Lunar Solar Power (LSP) System: Practical Means to Power Sustainable Prosperity*

Dave Criswell¹

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¹Inst. for Space Systems Operations, University of Houston and University of Houston-Clear Lake, Houston, TX  (mailto:drcriswell@comcast.net)

Abstract

The world now consumes ~ 14 terawatts of commercial thermal power (14 TWt). The surface of our Moon independably intercepts 13,000 TWs of solar power. This Lunar Solar Power is converted on the Moon into to electric power and then to beams of ~2.5 GHz microwaves to which Earth's atmosphere is transparent. Beam receivers on Earth convert the low-intensity microwaves (≤ 20% of sunlight) to commercial electric power. A given receiver outputs ~200 W/m2 of load following electric power to its regional electric grid. LSP facilities are made from the local lunar materials by small manufacturing units transported from Earth to the Moon (http://www.tipmagazine.com/tip/INPHFA/vol-8/iss-2/p12.pdf article and subsequent letters to the editor). The LSP System can quickly grow to provide ≥ 2 kWe/person to 10 billion people, ≥ 20 TWe, and enable GWP ≥ 800 T$/y. For scale, at 33% efficiency for oil-to-electricity ~ 1,000 million barrels of oil per day must be burned to produce the 20 TWe.
LUNAR SOLAR POWER (LSP) SYSTEM: PRACTICAL MEANS TO POWER SUSTAINABLE PROSPERITY

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DR. DAVID R. CRISWELL
drcriswell@comcast.net
cell 281-728-6063 and 281-486-5019 ph. & fax

To the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS


Denver, CO

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NEED: ADEQUATE GLOBAL POWER

• EXISTING GLOBAL POWER SYSTEM
  – 1 billion “rich” people use electric equivalent of ≥2 kWe/person
  – 5 billion “poor” people use ≤0.6 kWe/person
  – GWP ~ 45 T$
  – Global power use is equivalent of
    • ~220 million barrels of oil/day, or
    • ~4.8 \times 10^{12} \text{ Watts-electric} = 4.8 \text{ TWe}
  – Not renewable, polluting, depends on politically sensitive regions, too expensive for most people, must move molecules

• NEEDED GLOBAL POWER SYSTEM
  – Now (≥2 kWe/person \cdot 6 billion people) ≥ 12 TWe
  – By 2050 10 billion prosperous people will need ≥ 20 TWe
  – Power must be clean, safe, affordable, dependable, & sustainable
  – Power from photons and electrons
  – Can enable GWP > 800 T$ by 2050 (Match W. Europe 42 T$/TWe-Y)
SOLUTION: LUNAR SOLAR POWER SYSTEM

• SUN SENDS 13,000 TWs OF RELIABLE SOLAR POWER TO LUNAR SURFACE
• BASES ON MOON CONVERT SOLAR POWER TO MICROWAVE BEAMS

• BEAMS DELIVER POWER TO RECTENNNAS
  - Safe (<20% of sunlight)
  - Reliable (through clouds, rain, smoke, etc.)

• RECTENNNAS ON EARTH
  - Convert beams to electricity
  - Deliver electricity to power grid
  - ≥200 We/m² or 10*renewables
POWER BEAMING

- SPECIALIZED FORM OF RADAR
- EARTH-TO-MOON DEMONSTRATED BY ARECIBO

- MOON-TO-EARTH BEAMING IS REASONABLE EXTENSION OF EXISTING TECHNOLOGIES
  - Large phased arrays
  - Distributed arrays (ex. VLA)

- MASSLESS POWER LINES
PHASED ARRAY RADAR

• PROJECTED BEAM
  – Near-field peak ~ 25,000 W/m² (5% duty-cycle)
  – Near-field average ~ 130 W/m²
  – Beamed to space equivalent of ~100,000 barrels of oil over 39 years (assume 35% conversion efficiency)

• SPACE GUARD
  – Eglin A.F.B., FL
  – Segmented transmitter (left)
  – Operated 24/7 since 1968
  – Upgraded in 1999 while in full operation
  – Largest of several dozen National Missile Defense units
  – Meet EPA regulations
EARTH’S MOON & LSP POWER BASES

• MOON WITH BASES
  – Receives 13,000 TWs
  – Bases built using known lunar materials in known environment

• 10 POWER BASE PAIRS
  – Always face the Earth
  – Beam ~20 – 30 TWe to Earth

Harvested Moon
DEMONSTRATION LSP BASE

- EARTH IS FIXED IN SKY
- BASE IS COMPOSED OF POWER PLOTS
- POWER PLOT - BASIC UNIT
  - #1 Solar arrays, buried wiring
  - #2 Microwave transmitters
  - #3 Reflectors overlap to form the large power-base aperture as seen from Earth
- #1, 2, & 3 ARE MADE FROM LUNAR MATERIALS BY MOBIL (#4 & #5) & FIXED (#6) PRODUCTION EQUIPMENT

Harvesting the Moon
EXPONENTIAL GROWTH OF POWER PLOTS

- INSTALLATION UNITS (pink) designed so that ~90%, by mass, can be made of lunar materials
- Import additional MANUFACTURING UNITS (red) that make new INSTALLATION UNITS
- Enables exponential growth of POWER PLOTS (yellow)
MASS & COST PROJECTIONS

- 20 TWe BY 2050 & 1,000 TWe-y BY 2070 (WEC18th)

  - 90% local manufacturing on Moon & tele-operation from Earth
  
  - \(1 \cdot 10^5\) km\(^2\) of reflective rectennas on Earth (0.8 T$)*

<table>
<thead>
<tr>
<th>TOTAL MASS TO MOON (tonnes)</th>
<th></th>
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<tbody>
<tr>
<td>Micro-manufacturing</td>
<td>24,361</td>
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<tr>
<td>Hot Forming</td>
<td>10,313</td>
</tr>
<tr>
<td>Beneficiation</td>
<td>3,212</td>
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<tr>
<td>Habitats, shops, mobile units</td>
<td>22,085</td>
</tr>
<tr>
<td>Chemical Refining</td>
<td>2,469</td>
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<tr>
<td>Gather &amp; eject to orbit</td>
<td>438</td>
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<tr>
<td>Excavation</td>
<td>80</td>
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<tr>
<td>Cold Assembly</td>
<td>28</td>
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<tr>
<td>TOTAL</td>
<td>62,915</td>
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<table>
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<tr>
<th>PEOPLE (6 month tours)</th>
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<tbody>
<tr>
<td>Moon</td>
<td>436</td>
</tr>
<tr>
<td>Lunar Orbit</td>
<td>59</td>
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<tr>
<td>Earth Orbit</td>
<td>63</td>
</tr>
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<tr>
<th>LUNAR &amp; SPACE COST (2000$)</th>
<th>0.8 T$</th>
</tr>
</thead>
</table>

| ENGINEERING COST (¢/kWe-h)                  | 0.1    |

- COST DISTRIBUTION
  
  - ~75% first 30 years
  
  - ~12 years breakeven

- TOTAL REVENUE ~80 T$

  @ 1 ¢/kWe-h

- REVENUE NOT INCLUDED

  - Clean energy premium

  - Rectenna area dual-use
**SUN->MOON->EARTH GRID**

- **SOLAR POWER BASES ON MOON**
  - Energize the Moon –> Earth electric grids
  - Powers rectennas worldwide (load following)
    - Sustainable net-new energy
    - Safe (< 20% of sunlight)
    - Reliable (through clouds, rain, smoke, etc.)
    - < 1/10th cost per kWe-h of alternatives
  - Exponential growth of sustainable prosperity

- **LSP System**
  - Based on >1B$ of space power & lunar studies
  - Profitable with 1980s technology
  - Enables sustainable exploration & development of our solar system
RECTENNA ELECTRICITY

• DOES NOT PRODUCE GREENHOUSE GASSES, FUEL SPILLS, NUCLIDES, DUST, INDUSTRIAL WASTES, ETC.
• ELIMINATES NEED FOR HAZARDOUS FACILITIES (OIL, NUCLEAR, DAMS, MINES, ETC.)
• ENABLES REMEDIATION OF ENVIRONMENTAL DAMAGE, REMOVAL OF INDUSTRIAL CO$_2$ FROM ATMOSPHERE, RECYCLING OF GOODS & SYNTHETIC FUELS, DESALINATED & RECYCLED WATER, AND NON-POLLUTING SERVICES AND TRANSPORT
• ALLOWS DUAL USE OF LAND UNDER RECTENNA
• ENABLES BIOSPHERE-INDEPENDENT POWER
20th CENTURY CARBON WEALTH

• 20th CENTURY WEALTH TOOLS
  – Mining & transport
  – O₂ & carbon-fired electric generators
  – Power lines
  – Electric “engines”
  – Electronics

• OUR AIR’S FREE O₂ & MINED FUEL-MOLECULES ARE MOVED & BURNED TO MAKE ELECTRICITY
GREEN CARBON TRANSITION

• ENERGY INDUSTRY GROWTH TO LSP SYSTEM
  – Power beaming
  – Redirectors (space)
  – Rectennas

• BENEFITS
  – Immediate CO₂ sequestration
  – Enhanced recovery of hydrocarbons
  – Secure distribution of electric power
  – Green Carbon Power to users
ENERGY POTENTIAL & ISSUES

- LSP CAN PROVIDE >1 TWe WITHIN 15 YEARS AND EXPONENTIAL GROWTH THEREAFTER
- NO TECHNICAL BARRIERS
  - Key operational technologies are understood (PVs, radar)
  - Key industrial steps can be demonstrated on Earth and then on Moon
  - Small-scale manufacturing can grow using lunar resources
- POLICY & COST ISSUES
  - Permanent legal & industrial system to enable lunar development
  - Joint U.S.-industry LSP demo to enable prudent private investment
  - Microwave spectrum re-allocations
- SUSTAINABILITY
  - > 1 billion years
  - Can use Lunar Solar Power to protect & nurture Earth’s biosphere
  - Can enable humans to settle permanently beyond Earth
OUR SUN, EARTH, & LUNAR POWER

• OUR SUN
  – 26 trillion times our present commercial power
  – Paid for, no operating costs

• OUR POWER SYSTEMS
  – Move molecules globally
  – Push limits of biosphere
  – Limit economic growth

• LUNAR SOLAR POWER SYSTEM
  – Moon directly accesses 13,000 TWs of our sun’s power
  – LSP System uses available & proven technologies
  – Outputs pure electricity at Earth with least infrastructure
  – Enables clean & sustainable exponential economic growth
RECENT LSP REFERENCES