Production of Solar Cells in Space from Non Specific Ores by Utilization of Electronically Enhanced Sputtering

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An ideal method of construction in space would utilize some form of the “Universal Differentiator” and “Universal Constructor” as described by Von Neumann (1). The Universal Differentiator is an idealized non ore specific extractive device which is capable of breaking any ore into its constituent elements, and the Universal Constructor can utilize these elements to build any device with controllability to the nanometer scale. During the “Human Exploration Initiative” program in the early 1990s a conceptual study was done (2) to understand whether such devices were feasible with near term technology for the utilization of space resources and energy. A candidate system was proposed which would utilize electronically enhanced sputtering as the differentiator. Highly ionized ions would be accelerated to a kinetic energy at which the interaction between them and the lattice elections in the ore would be at a maximum. Experiments have shown that the maximum disintegration of raw material occurs at an ion kinetic energy of about 5 MeV, regardless of the composition and structure of the raw material. Devices that could produce charged ion beams in this energy range in space were being tested in the early 1990s. At this energy, for example an ion in a beam of fluorine ions yields about 8 uranium ions from uranium fluoride, 1,400 hydrogen and oxygen atoms from ice, or 7,000 atoms from sulfur dioxide ice. The ions from the disintegrated ore would then be driven by an electrical field into a discriminator in the form of a mass spectrometer, where the magnetic field would divert the ions into collectors for future use or used directly in molecular beam construction techniques. The process would require 10-7 Torr vacuum which would be available in space or on the moon. If the process were used to make thin film silicon solar cells (ignoring any energy inefficiency for beam production), then energy break even for solar cells in space would occur after 14 days.


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First International Symposium on Nanotechnology,
Energy and Space,

Center for Adv. Materials at U. Houston,
Clear Lake Hilton, Houston Texas
26 October 2009
Super Automation using Space Resources

Advanced Automation for Space Missions
NASA CP 2255
Proceedings of the 1980 NASA ASEE Summer Study, Santa Clara California

Self-Replicating Lunar Manufacturing Facility

- 100-ton seed (4 Apollo Landings) produces 100-tons same materials
- for simple exponential doubling growth
  \[ T = 1 + \log_2 N, \text{ where } T \text{ is elapsed time, } N = \text{ number of seeds} \]
- Then Productivity, \( P \), in tons/year is, \( P = 100 \times \log_2 N \)
- If each unit works only on replicas and units cooperate in replication,
  - We get “fast exponential” growth where \( T = 1 + \frac{1}{2} + \ldots + \frac{1}{N} \)
- In 18 years expansion we have 4 billion tons which is roughly the entire industrial output of humanity (1980).
What would be the Ideal technology for construction in Space?

- **Robots in the Desert Story**
- **Universal Differentiator**
  - Has the ability to take any ore or other complex material and break it down into its constituent elements.
- **Universal Constructor**
  - Has the ability to construct any device including a copy of itself from a soup of elements of constituent parts.
- With sufficient material and energy Space industrial capacity develops exponentially.

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Schematic view of a particle beam differentiator
Schematic view of an element collector
Schematic view of a molecular beam assembler
Humans in the Loop Self-Reproducible Self-Sufficient Habitat in Free Space

<table>
<thead>
<tr>
<th>Habitat Geometry</th>
<th>Number of People/unit</th>
<th>Planned US Launch capability</th>
<th>Testable on the Moon</th>
</tr>
</thead>
<tbody>
<tr>
<td>O’Neill Cylinders</td>
<td>2,000,000</td>
<td>Beyond</td>
<td>No</td>
</tr>
<tr>
<td>Bernal sphere</td>
<td>20,000</td>
<td>Beyond</td>
<td>No</td>
</tr>
<tr>
<td>Stanford Torus</td>
<td>10,000</td>
<td>Beyond</td>
<td>No</td>
</tr>
<tr>
<td>Bolo (1975)</td>
<td>200</td>
<td>Difficult</td>
<td>Difficult</td>
</tr>
<tr>
<td>Homestead Bolo</td>
<td>10</td>
<td>Yes</td>
<td>Yes</td>
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</table>
Affordable Space Solar Power + Human Colonies in Free Space
Built using Lunar and Asteroid Materials

Sun pumps out $4 \times 10^{26}$ watts (40 million times the needs of even a projected Solar System Society).

Senate Committee on Aero and Spa. Sci. Dr. O’Neill, 1976
Solar Power Satellite – “the killer app.”

Space Solar Power Satellite suggested by Dr. Peter Glasser in 1968
21 by 5 km Satellite would provide 10 GW to Earth by Microwave Beam

“No alternative at all was found to the manufacture of solar satellite
Plants as the major commercial enterprise of the colony.”
A Comparison of small bolos to the 1975 NASA Ames project using an almost identical model (1975 economics). This shows the economic benefit of early spaced based labor achieved through smaller permanent habitats.
Lunar Soil Composition

- Oxygen: 42%
- Silicon: 21%
- Iron: 13%
- Calcium: 8%
- Aluminum: 7%
- Magnesium: 6%
- Other: 3%
### Engineering with Lunar Elements

<table>
<thead>
<tr>
<th>Lunar Elements Only</th>
<th>Material Class</th>
<th>Lunar Elements Plus ~ 5% or Less Earth Imports</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Capacity</td>
<td>Limited Capacity</td>
</tr>
<tr>
<td></td>
<td>High Capacity</td>
<td>Limited Capacity</td>
</tr>
<tr>
<td>Al</td>
<td>Mg</td>
<td>Fe</td>
</tr>
<tr>
<td>Wgt</td>
<td>BC</td>
<td>0</td>
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<tr>
<td>EC</td>
<td>1060</td>
<td>M1A</td>
</tr>
<tr>
<td>1100</td>
<td>A3A</td>
<td>1340</td>
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<td>2</td>
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<td>5510</td>
<td>5056</td>
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<tr>
<td>5310</td>
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<td>5154</td>
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<td>6101</td>
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<tr>
<td>Cast</td>
<td>A13</td>
<td>2</td>
</tr>
<tr>
<td>Al</td>
<td>Mag 35</td>
<td>2</td>
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**Waldin and Criswell**

14
# Engineering with Lunar Elements 2

<table>
<thead>
<tr>
<th>Material</th>
<th>Composition</th>
<th>Reinforced metals</th>
<th>Structural non metals</th>
<th>Electric / magnetic Materials</th>
<th>Conductors</th>
<th>Resitance alloys</th>
<th>Semiconductors</th>
<th>Dielectrics / ins.</th>
<th>Magnetics</th>
<th>Electrodes</th>
<th>Abrasives</th>
<th>Fluid / Volatiles, Cryogenic ambient mp &lt; 500 CNaH</th>
<th>Hydrosolutes, H3PO4, H2SO3, H3PO4</th>
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<tbody>
<tr>
<td>A12O3 in Al, Mg Fe, Glass in Mg, Ti5Si3 in Ti</td>
<td>A12O3 in Ni SiO2 in Ni</td>
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<tr>
<td>Cast Basalt, Dark Glass, Foamed Glass</td>
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<td></td>
<td>Structural non metals</td>
<td>Structural non metals</td>
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<tr>
<td>Al2O3, CaO, MgO, TiO2, SiO2, Spinel, Mixed ceramics, “S” fiber, Ti5Si3</td>
<td>Cr2O3, K2TiO3</td>
<td>Thermal materials, refractory insulation, fibers</td>
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<td>Fe, Al, Mg, Kanthal A-1</td>
<td>Ni-Cr</td>
<td>Conductors</td>
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<tr>
<td>Si</td>
<td>A1P, FeS2, NiO, CoO</td>
<td>Semi conductors</td>
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<td>Same as thermal except Ti5Si3 + titmates</td>
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<tr>
<td>Fe, Si—steels (M15, M5-8) Fe3O4, MgFe2O4, sendust</td>
<td>Permalloy Permendur Cr3</td>
<td>Magnetics</td>
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<td>Fe3O4, TiO</td>
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<tr>
<td>Same as refractory except CaO + garnets</td>
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<tr>
<td>O2, O3</td>
<td>SO2, SO#, CrO3</td>
<td>Fluid / Volatiles, Cryogenic ambient mp &lt; 500 CNaH</td>
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<td></td>
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<td>H2O (11%), H2O2 (6%), H2SO4, H2SO3, H3PO4</td>
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<td>H2S (6%), H3P (9%), Na2OH</td>
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Waldin and Crisswell
In Space Propulsion using Space Resources

Ultra Thin (2-3 micron) 
Ultra large surface area

Near Earth Asteroid

Nuclear Steam Engine 
Space Propulsion Economy

Ultra high performance solar sails – 
Thinner and higher surface area 
Than practical to launch from Earth

From K.E. Drexler, MIT, 1979
Advances in Power Production

Example:

Lunar Photovoltaic Power

- Small Rover evaporates lunar regolith thin films on lunar glass
- Predicted Energy Break Even $< 1$ Lunar Day
- Predicted Grown Power $> 100$ KW / year / rover

Production of O$_2$ from Lunar Regolith (1 kT O$_2$/yr basis)
GROWTH INTO TOWNS AND CITIES

(a) Cylinder, Outside View.  
(b) Sphere, Outside View.  
(c) Toris, Outside View.  
(d) Cylinder, Inside View.  
(e) Sphere, Inside View.  
(f) Toris, Inside View.

- **Habitat**
  - 10 People
- **Propulsion**
- **Manufacturing**
- **Farm**
- **Shield**
- **1 g**
- **0 g**
- **5 m**
- **22 m**
- **1 km**
- **1 RPM**

* Shielded Transport