Microreactor System Design for NASA In Situ Propellant Production Plant on Mars

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Johnson Space Center, NASA

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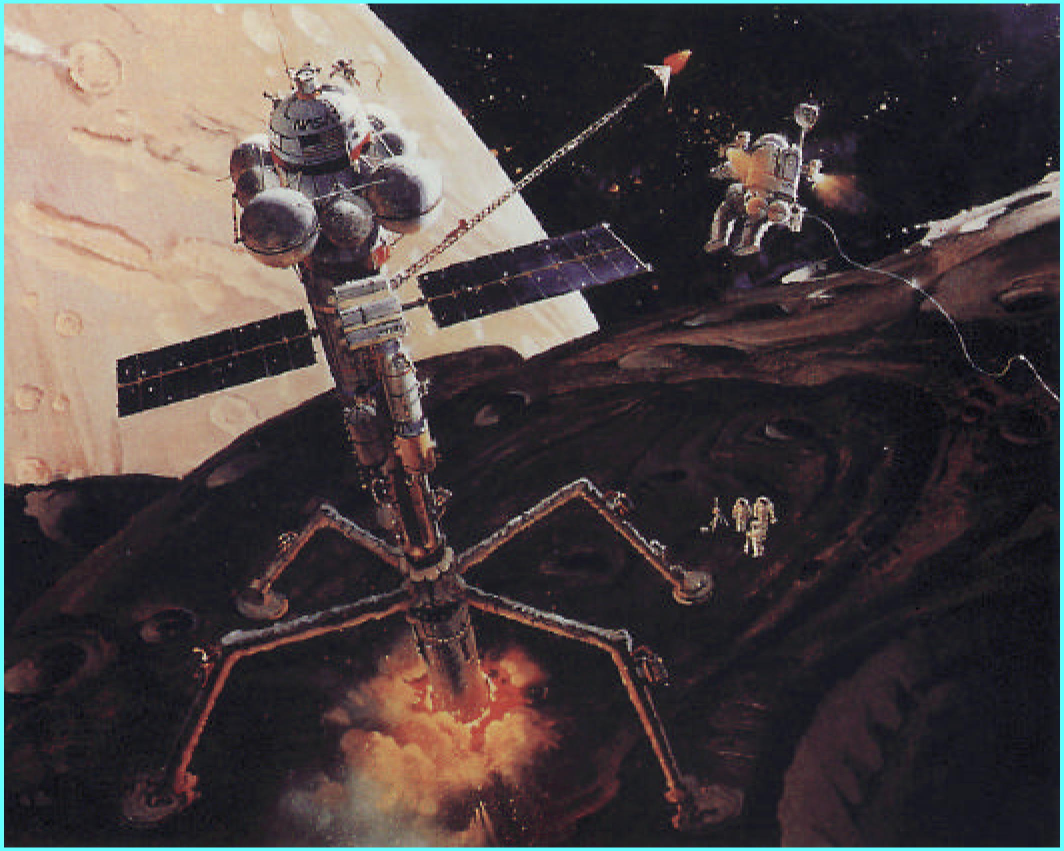
Human Exploration and Development of Space

In Situ Resource Utilization - "Living off the Land"



Consumable Production
Using "Natural Resources"

- Ascent Propulsion & Spacecraft Support
- Consumables for Planetary Rovers
- Environmental Control & Life Support System (ECLSS)
- Fuel Cell Power Generation
- Science Activities
- Construction & Manufacturing
- Commercial Applications

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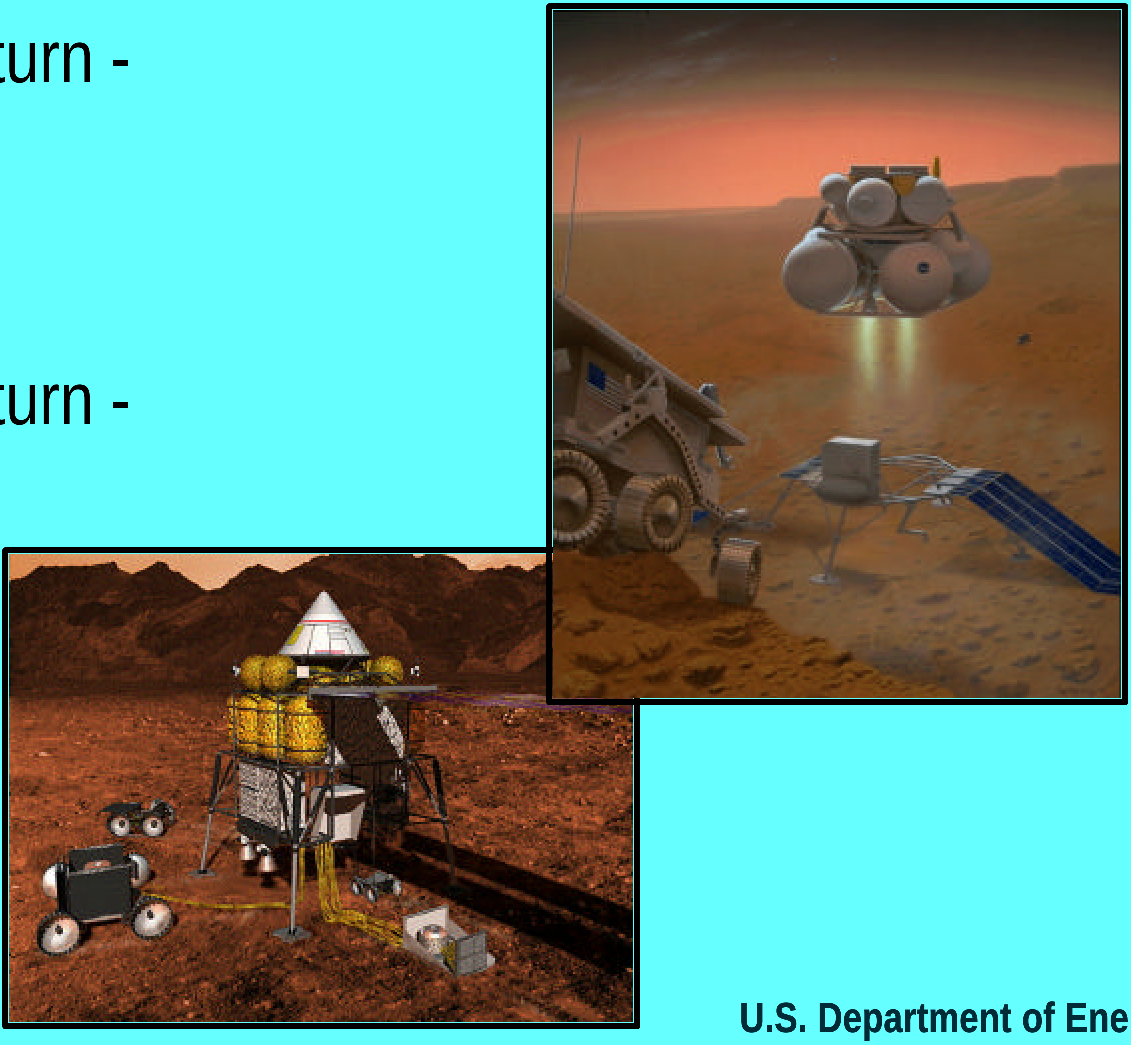
Overview

- Mission Scenarios
- In Situ Propellant Production
- Micro-ISPP Approach
- Size, Weight and Power Comparisons
- Conclusions

In Situ Propellant Production

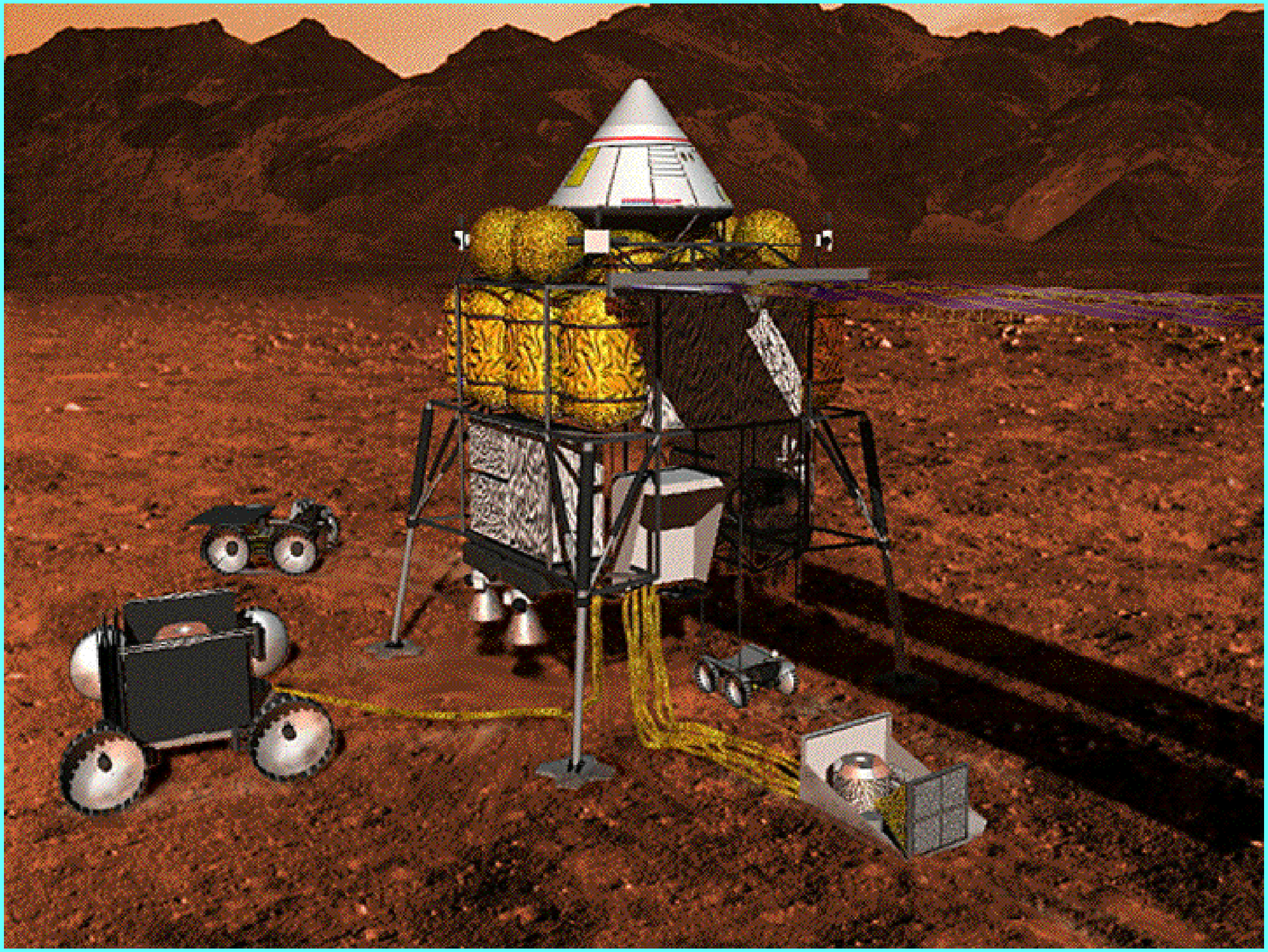
Three Mission Scenarios

- Robotic Sample Return - Orbital Rendezvous
- Robotic Sample Return - Direct Return
- Human Scale Mission -



Human Mission Scenario

Ascent vehicle arrives with ISPP plant



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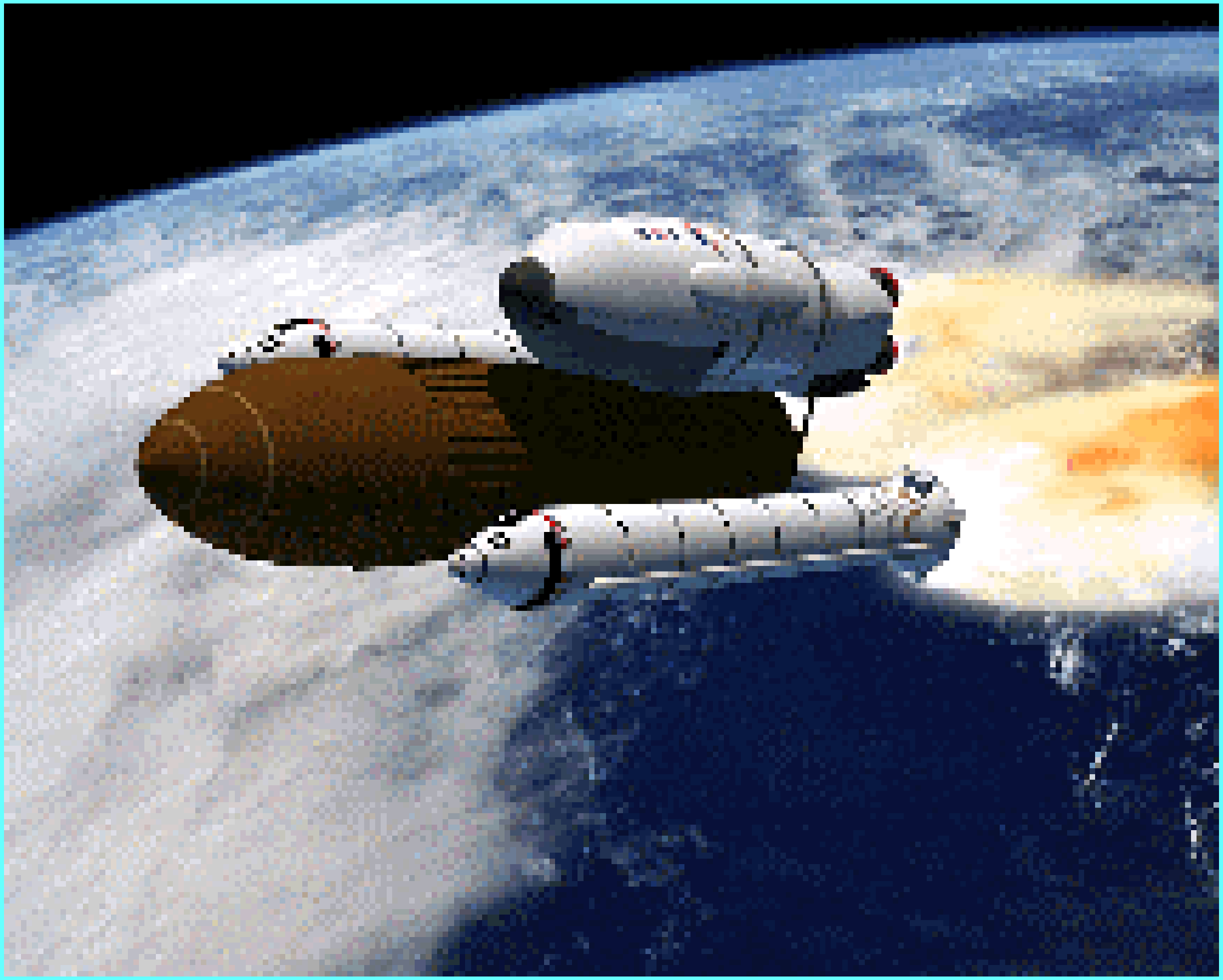
Human Mission Scenario

Astronauts leave 2 years later with propellant waiting on Mars



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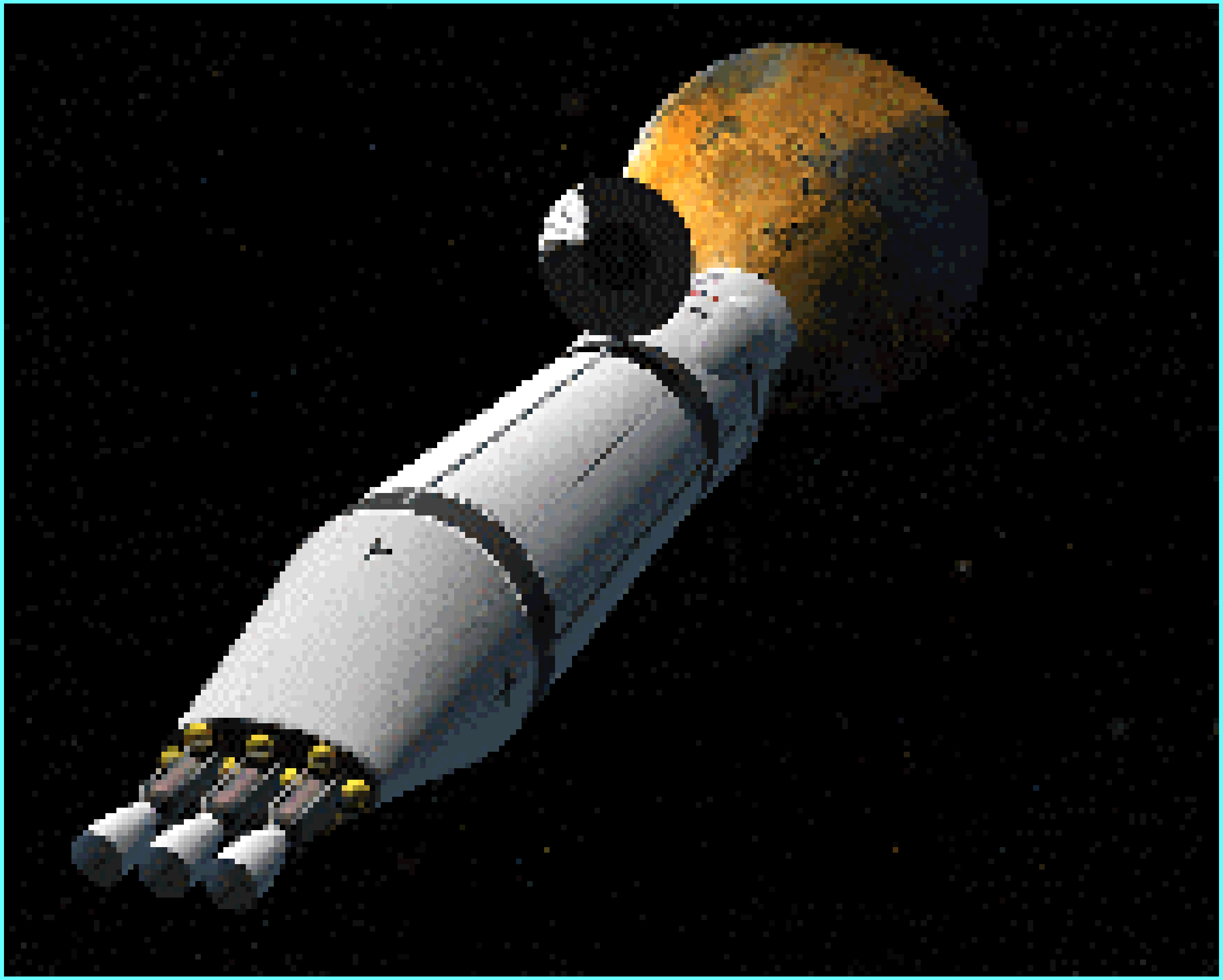
Human Mission Scenario

Astronauts take fast route to Mars



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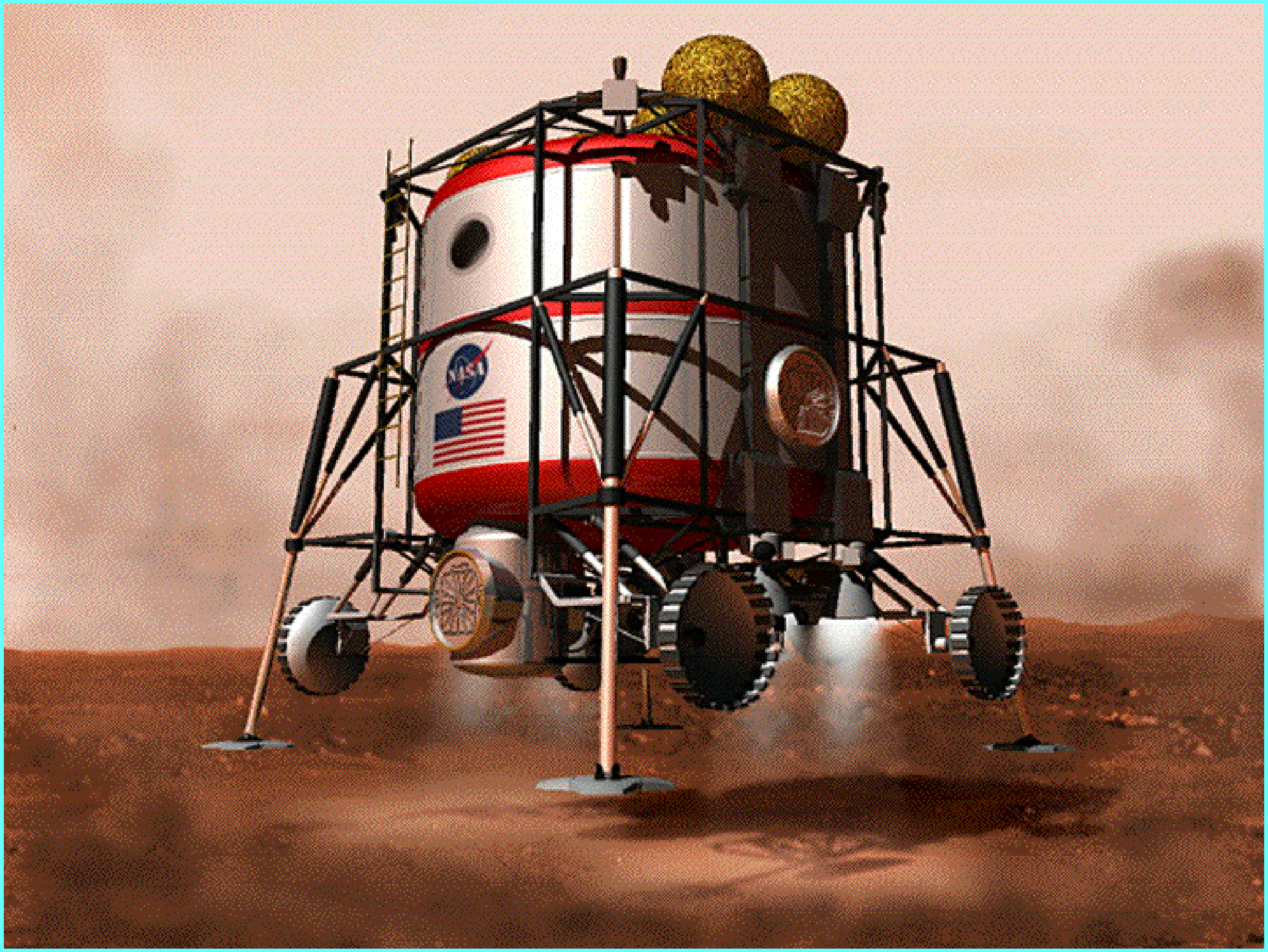
Human Mission Scenario

Astronauts spend up to 2 years on Mars



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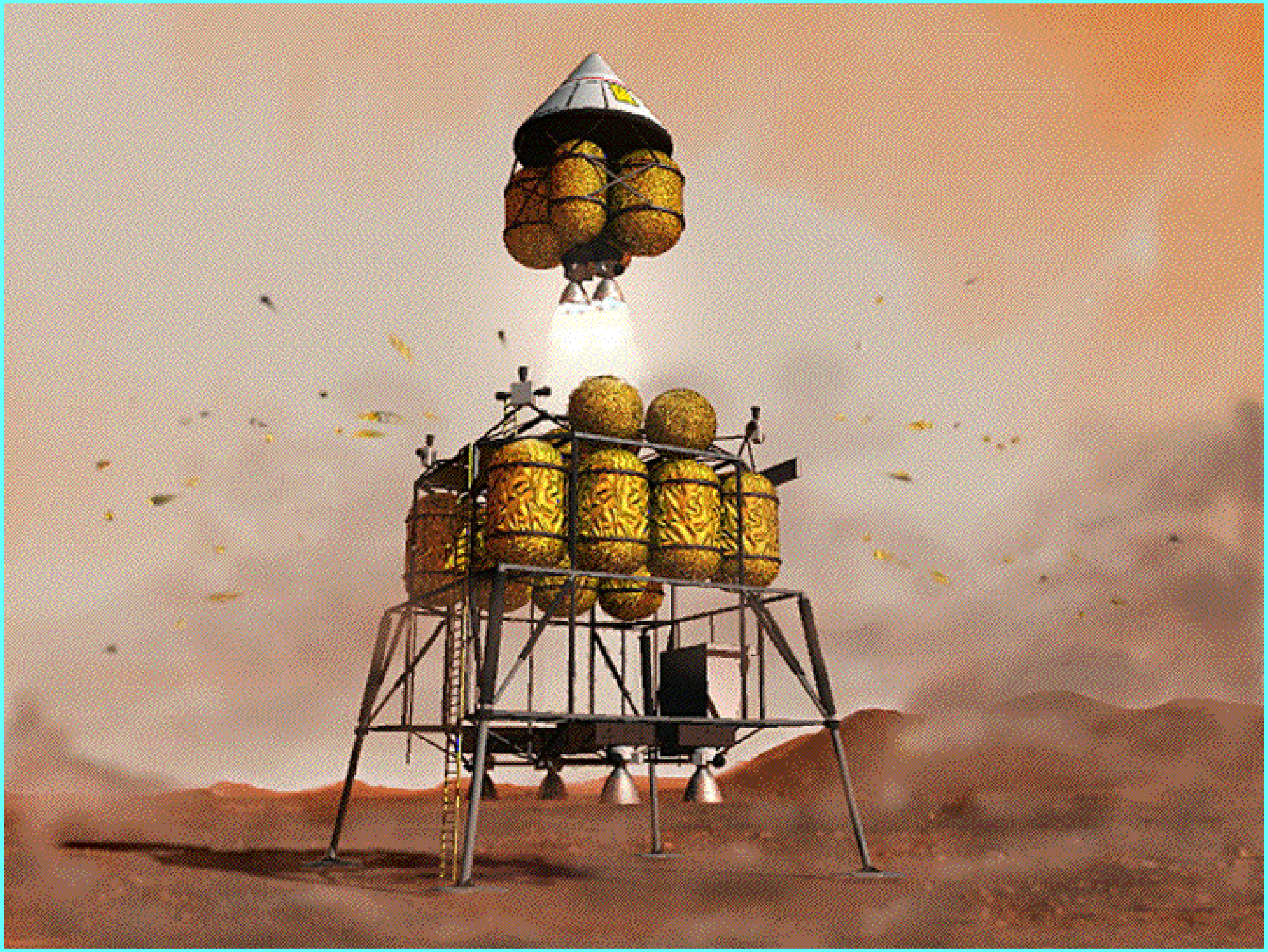
Human Mission Scenario

Astronauts Leave in Ascent Vehicle with ISPP propellants



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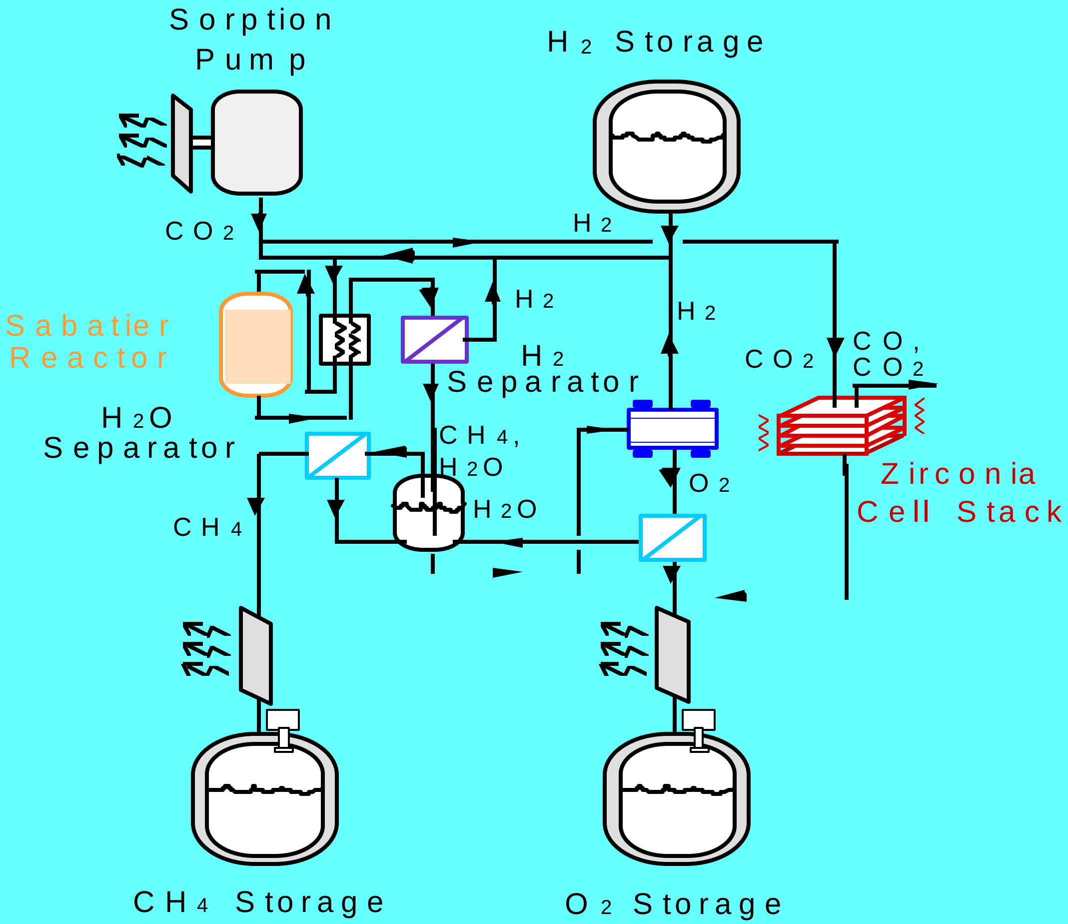
In Situ Propellant Production

Human Mission Scenario

- Ambient CO_2 available at 95%, 6-10 torr, and 150-270K
- Transport H_2 from Earth
- Chemical Conversion to Propellants for Ascent / Return
  - Collect and compress CO_2
  - Convert to propellants (CH_4 and O_2)
  - Cryogenic storage
- Production Requirements
  - 11,300 kg O_2 / 3000 kg CH_4
  - 300 Days, 24 hr/day
- Power Systems
  - Nuclear Reactor
- Mass Ratios Expected
  - Propellants / Hydrogen = 22
  - Propellants / (Hydrogen + ISRU plant) = 9.5

In Situ Propellant Production

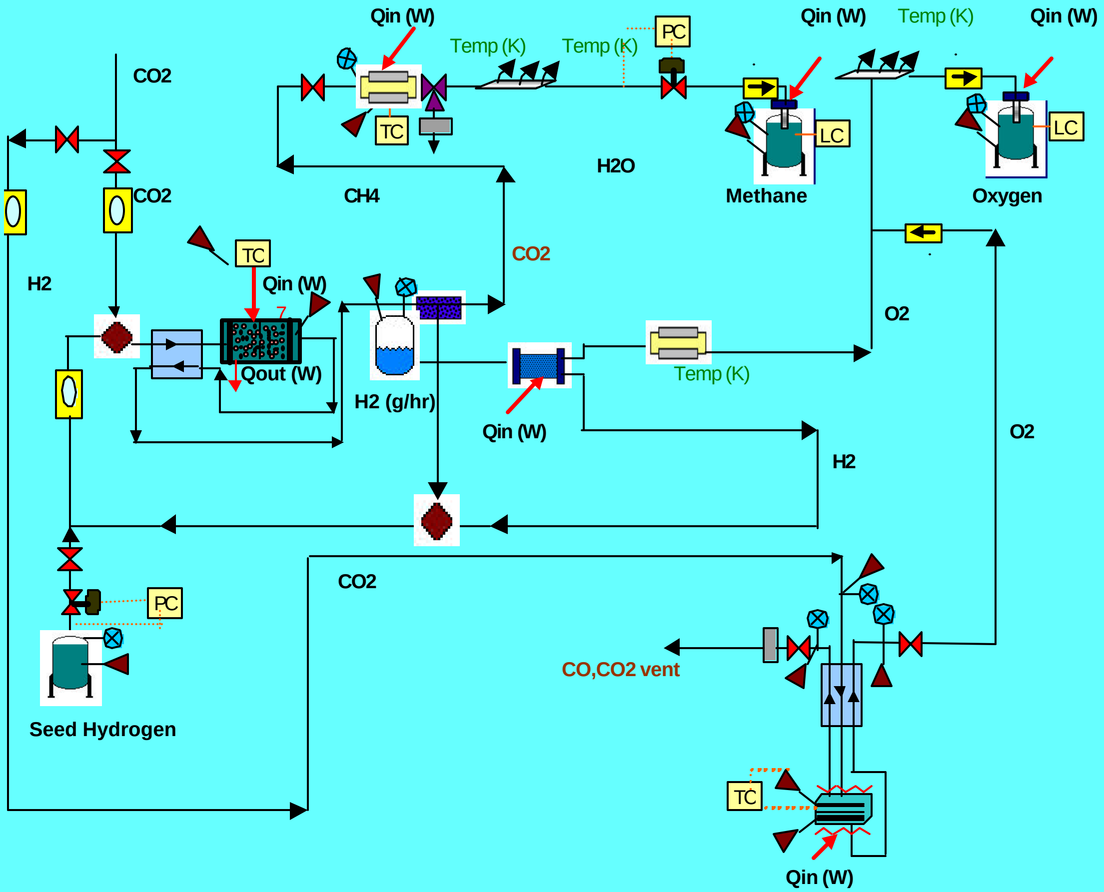
Baseline Flowsheet



- CO_2 compression
  - Mechanical Compression
  - Sorption Pump
  - Freeze - thaw
- Sabatier reactor
  - $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$
- Water Electrolysis
  - $2H_2O \rightarrow 2H_2 + O_2$
- Zirconia Cell
  - $2CO_2 \rightarrow 2CO + O_2$
- Separations
  - Nafion H_2 permeator
  - Sorption beds

In Situ Propellant Production

Baseline Flowsheet



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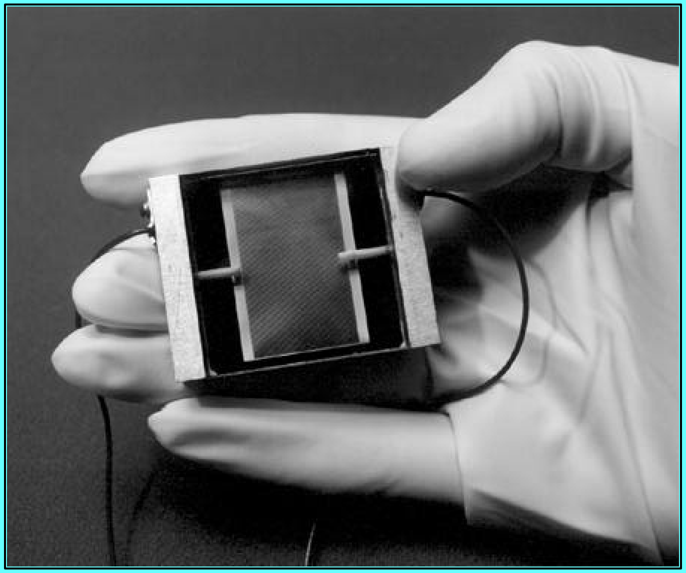
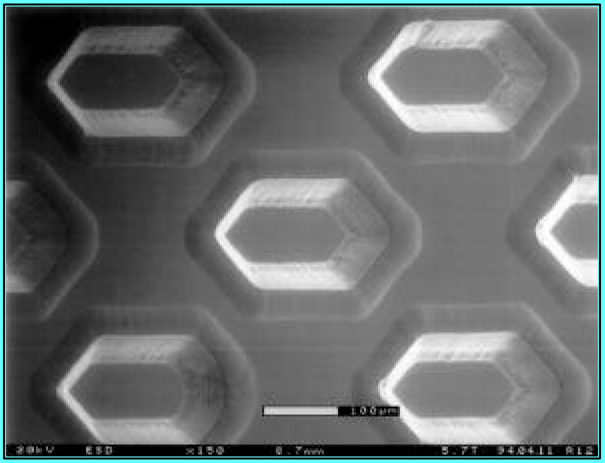
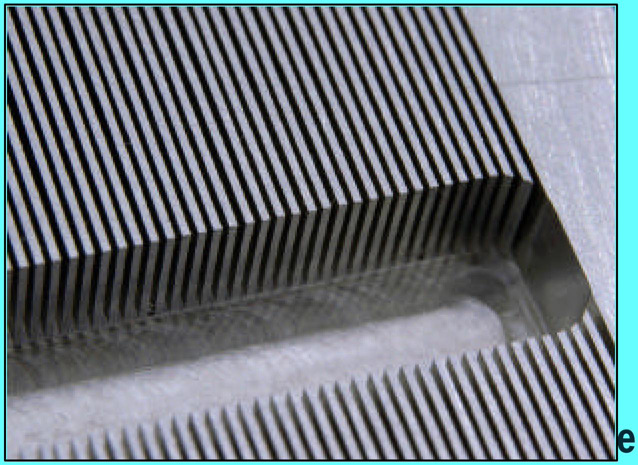
Microtechnology

- Microscale Advantages
  - Rapid heat/mass transport
  - Nonequilibrium chemical products
  - Surfaces forces
  - High productivity
- Compact Systems
- Integrated Systems
- Parallelism







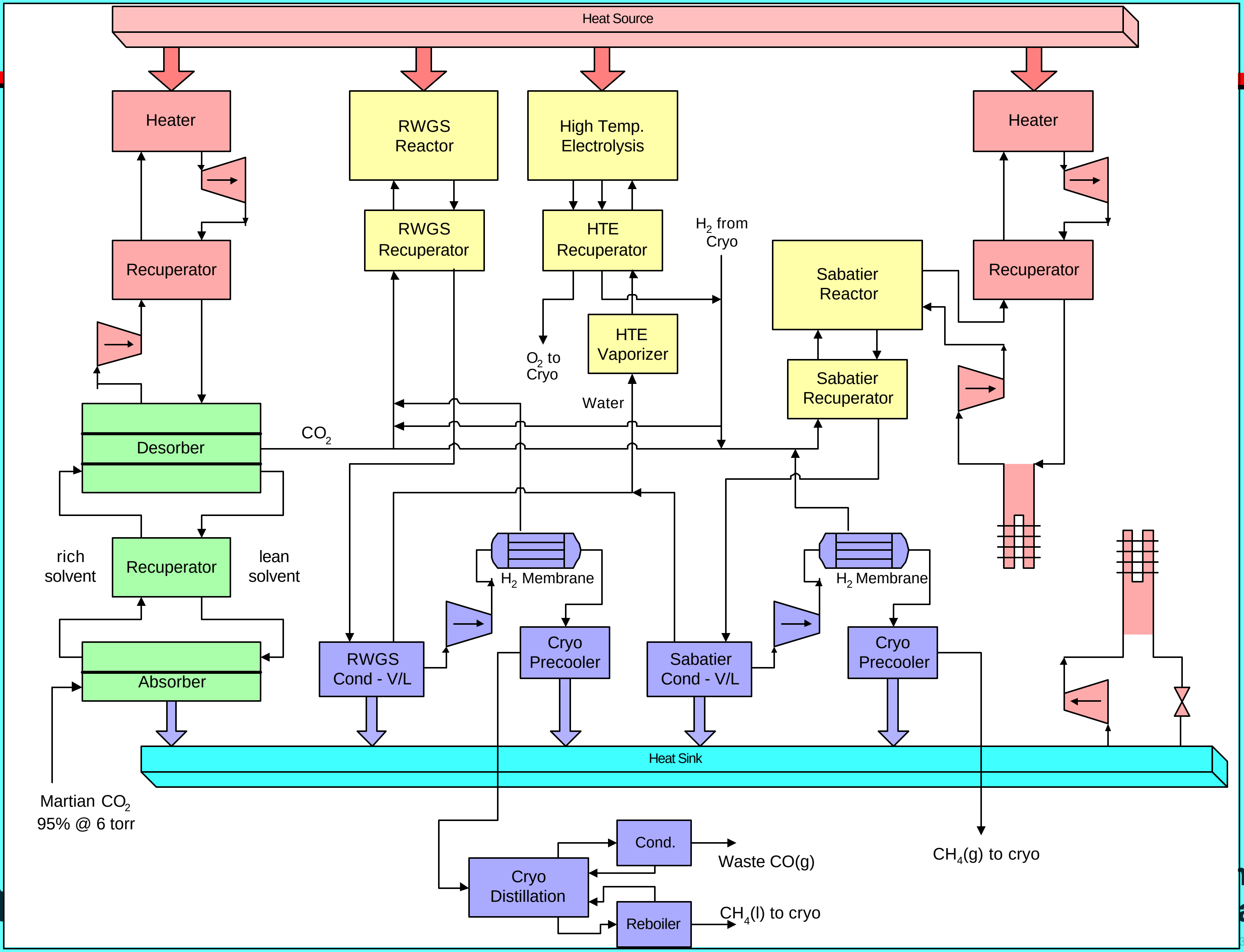
Micro-ISPP Approach

- Reduce Hardware Size and Mass?
- Better ISPP plant integration through energy cascading?
- Offer reliability advantages?
  - Parallelism reduces reliance on individual components.
  - Reduce redundancy requirements?
- Alternative power system options?
  - Heat driven process -- radioisotope?
  - Integration of power system and ISPP plant -- shared components?
  - Reduce power system size, weight, and heat rejection?

Micro-ISPP Approach

- Common high temperature heat source
- Preference for heat driven technologies over electrical
- Heat Integration
  - Energy cascading
  - Heat demand supplied by higher temperature waste heat
  - Cooling demand supplied by vapor compression heat pumps to common radiator

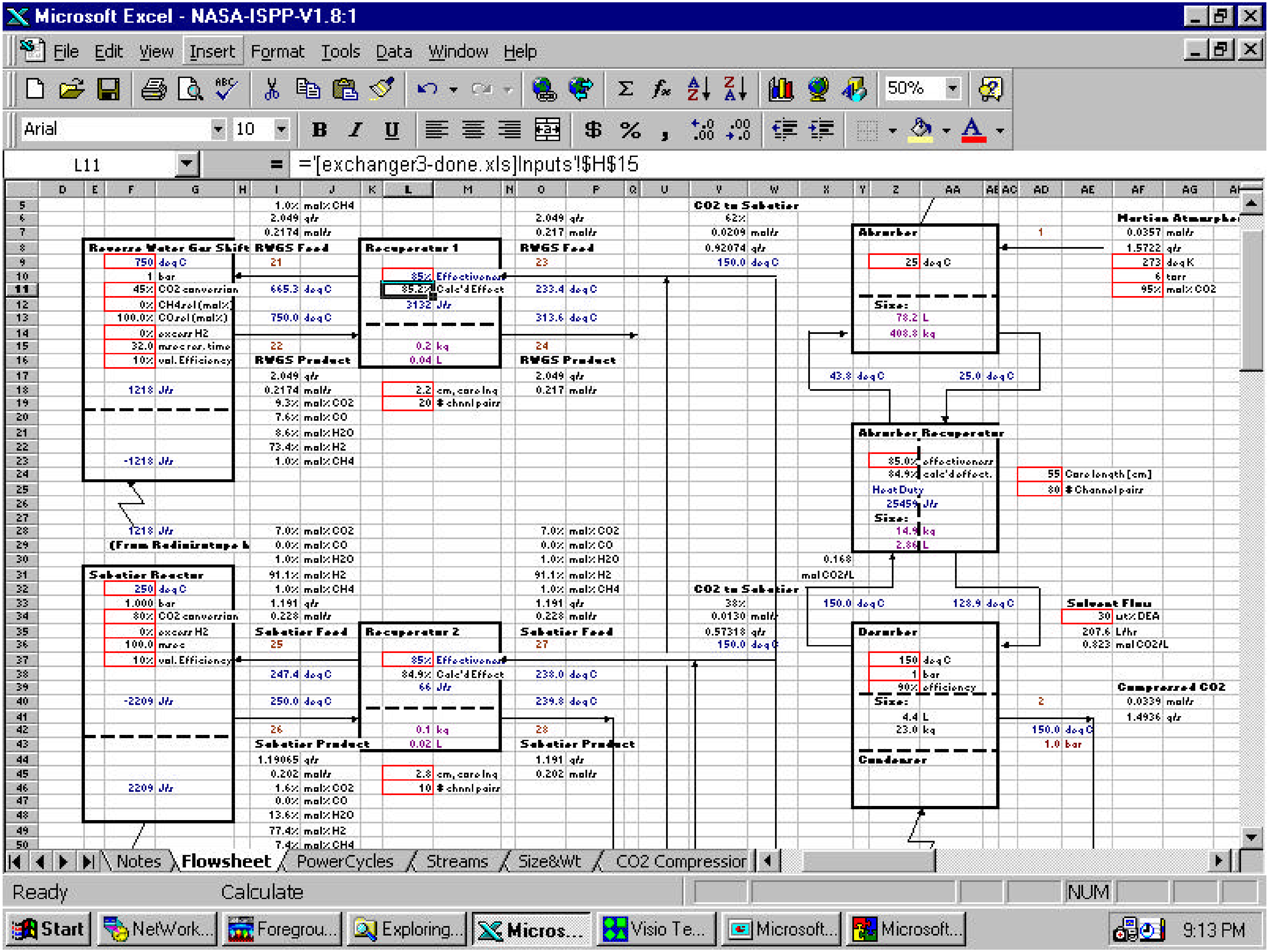
Micro-ISPP Flowsheet



Micro-ISPP Approach

Technology Selection

- CO_2 Compression
  - Thermochemical absorption cycle
  - Thermochemical adsorption cycle
  - Mechanical
  - Freeze-thaw cycle
- CH_4 Production
  - Sabatier reactor
- O_2 Production
  - Reverse water-gas shift reactor
  - Zirconia cell - CO_2 electrolysis
  - High temperature water electrolysis
  - Low temperature water electrolysis
- Separations
  - Condensation - phase separations
  - Polymeric membranes
  - Metallic membranes
  - PEM H_2 permeator
  - Cryogenic distillation
  - Sorption beds
- Heat Engines
  - Brayton cycle
  - Rankine cycle
  - Stirling cycle
- Heat Pumps
  - Vapor compression cycle
  - Reverse-Brayton cycle



='[exchanger3-done.xls]Inputs'!H15

1.0% mol% CH4
2.049 g/s
0.2174 mol/s

Reverse Water Gas Shift
750 deg C
1 bar
45% CO2 conversion
0% CH4sel(mol%)
100.0% COsel(mol%)
0% excess H2
32.0 msec res. time
10% vol. Efficiency
1218 J/s
-1218 J/s

1218 J/s
(From Radioisotope h

RWGS Feed
21
665.3 deg C
750.0 deg C
22

RWGS Product
2.049 g/s
0.2174 mol/s
9.3% mol% CO2
7.6% mol% CO
8.6% mol% H2O
73.4% mol% H2
1.0% mol% CH4

Recuperator 1
85% Effectiveness
85.2% Calc'd Effect
3132 J/s
0.2 kg
0.04 L
2.2 cm, core lng
20 # chnnl pairs

2.049 g/s
0.217 mol/s

RWGS Feed
23
233.4 deg C
313.6 deg C
24

RWGS Product
2.049 g/s
0.217 mol/s

CO2 to Sabatier
62%
0.0209 mol/s
0.92074 g/s
150.0 deg C

Absorber
25 deg C
Size:
78.2 L
408.8 kg

1

Martian Atmosphere
0.0357 mol/s
1.5722 g/s
273 deg K
6 torr
95% mol% CO2

43.8 deg C
25.0 deg C

Absorber Recuperator
85.0% effectiveness
84.9% calc'd effect.
Heat Duty
25459 J/s
Size:
14.9 kg
2.86 L

55 Core length [cm]
80 # Channel pairs

0.168
mol CO2/L

7.0% mol% CO2
0.0% mol% CO
1.0% mol% H2O
91.1% mol% H2
1.0% mol% CH4
1.191 g/s
0.228 mol/s

7.0% mol% CO2
0.0% mol% CO
1.0% mol% H2O
91.1% mol% H2
1.0% mol% CH4
1.191 g/s
0.228 mol/s

Sabatier Reactor
250 deg C
1.000 bar
80% CO2 conversion
0% excess H2
100.0 msec
10% vol. Efficiency
-2209 J/s
2209 J/s

Sabatier Feed
25
247.4 deg C
250.0 deg C
26

Sabatier Product
1.19065 g/s
0.202 mol/s
1.6% mol% CO2
0.0% mol% CO
13.6% mol% H2O
77.4% mol% H2
7.4% mol% CH4

Recuperator 2
85% Effectiveness
84.9% Calc'd Effect
66 J/s
0.1 kg
0.02 L
2.8 cm, core lng
10 # chnnl pairs

Sabatier Feed
27
238.0 deg C
239.8 deg C
28

Sabatier Product
1.191 g/s
0.202 mol/s

CO2 to Sabatier
38%
0.0130 mol/s
0.57318 g/s
150.0 deg C

150.0 deg C
128.9 deg C

Desorber
150 deg C
1 bar
90% efficiency
Size:
4.4 L
23.0 kg

Condenser

Solvent Flow
30 wt% DEA
207.6 L/hr
0.823 mol CO2/L

2

Compressed CO2
0.0339 mol/s
1.4936 g/s

150.0 deg C
1.0 bar

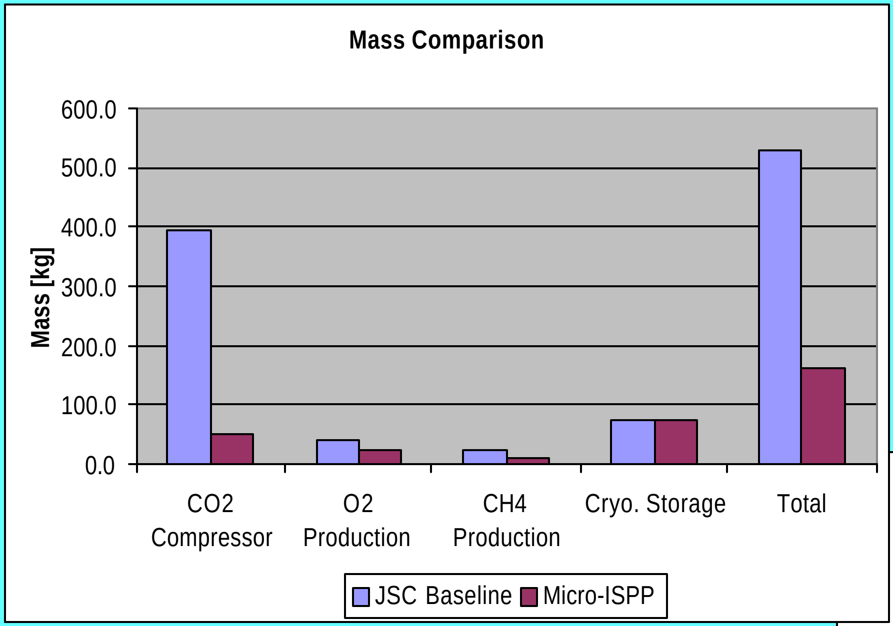
Mars ISPP Plant

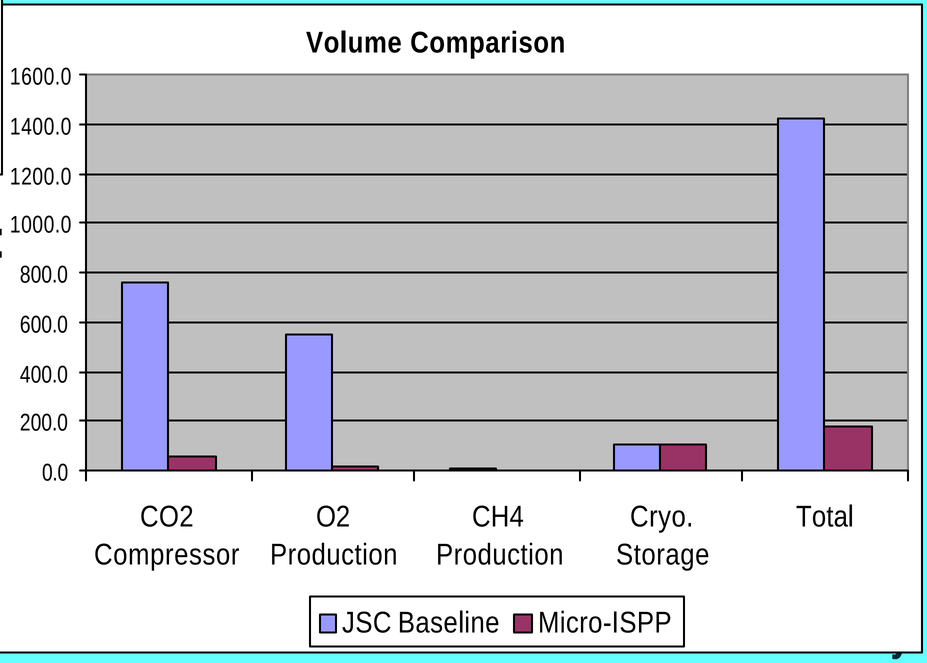
Size, Weight and Power Comparisons

- Qualifications:
  - Zirconia cell power requirement uncertain.
  - Micro-ISPP water electrolysis technologies based on emerging fuel cell technologies - size is projected.
  - Suitability of plastic for low temperature micro-ISPP components?
  - JSC Human Mission baseline evolving from mechanical compression to freeze-thaw cycle.

Mars ISPP Plant

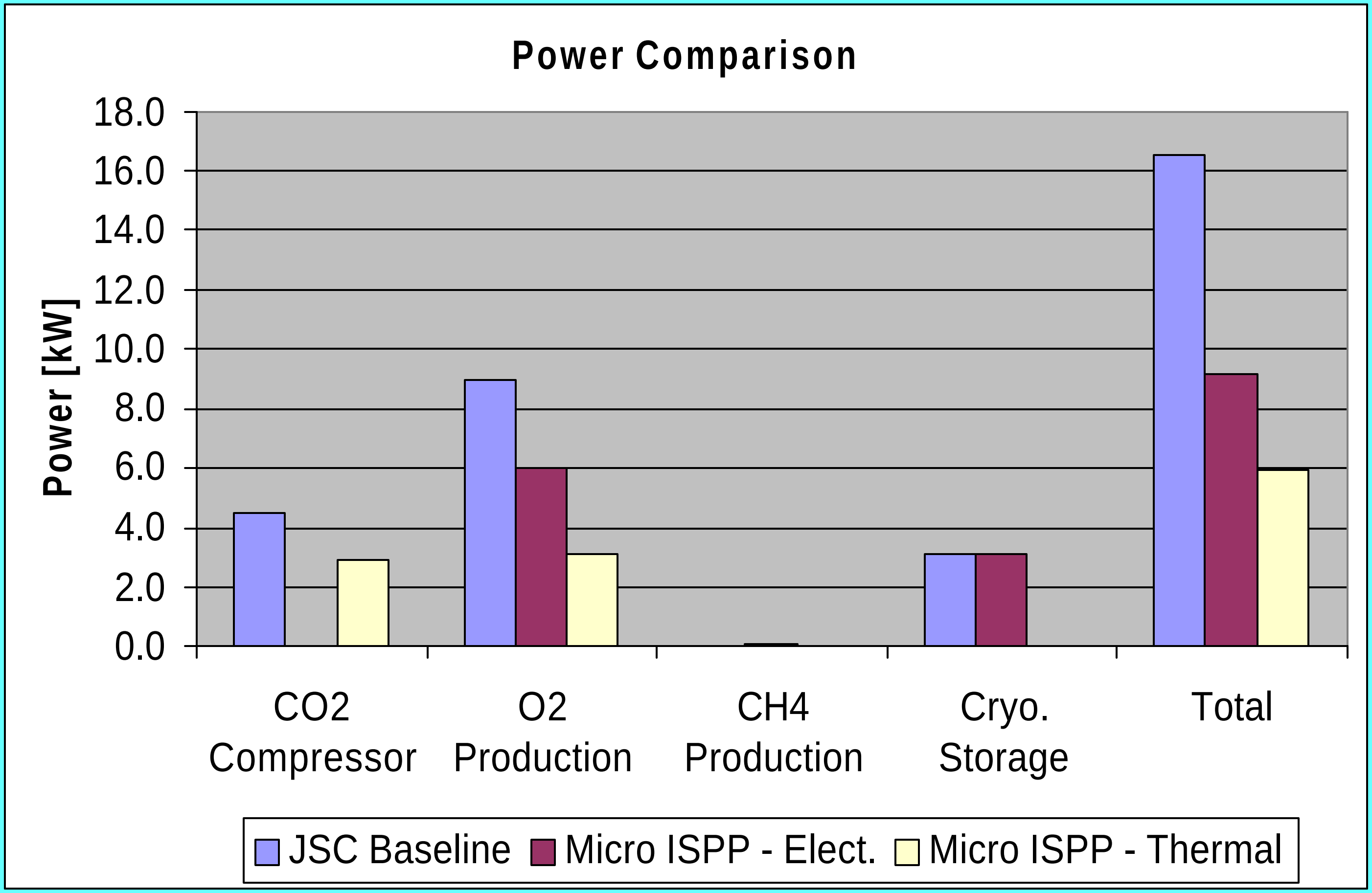
Size, Weight and Power Comparisons


Mass Comparison


Volume Comparison

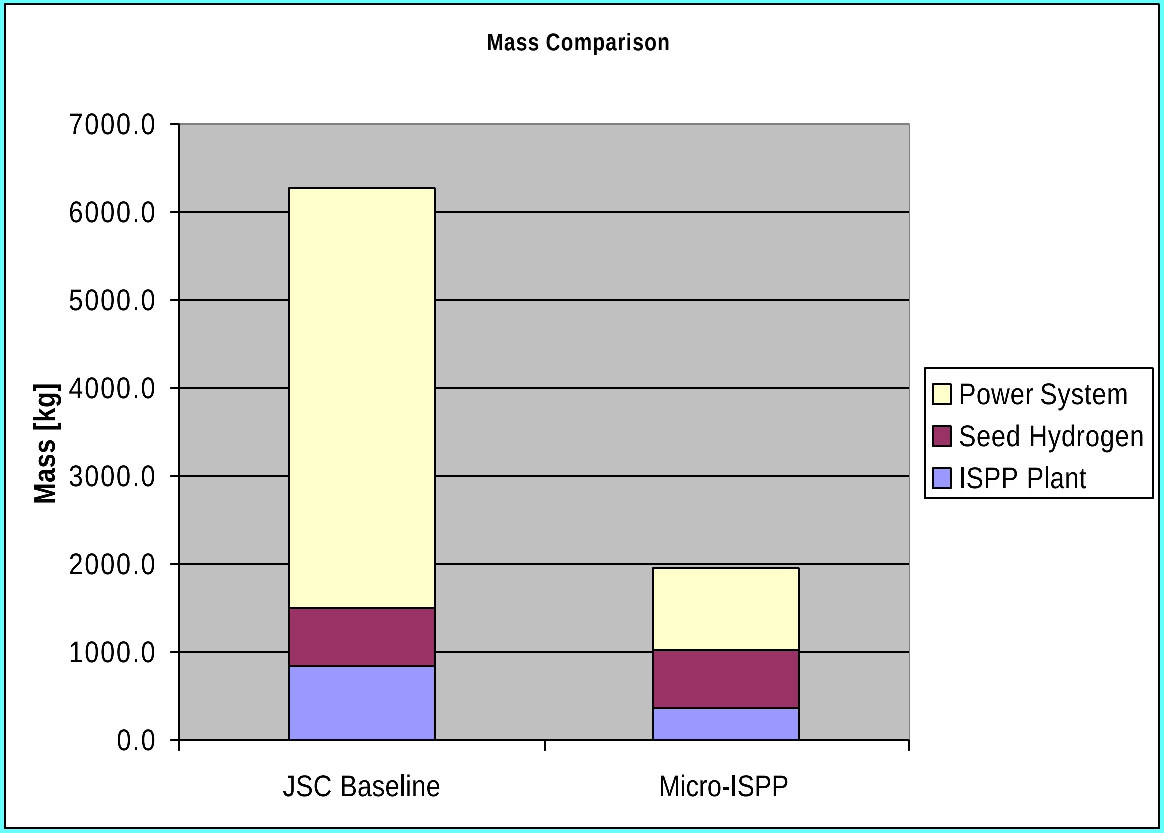
Mars ISPP Plant

Size, Weight and Power Comparisons



Mars ISPP Plant

Size, Weight and Power Comparisons



- Mass ratio for ISPP plant + H_2
  - Baseline = 9.5
  - Micro-ISPP = 14
- Mass ratio for total system
  - Baseline = 2.3
  - Micro-ISPP = 7.3

Conclusions

- Microtechnology has potential for significantly decreasing size and weight of ISPP plant for both human scale and robotic sample return missions.
- The Micro-ISPP offers reliability advantages through parallelism.
- Integration and energy cascading is facilitated and thermal-based power systems become more attractive.

- **Truth in advertising:** The many assumptions and projections made in this study require validation and development to realize the actual benefits.