MARRS

Mars Atmosphere Resource Recovery System

MARRS

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ERG

Engineering Research Group

the chemical and mechanical engineering sciences

Making Oxygen from Martian Air

Mostly CO_2 with oxygen, CO and water as trace components!

Ref: qust.arc.nasa.gov/mars/background

Composition (Viking Data)

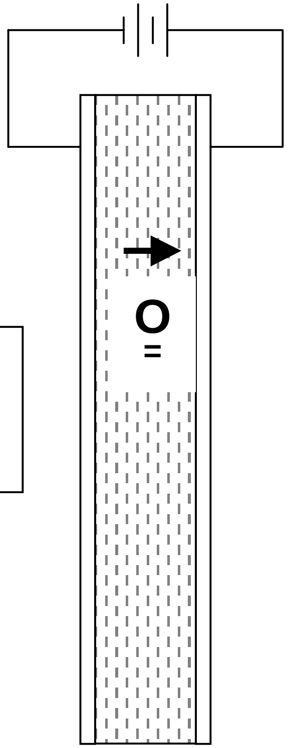
Component	% by vol
CO2	95.32
Nitrogen	2.7
Argon	1.6
Oxygen	0.13
CO	0.07
Water	0.03
Neon	0.00025
Krypton	0.00003
Xenon	0.000008
Ozone	0.000003
Missing	0.149709
	100

Electrolysis of CO_2

- *Compression of CO_2 followed by electrolysis yields CO and O_2*
- *Experiment on Mars 2001 lander -- MAAC* & MIPS**

$$2e^- + CO_2 \rightarrow CO + O^=$$

$$O^= \rightarrow 1/2\ O_2 + 2e^-$$



Overall Reaction:

$CO_2 \rightarrow CO + 1/2\ O_2$

700-900°C

A great method for small scale O_2 & CO production, but …

*

- *MIPS - Mars In-Situ Propellant Precursor*
- *MAAC - Mars Atmosphere Acquisition and Compression*

YSZ electrolyte

(yttria-stabilized zirconia)

Martian Atmosphere is 0.13% O_2

0.0006% oxygen in the ocean

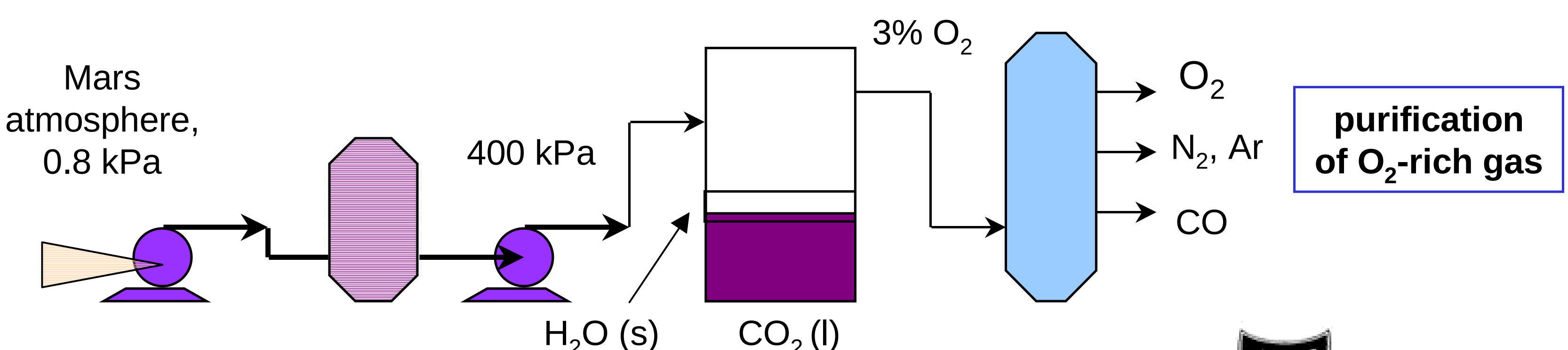
Does the fish electrolyze water to get oxygen?

Ref: Deep-Sea Research, Vol.17, pp 721-735

How can we best use the Martian atmosphere?

MARRS* - *A New Process For Recovering Oxygen and Water on Mars*

1. **Compress** the atmosphere,
2. **Condense** the carbon dioxide,
3. **Separate** the carbon dioxide from the permanent gases,
4. **Concentrate** and use the resulting oxygen, water, CO, N2 and Ar

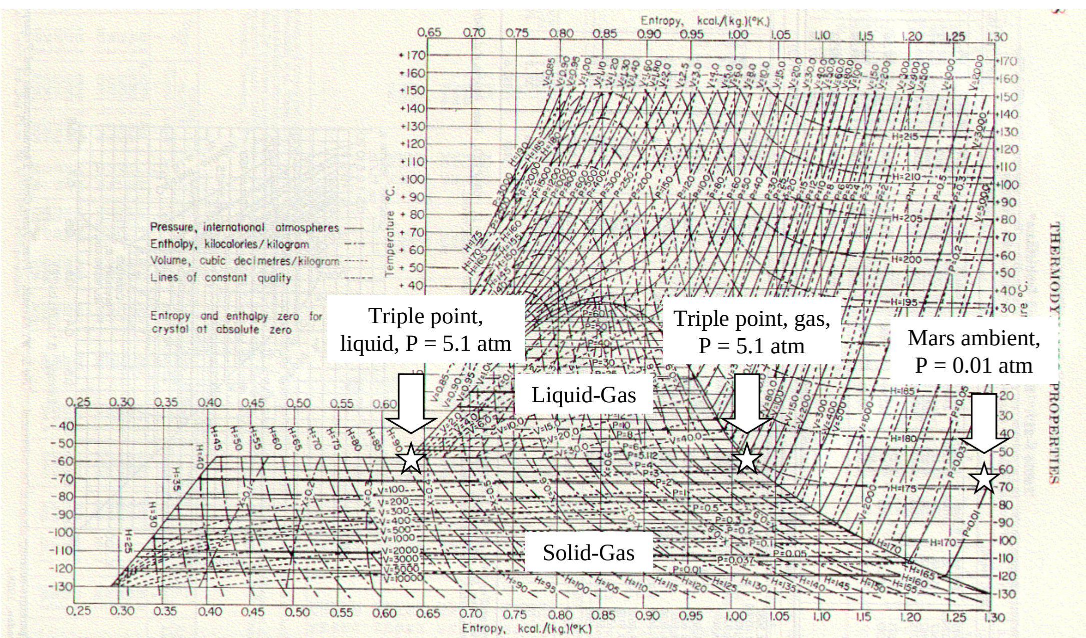


AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

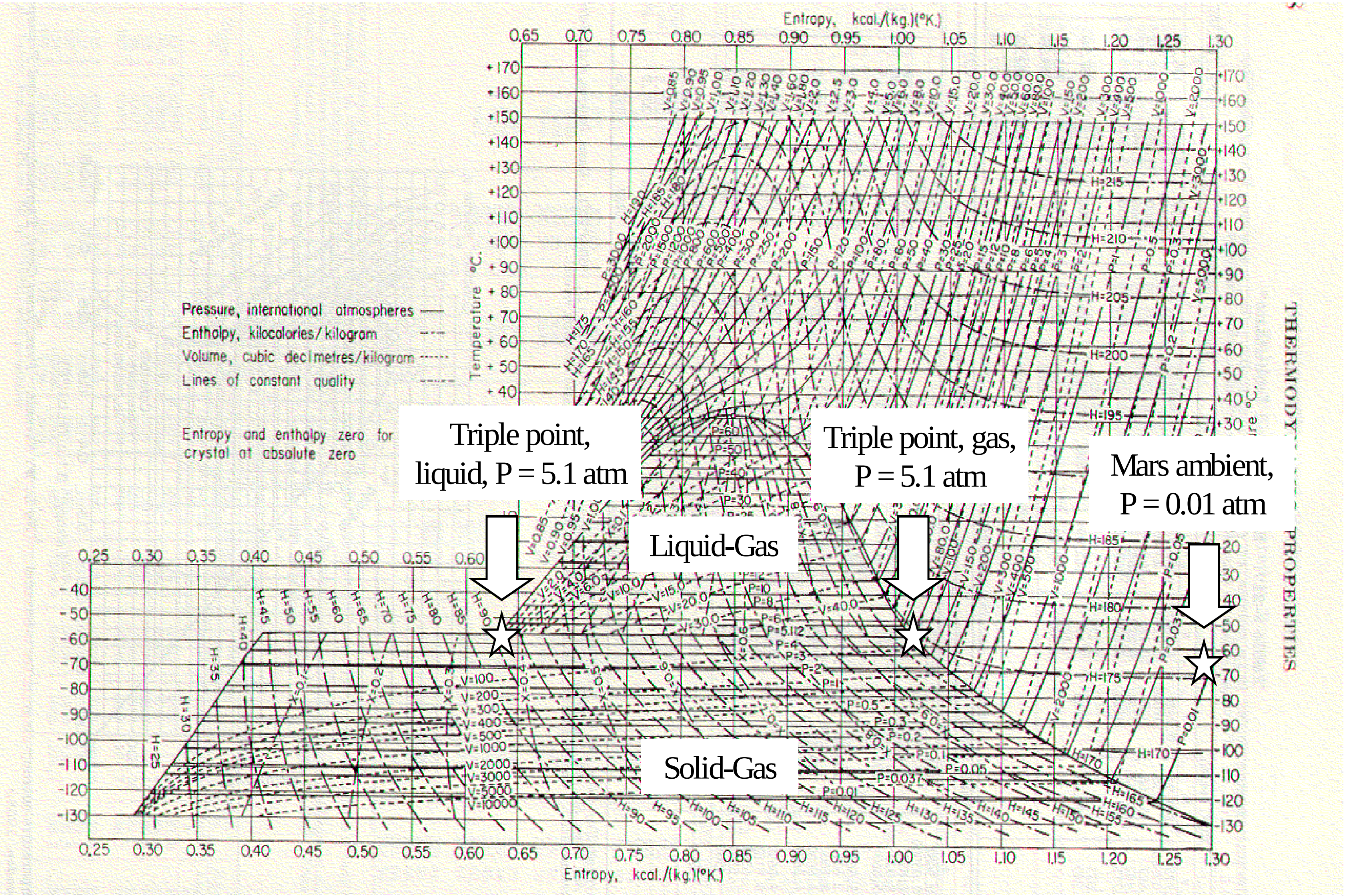
*U.S. Patent pending

Compression Energy

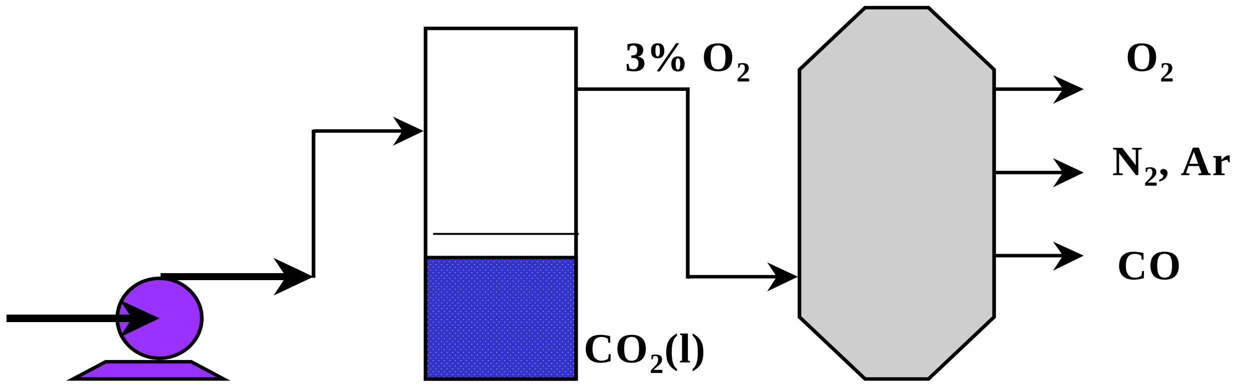
- Mars has an atmosphere that is easily condensable
  - unlike the Earth.
- The energy to liquefy the CO_2 is unexpectedly low
  - even better with good energy recovery



- The temperature-entropy diagram provides key data
- The chemical engineering says "no solids please."
- Compress to pressure above the triple point.


Entropy, kcal./(kg.)(°K.)
Temperature °C.
Pressure, international atmospheres
Enthalpy, kilocalories/kilogram
Volume, cubic decimetres/kilogram
Lines of constant quality
Entropy and enthalpy zero for crystal at absolute zero
Triple point, liquid, P = 5.1 atm
Triple point, gas, P = 5.1 atm
Mars ambient, P = 0.01 atm
Liquid-Gas
Solid-Gas
THERMODYNAMIC PROPERTIES

The Permanent Gases Will Separate!



- Apply Raoult's Law + Clausius-Clapeyron equation to estimate distribution of gases

$$X = Y\,P_T/P_S$$

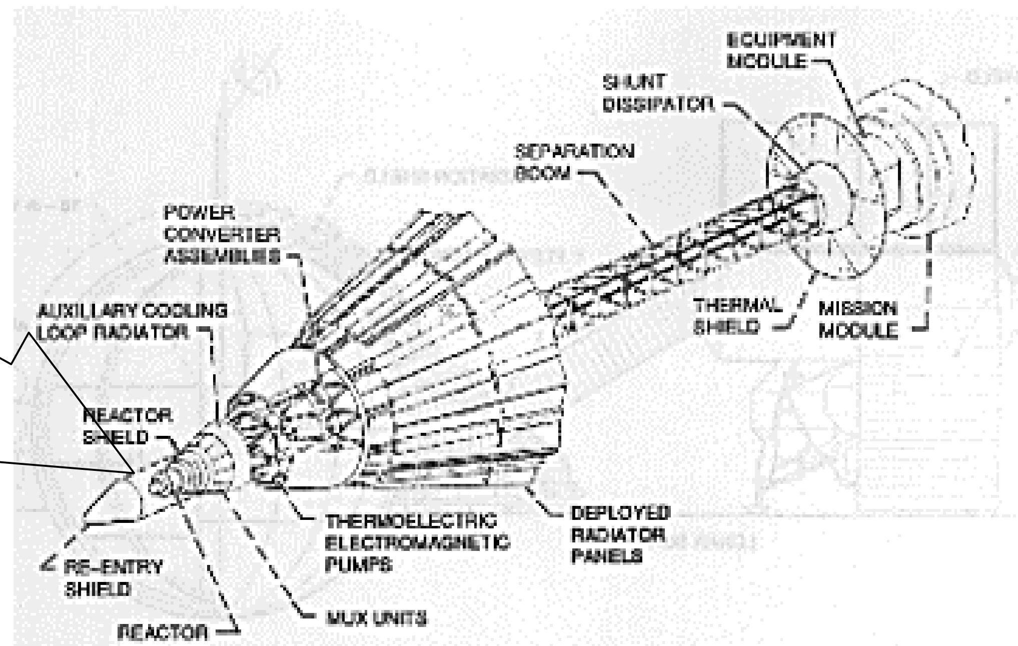
$$\ln X = \ln [Y\,P] - [H_V/R]\,[1/T_B - 1/T]$$

- After condensation, oxygen is concentrated 27-fold.
  - **A surprising result** - *much better than expected*
  - Product gas is still mostly CO_2

MARRS

SP-100 Reactor Supplies the Energy

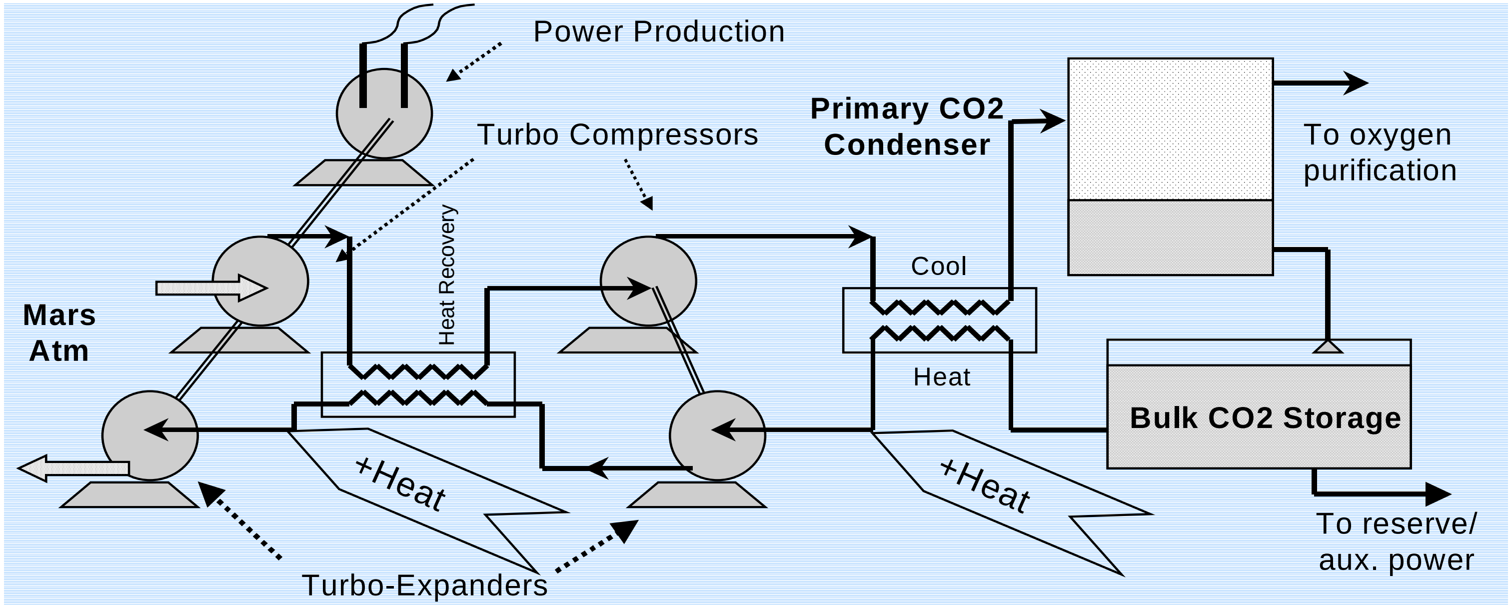
The Reactor!



- **5 megawatts**
- **30 liters**
- **300 kg**
- **System mass of 2200 kg.**

- Adapt temperatures and materials for the Martian atmosphere

MARRS Product Manifest



MARRS Product Manifest: Basis: SP-100 Space Reactor, 40% Compression Efficiency						
Kilograms produced from one 5 MW thermal source, per hour						
	L CO2	O2	N2	Ar	CO	H2O
Energy Recovery, %						
0	22172.6	22.0	799.4	676.6	20.8	5.8
20	0	27.5	999.3	845.8	26.0	7.3
40	0	45.8	1665.4	1409.6	43.3	12.1
60	0	114.6	4163.5	3524.0	108.3	30.2
80	0	572.9	20817.7	17619.8	541.7	151.0

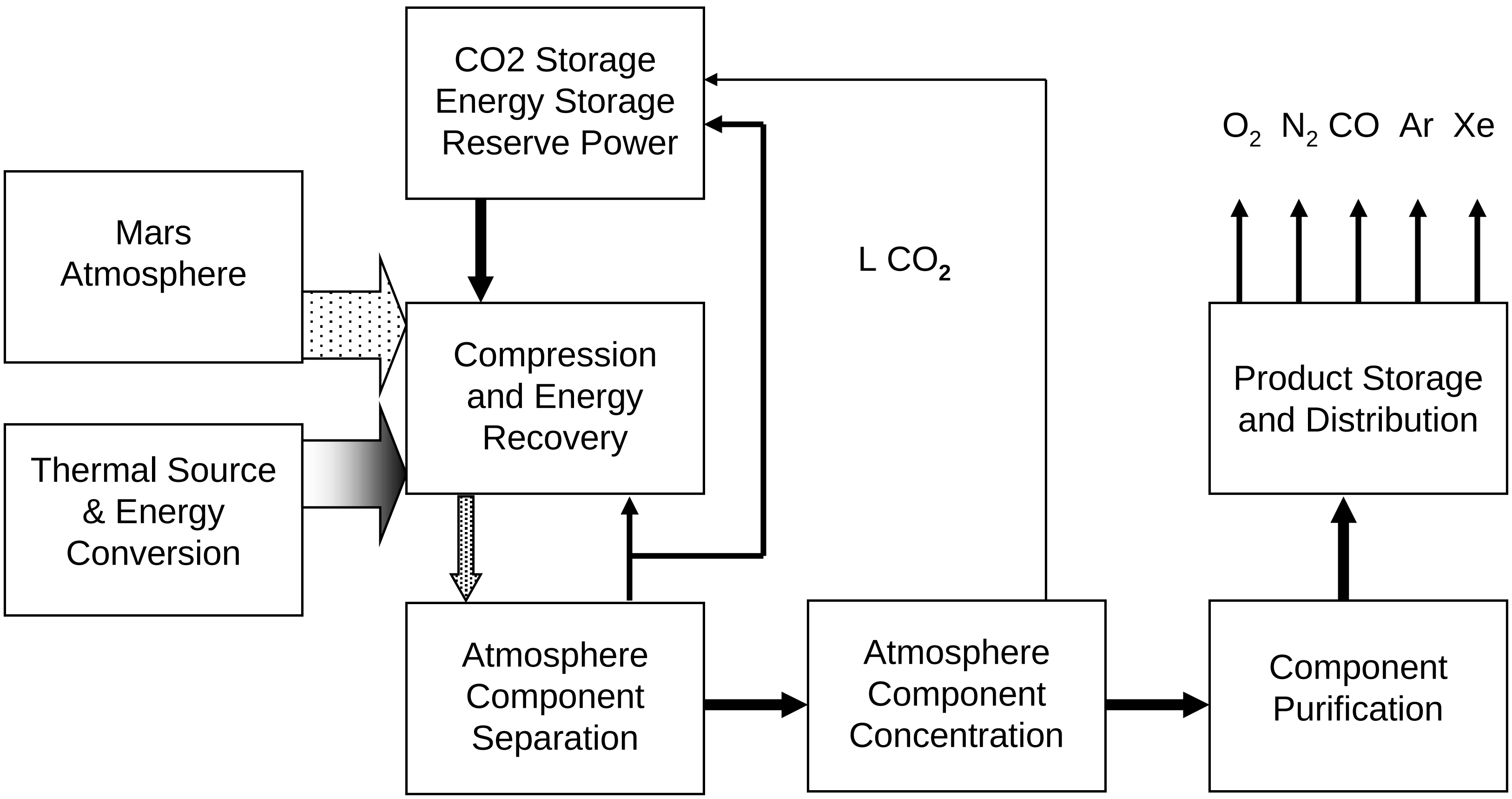
An Integrated Resource Architecture

- MARRS provides products --
  - Oxygen
  - Water
  - Nitrogen and argon, components of air
  - Carbon monoxide, a fuel precursor
  - Mechanical and electrical power

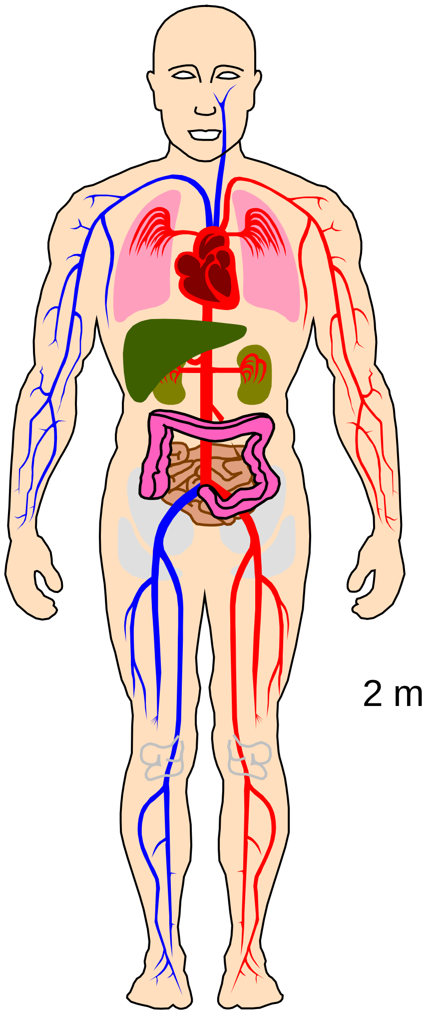
- MARRS supplies an open-cycle working fluid, and propellants
  - Liquid CO_2 in very large amounts
  - For drilling and other stationary machinery
  - For local transportation
    - with transportable heat source

Functional Elements of Making Air on Mars

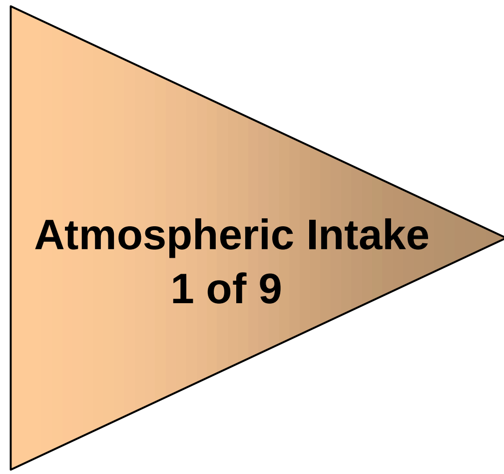
All it takes is energy, equipment, and knowledge



Equipment Dimensions

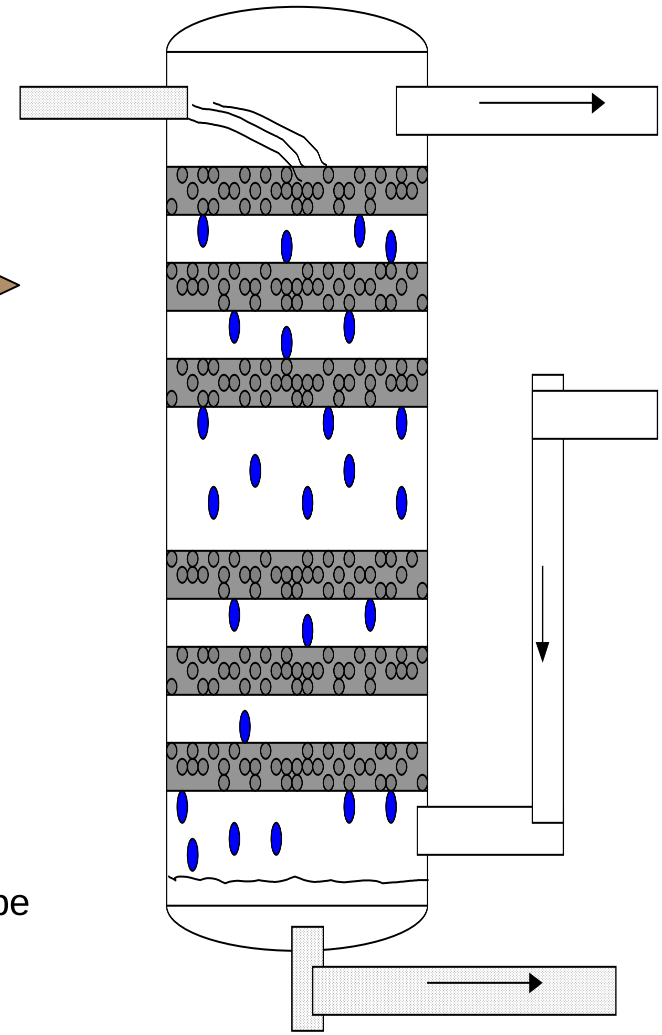


2 m



Compressed Atmosphere Pipe

Condensed-Phase, 2-Phase Pipe



Primary Separation Vessel

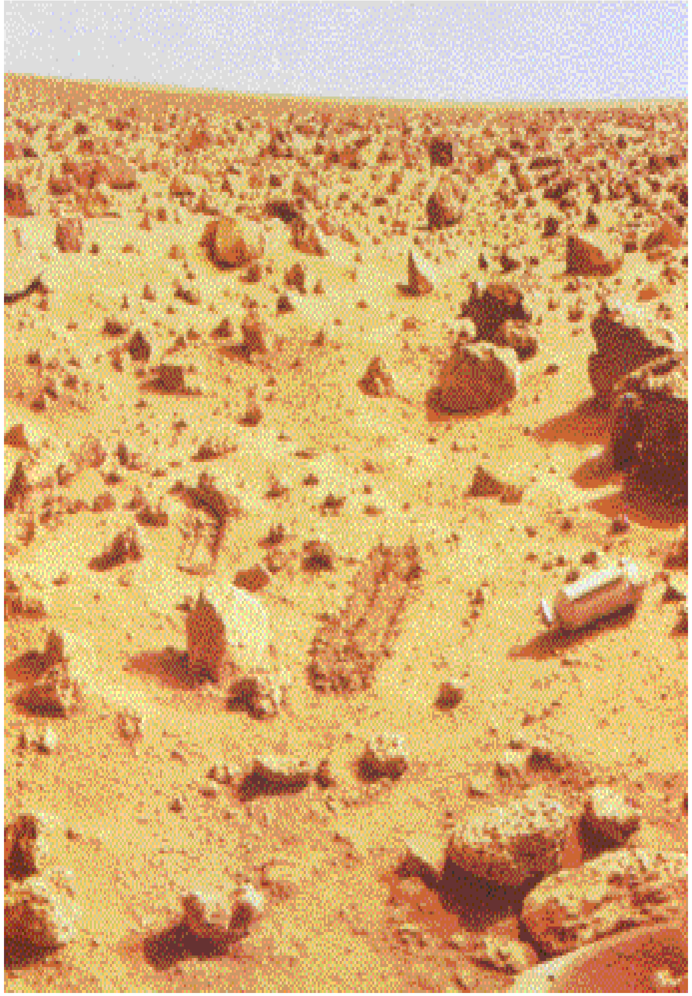
MARRS vs. Electrolysis

Mass Comparison for Oxygen Production (Roughest Estimate)				
	MARRS		**Electrolysis**	
	SP-100	PV	SP-100	PV
Mass (kg/kg O_2/day)	2 to 4	?	8 to 16	300-1200
Energy (kw/kg O_2/day)	10 to 40		10 to 20	
Co-products	carbon monoxide		carbon monoxide	
	water			
	nitrogen			
	argon			
	(inert gases)			

- Continuous extraction process benefits from economies of scale
- Electrolysis attractive for small systems

MARRS Research for NIAC

- Focus on processing of the atmospheric gases
  - The chemical engineering
- Provide a good estimate of how much compression is needed
- Make first estimate of launch mass
- Outline architecture and compression strategy
  - A good architecture makes MARRS a "pull" technology
  - It must accommodate dramatic environmental variability.



The Martian Dead State

- The “dead state” is a term for the ground state that determines efficiency
- Second law process analysis tells where the inefficiencies occur
- For large in-situ installations, high efficiency is a primary design goal

Energy ~ $1/\eta$

Mass ~ $1/\eta$

MARRS chemical engineering will include process design with second law optimization.

MARRS -- An Enabling Technology

- Uniquely uses the Martian environment
- Helps define new disciplines in space technology
    - Planetary chemical engineering
- Many MARRS concepts applicable to other planetary bodies

- ***NIAC*** provides a unique opportunity to introduce MARRS and other unique ideas into NASA's advanced planning
- Planetary chemical engineering will be introduced to the AIChE in November