# Lunar Solar Power Generation, "The LUNA RING", Concept and Technology

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SHIMIZU Corporation

Invited Research Scientist
Human Space Technology and Astronauts Department
JAXA

SHIMIZU CORPORATION

JUSTSAP 2009

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- ☑ About SHIMIZU
- ☑ SHIMIZU Future Space Programs
  - Space Robotics for Construction
  - In-situ Resource Utilization
- ☑ SHIMIZU's Dream "LUNA RING"

# Shimizu Profile

History : 1804 founded in Tokyo

Business : Engineering & Construction

Total sales : JP¥1,887.5B. (2009, Shimizu Group)

(US$ 21B.  @1$=¥90)

Institute of Technology :

- R&D for Construction Technologies and Methods, including Space Robotics and Lunar Development
- 266  research scientists and engineers

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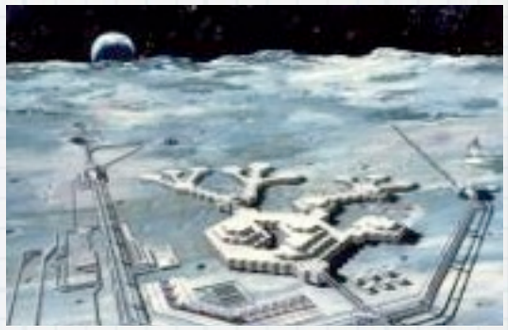
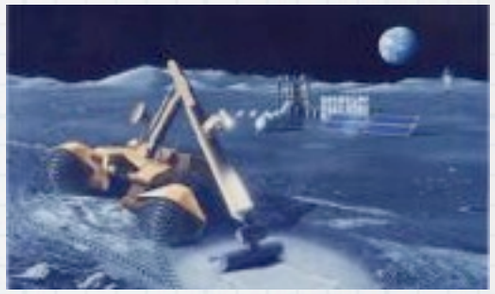
# Space Development @ Shimizu



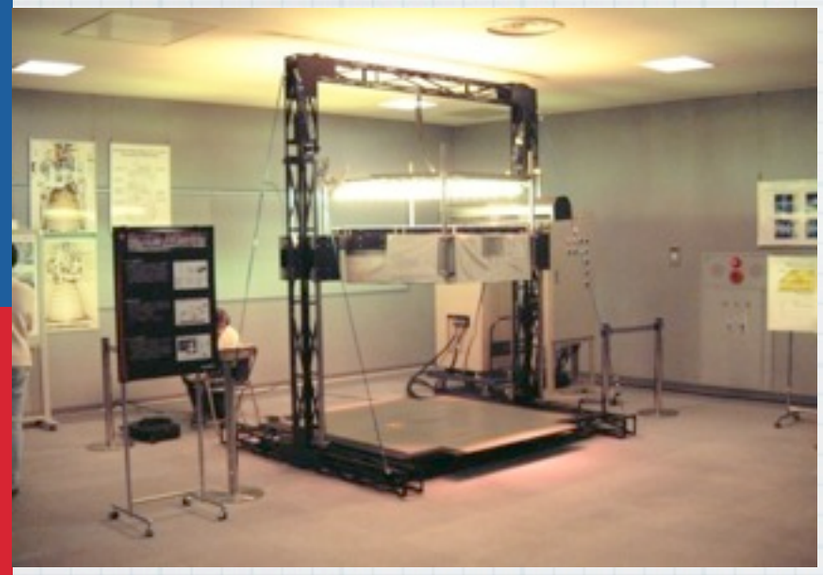


1987: Establish "Space Project Office"

- Establish "CSP-Japan" w/ CSP-Associates
- Concrete Lunar Base Concept
- Space Hotel Concept

Early 1990s: Joint study w/ US organizations.

- Lunar base: McDonnell Douglas, Martin Marietta
- ISRU plant: General Dynamics
- Lunar oxygen production: NASA, Carbotek
- Space robotics: CMU
- Large scale space structure: University of Colorado



Late 1990s: Development

- Telerobotics experiments on LEO: NAL
- Lunar soil simulant: NASDA

After 2000: R&D

- Lunar rover: JAXA
- SSPS: JAXA
- Economical Development of Space: NASA
- Lunar excavation: JAXA

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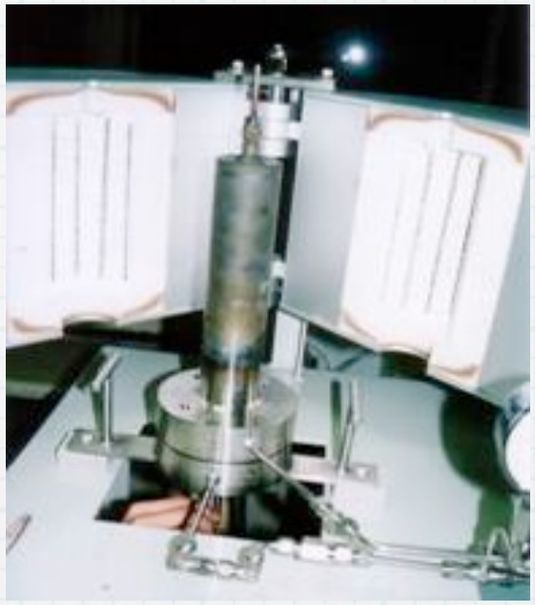
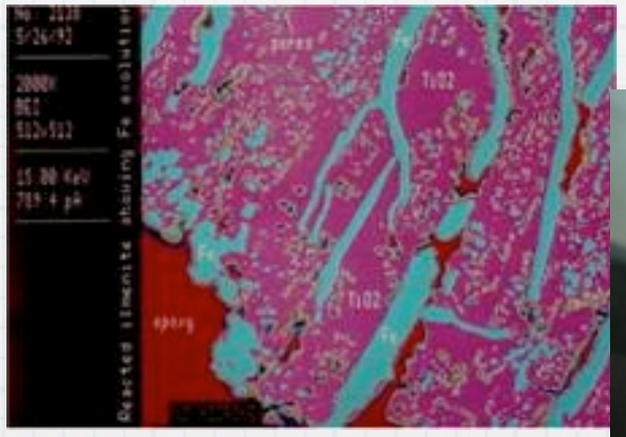
# Lunar Oxygen/ Water Production

Lunar Gravity Test of Fluidized Bed Reactor

$H_2$ Reduction Reactor





Reduced Lunar Sample Apollo17 No.70035

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# Robotic Construction Work on Orbit - ETS-7

JAXA (former NAL) & Shimizu Corp.

10times faster

- Telerobotic construction work on the Low Earth Orbit.
- Deployable and assembling truss structure were manipulated by 7-DOF robot arm.

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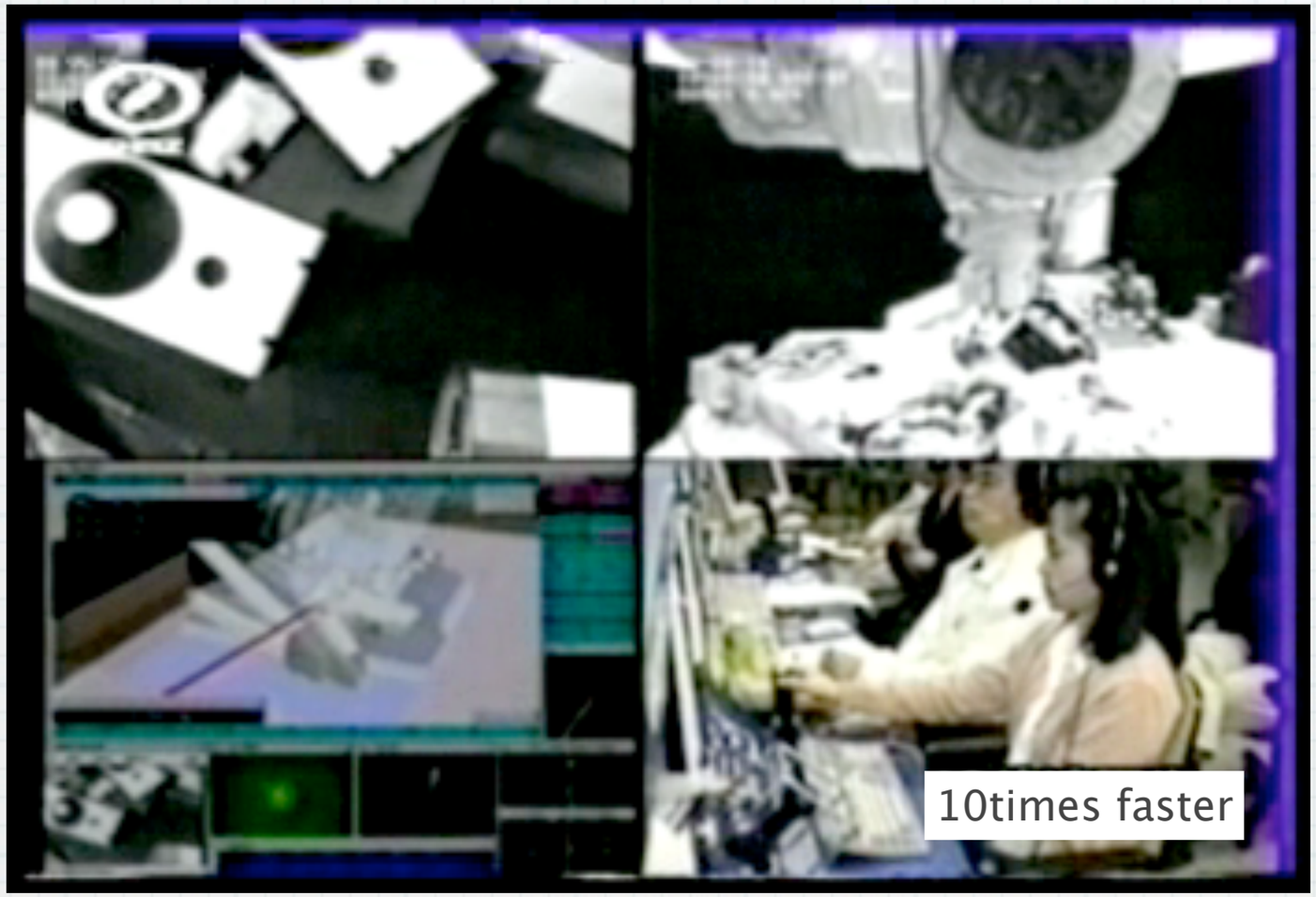
# Robotic Construction Work on Orbit - ETS-7



JAXA (former NAL) & Shimizu Corp.

- Telerobotic construction work on the Low Earth Orbit.
- Deployable and assembling truss structure were manipulated by 7-DOF robot arm.

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# Lunar Soil Simulant

## Chemical Compositions of Simulants

| | Apollo-16 #1 | NU-LHT-1M (NASA) #1 | Kohyama (Shimizu) #2 | Apollo-12 #1 | JSC-1A (NASA) #1 | FJS-1 (Shimizu) #1 | Oshima (Shimizu) #2 |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 45.00 | 46.6 | 47.49 | 46.30 | 46.8 | 49.14 | 44.4 |
| $TiO_2$ | 0.54 | 0.115 | 0.14 | 3.00 | 2.44 | 1.91 | 5.54 |
| $Al_2O_3$ | 27.30 | 21.55 | 22.59 | 12.90 | 13.9 | 16.23 | 12.6 |
| FeO | 5.10 | *5.08 | *8.53 | 15.10 | *12.1 | *13.07 | *16.1 |
| MnO | 0.30 | 0.09 | 0.17 | 0.22 | 0.21 | 0.19 | 0.36 |
| MgO | 5.70 | 9.5 | 10.24 | 9.30 | 5.6 | 3.84 | 7.0 |
| CaO | 15.70 | 12.6 | 8.02 | 10.70 | 10.5 | 9.13 | 9.7 |
| $Na_2O$ | 0.46 | 0.965 | 1.65 | 0.54 | 3.89 | 2.75 | 2.09 |

*FeO includes $Fe_2O_3$ for simulants

#1: NASA MSFC analysis
#2: Shimizu analysis

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# Lunar Soil Simulant

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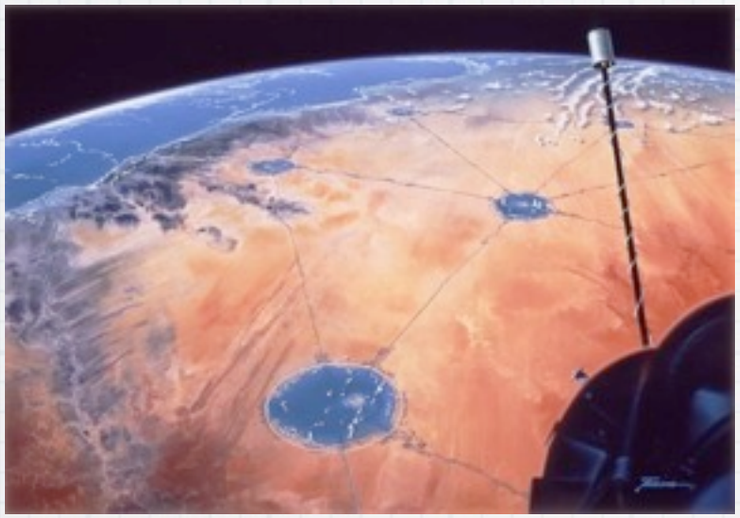
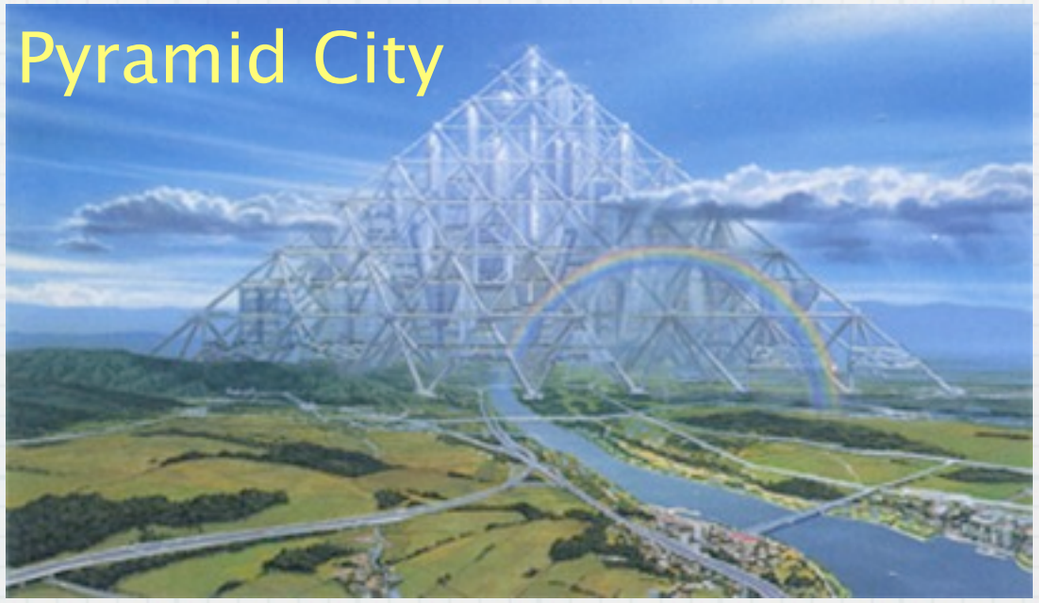
# Pursuing New Frontiers SHIMIZU's Dream 80s, 90s



Desert Aqua-Net

Urban Geo-Grid



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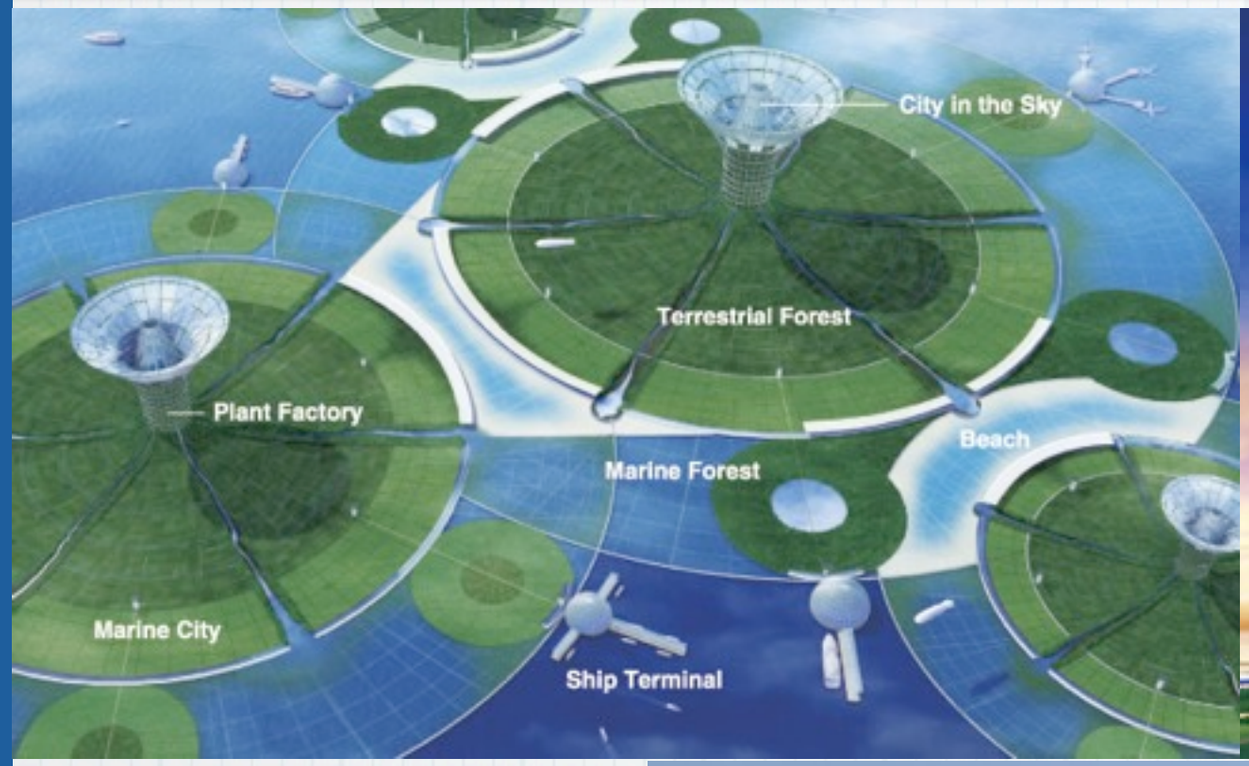
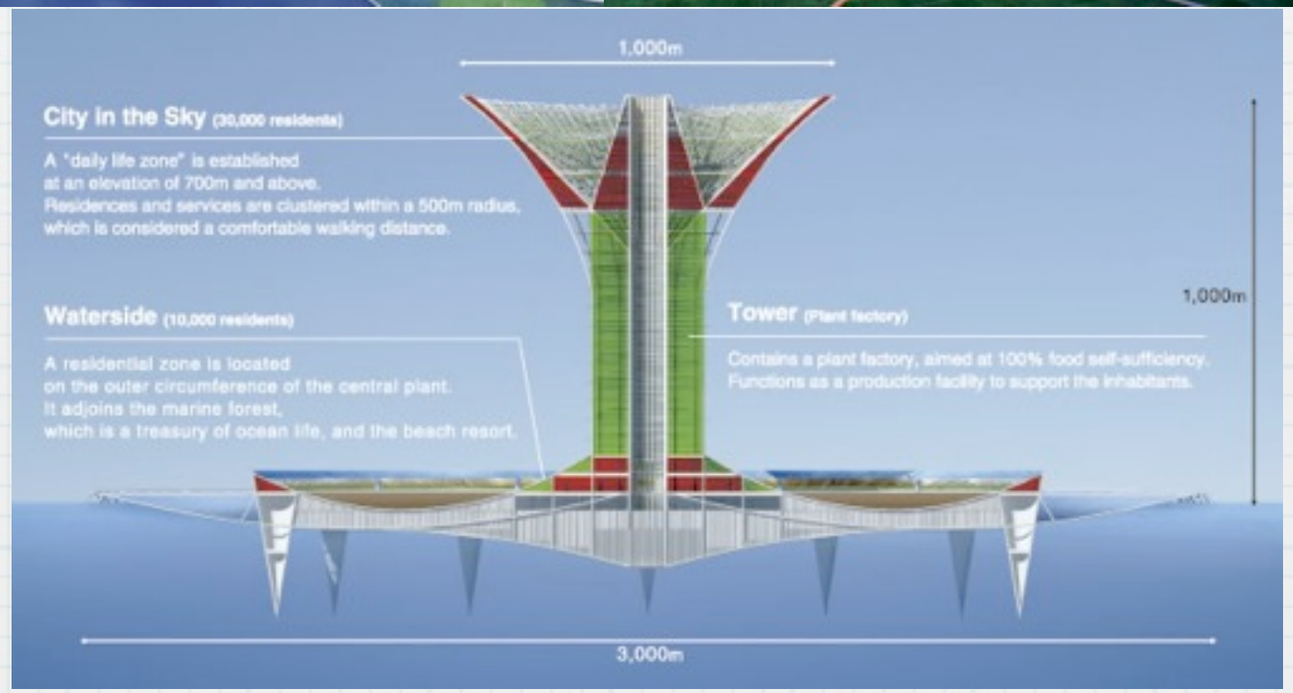
# Pursuing New Frontiers SHIMIZU's Dream 2008



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# Vision of
# the SHIMIZU's Dream 2009

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Permanent welfare for mankind
on the healthy blue planet

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# Vision of the SHIMIZU's Dream 2009

Permanent welfare for mankind on the healthy blue planet

Retain human culture and technology.

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Retain human culture and technology.

Resolve food and water issues.

# Vision of
# the SHIMIZU's Dream 2009

Permanent welfare for mankind
on the healthy blue planet

Retain human culture and technology.

Resolve food and water issues.

Revive the global environment.

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# THE ENERGY PARADIGM SHIFT

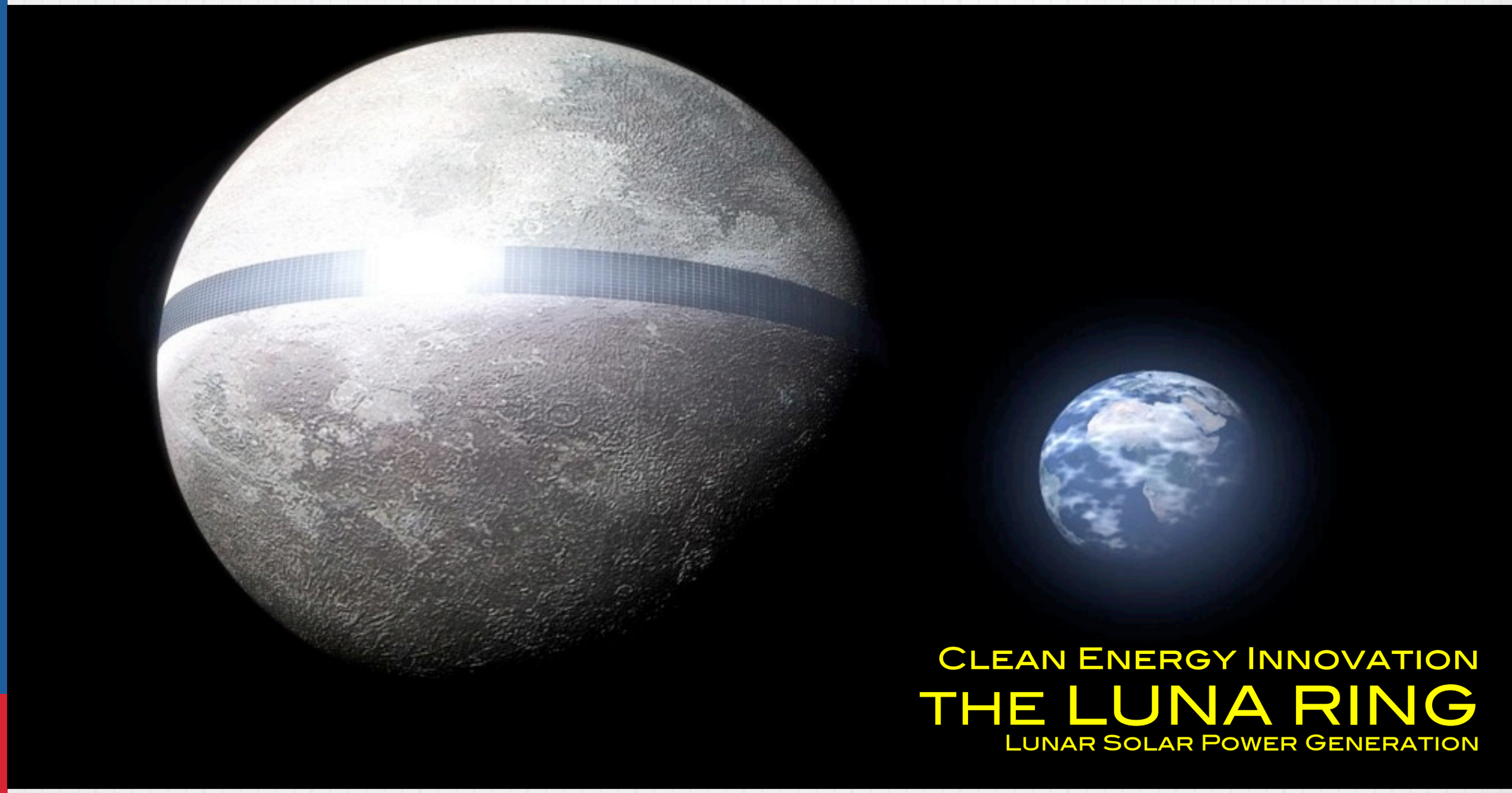
Economical use of limited resources

# THE ENERGY PARADIGM SHIFT

Economical use of limited resources

Unlimited use of clean energy

# THE LUNA RING

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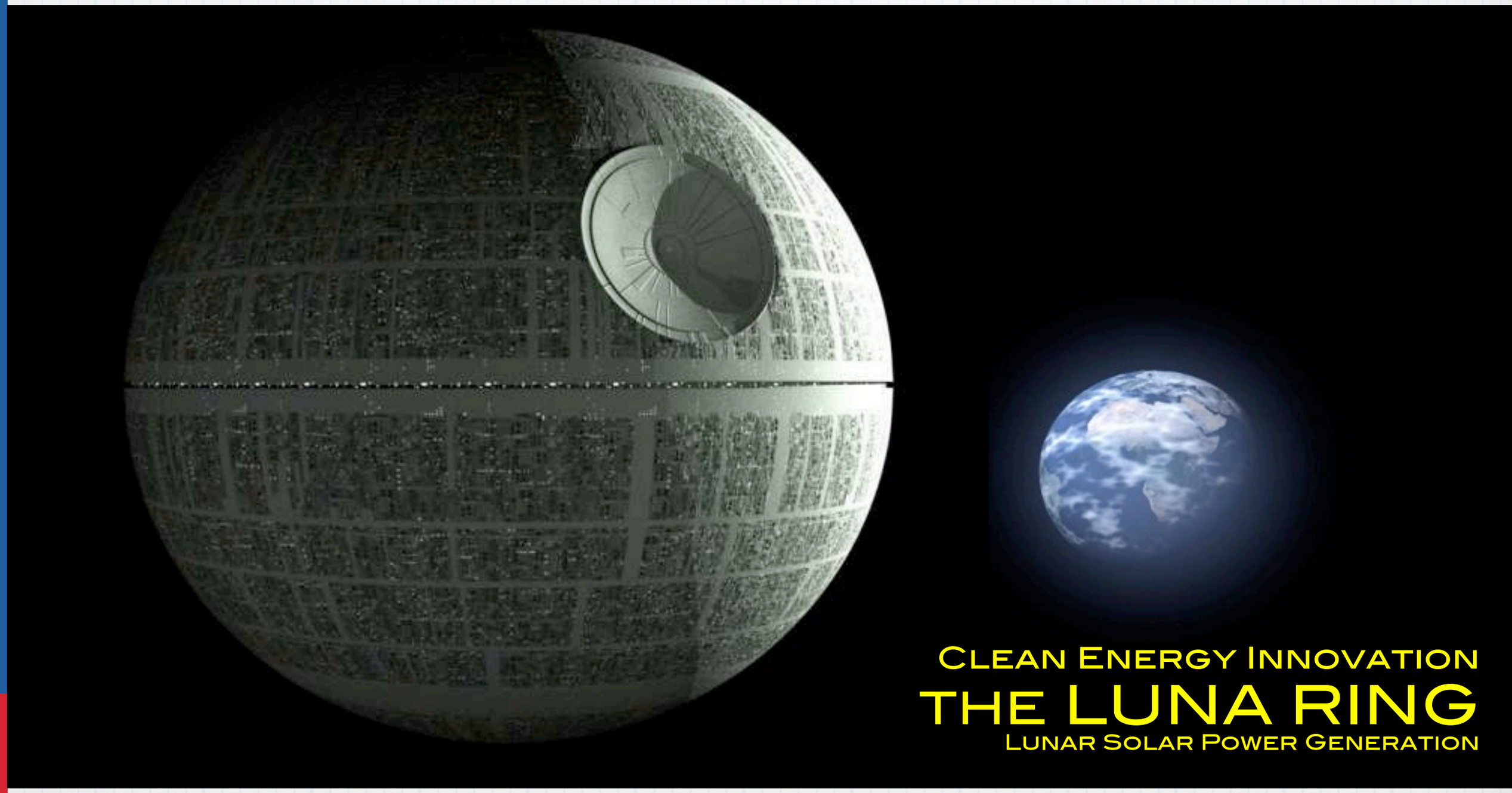
# THE LUNA RING

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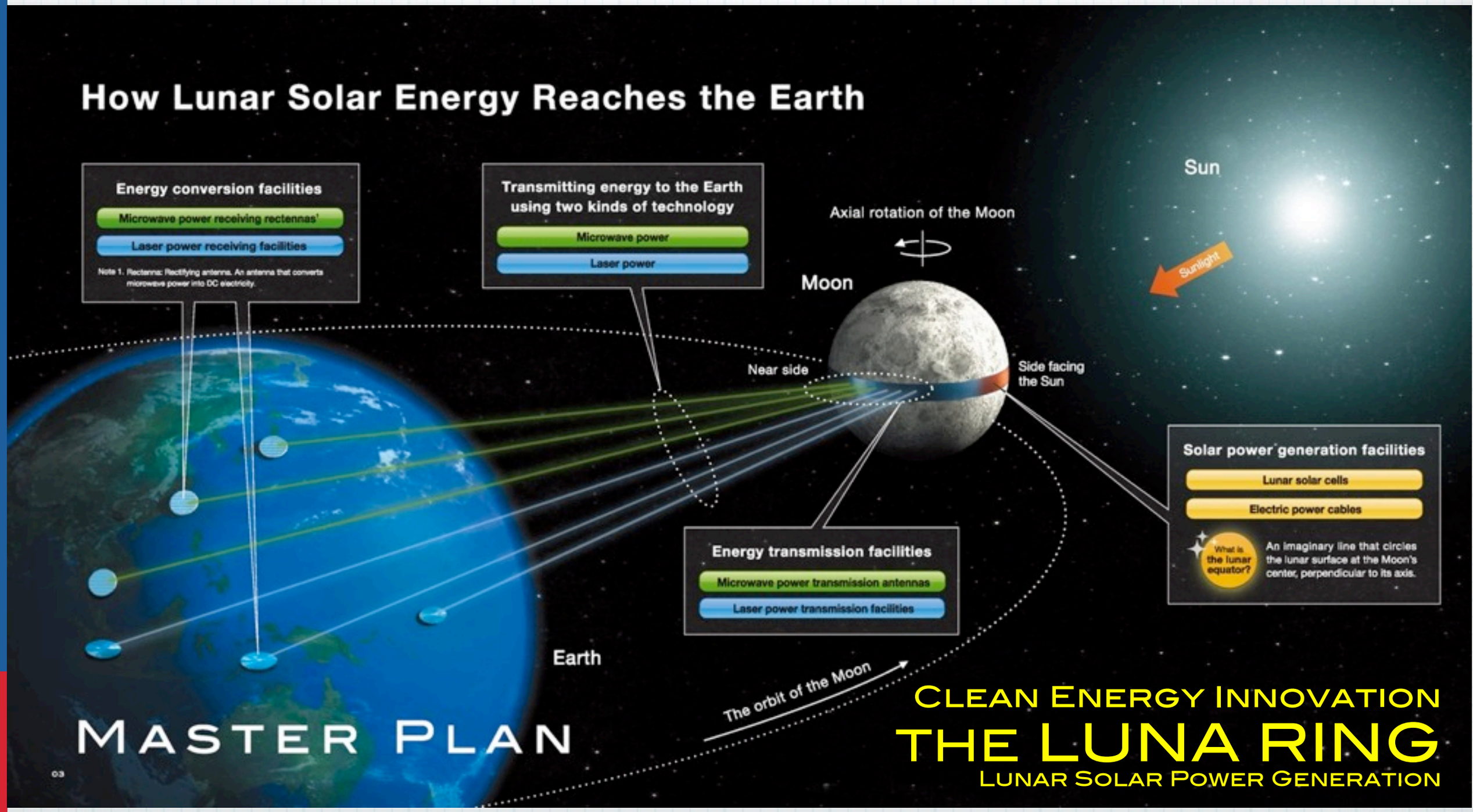
# MASTER PLAN

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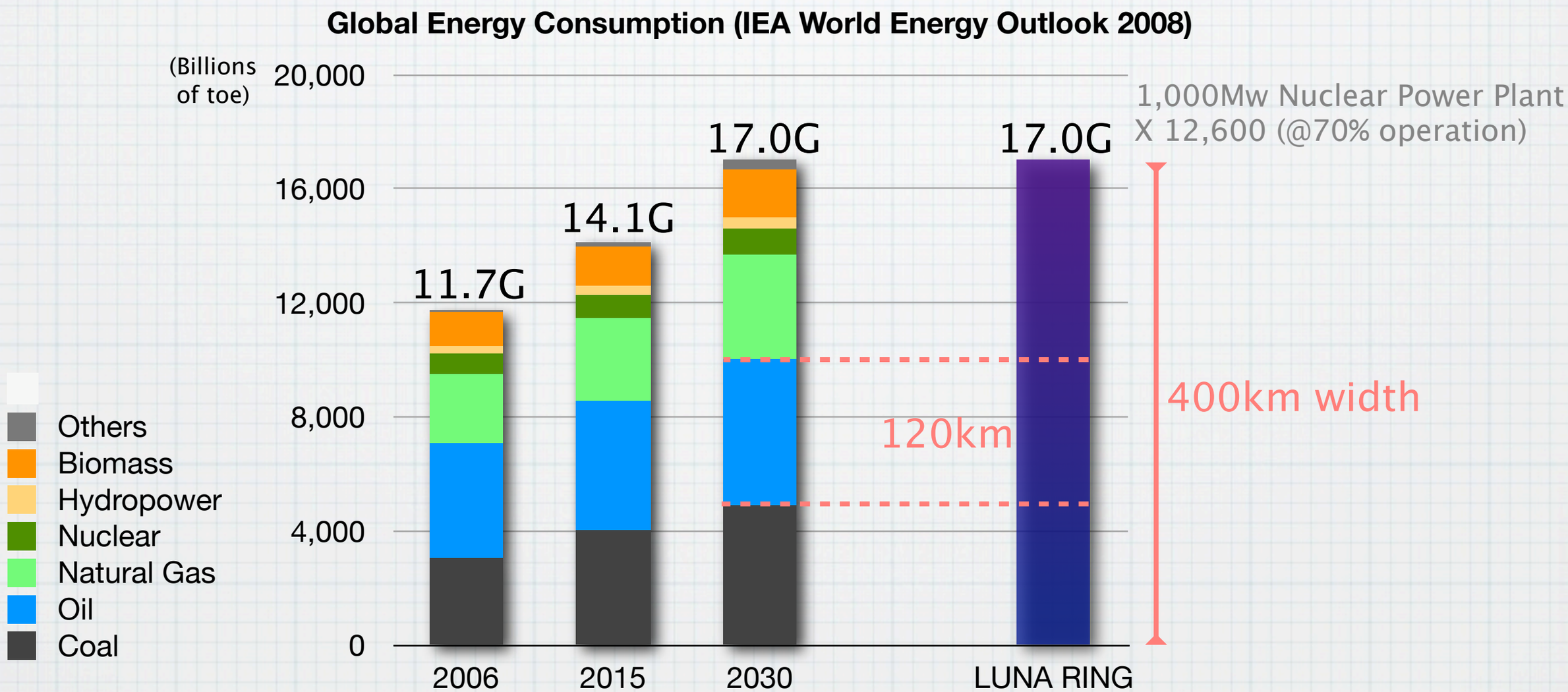
# Lunar Solar Cells Surpass Fossil Fuels

The 400km-wide LUNA RING will supply the energy the world needs in 2030.




0.22 toe (tones of oil equivalent) = 1 MWh

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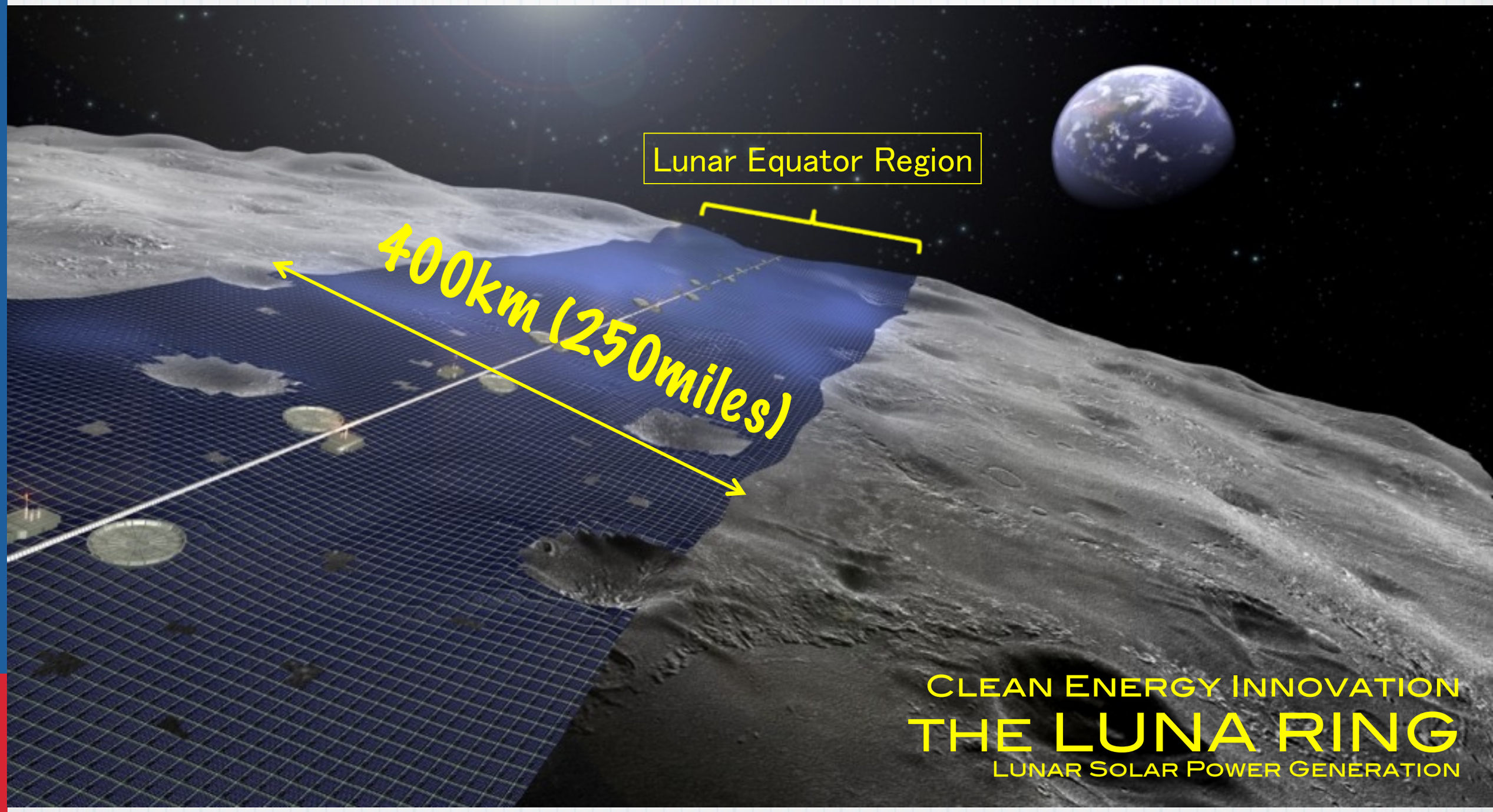
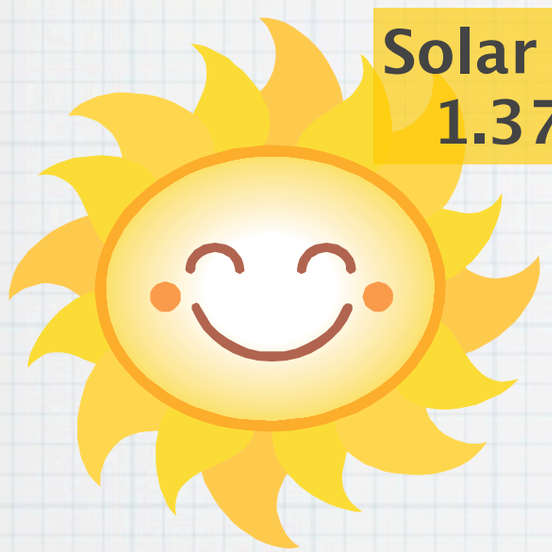
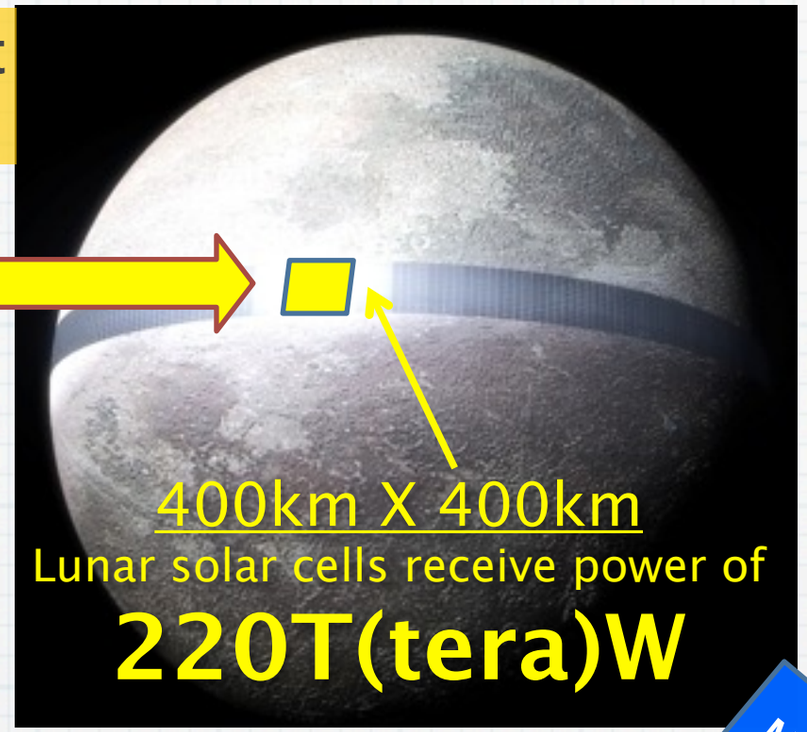
# LUNAR SOLAR BELT



# Energy Estimation



**Solar constant**
**1.37kw/m²**




Power generating efficiency
**20%**
(Lunar solar cells)

+

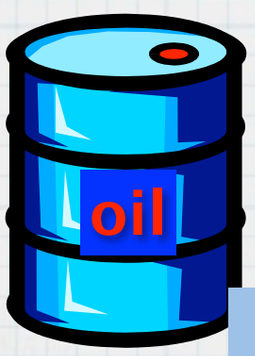
Transmitting efficiency
**20%**
(on the Moon to electric)

=

4% total efficiency

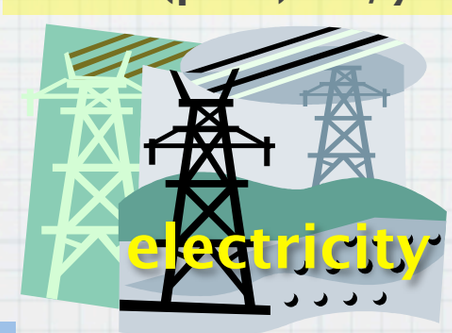
Microwave/Laser

Global Energy Consumption in 2030
**17Gtoe/year**
(IEA World Energy Outlook 2008)




0.22toe=1MWh
(conversion rate, OECD)

**77.3P(peta)Wh/year**



Generating capacity
**8.8T(tera)W**

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# ENERGY EFFICIENCY

Solar energy -> Microwave trans. -> Electric supply

| Operation | | Efficiency (%) |
|---|---|---|
| Moon | Lunar Eclipse Impact* | 99.9 |
| Moon | Solar Concentration | 95 |
| Moon | Energy Conversion | 17 |
| Moon | Surface Transmission | 85 |
| Moon | DC to Microwave | 75 |
| Transmission | Atmospheric Transmissivity | 98 |
| Earth | Microwave to DC | 76 |
| Earth | Surface Transmission | 95 |
| | Sub-total(%) | 7.277488 |
| | Operating rate : 80% | 5.82199 |

Solar energy -> Laser trans. -> H2 production

| Operation | | Efficiency (%) |
|---|---|---|
| Moon | Lunar Eclipse Impact* | 99.9 |
| Moon | Solar Concentration | 95 |
| Moon | Energy Conversion | 17 |
| Moon | Surface Transmission | 85 |
| Moon | DC to Laser | 35 |
| Transmission | Atmospheric Transmissivity | 98 |
| Earth | Laser to DC | 65 |
| Earth | Electrolysis | 90 |
| | Sub-total(%) | 2.751737 |
| | Operating rate : 80% | 2.20139 |

50%

50%

Total Efficiency 4.01%

* : There are 85 times total lunar eclipses and 57 times partial eclipses in 21st century. Average period of a eclipse is estimated to 6-hours and 1.42 times eclipse per year makes 8.52-hours/year.

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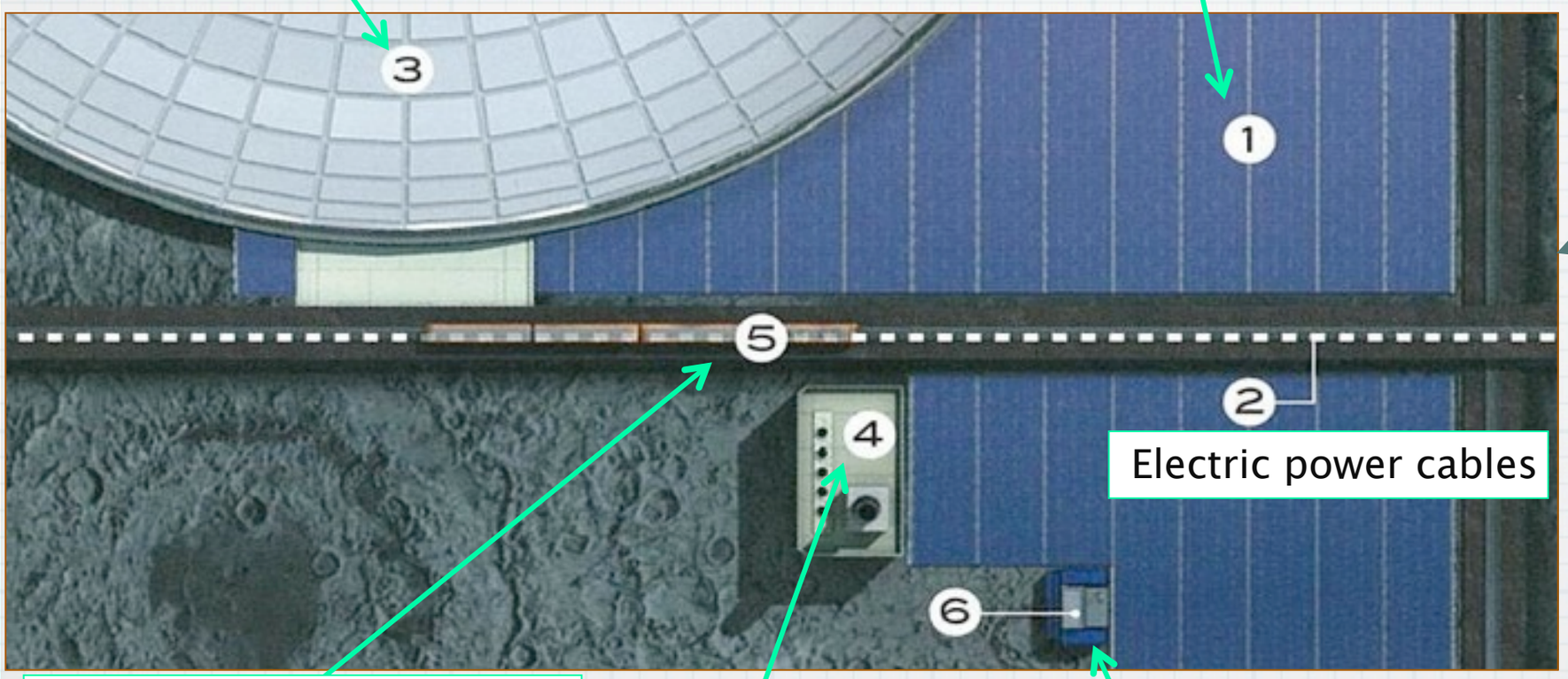
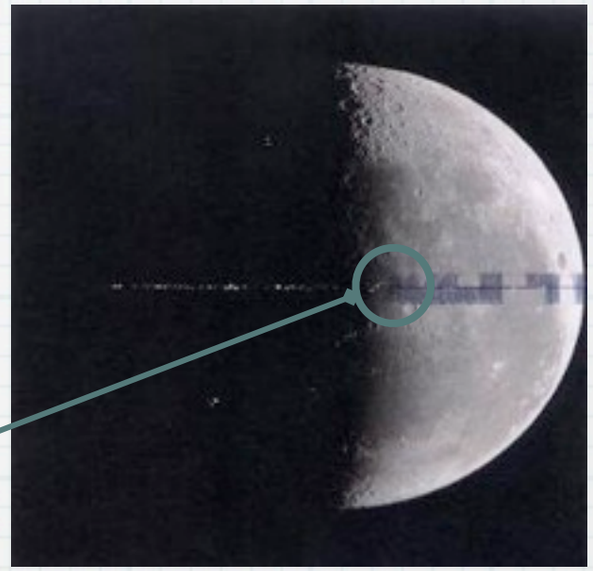
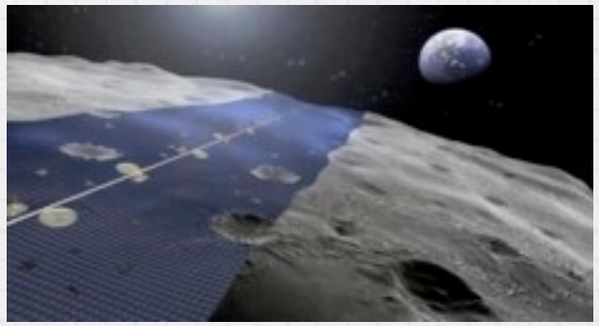
# SOLAR BELT CONSTRUCTION

1. Lunar solar cells are grown from transportation route to higher latitude.
2. Energy transmission facilities are located on the nearside of the Moon.
3. Lunar resources are used for solar cells and construction materials.





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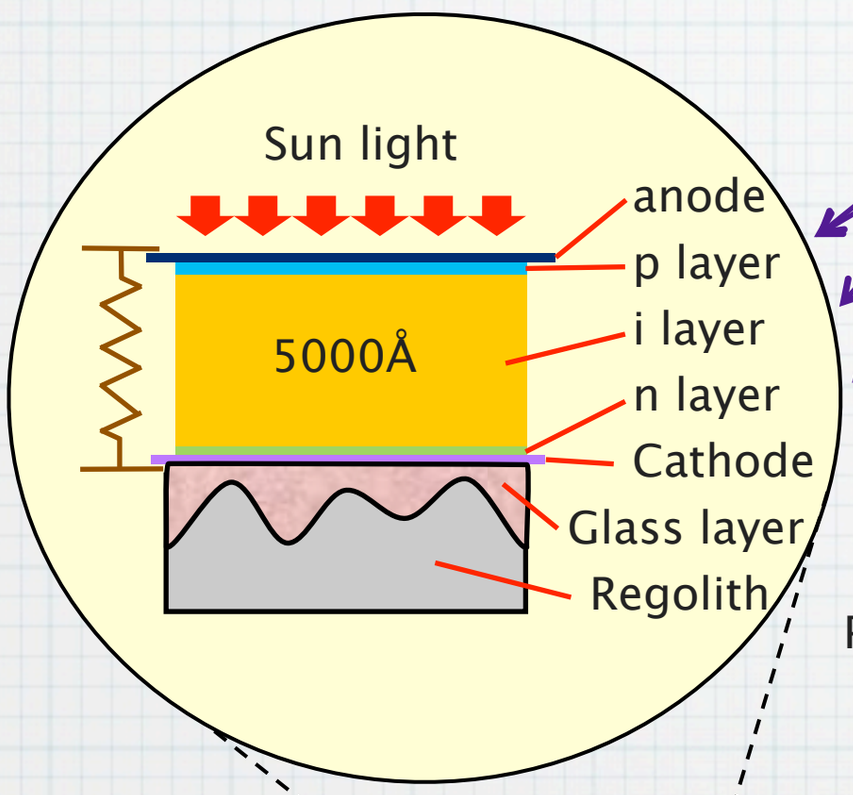
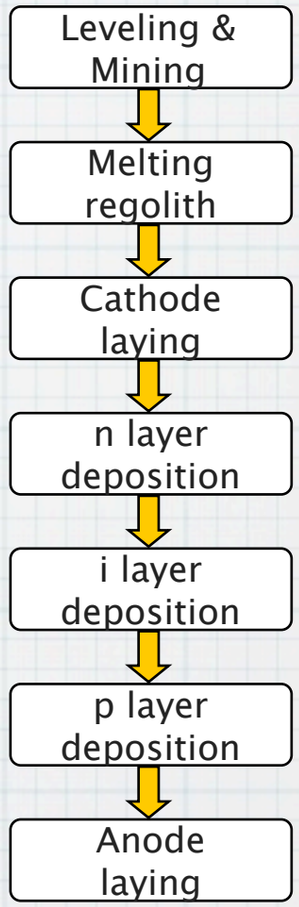
# SOLAR CELL PRODUCTION

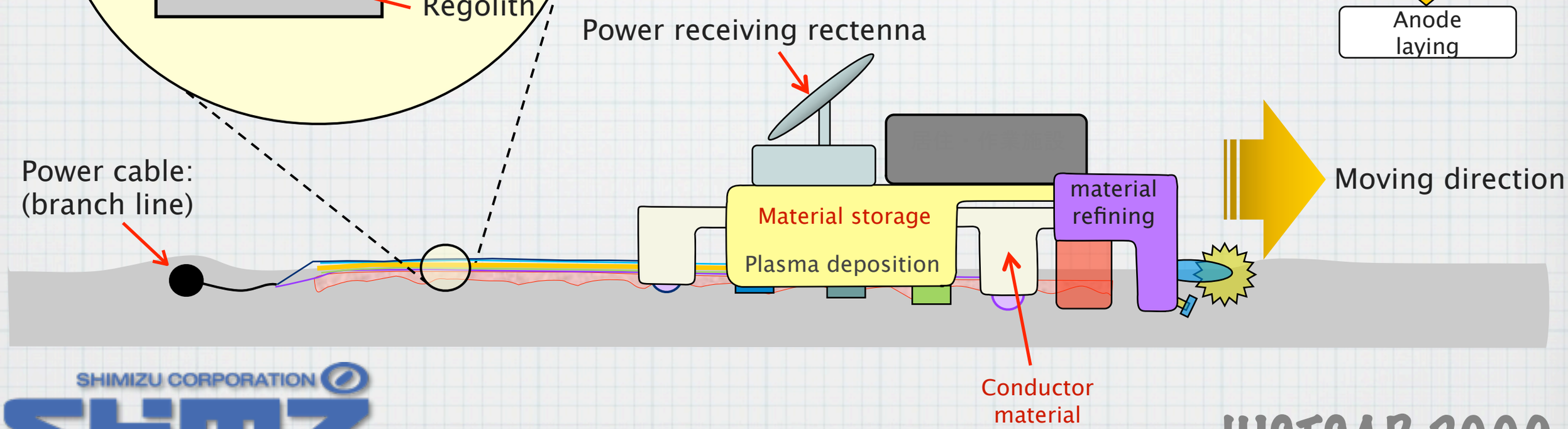
1. Maximum use of Lunar resources.
2. Continuous solar cell production by self-mobile production plant




Mono-Silane gas ($SiH_4$)
Diboran gas ($B_2H_6$)
Phosphine gas ($PH_3$)

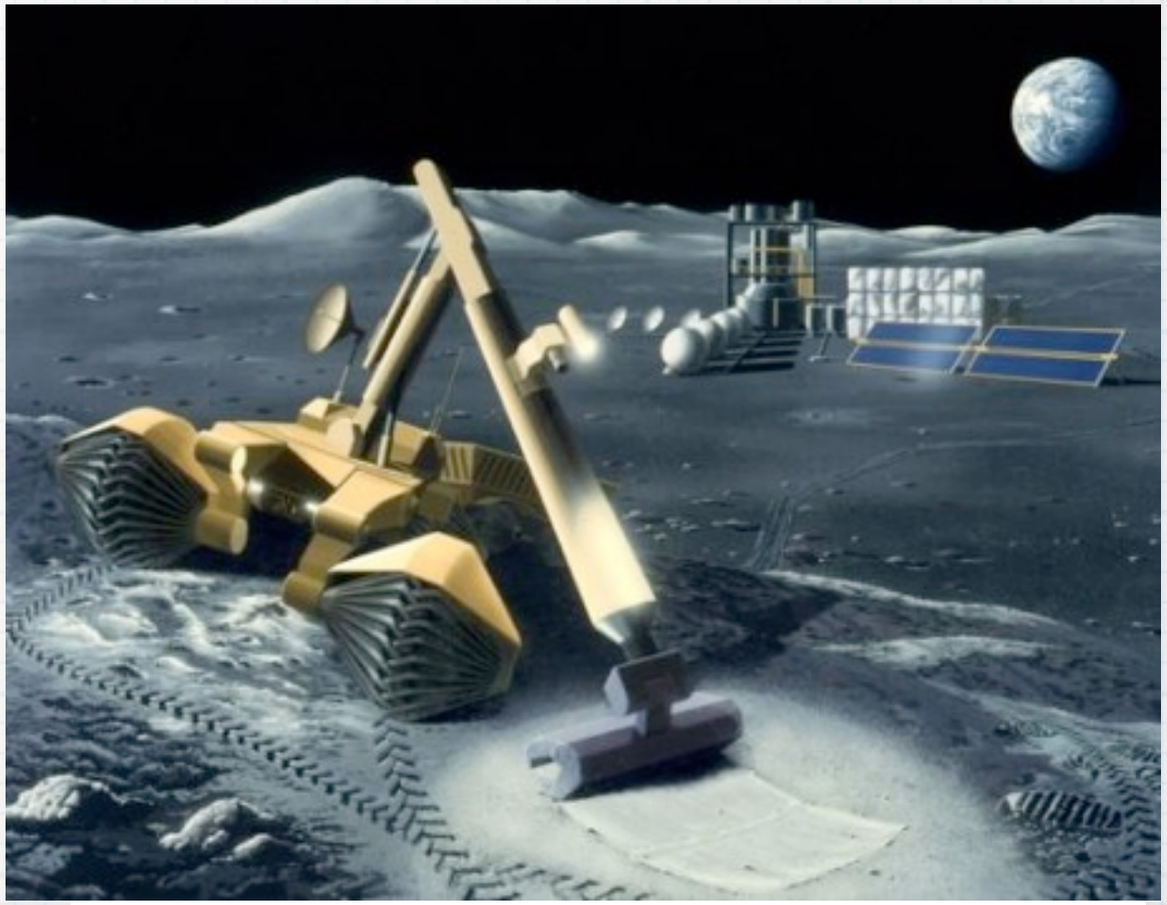
$SiO_2$ : 50 % of Regolith
$Al_2O_3$ : 15 % of Regolith
B : 10 μg/g in Breccia
P : 2,000 μg/g in Breccia

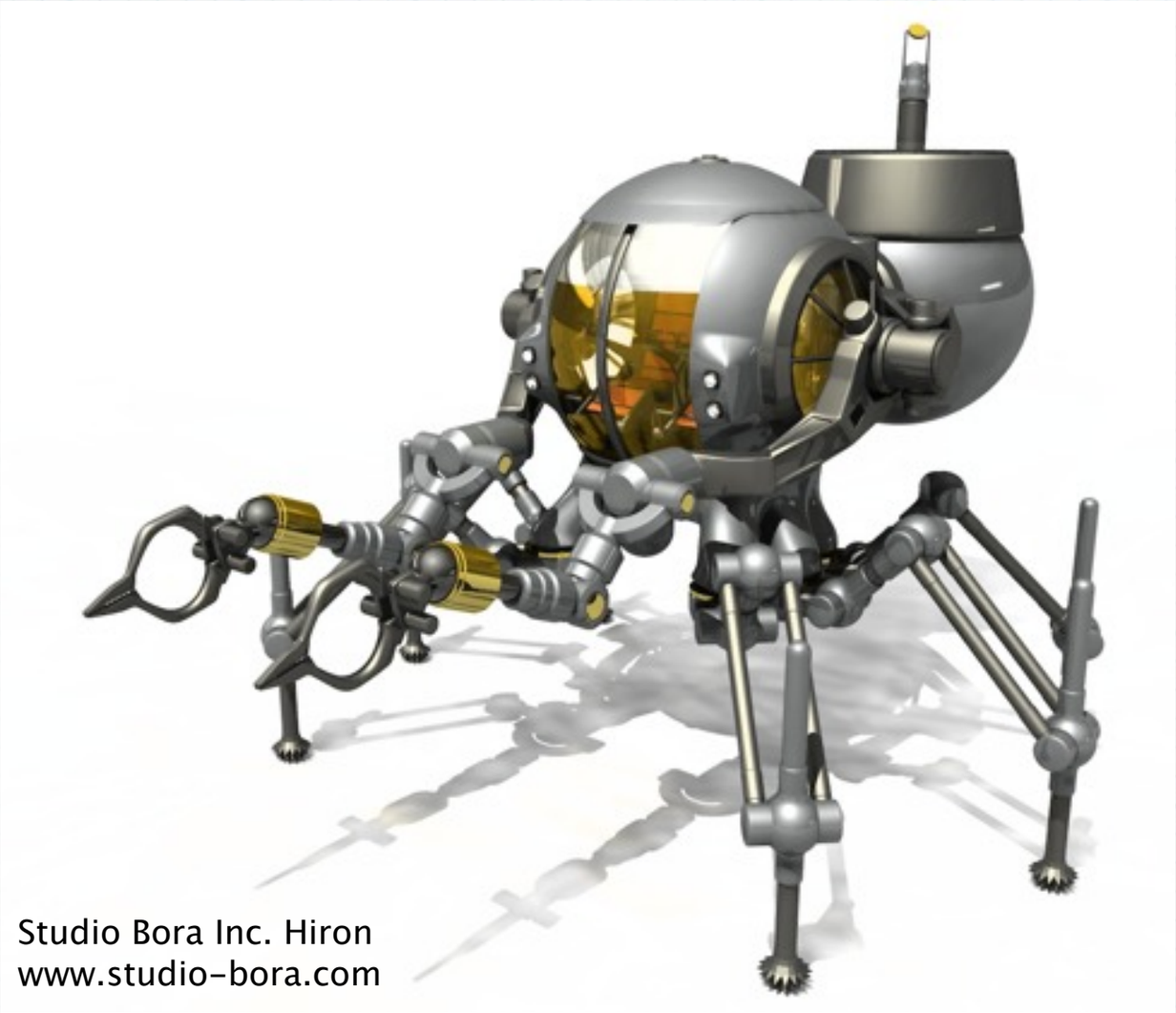


# ROBOTIC CONSTRUCTION

- 24hours/7days construction operation.
- Human minimum, robot maximum.





# EVA Work

# The Sun Revitalize the Earth

## Shift from Fossil Fuels to Clean Energy

- No use of fossil fuels as energy sources
  - Prevent air pollution, acid rain and soil pollution.
  - Prevent CO2 release and global warming.
  - Prevent desertification and sea level rise.
- Global conversion to a hydrogen society

## Clean Energy in Every Corner of the World

- Stable supply of water and food
- Realization of a complete recycling society
- Elimination of energy resource problem and energy supremacy

# Today's Work, Tomorrow's Heritage

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http://www.shimz.co.jp/english/index.html

CSP Japan

# Today's Work, Tomorrow's Heritage

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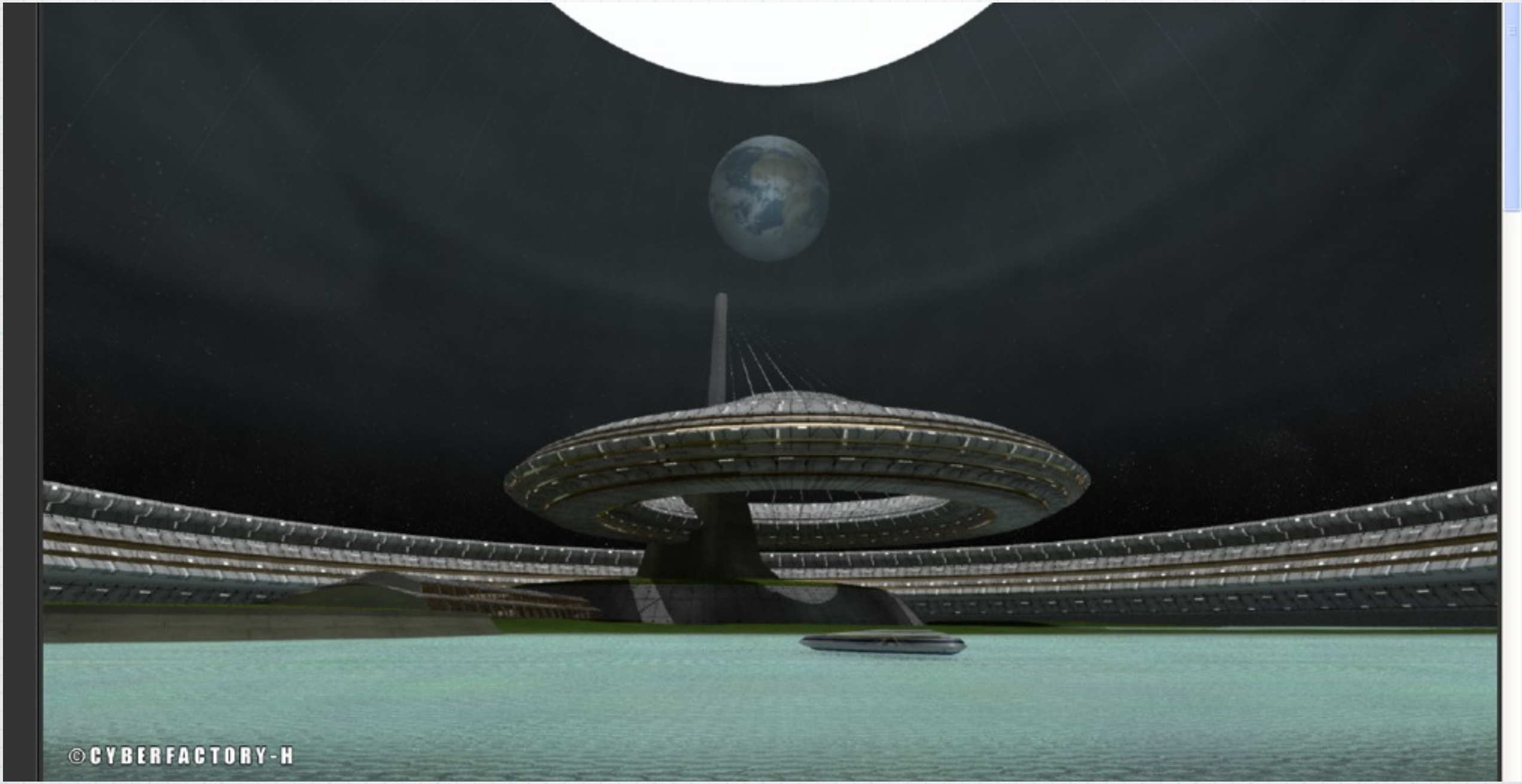
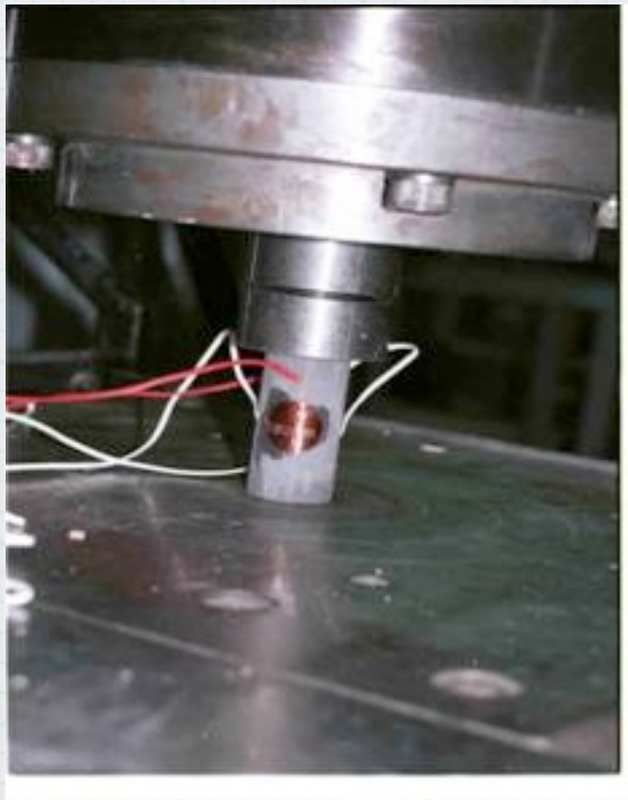
CSP Japan


©CYBERFACTORY-H

# Cast Basalt Construction Material

Solar Concentrator
(@ Boeing, Huntington Beach)

Cast Basalt
Specimens



Strength Test of
Cast Basalt

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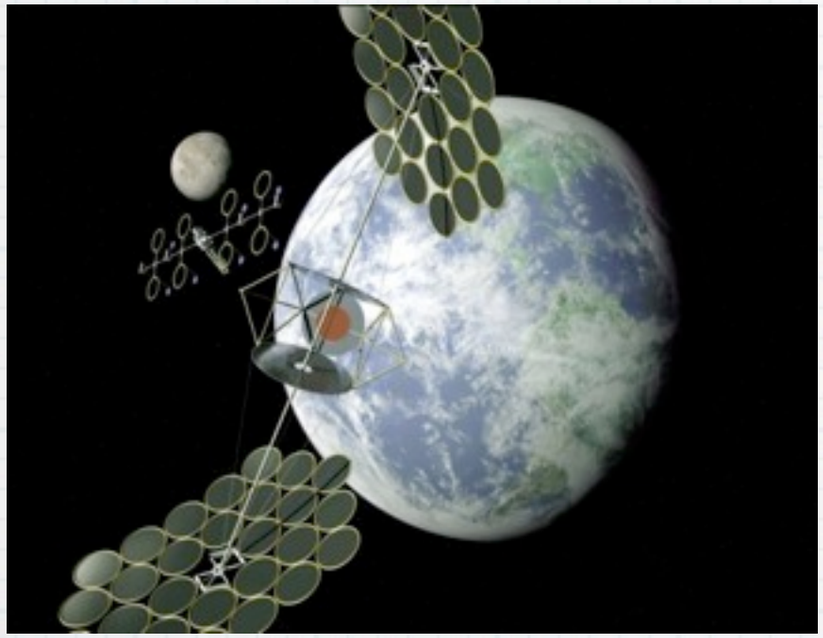
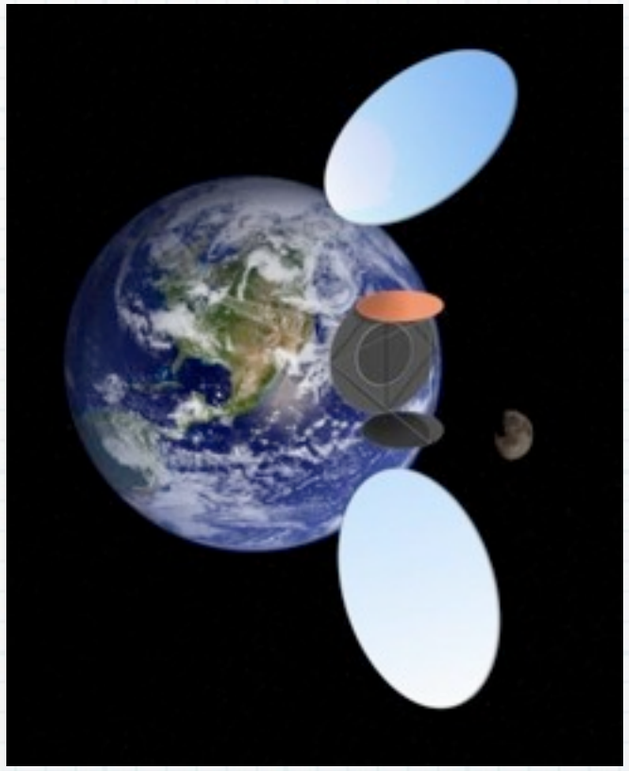
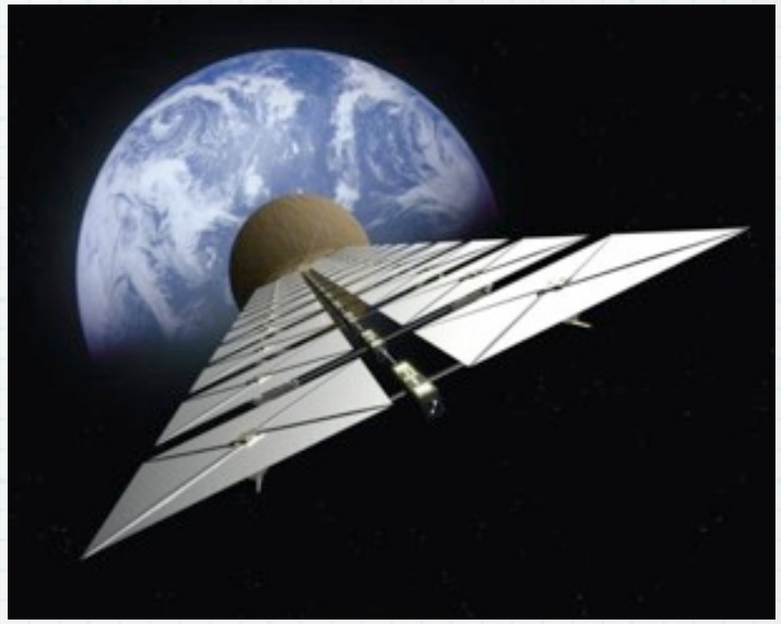
# SPS/SSPS Concepts



NASA SPS Freshlook study

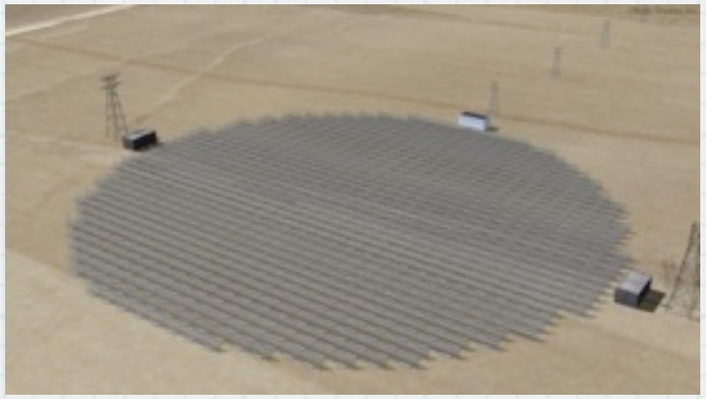


JAXA M-SSPS

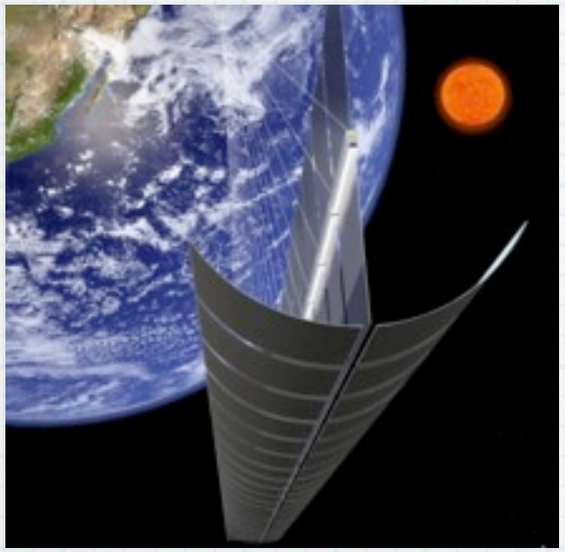


ESA, European Space Agency

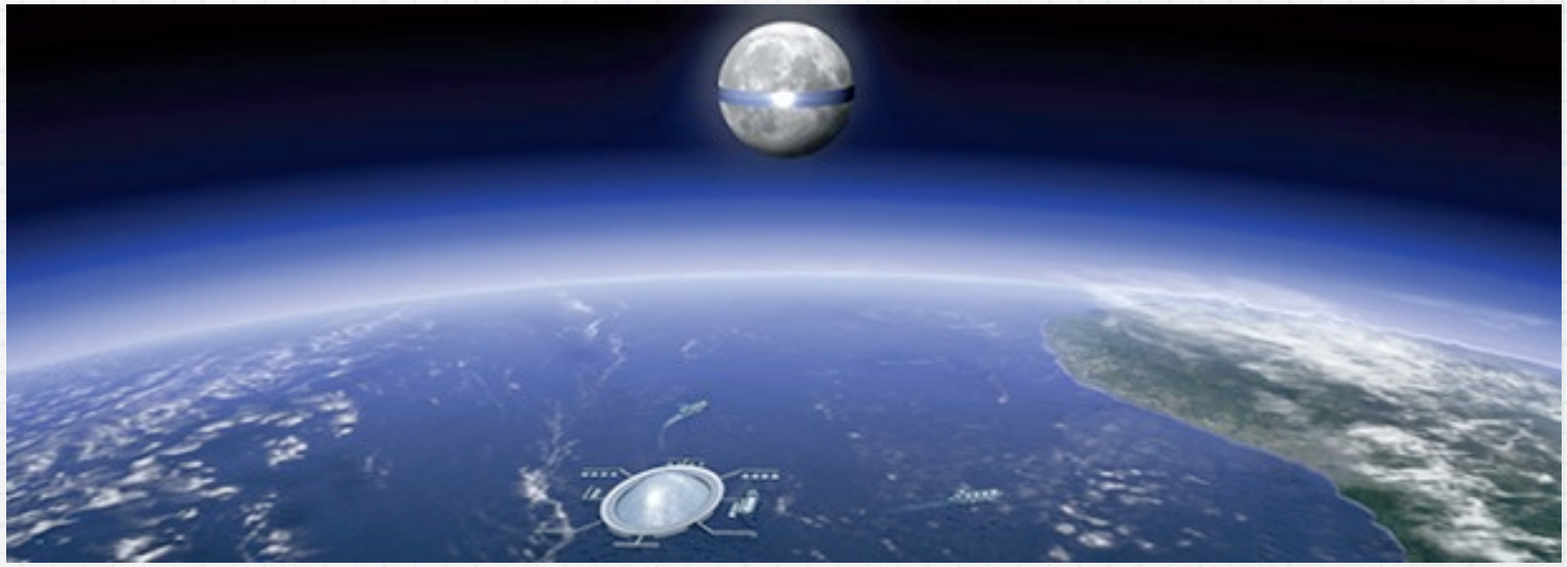
Microwave power transmission is in the planning phase.



# LASER POWER RECEIVING FACILITY CONCEPT



JAXA　L-SSPS



Shimizu　Luna-Ring

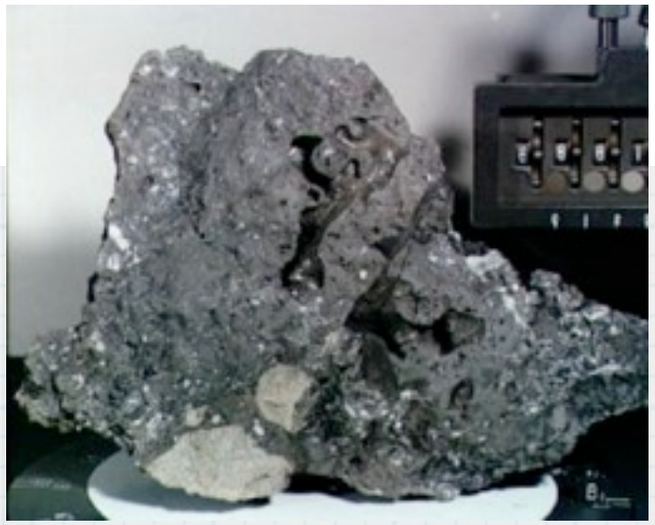
Laser power transmission is in the conceptional phase.

# LUNAR RESOURCES

Incompatible Trace Elements
Miscellaneous Minor Elements
Siderophile Elements
Vapor_Mobilized Elements
Solar_Wind_Implanted Elements

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H | | | | | | | | | | | | | | | | | He |
| Li | Be | | | | | | | | | | | | B | C | N | O | F | Ne |
| Na | Mg | | | | | | | | | | | | Al | Si | P | S | Cl | Ar |
| K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr |
| Rb | Sr | Y | Zr | Nb | | Mo | | Ru | Pb | Ag | Cd | In | Sn | Sb | Te | I | Xe |
| Cs | Ba | La... | Hf | Ta | | W | Re | Os | Pt | Au | Hg | Tl | Pb | Bi | | | |
| | | Ac.. | | | | | | | | | | | | | | | |

*Lunar Sourcebook*



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Space utilization for the planet Earth.

The energy paradigm shift opens the door to a sustainable society.

In 2035, the Luna Ring project is initiated to realize the infinite coexistence of mankind and the Earth.

# Acknowledgement

Team members "The Luna Ring" 2009

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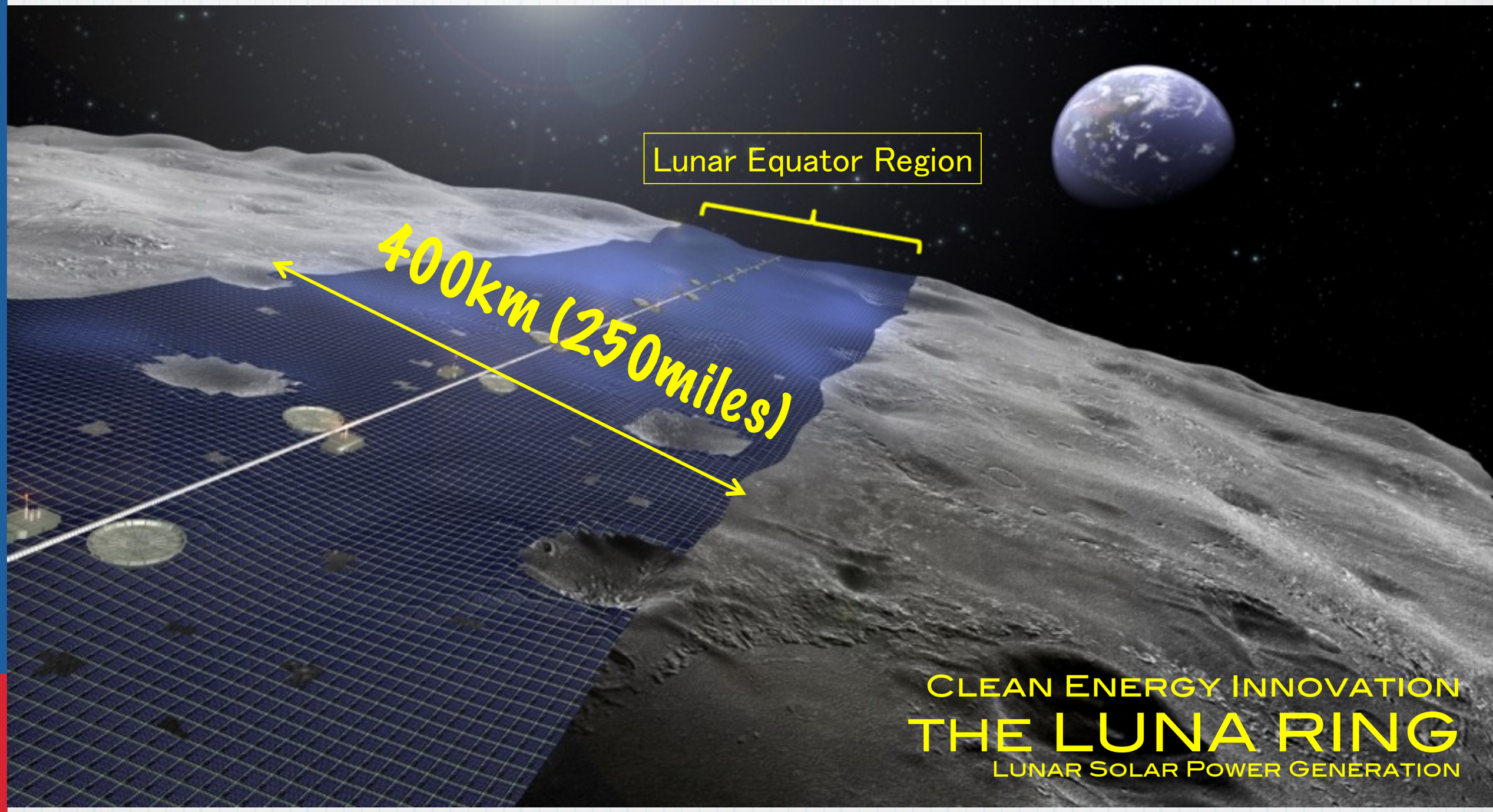
# LUNAR SOLAR BELT

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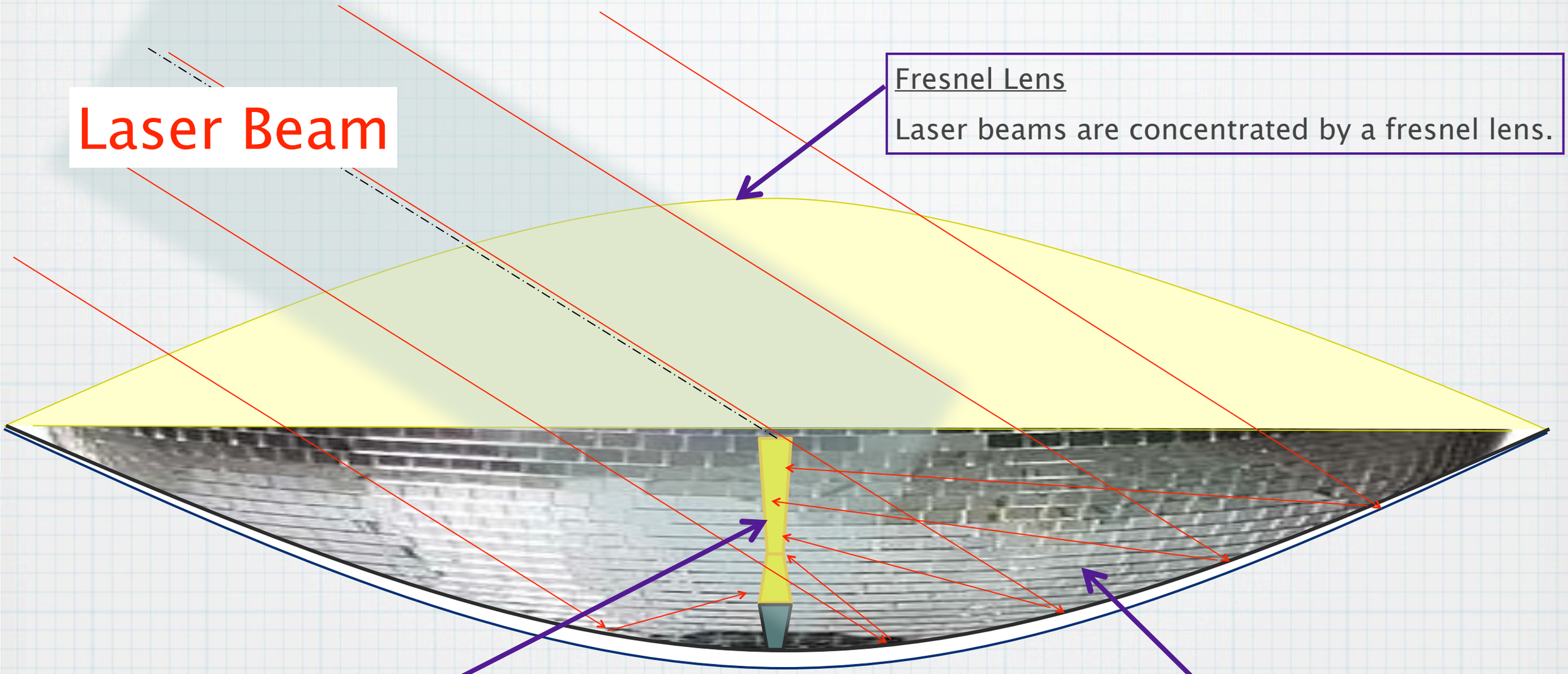
# LASER POWER RECEIVING FACILITY




Fresnel Lens

Laser beams are concentrated by a fresnel lens.

Photoelectric Conversion Element

Gathered laser beams are converted by high-temperature photoelectric conversion elements.Thermal energy of laser beam and sunlight generate additional electric power.

Mirror

Concentrated laser beams are gathered by numerous controlled mirrors to photoelectric conversion elements.