



Atmospheric Processing Module for Mars Propellant Production

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The 16th Annual Mars Society Convention

The University of Colorado, Boulder

August 15-18, 2013



Outline

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

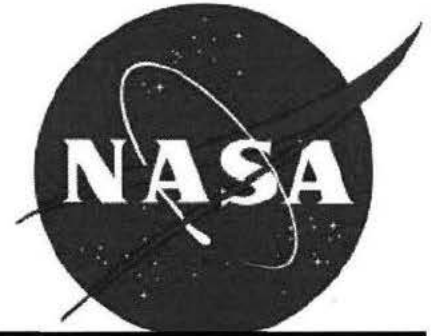


Introduction

- **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 - Mars Atmosphere and Regolith Collector/Processor for Lander Operations**
- The **Mars Atmospheric Processing Module (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



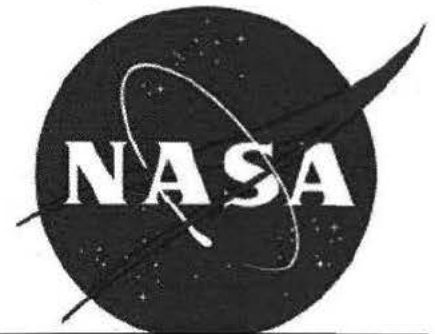
What is MARCO POLO?



- **Mars Atmosphere and Regolith COllector/PrOcessor for Lander 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:

- CO₂ capture from Mixed Mars atmosphere (KSC)
- Sabatier converts H₂ and CO₂ 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 CO₂ 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

Water Processing Module: (JSC)

- Currently can process 520g/hr of water (max 694 g/hr)

Life Detection Drill: (ARC-Honeybee)

- Replaces excavator mockup
- Takes core samples
- Provides some feed to Soil Dryer

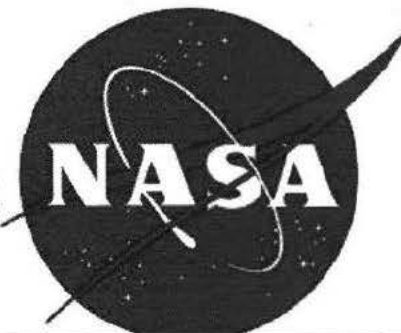
1KW Fuel Cell and consumable storage (JSC & GRC)

- Using metal hydride for H₂ storage due to available
- 1KW No Flow Through FC (GRC)
- 10KW FC not shown (JSC)

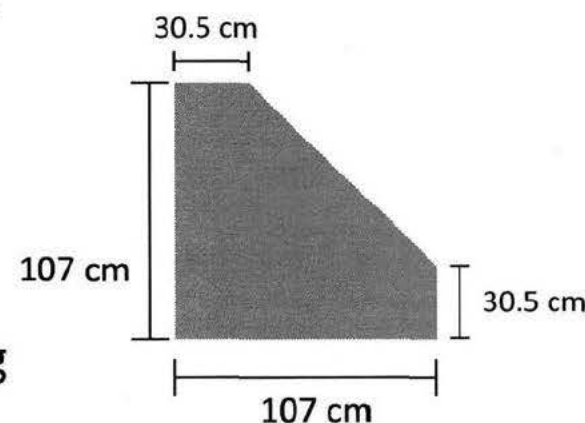
3m x 3m octagon lander deck



APM Goals/Requirements

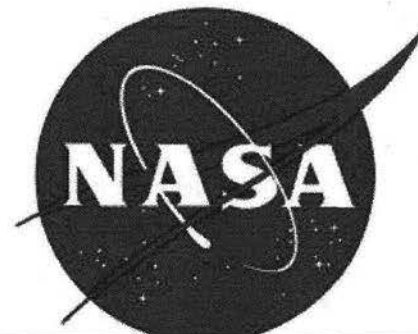


- Collect and purify 88 g CO₂/hr (>99%)
 - From simulated Martian atmosphere
 - 10 mbar; 95% CO₂, 3% N₂, 2% Ar
- Supply 88 g CO₂/hr at 50 psia to the Sabatier reactor
- Convert CO₂ to 31.7 g CH₄/hr and 71.3 g H₂O/hr
- Operate autonomously for up to 14 hr/day
- Minimize mass and power
- Fit within specified 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



Sabatier Reactor

Methane
Dryer (Future)

CO₂ ballast tanks not shown
Chiller

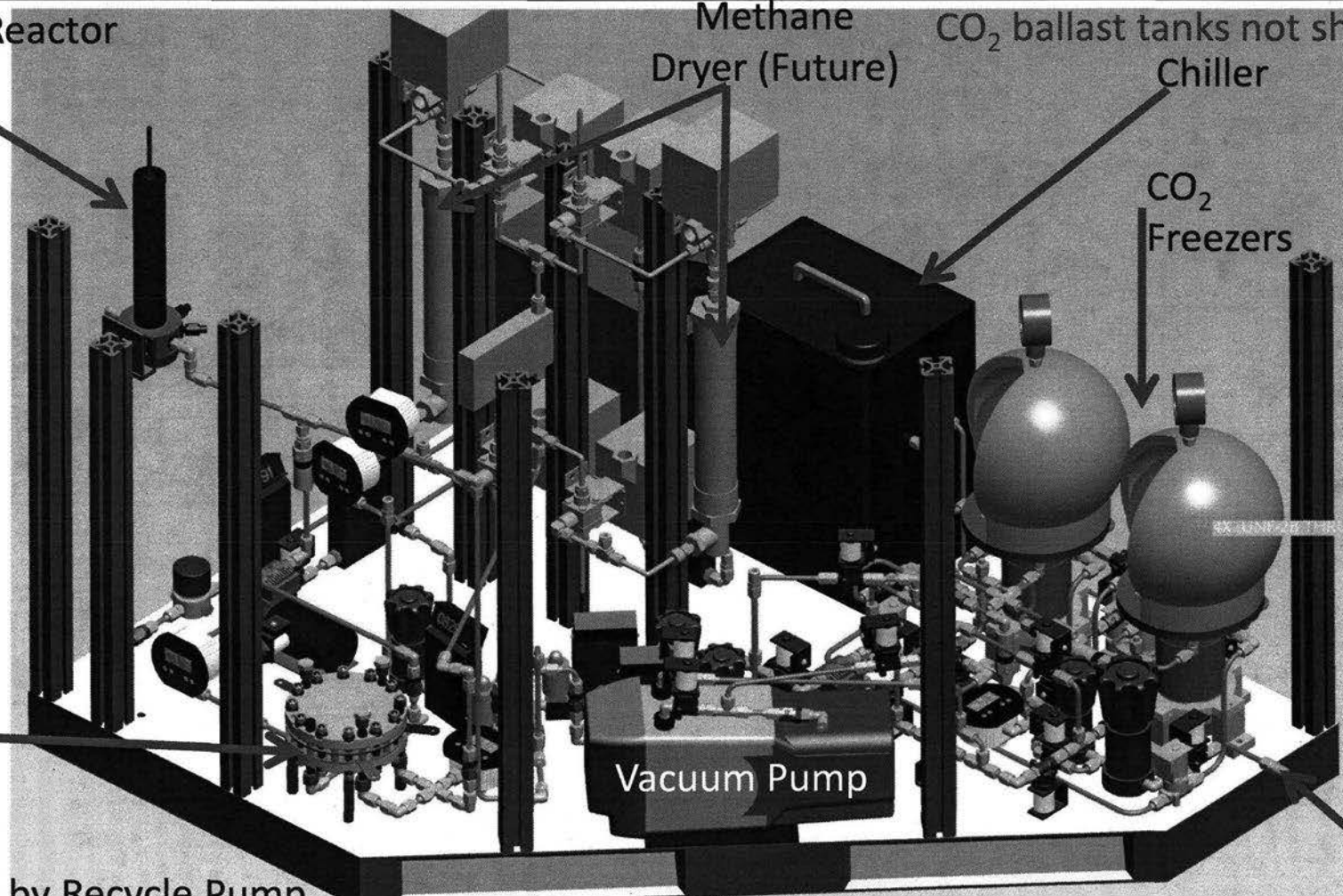
CO₂
Freezers

Electro-
chemical
Methane
Separator

[Replaced by Recycle Pump
and Membrane Module]

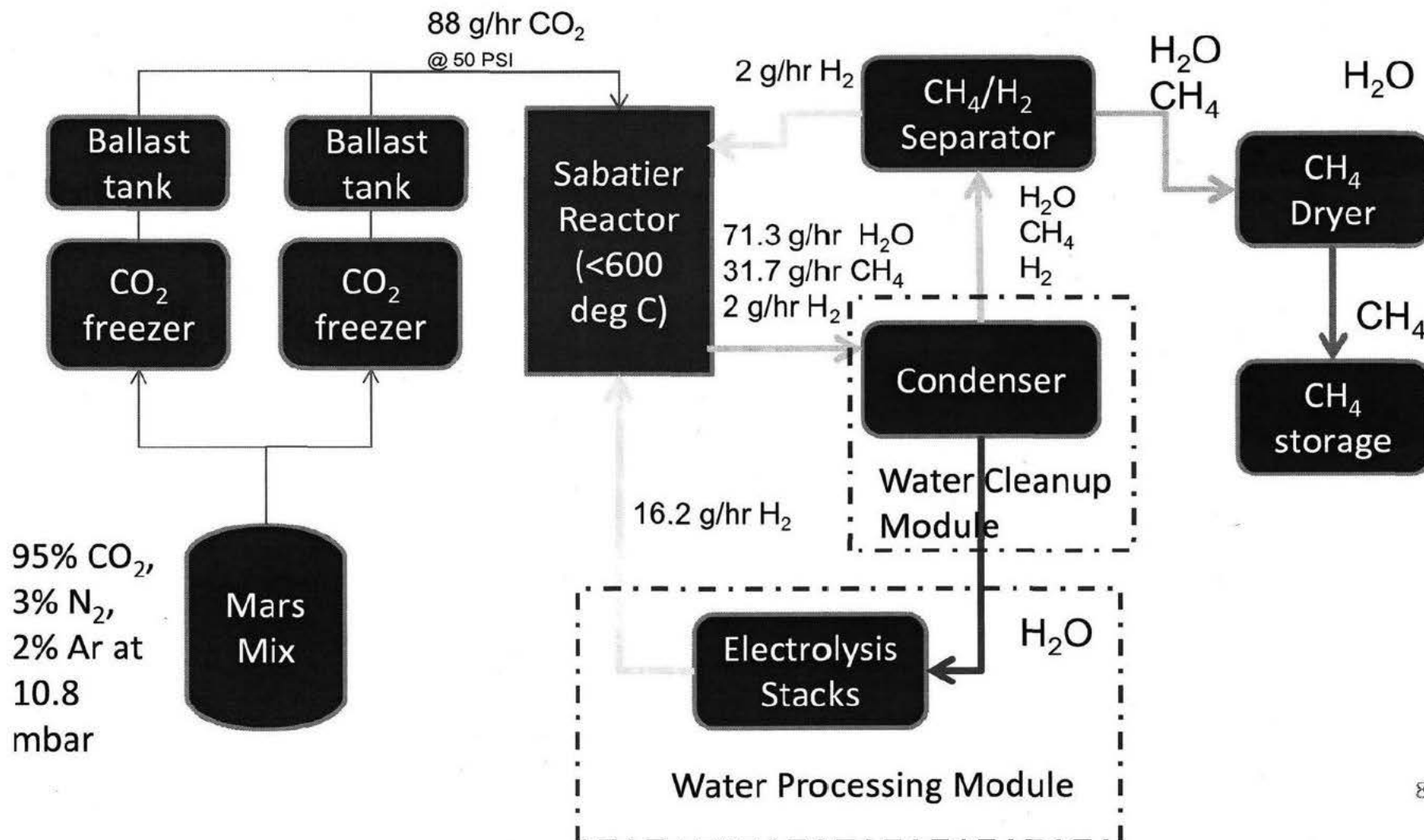
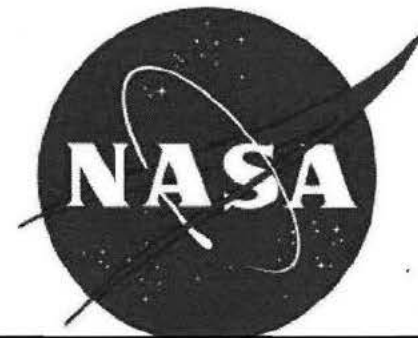
Vacuum Pump

Mixed
Mars
Gas
Input



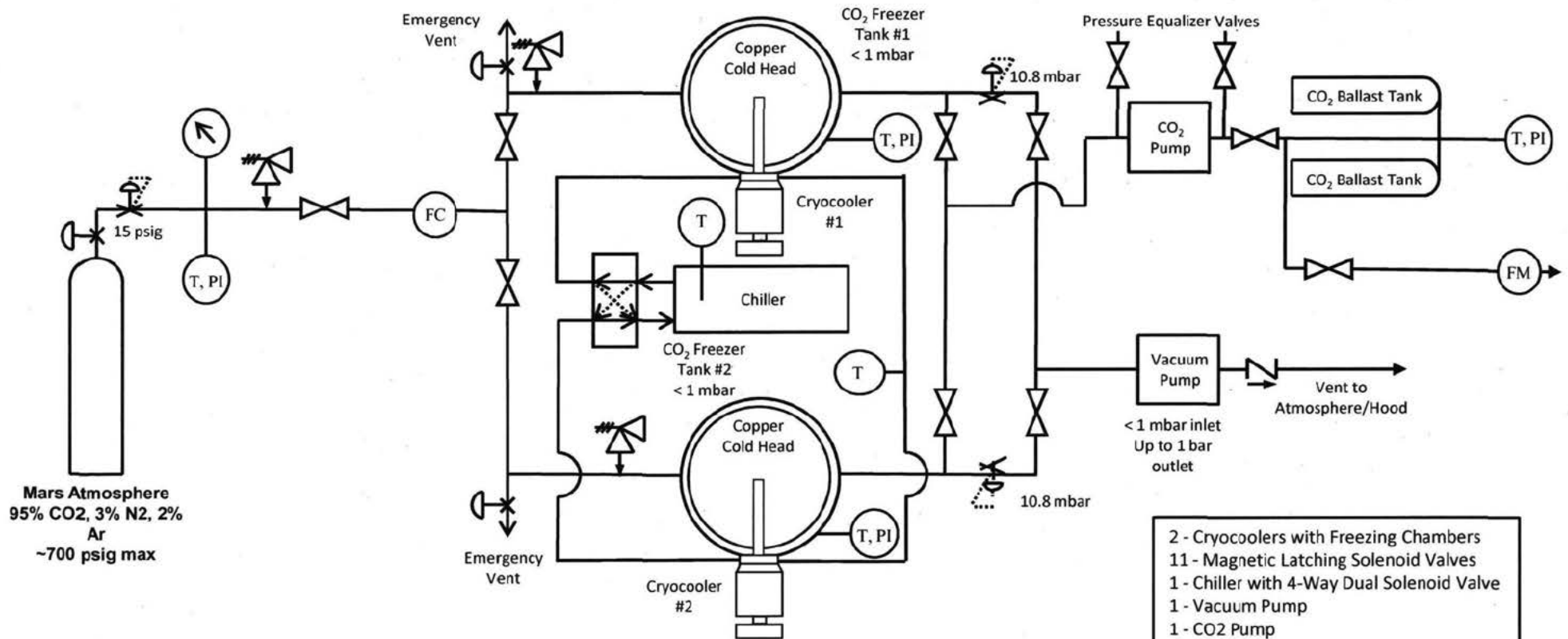


Atmospheric Processing Operations





CO₂ Freezer – Final Design



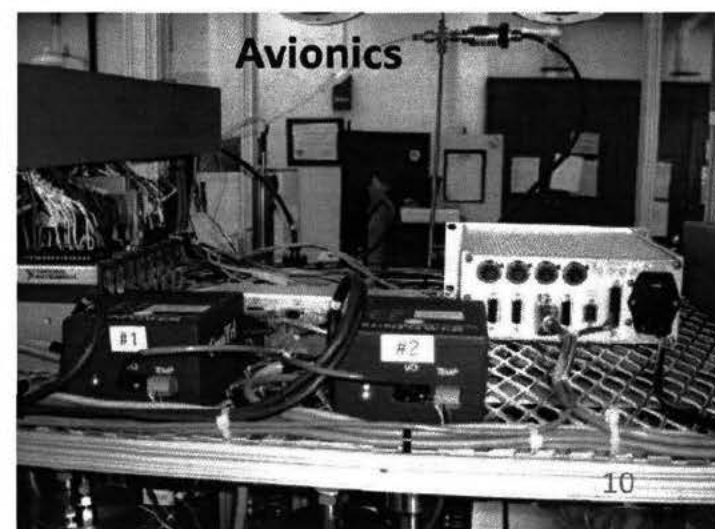
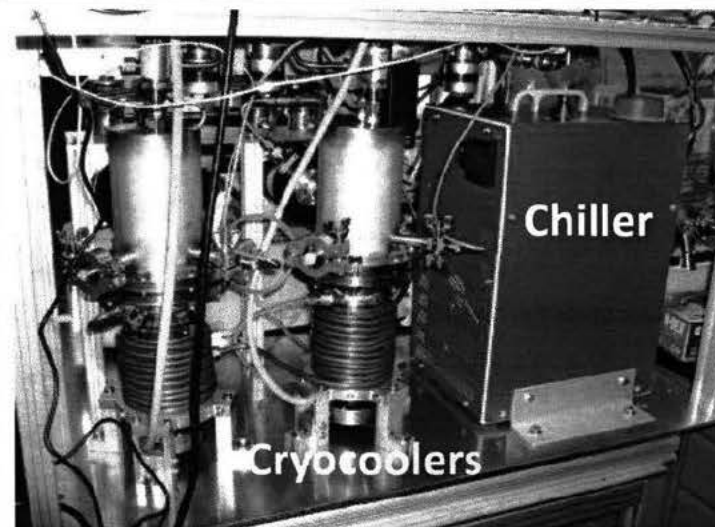
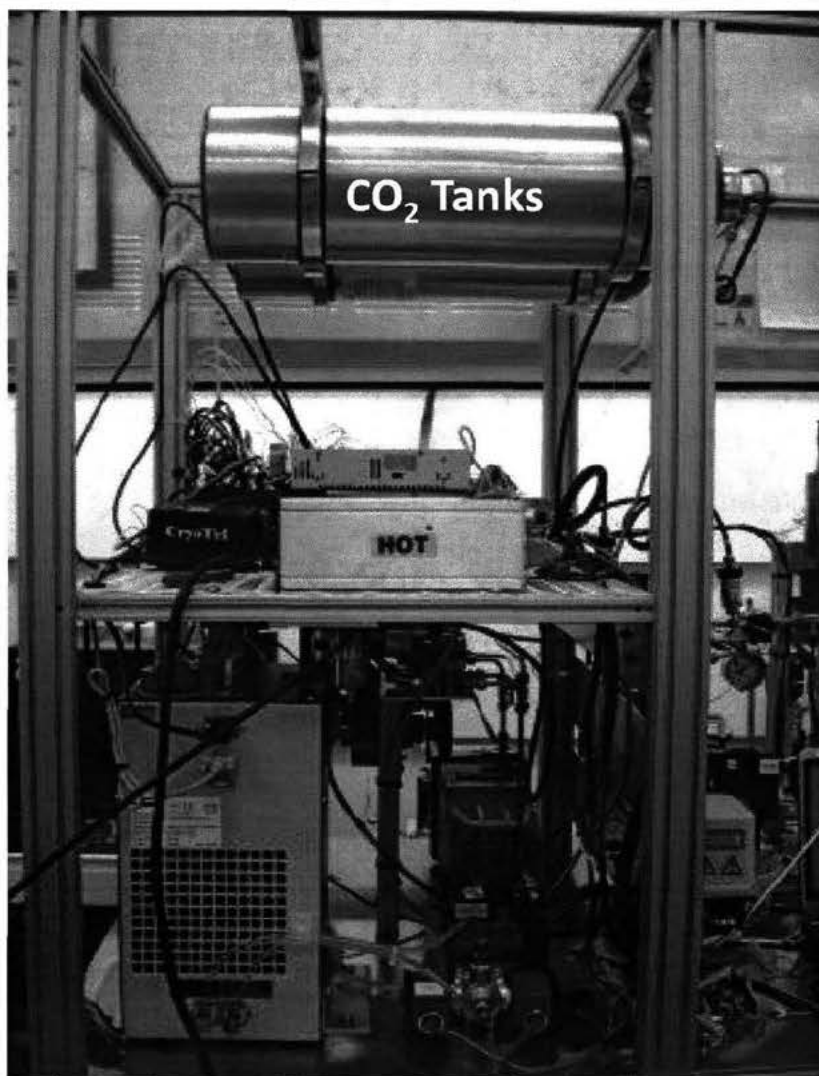
- 2 - Cryocoolers with Freezing Chambers
- 11 - Magnetic Latching Solenoid Valves
- 1 - Chiller with 4-Way Dual Solenoid Valve
- 1 - Vacuum Pump
- 1 - CO₂ Pump
- 2 - CO₂ Ballast Tanks
- 2 - Vacuum Back Pressure Regulators
- 3 - Pressure Relief Valves
- 1 - Flow Controller
- 1 - Flow Meter
- 3 - Thermocouples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



CO₂ Freezer

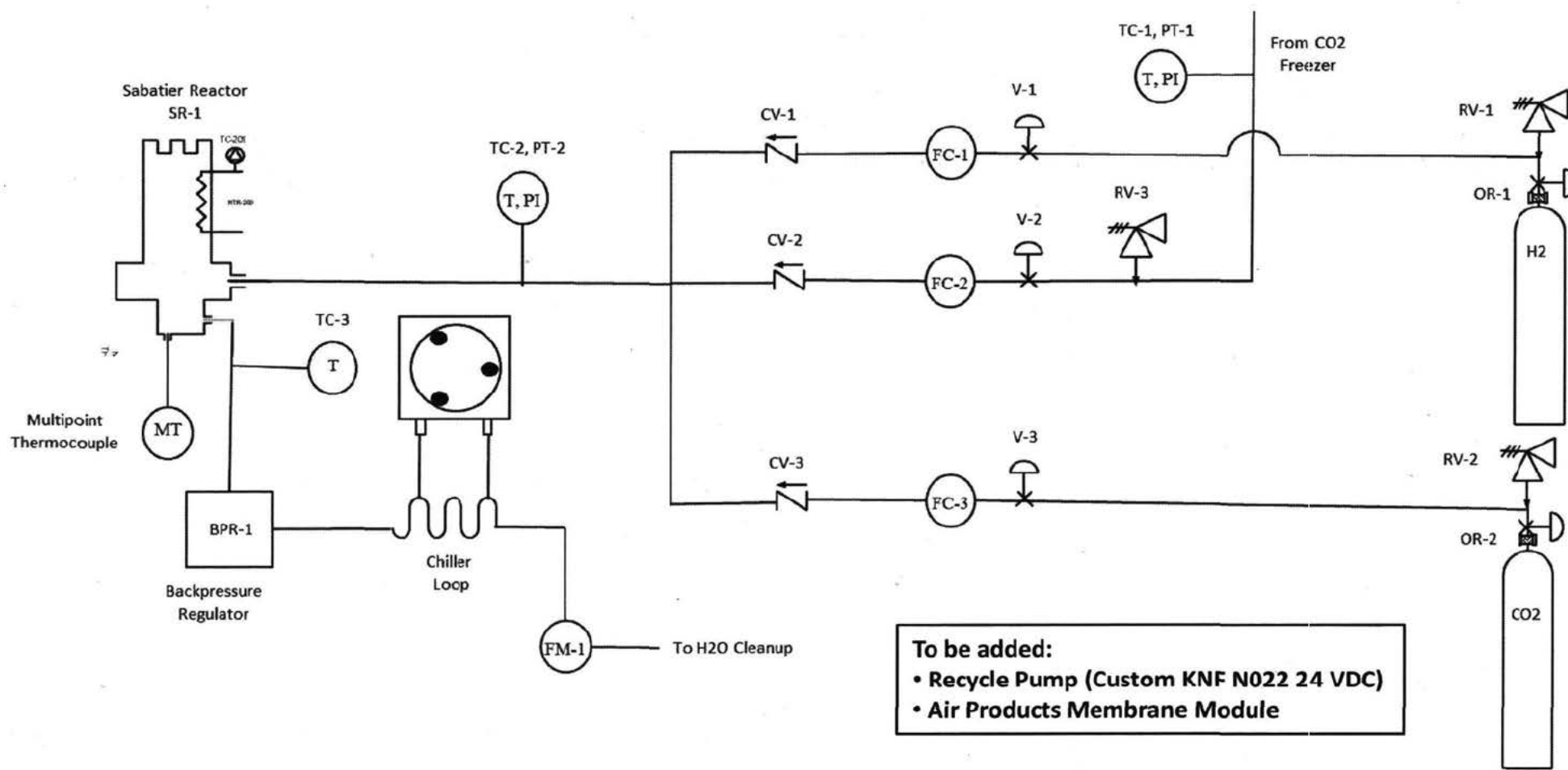
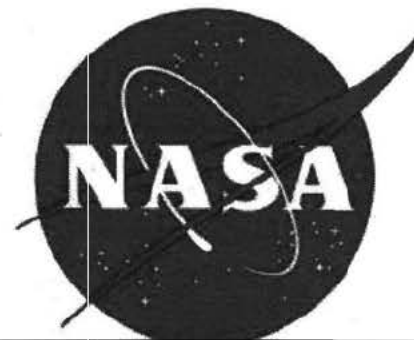


Copper Cold Head



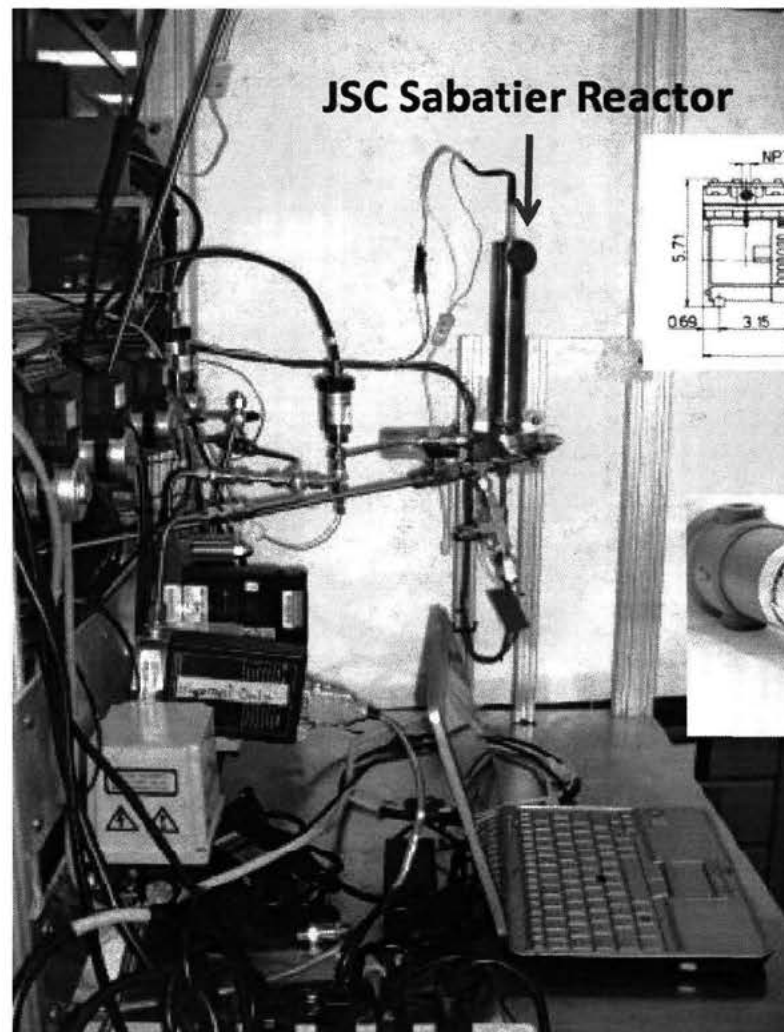
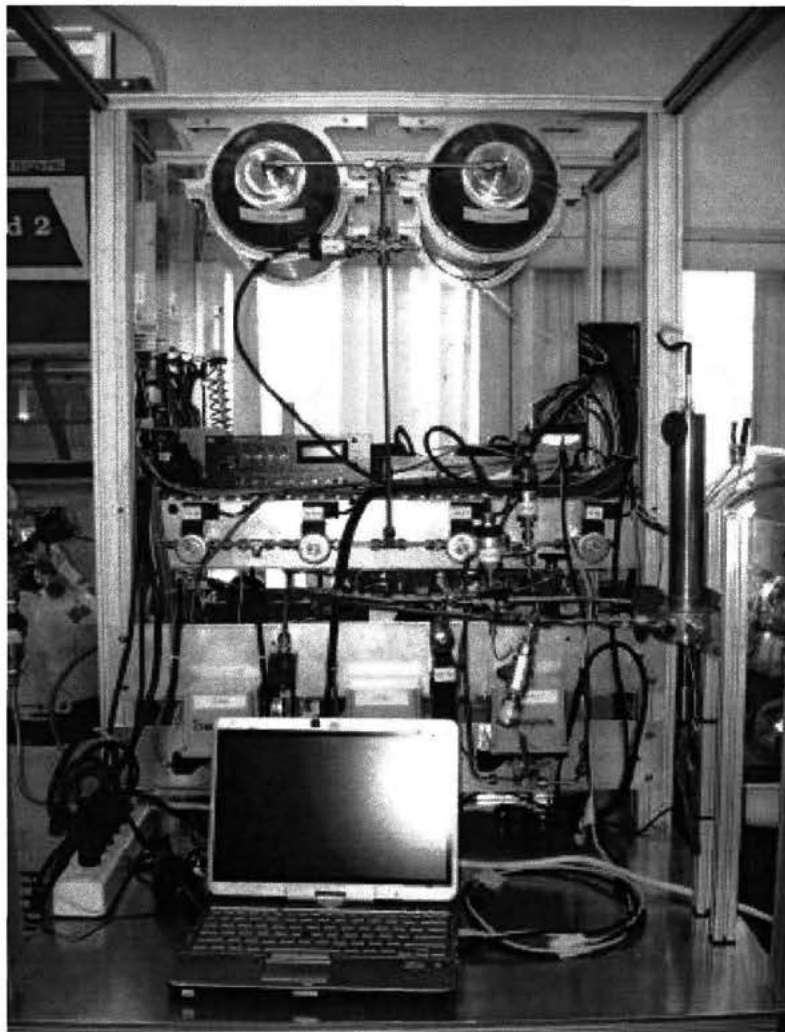
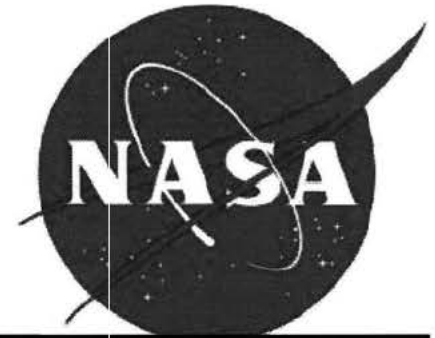


Sabatier Subsystem Design

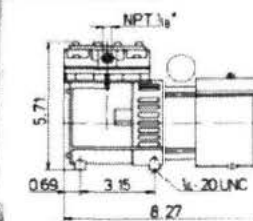




Sabatier Subsystem



JSC Sabatier Reactor



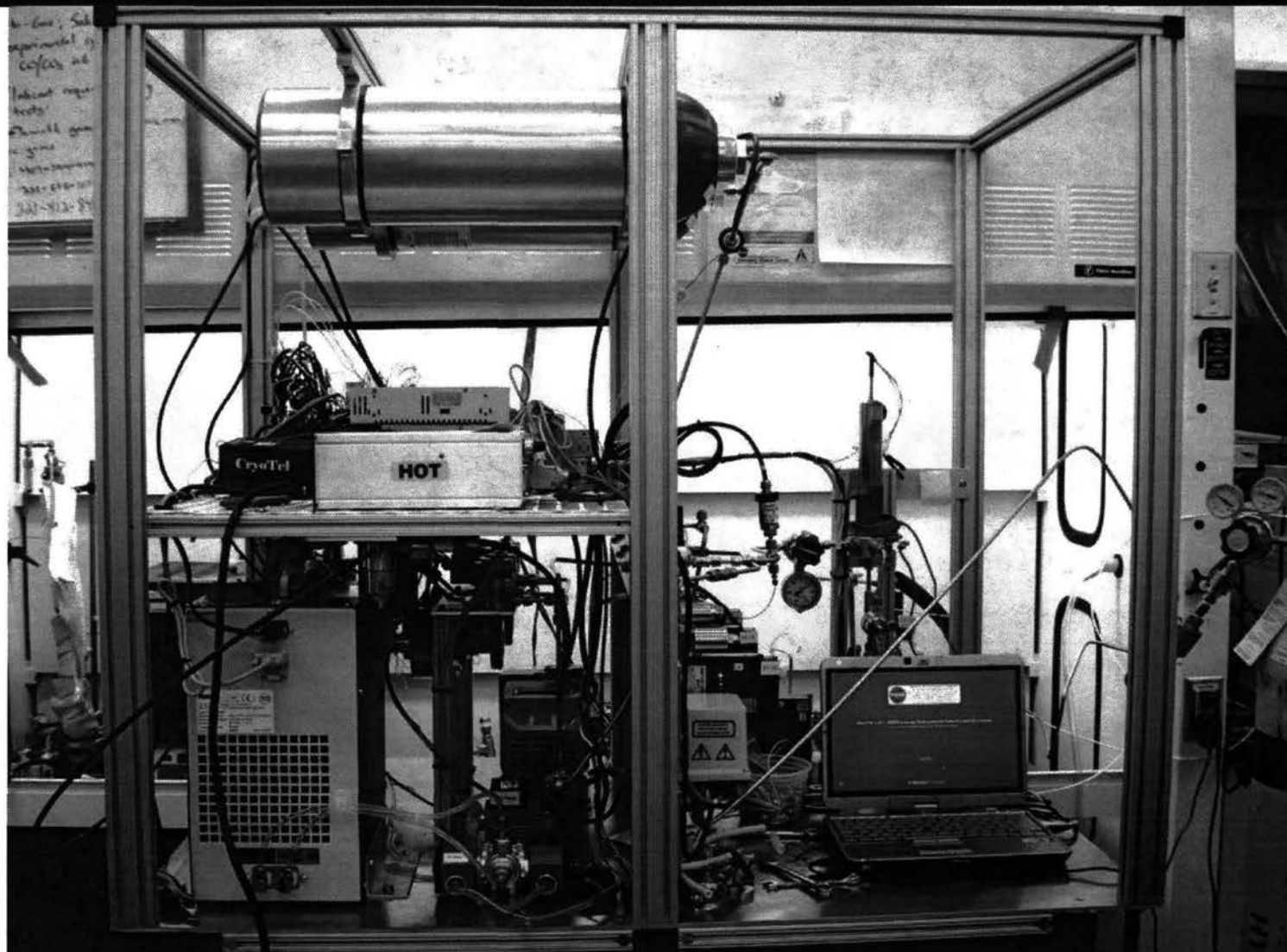
Recycle Pump



Membrane Module (Cut-Away View)

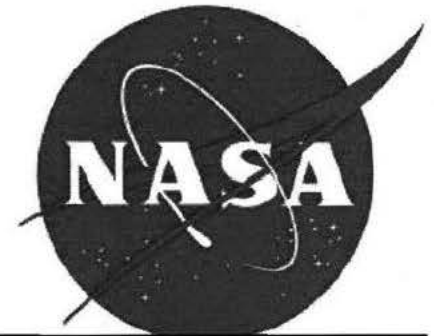


Atmospheric Processing Module

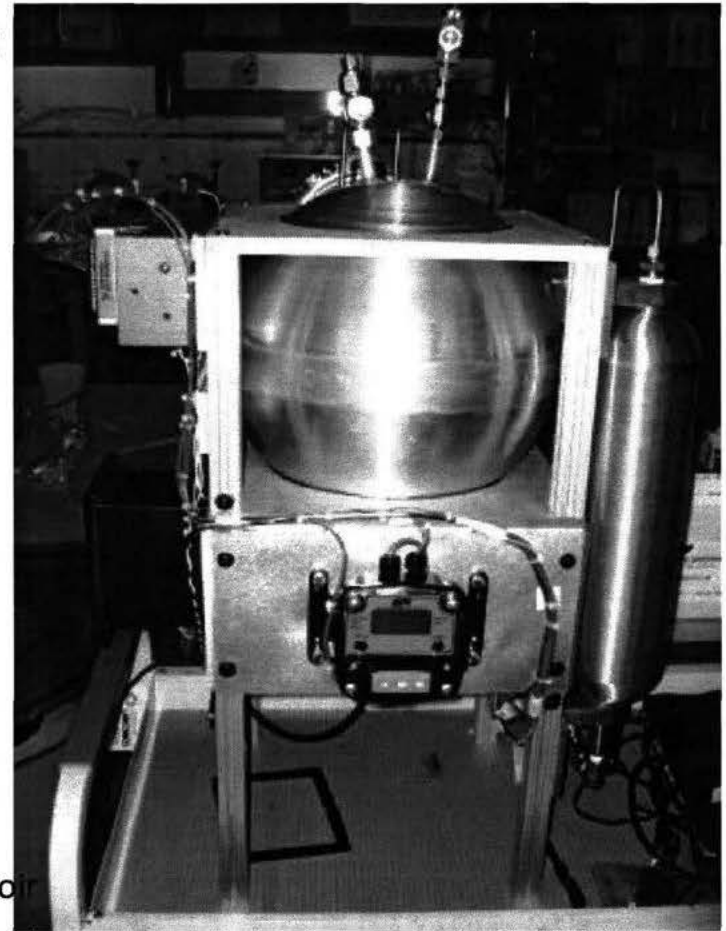
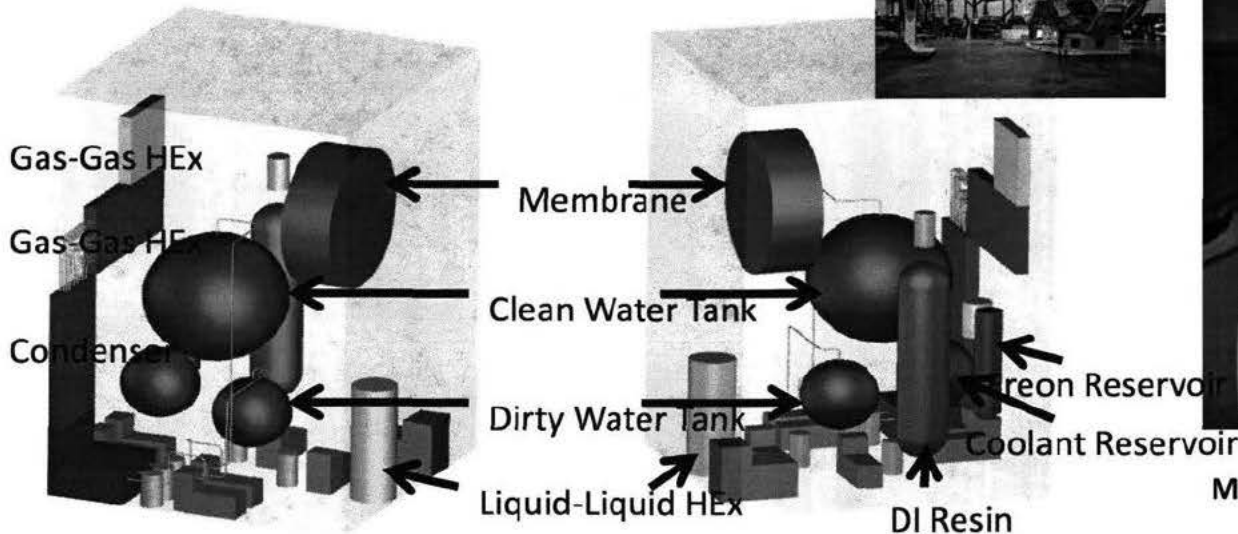




Water Cleanup Module (KSC)



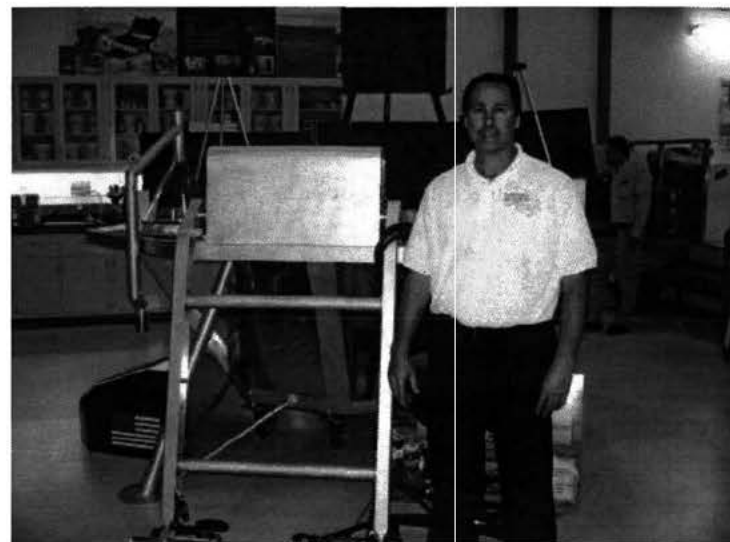
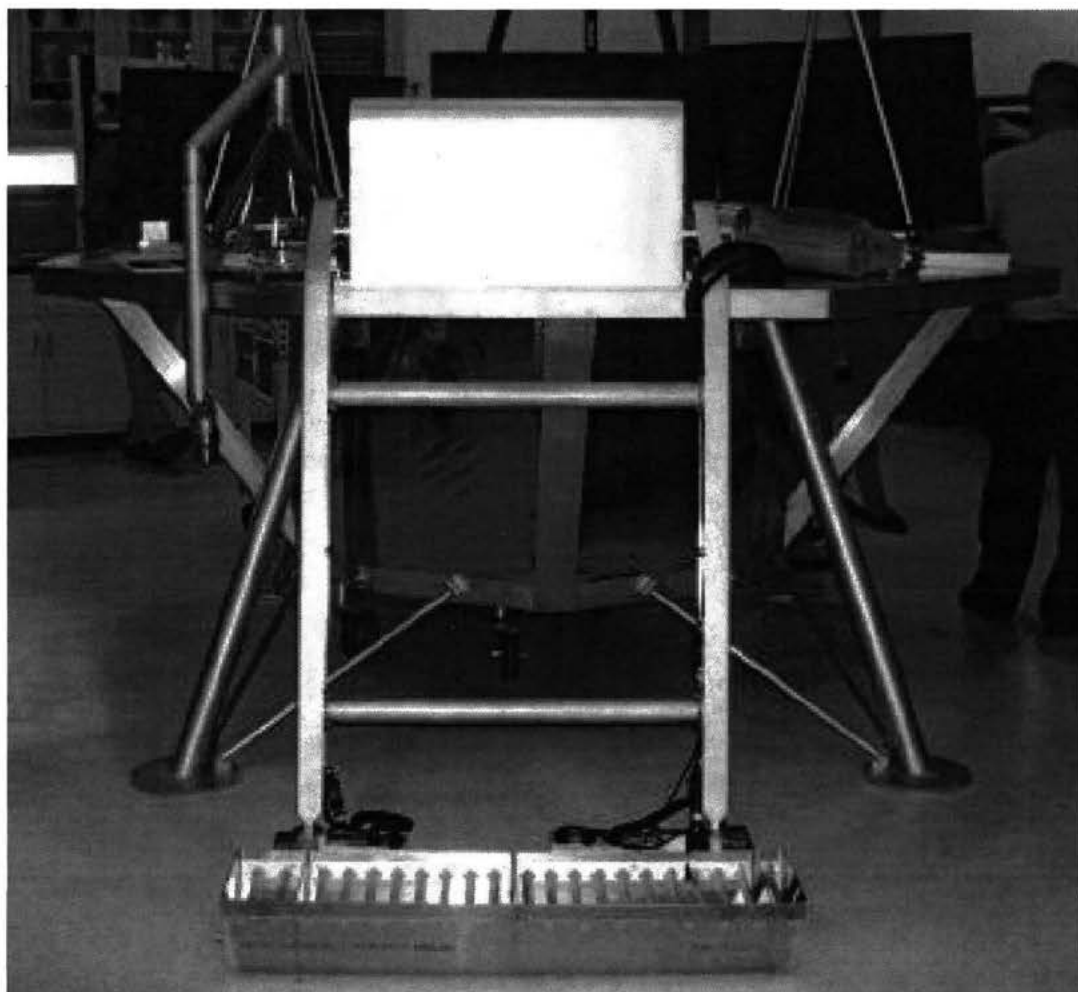
- Tested with Water Processing Module at JSC last summer
- Used to recycle fuel cell water from the MMSEV to H_2 and O_2
- MMSEV = Multi Mission Space Exploration Vehicle



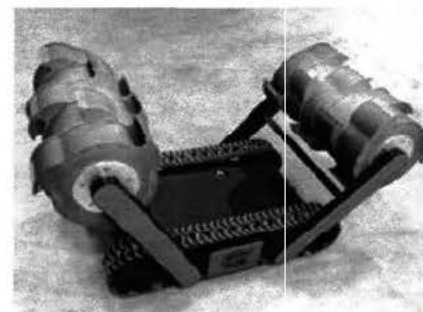
Membrane separator not included in the final version



Lander and Soil Processing Module (KSC)



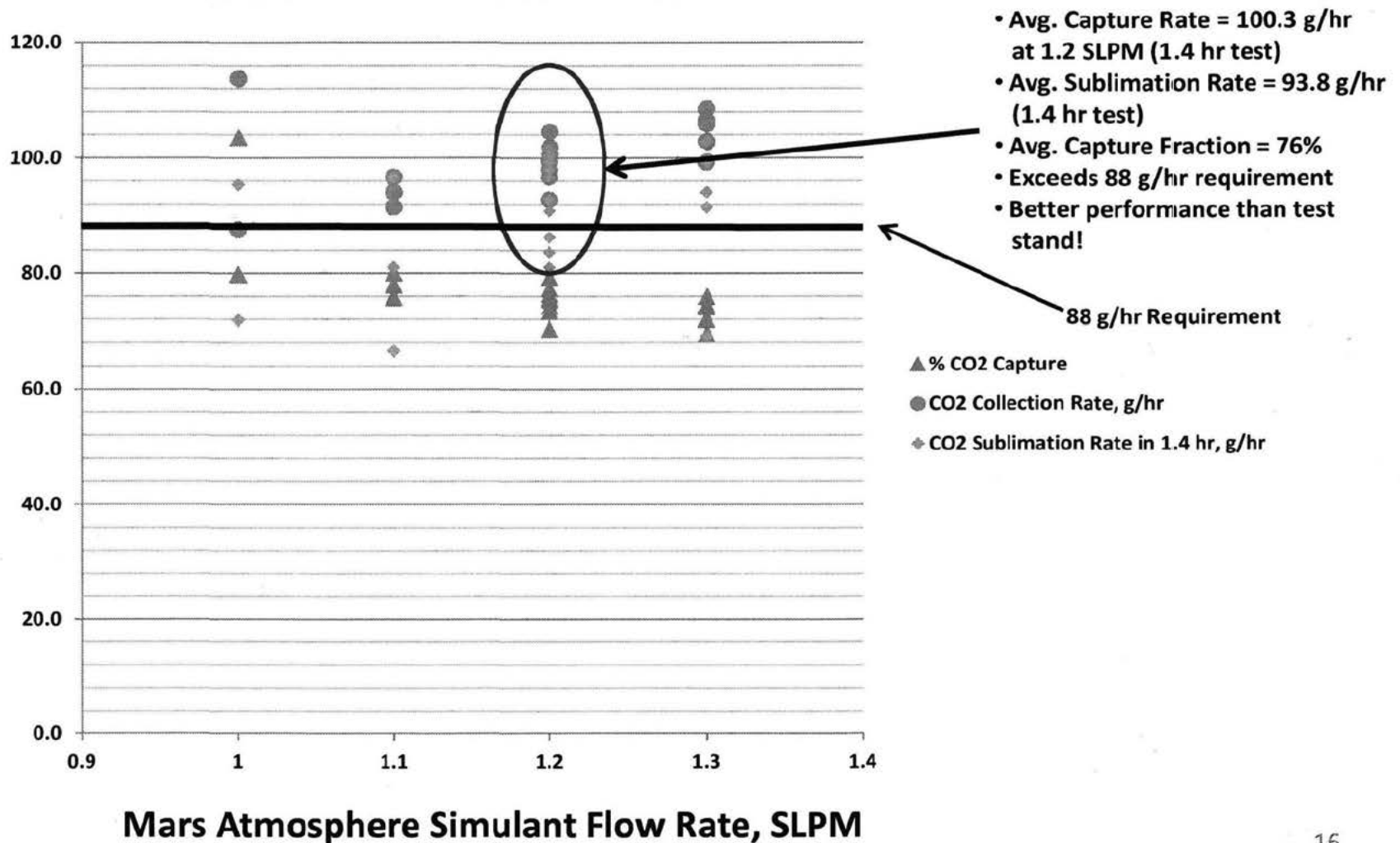
Van Townsend (KSC/ESC) with MARCO POLO lander and
Soil Processing Module (under construction)



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

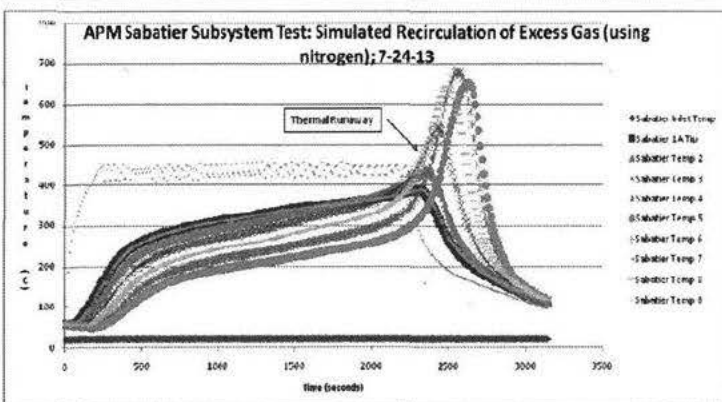
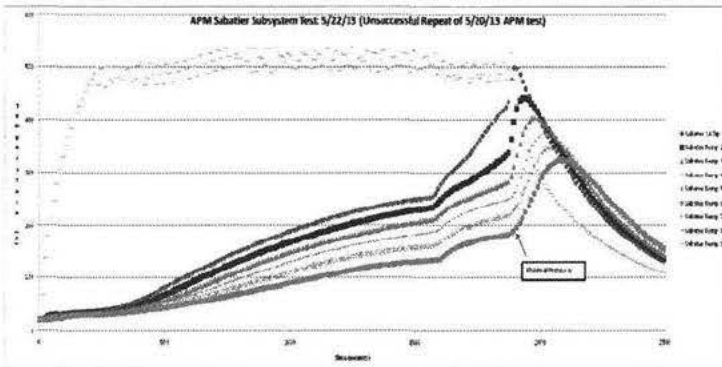
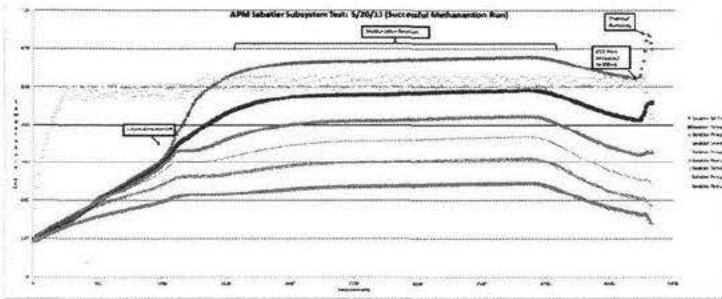
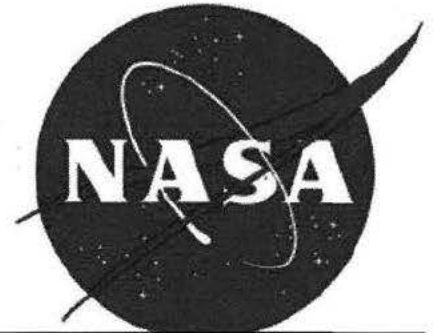


CO₂ Freezer Testing





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)
- Decided to build redesigned Sabatier reactor



Current Status



- **CO₂ Freezer Subsystem essentially complete**
 - Fully automated and fluid system functional
 - Need replacement CO₂ 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 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

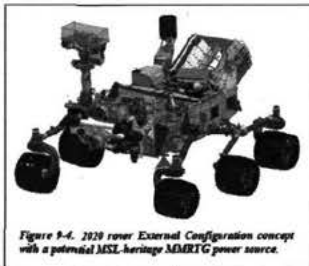


Figure 3-4. 2020 rover External Configuration concept with a potential MSL heritage MMRTG power source.

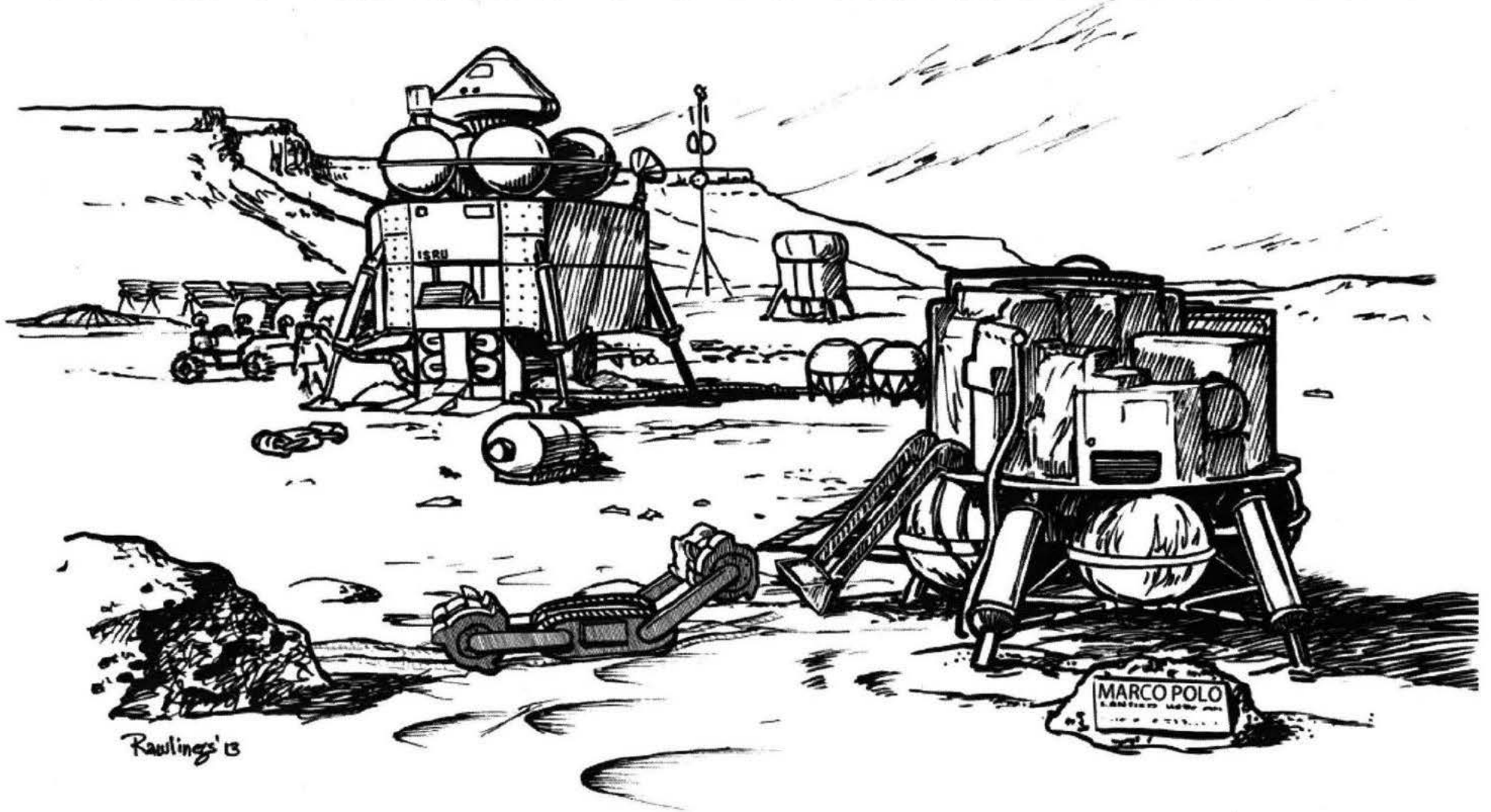
Instrument/Demo	Purpose	SKG Addressed	P-SAG Priority	HAT Priority	Comments
O ₂ production from atmosphere	Collect atmospheric carbon dioxide. Analyze dust (size, shape, number) during CO ₂ collection. Produce small quantities of oxygen and analyze its purity (option).	B6-1: Atm. ISRU B4-2: Dust properties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

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	10	Sampling (approximately 24 times a day)
Atmospheric ISRU demo - CO ₂ capture + dust - CO ₂ capture + O ₂ production	10 20	30-50 100-150	Operate 7 to 8 hrs per sol, and as many sols as possible. Operate CO ₂ capture and O ₂ 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

