In situ Resource Utilization: How to Live and Thrive in Space

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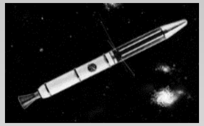
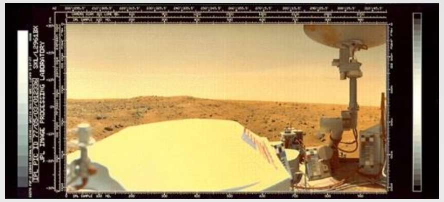
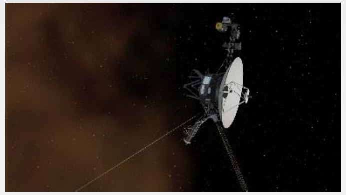
Significant Events in Space

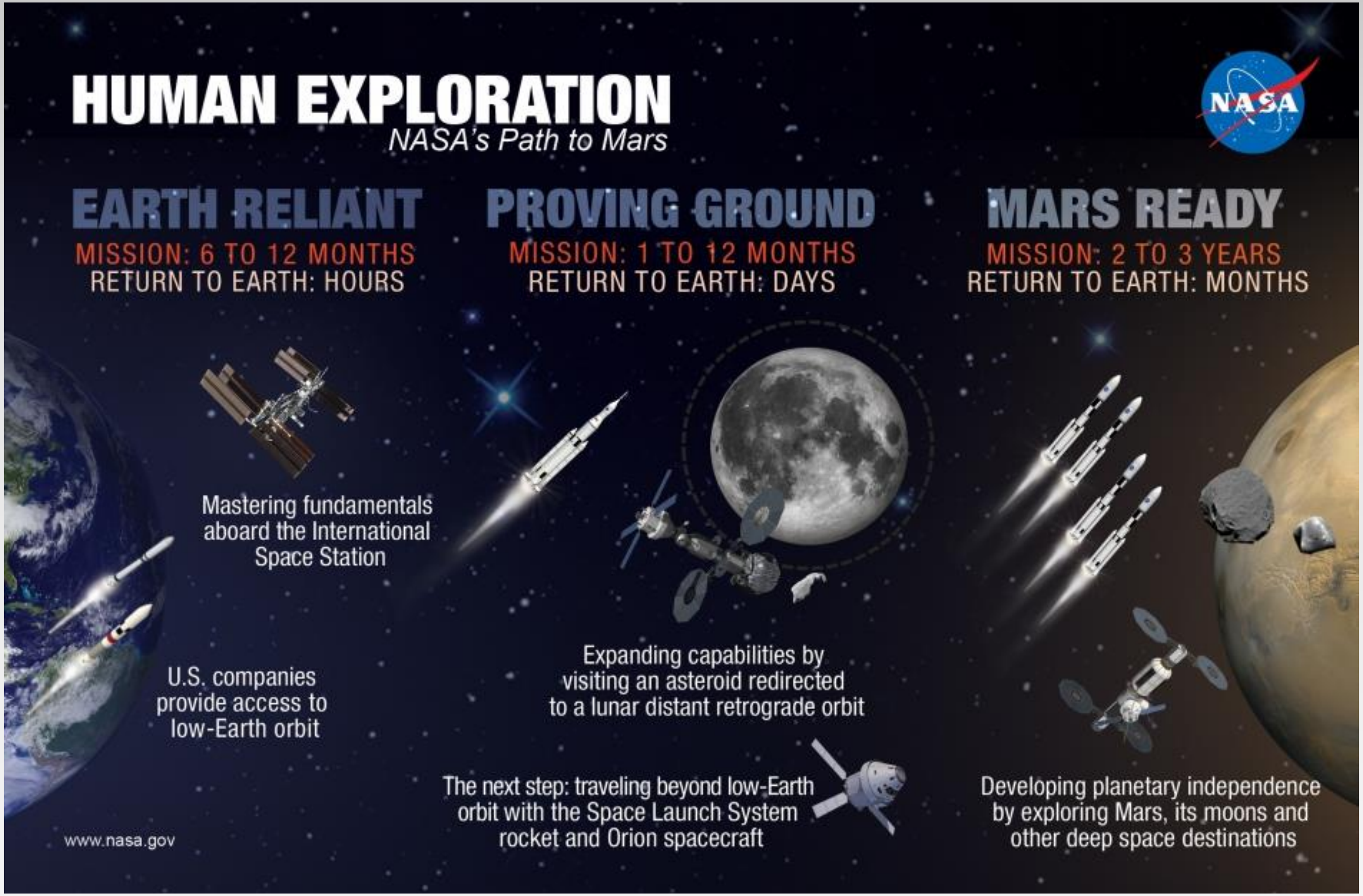


- ❑First American Satellite – 1958
- ❑First American to Orbit Earth – 1962
- ❑First American Spacewalk – 1965
- ❑First Manned Lunar Landing – 1969
- ❑First Robotic Landing on Mars – 1971
- ❑Space Shuttle Flights – 1981-2011
- ❑Continuous human occupation of space – 2000 - present
- ❑First Spacecraft to Leave the Solar System – 2013-2014

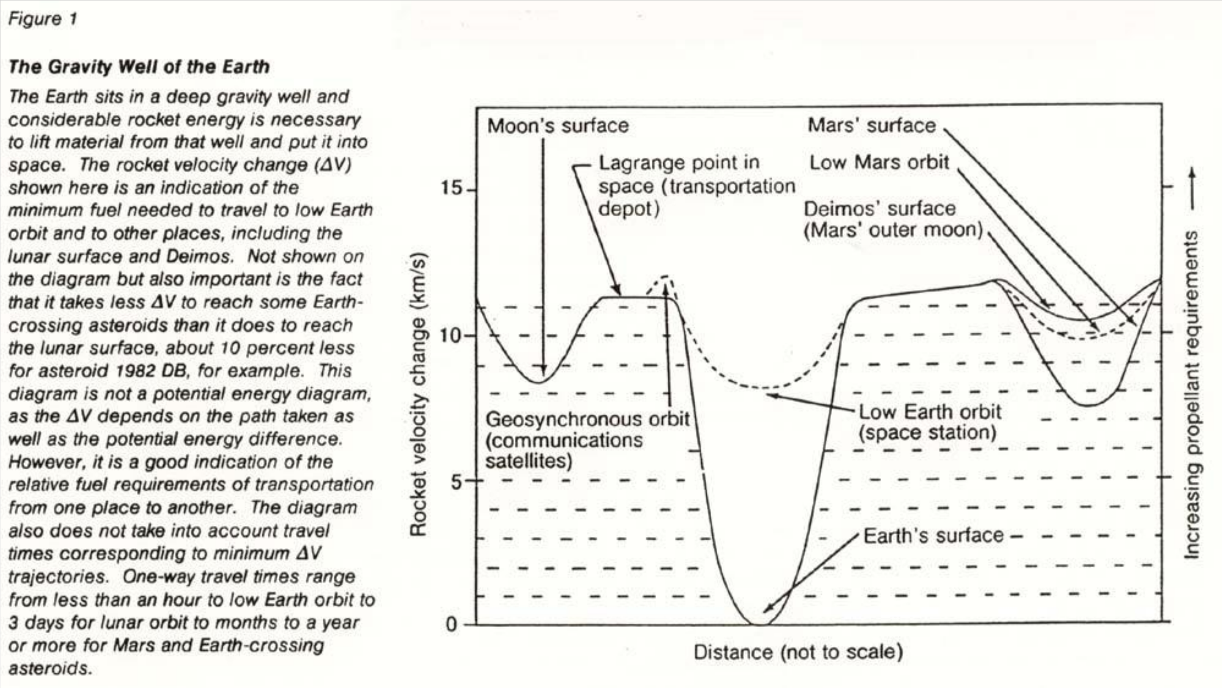




Significant Events in Space



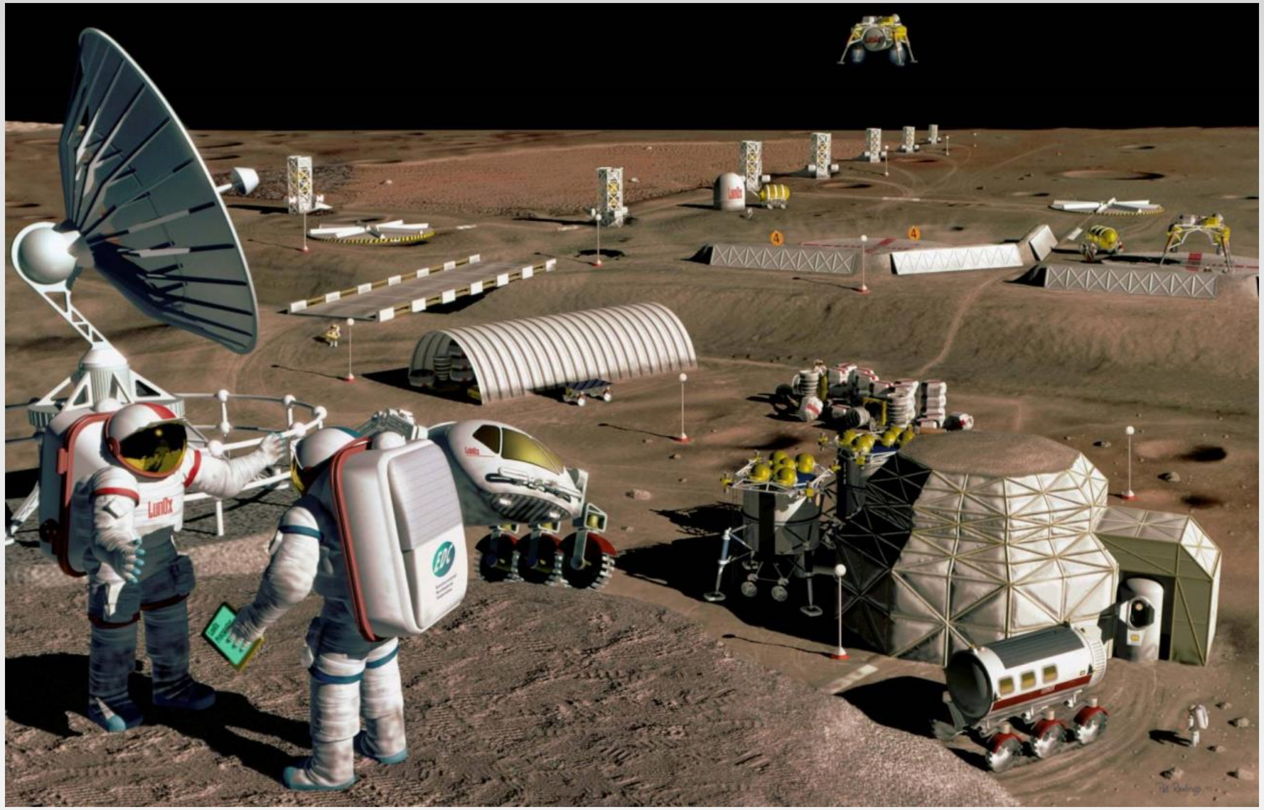
Gravity Wells and Gear Ratios



- NASA SLS will weigh 30,000 metric tons and deliver 130 metric tons to Low Earth Orbit (LEO)
- 20:1 gear ratio going from LEO to Mars surface
- One SLS launch can send 6.5 metric tons to Mars surface
- Proposed need of 5.8 metric tons of methane for return trip from Mars

Introduction to ISRU

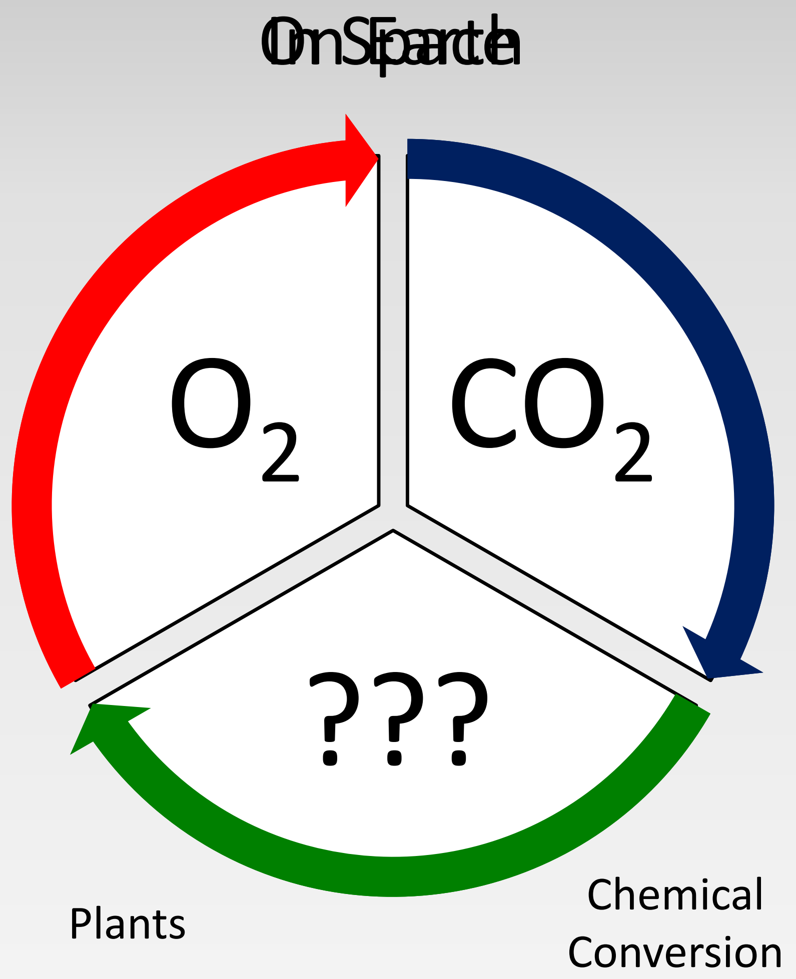
- **What is ISRU? – I**n **S**itu **R**esource **U**tilization
  - **"Living off the land"**
  - **Use Space Resources to reduce cost and risk for NASA missions**
  - **Already used with Solar Panels for power**
- **What do we need?**
  - **Life Support: Air, water, food**
  - **Propellant**
  - **Structures**
- **Key space resources:**
  - **Lunar regolith and polar water ice/volatiles**
  - **Asteroid regolith, metals, and volatiles**
  - **Martian atmosphere and water ice/hydrates**



Introduction to ISRU

- What do we need?

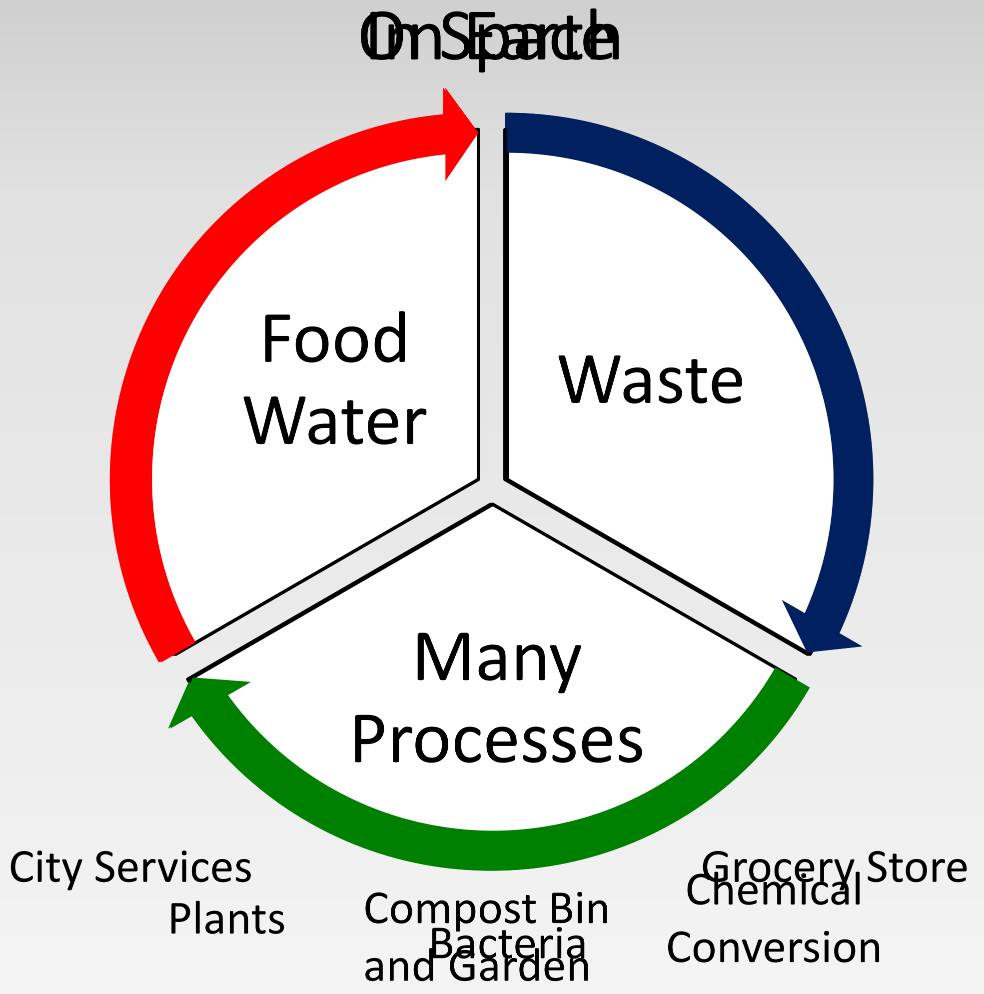
  We need to breathe



Introduction to ISRU

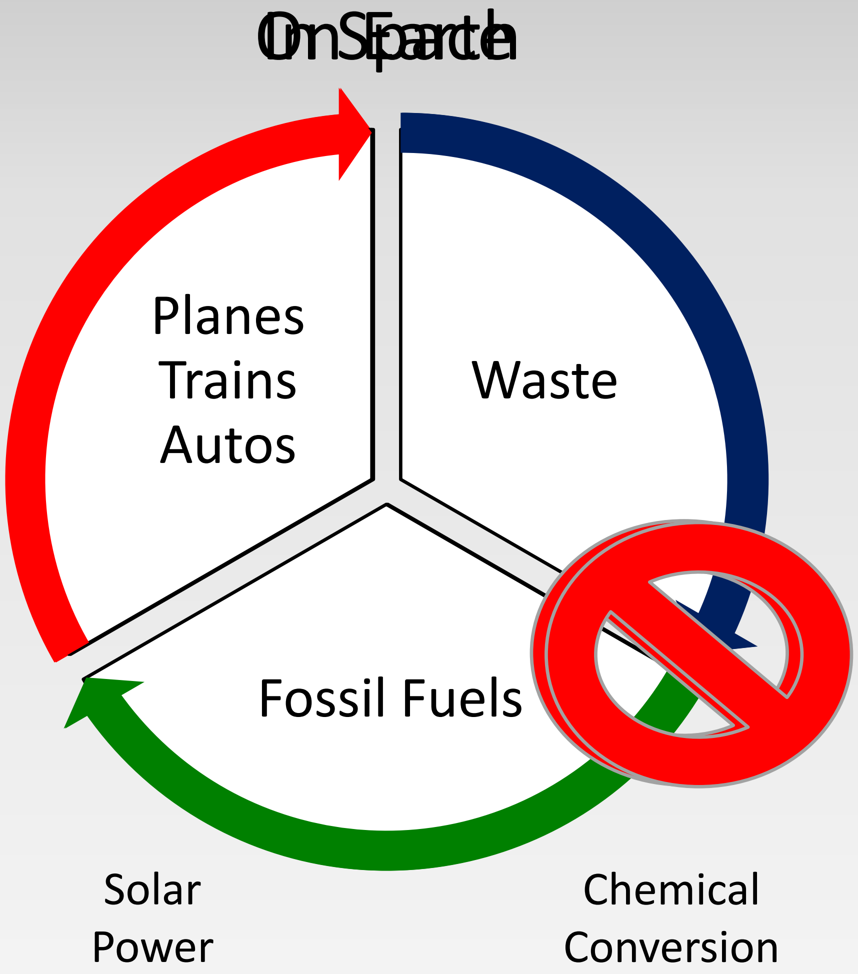
- What do we need?

  We need to eat/drink



Introduction to ISRU

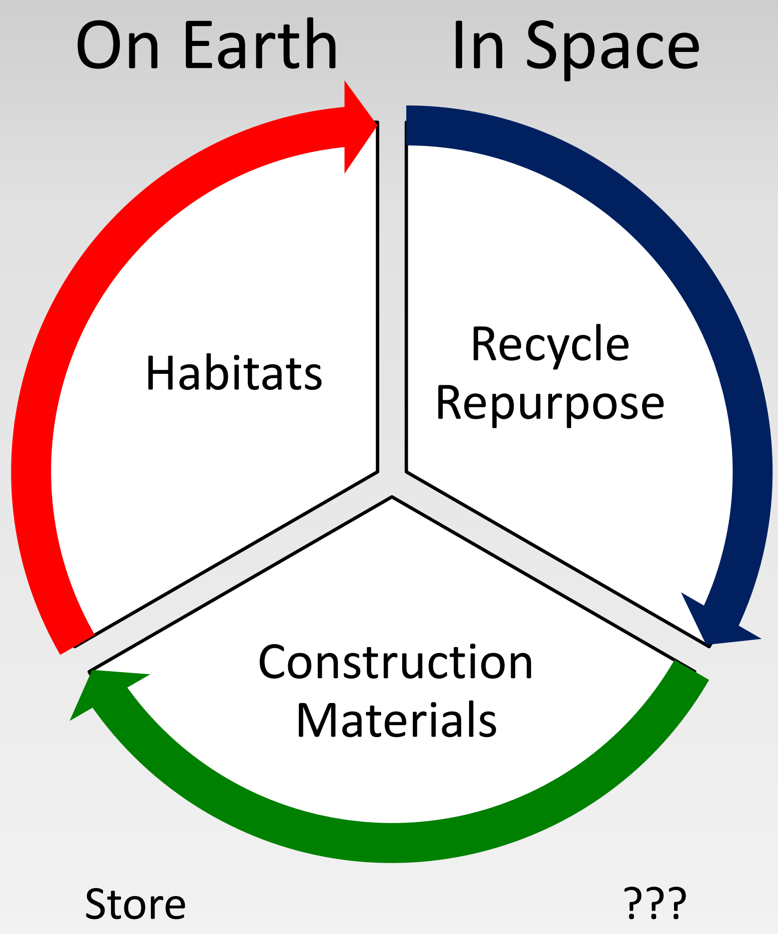
- What do we need?
  - Transportation



Introduction to ISRU

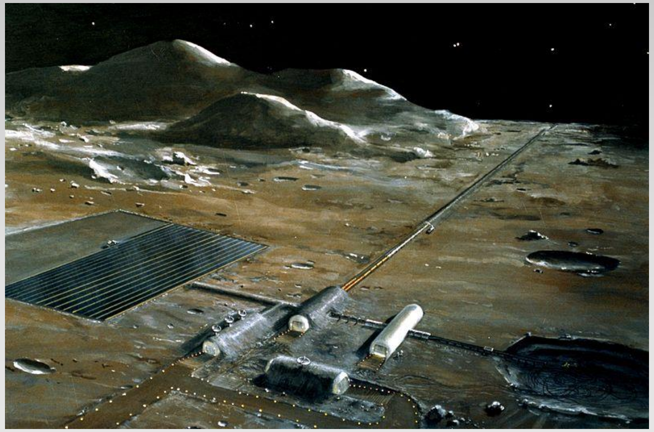
- What do we need?

  Shelter

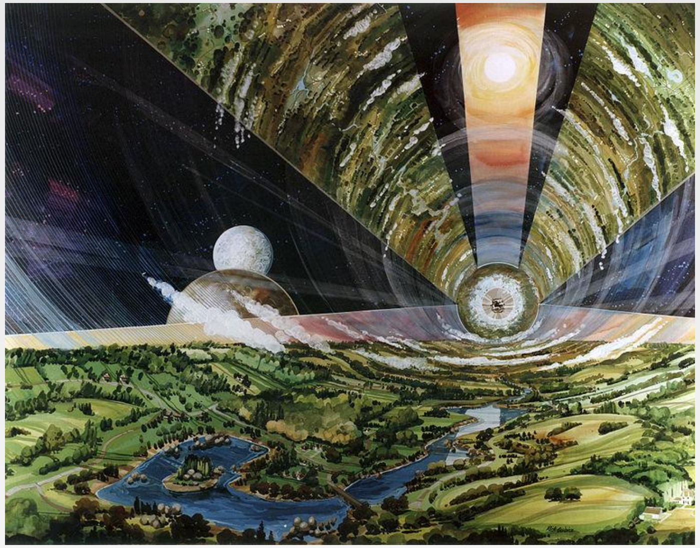


ISRU in Books and Pop Culture

- The High Frontier, Gerard K. O'Neill, 1977
- The Case for Mars, Robert Zubrin, 1996
- Runaround, Isaac Asimov, 1942
- The Moon is a Harsh Mistress, Robert Heinlein, 1966
- Total Recall, 1990, based on "We Can Remember it for you Wholesale", Phillip K. Dick, 1966
- Interstellar, 2014
- The Martian, 2015



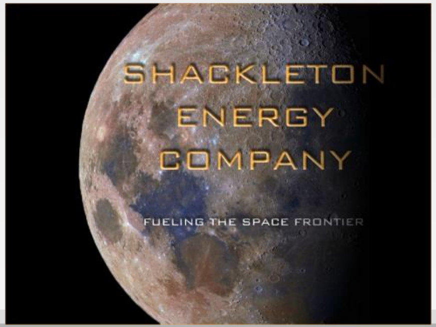
Mass driver on the moon



O'Neill cylinder

ISRU Businesses

- Planetary Resources: asteroid mining, $1.5 million crowd sourced for asteroid telescope. www.planetaryresources.com/
- Golden spike - monetize exploration of the moon. goldenspikecompany.com/
- Moon Express – mine moon for rare metals. www.moonexpress.com/
- Shackleton Energy – mine water on moon for propellant. www.shackletonenergy.com/

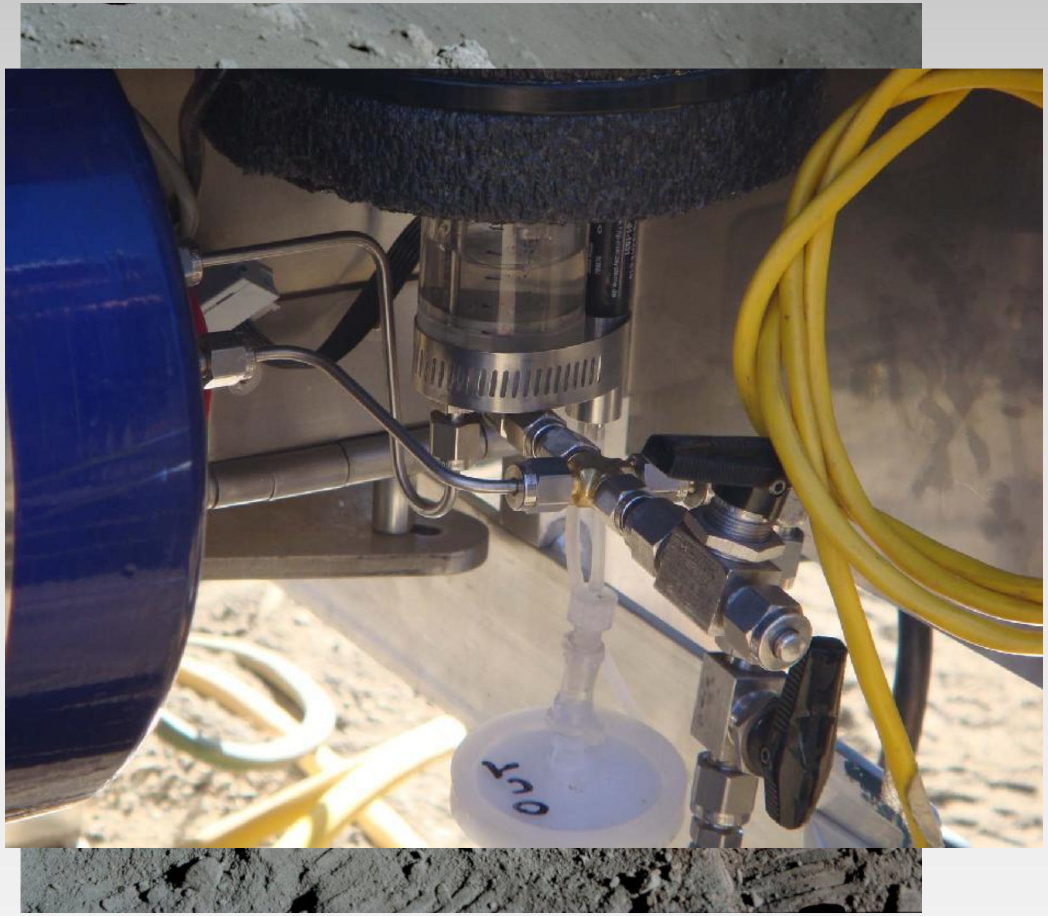


ISRU – Earth's moon

James Irwin, Apollo 15

- All needs brought from Earth

ISRU – Earth's moon – Before 2009



Lunar Regolith (soil)

- Needs come from regolith
  - Hydrogen reduction:

$$FeTiO_3 + H_2 \rightarrow Fe + TiO_2 + H_2O$$
$$H_2O \rightarrow H_2 + O_2$$

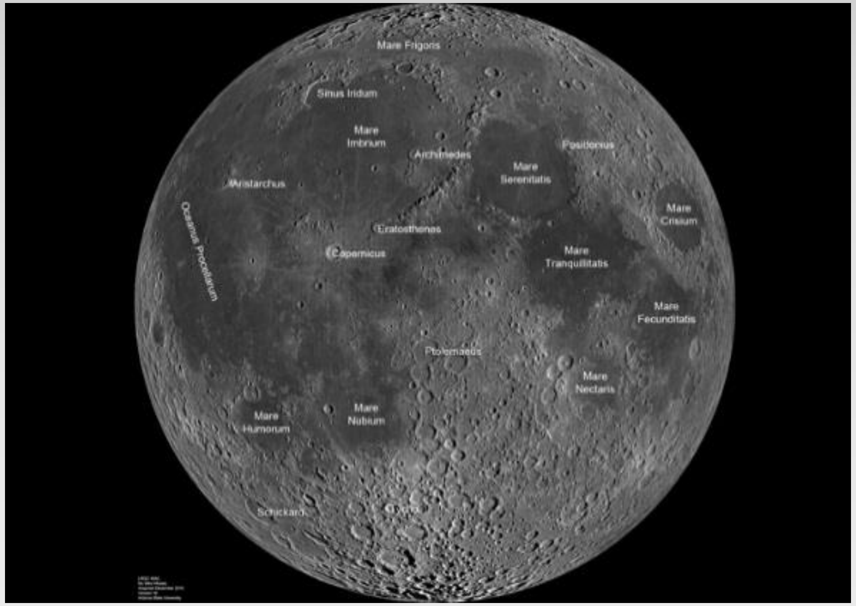
  - Carbothermal reduction

$$MO_x + xCH_4 \rightarrow M + xCO + 2xH_2$$
$$xCO + 3xH_2 \rightarrow xCH_4 + xH_2O$$
$$xH_2O \rightarrow xH_2 + 0.5xO_2$$
$$MO_x \rightarrow M + 0.5xO_2$$

  - Molten regolith electrolysis

$$MO_x \rightarrow M + 0.5xO_2$$

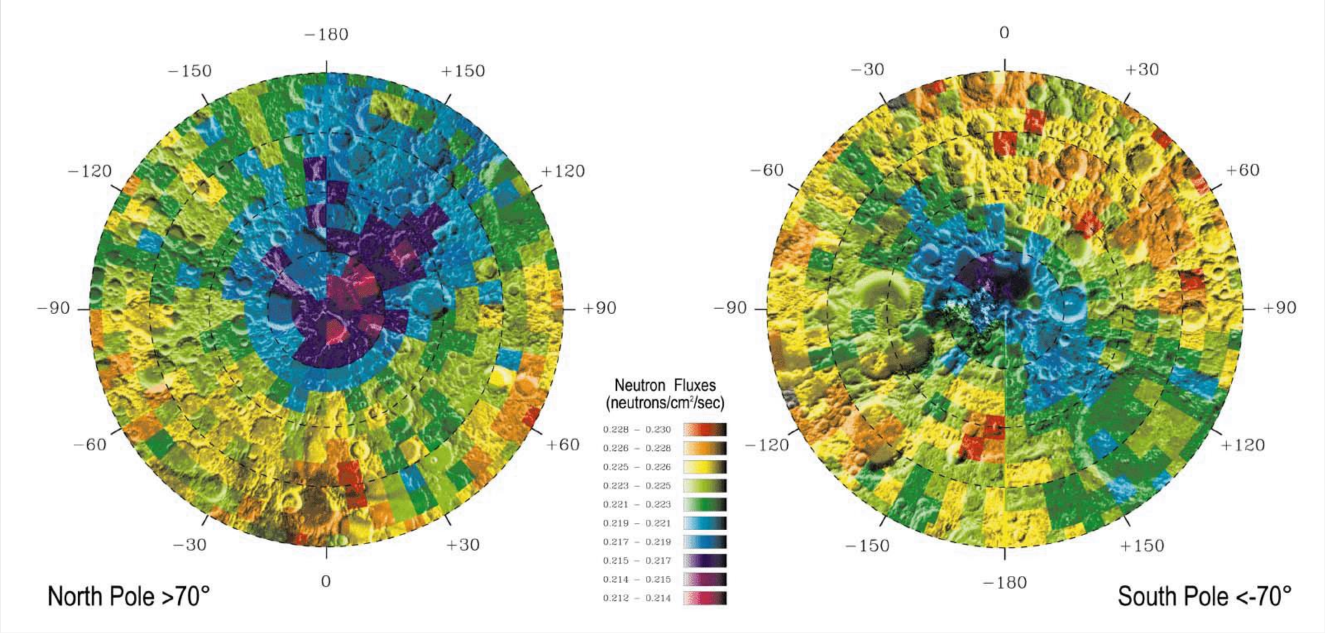
ISRU – Earth’s moon – After 2009



Lunar nearside mosaic taken by Lunar Reconnaissance Orbiter

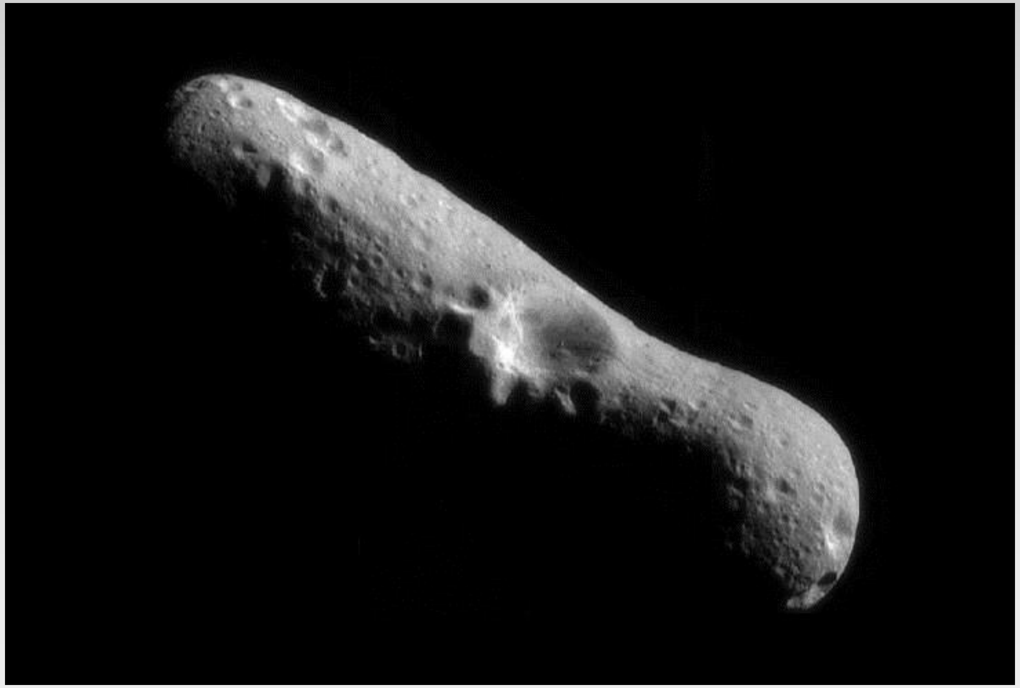
- ❑Water was discovered in 2009

$$H_2O \rightarrow H_2+O_2$$



Lunar Prospector Neutron Spectrometer

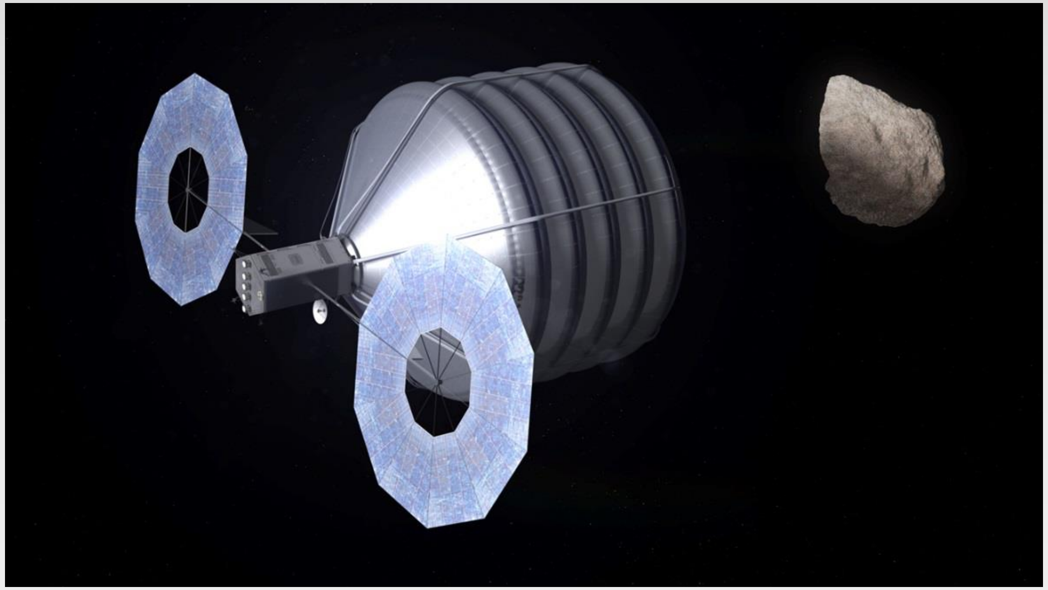
ISRU – Asteroids



Eros, the first asteroid to have it's picture taken by an orbiting craft in 2000 by NASA's NEAR mission

- Many classes of asteroids
- Metals (Ni, Fe, Pt, ???)
- Water
- Hydrocarbons
- Keck Asteroid Retrieval Feasibility Study recommends a carbonaceous C-type asteroid, containing up to 40% volatiles
- Produce fuel and structures
  - Heat shields
  - Turn an asteroid into a spacecraft!

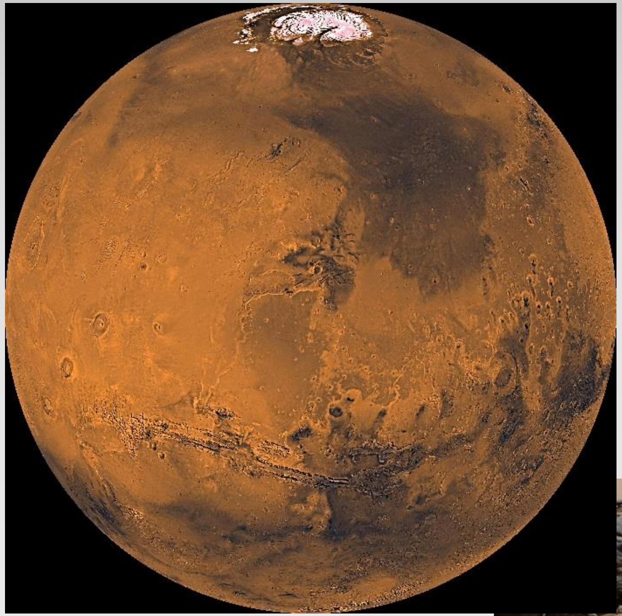
ISRU – Asteroids



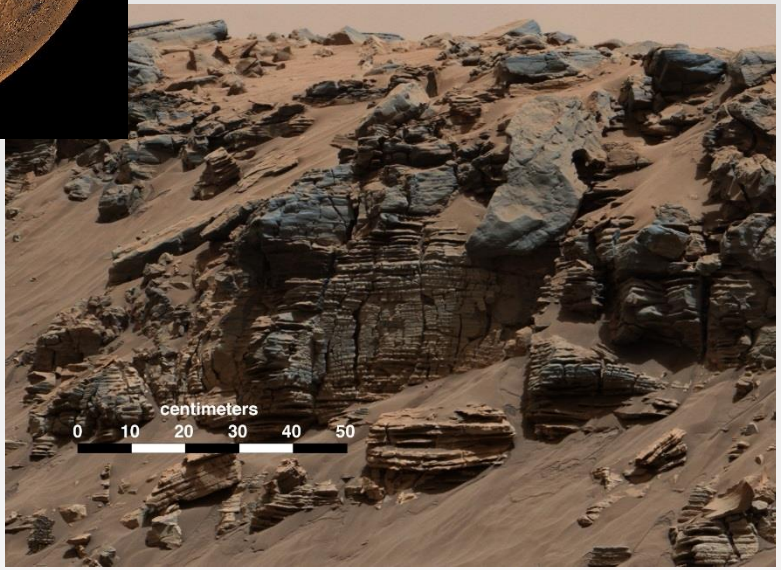
Concept for NASA’s Asteroid Redirect Mission: Robotic vehicle capturing an asteroid

Concept for NASA’s Asteroid Redirect Mission: Astronaut collecting samples

ISRU – Mars



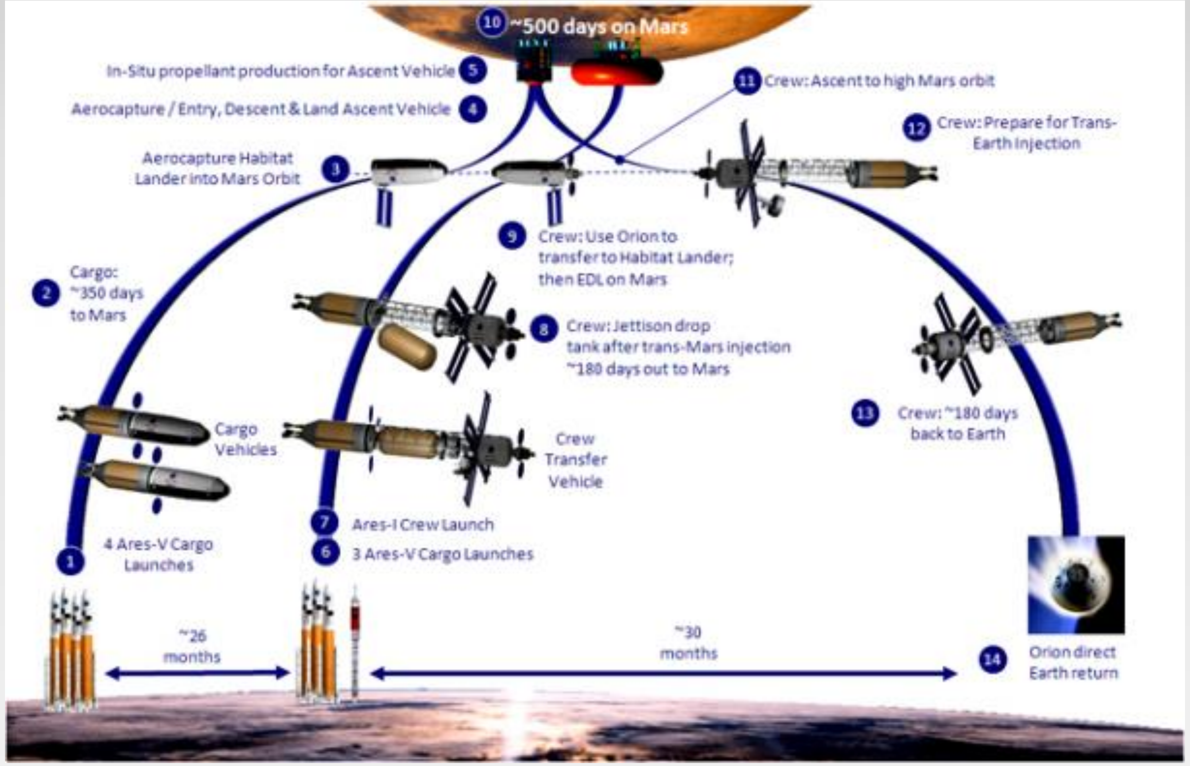
Mosaic of Mars taken during the Viking mission



Sedimentary rocks taken by NASA's curiosity rover

- Atmosphere of Mars
  - 96% CO_2; 2% Ar; 2% N_2
  - ~7 mbar (<1% Earth pressure)
- Water ice at poles, and up to 10% in the top meter of regolith

ISRU – Mars



- ISRU: Atmosphere only; solid oxide electrolysis

$$2CO_2 \rightarrow 2CO + O_2$$

- ISRU: Atmosphere and soil processing

$$Regolith + heat \rightarrow H_2O$$
$$H_2O \rightarrow H_2 + O_2$$
$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

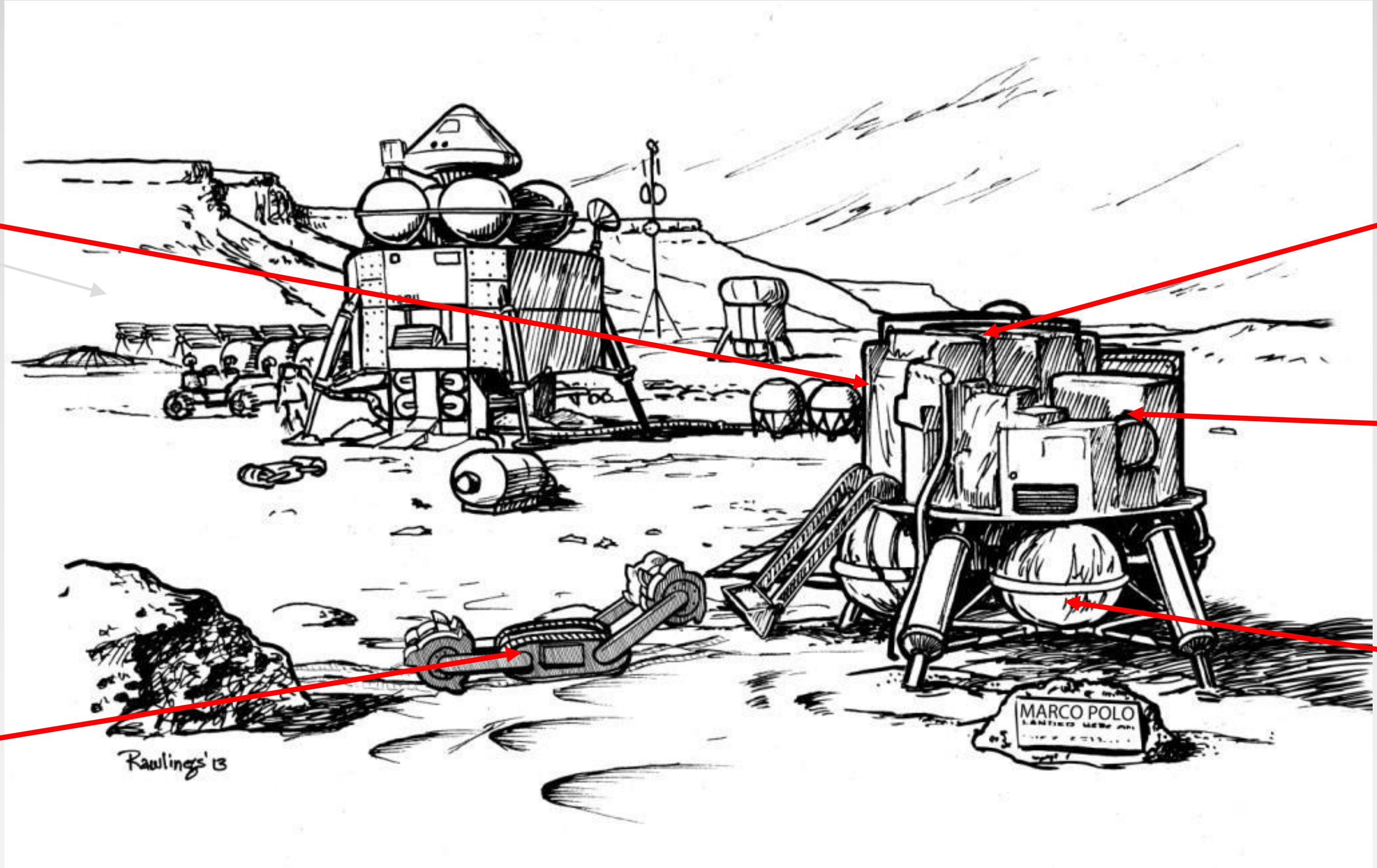
MARCO POLO: Mars Atmosphere and Regolith Collector/PrOcessor for Lander Operations

Oven

$Regolith + heat \rightarrow H_2O$

Electrolysis unit

$H_2O \rightarrow H_2 + O_2$



Atmospheric Processing Module (APM)

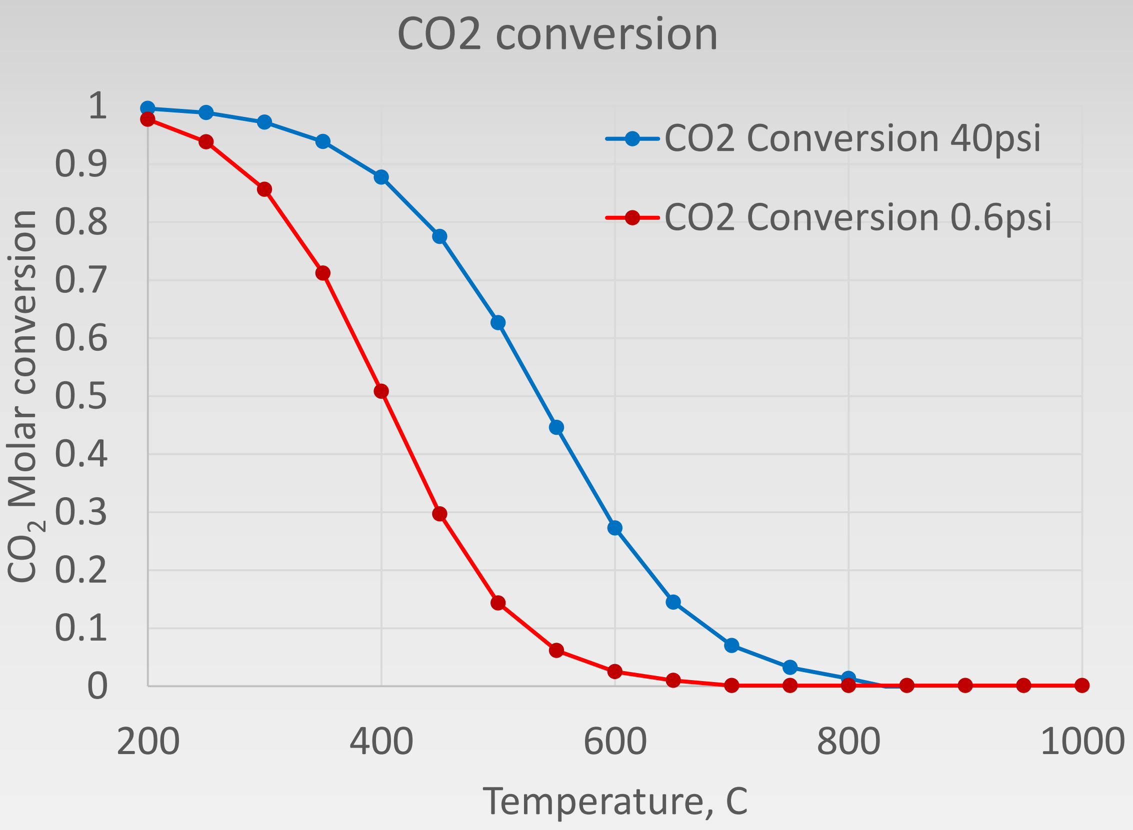
$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

Rover collecting regolith

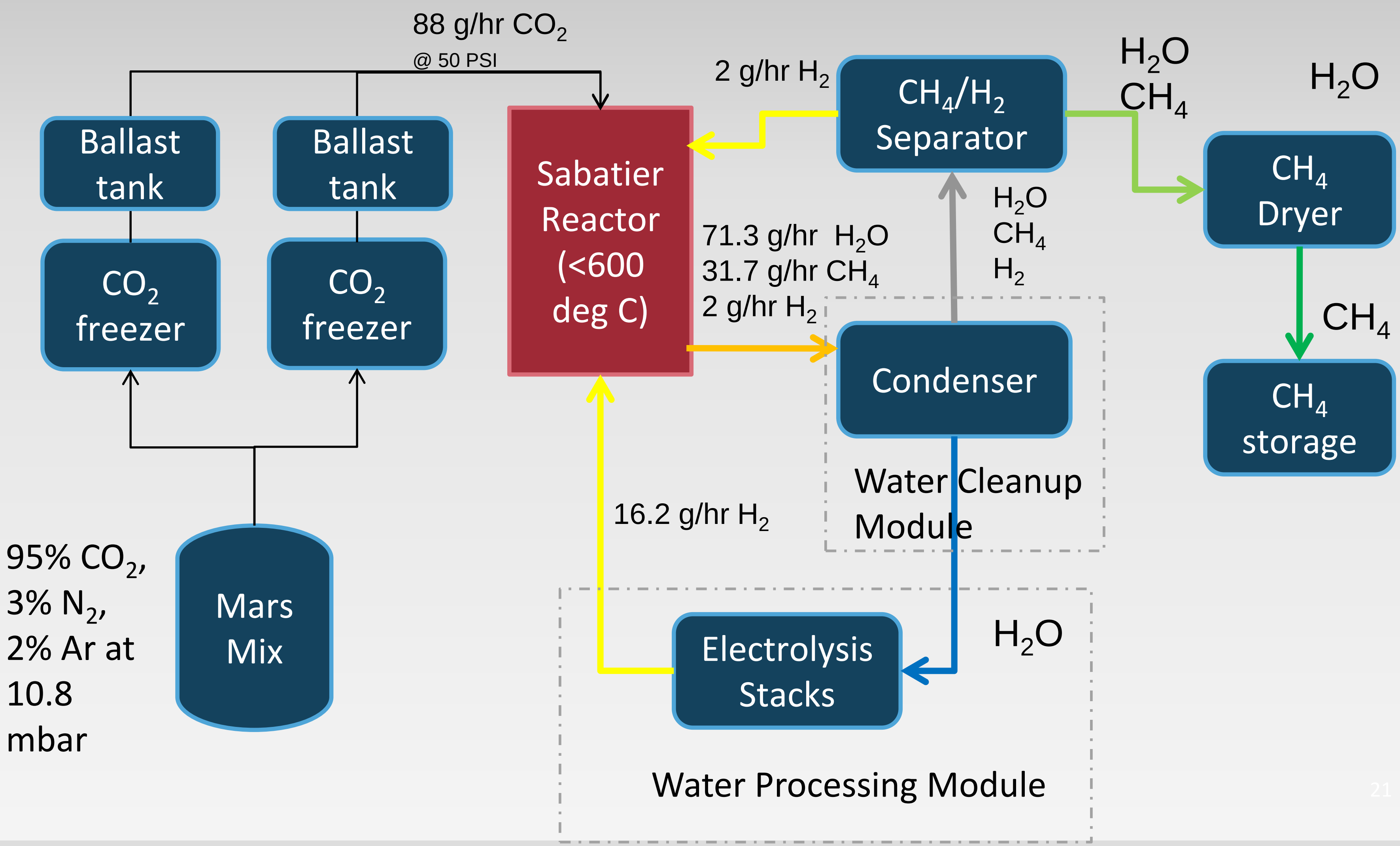
Fuel storage

MARCO POLO: APM

- $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$
- Why is this challenging?
  - Conversion to methane not as favorable at Mars atmospheric pressure
  - Methane production rate low if carbon dioxide is not compressed
  - Thermal management

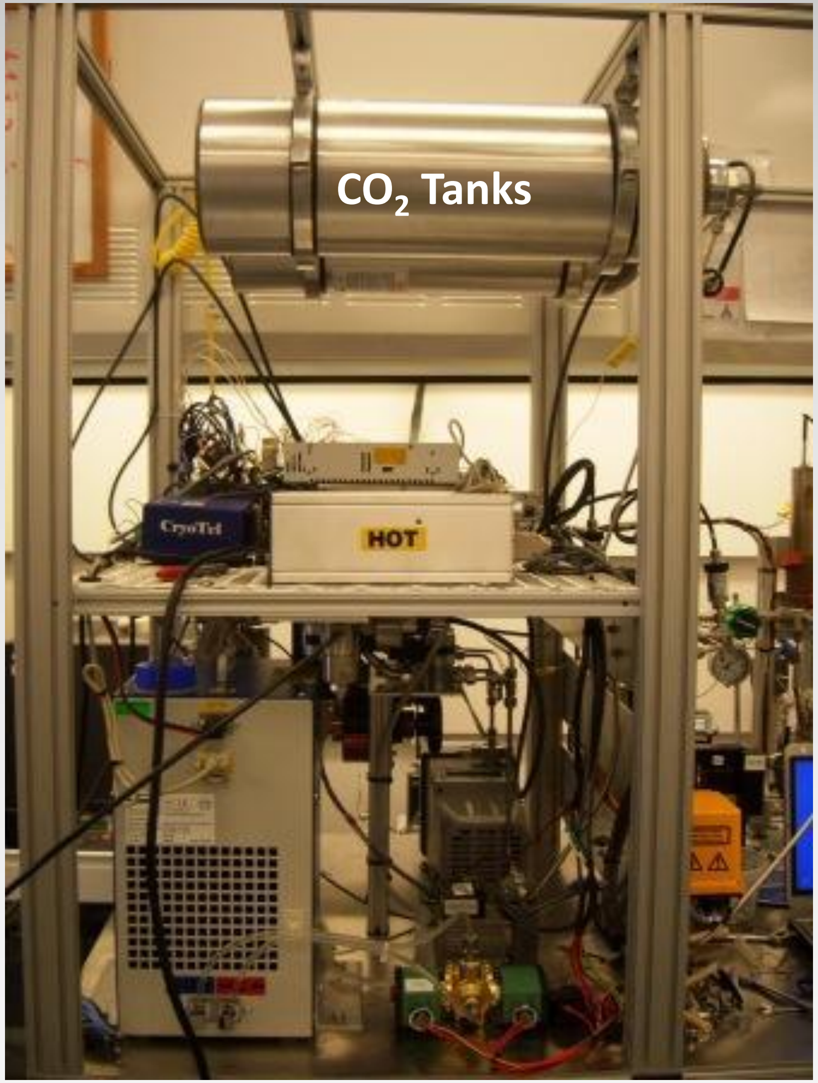


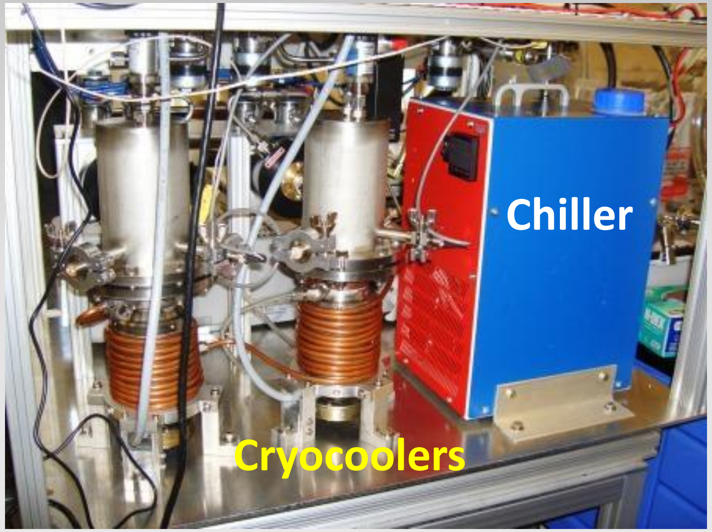
MARCO POLO: APM

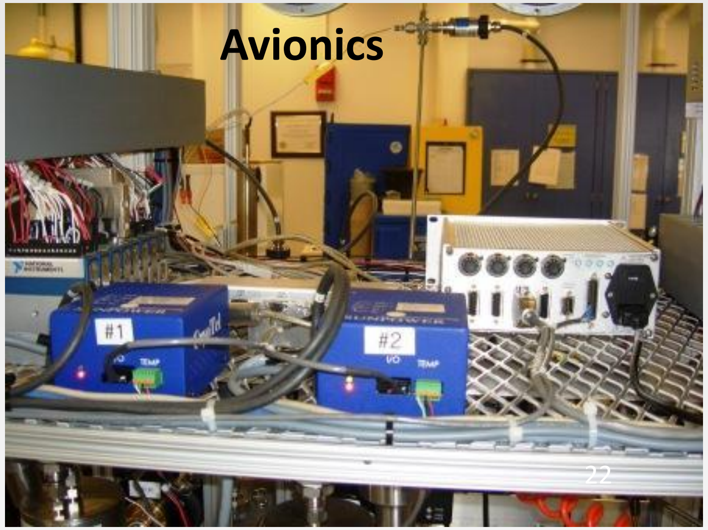


CO2 Freezer


Copper Cold Head

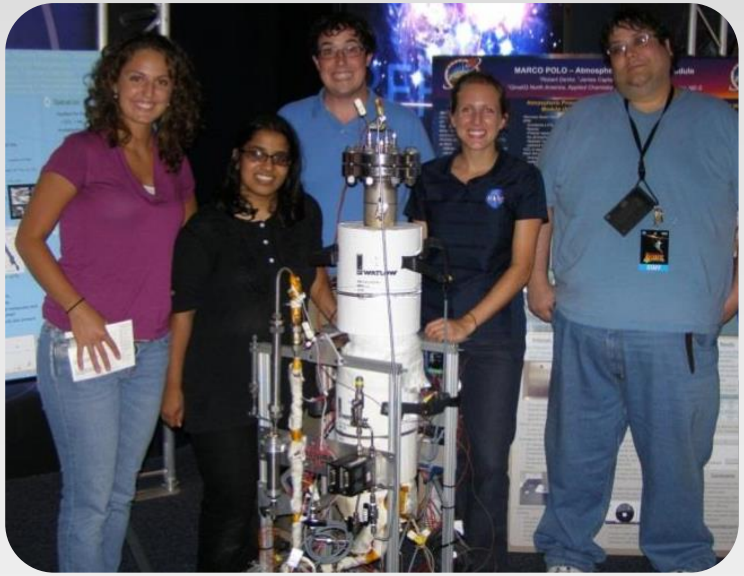






Trash to Gas

- The Trash to Gas project is a three-year study meant to develop promising trash processing technologies for future spaceflight missions
- Years one and two focused on developing five different technologies and selecting the most promising from among:
  - Catalytic Wet Air Oxidation
  - Incineration/Gasification
  - Ozone Oxidation
  - Pyrolysis
  - Steam Reforming
- Year three is focused on refining the most promising technology



Incineration/Gasification Team at Kennedy Space Center

Trash to Gas Benefits

- Stabilization of all combustible waste, including human wastes
- Volume reduction of stored waste
- Production of water for life support and/or propellants

Shuttle mission waste

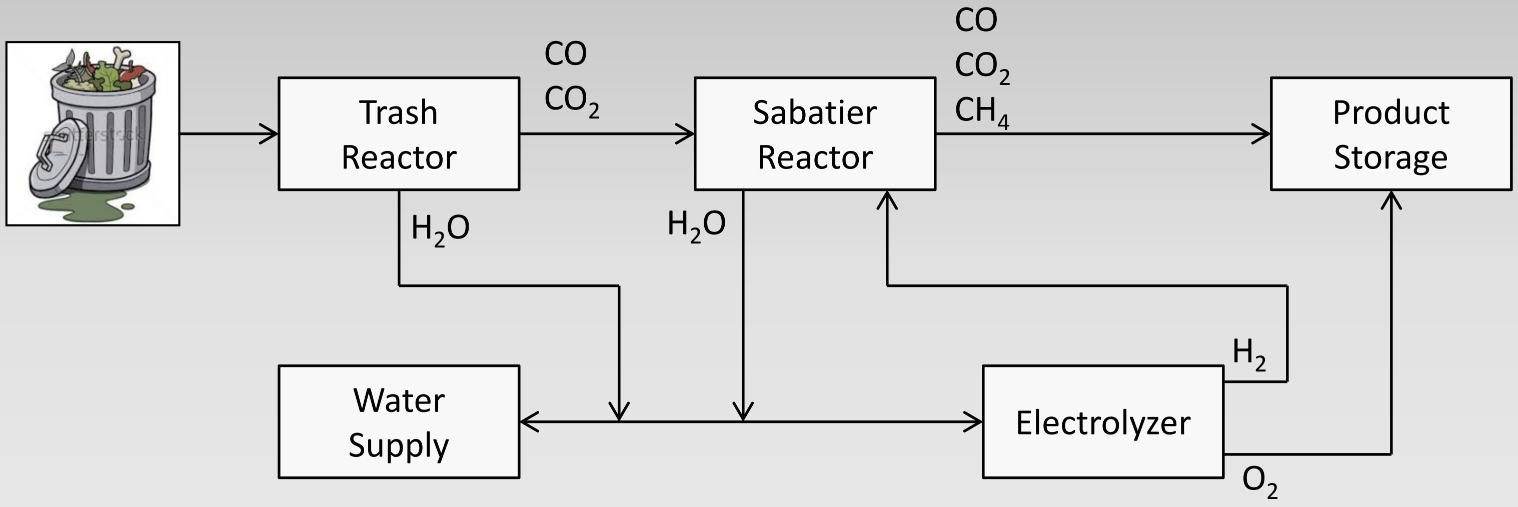
Food waste ‘football’

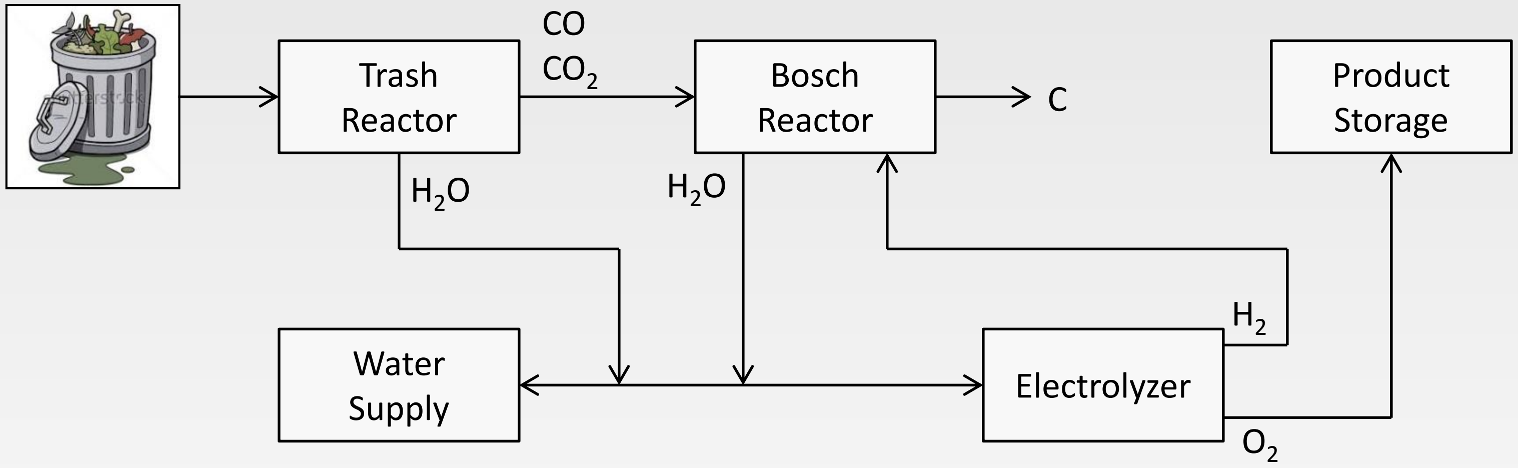
Oxygen

Water

Methane

Trash to Gas Benefits





- *Steam Reforming*

$$C_6H_{10}O_5 + 6O_2 \rightarrow 6CO_2 + 5H_2O$$
$$C_6H_{10}O_5 + H_2O \rightarrow 6CO + 6H_2$$
$$CO + H_2O \rightarrow CO_2 + H_2$$

- Sabatier/Methanation Reaction

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$
$$CO + 3H_2 \rightarrow CH_4 + H_2O$$

- Bosch Reaction

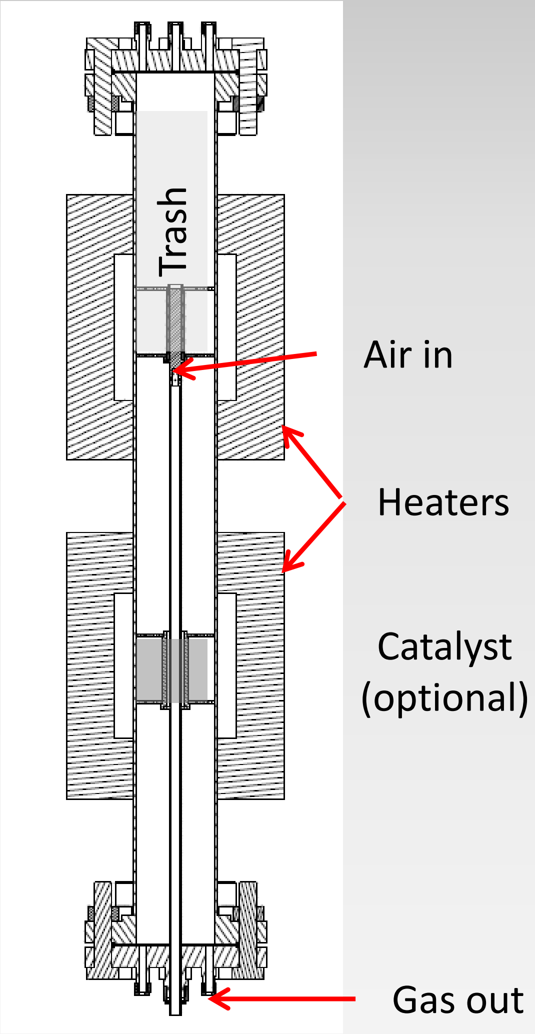
$$CO_2 + H_2 \rightarrow CO + H_2O$$
$$2CO \rightarrow CO_2 + C$$
$$CO_2 + 2H_2 \rightarrow C + 2H_2O$$

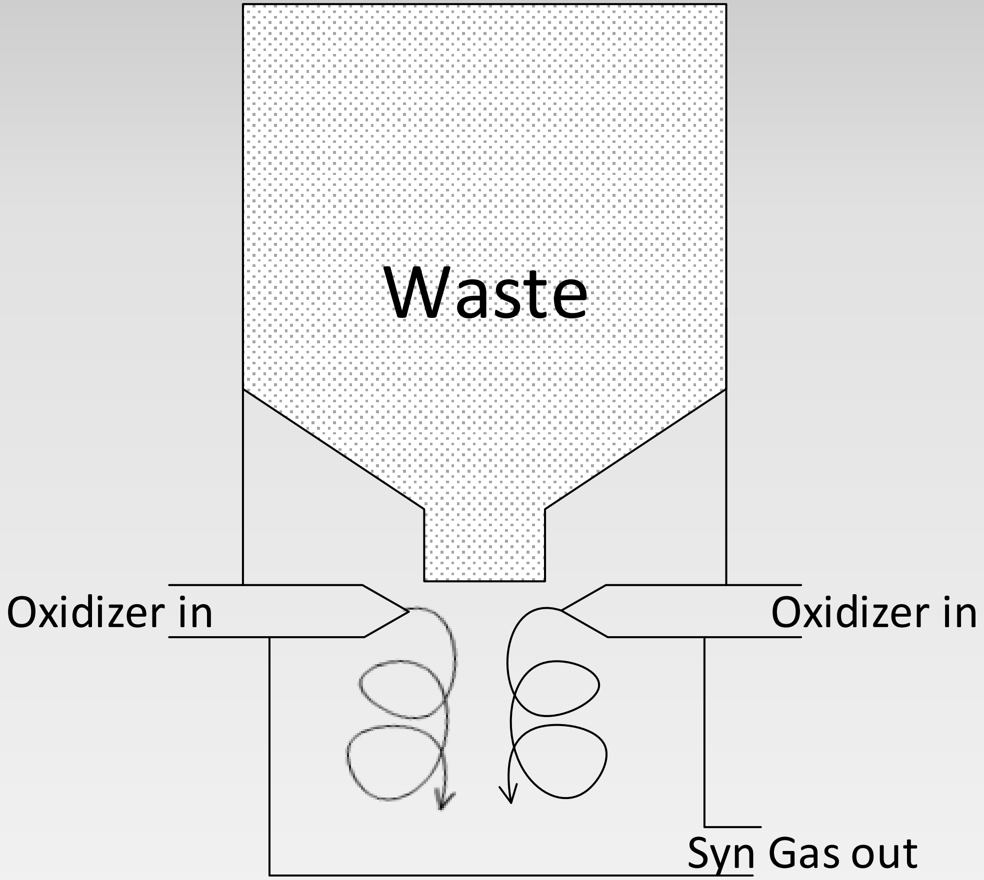
Trash to Gas Benefits

	Amount produced (+) or consumed (-), kg/yr						
	CH_4	CO_2	CO	O_2	H_2O	C_{solid}	H_2
Case 1 with Sabatier (maximize water recovery)	870	922	586	0	267		
Case 1 with Bosch (maximize water recovery)	--	--	--	--	3087	1155	96
Case 2 (maximize methane production)	1539	--	--	2317	-1210	--	--
No Conversion of solid waste with Sabatier	302	630	--	--	-127	--	--
No Conversion of solid waste with Bosch	--	--	--	--	1069	399	19

Trash to Gas: Microgravity Challenges

KSC Reactor



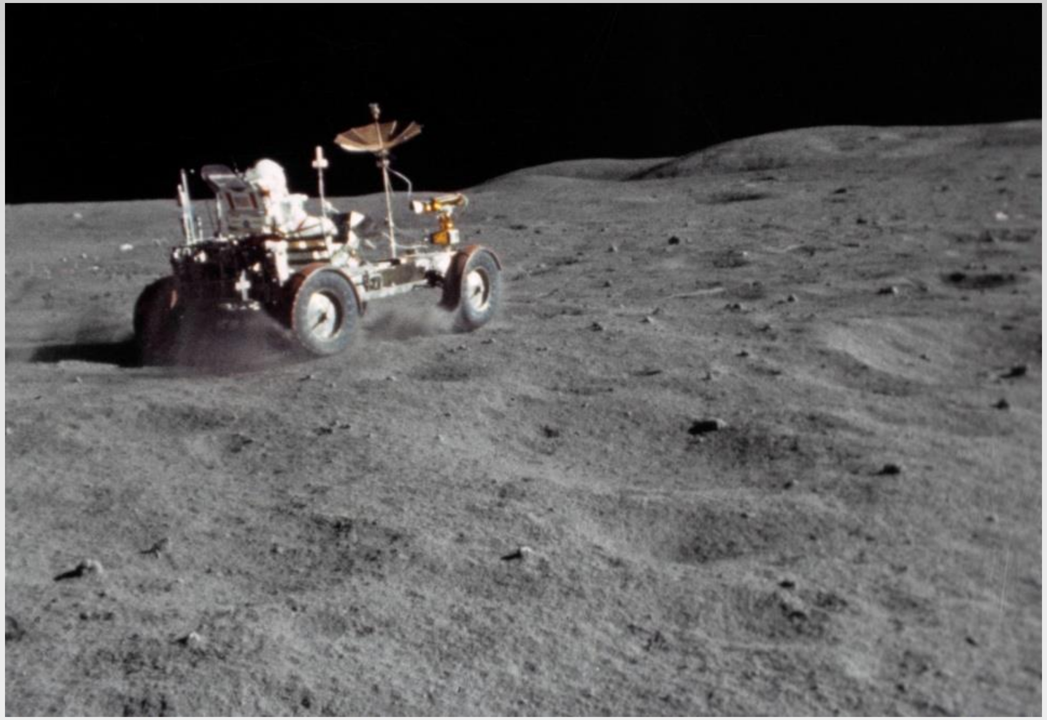


Downdraft gasifier

Trash to Gas: Microgravity Challenges

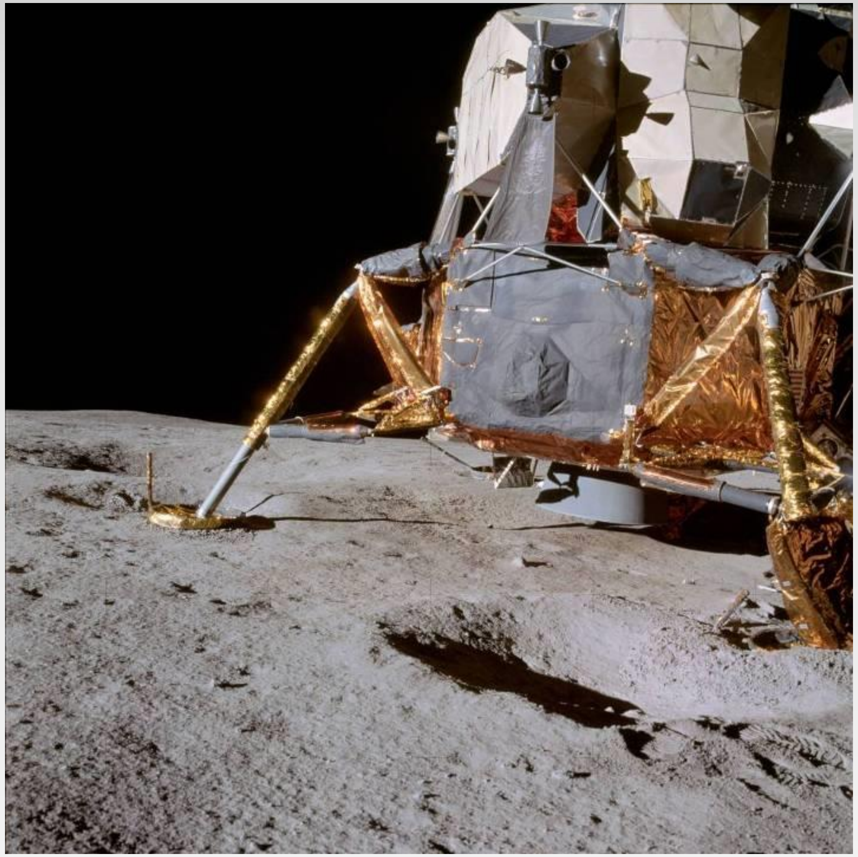
Building Materials in Space

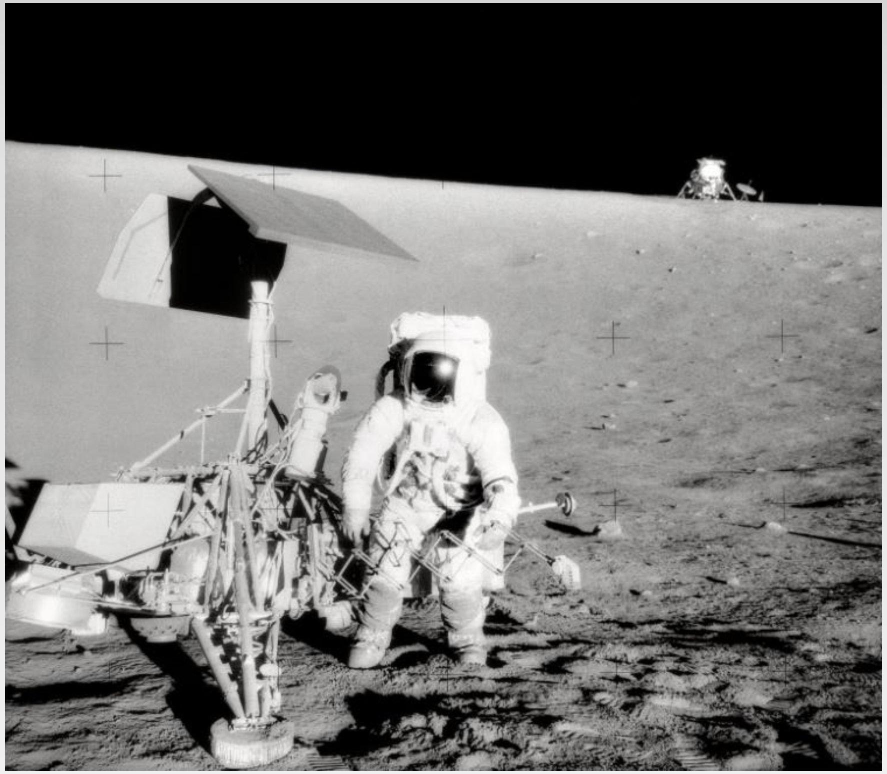
- Dust ejecta during lunar launch/landing can affect visibility, erode nearby coated surfaces and get into mechanical assemblies of in-place infrastructure
- Dust mitigation will be necessary for certain areas of the lunar habitat
- Surface stabilization can be used for roads, launch pads and other dust free areas



John Young, Photo S72_37002

Building Materials in Space

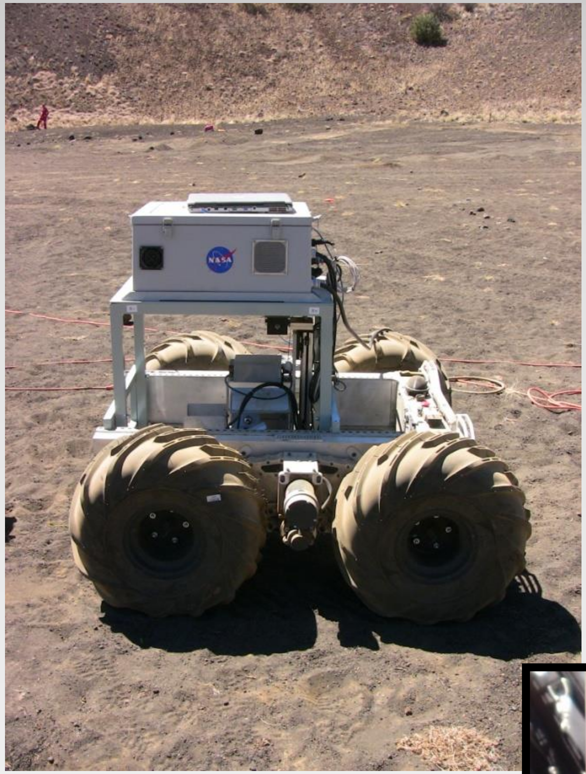




Charles Conrad Jr. and Surveyor III

Building Materials in Space

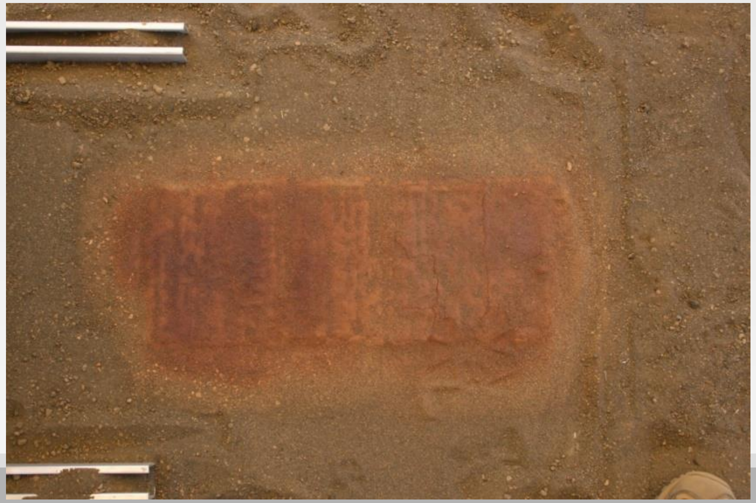
Cave in Hawaii used for shelter

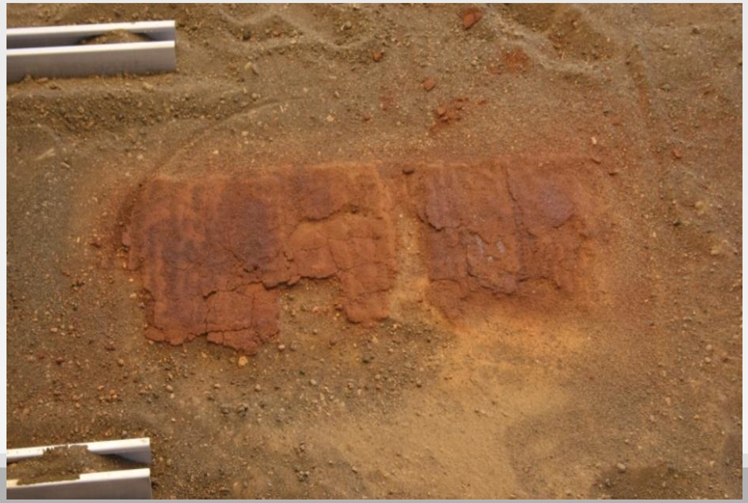


Large Area Surface Sintering System (LASSS) used to sinter the volcanic soil in Hawaii

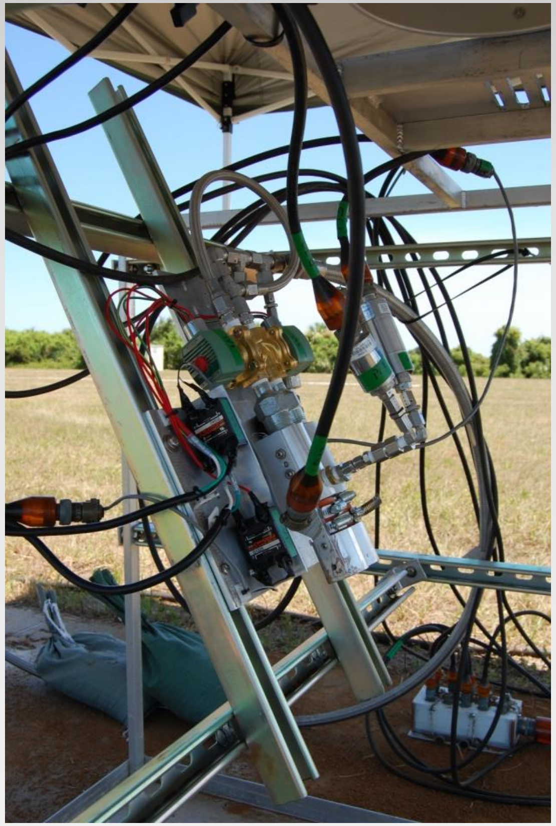
Building Materials in Space

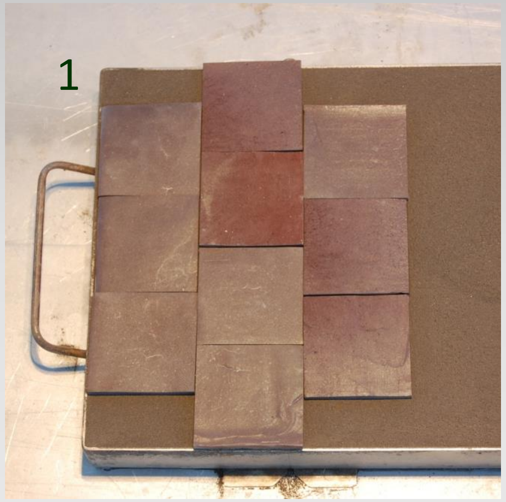
- Able to layer tephra and connect sintered areas
- Strengths from 30 – 240 psi
- Fired thruster on sintered area
- Environmental conditions caused issues

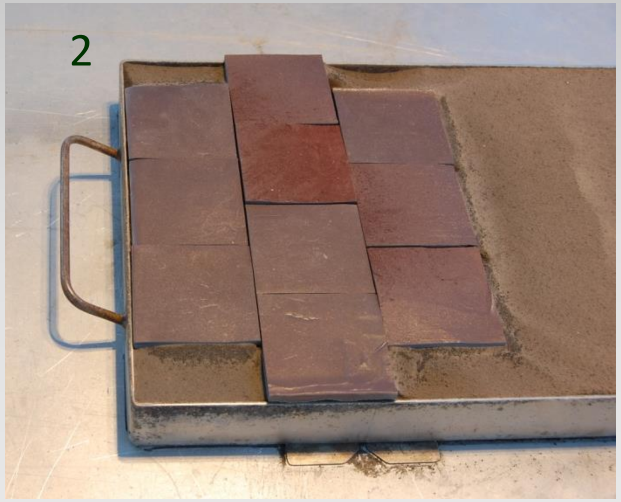




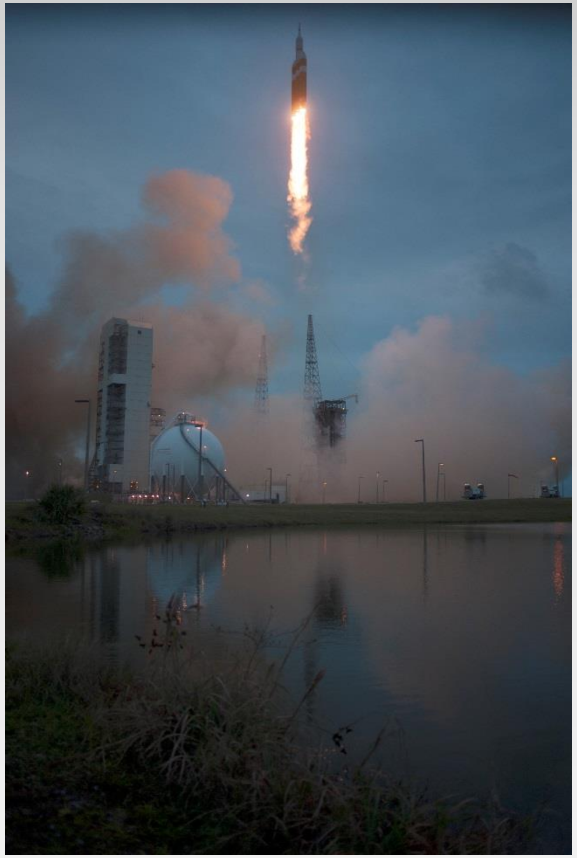
Building Materials in Space







Questions?



Orion lift off
Photo credit: NASA/Sandra Joseph and Kevin O'connell

The Orion floats in the Pacific with stabilizing balloons inflated as the USS Anchorage moves in to retrieve the spacecraft.