# Extraction Techniques-Oxygen

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Lecture 13

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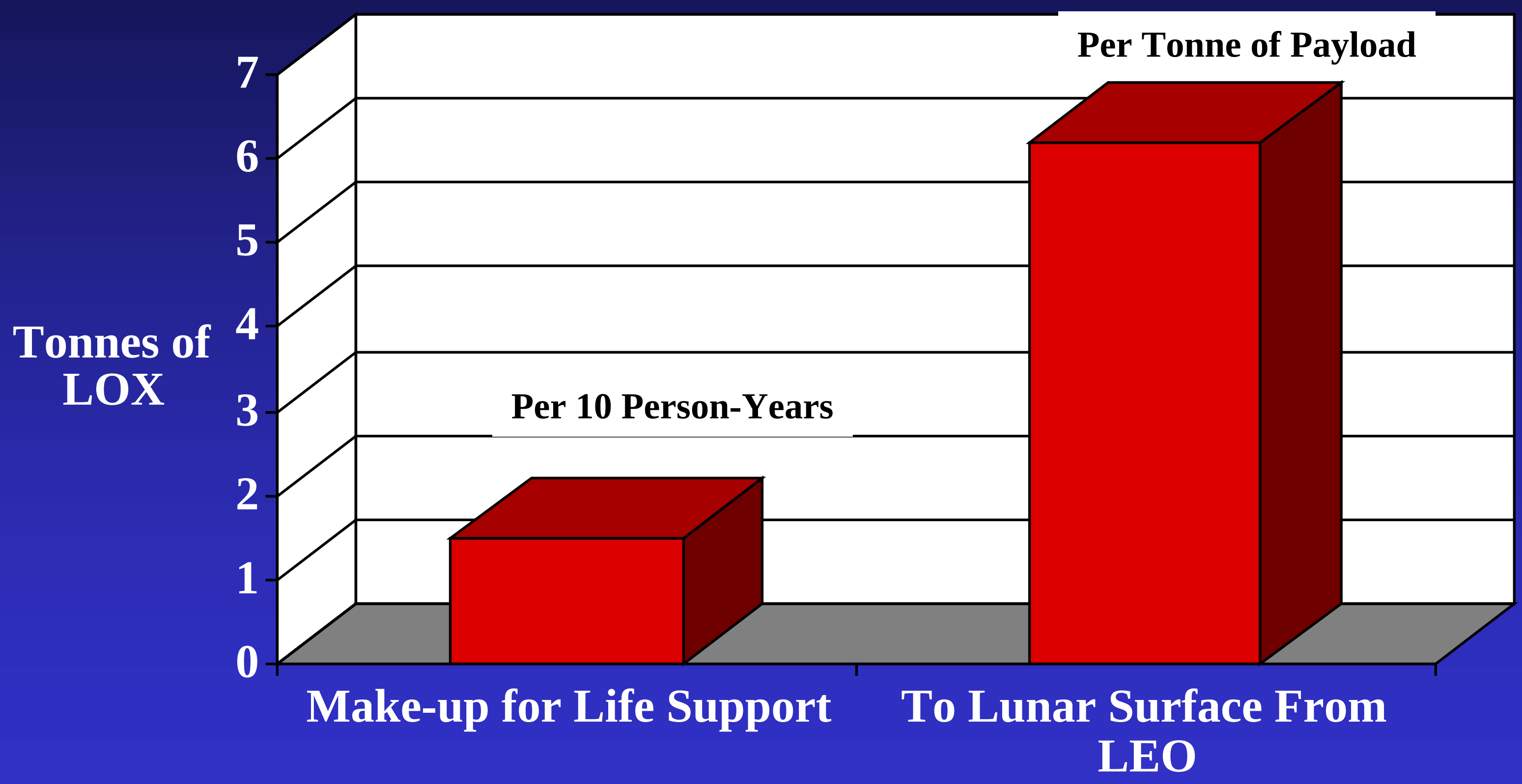
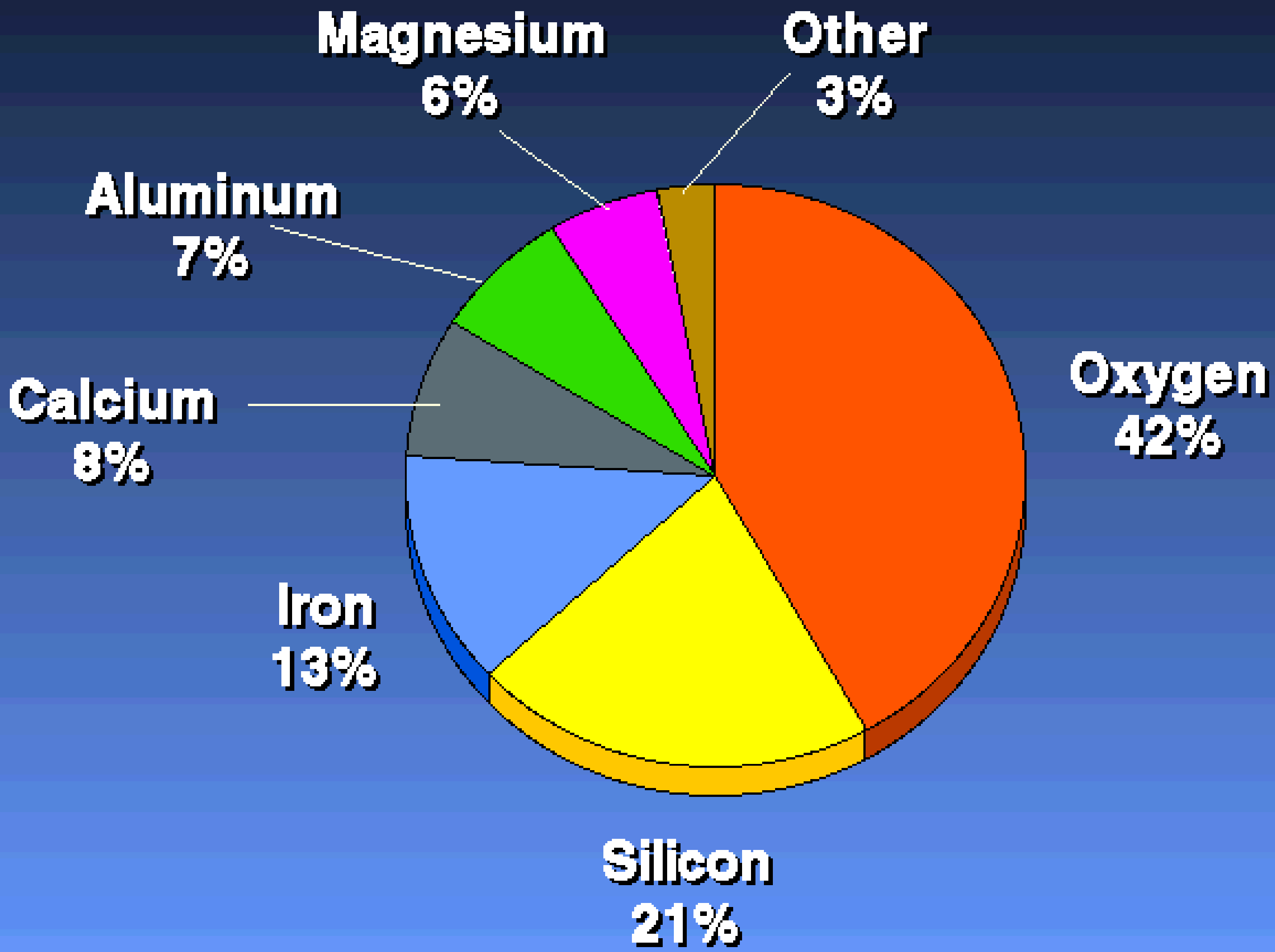
# There are Obvious Needs for Oxygen in a Lunar Base Scenario



# Lunar Soil Composition

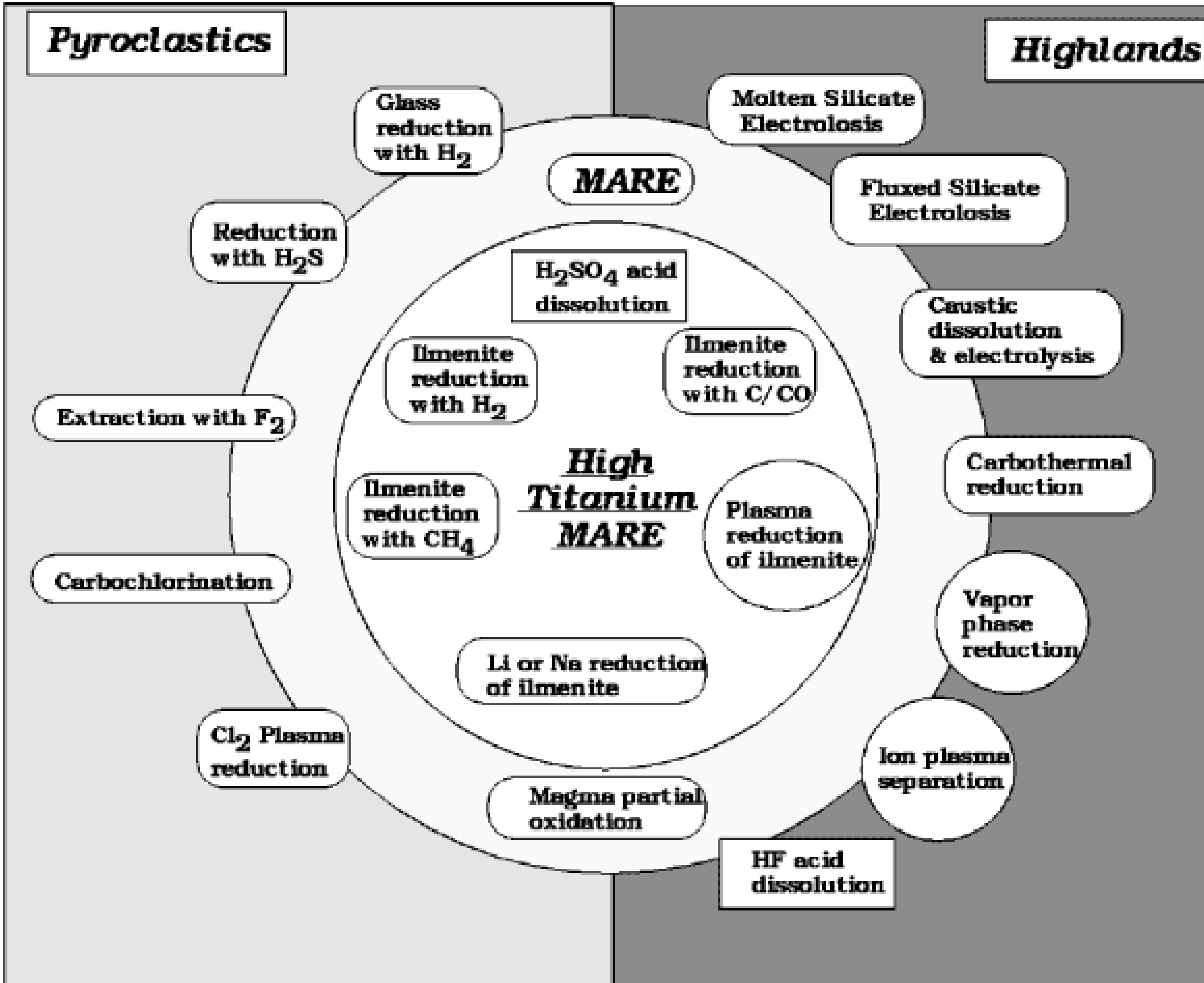


# There at Least 20 Ways to Extract Oxygen from Lunar Material

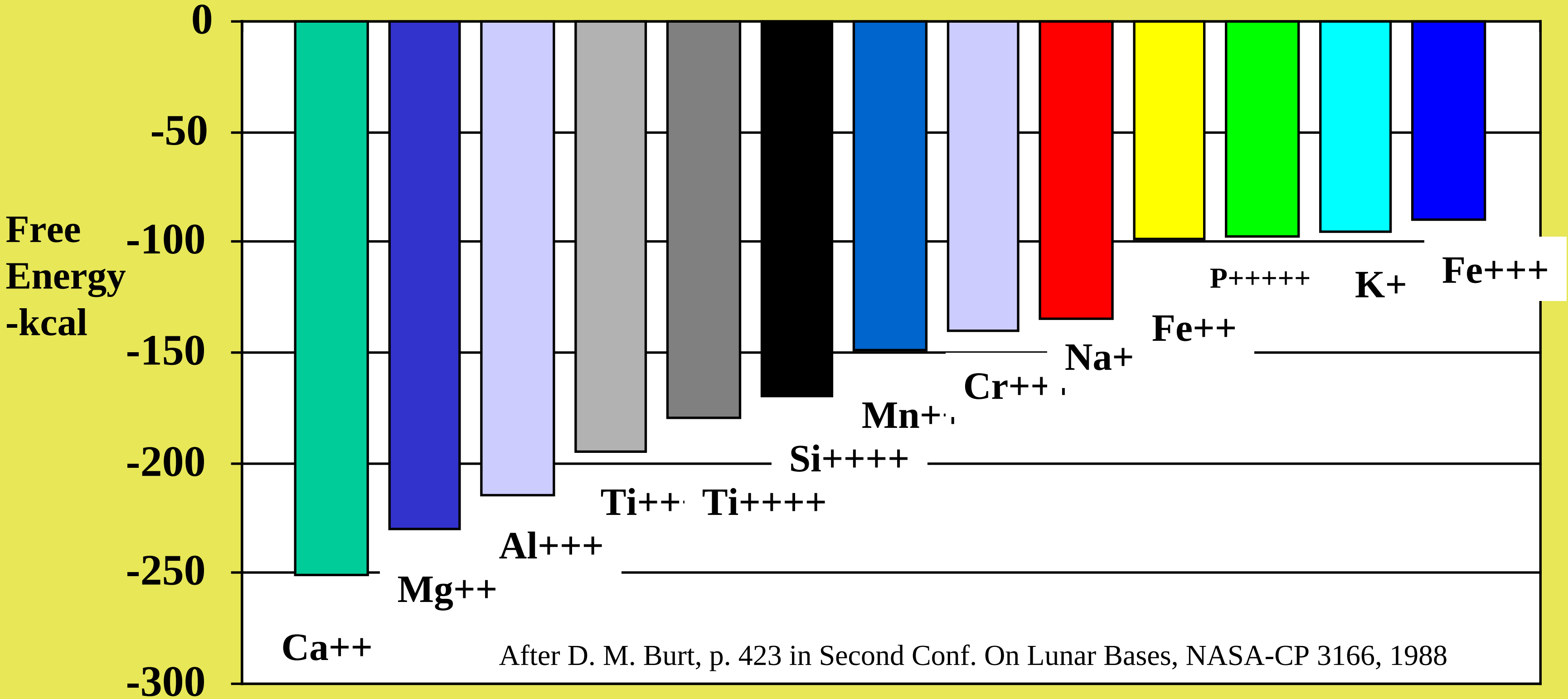
*Taylor & Carrier (1993)*

| | Solid/Gas Interaction | Silicate/Oxide Melt | Pyrolysis | Aqueous Solutions |
| --- | --- | --- | --- | --- |
| Most Favored | **Ilmenite Reduction With $H_2$**<br>**Glass Reduction With $H_2$** | **Molten Silicate Electrolysis**<br>**Fluxed Silicate Electrolysis** | **Vapor Phase Reduction** | |
| Possible | **Ilmenite Reduction C/CO**<br>**Ilmenite Reduction $CH_4$**<br>**Plasma Reduction $Cl_2$**<br>Reduction $H_2S$ | **Caustic Dissolution & Electrolysis**<br>**Carbothermal Reduction** | **Ion Plasma Separation** | |
| Long Shot | **Carbochlorination**<br>**Extraction with $F_2$** | **Magma Partial Oxidation**<br>**Li or Na Reduction of Ilmenite** | **Plasma Reduction of Ilmenite** | **HF**<br>**$H_2SO_4$** |

# 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



# 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% |

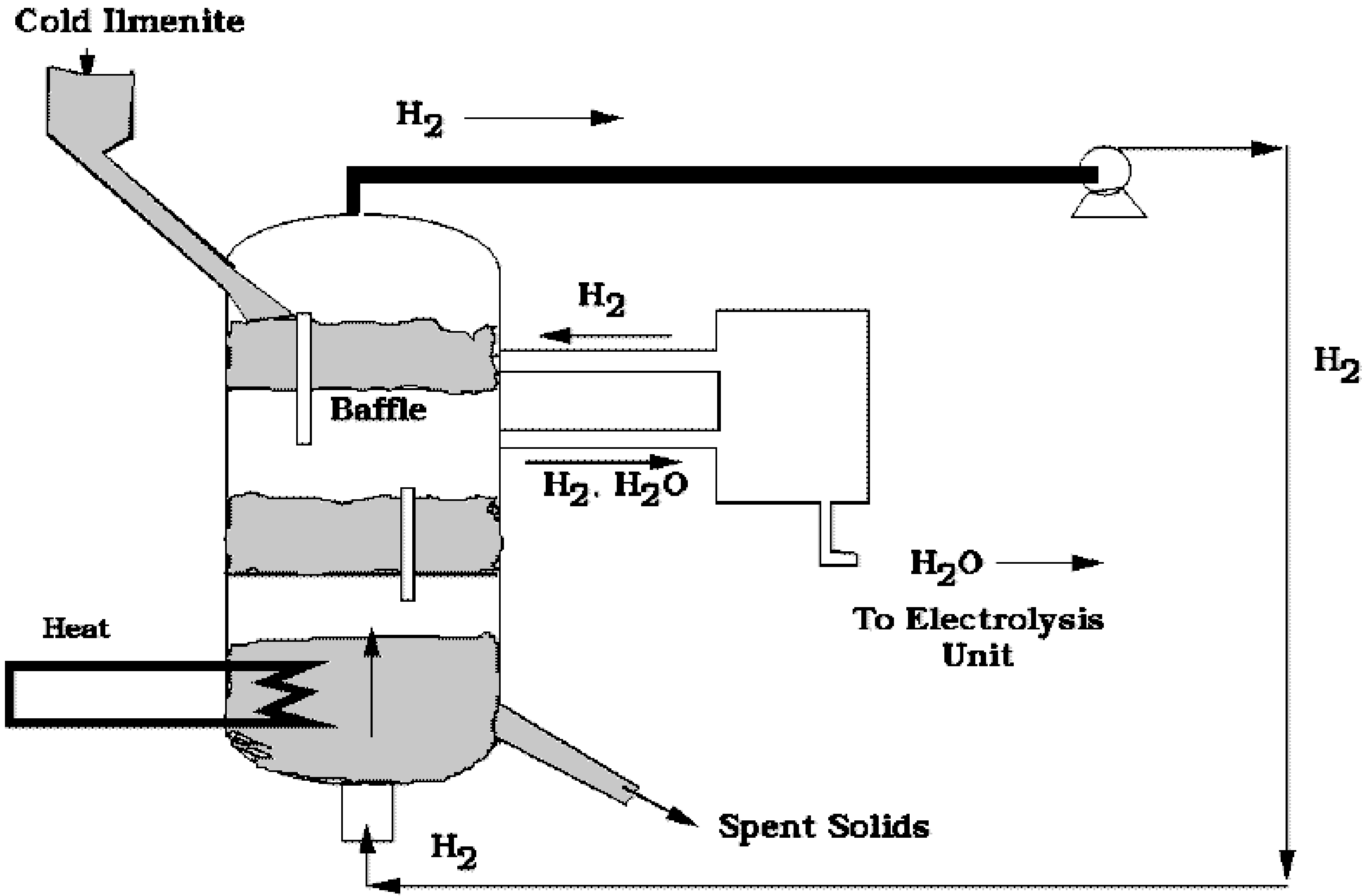
(Can be beneficiated from Mare Basalt rocks and Mare soils)

## Reduction Reaction

$$FeTiO_3 + H_2 \text{<--->} Fe + TiO_2 + H_2O$$

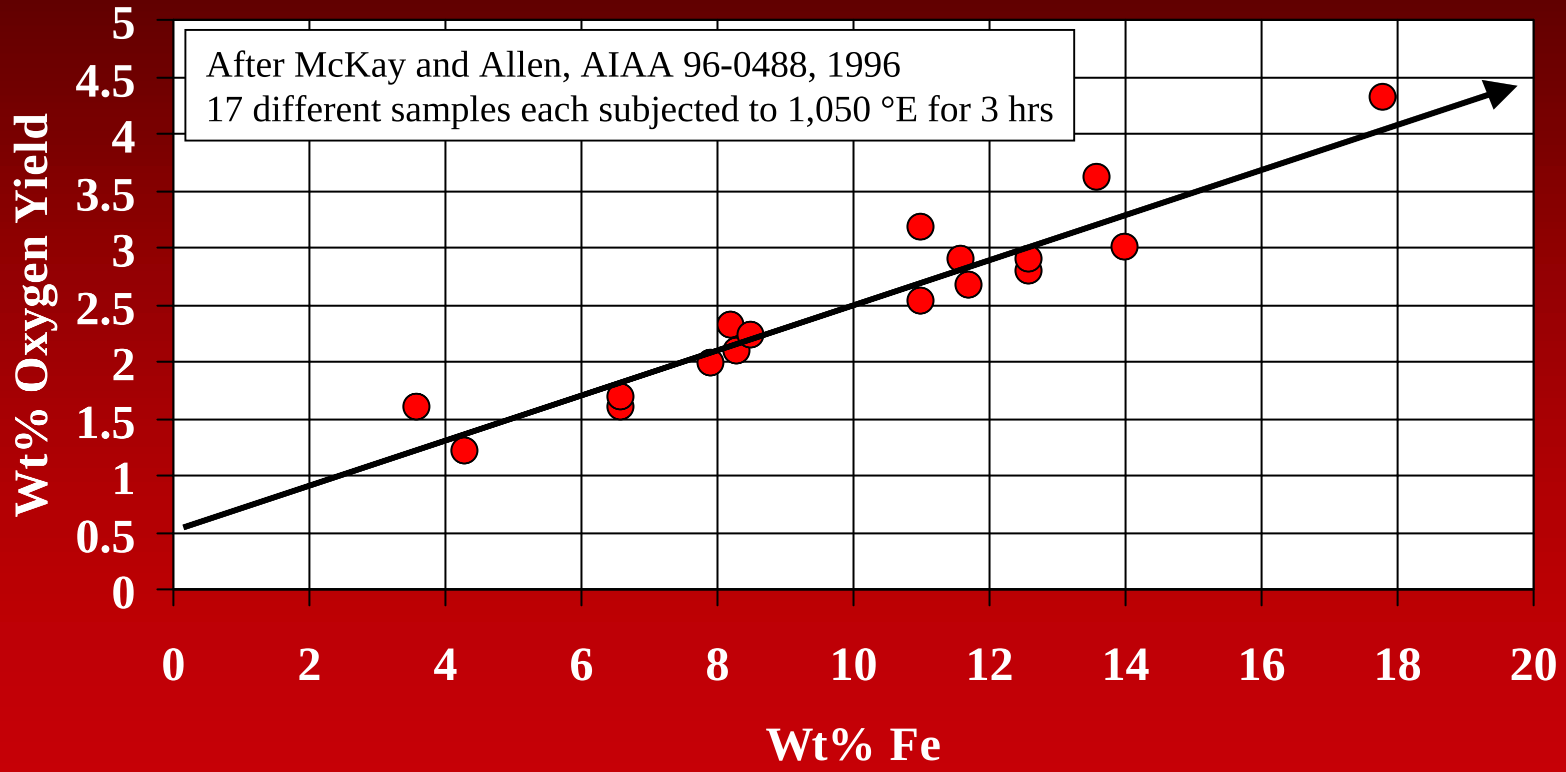
# Carbotek, Inc. has Patented a Hydrogen-Reduction TechniqueUsing a Fluidized Bed

***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.

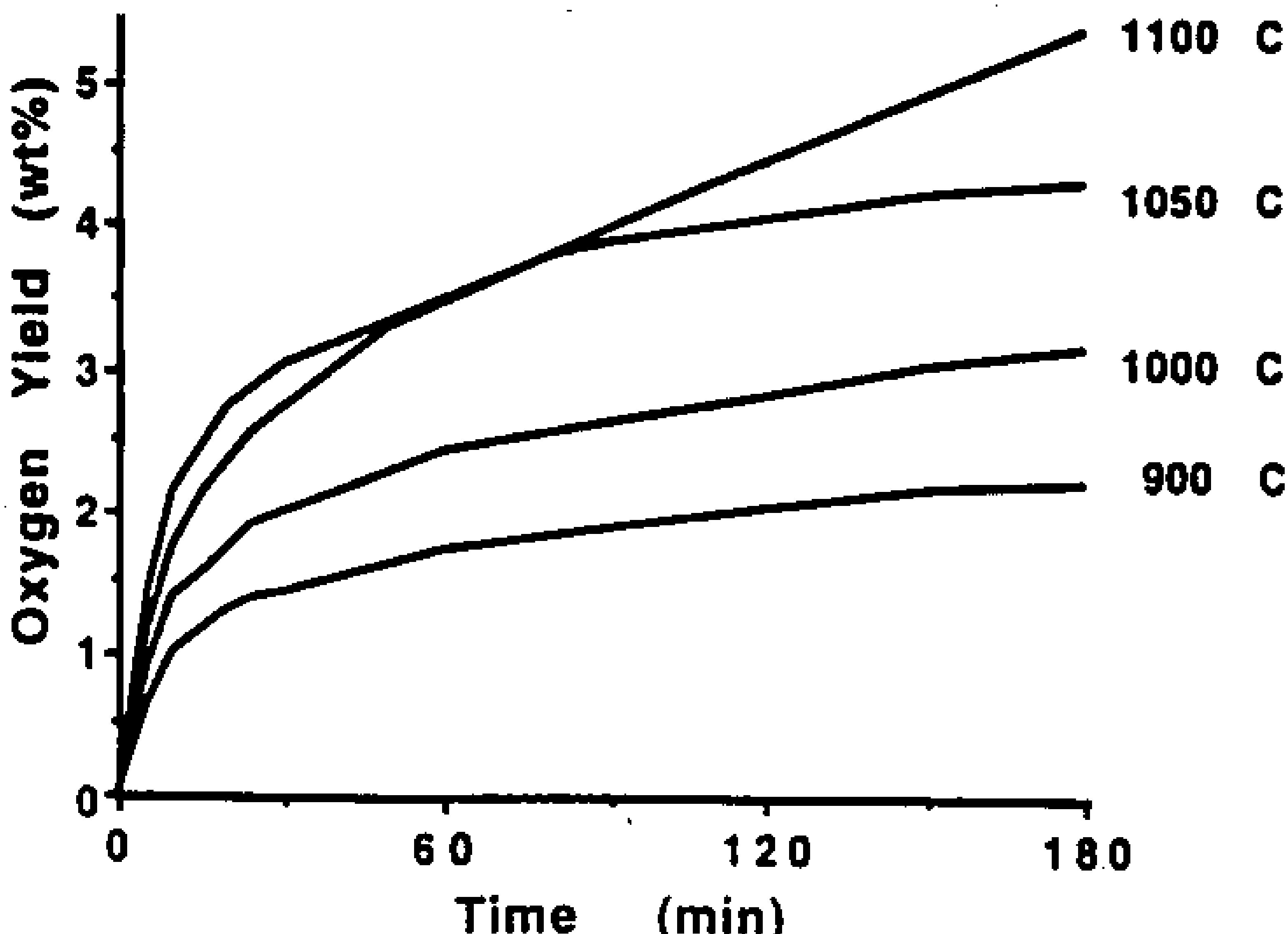
  – **$FeO$ (glass) + $H_2$ <---> $Fe°$ + $H_2O$**

  – **$2\ H_2O$ <---> $2H_2 + O_2$**

- 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
  - $FeTiO_3 + CO$ <--> $Fe + TiO_2 + CO_2$
  - $2\ CO_2$ <--> $2\ CO + O_2$

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

# Oxygen Can Be Extracted From Molten Silicates

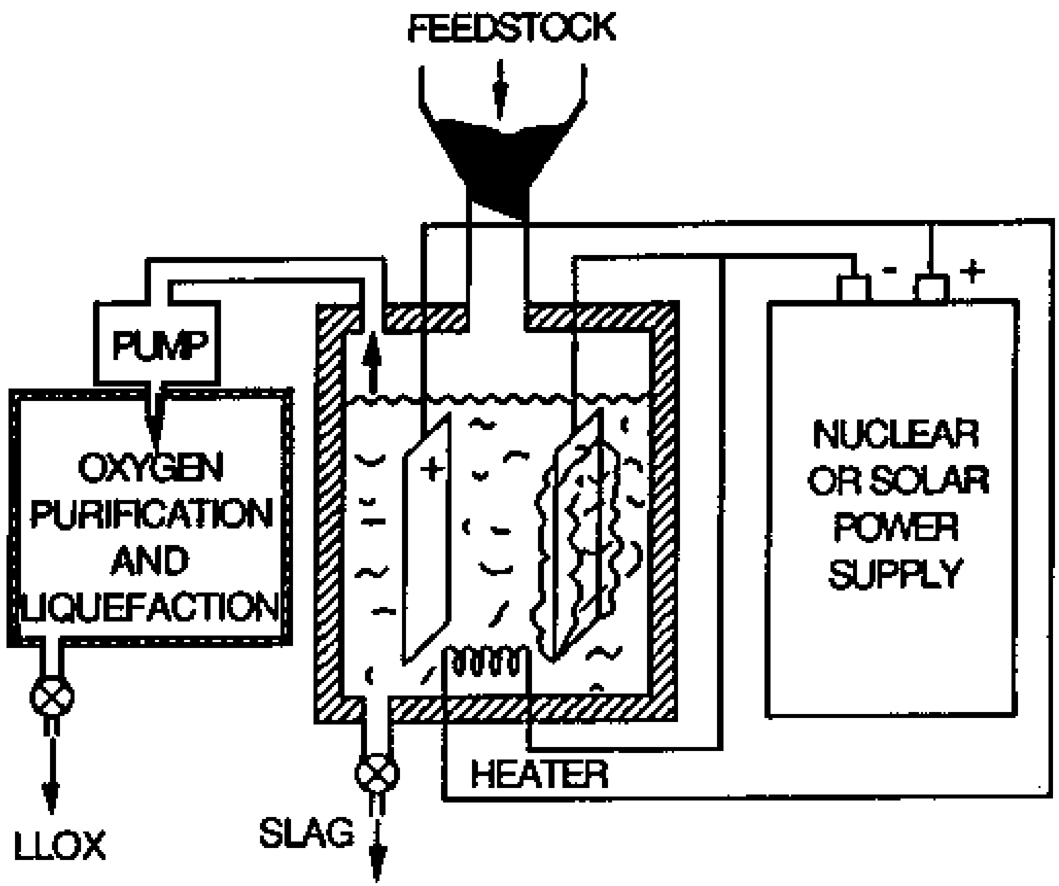
**Anorthite**
**$CaAl_2Si_2O_8$**

**Olivine**
**$(Mg,Fe)_2Si_2O_4$**

**Pyroxene**
**$Ca(FeMg)Si_2O_6$**

**Chromite**
**$FeCr_2O_4$**

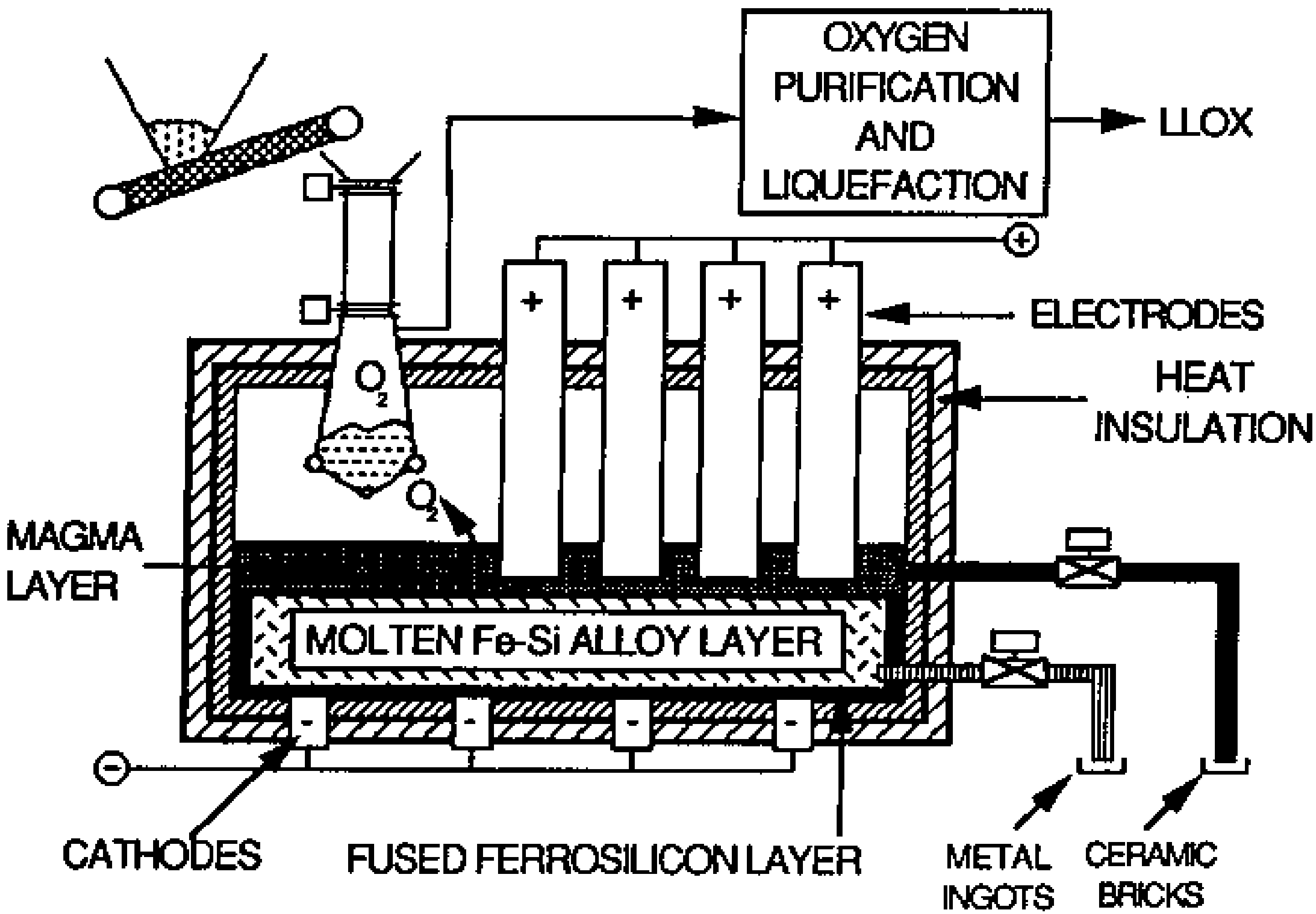
**Ilmenite**
**$FeTiO_3$**




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

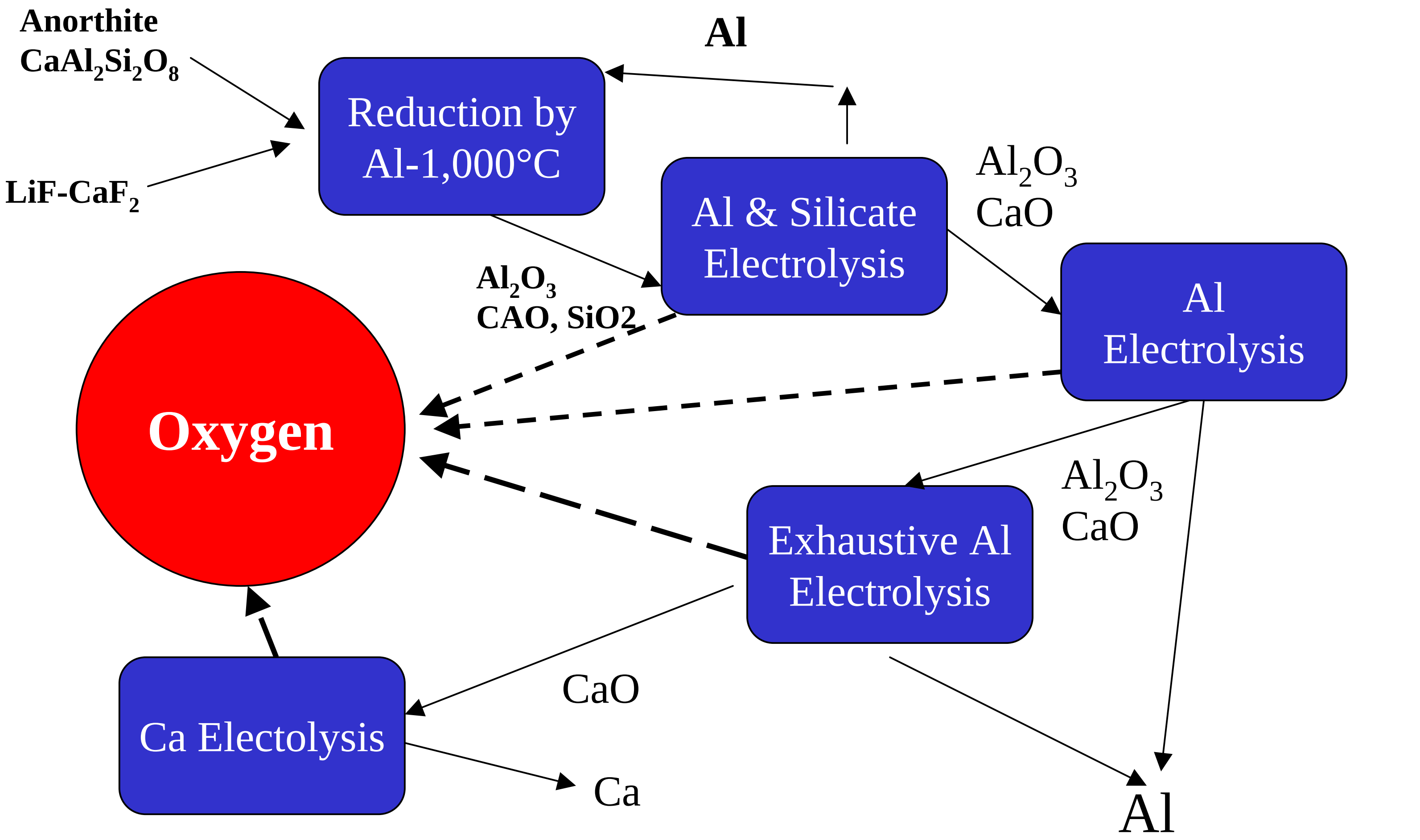
After L. A Taylor and W. D. Carrier III, in Resources of Near-Earth Space, Univ. of Arizona Press, (1993)

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

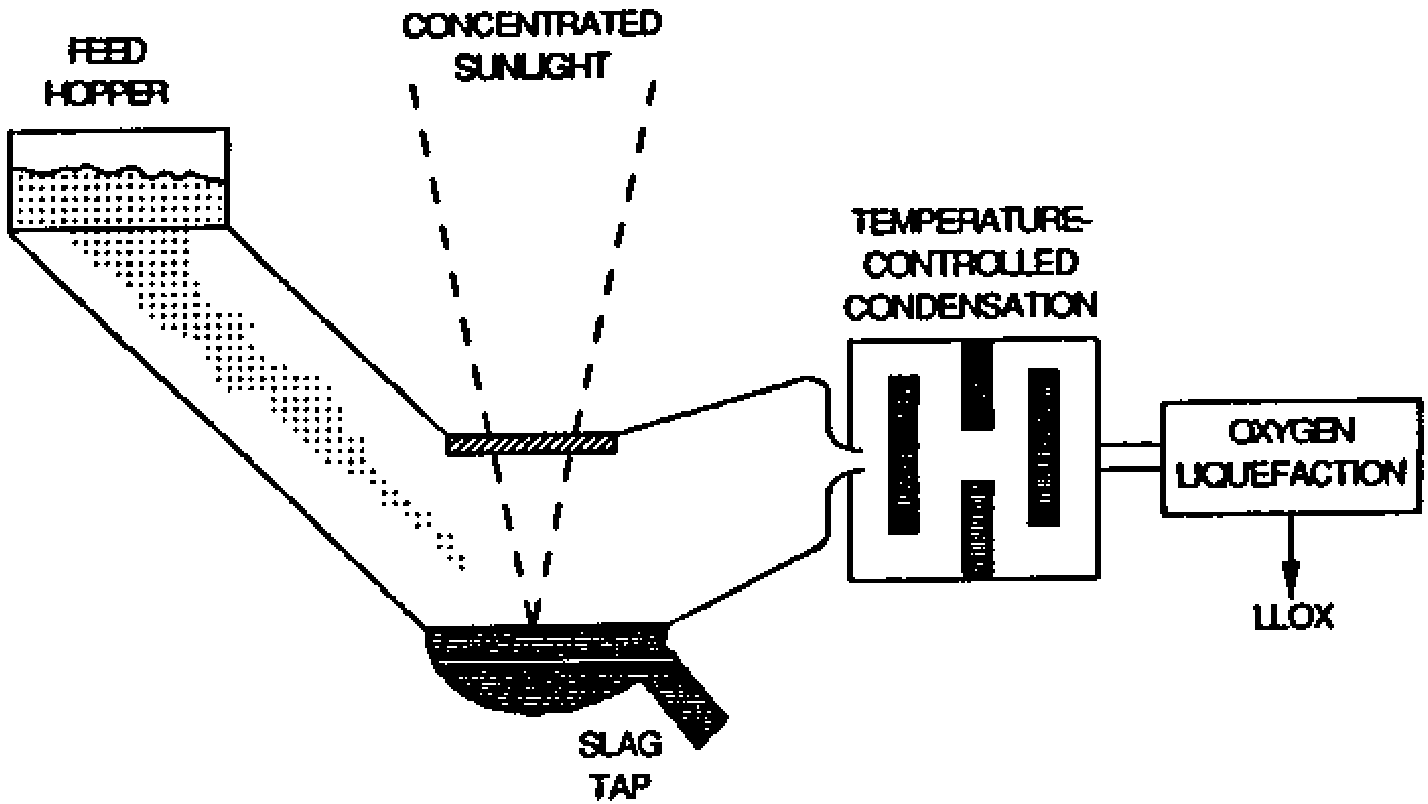



After McCullough and Mariz (1990), "Lunar Oxygen Production via Magma Electroysis", in Engineering, Construction and Operations in Space II: Proc. Space 90 (New York: Amer. Soc. of Civil Engrs.), pp. 347-356.

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

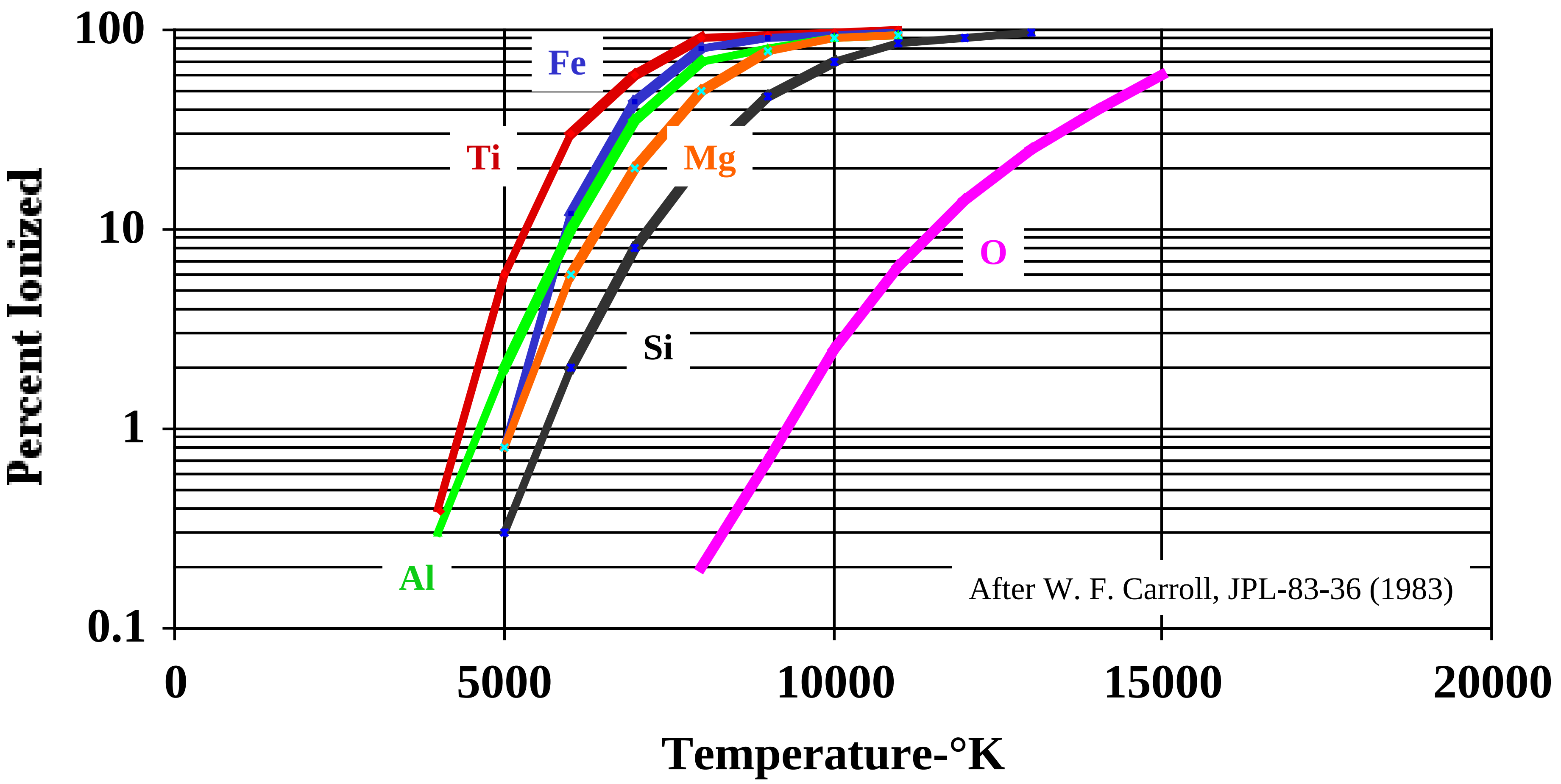


# Vapor Phase Reduction Utilizes Temperatures From 2,000 to 10,000 °K

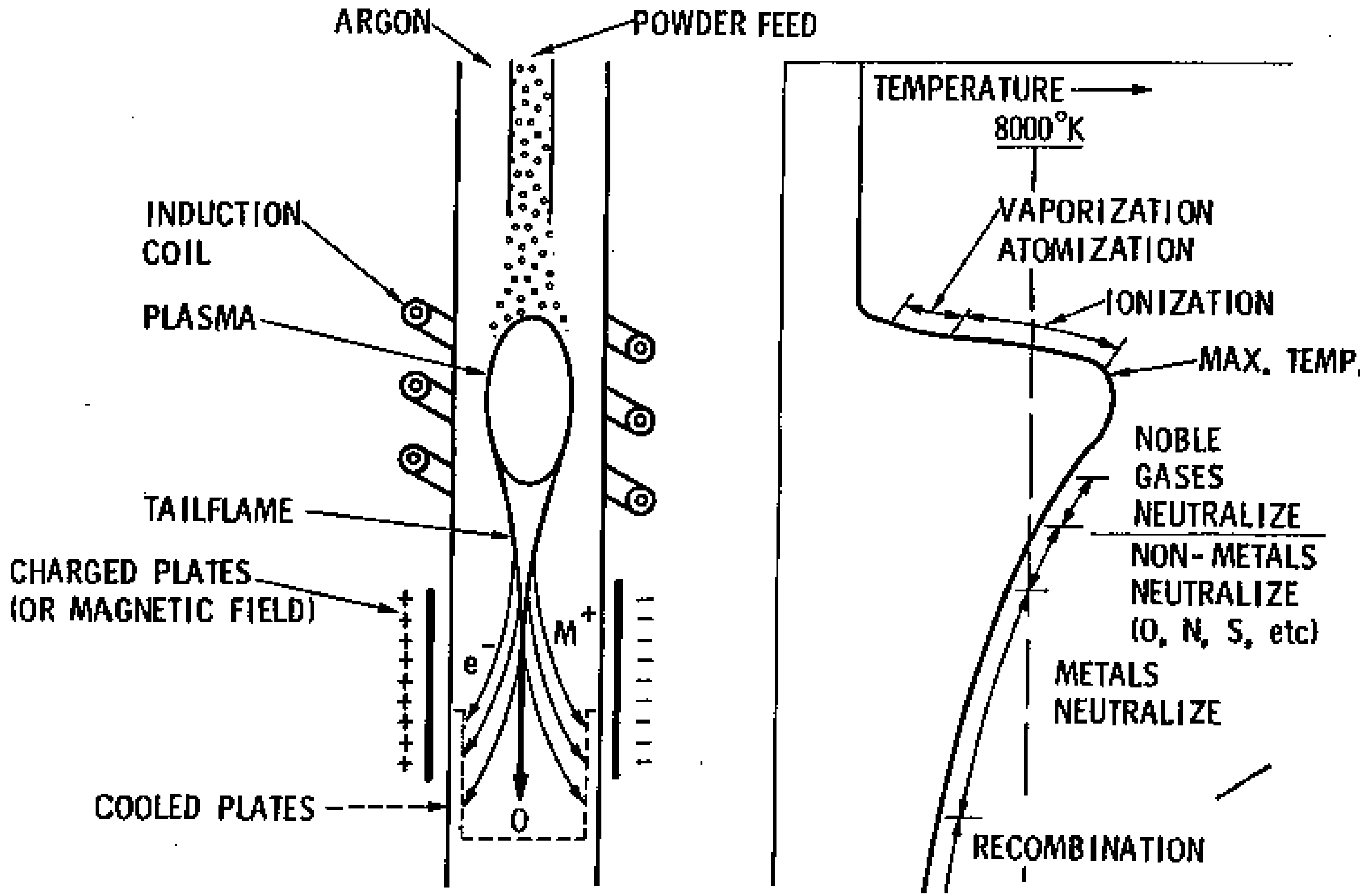



After L. A Taylor and W. D. Carrier III, in Resources of Near-Earth Space, Univ. of Arizona Press, (1993)

# The Metals in Lunar Material Ionize at Lower Temperatures Than Oxygen

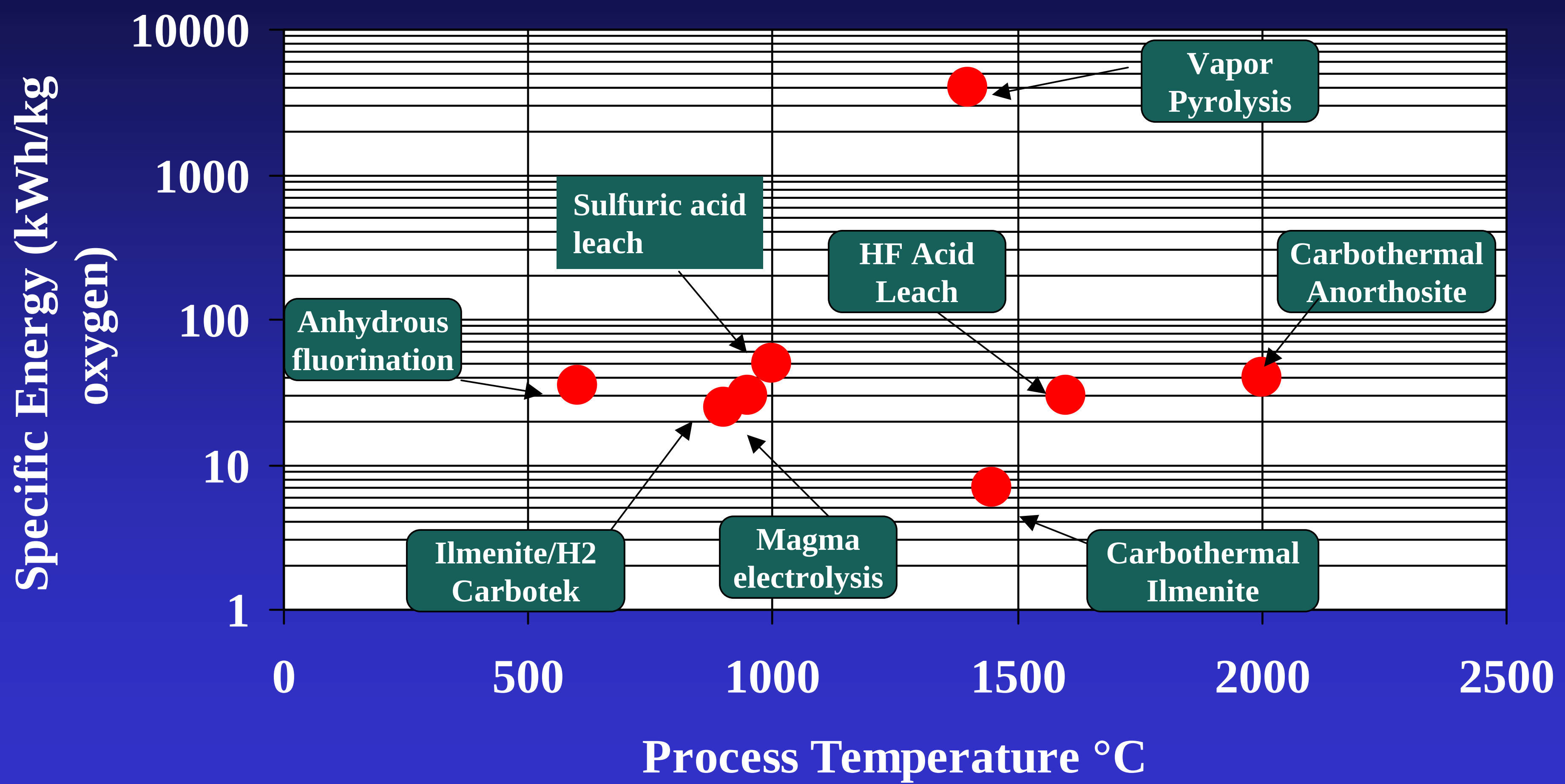


# Plasma Separation Processes Rely on the Fact That Metals Remain Ionized at Lower Temperatures Than Non-Metals



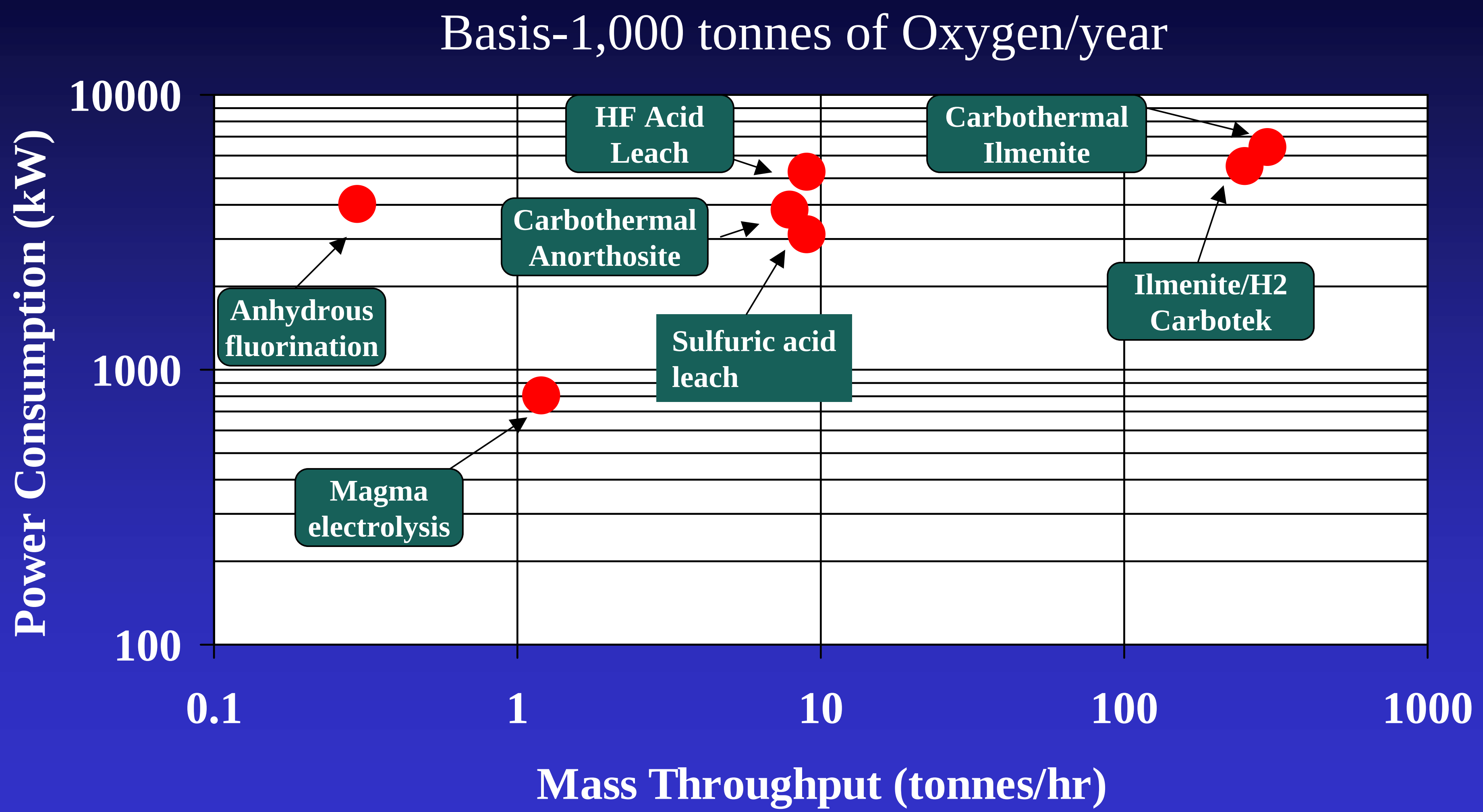

After W. H. Steurer, JPL Pub. 82-41 (1982)

# 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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