Extraction Techniques-Oxygen

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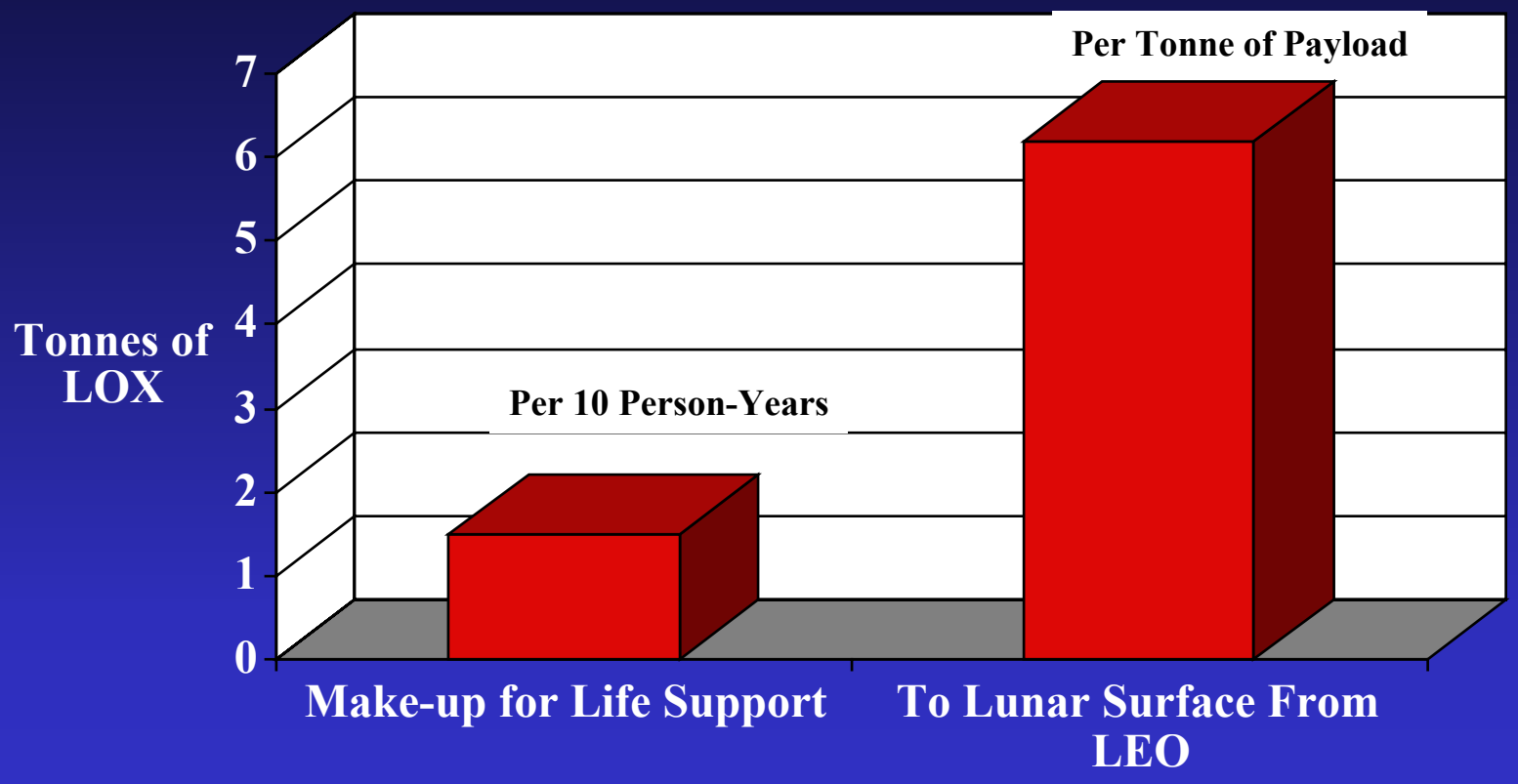
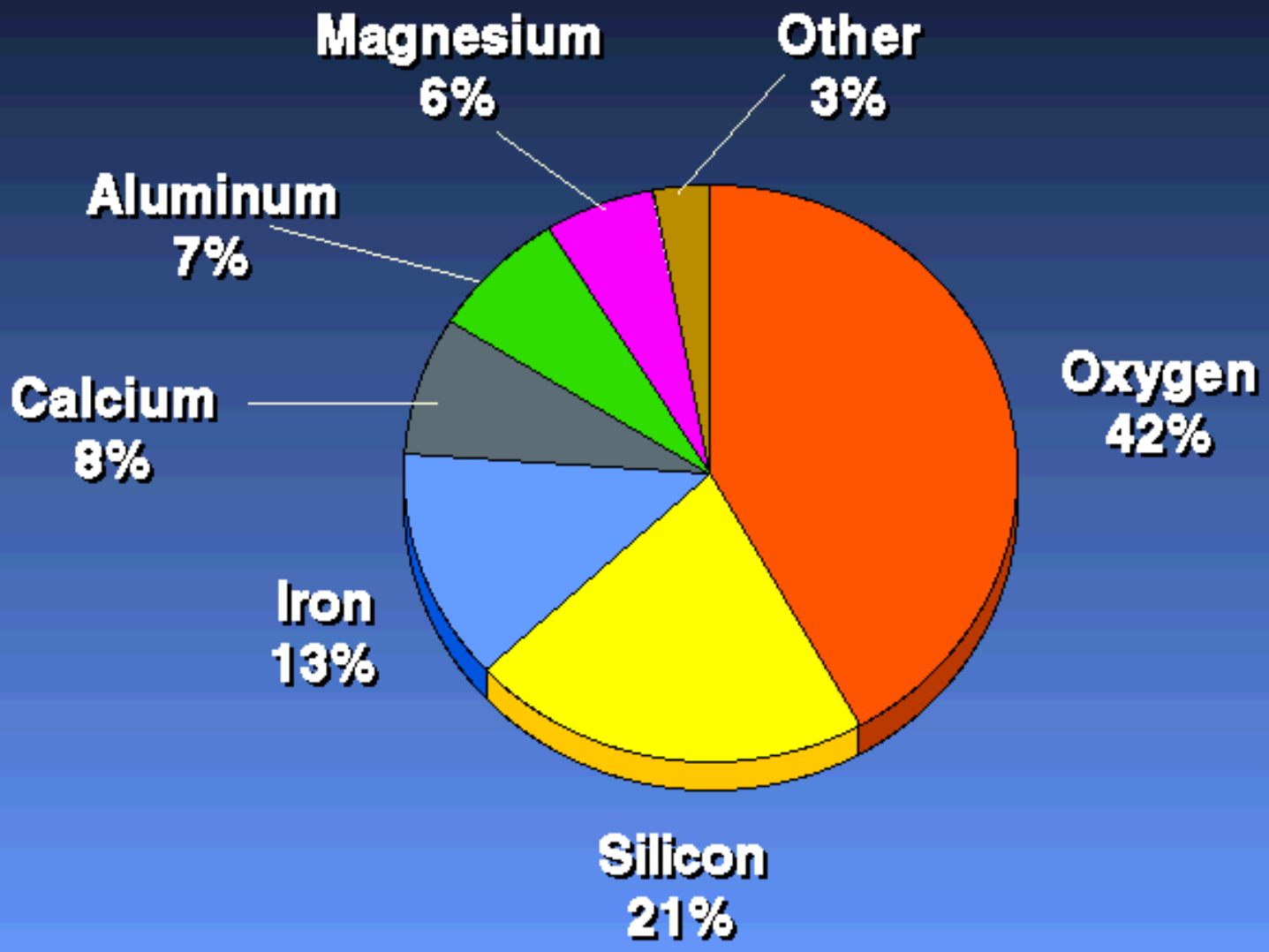
Lecture 13

October 3, 2001

There are Obvious Needs for Oxygen in a Lunar Base Scenario



Lunar Soil Composition

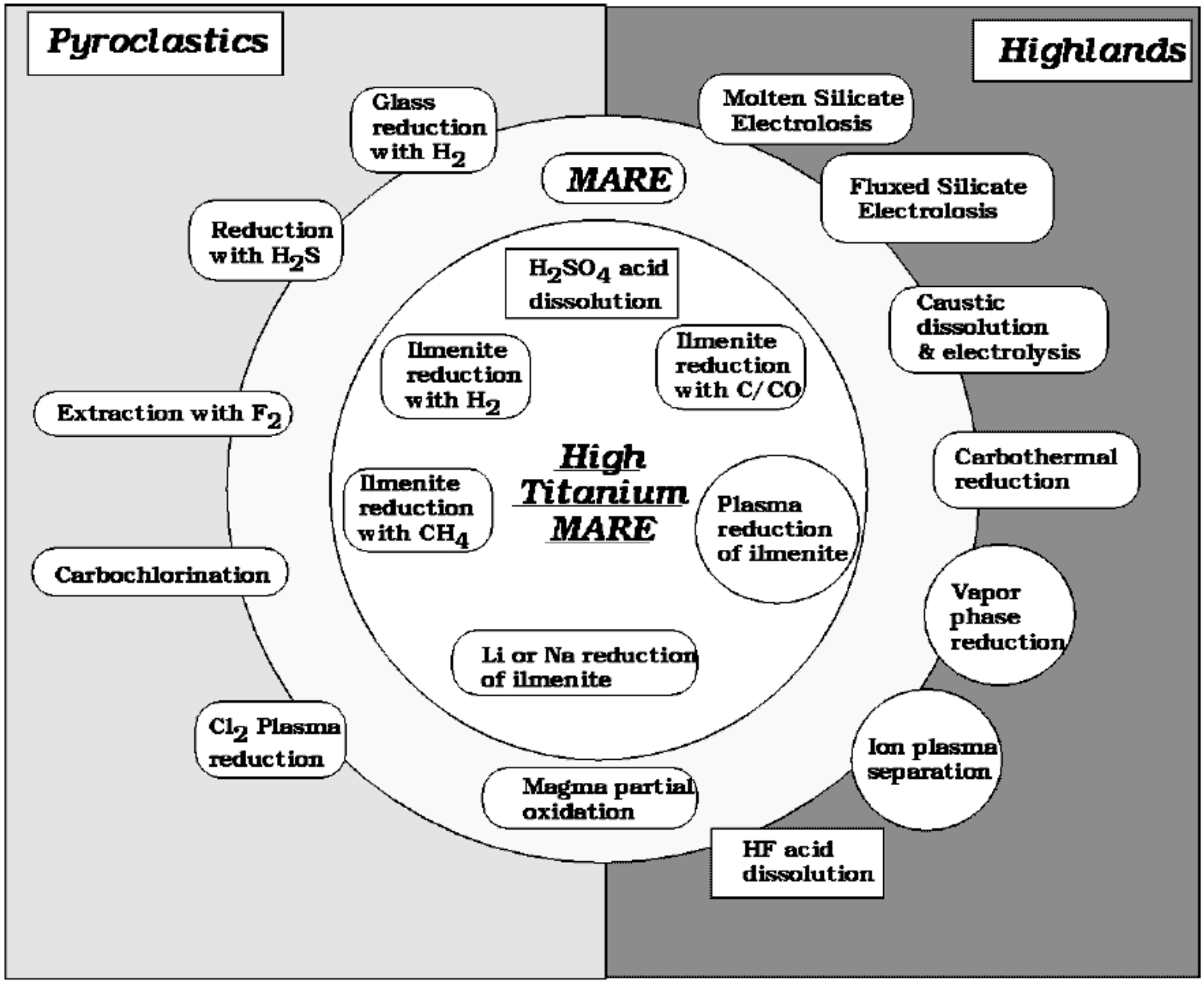


There at Least 20 Ways to Extract Oxygen from Lunar Material

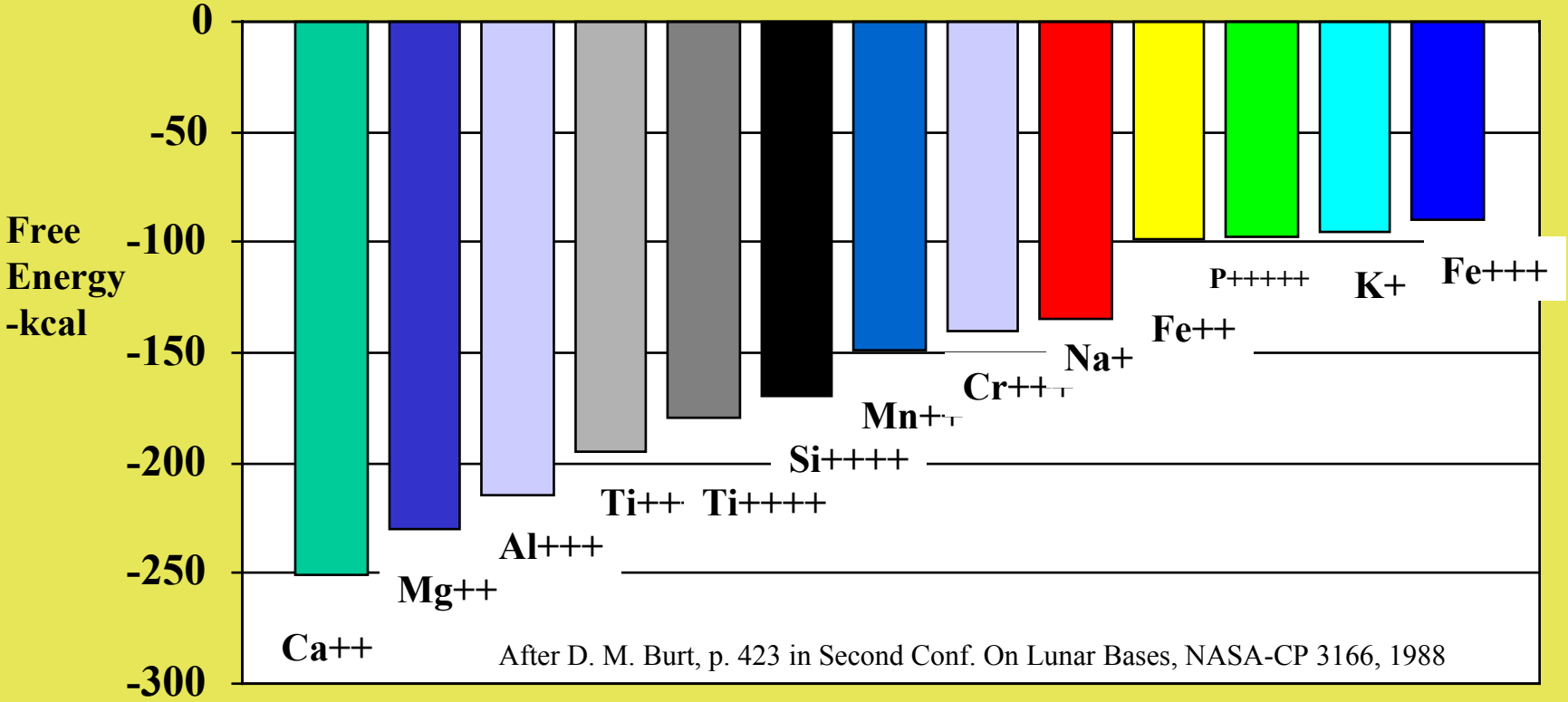
Taylor & Carrier (1993)

	Solid/Gas Interaction	Silicate/Oxide Melt	Pyrolysis	Aqueous Solutions
Most Favored	**Ilmenite Reduction With H2** **Glass Reduction With H2**	**Molten Silicate Electrolysis** **Fluxed Silicate Electrolysis**	**Vapor Phase Reduction**	
Possible	**Ilmenite Reduction C/CO** **Ilmenite Reduction CH_4** **Plasma Reduction Cl_2** Reduction H_2S	**Caustic Dissolution & Electrolysis** **Carbothermal Reduction**	**Ion Plasma Separation**	
Long Shot	**Carbochlorination** **Extraction with F_2**	**Magma Partial Oxidation** **Li or Na Reduction of Ilmenite**	**Plasma Reduction of Ilmenite**	**HF** **H_2SO_4**

The Feedstocks for Oxygen Production Can Come From Different Locations and Host material



It is Hardest to Extract Oxygen from Ca and Easiest from Fe



After D. M. Burt, p. 423 in Second Conf. On Lunar Bases, NASA-CP 3166, 1988

The Use of Hydrogen to Reduce Ilmenite for the Production of Oxygen Was First Proposed by Williams in 1979

- Ideal formula-$FeTiO_3$
- Actual Ilmenite composition-Apollo-12

TiO_2	52-54%
FeO	45%
Al_2O_3	0.3-0.4%
Cr_2O_3	0.2-0.4%
MgO	0.1-0.4%
MnO	0.3-0.4%

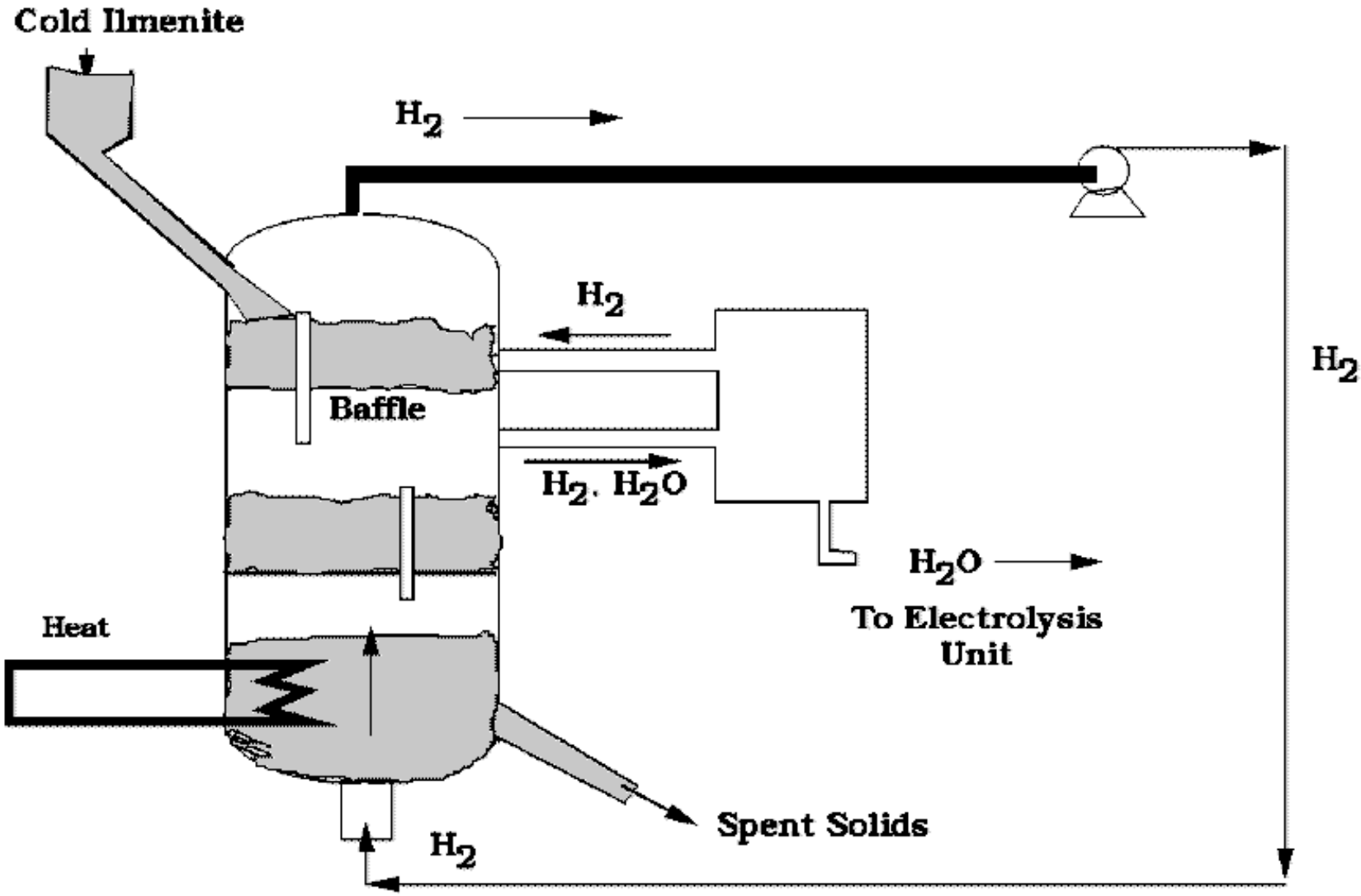
(Can be beneficiated from Mare Basalt rocks and Mare soils)

Reduction Reaction

$$FeTiO_3 + H_2 \longleftrightarrow Fe + TiO_2 + H_2O$$

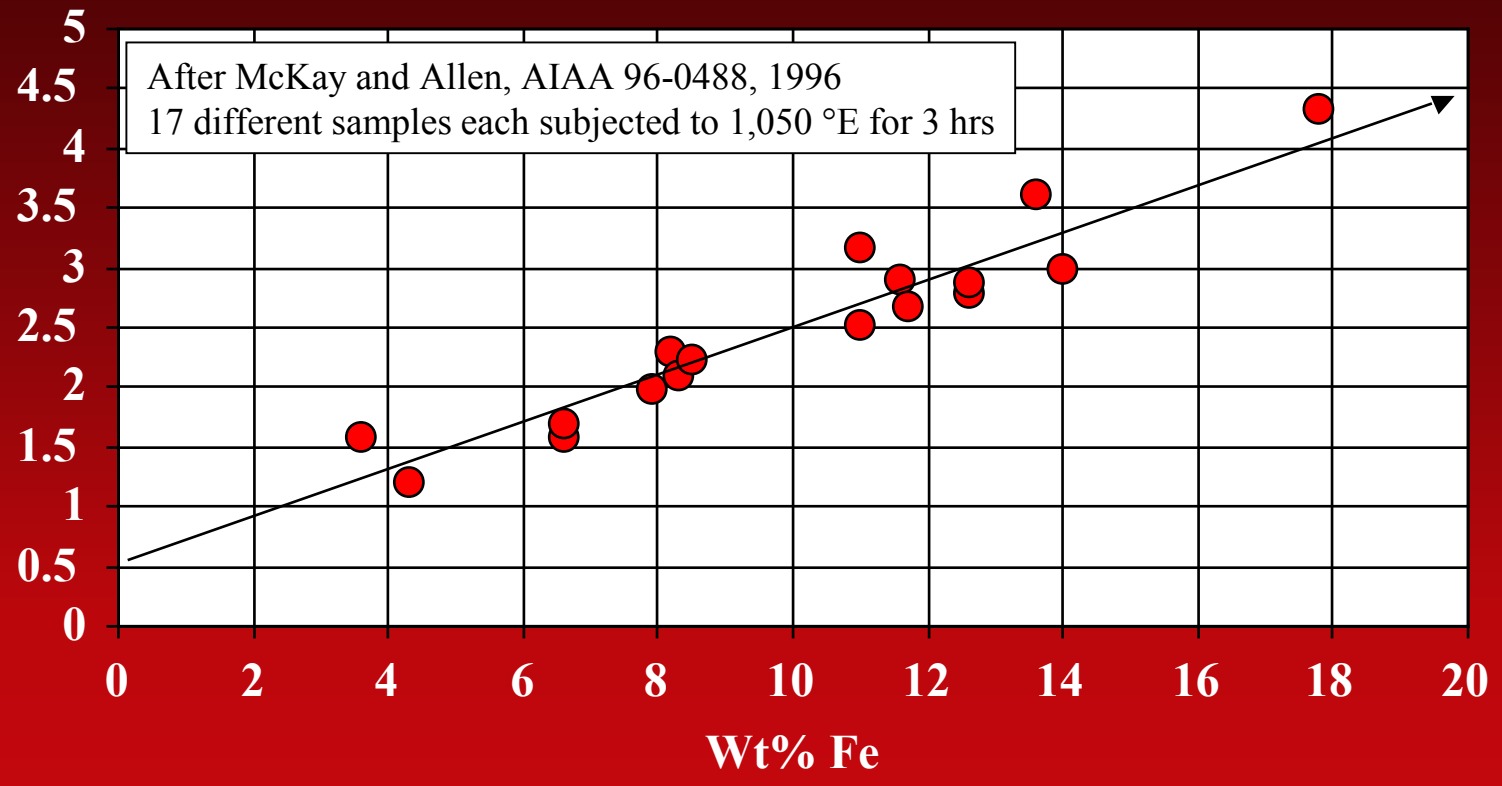
Carbotek, Inc. has Patented a Hydrogen-Reduction TechniqueUsing a Fluidized Bed

Patent # 4,938,946, July 3, 1990



Simplified Schematic of the Carbotek Process

The Yield of Oxygen from Lunar Soils in Contact with High Temperature Hydrogen is Strongly Dependent on the Initial Iron Content



Lunar Glass May be One of the Best Sources of Oxygen

- Some glass, particularly from the mare regions, can contain FeO up to 20 wt%
- Thermodynamically, the glass is considerably more unstable than the silicate materials from which it is formed.

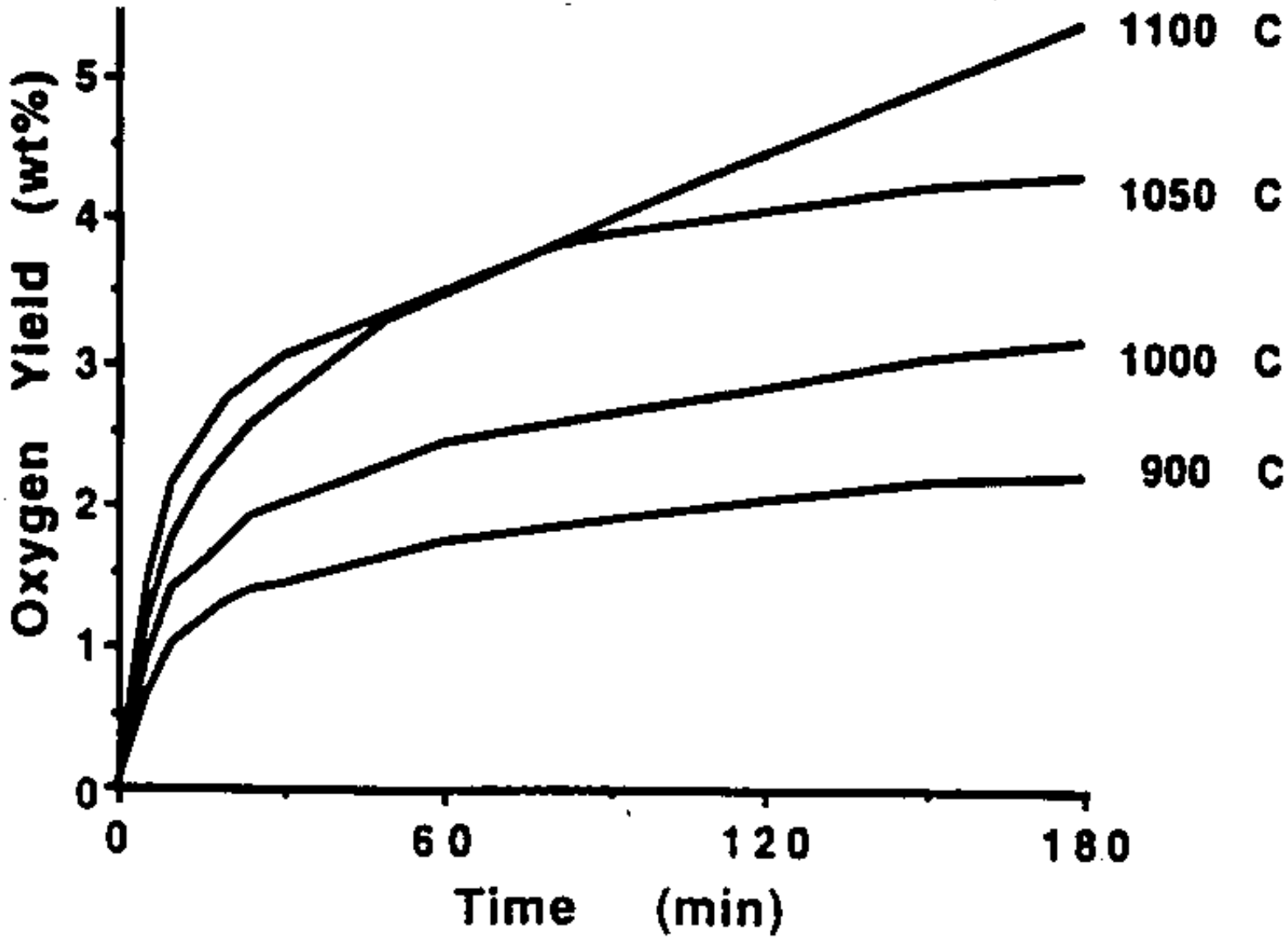
  – **FeO (glass) + H_2 <---> Fe° + H_2O**

  – **2 H_2O <---> 2H_2 + O_2**

- There are parts of the Moon that have blankets of pyroclastic volcanic glass 1 to 4 meters deep

After L. A. Taylor and W. D. Carrier III, in Resources of Near Earth Space, Univ. of Arizona Press (1993)

The Release of Oxygen From Lunar Volcanic Glass 74220 is Quite Rapid and Temperature Dependent



After C. C. Allen, R. V. Morris, and D. S. McKay, J. Geophysical Research, vol. 99, no. E11, p. 23,173 (1994)

Carbon Compounds Can Also be Used to Extract Oxygen from Lunar Materials

- Carbon Monoxide Cycle
  - $FeTiO_3 + CO \text{ <--> } Fe + TiO_2 + CO_2$
  - $2\ CO_2 \text{ <--> } 2\ CO + O_2$

- Methane Cycle
  - $FeTiO_3 + CH_4 \text{ <--> } Fe + TiO_2 + CO + 2H_2$
  - $2\ CO + 6H_2 \text{ <--> } 2\ CH_4 + 2\ H_2O$
    - $2\ H_2O \text{ <--> } 2H_2 + O_2$

Oxygen Can Be Extracted From Molten Silicates

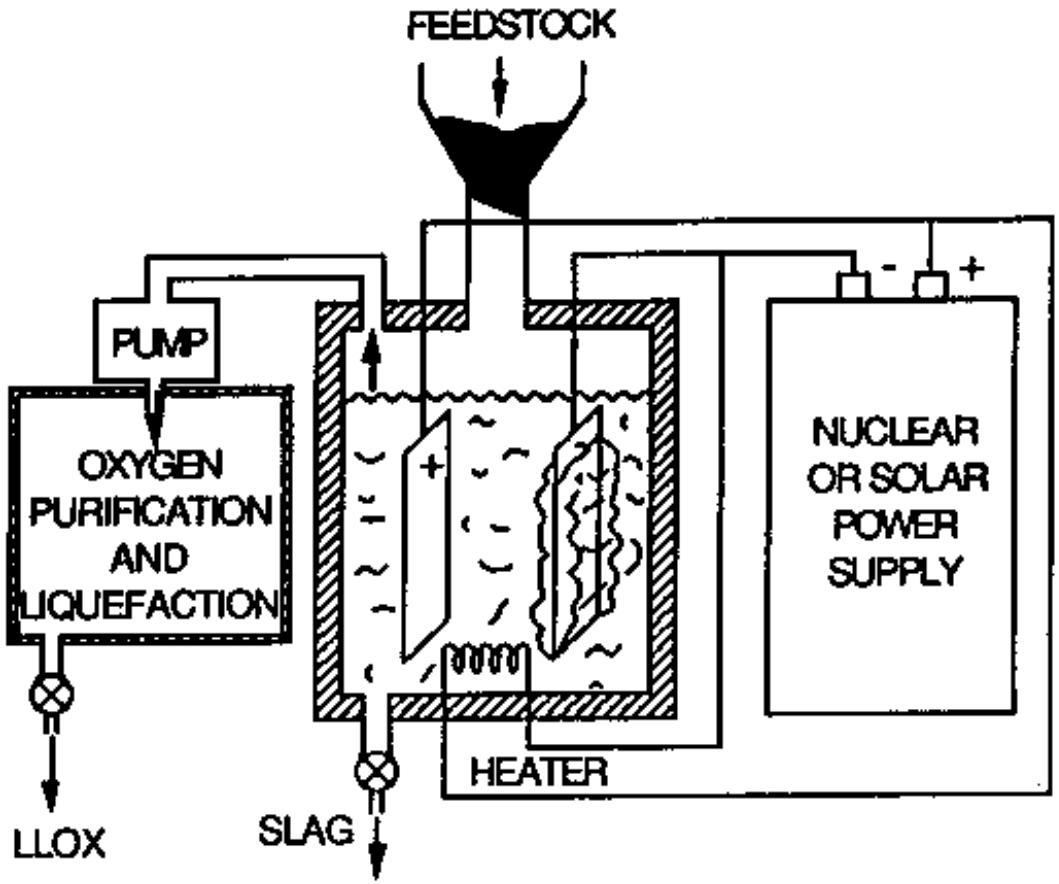
Anorthite
$CaAl_2Si_2O_8$

Olivine
$(Mg,Fe)_2Si_2O_4$

Pyroxene
$Ca(FeMg)Si_2O_6$

Chromite
$FeCr_2O_4$

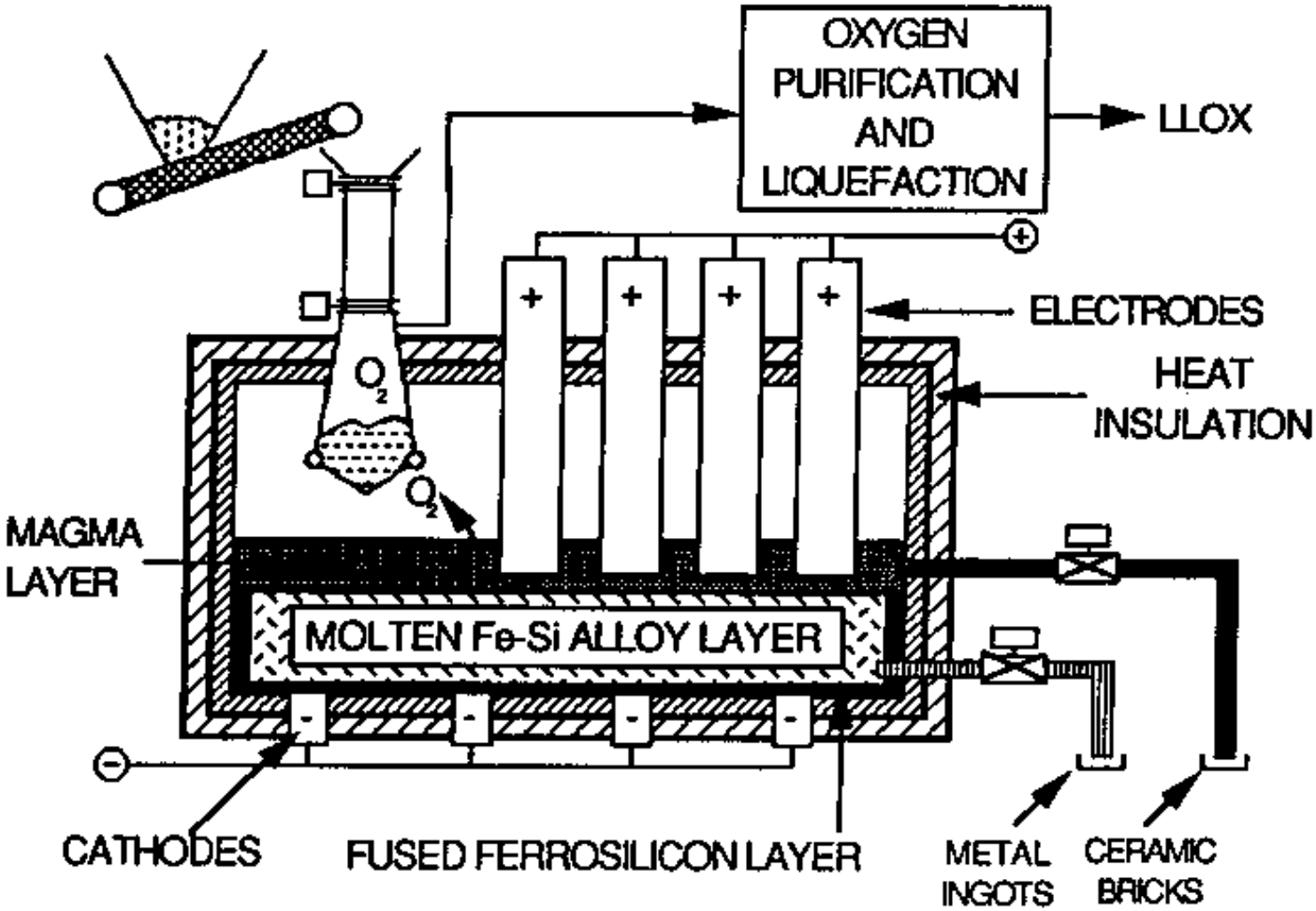
Ilmenite
$FeTiO_3$



- **Advantages: No moving parts, one step oxygen production**
- **Disadvantages: High temperatures, 1300-1700 °C, corrosion**

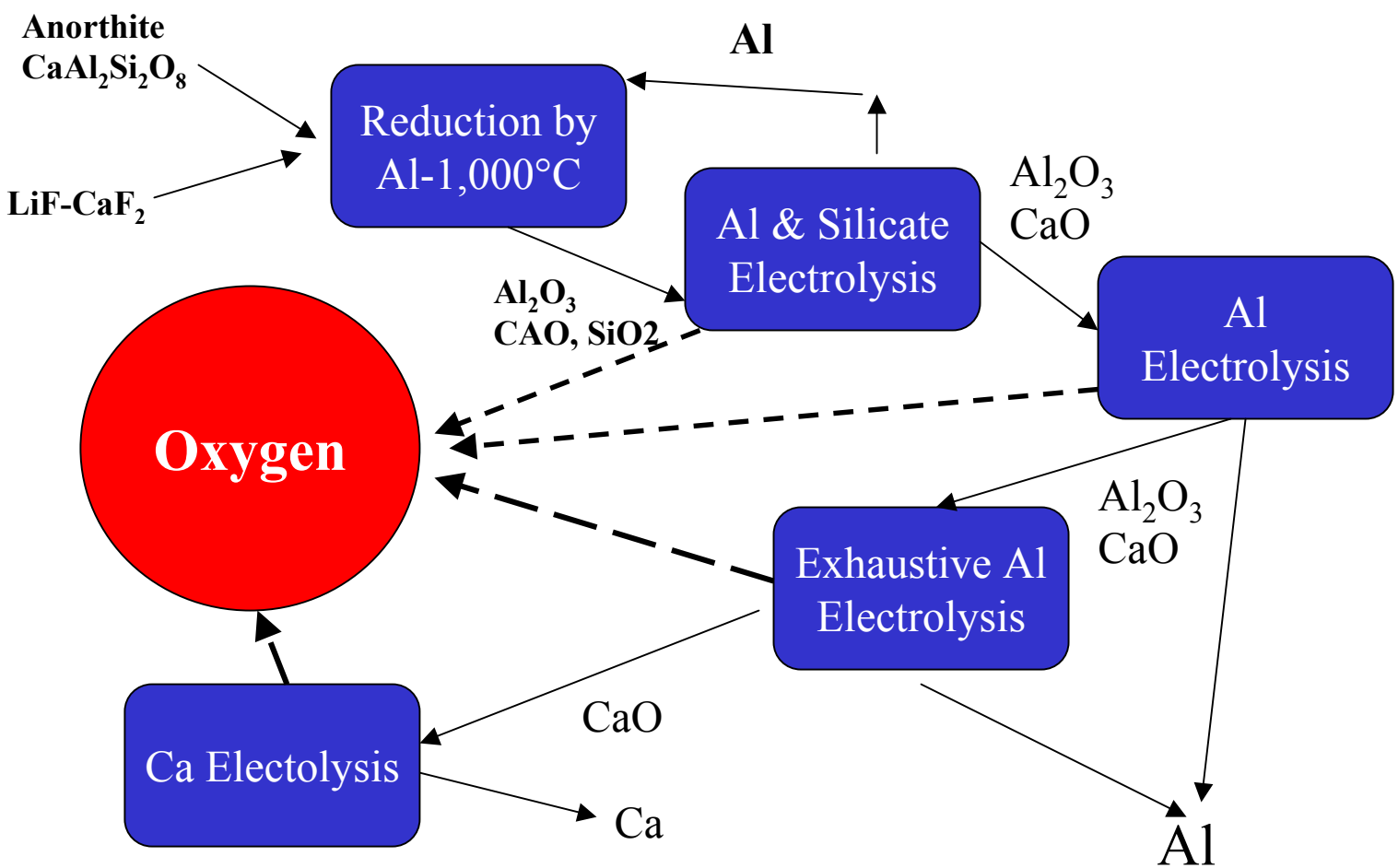
After L. A Taylor and W. D. Carrier III, in Resources of Near-Earth Space, Univ. of Arizona Press, (1993)

Many Other Useful Products Can be Derived From the Molten Silicate Process

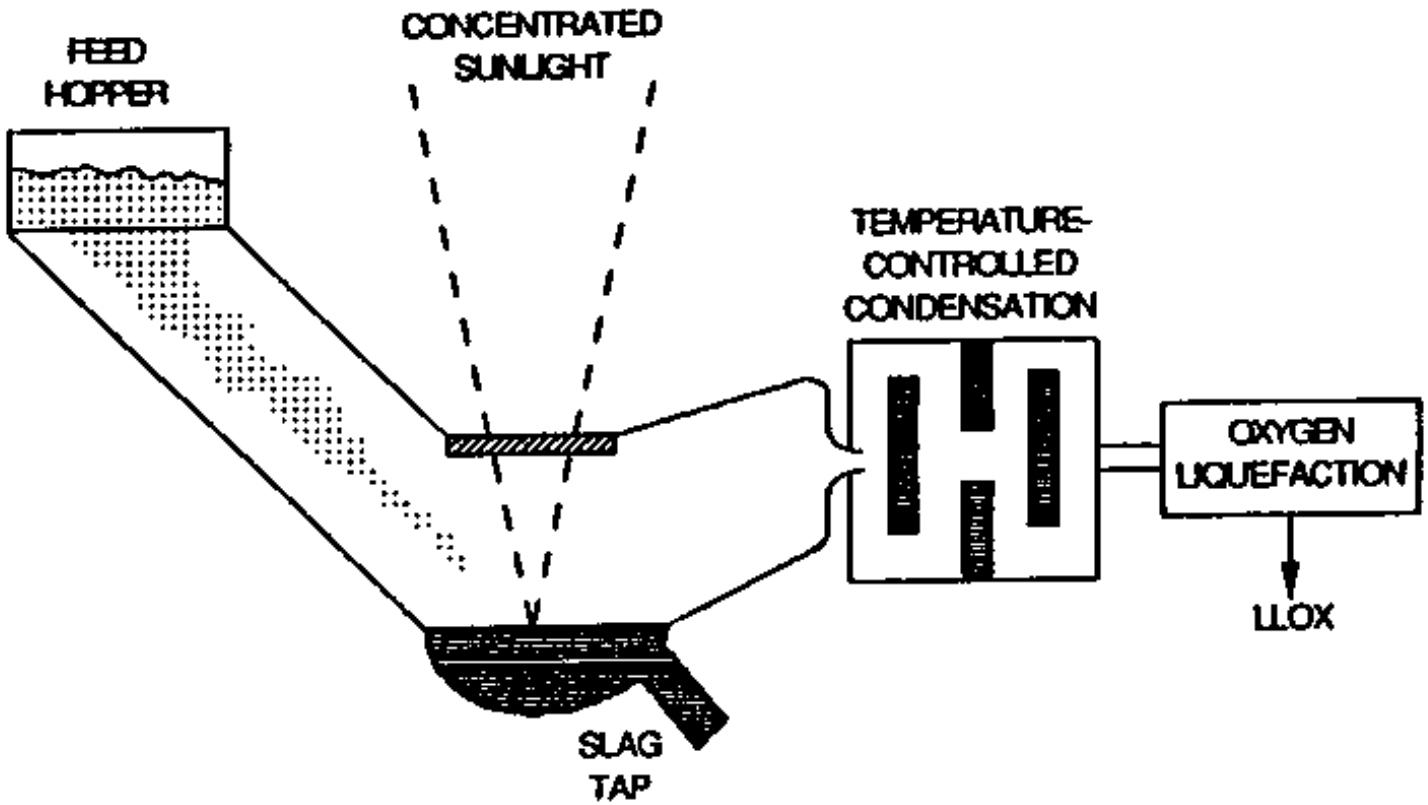


After McCullough and Mariz (1990), "Lunar Oxygen Production via Magma Electroysis", in Engineering,

The Fluxed Molten Silicate Process Can Produce Oxygen More Efficiently at Lower Temperatures

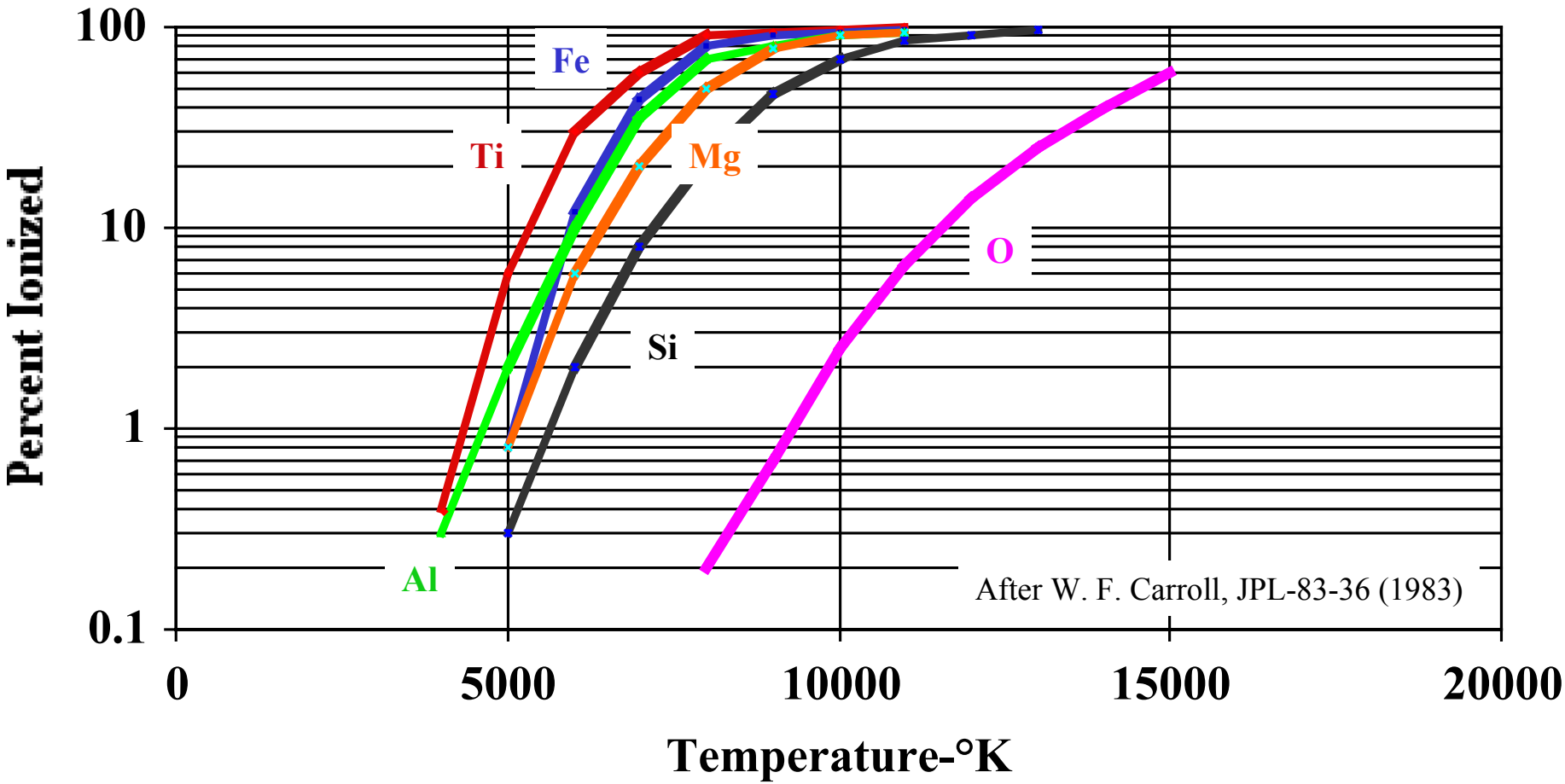


Vapor Phase Reduction Utilizes Temperatures From 2,000 to 10,000 °K

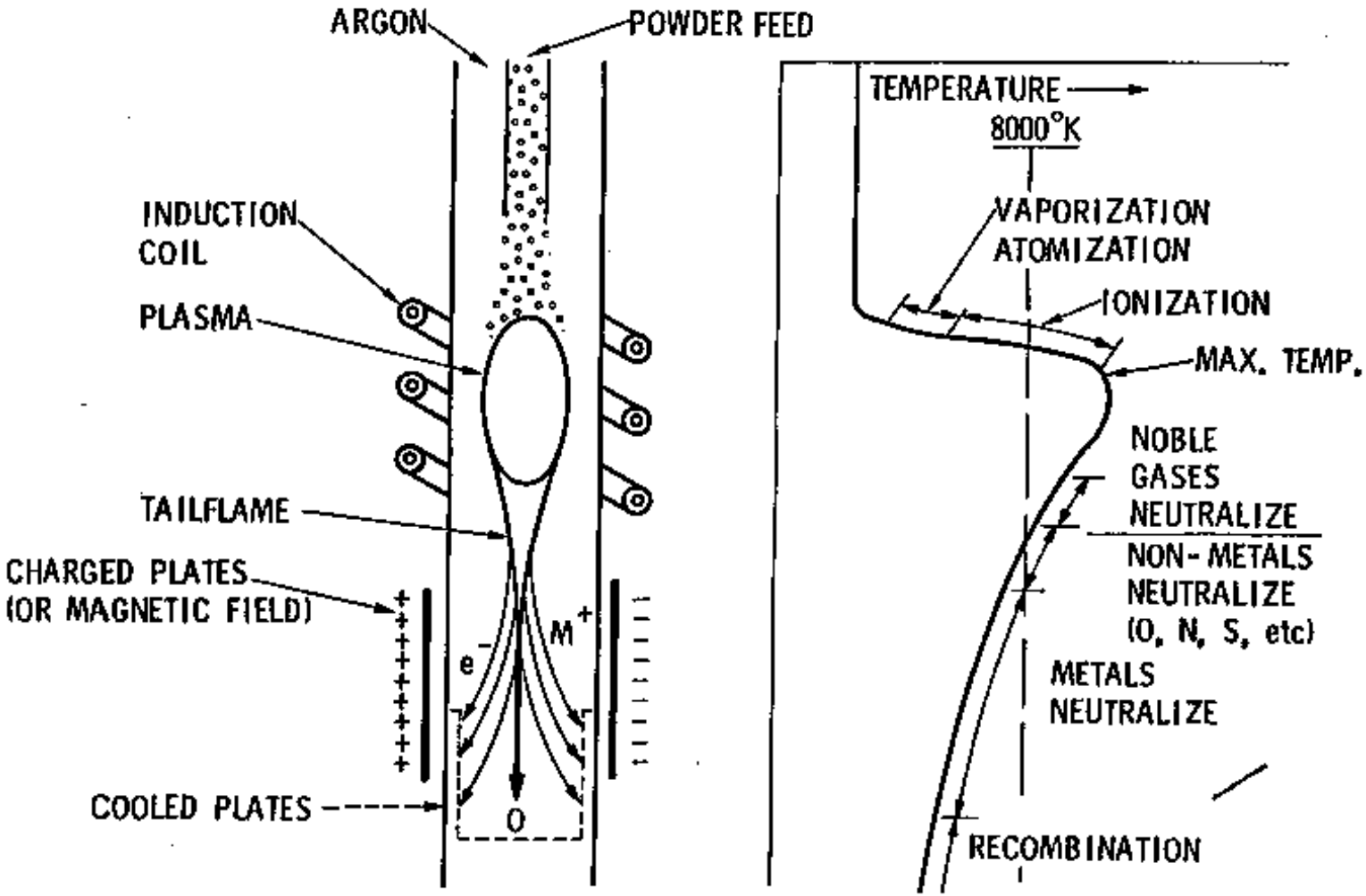


After L. A Taylor and W. D. Carrier III, in Resources of Near-Earth Space, Univ. of Arizona Press, (1993)

The Metals in Lunar Material Ionize at Lower Temperatures Than Oxygen

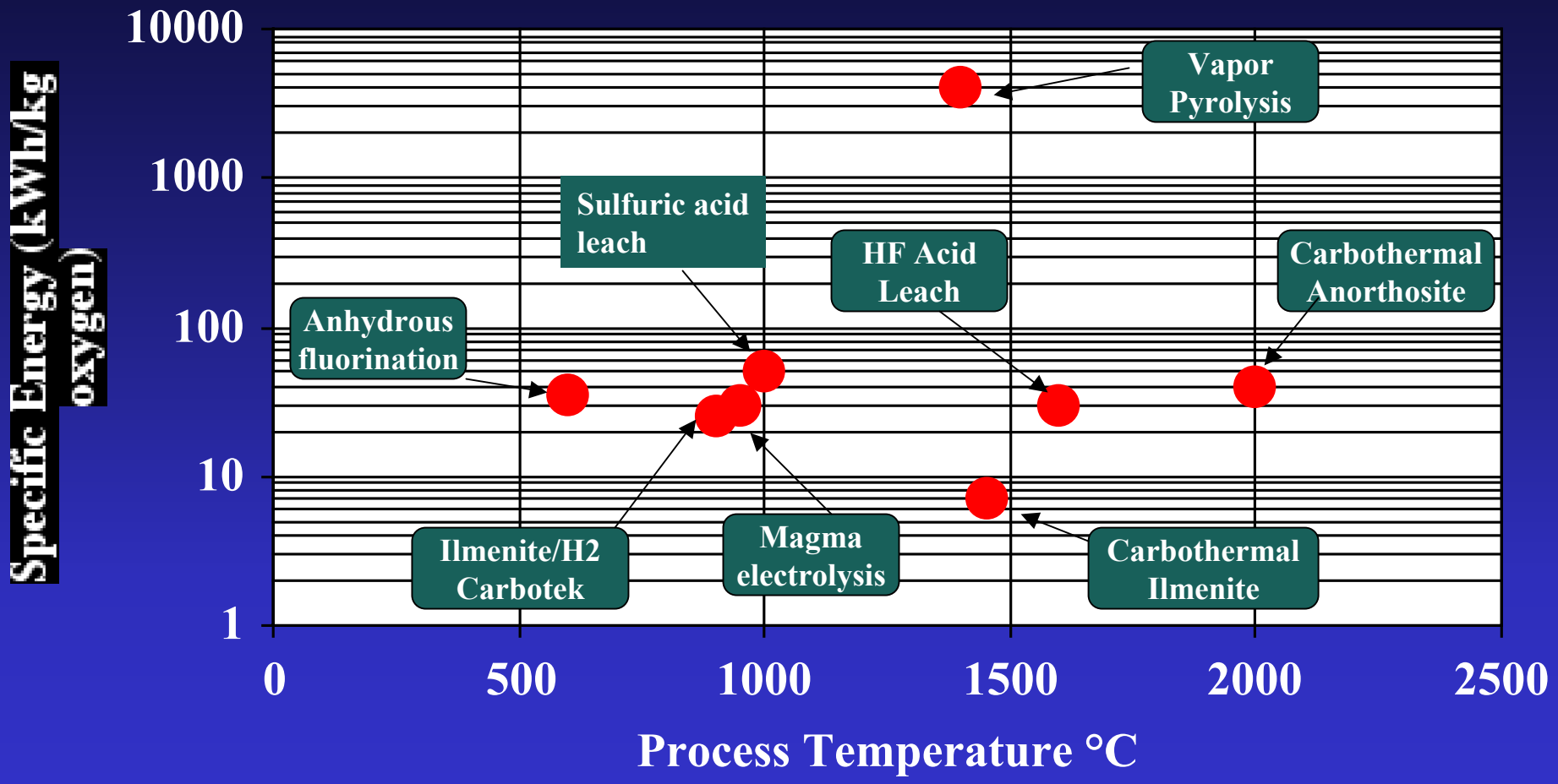


Plasma Separation Processes Rely on the Fact That Metals Remain Ionized at Lower Temperatures Than Non-Metals



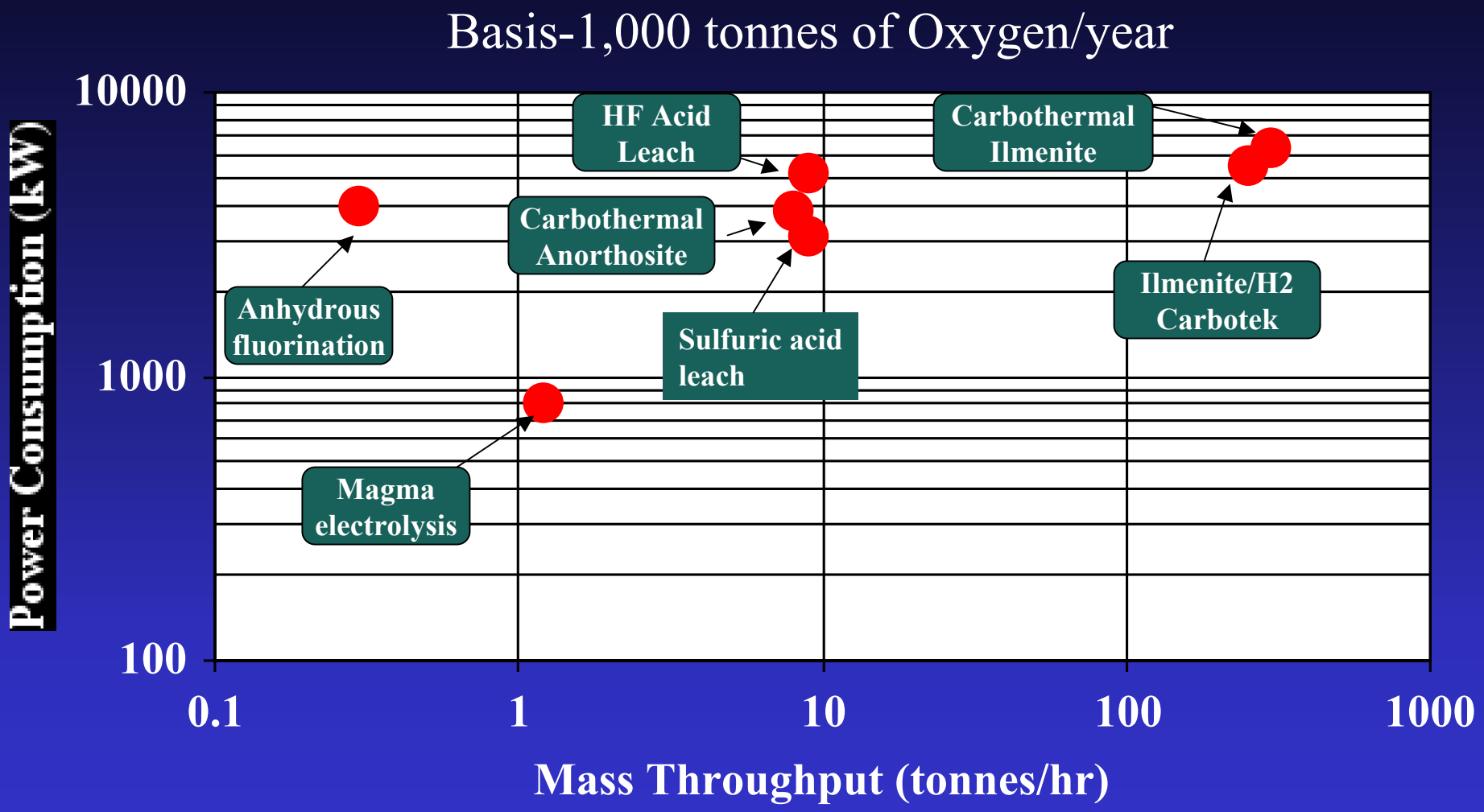
After W. H. Steurer, JPL Pub. 82-41 (1982)

The Majority of Lunar Oxygen Producing Schemes Require Between 20-50 kWh per kg of Oxygen Collected



After L. W. Mason, p. 1139, in Space 92, ASCE (1992)

The Ilmenite-Based Processes Require the Highest Mass Throughput and Power Consumption



After L. W. Mason, p. 1139, in Space 92, ASCE (1992)

Conclusions

- There are many ways to produce Oxygen on the lunar surface
- Hydrogen could play an important role in oxygen production
- Most of the methods could be tested on the Earth

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