Kickstarting a New Era of Lunar Industrialization via Campaigns of Lunar COTS Missions

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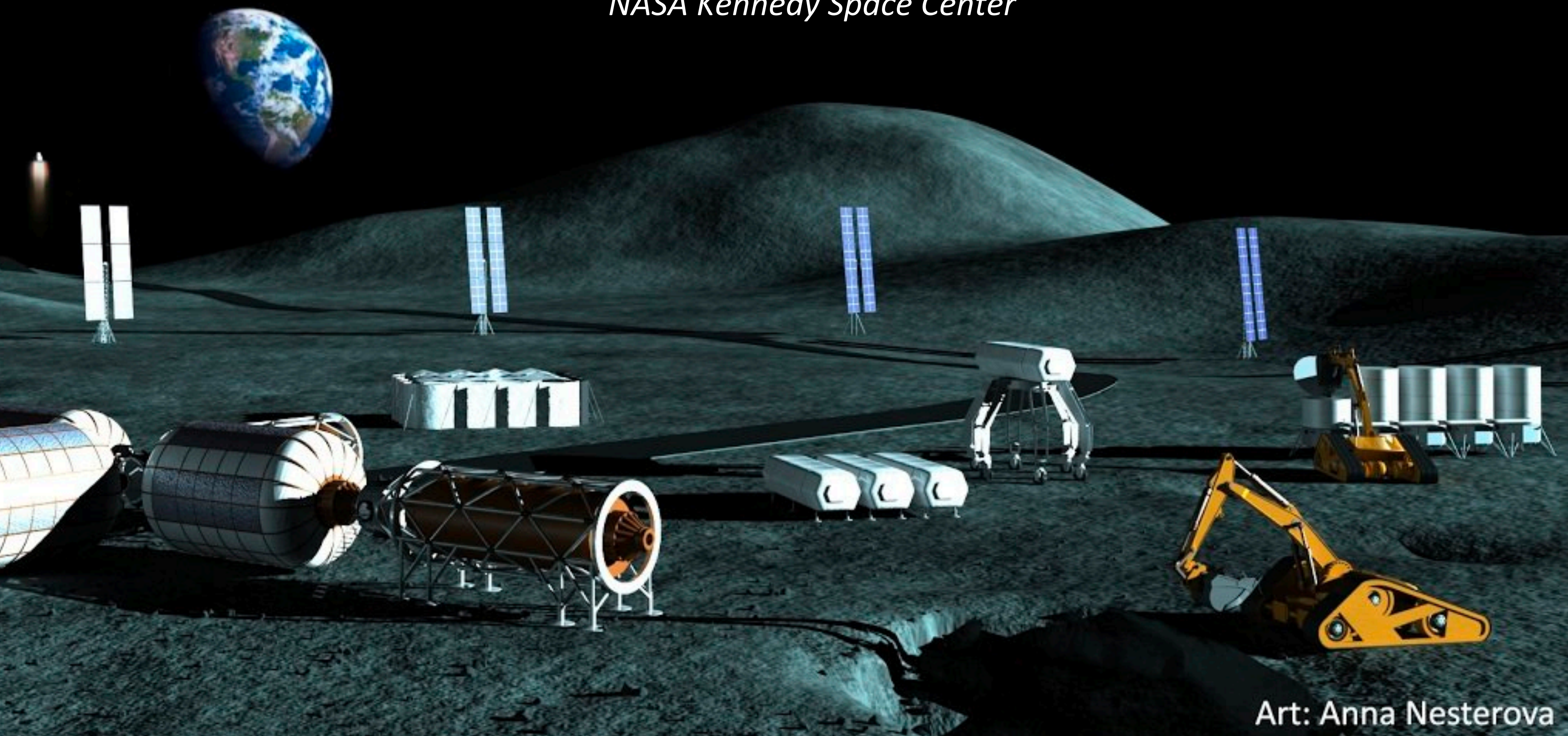
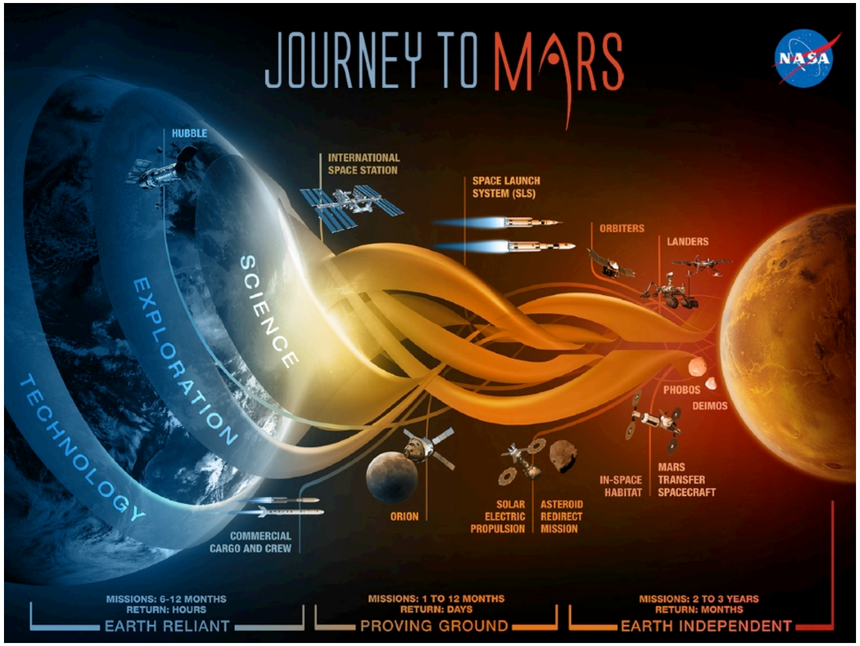


Background

- President Obama's 2010 National Space Policy set the following goal for NASA:
  - By the mid-2030's, send humans to orbit Mars and return them safely to Earth.
- As a result, NASA has established its Journey to Mars and Evolvable Mars Campaign (EMC) to:
  - Investigate architectures to further define capabilities needed for **a sustainable human presence on the surface of Mars**.
  - **Proving Ground Objective:** Understand the nature and distribution of volatiles and extraction techniques and **decide on their potential use in future human exploration architecture**.

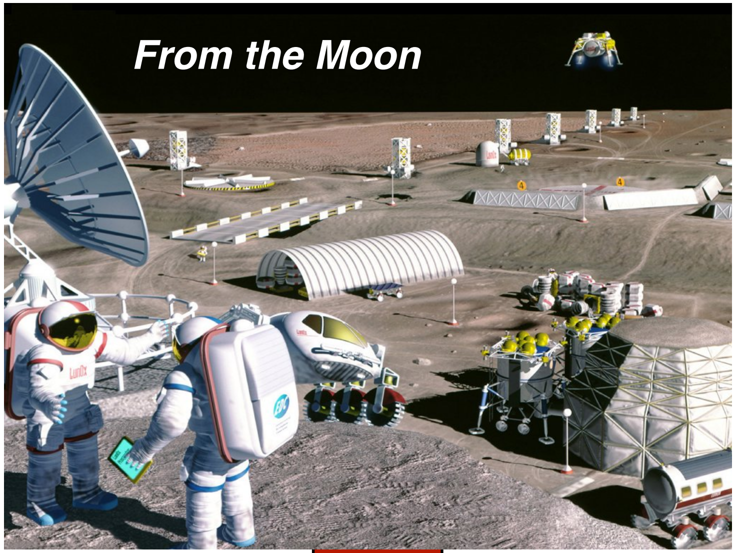


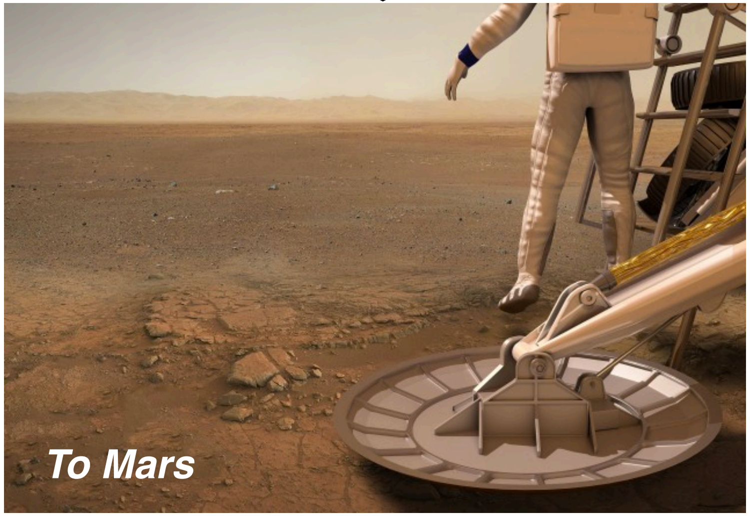
- Under the EMC, NASA has also developed a Pioneering Space Strategy with the following principles:
  - Implementable in the ***near-term with the buying power of current budgets*** and in the longer term with budgets commensurate with economic growth;
  - ***Opportunities for U.S. commercial business*** to further enhance the experience and business base;
  - Near-term mission opportunities with a cadence of human and robotic missions providing for ***an incremental buildup of capabilities*** for more complex missions over time;
  - Substantial ***new international and commercial partnerships***, leveraging the current International Space Station partnership while building new cooperative ventures.

Moon as a "Stepping Stone" to Mars

- Prospect and extract lunar resources **to assess the value proposition** to NASA and our partners.
  - *Lunar resources may prove beneficial for inclusion in future Mars architectures, e.g., lunar-derived propellant*
- **Apply the proven COTS model** to develop low-cost commercial capabilities and services, such as:
  - *Lunar Landers and Rovers*
  - *Resource Prospecting Techniques*
  - *Lunar Mining and ISRU capabilities*
  - *Lunar Relay Communication Satellites*
  - *Power Stations*
- **Use campaigns of missions**, instead of single missions, in a 3-phase approach to incrementally develop capabilities and lower risks.
- **Establish Economic Development goals** by incentivizing industry to create cis-lunar markets.
  - *NASA should not be sole customer; by targeting other customers and new markets, it will kickstart a new era of Lunar Industrialization.*

The Moon can serve as a Gateway to Mars and the rest of the Solar System.



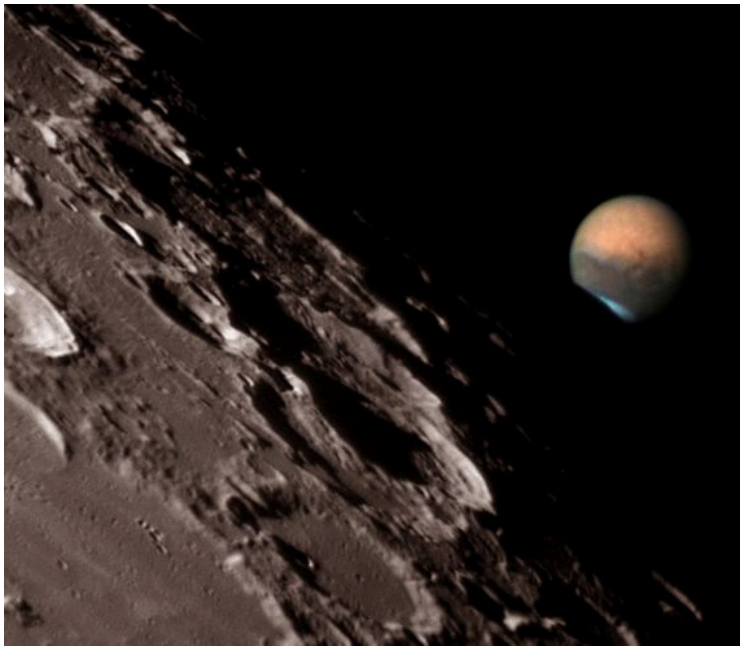


NASA Commercial Orbital Transportation Services (COTS)

- NASA's COTS acquisition model proved to be very effective in reducing development and operations costs.
  - Studies showed a ***10-to-1 reduction in development costs*** for Space-X's Falcon 9 rocket when compared to traditional FAR-based contracts.
  - Studies also showed that ISS cargo transportation ***services cost significantly less*** than previous Space Shuttle flights.

- **Best Practices from COTS** are summarized here:
  1. NASA and commercial partners ***share cost, development and operational risk*** to demonstrate new capabilities for mutual benefit.
  2. NASA makes ***long-term commitments to procure commercial services*** to help secure private investments.
  3. NASA encourages commercial partners to ***target other markets outside Government*** to make their business case close. NASA is anchor customer but not sole customer.
  4. NASA uses ***SAA's to enter into partnership*** with commercial partners to offer maximum flexibility in design solutions without the full demands and requirements of typical FAR-based contracts.
  5. NASA includes ***pay-on-performance milestones*** in SAA's to provide several off-ramps and reduce programmatic risk.
  6. Commercial partners ***retain Intellectual Property (IP) rights*** and operates and owns final product(s).

Lunar Commercial *Transfer* Services (LCOTS)



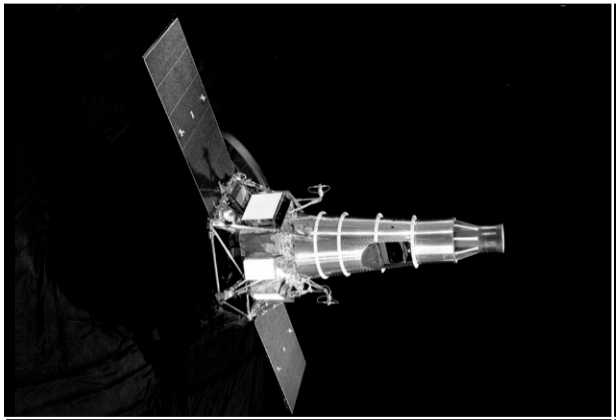
GOALS

- Establish affordable and economical cis-lunar capabilities and services.
- Enable development of a sustainable and economical exploration architecture for Mars and beyond.
- Encourage creation of new space markets to further reduce costs.

Approach

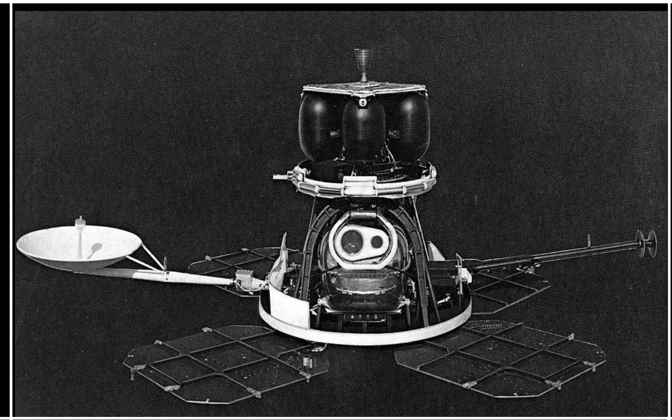
1. Use 3-phase approach to incrementally develop capabilities and services and lower programmatic risk.
2. Use proven COTS model to partner with industry to share cost and risk.
3. Determine technical and economic viability of extracting lunar resources.
4. Use Campaign of missions instead of single large mission.

Apollo Pre-Cursor Campaigns – An Historic Context



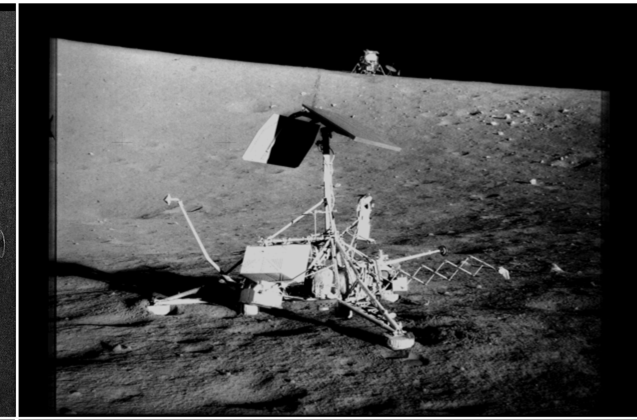
Ranger Campaign

- Designed to take images of the lunar surface until impact.
- Acquired knowledge of potential landing sites for Apollo missions.
- Ranger missions 1-6 Failed, 1961-64
- Ranger mission 7-9 were successful, 1964-64.



Lunar Orbiter Campaign

- Designed to map the lunar surface to aid in the selection of landing sites for Apollo lunar program.
- All five missions were successful and 99% of the Moon was mapped, 1966-67.

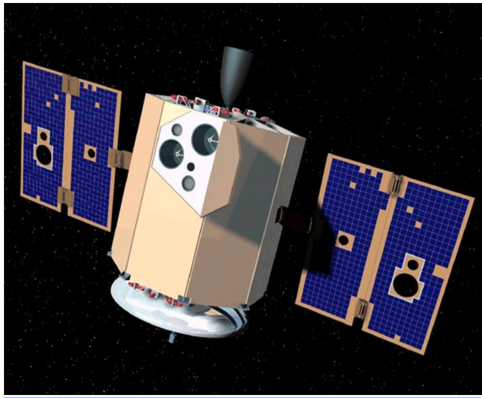


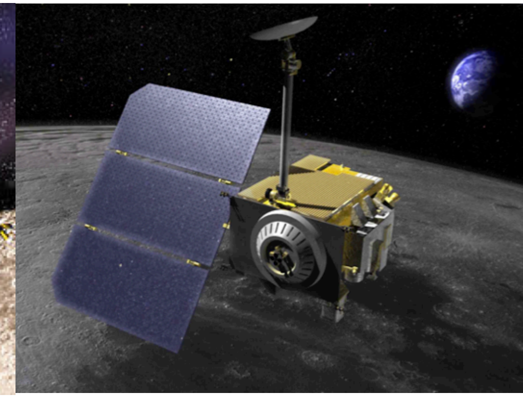
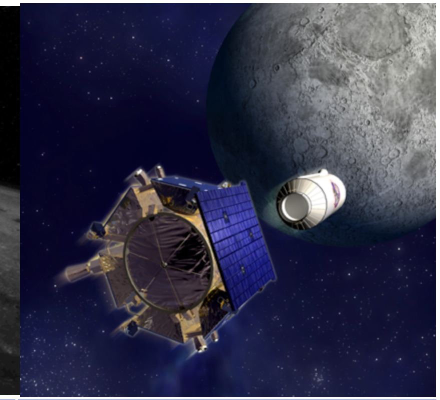
Surveyor Campaign

- Designed to soft land on the lunar surface and help evaluate the suitability of landing sites for Apollo missions.
- Five of seven missions were successful, 1966-68.

Each mission in a campaign benefited from learning from prior mistakes and took advantage of economies of scale to lower costs.

NASA’s post-Apollo Lunar Missions in Search for Water



Clementine 1994	Lunar Prospector 1998-99	LRO 2009-Present	LCROSS 2009
<u>Significant Findings</u> Its Bi-static Radar Experiment provided data suggesting the presence of water on the lunar surface near the poles.	<u>Significant Findings</u> On March 5, 1998, scientists announced that LP’s neutron spectrometer instrument had detected hydrogen at both lunar poles, which scientists theorized to be in the form of water ice.	<u>Significant Findings</u> Scientists using LRO’s Mini-RF radar have estimated the maximum amount of ice, as much as 5 to 10% of material, by weight, is likely to be found inside Shackleton crater located near the moon's South Pole.	<u>Significant Findings</u> Scientists found evidence that the lunar soil within shadowy craters is rich in useful materials, and also confirmed the presence of water in average concentration of 5.6% by mass.

These NASA missions have provided strong evidence for existence of millions of tons of water-ice on the Moon
We now need ground truth data to confirm.

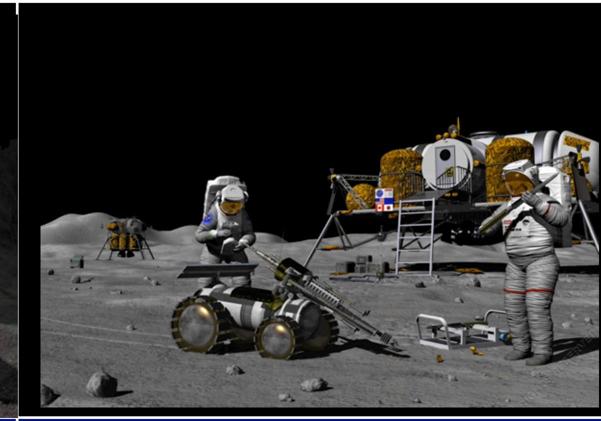
LCOTS Phased Implementation

Phase 1: Low-Cost, Commercial-Enabled Prospecting

- Prospect several sites for surface resources and hazards;
  - Identify areas of high concentrations of water-ice and other volatiles
  - Assess potential sites for hazards and accessibility
- Develop and demonstrate key capabilities in partnership with industry.
  - Lunar Landers and Rovers
  - Resource Prospecting Techniques
  - Lunar Mining and ISRU
  - Lunar Communication Satellites
  - Power Stations

Phase 2: ISRU Pilot Plant

- Develop a pilot-scale ISRU plant to extract water and produce up to 1 metric ton of propellant.
- Demonstrate capabilities for ISRU resource production.
- Demonstrate lunar transportation of large payloads from surface to cis-lunar propellant depot.
- Evaluate feasibility and economics of scaling up production to full scale.



Phase 3: Full-Scale Production

- NASA awards long-term contracts for Lunar ISRU production on the order of several metric tons per year.
- Awards are also made for delivery services to Cis-Lunar Depot.
- Full-scale ISRU facility development of approx 200 mt of propellant per year.
- **ISRU development and production facility cost has been estimated at $40B ($4B/year over 10 years).**

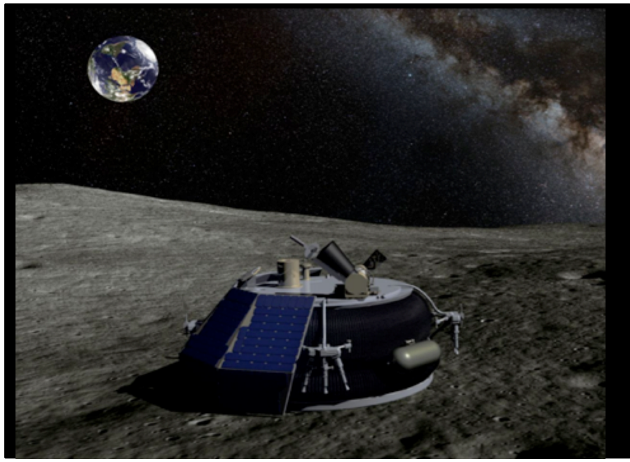
Phase I: Low-Cost, Commercial-Enabled Missions

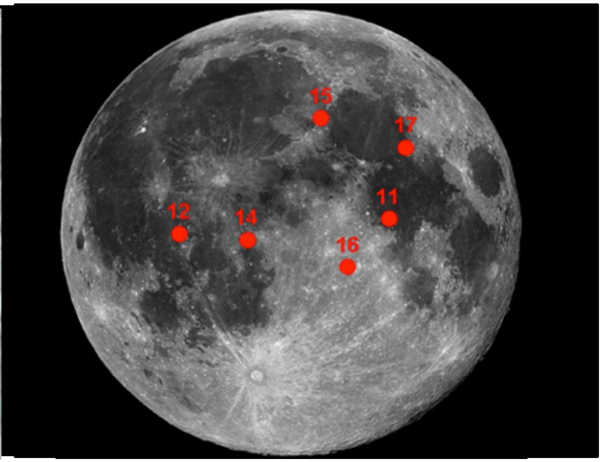
From Apollo Legacy to
21st Century
Robotic Lunar Exploration

Proposed Goals

1. **Conduct a campaign of low-cost, commercial-enabled lunar exploration missions** to prospect and extract lunar resources to meet NASA's mission needs and industry's commercial interests;
2. **Determine the economic viability of extracting resources** by testing various commercial tools, products and techniques in a lunar environment;
3. **Build an economic infrastructure** by partnering with industry to place fundamental systems in service, such as, power stations, lunar communication relay satellites, and ISRU facilities;
4. **Enable a robust cis-lunar commercial economy** by incentivizing industry to create new space products and markets;
5. **Inspire the next generation of space entrepreneurs** by conducting several educational and outreach activities.

Potential Landing Sites





Lunar Polar Landing Sites

- **North and South Poles** may contain an abundance of water ice below the surface in permanently shadowed regions (PSRs) and surrounding areas.
- **PSRs are very challenging** to operate in due to extreme low temperatures, low visibility, steep and rocky terrain, etc.
- **Several robotic missions are necessary** to determine quantities, depth, composition and accessibility of the water-ice concentrations.

Lava Tubes and Lunar Caves

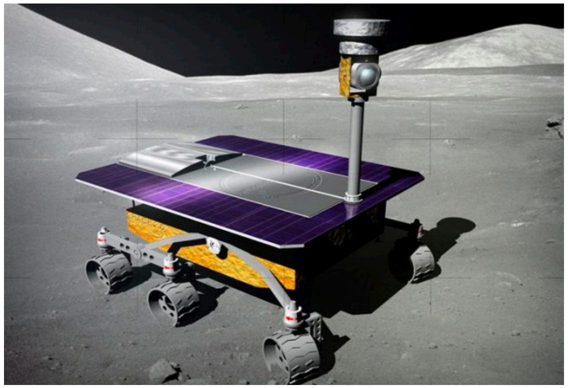
Several lava tubes and lunar caves exist in various locations on the Moon.

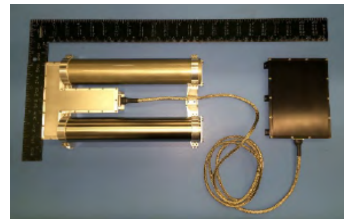
- These caves can serve as human habitations since they are very large and can provide a good amount of radiation shielding.
- Several robotic missions to these areas are necessary to provide structural integrity and radiation data as well as accessibility information of these caves.

Apollo Historical Landing Sites

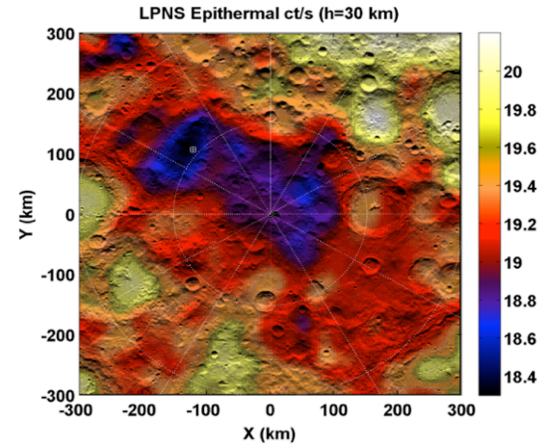
- **There are 6 Apollo landing sites** with existing US hardware almost 50 years old.
- These sites can provide valuable information on **micrometeorite damage** and hazards assessment on the 50-year old hardware.
- Some of the Apollo sites also offer very **intriguing geological areas** that may be rich in valuable resources. Missions to these areas would build on the Apollo legacy.

Potential Mission Objectives





Neutron Spectrometer



Low-cost commercial missions may be able to meet several ***exploration, science and commercial*** objectives with small instruments and commercial products. Sample list of mission objectives are as follows:

- Prospect for, characterize and locate potential resources on the Moon (e.g. ice concentrations at the poles and precious metals at the equator);
- Measure distributions and depths of areas with high hydrogen concentrations;
- Measure amounts of radiation at various sites, within lunar caves and/or lava tubes;
- Demonstrate ISRU technologies and operations, such as drilling, for extracting lunar resources.
- Precise delivery and remote operation of commercial products from the lunar surface.

SPACE PORTAL

LCOTS Partnership Strategy

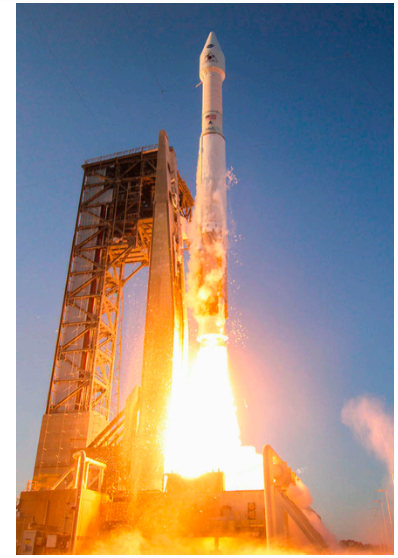
1. **Employ the proven COTS model**
   - Enables economical and sustainable missions
   - Establish "cost and risk-sharing" partnerships

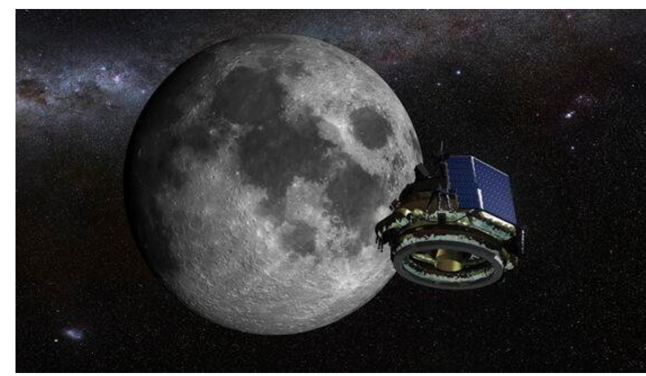
2. **Use available low-cost secondary payload opportunities**
   - On medium-class launch vehicles, e.g., SpaceX's Falcon 9 or ULA's Atlas V

3. **Partner with commercial and international organizations**
   - To leverage existing Lunar transportation and rover capabilities
   - E.g., Google Lunar X-Prize and CATALYST teams.

4. **Explore additional partnerships to develop other key capabilities**, such as:
   - Lunar Mining, Drilling and Excavation Techniques
   - Lunar Relay Communication Satellites
   - Lunar ISRU Operations
   - Solar or Nuclear Power Stations

5. **Partner with companies interested in being the first to develop commercial products for the Moon.**





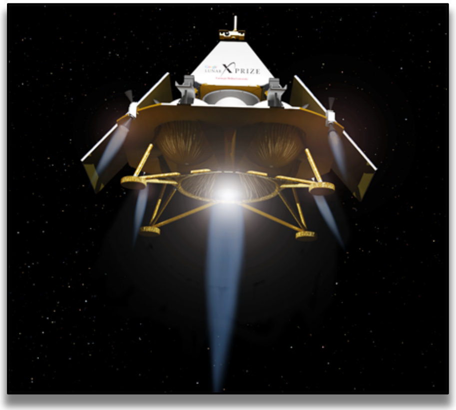
SPACE PORTAL

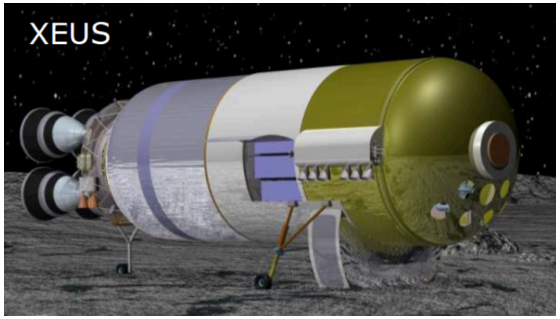
Launch Vehicle Payload Capabilities

Launch Vehicles	LEO (mt)	GTO (mt)	C3=0 (or Earth Escape)	Lunar Surface (mt)
Atlas 551	18.8	8.9	6.1	0.8 – 1.3
Falcon 9 FT (Full Thrust)	22.8	8.3	3.6 - 4.5	0.5 - 0.9
Vulcan Centaur	22	11	7.5	TBD
Vulcan ACES	35	17	12	3.8
Vulcan ACES Distributed Launch	N/A	N/A	30	12
Falcon Heavy	54.4	22.2	TBD	2.5 - 4.4

Potential Lunar Lander Options

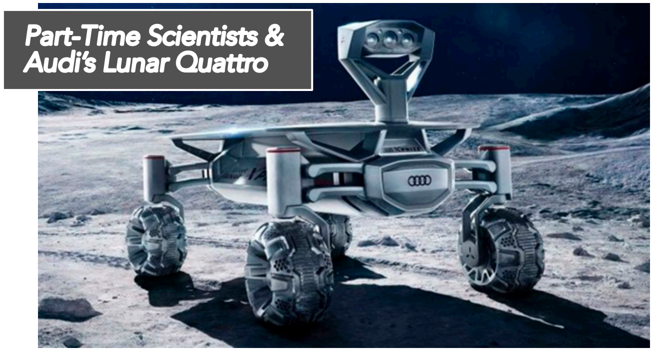
Lunar Lander Teams	Targeted First Mission and Capabilities
Astrobotic's GLXP Team	Planned for launch in late 2017 to Lacus Mortis. Peregrine capability ranges from 35 kg to 265 kg to lunar surface.
Moon Express GLXP Team	Signed launch agreement with RocketLab's Electron Launch Vehicle for 3 lunar missions from 2017 to 2020.
Masten Space Systems	Launch is TBD. Landers in development include Xaero, Xoie, Xombie and XEUS.
Israel's SpaceIL GLXP Team	Signed launch agreement via SpaceFlight with SpaceX's Falcon 9 for a late 2017 launch.
Germany's Part-Time Scientists GLXP Team	Planned for launch in 2017 to Apollo 17 landing site (Taurus-Littrow Valley).
ULA's XEUS, ACES derived Lander	Planned for launch early next decade on ULA's Vulcan launch vehicle. Lander capability is approx 3.8 mt to lunar surface for single launch and much greater using distributed launch.





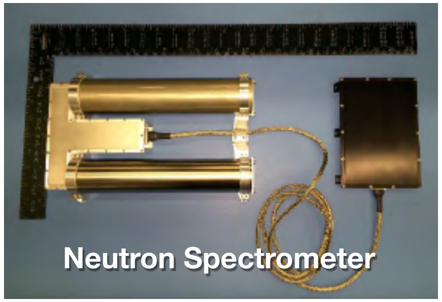
Potential Rover Options

Lunar Lander Teams	Targeted First Mission and Capabilities
Astrobotic/Carnegie Mellon University GLXP Team	Multiple rover options including Andy rover for first mission and Polar rover with excavation and planetary cave exploration capabilities.
iSpace Technologies operates Japan's Hakuto GLXP Team	Multiple rover options for resource prospecting and tethered rovers to explore polar craters and caves.
Chile's AngelicvM GLXP Team	The Unity Rover plans to deliver small payloads on first and follow-on missions.
Germany's Part-Time Scientists GLXP team partnered with Audi	The Audi Lunar Quattro is equipped with a 4-wheeled electrical drive chain, tiltable solar panels, rechargeable batteries and science grade HD cameras.

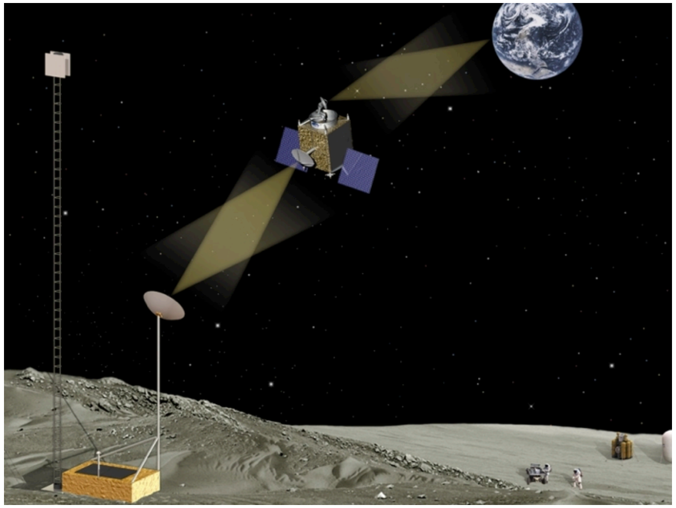


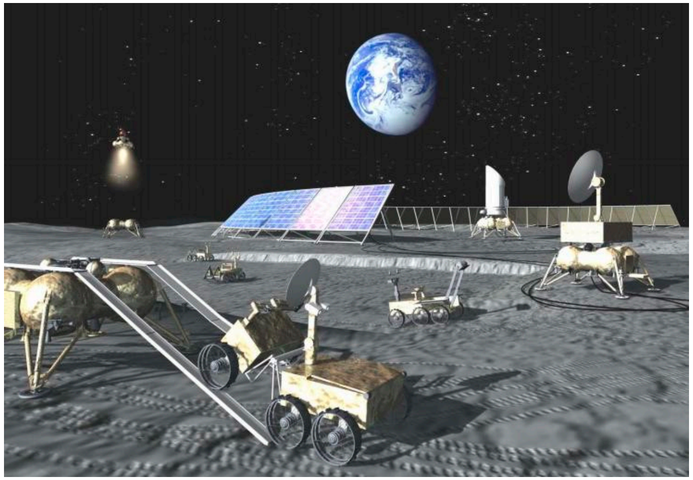
Resource Prospecting Instruments

Instrumentation Options	Key Measurements
Neutron Spectrometer System (NSS)	Senses hydrogen-bearing materials (eg. Ice) in the top meter of regolith.
Near-Infrared Volatile Spectrometer System (NIRVSS)	Identify volatiles, including water form (e.g. ice bound) in top 20-30 cm of regolith. Also provides surface temperatures at scales of <10 m
Camera, LEDs plus NIR spectrometer	Provides high fidelity spectral composition at range.
Camera and LEDs only	Measures soil and regolith composition at 100 micron scale.
Drills	Captures samples from up to 1 m; provides more accurate strength measurement of subsurface.



Lunar Infrastructure





<u>Lunar Communication Relay Satellites</u>

- Enables communication that are not in direct line of sight with Earth, such as, North and South Poles and Lunar Farside.
- Provides telemetry links and payload data relay from lunar orbit and lunar surface.

<u>Power Stations</u>

- Several options including solar, nuclear and power beaming from solar satellites.
- Several challenges to overcome including 14-day night time periods and PSRs at poles.

<u>Landing Zones</u>

- To enable safe, reliable and successful landings, landing zones should include landing pads and local navigation aids.

Government can be a catalyst to lunar industrialization by setting in place the infrastructure needed for new lunar industries to flourish.

Potential Lunar Industries

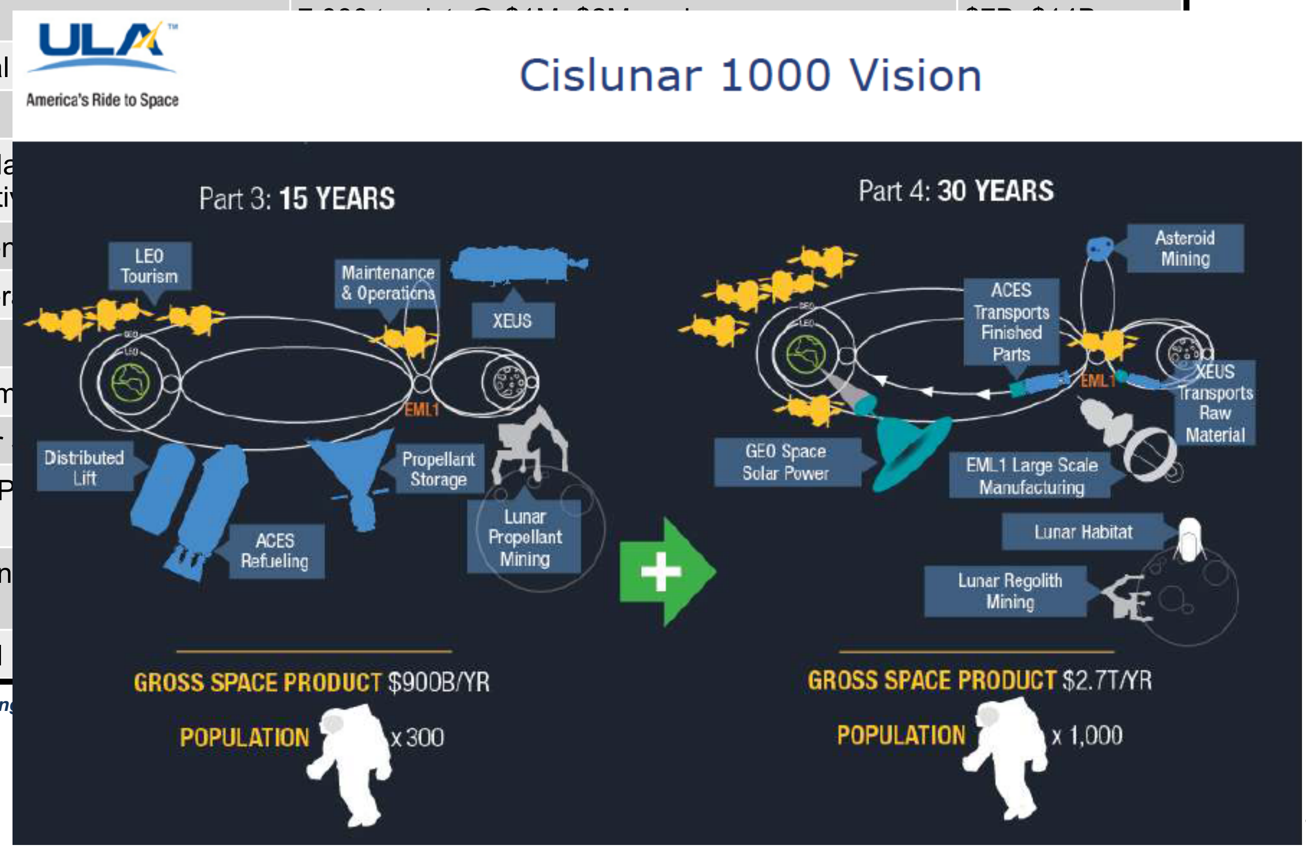
- Recent studies have investigated the potential of near-term and long-term commercial opportunities for cis-lunar and lunar markets as shown below.
- Although preliminary results show significant markets and revenue streams, additional economic analysis is needed to determine realistic return on investments.

Market opportunities	10 years Pessimistic	10 years Central	10 years Optimistic	25 years Pessimistic	25 years Central	25 years Optimistic
Established market opportunities						
Scientific and technical data	38	53	77	38	53	77
Payload hosting	233					
Spacecraft and hardware	202					
Subsystems and proprietary technologies	6					
Sub-total	478					
Emergent market opportunities						
Lander systems	144					
Lunar rovers	70					
Lunar/asteroid/planetary orbiters	112					
Lunar samples	46					
Mars rovers	90					
Sub-total	463					
Future market opportunities						
Support extended duration crew missions	n/a					
Lunar mining	n/a					
Lunar In-Situ Resource Utilisation	n/a					
Asteroid mining	n/a					
Sub-total	n/a					
Technology transfer opportunities						
Sub-total	146					
OVERALL ESTIMATE OF MARKET VALUE	1,08					

Reference: Google Lunar XPRIZE Market Study 2013, pr

Source	Basis	Annual Income
Tourism		
Space Burial		
Helium-3		
Diplomats/Na Representati		
Entertainmen		
Mining/Miner		
Science		
Solar System		
Solar Power		
Knowledge P Library)		
Manufacturin		
Total Annual		

Reference: Xingmen



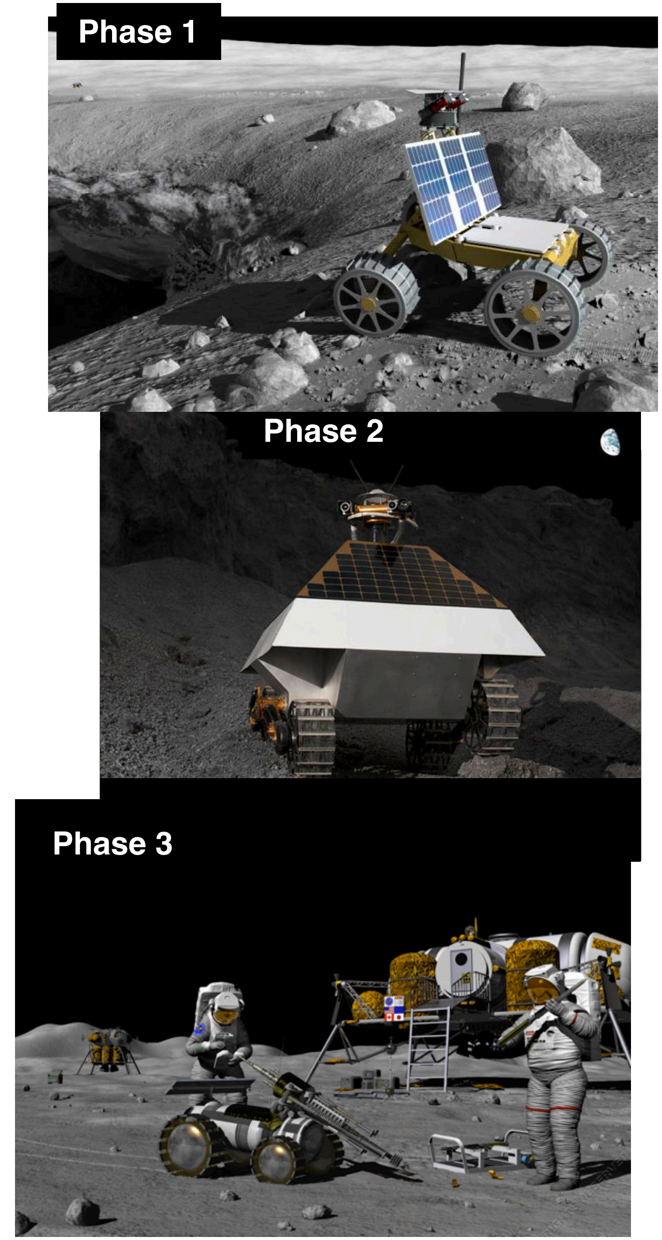
Next Steps

- Continue to investigate and develop 3-Phase approach for Lunar ISRU development.
  - Develop mission objectives, budgets and schedule options for each phase.

- Conduct 1-day Lunar Industrialization Workshop to determine readiness level from industry.
  - To determine readiness level of industry
  - Areas of interest for public private partnerships.
  - Follow-up with industry interviews.

- Continue to develop life cycle cost and economic assessment for:
  - Extracting lunar resources and creating lunar-derived propellant on a pilot-scale;
  - Full-scale ISRU facility for creating approx 200 mt of propellant per year;
  - Delivery to a propellant depot at a cis-lunar destination.

Lunar COTS 3-phase approach has great potential of yielding an economical and sustainable approach for reaching Mars and beyond.



Questions?