

# LUNAR ROVERS AND THERMAL WADIS BASED ON PROCESSED REGOLITH

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Battelle Memorial Institute

# LUNAR ROVERS AND THERMAL WADIS BASED ON PROCESSED REGOLITH

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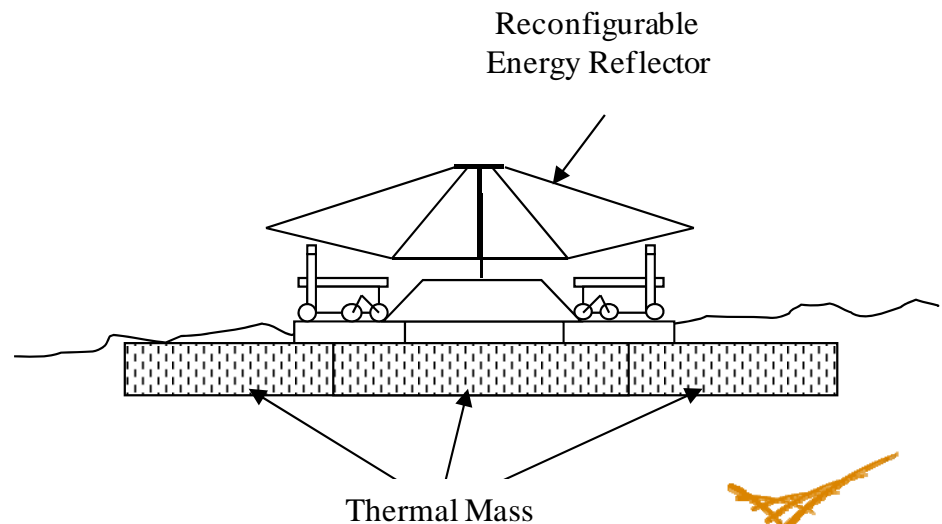
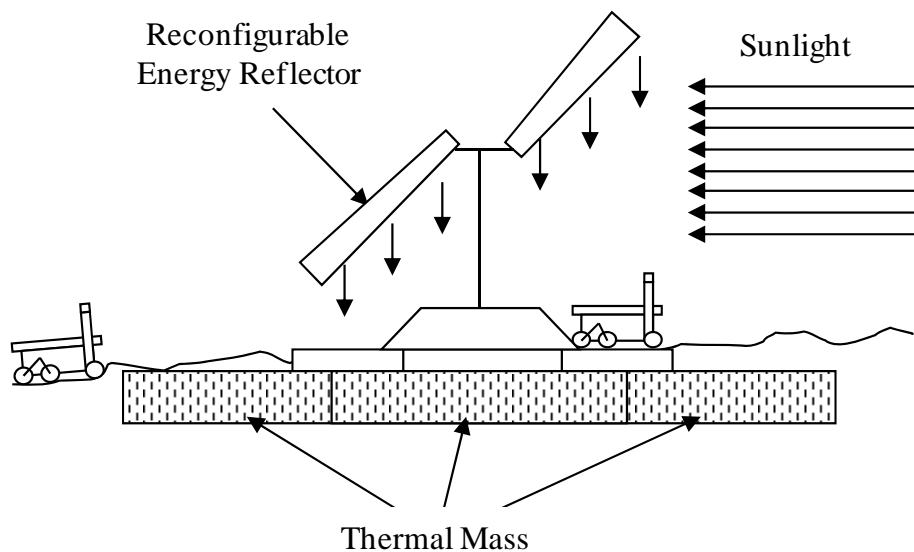
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# Capsule

## ▶ Lunar Rovers

## ▶ Thermal Wadis

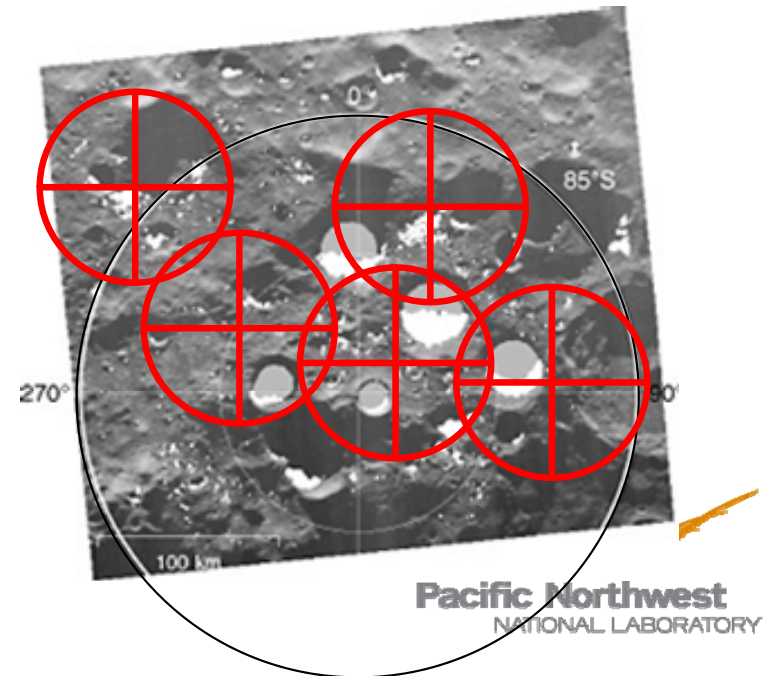
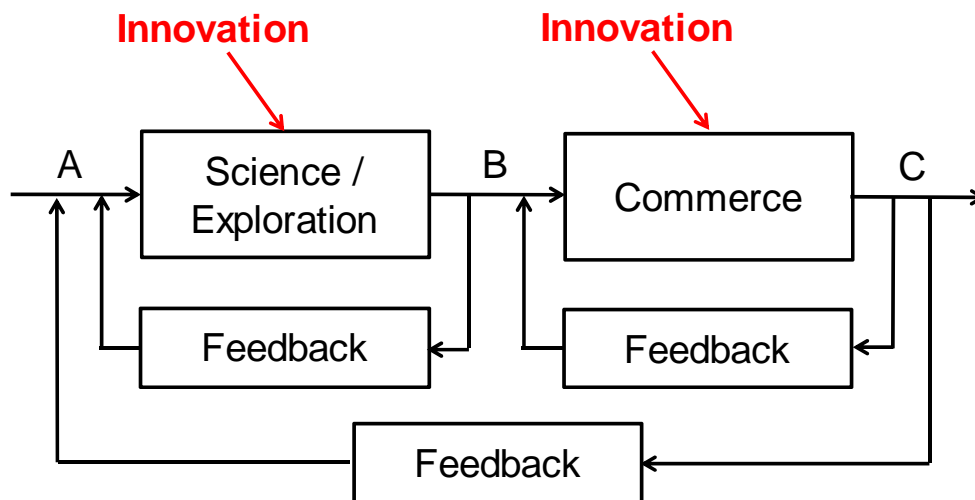
- Engineered sources of heat
- Based on minimally processed lunar regolith
- Enable rovers to survive for years on the lunar surface



Patent Pending

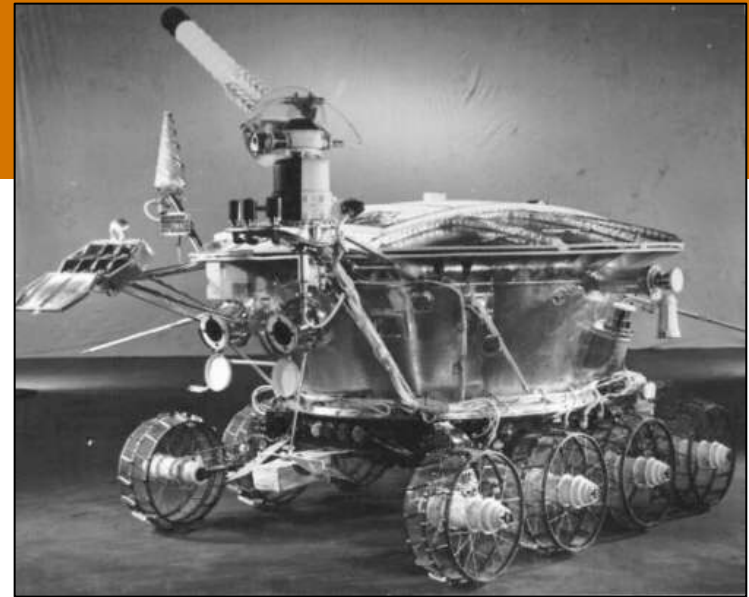
# Continuing.... from the NASA Lunar Science Institute Conference (July 22-24)

- ▶ “Long-Term **Sustainability** on the Moon”
  - Sustainability metrics include **Productivity** (ratio of value to cost)
  - **Feedback Loops** associated with Sustainability
  - Apollo Program and other historical precedents
  - **Lunar Resources, Rovers** and other ways to enhance Productivity and encourage the Sustainability of the lunar enterprise
  - **Thermal Wadis** and **Networks of Thermal Wadis**
  - **“Think like an Economist”**

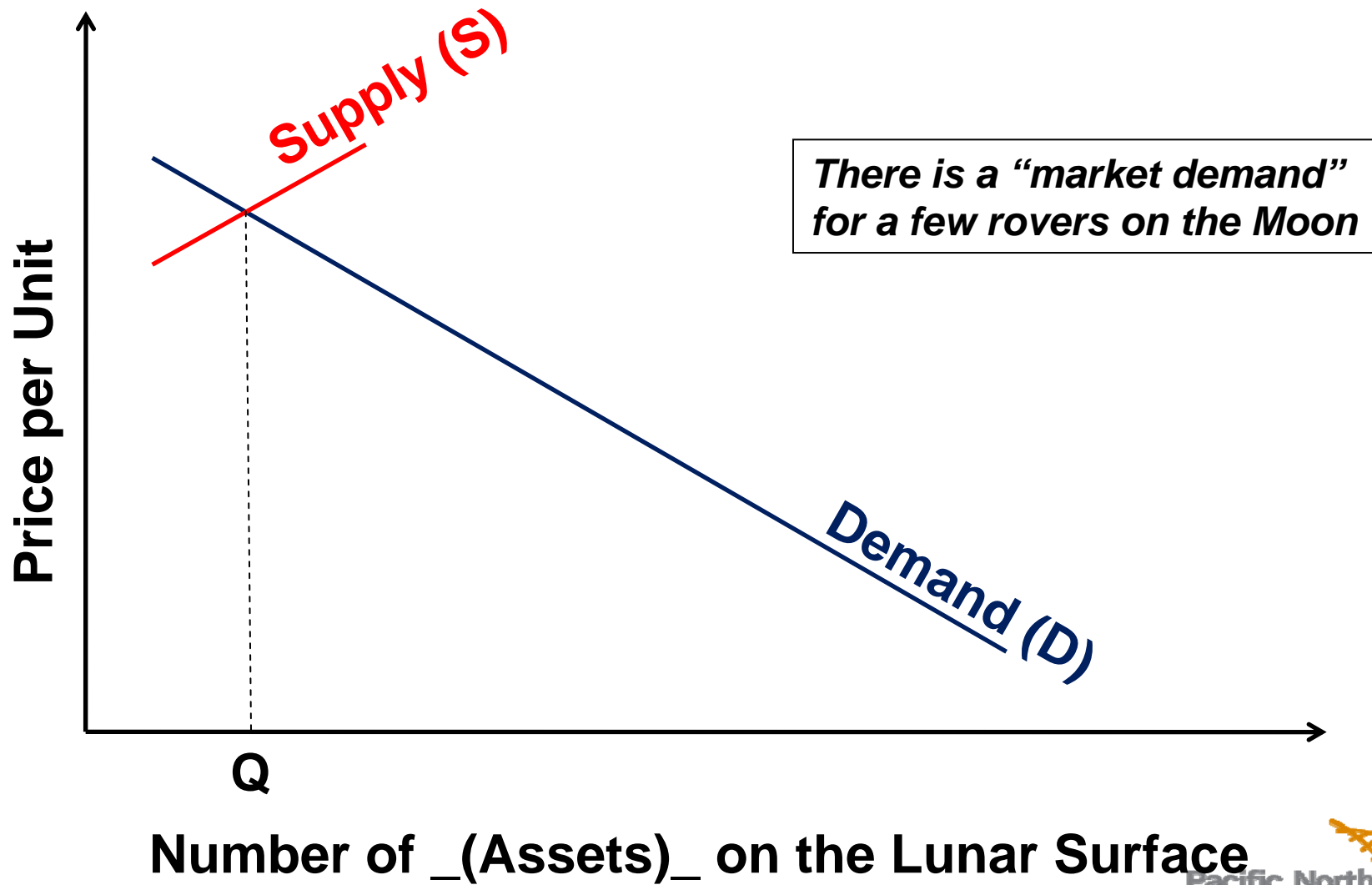


# Teleoperated Rovers

- ▶ Highly versatile science and exploration platforms
- ▶ Unusually attractive to the public (e.g., politically sustainable)
- ▶ Problem: Lifetimes
  - Rover subsystems cannot survive extremely cold lunar temperatures
- ▶ Problem: Costs
  - High cost to transport rover systems to the lunar surface
  - Even higher cost to develop rover systems



# The Economics of Teleoperated Rovers - I



Number of \_(Assets)\_ on the Lunar Surface

# Shifting the Supply Curve

## ▶ *Develop one or more classes of standard rover platforms*

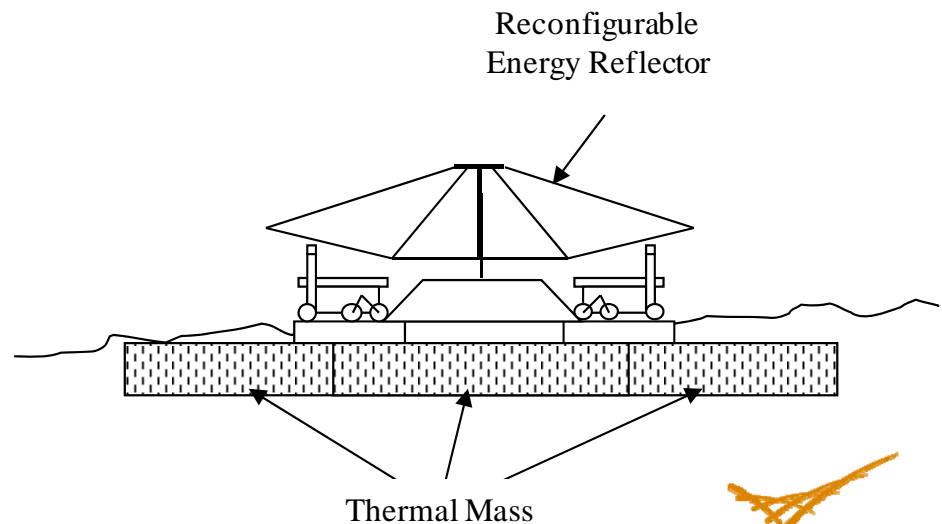
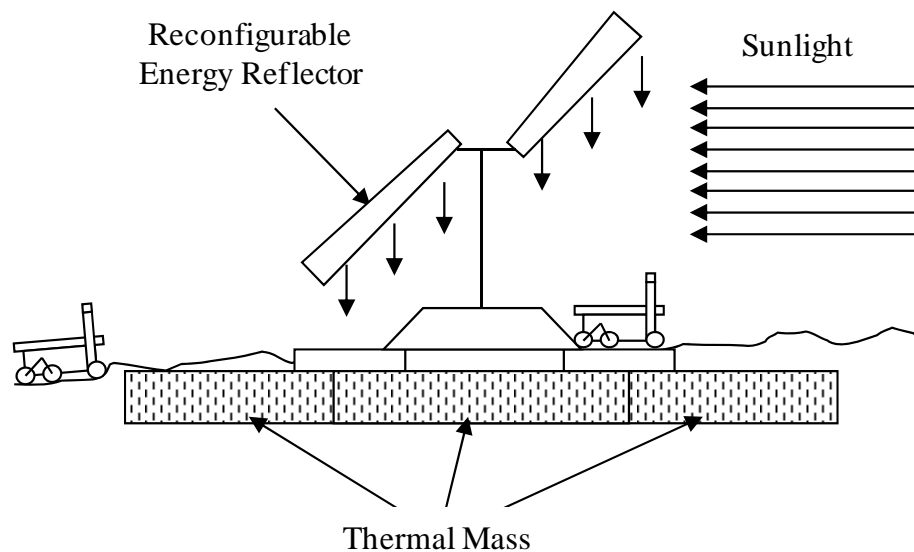
- Standard chassis, mobility, communications, navigation, power
- Standard interfaces for instrument packages
- Standard and unique instrument packages

- Ground-penetrating radar
- Gravimeter/gravity gradiometers
- Rock abrasion tools
- Pancams
- High definition cameras
- 3-D imagers
- Multi- or hyper-spectral imagers
- Gas chromatograph / mass spectrometers
- Various spectrometers (infrared, Raman, thermal emission, alpha proton x-ray, gamma-ray, Mossbauer)
- Microscopic imagers
- Radiation sensors/dosimeters
- Drills/corers

# Shifting the Demand Curve

## ► *Develop and Deploy Thermal Wadis*

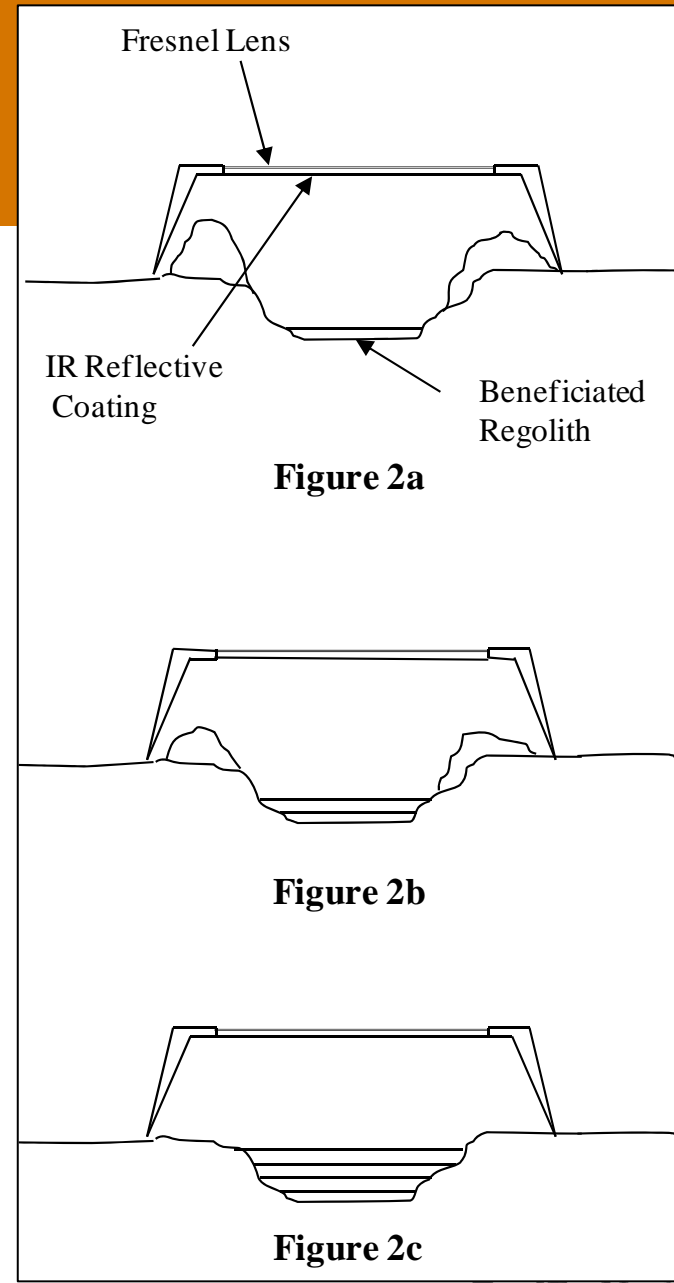
- Engineered sources of heat (and power)
- Based on minimally processed lunar regolith
- Enable rovers to survive for years on the lunar surface



Patent Pending

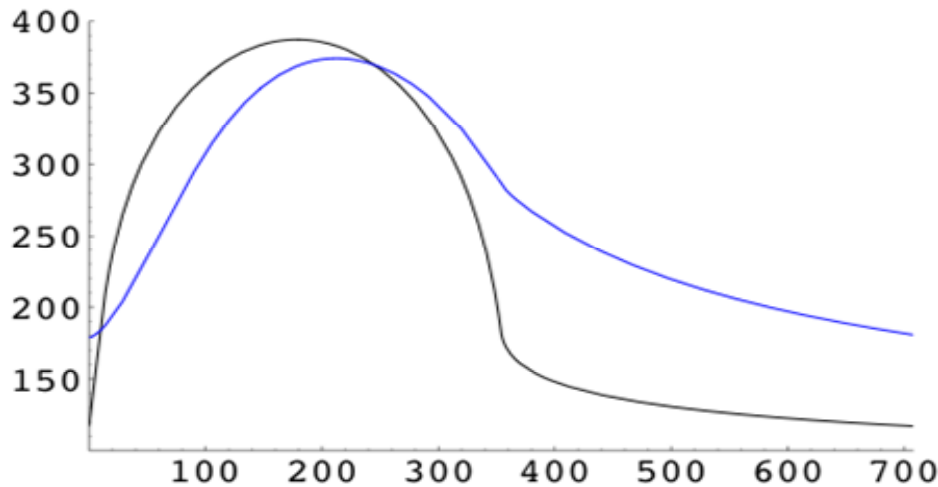
# Thermal Wadi – Methods of Making...

- ▶ Use microwave sintering to produce “thermal bricks”
- ▶ Use solid waste products (tailings) of an oxygen-from-regolith processing
- ▶ Use concentrated solar energy to melt regolith (insitu)
- ▶ Alternately.....



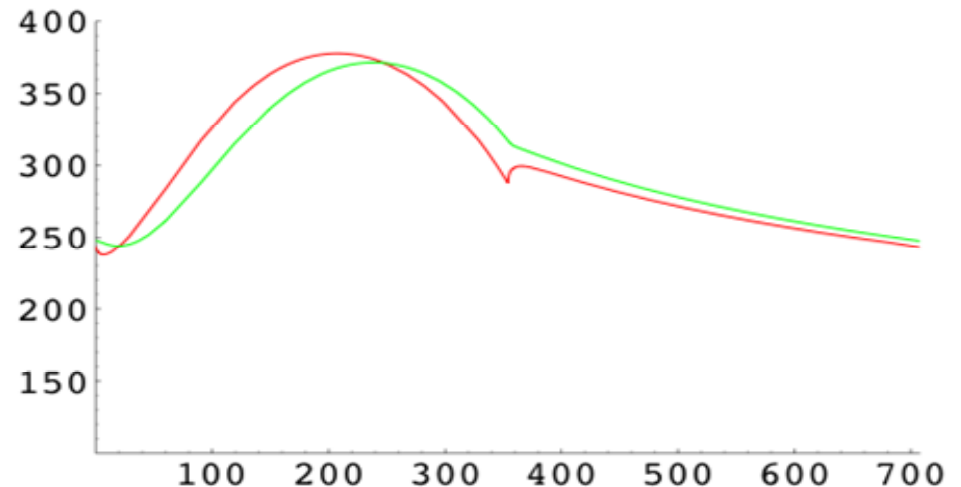
Pacific Northwest  
NATIONAL LABORATORY  
Patent Pending

# Thermal Wadi – Preliminary Thermal Analysis for Equatorial Regions



**Figure 3a**

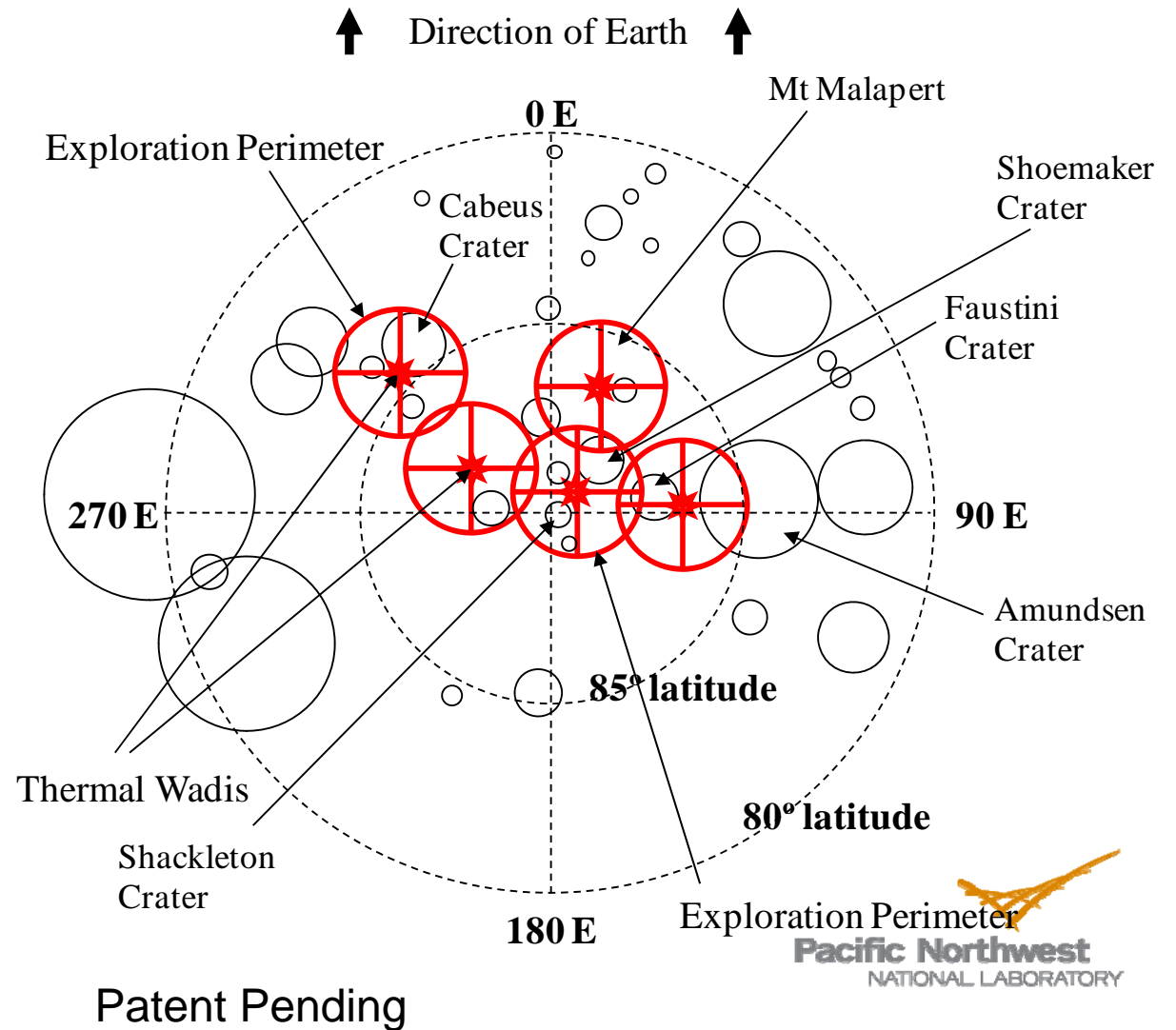
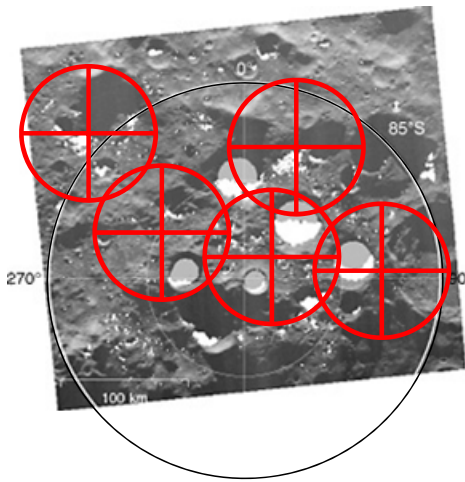
Surface temperature at steady state in a 27-day diurnal cycle. Black curve – native regolith. Blue curve – 50 centimeter deep layer whose thermal properties are the same as basalt rock. Surface emissivity is assumed to be 0.90 for both cases.



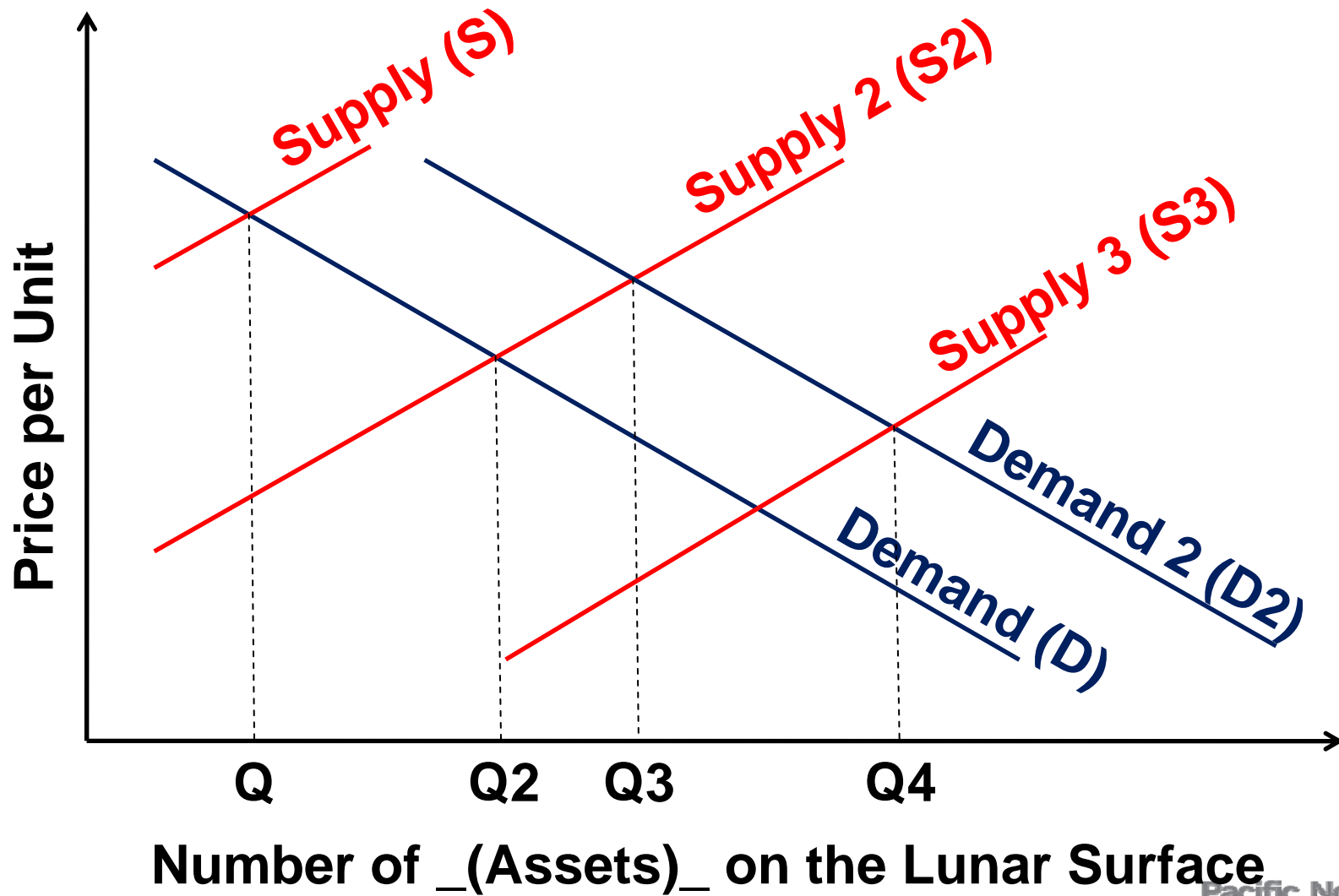
**Figure 3b**

Surface temperature (red curve) and temperature at mid-depth (green curve) at steady state in a 27-day diurnal cycle. The medium is a 50 centimeter deep thermal mass with the thermal properties of basalt rock. Surface emissivity is assumed to be 0.90 during the lunar day and is effectively reduced to 0.25 during the night through the use of an IR reflector.

# Thermal Wadi Networks



# The Economics of Teloperated Rovers -- II



Number of (Assets) on the Lunar Surface

# Conclusions

- ▶ *Reducing Costs* (e.g., by introducing Standard Classes of Rovers and standard instruments) – Shifts the supply curve, increasing “market demand” for science and exploration rovers and other assets on the lunar surface
- ▶ *Increasing Longevity* (e.g., by placing Thermal Wadis on the lunar surface) – Shifts the demand curve, increasing the “market demand” for science and exploration rovers and other assets on the lunar surface
- ▶ *Coupling these together* – Potentially enables a paradigm change in the productivity of lunar assets
  - Encourages a much broader degree of ***Participatory Lunar Science and Exploration*** than otherwise achievable.
  - Increases the productivity of humans on the Moon.
  - Accelerates the characterization of the ***Resource Potential*** of the Moon, potentially enabling an even stronger positive feedback loop.

# References

- ▶ Wegeng, R.S., J.C. Mankins, L.A. Taylor and G.B. Sanders, "Thermal Energy Reservoirs from Processed Lunar Regolith", 2007 International Energy Conversion Engineering Conference, June 2007.
- ▶ Wegeng, R.S., J.C. Mankins, R. Balasubramaniam, K. Sacksteder, S.A. Gokoglu, G.B. Sanders and L.A. Taylor, "Thermal Wadis in Support of Lunar Science and Exploration", 2008 International Energy Conversion Engineering Conference, July 2008.
- ▶ Balasubramaniam, R., Wegeng, R.S., Gokoglu, S.A., Suzuki, N.H., and Sacksteder, K.R., "Analysis of Solar-Heated Thermal Wadis to Support Extended-Duration Lunar Explorations," accepted by the 47th AIAA Aerospace Sciences Meeting, Orlando, January 2009.

***“From the Moon to the Earth”***



# Historical Precedents

- **17<sup>th</sup> Century**
  - Jamestown
  - Other New World Colonies
- **18<sup>th</sup> Century**
  - United States of America
- **19<sup>th</sup> Century**
  - Erie Canal
  - Louisiana Purchase, Lewis and Clark
  - Transcontinental Railroads
- **20<sup>th</sup> Century**
  - Electricity
  - Automobiles and Air Travel
- **21<sup>st</sup> Century**
  - The Vision for Space Exploration
  - The Robotic International Lunar Network
  - Manned Outpost

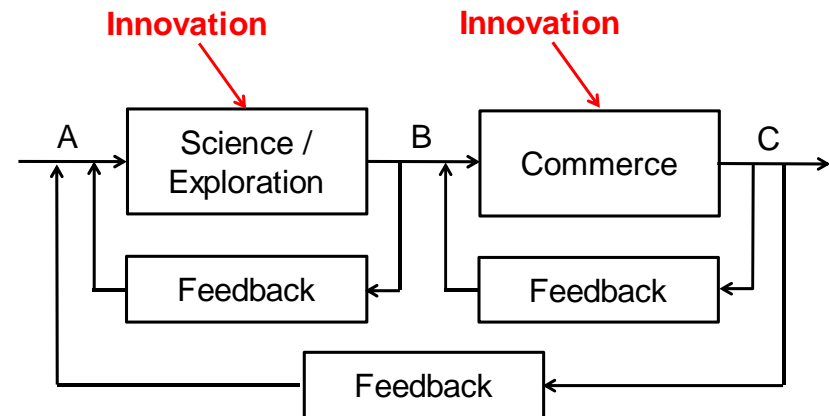
# Historical Precedents

## ▶ The Louisiana Purchase

- Purchased from France
- President Jefferson commissioned Lewis and Clark on a journey of exploration to the Northwest
- “The Northwest won’t be settled for 1,000 years” – Thomas Jefferson

## ▶ Steam Engines

- Paddlewheel Steamboats
- Railroads



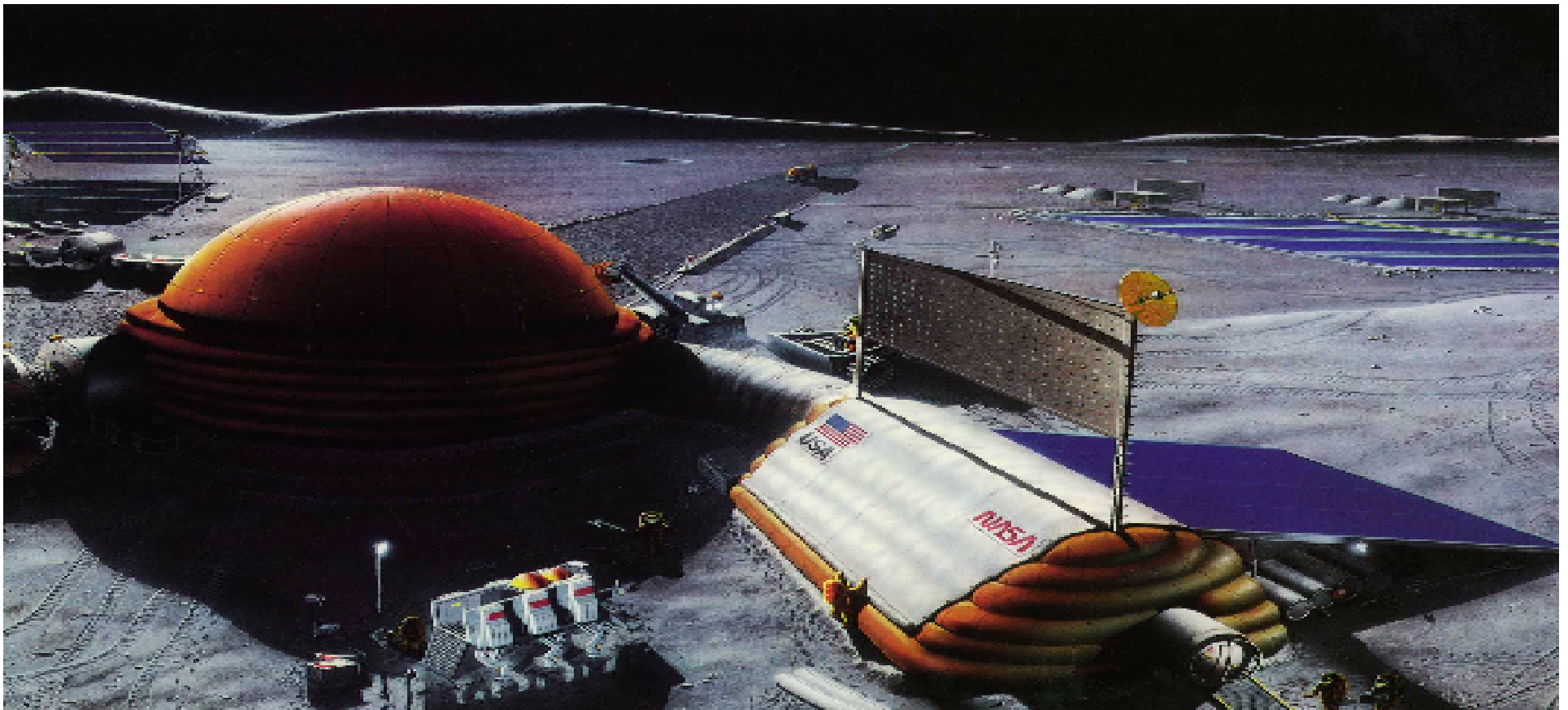


# Apollo Program

- ▶ Was the Apollo Program Sustainable?
- ▶ Sustainability isn't just about politics
  - *Value*
  - *Cost*
  - *Productivity*
  - *Energy & Resources*
- ▶ *Think like an Economist*

# Lunar Resources

- ▶ Oxygen (for breathing, power generation, propulsion)
- ▶ Hydrogen and other fuels
- ▶ Structural materials (Al, Ti, Fe)
- ▶ Electronics materials (Si)



# Rover Productivity

- ▶ How do we improve the productivity of a rover system?

Perform  
Science &  
Exploration

Engage  
Multiple  
Institutions

Use  
Advanced  
Electronics

Enable  
Years of  
Operation

$$Productivity = \frac{Value}{Cost}$$

Minimize  
Mass

Deploy  
Multiple  
Units

Standard  
Functions

Standard  
Interfaces