

# **Whither Lunar Exploration and Lunar Resources?**

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## Battelle Overview

- Founded by Will of Gordon Battelle in 1929 as a non-profit, charitable trust to provide “the greatest good to humanity”
  - Creative and research work
  - Making of discoveries and inventions
  - Better education of men and women for employment
  - Societal and economic impact
- World’s largest independent non-profit R&D corporation, conducting more than \$5 billion in annual R&D
- 80 years of research and development leadership
- Major business areas are contract R&D, laboratory operations, and commercialization/commercial ventures
- Minimum of 20% of net profit goes to charitable causes — primarily STEM education



# Participatory Lunar Exploration and Education

- A new Value Proposition for Space Exploration
- Participatory Exploration and Education workshop held in April 2010
  - Included STEM (Science, Technology, Engineering and Math) High School students and educators
  - Focus Question: *What is the design of a lunar exploration program that substantially supports national education goals?*
- Participatory Exploration and Education can
  - Thoroughly engage students in exploration activities
  - Encourage students to enter into STEM educational disciplines
- Students can be engaged in the evaluation of a virtual “firehose stream” of data coming in from lunar missions like the Lunar Reconnaissance Orbiter
- The Moon’s proximity makes it ideal for engaging teams of students and educators in the teleoperation of resource prospecting rovers



# Equations

## Thermodynamics

$$q-w = \Delta h + \Delta ke + \Delta pe$$

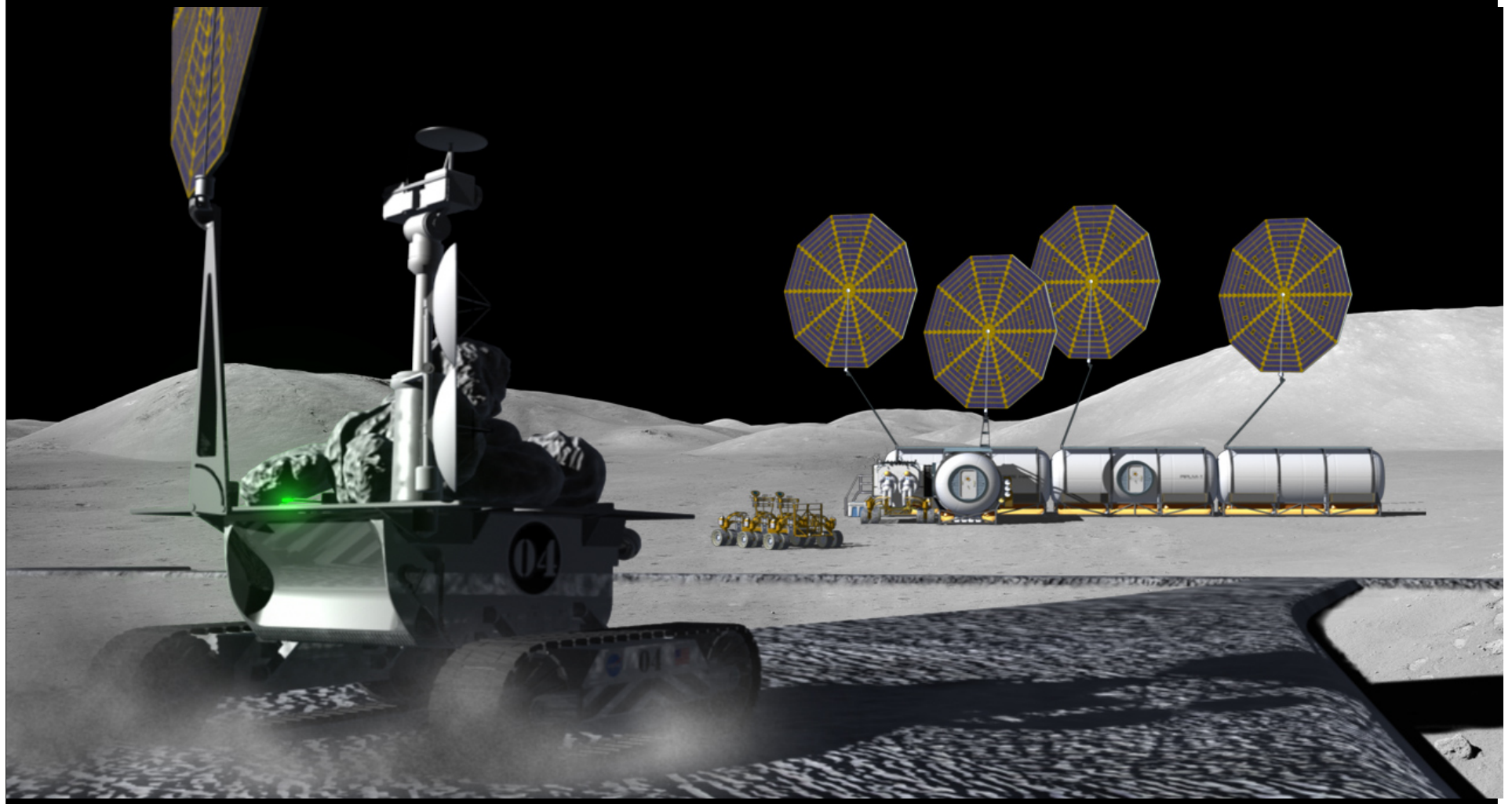
## Fuel Cell / Electrolysis



## Synthetic Fuels

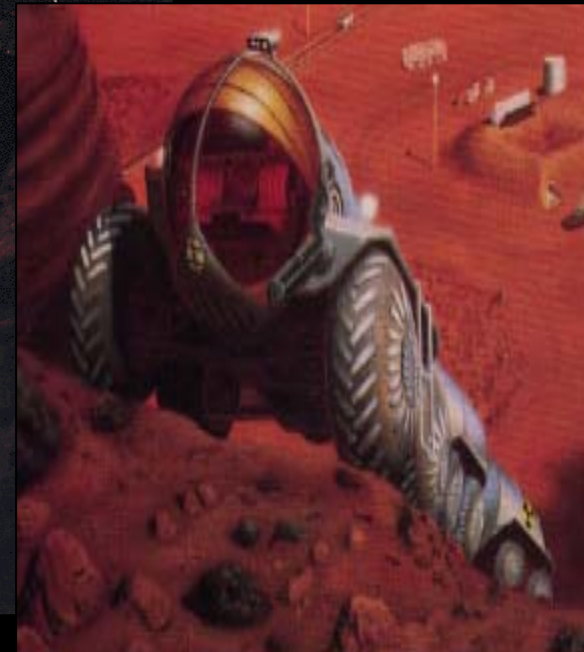


# Lunar Outpost Family Photo with Rover



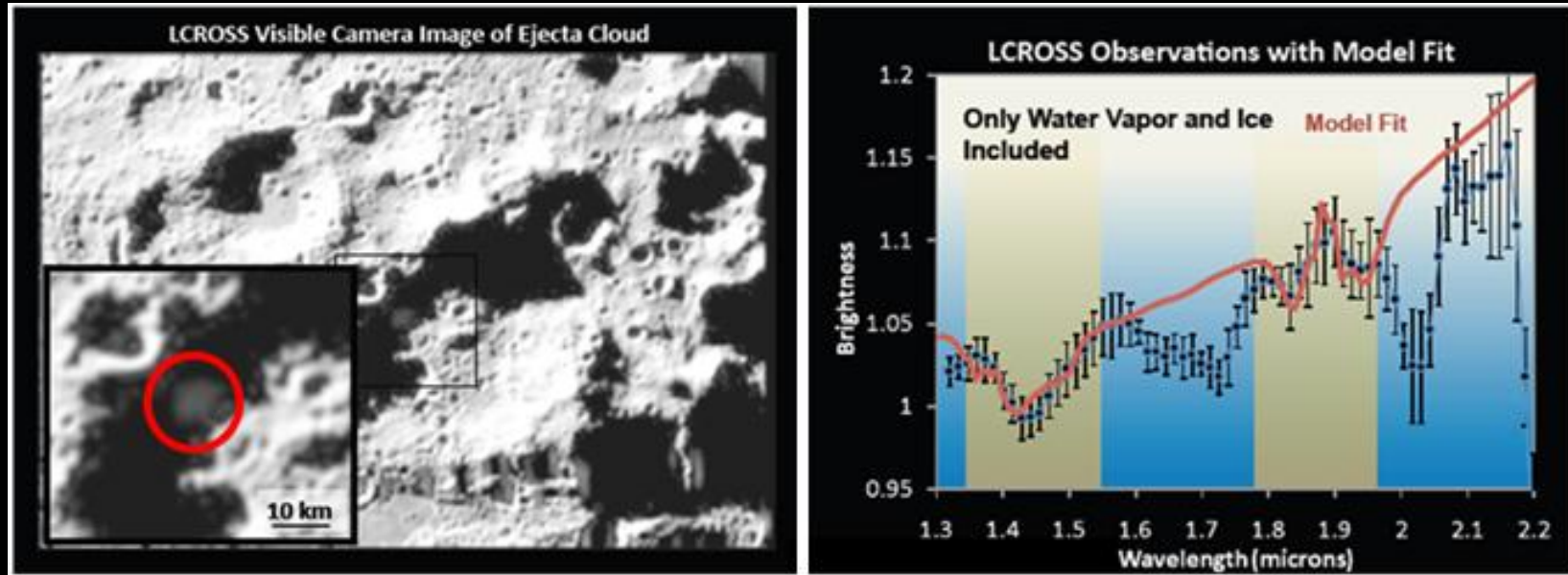


# Exploration ... In a New Context



*...the Moon, Mars and it's Moons, and Asteroids...*

# The Moon has “The Right Stuff”



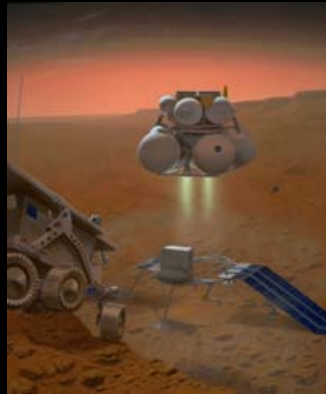
- Chandrayaan-1, LCROSS and LRO confirm lunar water
- LCROSS spectral analysis suggests other volatiles present
  - Methane ( $\text{CH}_4$ ), carbon dioxide ( $\text{CO}_2$ ), other hydrocarbons and ammonia ( $\text{NH}_3$ ), such as are found in comets
- Conclusion: The Moon has the materials that we need to support human biological requirements (life support and food production)

# Robotic Precursor Missions

## Potential Examples

### *Mars In Situ Sample Return*

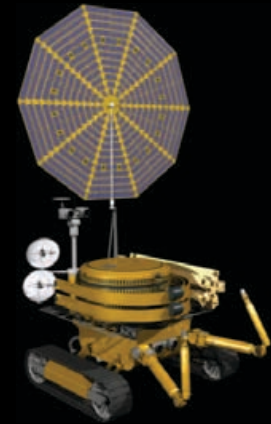
- *With In Situ Propellant Production*
- *Using solar-thermochemical methods*



- *Investigations to determine if life evolved separately on Mars*
- *Advances renewable methods for producing transportation fuels for the Earth*

### *Participatory Lunar Exploration*

- *Many rover prospectors*
- *Teleoperated from the Earth*
- *Heat and power from thermal wadis*

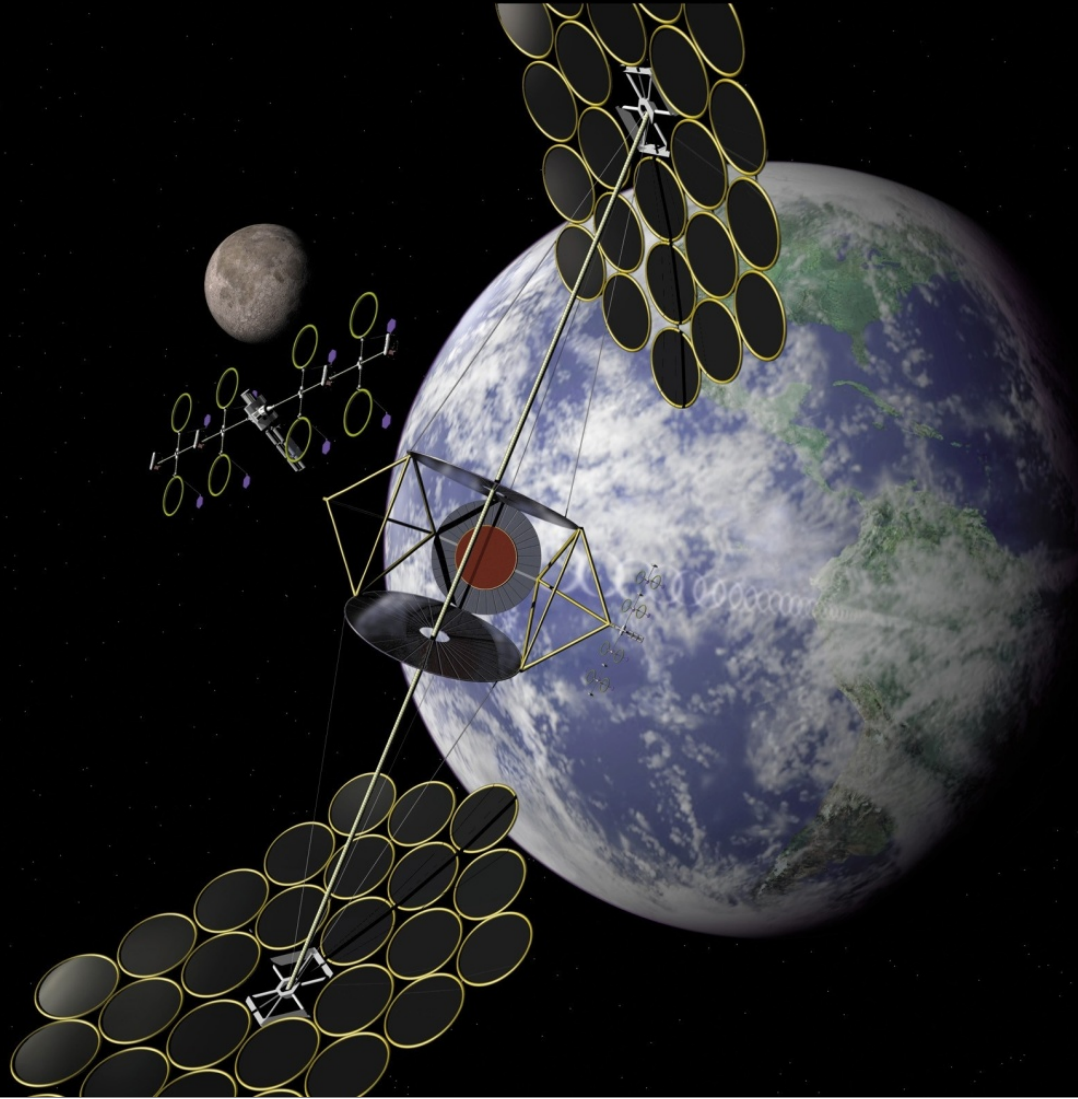


- *Engages thousands of students, attracting them into STEM education programs*
- *Provides the economic basis for the return of humans to the Moon*



# Flagship Demonstration Missions

## Potential Example: Space Solar Power

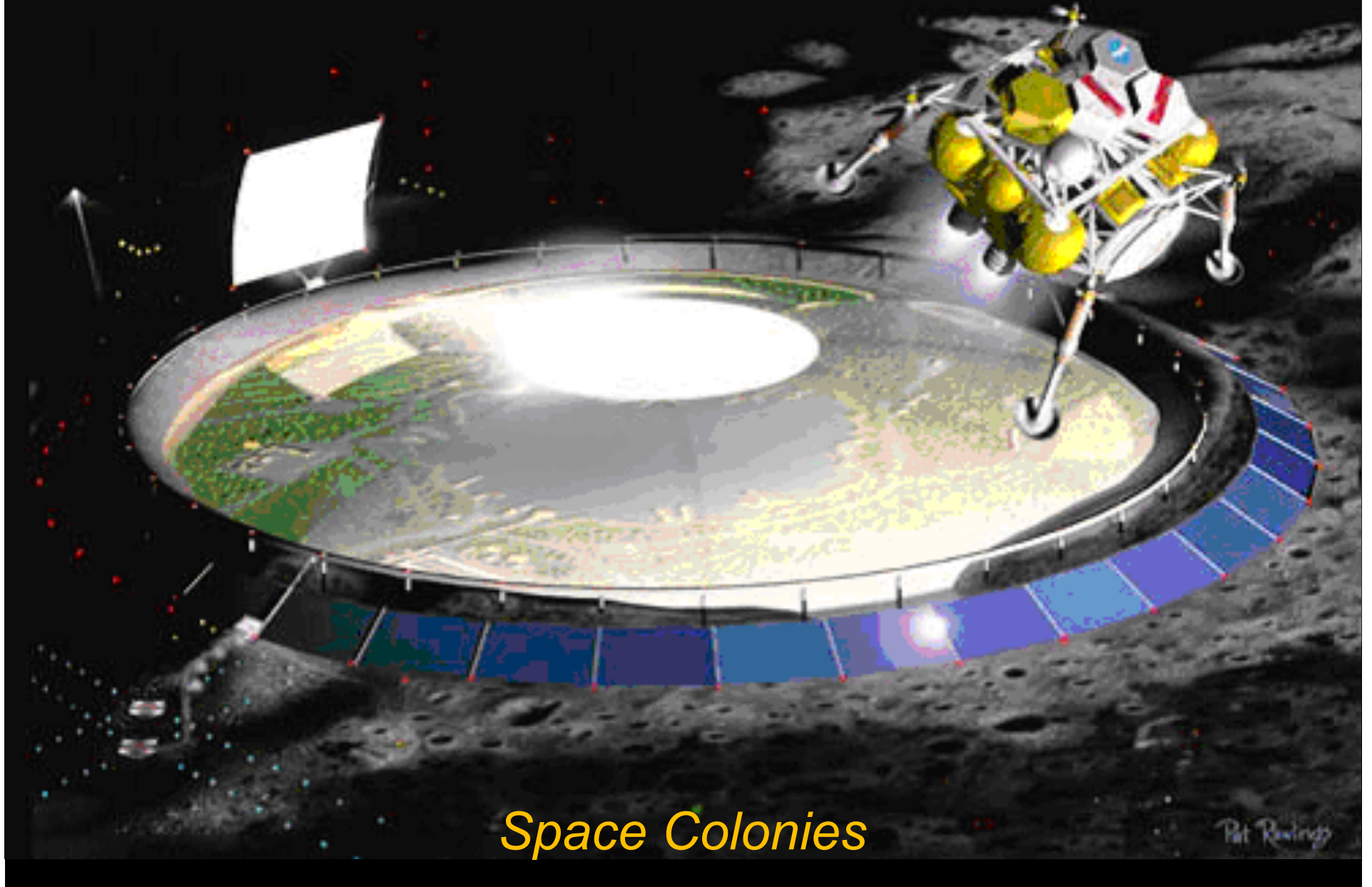


# 21<sup>st</sup> Century Space Exploration

*Can space resources  
make exploration beyond  
LEO more affordable?*

*Can space resources  
provide direct benefits  
to the Earth?*

# 21<sup>st</sup> Century Space Exploration



*Space Colonies*

Pat Rawlings



# 21<sup>st</sup> Century Space Exploration



*ke = 0.780 kilowatt-hours/kg*

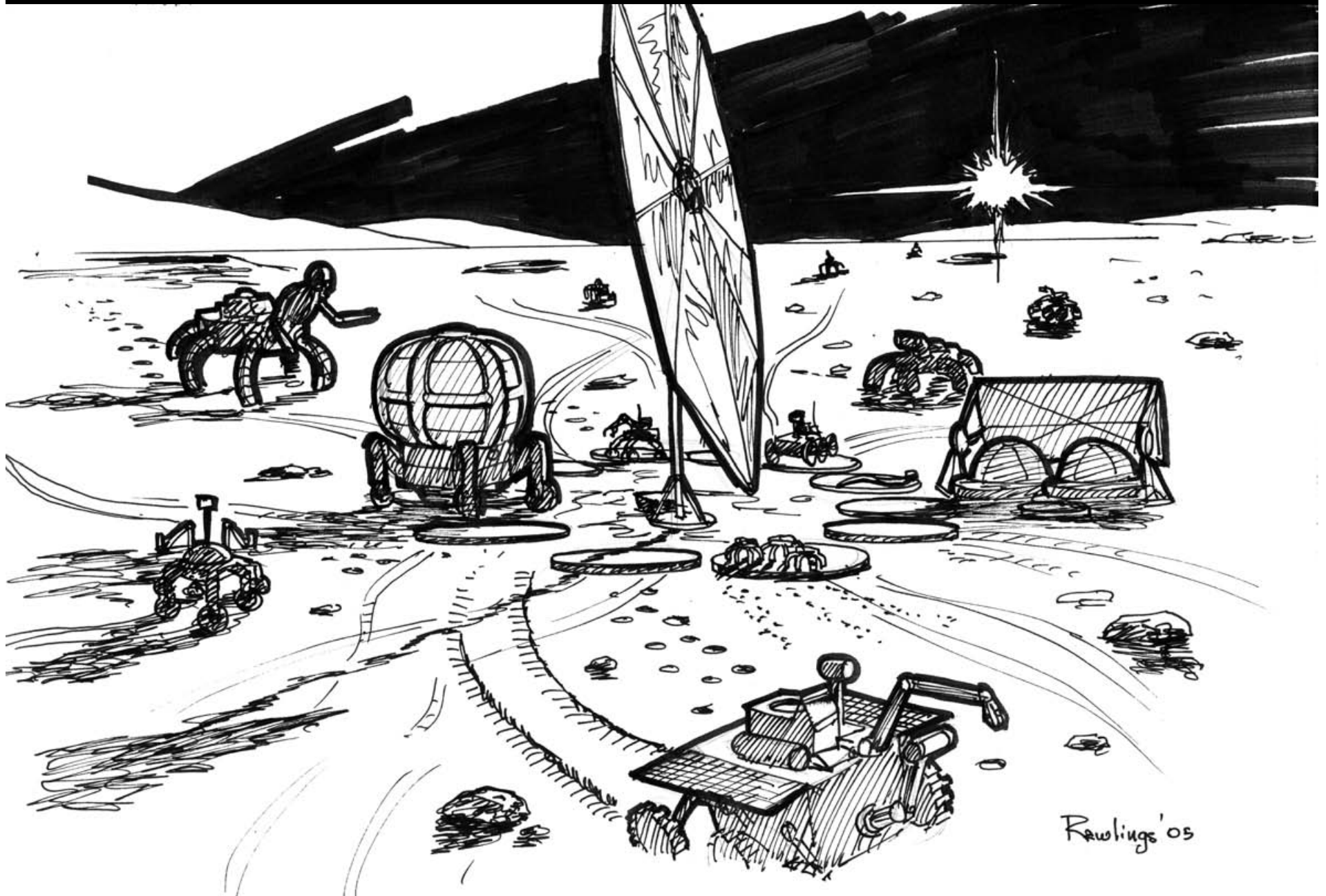


# 21<sup>st</sup> Century Space Exploration

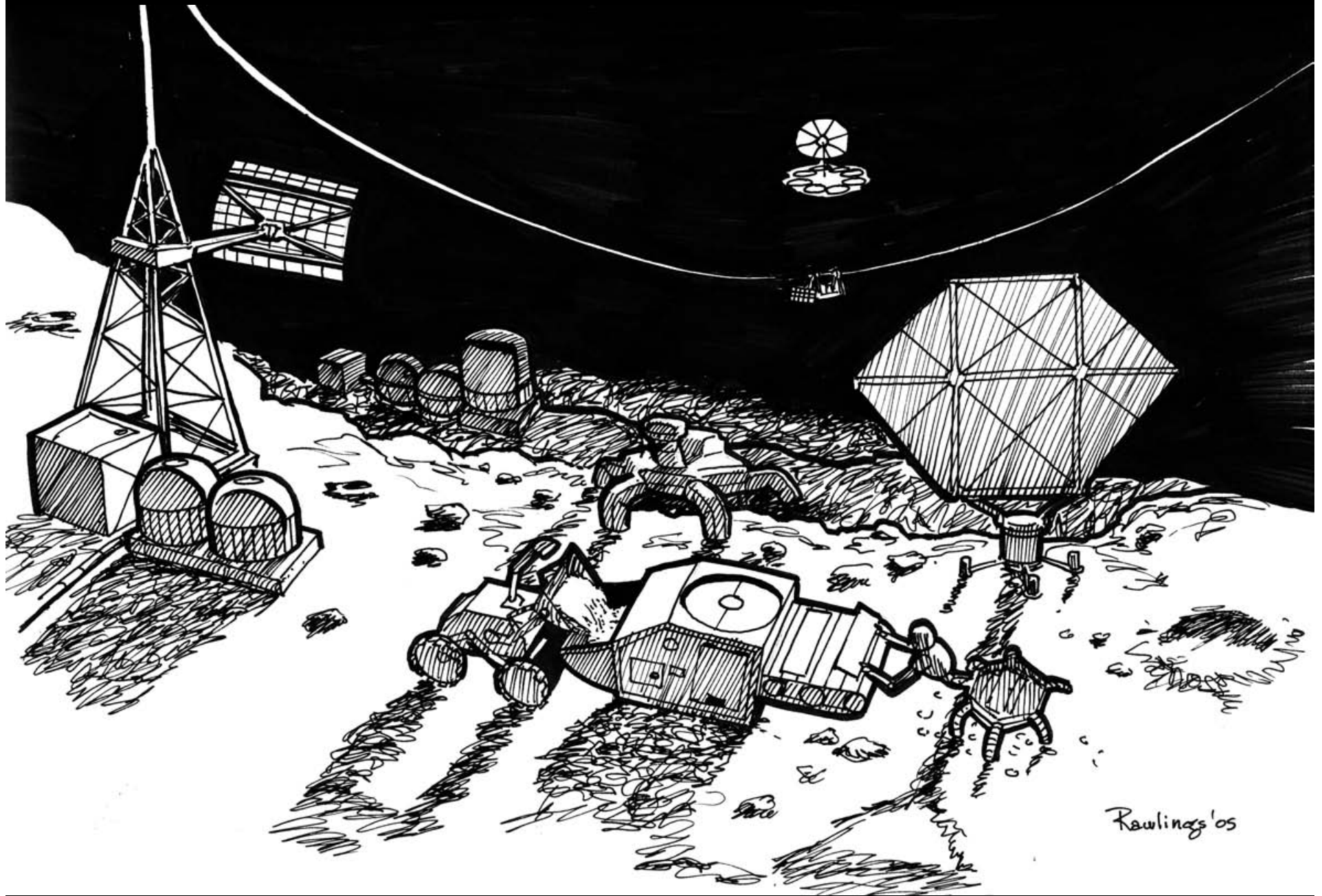
*What advice  
– technical or business –  
should we be providing to NASA,  
OMB and others?*

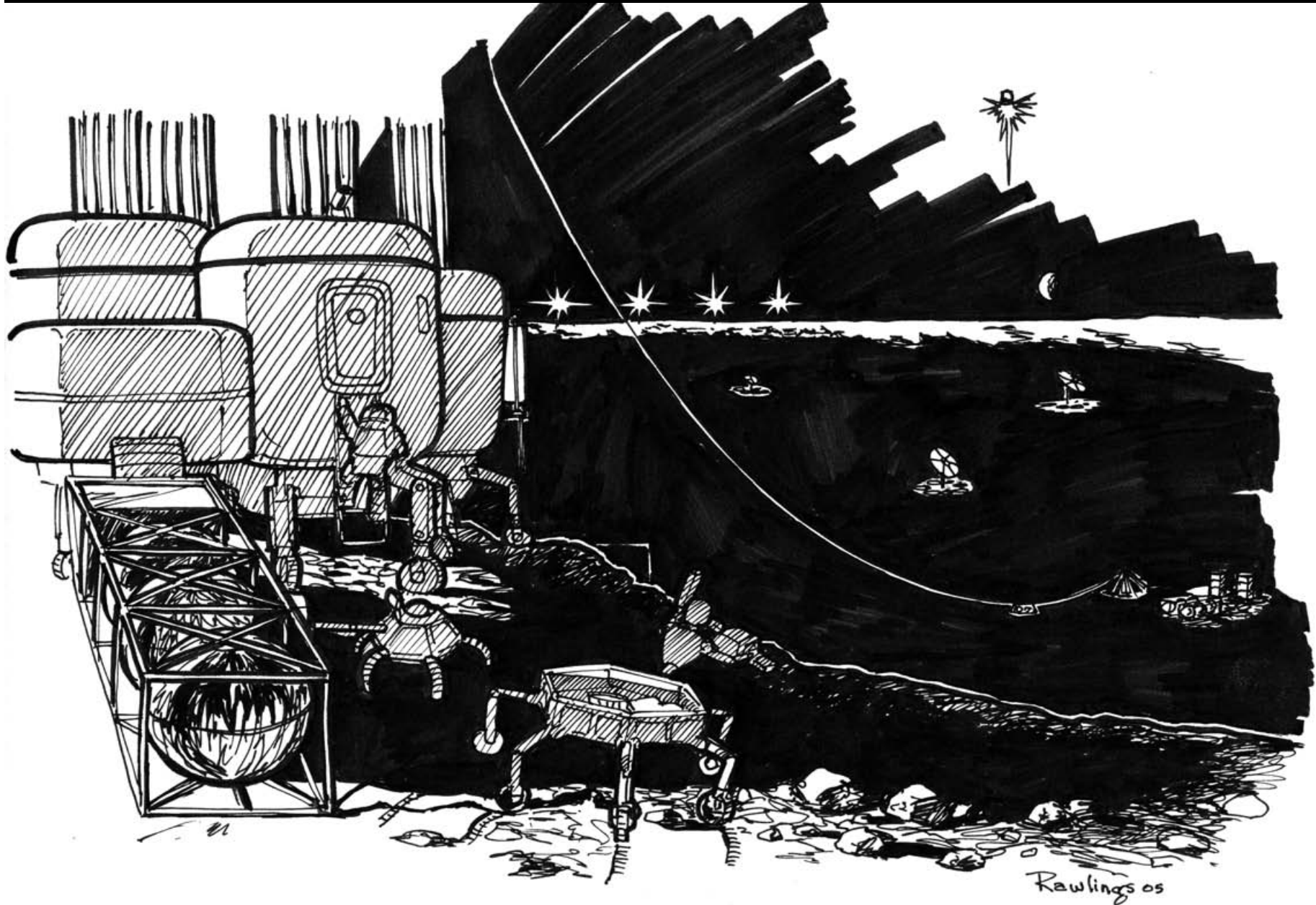
# 21<sup>st</sup> Century Space Exploration



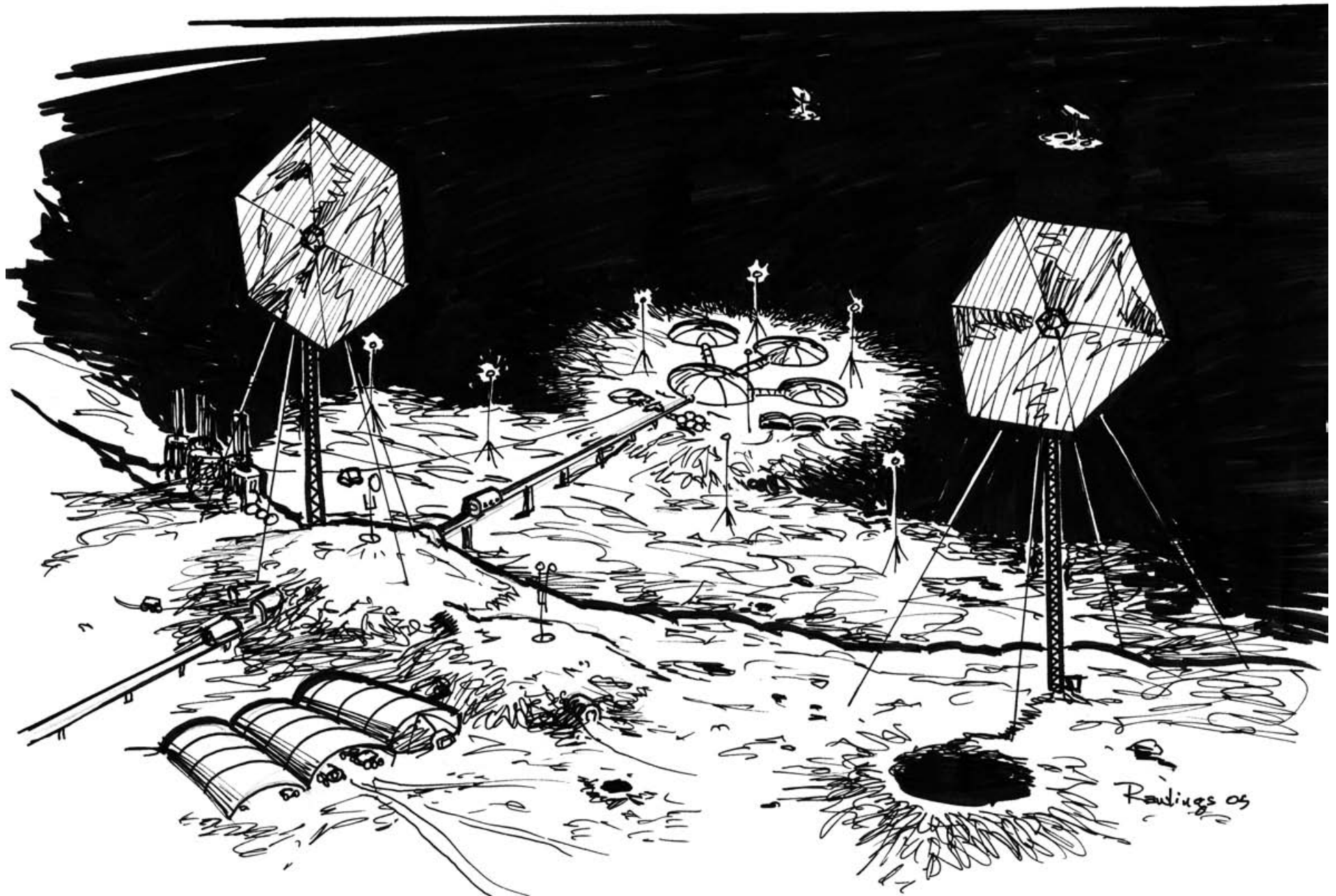


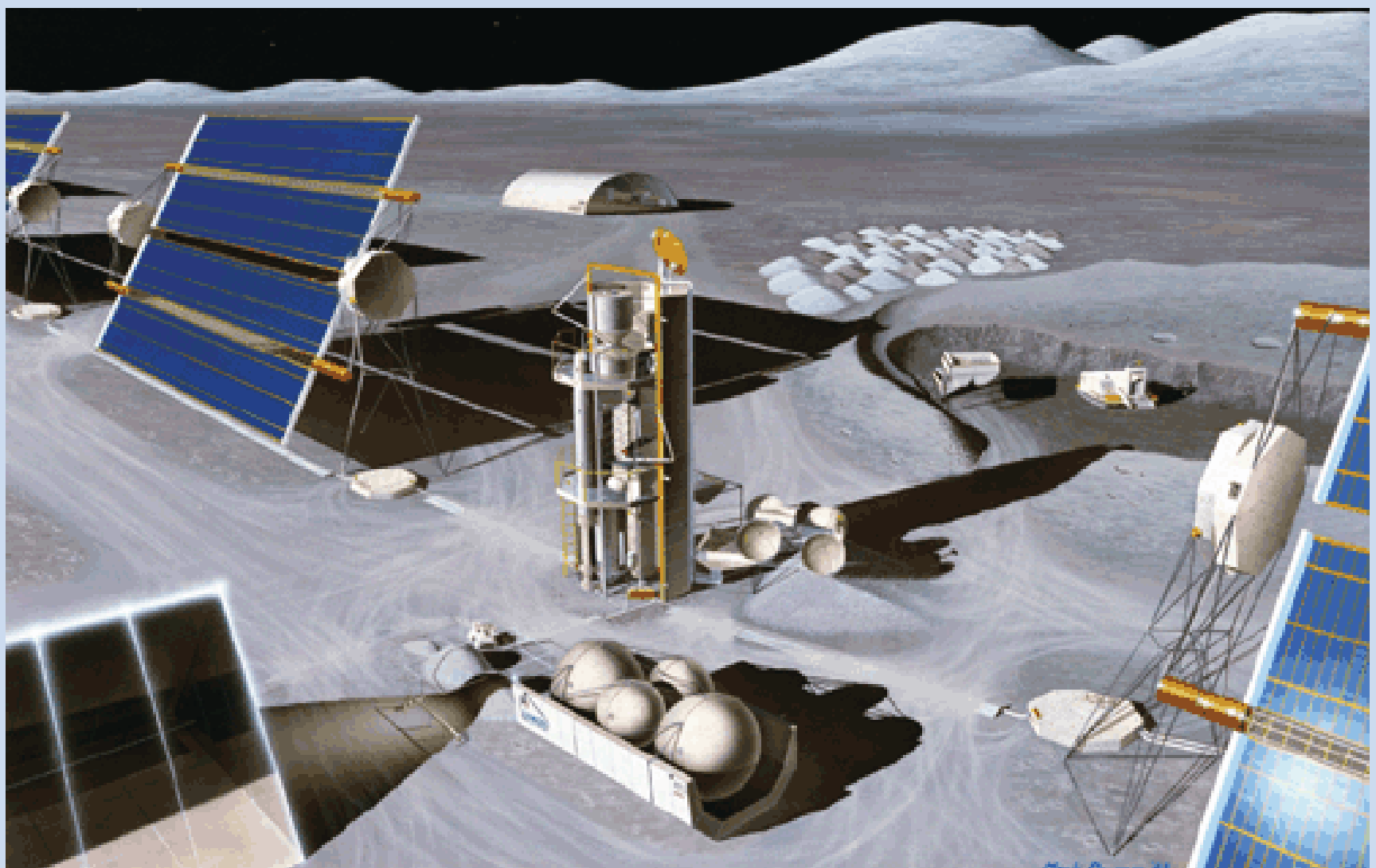












(NASA/Eagle Engineering artist Mark Dowman)