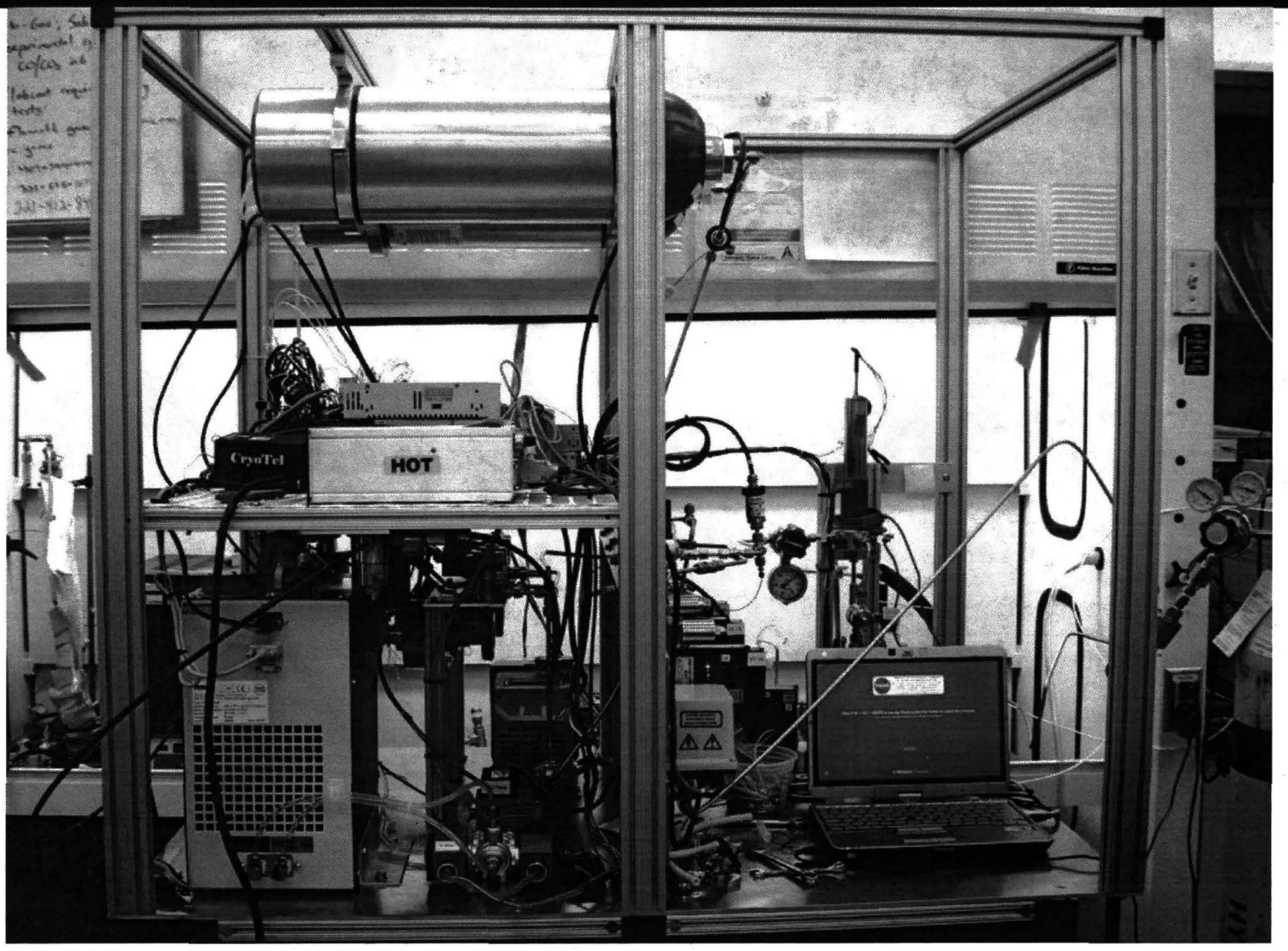




Recycle Pump

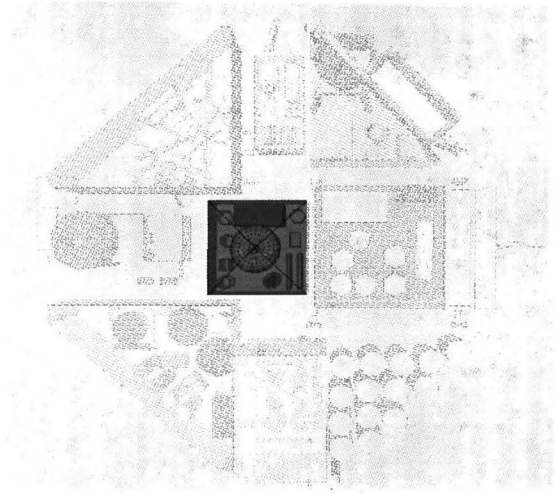


Membrane Module (Cut-Away View)

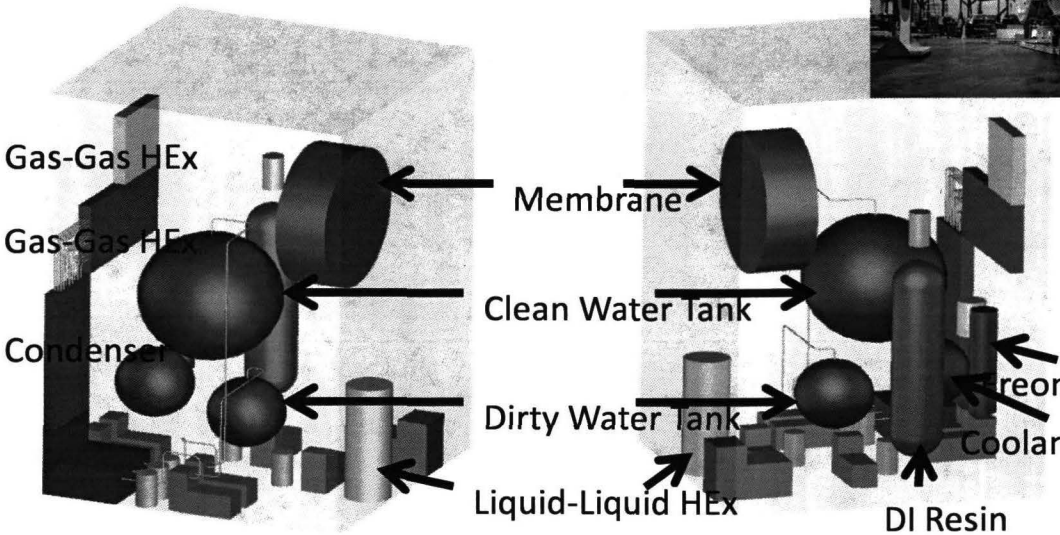
# Atmospheric Processing Module

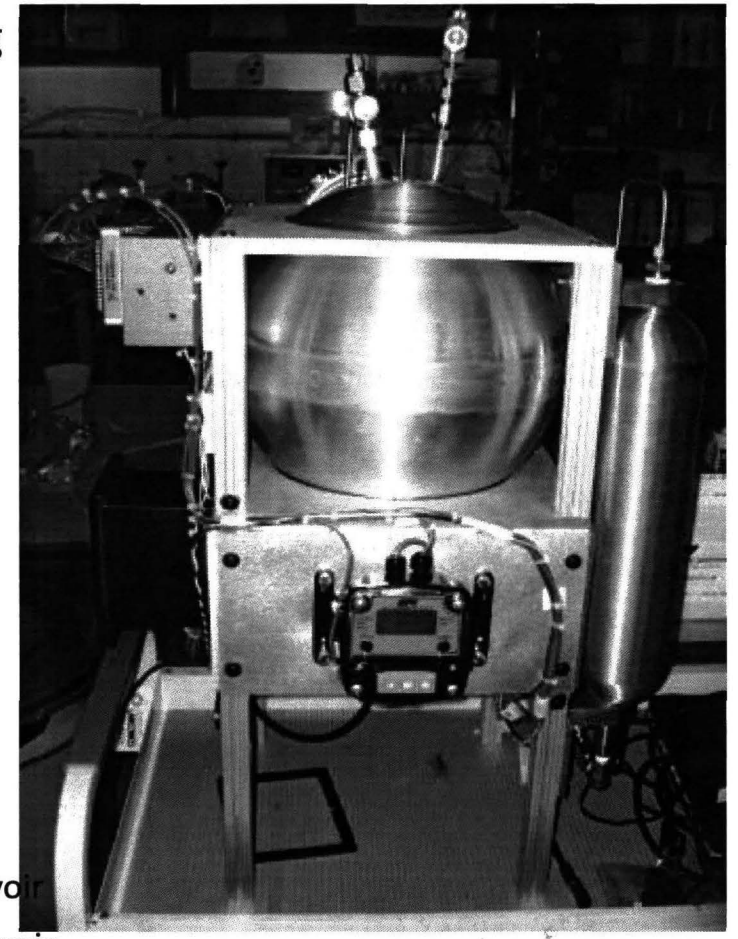


# Water Cleanup Module (KSC)



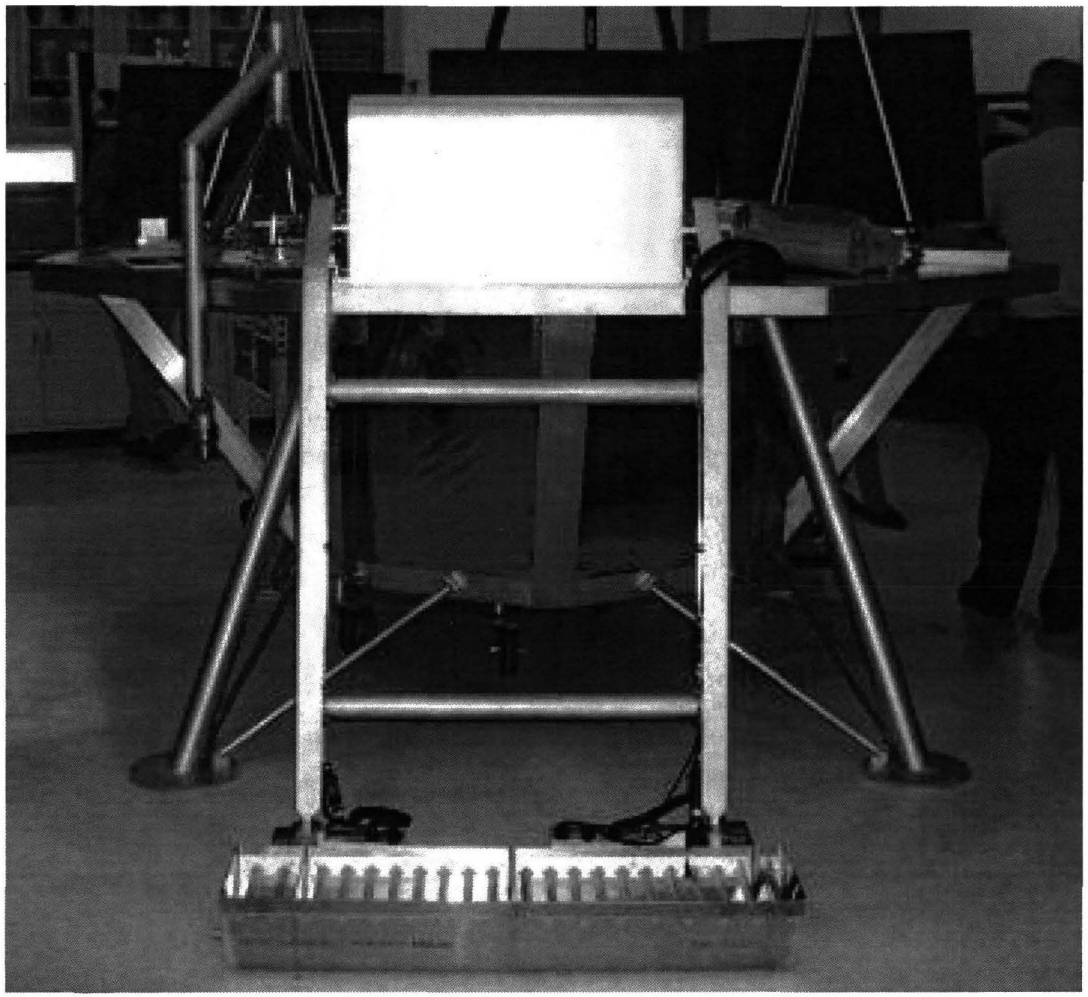
- Tested with Water Processing Module at JSC last summer
- Used to recycle fuel cell water from the MMSEV to $H_2$ and $O_2$
- MMSEV = Multi Mission Space Exploration Vehicle

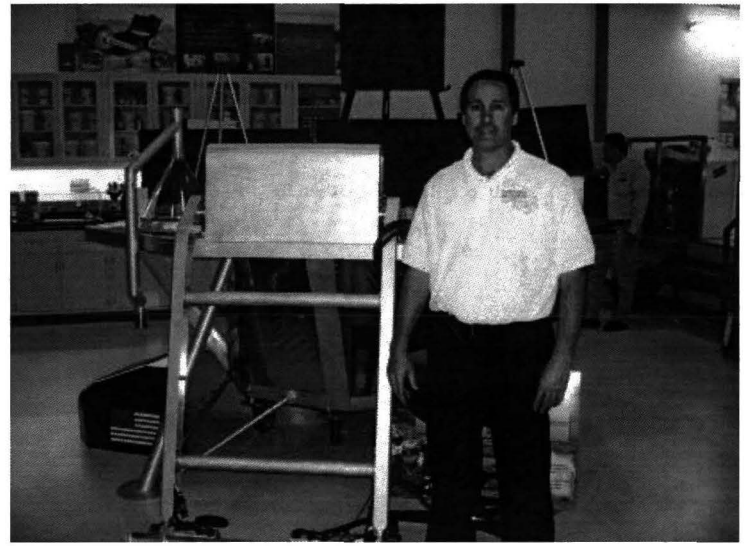


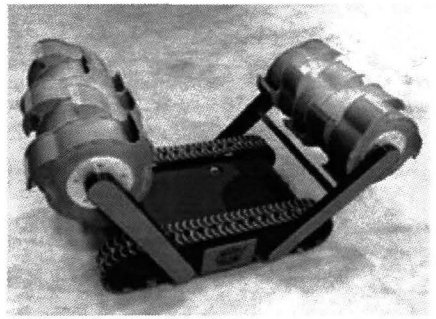
**Membrane separator not included in the final version**

# Lander and Soil Processing Module (KSC)



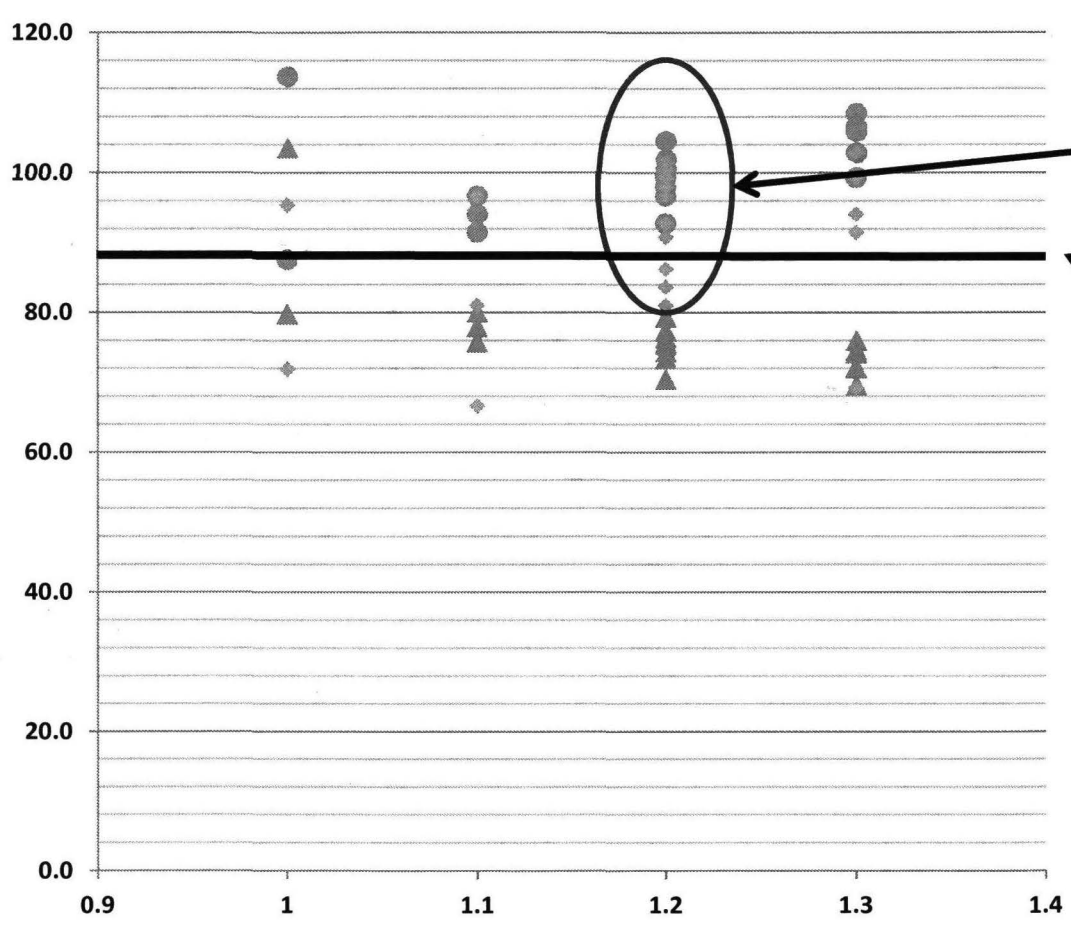


Van Townsend (KSC/ESC) with MARCO POLO lander and Soil Processing Module (under construction)



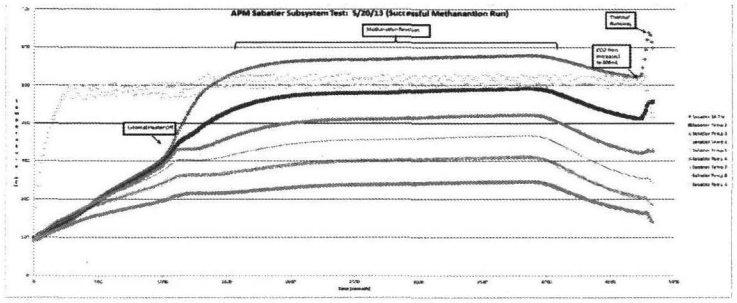
RASSOR (Regolith Advanced Surface Systems Operations Robot) will feed the hopper

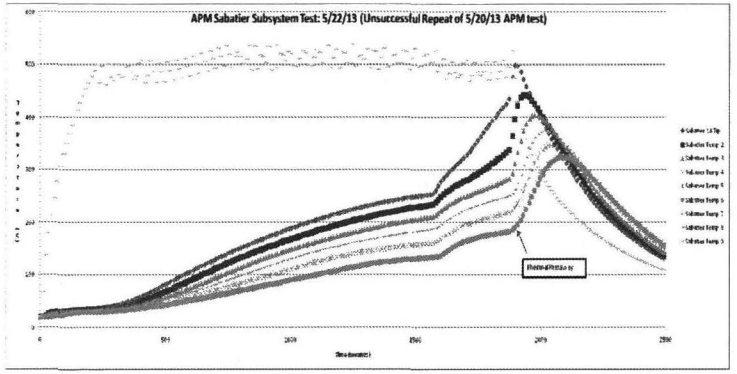
# $CO_2$ Freezer Testing

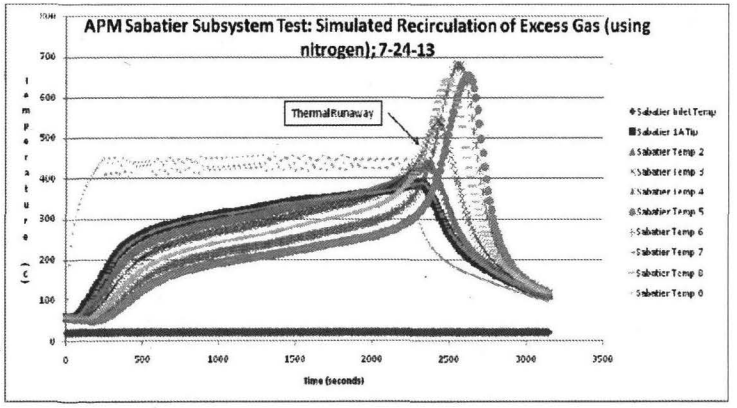



- Avg. Capture Rate = 100.3 g/hr at 1.2 SLPM (1.4 hr test)
- Avg. Sublimation Rate = 93.8 g/hr (1.4 hr test)
- Avg. Capture Fraction = 76%
- Exceeds 88 g/hr requirement
- Better performance than test stand!

# JSC Sabatier Testing

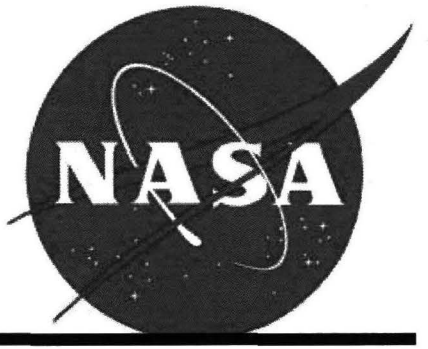



- JSC Testing was successful (>99% conversion at 4.5:1 $H_2/CO_2$ ratio)
- First three KSC tests overheated
  - >600°C
- One test did not overheat (top) at 250 sccm $CO_2$ vs. 747 sccm desired (1000 sccm $H_2$)
  - Duplicate run did overheat (middle)
- Twelve tests at various flow rates overheated
- Two tests with simulated recycle gases ($N_2/H_2/CO_2$ = 6.0/3.35/0.75 SLPM) was slower to overheat, but still did so (bottom)
- <u>Decided to build redesigned Sabatier reactor</u>


# Current Status




- **$CO_2$ Freezer Subsystem essentially complete**
  - **Fully automated and fluid system functional**
  - **Need replacement $CO_2$ pump to reach 100 psi for overnight storage capability (KNF NPK09 rocking piston pump leaks - normal for design)**
  - **Chiller being returned by vendor after inspection showed no defects**
- **Sabatier Subsystem**
  - **Fluid system automated and functional**
  - **New reactor being designed**
    - **Based on proprietary design by Pioneer Astronautics**
  - **Need to add recycle pump and membrane module**
  - **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 2018 robotic Mars mission using a SpaceX 'Red Dragon' capsule as part of an Ames-led science effort**

# NASA Plans for Mars ISRU

- **Mars 2020 Mission Science Definition Team Report (July 1, 2013):**
- **"The highest priority HEOMD payload is the demonstration of $CO_2$ capture and dust size characterization for atmospheric ISRU" p. 63**
- **"Collect atmospheric carbon dioxide. Analyze dust (size, shape, number) during $CO_2$ 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**

| Instrument/Demo | Purpose | SKG Addressed | P-SAG Priority | HAT Priority | Comments |
|---|---|---|---|---|---|
| O2 production from atmosphere | Collect atmospheric carbon dioxide. Analyze dust (size, shape, number) during CO2 collection. Produce small quantities of oxygen and analyze its purity (option). | B6-1: Atm. ISRU<br>B4-2: Dust properties | H | H | Reduces risk for human missions and possible Mars sample return |

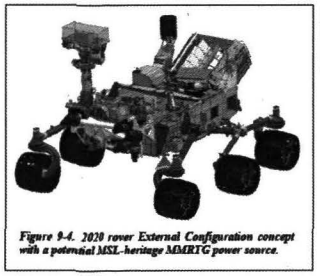


*Figure 9-4. 2020 rover External Configuration concept with a potential MSL-heritage MMRTG power source.*

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

| Instrument/Demo | Mass (kg) | Power (W) | Operational Concept |
|---|---|---|---|
| MEDLI+ | 15.1 | 10 | Operates during EDL |
| Surface weather station | 1.3 | 19 | Sampling (approximately 24 times a day) |
| Atmospheric ISRU demo<br>- CO2 capture + dust<br>- CO2 capture + O2 production | 10<br>20 | 30-50<br>100-150 | 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 |

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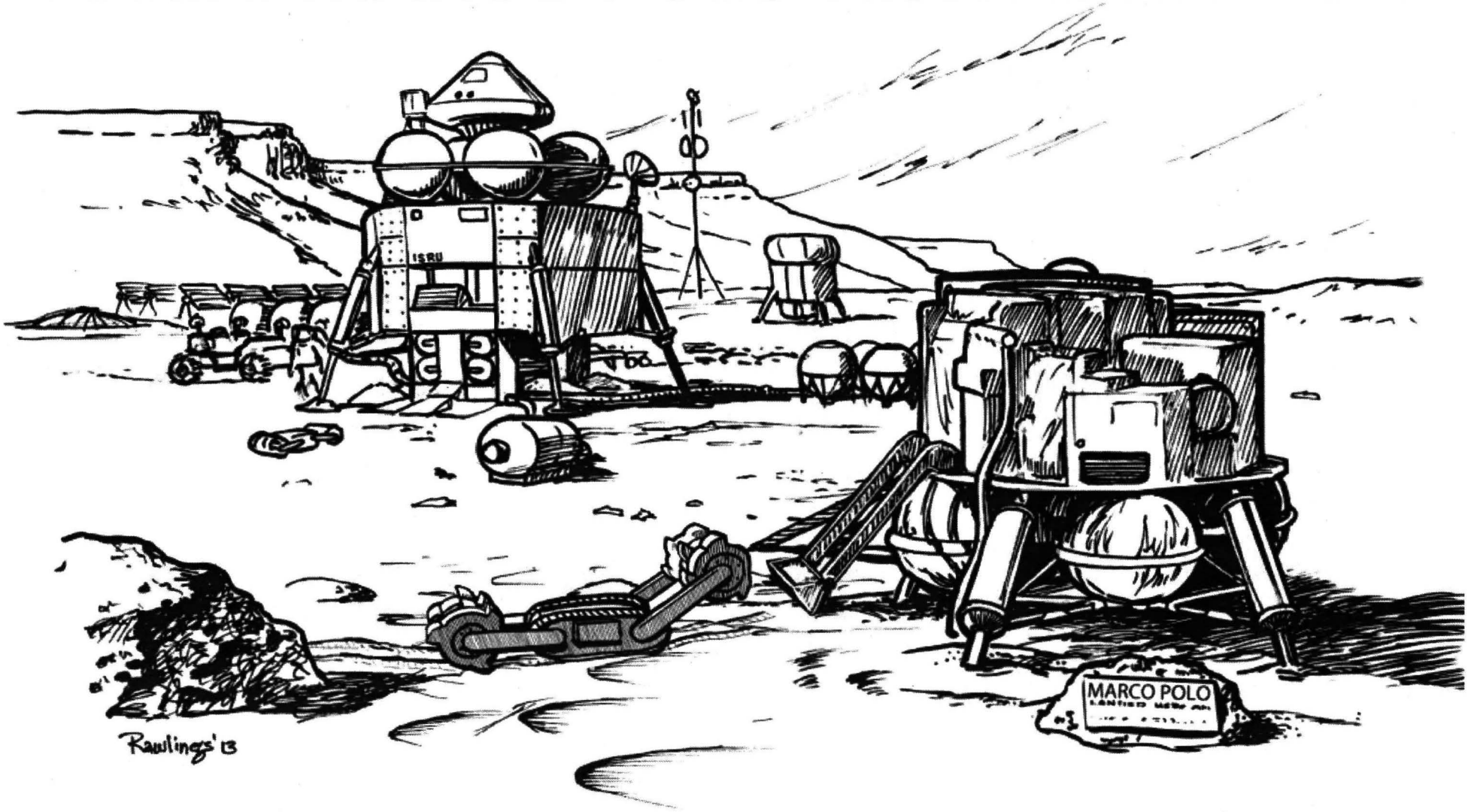
# Future MARCO POLO Historic Marker?



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## Any Questions?

## Ultimate Destination - Mars