Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Astronomy & Astrophysics	**mA1**	Perform radio astronomy to map the cosmic web and observe other astronomical objects.	Radio interferometry antenna arrays, as well as single-dish antennae, located on the far-side of the Moon could provide data on exotic phenomena in the universe: pulsars, black holes, planetary radio emissions, and the remnants of the big bang.	Radio astronomy is enabled by being on the far side of the Moon. Low frequencies can not be observed from the Earth because they are absorbed by the atmoshere. High frequencies can not be observed from the Earth because the radio environment on Earth is too noisy. The far side of the Moon, lacking an atmosphere and shielded from the Earth's radio noise, is ideal.		**X**				
Astronomy & Astrophysics	**mA2**	Perform interferometry on the lunar surface to observe the universe at UV, optical, and infrared wavelengths.	Perform interferometry on lunar surface to observe the universe at UV, optical and infrared wavelengths, including observations of extra-solar planets.	Interferometry on the Moon is enabled because the Moon is a dark site without an atmosphere. Locating a telescope in the bottom of a crater could have additional advantages for IR observations because of the cold temperature there. However, the Moon offers a harsher environment for interferometry in the UV, optical, and NIR than does deep space. Large thermal variations, mechanical distortions due to lunar gravity, dust, and seismic noise are all absent in deep space.		**X**				
Astronomy & Astrophysics	**mA3**	Detect gravitational waves to observe a variety of astrophysical and cosmological phenomena that are unobservable in the electromagnetic spectrum.	Gravitational waves are created from merging supermassive black holes and binary compact objects. Gravitational waves are expected to be detected by ground and space-based systems in the next decade. The Moon offers another stable platform on which to place detection instruments.	The Moon affords a stable base for the widely spaced detectors required to detect gravitational waves. However, the longest feasible baselines for gravitational wave interferometry on the Moon would be about 100 km (e.g. on the rim of the Newton Crater), only one order of magnitude longer than those currently existing on Earth. Although lunar seismic noise could be nullified with existing technology, the thermal requirements (the factor that would ultimately limit performance) on a lunar gravitational wave interferometer would be severe, worse than on Earth or deep space.		**X**				
Astronomy & Astrophysics	**mA4**	Detect and monitor exoplanets to gain perspective on the uniqueness of the Earth and our solar system.	Monitor nearby stars over time to detect transit by planets.	Understanding extrasolar planetary systems is critical for gaining perspective on the uniqueness of our own solar system and the Earth within it. Photometric accuracy of instruments on the Moon would be better than could be obtained from Earth because of the blurring effects of the Earth's atmosphere. There may be no improvement over space-based telescopes in this regard.		**X**				

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Astronomy & Astrophysics	**mA5**	Perform long-duration measurements of energetic particles at the Moon's surface to gain understanding of nucleosynthesis processes in supernovae and other stellar sites.	Perform long duration measurements of energetic phenomena such as cosmic rays and solar energetic particles. Cosmic rays could be measured by large arrays of high-energy cosmic ray detectors placed on the lunar surface. Studying the lunar regolith could provide information on solar energetic particles.	Because the Moon is outside the Earth's magnetosphere and lacks an atmosphere, energetic solar particles and cosmic rays of all energies and types reach the lunar surface without attenuation or degradation. Installing large detector arrays would enable searches for very rare cosmic rays, such as the ultra-heavy cosmic rays (those in the iron-group to the trans uranic group). Such searches would inform us of the nucleosynthetic processes that occur in supernovae and other stellar sites.		**X**				
Astronomy & Astrophysics	**mA6**	Search for exotic states of nuclear matter to understand the composition of the universe.	Theordtically predicted to be the stablest form of matter, but never observed, is Strange Quark Matter. Such matter might exist in the form of "nuggets," produced primordially or from neutron stars. These would have large nuclear densities and be capable of passing through the Moon, leaving behind a linear seismic signature. A network of seismometers evenly spaced on the Moon could identify a Strange Quark Nugget event.	Strange Quark Matter is theoretically the stablest form of nuclear matter, and may exist in the interior of neutron stars. It might have also been produced during the Big Bang, but it has never been directly detected. The relatively low seismic noise on the Moon may make it an attractive location to search for Strange Quark Nuggets that leave a linear seismic signature. Seeing this signature on the Moon would constitute a discovery of profound importance to nuclear physics and astrophysics.		**X**				
Astronomy & Astrophysics	**mA7**	Make precise measurements of the Moon's position to test Einstein's theory of general relativity.	Placing lunar laser transponders at a number of sites on the near side of the Moon would allow the relative motion of the Moon with respect to the Earth to be measured to the millimeter level of accuracy. Laser pulses sent from the Earth to the Moon would trigger coherent return pulses from the lunar laser stations. The responding pulses would be received and timed at Earth tracking stations providing unparalleled orbital positional accuracy. The Apollo retroreflectors have been used for this purpose, but these yield a very small signal that limits accuracy.	Laser ranging measurements of the Moon's position have given us some of our most accurate tests of Einstein's theory of gravity (which has so far passed all its tests). Placing laser transponders on the Moon would significantly enhance the power of these tests.		**X**				
Astronomy & Astrophysics	**mA8**	Detect and monitor Near Earth Objects (NEO) to discover threats to the Earth and Moon.	Conduct sky surveys from the lunar surface to detect NEOs, determine their orbits, assess their physical characteristics, and evaluate the potential hazard to Earth and the Moon.	The long lunar night and the absence of atmosphere make the Moon an attractive location for discovering NEOs that might otherwise go undetected from Earth or Low Earth Orbit. Earth's impact crater history and the ever increasing catalog of newly discovered NEOs demonstrate the importance of NEO research for global protection.		**X**		**X**	**X**	
Astronomy & Astrophysics	**mA9**	Evaluate the Moon's potential as an observation platform to maximize investments in astronomy and astrophysics.	Carry out a site survey of the Moon and characterize aspects of the lunar environment to determine the best locations for various telescopes. Consider dust contamination, seismic environment, thermal environment, radio environment, and other variables. Emplace a small telescope in a representative location before investing in a larger, more expensive telescope.	A lunar telescope will be very expensive. Studying the lunar environment will bring better understanding of the observations that can be most effeciently conducted from the Moon, as well as which sites are best suited to different telscopes. This information will inform the telescope selection and siting and help to optimize the scientific return.		**X**				

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					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Heliophysics	**mHEO1**	Image the interaction of the Sun's heliosphere with the interstellar medium to enable identification and comparison of other heliospheres.	Image the heliospheric boundaries in the extreme ultraviolet and soft x-ray wavelenths. Investigate the interactions of the stellar nebula (the heliosphere), in its various stages of formation and evolution, with its local interstellar medium.	Determining the interaction properties of our own heliosphere with the local interstellar medium will enable us to identify and compare other heliospheres.		**X**				
Heliophysics	**mHEO2**	Perform low-frequency radio astronomy observations of the Sun to improve our understanding of space weather.	Perform low-frequency radio astronomy observations of the Sun. Observe transient solar Type II sources to enable identification and tracking of Earth-directed shocks associated with solar particle events and enable measurement of solar wind properties throughout the heliosphere.	Earth-directed shocks associated with particle events are potentially hazardous to astronauts and orbiting assets. Detecting and tracking these events would provide some advanced warning so that humans and equipment could be protected as best possible. In addition, because these observations could probe space from a few solar radii out to 1 AU, the observations would allow greatly improved space weather forecasting, improved understanding of shock formation and evolution, and detailed mapping of the interplanetary electron density and magnetic field topology. Imaging observations have never been achieved at frequencies below 10MHz because of the Earth's ionospheric effects.	**X**	**X**	**X**			
Heliophysics	**mHEO3**	Study the dymanics of the magnetotail as it crosses the Moon's orbit to learn about the development and transport of plasmoids.	Place detectors on the Moon or on satellites orbiting the Moon to provide regular measurements of the Earth's magnetotail, which crosses the lunar orbit for approximately five days of every month. Arrays of detectors could be used to study the small scale shape, structure and dynamics of plasmoids, as well as other tail regions and boundaries. Active release experiments, observed from the Moon, could also be used to measure plasmoid transport.	The Moon is an ideal location for studying the development and transport of plasmoids, which travel down the Earth's magnetotail after substorm onset. Substorms are the basic process by which energy is stored and released in the magnetotail.		**X**				

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					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Heliophysics	**mHEO4**	Study the impact of the Moon on the surrounding plasma environment and incident solar wind to better understand the magnetotail.	The Moon perturbs the surrounding plasma environment. As an absorber, the Moon shadows solar electrons, and the resulting position of the shadow can be used to determine the convection electric field. In addition, lunar pick-up ions that have been detected in the magnetotail can be used as a unique tracer to track transport in the magnetotail.	Measuring the convection electric field, and using ions as tracers, are both important aspects of understanding ion transport in the magnetotail.		**X**				
Heliophysics	**mHEO5**	Analyze the composition of the solar wind to improve our understanding of the composition and processes of the Sun.	The solar wind reflects the composition of the Sun and physcial processes in the corona.	Analysis of the composition of the solar wind will give new information on how the solar system was formed and on the coronal processes.		**X**				

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					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Heliophysics	**mHEO6**	Image the interaction of the ionosphere and magnetosphere to understand space weather in the regions of space where most commercial and military space operations occur.	Photon and particle imaging of the global ionosphere, thermosphere, mesosphere, and magnetosphere can be accomplished with instrumentation located either on the lunar surface, in lunar orbit, or in other orbital locations via trans-lunar assets.	Global observations of ionospheric, thermospheric, mesospheric, and magnetospheric phenomena provide measurements that are key to understanding space weather in the regions of space where most commercial and military and space operations occur. These measurements will also provide constraints to global ionospheric models and provide keys to solving compelling questions associated with the coupling between these two regions and coupling of the high and mid-equatorial regions of the ionosphere.		**X**		**X**		
Heliophysics	**mHEO7**	Perform high-energy and optical observations of the Sun to improve our understanding of the physical processes of the Sun.	Perform high-frequency (X-ray and gamma ray) and optical observations of the Sun. Uninterrupted observations can be extended to up to a half lunar day, or 14 Earth days (the duration of the East-West passage of an active region of the Sun).	The high-quality observations made possible by large lunar-based high-energy and optical solar observations telescopes will greatly improve our understanding of the physical processes responsible for particle physics in the Sun and in other astrophysical sources. Optical and infra-red magnetographs at the very high spatial resolutions made possible will also allow us to identify the conditions preceding solar eruptive events that are potentially hazardous to astronauts and equipment on the Moon on interplanetary flights, and to power transmission and communications on the Earth. The Moon provides an exceptionally large platform on which to position instruments that can be used to provide uninterrupted observations of the Sun over extended periods of time. The gradual rotation rate of the Moon also allows horizon occultation measurements (at a drift rate of ~0.5 arc seconds/second) to be made.	**X**	**X**	**X**			

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Heliophysics	**mHEO8**	Analyze the Sun's role in climate change to gain a better overall understanding of climate.	Collect simultaneous observations of the earthshine (photometry and spectra), particle flux, and solar irradiance covering the electromagnetic and charged particle spectrum. The earthshine gives an instantaneous measure of the Earth's reflectance, and over a month, the total reflectance (Bond albedo) of Earth can be measured. The irradiance plus Bond albedo gives the net sunlight reaching Earth, and sun-directed hardware gives a broad spectrum of near-Earth measurements of solar activity.	It is generally acknowledged that the 0.1% variation in irradiance over a solar cycle is too small to be climatologically significant, but there are terrestrial signatures of the cycle, as well as signs of apparent longer-term wanderings of solar output. The simple measurements of the solar output and Earth's reflectance from the unique lunar perch give an excellent opportunity to determine what solar signal is being amplified near the Earth. Such knowledge will advance our understanding of the dynamics of the Sun and the Earth's response. Such knowledge is essential to predicting future climate change.		**X**		**X**		

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					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Earth Observation	**mEO1**	Use the Moon as a remote sensing platform for monitoring the Earth's magnetosphere, to develop predictive and mitigation capabilities for magnetosphere-driven events.	Observe electromagnetic behavior due to solar activity, and understand any resulting damaging behavior. Gain understanding of magnetosphere interactions with lower regions of the atmosphere, with the objective of developing predictive and mitigation capability.	Gaining a better understanding of the impacts to society by magnetosphere-driven event impacts can guide mitigation priorities and response.		**X**		**X**		
Earth Observation	**mEO2**	Create solid Earth, topography, altimetry, tomography, and vegetation map.	Form Synthetic Aperature Radar images of the Earth from the Moon's surface using the relative motion of the Earth with respect to Moon. Utilize multiple antennas to form a microwave interferometer with a long baseline and extreme stability. This configuration also allows bistatic operation for remote sensing of complex terrestrial processes.	Synthetic Aperature Radar will provide an all-weather capability to observe the Earth. Using a dual-band will also allow global observation of the ionosphere. Placing the observation capability on the Moon will provide the capability to observe the entire Earth's disk at any given time. The very large baseline allowed by interferometry on the Moon will create very accurate topography maps.		**X**		**X**		
Earth Observation	**mEO3**	Observe the Earth's atmospheric composition to characterize its dynamics.	Use multipsectral passive sensors with 1-km horizontal resolution to cover the UVA-TIR range for global mapping of tropospheric and stratospheric composition including ozone, CO, NO2, HCHO, BrO, aerosols, CO2, and CH4.	Continuous observation of Earth's disk for the sunlit portion (solar backscatter) and whole disk (IR emission) offers a unique vantage point for characterizing surface fluxes of gases, global-scale transport of pollution, and ozone and aerosol dynamics.		**X**		**X**		
Earth Observation	**mEO4**	Observe the Sun-Earth system to understand the reaction of the Earth's atmosphere to solar activity.	Make simultaneous observations of the Earth and Sun from 60 nm to 1 micron to observe the effect of solar flares and coronal mass ejections on the Earth's atmosphere.	Understanding the reaction of the Earth's atmosphere, especially the mesosphere, stratospheric ozone, and troposphere, to solar activity will help estimate the effect of long term solar changes on climate and composition.		**X**		**X**		
Earth Observation	**mEO5**	Determine the Earth BRDF (bi-directional reflectivity distribution function) for use in climate studies.	Make observations at many wavelengths between 0.34 and 1.5 microns to determine the BRDF of the Earth at the special angles that are available from a lunar perspective. In particular, observe the Earth "Hotspot" when the Sun, Moon, and Earth are aligned in this order.	These observations will fill in gaps in our knowledge of the Earth's BRDF that are needed to calculate the radiative balance of the Earth for climate studies. LEO satellites cannot provide this information.		**X**		**X**		
Earth Observation	**mEO6**	Measure the Earth's ocean color to understand its health.	Measure sub-surface marine phytoplankton fluoresence with active lidar.	Results will afford an understanding of the physiological status and health of marine ecosystems, especially those that are sub-surface.		**X**		**X**		

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					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Earth Observation	**mEO7**	Map the surface composition of the Earth, from a whole-disc perspective, to provide information on land use, composition, and change.	Perform moderate resolution (250 - 500 m per pixel) UV-VIS-SWIR-TIR multi- to hyper spectral mapping of the Earth's surface from a fixed lunar position.	Data from a MODIS/ASTER/Hyperion - like instrument of the whole Earth disc would provide information on land surface mineralogy, land use/land cover change, and biomass/ecosystem monitoring. These datasets (depending on spatial and spectral resolution) could also be useful for observing ocean color and sea surface temperature, as well as for atmospheric studies such as detecting, mapping, and monitoring the large dust emission events in China and the Sahara in near-real time.		**X**		**X**		
Earth Observation	**mEO8**	Measure the paleo solar constant to understand climate history.	Monitor variability of solar energy output for century to millennium time scales in borehole with temperature string.	Understand past climate variability as driven by solar input.		**X**		**X**		
Earth Observation	**mEO9**	Observe the Earth's ice surfaces over time to understand how they are impacted by climate change.	Assess flow velocity of major ice bodies (Greenland, Antarctica) with Interferometric Synthetic Aperture Radar (InSAR). Monitor sea ice extent and concentration in the polar regions.	Understand the dynamic response of major ice masses to climate change and variability, represented by fresh water flux from ice sheets. Gain a partial assessment of sea level rise, sea ice transport (fresh water flux) and ice concentration as a surrogate of climate forcing in the Northern Hemisphere.		**X**		**X**		
Earth Observation	**mEO10**	Monitor Earth's "hot spots" to detect and monitor volcanic activity.	Perform multispectral thermal infrared observations (2 - 14 microns) of the whole Earth disc with lunar-based sensors. These observation are not dependent on local "day/night" conditions. With 1km/pixel spatial resolution, observations could provide near instananeous detection and monitoring of volcanic eruptions and fires.	A lunar-based infrared instrument could provide whole Earth thermal data with a temporal frequency of seconds. This data is critical for monitoring and responding to large volcanic eruptions. Current Low Earth Orbit and Geosynchronous Orbit satellites provide only 1-8 km/pixel resolution data, with temporal frequencies from 15 minutes to 6 hours. These instruments also do not provide a whole-Earth perspective. A lunar instrument (if multi to hyperspectral) could also be useful for atmospheric monitoring and surface composition/radiant flux measurements.		**X**		**X**		
Earth Observation	**mEO11**	Calibrate Earth shine to validate Earth albedo and energy balance observations.	Earth shine (brightness of the unlit portion of the Moon as seen from Earth) has been demonstrated to be related to Earth albedo and implicitly to cloud amount, optical thickness etc. Earth shine measurements have been made with Earth-based instruments for decades. The objective here is to measure true Earth albedo (and cloud amount, etc.) from the Moon and calibrate these with current and past Earth-based Earth shine measurements.	Because Earth shine measurements are available from decades past, a reconstruction of Earth albedo, with implications for cloud amount, optical thickness etc., are possible. These values relate to the energy balance of the Earth system and thus responses of the Earth system to variations in the balance.		**X**		**X**		

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					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Earth Observation	**mEO12**	Observe lightning on the Earth to develop a lightning climatology for climate monitoring.	Perform continuous monitoring of lightning of the Earth disk presented to the Moon. Use this data to develop a complete lightning climatology, i.e. an understanding of lightning as a function of time of day, season, and location.	With a full lightning climatology, changes in lightning frequency and distribution can be used as potential markers for climate variability and change.		**X**		**X**		

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					Exploration Preparation	**Scientific Knowledge**	**Human Civilization**	**Economic Expansion**	**Global Partnerships**	**Public Engagement**
Geology	**mGEO1**	Determine the internal structure and dynamics of the Moon to constrain the origin, composition, and structure of the Moon and other planetary bodies.	Determine the internal structure and dynamics of the Moon. Data obtained will address core-mantle-crust transitions, phase heterogeneity, degree of seismic activity, the foci for Moonquakes, lower crust/upper mantle interactions, planetary anisotropy, and seismic hazards for future experiments and structures.	The Moon presents the best opportunity to characterize the early differentiation into structural parts of a planetary body of substantial size which has not been significantly modified by the major ongoing processes experienced by the Earth. These structural parts include not only core, mantle, and crust, but features produced by large impacts, such as mascons. Seismic exploration could also help reveal lunar resources and construction site hazards, buried lava tubes, etc.	X	X	X			
Geology	**mGEO2**	Determine the composition and evolution of the lunar crust and mantle to constrain the origin and evolution of the Moon and other planetary bodies.	Determine the composition and evolution of the lunar crust and mantle. Synthesize data from both remote sensing and sample analysis to inventory and map rock types, determine their sequence and structure, and model crustal evolution in space and time. Use craters and basins to access varying crustal levels. Evaluate sample types from selected impact basins (e.g., South Pole-Aitken), especially with a view to probing the lower crust and/or mantle composition. Study samples of young lava flows and pyroclastic deposits to understand mantle evolution.	The Moon's crust shows an example of a small, differentiated planet; its study will allow us to better understand early planetary evolution and crustal genesis. The Moon presents the best opportunity to geochemically characterize early fundamental processes of a planetary body of substantial size, including the early differentiation into component parts, the production of an early crust, and the genesis of basalts from various mantle depths.	X	X				
Geology	**mGEO3**	Characterize the lunar geophysical state variables to constrain the origin, composition, and structure of the Moon and other planetary bodies.	Characterize the lunar geophysical state variables, including the lunar gravitational potential field (in detail), heat flow, lunar rotational fluctuations, lunar tides and deformation, and the present and historic magnetic fields.	Characterizing these geophysical parameters in a planetary body other than Earth enables a more fundamental understanding, not only of the Moon, but of the importance of these parameters in all solid bodies.		X	X			
Geology	**mGEO4**	Determine the origin and distribution of lunar volatiles as one input to understanding the origin, composition, and structure of the Moon and other planetary bodies.	Determine the origin of lunar volatiles, including those from endogenous (e.g. from the lunar interior) and exogenous (delivered from outside the Moon) processes, and the redistribution of these volatiles by geologic processes operating over time, including escape from the Moon. This will lead to predictive models of the distribution of volatiles on a broad scale.	Although the Moon is a volatile-poor body, characterizing the uncommon occurrence of its more readily volatilized elements can address questions of lunar origin and the chemical nature of its interior, as well as enable characterization of the volatile content of lunar impactors over time. The results of this investigation could provide additional value to Lunar Resource Utilization.		X	X			
Geology	**mGEO5**	Characterize the crustal geology of the Moon to identify the range of geological materials present.	Characterize the broad geology of the Moon from detailed study of the lunar regolith. The lunar regolith at any site primarily represents a sampling of local rock units, but a minor part represents contributions from more sites. Thus the regolith gives some degree of statistical sampling of rocks over an appreciable area.	Detailed studies of the regolith at individual sites can identify the range of geological materials present, locate and identify exotic, rare samples, and give insight into the variety of petrological units present on the Moon.		X				
Geology	**mGEO6**	Characterize the impact process on the Moon and other planetary bodies to understand this complex process.	Study the physical and compositional effects of hypervelocity impact using lunar craters, from micron-sized zap pits to multi-ring basins. Study excavation and modification stages of impact process and their physical and compositional effects. Study the transport and mixing of materials as a result of impacts. Study the morphology of freshly formed craters and of their ejecta distribution.	Characterize the complex impact process of the Moon and other planetary bodies. This activity will also help characterize the recent impact rate and gardening rate.		X	X	X		

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Geology	**mGEO7**	Characterize impact cratering over the Moon's geologic history, to understand early solar system history.	Characterize the flux and crater production function (impactor flux as a function of size) of impacting bodies in the Earth-Moon system, over the course of geologic history. Emphasize time variations in flux of objects, the nature and origin of the impactors and their possible role in delivering volatiles, the nature of the late heavy bombardment (cataclysm), and the densities and ages of major lunar basins.	The Moon is the best available laboratory for studies that illuminate aspects of the early solar system history. Early impactors defined much of the surface geology of the inner planets, and may have influenced early life on Earth and evolution of the atmospheres of Earth and Mars. The measured densities of impact craters on the Moon are the basis for calibration of the ages of surfaces of other planetary bodies throughout the inner Solar System, including Mars, and represent our primary means of determining relative and absolute ages of planetary surfaces. In addition, this characterization may provide a baseline for evaluating impact-generated, short-term climatic perturbations, and may facilitate our evaluation of the current impact threat to Earth.	X	X				
Geology	**mGEO8**	Study meteorite impacts on the Moon to understand the early Earth history and origin of life.	Determine the timing and composition of impactors to study the impact history of the Moon. Look at lunar cratering flux, regoliths, and ages of specific lunar craters and basins. Search for material impact-ejected from Earth and other bodies to research characteristics of the early Earth and the origin of life between 0.55 billion and 4.4 billion years.	Studying meteorite impacts on the Moon could yield an understanding of the impact history of the solar system and the early history of the Earth and the origin of life. On Earth, terrestrial analyses of zircons are starting to give clues about the thermal and aqueous history of early Earth. But information on solar variations, cosmic dust input, and unmetamorphosized samples of the early Earth surface have been mostly destroyed, but may exist on the Moon. This evidence may constrain theories regarding the potential interplanetary transfer of life due to meteoritic exchange between Earth and Mars. Data supporting or rejecting evidence of past life might be obtained without the complicating factor of contamination.		X				
Geology	**mGEO9**	Study the lunar regolith to understand the nature and history of solar emissions, galactic cosmic rays, and the local interstellar medium.	Investigate records of past solar particles and irradiance, galactic cosmic rays, and dust from the interstellar medium that are preserved in lunar regolith. This is a record in time, energy, composition, and ionization state. Some of this record consists of buried regolith sections which may have preserved a snapshot of solar radiation, cosmic rays, and the interstellar medium properties at a specific and easily datable time. A series of such time capsules back to 4Gy or earlier would be a record of solar wind, energetic particles, and interstellar dust through time. Finding this series involves searching for identifiable layers of "fossil regolith" that can be dated to track changes in the Sun and galactic cosmic rays through time, and movement of the cosmic dust cloud. This objective will support heliophysics investigations and could be synergistic with the use of the lunar regolith for resource utilization.	The value to this investigation is in uncovering the histories of the Sun, cosmic radiation, and the local interstellar medium from the beginnings of the solar system to the present. First, a history of solar wind and solar energetic particle variations over time provides data criterium that solar and stellar models must meet. Second, a histroy of cosmic ray variations over time provides data that restricts models off the evolution of the Milky Way and the universe. Correlating cosmic ray fluxes and cloud cover (and in turn, average temperatures) and radiation levels at Earth (which affect the evolution of life) can yield significant understanding of both the history of our planet and the evolution of the galaxy and the universe. Finally, a history of galactic dust from the interstellar medium over time would provide data for how the solar system moves around the galaxy.	X	X				

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					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Geology	**mGEO10**	Determine lunar regolith properties to understand the surface geology of the Moon and other planetary bodies.	Determine lunar regolith properties, such as structure (layering and depth variations) and composition, and its modes of formation and evolution.	Regolith is an important part of the Moon's surface geology. Because impacts produce a surface regolith on all planetary bodies without atmospheres, it is important to study the processes and end products associated with these regoliths. Understanding the surface geology will also provide additional value to Lunar Resource Utilization and the construction of a lunar base.		**X**	**X**			
Geology	**mGEO11**	Characterize the lunar regolith to understand the space weathering process.	Characterize the lunar regolith exposed at lunar surfaces of various ages. Evaluate the upper-surface stratigraphy, and sample regolith from terranes of diverse composition and age. Map regolith maturity and identify regions that contain ancient regolith.	The Moon is a natural laboratory for characterizing the space weathering of planetary bodies without air or water. Impacts on the Moon over its history have produced a variety of surface ages on the lunar surface, from very new to ancient, which can be investigated via the regolith. Evaluating space weathering is an important part of understanding the potential hazards for resource mining on asteroids and characterizing space weather risks to the Earth.		**X**	**X**	**X**		
Geology	**mGEO12**	Characterize lunar volatiles to reveal the nature of impactors on the Moon.	Determine the concentration, chemistry, phase relations, temperatures, geotechnical properties, photometry, morphology, topography, distribution and inventory of lunar volatiles. Of particular interest, characterize the volatile phase in the permanently shadowed regions near the lunar poles.	Characterizing lunar volatiles could reveal the chemical nature of impactors on the Moon through time, as the impactors are the likely source of the volatiles present.		**X**	**X**	**X**		
Geology	**mGEO13**	Characterize transport of lunar volatiles to understand the processes of polar volatile depost genesis and evolution.	Understand surface transport of volatile atoms and molecules in the lunar environment, including to polar cold traps.	Characterize transport of volatile elements on the lunar surface as a guide toward understanding the processes of polar volatile deposit genesis and evolution on airless planets.		**X**				
Geology	**mGEO14**	Characterize potential resources to understand their potential for lunar resource utilization.	Locate and quantify (develop maps at appropriate scales) surface/near-surface deposits of potentially valuable resources, including both minerals and volatiles (especially water).	Future exploitation of lunar resources is facilitated if a global surface map of these resources exists. Such a resource map is also of scientific value in helping to define variations in surface compositions.	**X**	**X**	**X**	**X**		
Geology	**mGEO15**	Provide curatorial facilities and technologies to ensure contamination control for lunar samples.	Provide the capability to curate samples on the Moon before transporting them to Earth. This involves protecting them from contamination while on the Moon and during transport to Earth. It also requires development of an information system to keep track of samples (collection locality, specimen type, location in curatorial facility, etc.). This applies to biological as well as geological samples, and to samples of the products of resource extraction experiments.	To make accurate analyses of geological samples collected on the Moon, the samples must be kept clean from contamination from other samples and habitat gases, dust, and other human-generated materials. Numerous samples will be collected, so it is also important to keep track of each one and its collection location to avoid confusion during analysis.	**X**	**X**		**X**		
Geology	**mGEO16**	Provide sample analysis instruments on the Moon to analyze lunar samples before returning them to Earth.	Provide instrumentation on the lunar surface to serve a screening function for lunar sample collection. Have the ability to select the most valuable samples for return to Earth.	Analytical instruments at a lunar base will allow us to choose which samples to return to Earth, hence making the best use of cargo space and mass. It also allows astronauts to receive preliminary data on samples collected to help in planning additional field observations. Automation is useful so that astronauts do not have to spend significant amounts of time doing rock analyses.	**X**	**X**		**X**		

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Materials Science	**mMAT1**	Study the effects of the lunar environment on materials so as to design mitigation strategies to enable robust performance during extended stays.	This research aims to understand the long-term effects of the lunar environment on materials. Unique aspects of the lunar environment to be studied include fractional gravity, radiation bombardment, thermal cycling, and dust. Understand the individual as well as cumulative effects of each of these variables, such that results can be extrapolated to the Mars case.	Understanding the effect of the lunar environment on materials will allow engineers to choose or design materials which will best withstand extended use on the Moon. This will enable long-duration stays and eventual settlement on the Moon.	**X**	**X**	**X**	**X**		
Materials Science	**mMAT2**	Investigate the development of new materials in the lunar environment to determine the feasibility of this activity.	Use the lunar environment, specifically 1/6 g and ultra-high vacuum, to develop new types of materials for use in space or on Earth. Investigate the use of lunar resources in materials processing.	Low gravity is a unique feature of the Moon that can be exploited to enable the use of materials processing strategies that are not possible or ineffective on Earth. Determine if this is a feasible activity.		**X**	**X**	**X**		
Materials Science	**mMAT3**	Examine the Apollo, Lunakhod, and/or Surveyor spacecraft to determine the long term effects of the lunar environment on materials.	A thorough study of spacecraft materials exposure effects in the lunar environment could be performed through photographic surveys, in-situ measurements of materials properties, and/or the return of spacecraft materials for analysis on Earth.	These spacecraft have been exposed to the lunar and solar radiation, thermal, dust, and micro-meteorid environments for over 30 years. Analysis of the effects of this long duration environmental exposure on these materials would provide designers of future lunar exploration spacecraft with a unique view into the environmental factors that need to be accounted for in their future changes.		**X**	**X**	**X**		

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Human Health	**mHH1**	Understand the fundamental biological and physiological effects of the lunar environment on human health and the fundamental biological processes and subsystems upon which health depends to understand the long-term human response to the lunar environment.	Conduct fundamental research to understand the physiological and biological effects of the lunar environment on humans. Effects of fractional gravity, radiation bombardment, and dust on biological systems must be investigated through lunar cell, animal, and human research. Understand the fundamental physiological and biological effects on humans (such as bone and muscle loss, diminished immune efficiency, slower wound healing, human nutrition needs, and poorer cognitive performance, in addition to pointing out unanticipated effects of the exploration environment), as well as the effects on the fundamental biological processes and subsystems upon which health depends. With appropriate equipment and facilities, the lunar environment can provide a range of gravitational data points from 1/6 to 1g and beyond, to help understand the effects of gravity levels other than 1g.	Keeping humans healthy and at peak performance during extended stays on the Moon will require an understanding of how features of the lunar environment affect human health, starting from fundamental biological and physical processes. This knowledge will provide data toward understanding the risk present in the system, aiding the design of mitigation strategies. Studies can provide data points for understanding the effects of gravity levels between 1/6 and 1g, the effects of the mixed-type radiation spectrum, and the consequences of exposure to unhydrated lunar dust, none of which can be simulated on Earth, enabling the design and development of countermeasures. Research testing the adequacy of lunar gravity (1/6) as an effective countermeasure against muscle deconditioning and bone loss may also inform the design of possible future artificial gravity space vehicles. Some fundamental breakthroughs in lunar biological/physiological science and technology are likely to drive advances in terrestrial medicine and may also lead to new commercial products and therapies	**X**	**X**	**X**	**X**		
Human Health	**mHH2**	Understand the effects of the lunar environment, in particular partial gravity, on human performance and human factors to understand and promote human productivity in an off-Earth planetary environment.	Study the human performance and human factors effects of the lunar environment, including partial gravity, dust, and radiation. Human factors research aims to understand whole body coordination strategies, including balance, posture, locomotion, work capability, endurance, and speed of humans in fractional gravity, and the effect of isolation and communication lag on performance and mission coordination. In conjunction, the impact of countermeasures, such as improved mission tasking, rovers and other tools, and EVA suits can be investigated. Radiation research would investigate the effects of large-particle bombardment on human behavior and cognitive function.	Predicting human capabilities for more complex Moon missions and future Mars missions is critical to designing the tasks and equipment with which to accomplish mission objectives. This can lead to improved productivity, as missions and mission-support are designed around the results of these studies. The lunar surface is one existing environment from which the effects of partial gravity can be researched.	**X**	**X**	**X**	**X**		
Human Health	**mHH3**	Understand the impact of extreme isolation on individual psychological health and group dynamics to ensure the long-term health, safety, and productivity of crews.	Lunar crews will be operating in an environment that is truly remote from Earth, especially on missions on the far side of the Moon. Such isolation may cause unprecedented psychological stress that could be mitigated by appropriate crew selection, mission control procedures, habitat design, diagnosis and treatment protocols, and other techniques. In order to develop appropriate techniques, first an understanding must be gained of the psychological impacts of isolation on individuals and groups.	Understanding the impact of isolation on crews will enable the development of appropriate mitigation strategies to ensure the long-term health, safety and productivity of inhabitants on the lunar surface and Mars.	**X**	**X**	**X**	**X**		

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					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Human Health	**mHH4**	Understand the effects of vehicle, habitat, and EVA suit pressures and oxygen concentrations on human health so as to design mitigation strategies for extended stays.	Understand the effects of vehicle, habitat, and EVA suit pressures and oxygen concentrations on human health. Consider the whole habitat, closed ECLS environment (not just pressures). Vehicles and habitats will likely operate at 8.0 psia and up to 34% oxygen while suits will operate at 4.3 psia and 100% oxygen.	Crews will spend all of their time either in vehicles and habitats or in frequent EVAs. The long-term effects and interactions of pressure and oxygen concentration in a reduced gravity environment must be understood in order to design safe habitats and vehicles and develop appropriate protocols for safely carrying out frequent EVAs on the planetary surface. This will ensure long-term safety of inhabitants on lunar surface.	**X**	**X**	**X**			
Human Health	**mHH5**	Understand the impact of the lunar environment on terrestrial microbes to understand potential health risks to crews.	Study the impact of the lunar environment on multiple generations of terrestrial life forms that impact human health. Investigate the fidelity of replication of human microbial flora for variants, increase in virulence, and development of antibiotic resistance over thousands of generations (100 days = 5000 generations for some organisms).	Increase our knowledge of risks to human health and concomitantly increase our capability to manage, mitigate, or eliminate microbial risks to human health. Improved understanding of accelerated microbe mutation and virulence may help in the development of anti-microbial therapies for evolving terrestrial microbes.	**X**	**X**	**X**	**X**		
Human Health	**mHH6**	Study mammalian reproduction in different gravity environments to understand the impact of gravity on reproduction.	Conduct scientific research on animals or cells to determine the likely effects of the lunar environment on the ability of humans to reproduce normally (including embryogenesis, embryonic and fetal development, parturition, and post-partum growth and development). Areas of particular concern include whether critical periods of exposure to gravity exist for normal development; if there are effects from space radiation; and what the toxicity is of the unavoidable exposure to lunar dust.	The extrapolation of results of this research to human reproduction will be critical for determining whether and how humans will be able to develop permanent settlements off Earth. The results of this research will enhance human understanding of the effects of gravity on species reproduction, no matter the answer.	**X**	**X**	**X**	**X**		
Human Health	**mHH7**	Deploy effective in-site and remote health care systems to ensure crew health on the Moon.	Develop and deploy in-situ and teleoperated medical practices to deal with common ailments (e.g. colds, flu) and possibly more serious problems (e.g. muscle strains, broken bones) . Tools include tele-operated medical equipment and practices, diagnosis, therapy, and treatment. Quantify space-normal physiology and biochemistry and monitor crew physiology during IVA/EVA. Vaildate computational models for comparison to 1g and enable prediction, diagnosis, and treatment.	Developing medical support for good crew health is essential to the success of human exploration missions to the Moon and Mars, reducing overall mission risk. Developing in-situ medical support to monitor conditions, diagnose symptoms, and treat medical conditions will maintain crew health and increase the autonomy, safety, and efficacy of surface operations.	**X**	**X**	**X**	**X**		

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					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Human Health	**mHH8**	Provide leisure activities to support the psychological health of those living on and visiting the Moon.	Provide leisure activities, in the form of arts, entertainment, and recreation, for people living on and visiting the Moon. Initially, passtimes may consist of activities similar to Earth entertainment (satellite TV, movies, music, and books). Over time, take advantage of the lunar environment for unique activities such as 1/6-g sports and games. Physical sports and games can be designed to materially enhance and benefit specific aspects of physical fitness, strenth, and endurance that will benefit the health and productivity of long-duration explorers in the outpost and settlement phases of lunar exploration.	Recreation activities, such as arts, entertainment, and recreation, can enhance the psychological well-being, productivity, and physical fitness of people working in high-stress environments over a long period of time. Having these activities on the Moon will support the psychological health of crews and, as they become more unique to the lunar environment, could become main attractions for lunar tourists.			**X**	**X**		**X**

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilizatio	Economic Expansion	Global Partnerships	Public Engagement
Environmental Characterization	**mENVCH1**	Characterize the lunar thermal environment at several locations on the Moon to better understand the operational environment of the Moon.	Within strategic lunar regions, characterize environmental hazards associated with extreme temperature fluctuations to a level of detail sufficient to design appropriate mitigation strategies and technologies. Include localized effects due to topagraphy.	Many lunar environmental parameters present unknown or uncharacterized risk to both robotic and human exploration, and thus require characterization to evaluate and mitigate. The required characterizations may require determination of both scientific and engineering properties.		**X**	**X**			
Environmental Characterization	**mENVCH2**	Characterize radiation bombardment at several locations on the lunar surface and subsurface to better understand the operational environment of the Moon.	Within strategic lunar regions, perform scientific investigations to study and characterize the lunar radiation environment by understanding the effects of solar activity, radiation from extra-solar sources, and induced radiation from the lunar surface on the operational environment.	Results of this characterization, plus an understanding of the effects of the radiation environment, will enable the creation of specifications for radiation shielding and other mitigation techniques. Appropriate radiation mitigation techniques are essential for ensuring crew health and equipment functioning during extended stays on the Moon. These measurements will also be used to improve and validate radiation predictive codes in a relevant environment. Simply characterizing the radiation environment will help validate and improve radiation models and improve understanding of the general solar system radiation environment, including that of Mars.	**X**	**X**	**X**			
Environmental Characterization	**mENVCH3**	Characterize micrometeorite bombardment at several locations on the lunar surface to better understand the operational environment of the Moon.	Within strategic lunar regions, perform scientific investigations to study and characterize size, frequency, and velocity/energy of the lunar micrometeorite environment. Understand the effect of micrometeorite impact on the strength characteristics of the soil.	Results of this characterization, plus an understanding of the effects of this environment, will enable the creation of specifications for micrometeorite impact shielding and other mitigation techniques. Appropriate mitigation techniques are essential for ensuring crew health and equipment functioning during extended stays on the Moon.	**X**	**X**	**X**			
Environmental Characterization	**mEHVCH4**	Characterize the dust environment at several locations on the lunar surface to better understand the operational environment of the Moon.	Within strategic lunar regions, study the properties of lunar dust, including size and shape classification, adhesion, chemical reactivity and composition, bio-toxicity, dielectric and optical response, interaction with the plasma environment, suspension properties, and abrasiveness. In addition, characterize dust transport and dust rheology to understand the effects to lunar surface operations such as solar array use, radiators, seals, etc.	In order to develop effective and optimal mitigation strategies for dust control, it is essential to understand the physico-chemical properties of dust. Using this data will enable the development of systems able to withstand extended use on the lunar surface, and development of dust mitigation techniques in general.		**X**	**X**			
Environmental Characterization	**mENVCH5**	Characterize geotechnical and particle-based properties of surface materials at several locations on the Moon to understand the lunar construction environment.	Within strategic lunar regions, characterize traditional geotechnical properties of lunar surface materials, including soil mechanics, tribology of regolith materials, effects on hard surfaces/cutting edges/brushes, electrostatic effects, shear and bearing strength, compaction-depth distribution, granular cohesion, granular transport/flow properties, and bulk density sufficient to support lunar civil engineering and excavation, traction, grinding, mixing and segregation in resource utilization. To accomplish granular materials modeling, also characterize particle friction, attraction, elastic, fracture/strength, and size and shape properties.	Results of the characterization of traditional geotechnical properties will enable the creation of engineering processes for using lunar surface materials in building tools, materials, and structures and an understanding of how the surface might support these structures. Results of characterization of the particle-based properties that enable modern granular materials modeling will enable the creation of lunar soil simulants, which will provide better predictive performance of machine-soil interactions for optimal design decisions for surface operations hardware.		**X**	**X**	**X**		

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					Exploration Preparation	Scientific Knowledge	Human Civilizatio	Economic Expansion	Global Partnerships	Public Engagement
Environmental Characterization	**mENVCH6**	Characterize lunar cratering physics due to rocket exhaust to design appropriate mitigation strategies for system safety.	Investigate quantity, distribution, and trajectory of lunar fines and other ejecta due to vehicle landing and launch operations to determine adequacy of mitigation strategies prior to emplacing hardware on the lunar surface in close proximity.	Developing a sustained human presence on the lunar surface will require emplacing infrastructure in the vicinity of the human and cargo vehicles launch and landing zones. Characterizing the impact of rocket exhaust on these zones will validate and/or enable development of appropriate means to mitigate the damaging effects of spraying lunar fines and other ejecta onto emplaced hardware and infrastructure. Appropriate mitigation strategies will assure vehicle systems are not damaged or adversely affected during launch and landing operations.	X	X	X			
Environmental Characterization	**mENVCH7**	Characterize the lunar atmosphere to understand its natural state.	Utilize early missions to characterize the pristine lunar atmosphere before increased robotic and human activity can contaminate it. To document the lunar atmosphere in its pristine state, early observational studies of the lunar atmosphere should be made, along with studies of the sources of the atmosphere and the processes responsible for its loss. These include a full compositional survey of all major and trace components of the lunar atmosphere down to a 1 percent mixing ratio, determination of the volatile transport to the poles, documentation of sunrise/sunset dynamics, determination of the variability of indigenous and exogenous sources, and determination of atmospheric loss rates by various processes.	Understand the natural lunar environment in the absence of terran activity. The lunar atmosphere is the only surface boundary exosphere in the solar system that is sufficient accessible to study in detail. Despite many Apollo and Earth-based measurements, numerous aspects of the lunar atmosphere remain unknown. In addition, having measurements of the "baseline" lunar environment will enable tracking of the environmental response to human activity.		X	X			
Environmental Characterization	**mENVCH8**	Characterize the lunar lightning environment to better understand its potential as a clean power source.	Characterize the amount of lunar lightining. If sufficient lunar lightning exits, evaluate its potential as a power source for lunar operations.	Lunar lightning could be used as a continuous, clean power source to support lunar operations. Less dependence on other power sources can provide better operational flexibility.		X	X			
Environmental Characterization	**mENVCH9**	Map the topography of the Moon to understand the features of the lunar environment.	Create detailed topographic maps of the Moon, showing the surface and subsurface features, including permanently shadowed regions, polar regions, large features, dust depth and shading, illumination characterizaion, and Earth line of sight characterization.	Understand the features of the lunar environment, especially in locations valuable as operations or landing sites, to plan operations and enable precision landings at certain key sites. Mapping of certain features will provide additional value to Lunar Resource Utilization.		X	X			
Environmental Characterization	**mENVCH10**	Map the surface electromagnetic field of the Moon to understand the operational environment of the Moon.	Perform scientific investigations to study and characterize the lunar magnetic field and plasma environment to determine their effects on communications, instrumentation and computer operations. The interaction of the near lunar electromagnetic and plasma environment are complicated by variations in solar UV intensity, the ambient plasma, formation of dust plasmas, surface composition and topology, magnetic anomolies, and the lunar wake.	The magnetic field and surface charging of the Moon is thought to drive the transport of micron-scale dust potential hazards. Understanding this will enable understanding of the effects of the lunar environment on manned and robotic surface exploration activities and various other scientific investigations. Studying the lunar crust's magnetic fields would extend the pioneering studies of Apollo 15/16 and Lunar Prospector to reach closure on questions regarding the physics of crustal magnetic anomaly formations. Quantification of distribution and properties of magnetic anomalies would clarify potential magnetic shielding benefits of colocated lunar bases.		X	X			

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Environmental Characterization	**mENVCH11**	Map the gravity field of the Moon to understand the operational environment of the Moon.	Perform scientific investigations to study and characterize the lunar gravity field environment to determine the effects of mass concentration on the gravity local field.	Having an accurate map of the lunar gravity field will improve the accuracy of navigation and precision landing, rendezvous and docking.		**X**	**X**			
Environmental Characterization	**mENVCH12**	Map seismic activity of the Moon to understand the operational environment of the Moon.	Perform scientific investigations to study and characterize lunar seismic activity to create a seismic map.	Seismic activity on the Moon could be very dangerous to structures. The distribution and magnitude of risks must be determined to create design specifications that will ensure safety.		**X**	**X**			

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					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Environmental Hazard Mitigation	**mEHM1**	Provide radiation shielding for surface operations to safeguard crews, materials, equipment, and infrastructure.	Solar and galactic radiation impacting the Moon must be managed in such a way as to minimize its impact on crew health and surface operations. This will involve materials and techniques to shield astronauts and sensitive electronics from typical radiation levels, and additional measures during times of intense solar activity. Material surfaces, particularly organic polymers, are also subject to degradation by high energy electromagnetic and particle radiation, and must be protected as well. This objective is synergistic with science objectives for studying regolith radiation history and life support objectives that identify regolith as a potential shielding mechanism.	The Moon lacks a significant magnetic field to deflect charged particles streaming from solar and extra-solar sources, and an atmosphere to attenuate high energy electromagnetic and particle radiation. Space radiation will impinge on the surface with sufficient energy and intensity to cause severe genetic damage to astronauts and to disrupt sensitive electronics. Without effective mitigation, certain sensitive instruments and electronics will fail and astronauts will not be able to work on the Moon for the long periods of time envisioned in lunar operations.	**X**		**X**			
Environmental Hazard Mitigation	**mEHM2**	Provide dust mitigation techniques to safeguard crews, materials, equipment, and infrastructure.	Using data on the properties of lunar dust, design crew and system protection so as to reduce the interference of dust. Minimize dust deposition and adhesion on equipment and EVA suits. Develop techniques for self-cleaning of critical equipment to minimize adhesion of dust.	Lunar dust could harm crews and equipment used on the Moon. Developing appropriate dust mitigation techniques could increase the life of systems and improve human health to enable longer duration stays on the Moon.			**X**			
Environmental Hazard Mitigation	**mEHM3**	Provide micrometeorite bombardment protection to safeguard crews, materials, equipment, and infrastructure.	Demonstrate mitigation strategies to protect surface infrastructure and vehicle systems from micrometeorite bombardment during surface operations	Micrometeorites bombarding the lunar surface could harm crews, equipment their habitats and other infrastructure. In order to ensure safe lunar operations, items must be protected from micrometeorites.	**X**		**X**			
Environmental Hazard Mitigation	**mEHM4**	Provide thermal protection from the lunar day/night extremes to safeguard crews, materials, equipment, and infrastructure.	Using data on the lunar thermal environment, design crew and system protection so as to ensure survival under the worst possible environmental extremes coupled with the maximum creditable equipment failure.	Provide comfort and ensure survival for the crew. Protect sensitive instrumentation from thermal cycling.			**X**			
Environmental Hazard Mitigation	**mEHM5**	Provide protection from rocket exhaust blast ejecta to safeguard crews, materials, equipment, and infrastructure.	Demonstrate and deploy a mitigation strategy to protect surface infrastructure and vehicle systems from lunar fines and other ejecta during launch and landing operations.	Spraying or eruption of lunar fines and other ejecta may have a damaging effect on emplaced or landing/launch systems, thus affecting their ability to perform or reducing their life. An effective mitigation strategy will allow for greater sustainability of equipment and infrastructure, while protecting crews and materials near the launch or landing site.	**X**		**X**			

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					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Operational Environmental Monitoring	**mENVMON1**	Monitor space weather in real time to determine and mitigate risks to lunar operations.	Observe the sun, its corona and space weather in real-time to detect solar and galactic events that will affect operations on the lunar surface. Implement warning systems to notify lunar inhabitants of such events. Implement mitigation techniques to protect lunar inhabitants, in the event of significant space weather activity.	Space weather activity impinging on the lunar surface could be very harmful for lunar inhabitants and their equipment. Detecting, warning, and mitigating these effects will protect lunar inhabitants and their equipment during long-duration surface operations. The same systems could be used to detect events that will affect Earth systems and long-duration space flight (ie. going to Mars).	X	X	X	X		
Operational Environmental Monitoring	**mENVMON2**	Monitor lunar environmental variables in real time to determine and mitigate risks to lunar operations.	Establish a lunar environmental monitoring station to measure real-time changes in environmental variables such as temperature, vibration, dust collection, radiation, seismic activity, and gravity.	Monitoring activities can provide real-time environmental information relevant to daily lunar operations. The ability to inform crews of potential hazards will increase operational mission safety.	X	X	X	X		
Operational Environmental Monitoring	**mENVMON3**	Monitor meteors and/or space debris in real time to determine and mitigate risks to lunar operations.	Monitor the solar system, especially the near-Earth/Moon environment for meteors, micrometeors, and other space debris that could potentially impact the lunar surface.	Detecting objects that could potentially impact the lunar surface will provide advance warning to lunar inhabitants, such that the risks from these objects can be mitigated. Monitoring for lunar surface safety could also detect objects destined for the Earth.		X	X	X		

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					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Life Support & Habitat	**mLSH1**	Provide safe and enduring habitation systems to protect individuals, equipment, and associated infrastructure.	During short and long-duration stays on the Moon, individuals will need a habitat that will protect them from the lunar environment. A number of implementation strategies are possible for this habitat, including placing habitats in lava tubes or using lunar regolith as protection from radiation, meteorite impact, and lunar seismic activity. Inside the habitats, basic life support and recreational activities should be provided to the crew. Over time, the life support systems should move from open to closed systems, with food production, water and air regeneration, and waste management systems.	Keeping astronauts physically and psychologically safe is critical to mission success. Using in-situ materials to create these habitats and moving from open to closed-loop life support systems have the advantage of reducing upmass to the Moon, which will in turn reduce mission costs and improve sustainability. In the long run, full utilization of in-situ materials and closed loop life support systems will enable self-sufficiency of lunar activities and allow for permanent settlement on the Moon.	**X**		**X**			
Life Support & Habitat	**mLSH1.1**	Emplace agriculture systems on the Moon to produce food and plants for lunar operations.	Agricultural systems include the operation of a greenhouse or farm using either imported soil from Earth, lunar regolith, or hydroponic systems as the growing medium. Products to be grown include food for inhabitants and plant matter for bioregenerative life support systems.	in-situ agricultural activities will be necessary for self-sufficiency of lunar operations. If lunar inhabitants can grow their own food and plant matter, they can greatly reduce the amount of supplies required from Earth.			**X**	**X**		
Life Support & Habitat	**mLSH1.2**	Emplace water management and recovery systems in consonance with mission needs to increase life support system closure.	Develop aqueous management systems that allow for safe water storage and, with increased mission duration, offer water recovery from wastewater streams.	Water recovery and management systems can increase the closure of the life support system. This will ultimately lower overall system mass, reduce the use of consumables, and and allow for more mission autonomy.	**X**		**X**	**X**		
Life Support & Habitat	**mLSH1.3**	Emplace air revitalization systems in consonance with mission needs to increase life support system closure.	Develop operational air revitalization systems that offer increased level of fidelity from removal of carbon dioxide and trace contaminants to recovering oxygen from the waste carbon dioxide stream.	Air revitalization systems can increase the air loop closure of the life support system. This will ultimately affect the overall system mass, reduce the use of consumables, and allow for more mission autonomy.	**X**		**X**	**X**		
Life Support & Habitat	**mLSH1.4**	Emplace waste management systems to handle human and manufactured waste and increase system closure.	Waste management systems will need to store, process, and dispose of human and manufactured waste in an appropriate manner. Ideally, as much waste as possible will be recycled to have minimal impact on the lunar environment.	Waste management is an essential function of any environment in which humans and equipment operate. Maximum processing and recycling of waste can improve the sustainability of lunar operations by increasing system closure.	**X**		**X**	**X**		
Life Support & Habitat	**mLSH2**	Develop and deploy closed loop life support systems to increase self sufficiency of future long duration human exploration missions and minimize the impact of humans on the environment.	Demonstrate environmental control and life support (ECLS) viability and operationability of (first partially) closed life support systems with water and air regeneration and waste processing systems. Implement intelligent monitoring and control over life support system components to reduce the crew overhead required to operate advanced systems. Maximize the system-level advantages (e.g. mass and volume) of advanced ECLS while ensuring reliable operation and minimizing crew time maintaining and operating these systems.	Closed loop life support systems enable long duration human settlement and exploration missions, including Mars missions, by providing the capability for self-sufficient operations with minimal impact on the surrounding environment. Maximize crew productivity by enabling computer-controlled systems to maintain breathable air and potable water supplies with minimal supervision. In addition, technology transfer to terrestrial applications can reduce the impact of the human waste burden on the Earth's environment as well.	**X**	**X**	**X**	**X**		

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					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Life Support & Habitat	**mLSH3**	Study key plant and bacterial species to evaluate the feasibility of integrating them into life support systems.	A number of plant and bacterial species have been identified for studying fundamental and applied topics related to the long term effects of the lunar environment on processes associated with bioregenerative life support systems.	These studies will determine the feasibility of integrating plants and microbes into the life-support systems for food production and treatment of water, air, and solid wastes. Successful closure of the life support system with ecologically balanced plant and microbial communities will reduce resupply logistics for extended lunar stays and Mars missions and facilitate significant terrestrial benefits, particularly in waste management. Additionally, the presence of plants on board may add to the psychological well-being of astronauts during extended missions.	**X**	**X**	**X**	**X**		
Life Support & Habitat	**mLSH4**	Develop and implement environmental monitoring systems to improve the efficiency of life support systems.	Monitor the internal and external environment for gasses, and monitor the aqueous environment for chemical and microbial species. Wherever possible, monitor these conditions autonomously.	Monitoring the crew environment is not only essential for assuring the safety of crew and the associated equipment, but more autonmous controls will enable improved the efficacy of the life support systems as well.	**X**	**X**	**X**	**X**		
Life Support & Habitat	**mLSH5**	Develop and implement fire detection and suppression strategies for the 1/6-g environment to ensure habitat safety.	Gravity level has a strong bearing on both fire detection and suppression strategies. Strategies for microgravity are quite different from the ones used for normal-g environment. Experiments can be conducted on the lunar surface to evaluate mitigation strategies and choose materials for construction of habitats and equipment.	Fire safety is a critical element of crew safety. Experimental data generated will be quite valuable in designing safe habitats. Availability of 1/6-g data and normal gravity data will bracket the Martian environment condition and pave the way for selecting safe materials for Mars applications.	**X**		**X**			

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					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
General Infrastructure	**mGINF1**	Emplace support services on the Moon, including emergency response, to enable increased lunar activities.	Provide support services such as emergency response, rescue, repair, reuse/recycle, and other logistics support, for use by all entities undertaking activities on the Moon. Develop systems that can have maximum extensibility for use on Mars.	Support services can be shared by all those who are living and working on the Moon. Emergency systems, in particular, can increase safety of operations by providing a mechanism to report and respond to an emergency. Having the services in place will enable further development of the Moon because new participants will not have to provide them for their activities.	**X**		**X**			
General Infrastructure	**mGINF2**	Establish a globally accepted lunar reference coordinate system to avoid confusion in planning and executing lunar missions.	Develop and implement a globally accepted lunar reference coordinate system. Utilize this system in planning and executing lunar exploration and habitation activities.	Establishing a single, globally accepted lunar coordination system will avoid confusion about lunar coordinate systems that already exist. This coordinate system can help coordinate mission planning and execution by eliminating confusion between different groups operating on the lunar surface.			**X**			
General Infrastructure	**mGINF3**	Deploy a Moon-based infrastructure that can service space-based assets to reduce the cost and increase the lifetime of space system operations.	Deploy a Moon-based infrastructure to service space based assets. The infrastructure should be able to service assets in cis-lunar space and other strategic locations in the Earth/Moon system (such as L2). The infrastructure could be capable of refueling, maintenance, and other service capabilities needed to support ongoing space operations.	A Moon-based operational service infrastructure could reduce the cost and increase the lifetime of space systems operating in the Earth/Moon system by providing the capability to repair and service assets that have already been launched from Earth. Development and operation of an infrastructure within the Earth/Moon system provides operational experience and equipment useful for buying down risk of missions further into the solar system.	**X**	**X**	**X**	**X**		
General Infrastructure	**mGINF4**	Establish warehouses on the Moon to make supply logistics more efficient.	Establish warehouses on the Moon to store supplies coming from Earth before they are needed in lunar operations.	If supplies can be sent to the Moon in bulk quantities more cheaply than for single-mission applications, having warehouses on the Moon is essential to store these items for the duration until they are needed. Inexpensive storage of goods between their points of origin and destination will be very important to the development of a sustainable and self-sufficient lunar operations.			**X**	**X**		

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Operations, Testing & Verification	**mOPS1**	Develop protocols for lunar operations to ensure more safe, effective, and routine surface activities.	Develop protocols, practices, procedures, and processes for lunar operations. Protocols will be necessary for EVA operations, utilizing automation assistance, and other interior and exterior lunar surface activities. Wherever possible, protocols should be consistent with the operational requirements and constraints of a Mars mission.	Developing and implemeting protocols for surface activities will enable more safe, effective, and routine operations. In particular, routine EVA operations will enhance the productivity of mission activities. Developing protocols with extensibility to Mars will reduce risks for future exploration.	**X**		**X**			
Operations, Testing & Verification	**mOPS2**	Engage in operations testing to understand how to best perform basic working tasks in the the lunar environment.	Engage in operations testing of techniques for living and working in the lunar environment. Individuals living on the Moon should learn how to do everyday things, such as cook, clean, and live their daily lives in the lunar habitat. Techniques must also be refined for basic work tasks, such as picking up/putting down items, assembly and disassembly, etc. Activity timescales should be applicable to early crewed Mars missions.	A systematic, comprehensive set of operations testing will characterize how fundamental living and working tasks are best accomplished in the lunar environment. This will speed the acclimitization to living on the Moon. Having activity timescales applicable to Mars missions will help develop techniques for future exploration.	**X**	**X**	**X**			
Operations, Testing & Verification	**mOPS3**	Establish crew-centered, real-time mission planning and control to enable self-sufficiency of lunar operations.	Establish crew-centered planning, scheduling, and control of mission operations, such that crews can plan their close-in operations activties in real-time. Earth-based ground control should only be utilized for mid-term and long-term planning, to serve as help desk and trouble shooting support, and to perform flight data reduction, analysis, and management.	Crew-centered operations will enable the self-sufficiency of lunar operations as crews no longer need to approve all actions with ground control. Crew-control in real-time will improve the efficiency of operations, reducing long-term lunar operations costs. These same techniques can be implemented for future Mars exploration missions.	**X**		**X**			
Operations, Testing & Verification	**mOPS4**	Develop equipment repair techniques to increase self-sufficiency of lunar operations.	Develop and demonstrate techniques and processes required to repair lunar surface equipment (e.g. habitats, transportation, life support, etc.) without use of an Earth to Moon logistics train. Provide the capability to manufacture parts as required to accomplish equipment repairs. Techniques and operational experience gained during lunar missions is directly extensible to future Mars missions.	Having effective repair equipment and techniques can increase lunar self-sufficiency while reducing infrastructure required to maintain lunar surface missions. This also reduces risk associated with lunar surface operations by providing local repair capability to mitigate problems as they occur on the Moon. Additionally, systems and techniques developed to accomplish lunar systems repair significantly support risk reduction for missions to Mars and beyond.	**X**		**X**	**X**		
Operations, Testing & Verification	**mOPS5**	Conduct Mars analog tests on the Moon to reduce the risks of future exploration.	Conduct Mars analog tests of protocols, practices, procedures and processes, as well as certain technologies, that would be used in carrying out Mars mission operations. The most important aspects of Mars missions to simulate are 1) the increased autonomy required, 2) the concomitant increase in required supporting automation and 3) the increased stress associated with the combination of long exposure to a hazardous environment and increased psychological isolation due to distance.	A Mars analog test can reduce risks related to future exploration missions by testing operations in an off-Earth planetary environment. Because the Moon is much closer to Earth than Mars, crews can more easily receive aid, if necessary.	**X**					

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Operations, Testing & Verification	**mOPS6**	Develop realistic remote training systems to prepare crews to handle unplanned situations.	Develop highly realistic training techniques such as the use of immersive, photorealistic 3D models of the lunar surface in virtual reality systems. Crews can train with these systems remotely.	Realistic training systems can prepare crews to handle unplanned emergencies or situations. Crews must be able to effectively deal with these situations to ensure safe operations. Any training which can be done remotely from Earth will be much less expensive than performing exercises on the Moon. If this technology is easily adaptable to the Mars environment, crews for future exploration missions can also be trained using the same systems.	**X**		**X**			
Operations, Testing & Verification	**mOPS7**	Evaluate astrobiology protocols and measurement technologies that will be used to test for life on other planets.	Evaluate contamination control protocols and establish no-life baselines for scientific technologies that will be used to test for life on other planets.	Astrobiology protocols and technologies can be uniquely tested on the Moon since it is devoid of life. These technologies can be used to test for life elsewhere in the solar system. Operational tests away from the Earth provide more relevant validation of approach.	**X**	**X**	**X**			
Operations, Testing & Verification	**mOPS8**	Evaluate planetary protection protocols to develop the next generation planetary protection policy.	Evaluate planetary protection protocols by first characterizing the biological effects of human activity on the lunar surface. Develop and test decontamination of astronauts and equipmement returning from the Moon, to control forward and backward contamination, as precursor to human return from Mars. Include consideration of lunar commerce when designing and implementing such regulations so as not to unduly cripple lunar commerce.	Understanding the impact of human activity on the lunar surface is necessary to develop the next generation of planetary protection protocols. These protocols will help prevent forward environmental contamination of sites on the Moon and backward contamination of crew and cargo returning to Earth. After evaluating these protocols, they can be used as models for protocols for future Mars exploration missions.	**X**	**X**		**X**	**X**	

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Power	**mPWR1**	Develop lunar power generation, storage, and distribution systems to satisfy the energy demands of lunar operations.	Develop power generation, storage, and distribution technologies and systems to satisfy the energy demands of lunar habitats, equipment and infrastructure, and mobility systems. Over time, the power system capacity should grow to meet the growing needs of lunar operations. Power can be generated on the lunar surface or in lunar orbit, and over time lunar resources may be utilized for power systems. Maximize the potential for these systems to be used for Mars exploration missions.	A reliable power supply and distribution infrastructure is critical to meeting the goals of the lunar missions, especially over long lunar nights. As a rising amount of power is generated on the Moon or in lunar orbit, self-sufficiency of lunar operations will increase. Additionally, lunar operations can serve as a testbed for power technologies for future Mars missions.	**X**		**X**			
Power	**mPWR2**	Utilize Earth-generated power to satisfy the demands of lunar operations.	Lunar base power, even during the two week lunar night, could be provided by laser or microwavepower beaming from Earth. Power could be relayed from two different Earth sites, to provide redundancy, through GEO satellites, to the lunar surface.	The scope of lunar exploration may be limited by the availability of electrical power on the lunar surface. Beaming power from the Earth could provide power to the lunar base for long durations.			**X**			
Power	**mPWR3**	Develop lunar power generation, storage, and distribution systems to export power for use by Earth and space applications.	Generate power on the Moon or in lunar orbit and distribute that power to Earth and space applications. In-situ lunar power sources such as photovoltaic cells could enable power production and distribution to become a profitable commercial enterprise based on the Moon.	Lunar power production and distribution based on the Moon could be profitable if in-situ lunar resources are utilized. If so, this could be a market for commercial companies. Extending power distribution (if a market for excess power exists) to Earth and space applications could be a valuable extension of this market. Distributing power to Earth could alleviate power resource constraints on Earth. Distributing power to space applications could reduce their launch weight.			**X**	**X**		

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Communication	**mCOM1**	Implement a secure, reliable, robust, interoperable and scalable telecommunications capability to support expanding telecom needs of exploration operations.	Implement telecommunications capabilites to meet lunar needs that can evolve to meet Mars needs. This capability should be scalable to meet lunar requirements as they expand in scope. The networks should support communications functions such as voice, data, and image transmission to other lunar locations (including to teleoperated equipment), to Earth, and possibly to other space locations. Interoperability provides flexibility to use commercial and international partner systems and to accomodate new technology as it becomes available.	Telecommunications networks are vital to coordinating lunar activities as they increase in capacity and become increasingly dispersed across the lunar surface. Having the capability to transmit multiple types of data will enable more complex and productive lunar activities. A secure, reliable and robust network is essential for ensuring continuous and safe mission operations. Scalable networks are essential to accommodate growth beyond the initial outpost while maintaining quality of service. Interoperability enables the use of commercial systems and joint operations with international partners.	**X**		**X**			**X**
Communication	**mCOM1.1**	Implement an early communications capability to support lunar robotic activities prior to human needs.	Implement communication capabilites including telemetry, tracking, and control (TT&C) and mission data transmission to meet early lunar robotic needs. Robotic mission communications are either direct to Earth or relayed depending on where the mission goes. Early communication systems can be used to test technology for subsequent systems that meet human mission needs.	Communications are essential to be able to control and return data from early robotic missions that survey lunar sites.		**X**	**X**			
Communication	**mCOM1.2**	Implement secure, reliable, robust, and scalable communications between lunar assets and the Earth to support human mission needs.	Implement communication capabilites including telemetry, tracking, and control (TT&C), voice, video, and mission data transmission between the Earth and lunar surface and orbiting assets for human missions. Communications are either direct to Earth or relayed depending on where the mission goes.	Communications between Earth and the Moon are essential for control of systems and execution of operations as well as supporting public engagement. Scalable communications support growth from the initial landed element to the outpost and beyond. Communication systems are an excellent opportunity for commercial and international participation.			**X**	**X**	**X**	**X**
Communication	**mCOM1.3**	Implement secure, reliable, robust, and scalable communications between lunar assets to support human mission needs.	Implement communication capabilites including telemetry, tracking, and control (TT&C), voice, video, and mission data transmission between surface-surface and surface-orbiting assets for human lunar missions. Communications are either direct between assets or relayed depending on visibility and range.	Communications between lunar assets are essential for control of systems and execution of operations as well as providing local control in preparation for Mars missions. Scalable communications support growth from the initial landed element to the outpost and beyond.	**X**		**X**			
Communication	**mCOM2**	Establish high-bandwidth communications that support public engagement activities.	Provide a communications network capable of transmitting commands, high quality imagery, video, and sensor data in real time for mission and public outreach use. This network can also support real-time Earth-based teleoperation of robotic systems.	Many public engagement activities will rely on significant quantities of imagery, video and other type of data to provide a virtual presence for individuals wishing to experience lunar exploration remotely via, among other things, the remote control of robots. These remote activities could generate revenues for a commercial company providing the services, and could increase public engagement in lunar activities.	**X**		**X**	**X**		**X**

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Position, Navigation & Timing	**mPNT1**	Provide position, navigation, and timing capabilities to support lunar operations and evolve to support Mars operations.	Provide position, navigation and timing for lunar operations, including orbit determination, orbital maneuvers, precision landing, hazard avoidance, surface movement, surface mapping, and scientific investigations. Provide global access and persistent coverage, possibly combined with a communications infrastructure. Develop lunar PNT capabilities to be extensible to Mars operations.	A lunar PNT system augments Earth-based PNT for lunar operations, while providing optimal autonomy from Earth. If the PNT infrastructure is interoperable with other lunar infrastructure, it may lower the cost for subsequent missions and become a catalyst for lunar activities. A PNT system could be developed and operated by a commercial entity.	**X**		**X**	**X**		
Position, Navigation & Timing	**mPNT1.1**	Establish guidance capabilities with increasing levels of autonomy and standardization to support Moon and Mars operations.	Provide standardized guidance hardware and software components for the family of exploration systems. Guidance should become autonomous and highly automated as part of the exploration Command, Control, Communication and Information (C3I) framework.	Guidance capabilities will decrease in cost over time through through hardware, software, and information standardization that reduces the need for custom design, development, testing and evaluation, and increasing autonomy that reduces the need for manual operations. Guidance systems perfected for lunar operations will be capable of Mars operations with little modification.	**X**		**X**	**X**		
Position, Navigation & Timing	**mPNT1.2**	Establish tracking capabilities to assist vehicles in cislunar space and mobile surface systems in determining their position and velocity.	Provide services for tracking vehicles in space and on the surface including 1- and 2-way range, position, and velocity, to support navigation. Standardized tracking services are part of the exploration Command, Control, Communication and Information (C3I) framework.	Tracking capabilities will decrease in cost over time through through hardware, software, and information standardization that reduces the need for custom design, development, testing and evaluation, and increasing autonomy that reduces the need for manual operations. Tracking systems perfected for lunar operations will be capable of Mars operations with little modification.	**X**		**X**	**X**		
Position, Navigation & Timing	**mPNT1.3**	Establish time and clock capabilities to assist vehicles in cislunar space and surface systems in determining their relative and absolute time.	Provide time services including a solar system wide time scale, time dissemination, and calibration. Standardized timing services are part of the exploration Command, Control, Communication and Information (C3I) framework supporting precision navigation, mission operations, and science data time tagging.	Time capabilities will decrease in cost over time through hardware, software, and information standardization that reduces the need for custom design, development, testing and evaluation, and increasing autonomy that reduces the need for manual operations. Tracking systems perfected for lunar operations will be capable of Mars operations with little modification.	**X**		**X**	**X**		
Position, Navigation & Timing	**mPNT1.4**	Establish attitude control capabilities to assist exploration vehicles in cislunar space in stationkeeping and maneuvering operations.	Provide attitude control capabilities including inertial, locally fixed, and relative to proximity vehicles for transit, stationkeeping, descent/ascent, and rendezvous and docking operations. Standardized attitude control services are part of the exploration Command, Control, Communication and Information (C3I) framework.	Attitude control capabilities will decrease in cost over time through hardware, software, and information standardization that reduces the need for custom design, development, testing and evaluation, and increasing autonomy that reduces the need for manual operations. Attitude control systems perfected for lunar operations will be capable of Mars operations with little modification.	**X**		**X**	**X**		

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Position, Navigation & Timing	**mPNT1.5**	Establish emergency position determination services to support Search and Rescue (SAR).	Provide emergency position determination and distress alerting for surface users to aid in rescues similar to the Committee On Space Research-Search And Rescue Satellite Aided Tracking (COSPAS-SARSAT) international satellite-based search and rescue system.	Emergency position determination can be utilized to provide Search and Rescue information for all individuals on the Moon. International cooperation mechanisms from Earth can be translated into international cooperation in space for the same reason: to save lives.	**X**		**X**	**X**	**X**	

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Transportation	**mTRANS1**	Provide redundant transportation to and from the Moon to increase access to the Moon.	Provide transportation for travel between the surface of the Earth to the surface of the Moon and points in between (i.e. from Earth orbit to lunar orbit). Ideally, at least two crew transportation systems and a number of cargo systems (including a heavy lifter) should be developed.	Transportation systems for both crew and cargo are essential for enabling all lunar exploration activities. Developing more than one system capable of transporting both crew and cargo will enable ongoing transportation to the Moon, in the event that one transportation system becomes inoperable. Interoperability between systems can maximize their redundancy. Finally, because transportation costs have traditionally been a major contributor to the price of space missions, lowering the cost of transportation could initiate increased lunar development, including commercial activity.	**X**		**X**	**X**		
Transportation	**mTRANS2**	Develop an autonomous lander to utilize for routine landing operations.	Demonstrate an autonomous lander, with technologies such as autonomous guidance and navigation and control for landing, including hazard avoidance and precision landing capability. Utilize the lander, if possible without a human operator, for routine landing operations.	An autonomous lander reduces mission risk by removing the human in-the-loop from guidance, navigation, and control of landings. Assuming the lander can be safely operated without a human present, it can be utilized for routine landing of supplies and equipment, without incurring the cost of man-rating the system.	**X**		**X**			
Transportation	**mTRANS3**	Develop cryogenic fluid management, storage, and distribution systems to extend the lifetime and reduce the launch mass of exploration systems.	Develop and deploy cryogenic fluid management, storage, and distribution system. The basic elements and functions of such a system include: storage, pressure control, fluid transfer, fluid couplings, instrumentation, leak detection and quantity gauging. Combinations of passive and active thermal control (refrigeration) ensure that cryogenic propellant can be stored indefinitely with no losses, i. e. with zero boil off (ZBO) losses. Systems with this technology can be utilized for lunar surface operations and in space refueling.	Future scientific and exploration missions can be greatly enhanced with the development of a robust zero-loss cryogenic fluid management, storage and distribution system. Lunar and Mars surface operations can be extended if cryogenic fluids, such as life support gasses and high energy propellants, can be stored and distributed safely, with zero-loss, for long periods in the space environment. Utilizing similar storage and distribution systems in Earth or lunar orbit can enable refueling of exploration probes, such that they can be launched from Earth with less fuel onboard. This provides more launch payload mass for equipment and instrumentation.	**X**		**X**			
Transportation	**mTRANS4**	Establish a lunar base traffic management system to ensure safe take-off and landing operations.	Establish a lunar base traffic management system. Define landing zones for cargo and crew landers and establish safe traverse routes in the immediate vicinity of surface infrastructure elements.	A systematic, analytical method of defining landing zones protects active surface infrastructure from plume ejecta damage while maintaining easy access between landers and the final surface destinations of the crew and cargo. As surface infrastructure builds up, it must be protected from human and robotic rover traffic (vibration, kicked up dust, rolling over cables, collision hazard, etc.).	**X**		**X**			

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Surface Mobility	**mSM1**	Provide surface mobility capabilities to move crew outside the local area of a lunar outpost.	Develop and utilize short range and long range mobility systems to transport crew to different locations on the lunar surface, outside the local area of a lunar outpost. Short-range systems may transport crew directly across the lunar surface, while long-range systems may "fly" from one lunar location to another. Wherever possible, mobility systems should be able to operate with minimal human support and designed for maximum extensibility to Mars.	Mobility systems that move crews to different locations across the lunar surface will enable additional scientific studies and exploration of the Moon. Coupled with systems that transport cargo, crew mobility systems can enable more complex scientific and exploration activities requiring large instrumentation, as well as emplacement and maintenance of infrastructure across the lunar surface. Developing capabilities with extensibility to Mars will reduce risks for future Mars exploration missions.	**X**		**X**			
Surface Mobility	**mSM2**	Provide surface mobility capabilities to move cargo and equipment outside the local area of a lunar outpost.	Develop and utilize short range and long range mobility systems to transport cargo and equipment to different locations on the lunar surface, outside the local area of a lunar outpost. Short-range systems may transport cargo and equipment directly across the lunar surface, while long-range systems may "fly" from one lunar location to another. Wherever possible, mobility systems should be able to operate with minimal human support and designed for maximum extensibility to Mars.	Mobility systems that move cargo and equipment to different locations across the lunar surface will enable emplacement of infrastructure across the lunar surface. Coupled with systems that transport crew, cargo mobility systems can enable more complex scientific and exploration activities requiring large instrumentation, as well as emplacement and maintenance of infrastructure across the lunar surface. Developing capabilities with extensibility to Mars will reduce risks for future Mars exploration missions.	**X**		**X**			
Surface Mobility	**mSM3**	Provide surface mobility capabilities for local operations within a lunar outpost complex.	Develop and utilize short-range surface mobiliity system to support local operations within a lunar outpost complex. Within a complex, systems to enable construction and maintenance of the lunar outpost will be most useful. Examples of necessary capabilities include site preparation, cargo delivery, construction support, and infrastructure inspection. Mobility systems may be embedded in construction and maintenance equipment, or be a platform to support multiple tools. Wherever possible, systems should be able to operate with minimal crew support.	Mobility systems will enable operations within a lunar outpost complex, including the efficient construction and expansion of a permanent lunar outpost. Tools that can operate independently of crew support will free up crew time for those tasks requiring human involvement. Developing capabilities with extensibility to Mars will reduce risks for future Mars exploration missions.	**X**		**X**			

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Crew Activity Support	**mCAS1**	Develop a high performance EVA suit to enable effective and safe crewed surface operations.	Develop a high performance EVA suit that allows crews to operate safely on the lunar surface. Ideally, the suit is lightweight, allows for dextrous manipulation of objects, supports unhindered movement, and minimizes the amount of regolith that crews and habitats are exposed to.	A high performance EVA suit will enable crews to safely and effectively operate on the lunar surface. Giving crews the ability to perform a range of activities on the lunar surface, without tiring over many hours, will improve their productivity.	**X**		**X**			
Crew Activity Support	**mCAS2**	Develop robots to support local operations outside of the facilities within a lunar outpost complex.	Develop and utilize robots to support local operations within a lunar outpost complex. Robot capabilities can range from crew-assistened, teleoperated, or autonomous. Robots outside of facilities such as habitats and laboratories can perform construction and maintenance tasks for the Moon base and function as bulldozers, dextrous manipulators, drilling robots, etc. Wherever possible, systems should be designed with maximum extensibility for Mars exploration.	Robots can perform tasks at the Moon base that are too physically difficult for crews. Synergy between human and robotic activities will enhance productivity within the Moon base. Robots that can operate independently of crew support will free up crew time for those tasks requiring human involvement. Developing capabilities with extensibility to Mars could reduce risk for future Mars exploration missions. Finally, these robotic systems may have terrestrial applications as well.	**X**		**X**	**X**		
Crew Activity Support	**mCAS3**	Develop robots to support local operations inside of the facilities within a lunar outpost complex.	Develop and utilize robots to support local operations within a lunar outpost complex. Robot capabilities can range from crew-assistened, teleoperated, or autonomous. Robots inside facilities such as habitats, laboratories, and greenhouses can support crews as porters, secretaries, gardeners, laboratory assistants, and task aides. Wherever possible, systems should be designed with maximum extensibility for Mars exploration.	Robots can perform tasks at the Moon base that are too tedious and repetitive for crews. Synergy between human and robotic activities will enhance productivity within the Moon base. Robots that can operate independently of crew support will free up crew time for those tasks requiring human capabilities in research, integration, and decision-making. Developing capabilities with extensibility to Mars could reduce risk for future Mars exploration missions. Finally, these robotic aides may have terrestrial applications as well.	**X**		**X**	**X**		

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Crew Activity Support	**mCAS4**	Develop robots to support exploration activities outside the local area of a lunar outpost.	Develop and utilize robots to support exploration activities outside the local area of a lunar outpost. Robot capabilities can range from crew-assistened, teleoperated, or autonomous. Robots can be utilzied by crews exploring the lunar surface and performing field science. Robots can perform repetitive precision work, such as deploying geophysical monitoring stations or conducting geologic and route reconnaissance. Wherever possible, systems should be designed with maximum extensibility for Mars exploration.	Robots can perform tasks that are too physically difficult, require precision, or tedious for crews. The pairing of human explorers and capable robotic assistants has been recognized as a significant "research multiplier," expanding the envelope of possible human exploration. Robots that can operate independently of crew support will free up crew time for those tasks requiring human capabilities in research, integration, and decision-making. Developing capabilities with extensibility to Mars could reduce risk for future Mars exploration missions. Finally, these robotic aides may have terrestrial applications as well.	**X**	**X**	**X**	**X**		
Crew Activity Support	**mCAS5**	Develop teleoperation capabilities to determine the feasibility of remote operation of equipment on the lunar surface.	Develop teleoperation capabilities to determine the feasibility of remote operation of equipment on the lunar surface. Develop prototype systems to test the utility, effectiveness, and efficiency of teleoperation. Teleoperation could be controlled by individuals on the Moon, in space, or on Earth, and will require the technology to link operators across time delays to the surface systems.	Teleoperation capabilities allow remote operation of equipment, which can reduce crew overhead by reducing the amount of EVA required by lunar crews. Teleoperation can also be controlled by individuals not on the lunar surface, which will enable un-crewed testing and other operations when the crew is not present. By developing teleoperated testbeds, the utility, effectiveness, and efficiency of teleoperation can be tested before large-scale systems are implemented.	**X**	**X**	**X**	**X**		

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilizatio	Economic Expansion	Global Partnerships	Public Engagement
Lunar Resource Utilization	**mLRU1**	Characterize and quantify the resource potential of the Moon to assess the value of possible resource utilization applications.	Characterizing and quantifying the resource potential of the Moon includes activities that map out and generate greater understanding of these resources. Determining this may utilize remote sensing, in-situ methods, and resource extraction process evaluations, and economic and market studies that develop an appreciation of the specific applications, products, services and benefits that would accrue from the use of lunar resources. The resources of the Moon include, but are not limited to, materials found at or near the lunar surface and the chemical and physical properties of these materials, the lunar vacuum, the solar energy flux on the Moon, the solar wind, the relatively low lunar gravity and the high potential energy of the Moon's gravity well (compared to Earth), the temperature extremes of the lunar surface (including permanently shadowed regions), and the 28-day lunar diurnal period.	Characterizing and determining the resource potential of lunar materials will identify resource candidates and assess the value of various applications of these resources. This supports prioritization of budgets and activities that provide benefits from lunar resources by providing an understanding of the feasibility, costs, and benefits of these activities. This characterization also supports government and commercial investment in lunar infrastructure by estimating the uses and value of resource utilization activity. Finally, this supports long-term lunar planning, development, and implementation of the exploration strategy by providing insight about the potential for resource utilization for future exploration activities.	**X**	**X**	**X**	**X**		
Lunar Resource Utilization	**mLRU2**	Develop and validate tools, technologies, and systems that excavate lunar material, to enable lunar resource utilization.	Develop and validate tools, technologies, and systems that excavate lunar material. In particular, develop the capability to remove and move large masses of raw material in the lunar environment. Development and validation includes experimentally validating tools, software, components and systems that perform various engineering processing of extracted lunar resources. Wherever possible, systems should be designed with maximum extensibility to Mars.	Effective resource excavation is the first step in overall lunar resource utilization that involves extacting and processing resources from the lunar regolith. Each step of technology and system demonstration will reduce the economic, schedule, and political risks associated with activities that require lunar resource utilization. Following successful validation of excavation systems, plus validation of extraction and processing systems, resource utilization can begin. Lunar resource utilization could reduce the mass of materials and products that must be launched from Earth for activities on the Moon and other destinations. If resource utilization technologies can be applied to Mars, the risks for future exploration can be reduced.	**X**		**X**			
Lunar Resource Utilization	**mLRU3**	Develop and validate tools, technologies and systems that extract lunar resources, to enable lunar resource utilization.	Develop and validate tools, technologies, and systems that extract lunar resources from excavated lunar material. Development and validation includes experimentally validating tools, software, components and systems that perform various engineering unit operations associated with extracting. Wherever possible, systems should be designed with maximum extensibility to Mars.	Effective resource extraction is a necessary step in overall lunar resource utilization. Each step of technology and system demonstration will reduce the economic, schedule, and political risks associated with activities that require lunar resource utilization. Following successful validation of excavation and extraction systems, plus validation of resource processing systems, resource utilization can begin. Resource utilization could reduce the mass of materials and products that must be launched from Earth for activities on the Moon and other destinations. If resource utilization technologies can be applied to Mars, the risks for future exploration will be reduced.	**X**		**X**			

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	**Scientific Knowledge**	**Human Civilizatio**	**Economic Expansion**	**Global Partnerships**	**Public Engagement**
Lunar Resource Utilization	**mLRU4**	Develop and validate tools, technologies and systems that process lunar resources, to enable lunar resource utilization.	Develop and validate tools, technologies, and systems that process extracted lunar resources into products that may be utilized. Development and validation includes experimentally validating tools, software, components and systems that perform various engineering processing of extracted lunar resources. Wherver possible, systems should be designed with maximum extensibility to Mars.	Effective resource processing is a necessary step in overall lunar resource utilization. Each step of technology and system demonstration will reduce the economic, schedule, and political risks associated with activities that require lunar resource utilization. Following successful validation of resource processing systems, plus validation of excavation and extraction systems, resource utilization can begin. Resource utilization could reduce the mass of materials and products that must be launched from Earth for activities on the Moon and other destinations. If resource utilization technologies can be applied to Mars, the risks for future exploration will be reduced.	**X**		**X**			
Lunar Resource Utilization	**mLRU5**	Demonstrate lunar resource utilization systems to reduce risk for mission integration and commercial development.	Demonstrate pilot- and sub-pilot scale systems that utilize space resources safely, effectively, and in an energy-efficient manner. Examples of demonstrations include oxygen production from regolith for life support and propulsion; energy production, transport, storage, and distribution for outpost use; excavation and transport of regolith for radiation shielding and thermal moderation; water production for life support, radiation shielding, and cosmic ray telescopes; fuel production (as opposed to oxident production); fabrication and construction of structural and building materials; production of spare parts, machines and tools; and construction and site preparation using lunar materials and energy.	Systems demonstrations can confirm engineering of protocols, processes, and technologies required to ensure the safe, cost-effective use of in-situ resources. Successful demonstrations can reduce technological, economic, schedule and political risks associated with activities that extract and use lunar resources. This increases mission planner confidence, including for Mars applications, and supports and encourages government and commercial investment in establishing lunar infrastructure.	**X**		**X**	**X**		
Lunar Resource Utilization	**mLRU6**	Develop, validate, and incorporate new products and associated technologies and systems that effectively utilize lunar resources and products, to support further lunar resouce utilization.	Develop, validate, and incorporate into lunar architecture planning and missions specific new products that specifically utilize in-situ resources and resource-derived products instead of Earth-supplied consumables or products. This includes scientific, engineering, economic and market studies and investigations that consider and advance a wide variety of possible uses of lunar resources. Examples include the development of new propellants and fuels (such as powdered metal, silane, or sulfur); hybrid rocket motors that utilize lunar-based propellants; ceramics based on ceramic precursor materials available from lunar regolith; advanced thin-film deposition processes that exploit the "hard" lunar vacuum in manufacturing optical telescope mirrors, photovoltaic systems, solar concentrators and light-weight solar sails; and aneutronic fusion reactors based on He-3. Wherever possible, these products and systems should be designed with maximum extensibility to Mars.	Developing and validating specific new products that utilize lunar resources supports the design, development and utilization of lunar resource technologies and systems. This promotes mission planning and new technology and capabilility incorporation into the lunar architecture; enables robotic and human sortie missions to other locations on the lunar surface from an outpost (with reusable assets) instead of requiring a dedicated mission from Earth; reduces technological, economic, schedule and political risks associated with activities that extract and use lunar resources; and supports prioritization of budgets and activities that provide benefits from lunar resources. This further supports government and commercial investment in lunar infrastructure and possible products and services, the establishment of markets that utilize products and services derived from lunar resources; and supports long-term sustainability and self-sufficiency of lunar exploration.	**X**		**X**	**X**		

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilizatio	Economic Expansion	Global Partnerships	Public Engagement
Lunar Resource Utilization	**mLRU7**	Produce propellants and life support and other consumables from lunar resources, to improve the productivity of lunar operations.	Produce propellants and life support and other consumables from lunar resouces. Consumable production could be done via water extraction from lunar ice with conversion to hydrogen and oxygen, oxygen extraction from regolith, extraction of components of the solar wind from regolith, and using regolith as a medium in which to grow plants. The primary products of interest are propellants for transportation, oxygen and nitrogen for breathing, water for shielding and crew usage, food and other plant matter, and other chemicals for life support and exploration purposes (e.g., instrumentation gases).	Producing consumables from lunar resources can reduce the amount of materials that must be brought from the Earth. Lower launch masses will enable lower cost space transportation, including transportation to other exploration destinations. Early opportunities for consumable utilization include applications on the lunar surface and potentially in cis-lunar space (e.g., propellant delivery to GEO for satellite delivery and moving to new orbits). Utilizing lunar-produced consumables increases the potential for longer human-lunar missions, reduces costs associated with lunar activities, reduces mission risks from life support or transportation failures, enables new exploration capabilities such as hoppers, and improves productivity (value per unit cost) associated with activities on the lunar surface and elsewhere in space where lunar resources are applied.	**X**		**X**			
Lunar Resource Utilization	**mLRU8**	Construct facilities and manufacture hardware, materials, and other infrastructure growth products and capabilities from lunar resources, to improve the productivity of lunar operations.	Construct facilities and manufacture hardware, materials, and other products from lunar resources. Outcomes of interest include construction of shielding materials and other structural elements for habitats, shelters, fixed infrastructure and other facilities; preparation of landing pads and surface transport pathways; construction of facilities for energy production and storage (e.g., chemical storage tanks, electrical transmission systems, thermal energy storage reservoirs, etc); and production of solar photovoltaics.	Constructing facilities and manufacturing products from lunar resources can reduce the amount of materials that must be brought from Earth. Lower launch masses will enable lower cost space transportation, including transportation to other exploration destinations. Utilizing lunar-produced products increases the potential for longer human-lunar missions, reduces costs associated with lunar activities, and overall improves productivity (value per unit cost) associated with activities on the lunar surface and elsewhere in space where lunar resources are applied.	**X**		**X**			
Lunar Resource Utilization	**mLRU9**	Repair, fabricate and assemble parts and products using extracted and processed in-situ resources to support self-sustained, long duration missions.	Develop, validate, and incorporate into lunar architecture planning and missions technologies and systems that specifically utilize in-situ resources and resource-derived products to perform repairs, produce spare parts, produce new tools in-situ on an as-needed basis, and assemble tools, machines, and surface exploration hardware. In-situ resources for this capability include those derived from regolith, human and life support waste and trash, discarded descent stages, and any other discarded equipment.	The ability to repair, fabricate, and assemble parts and products in-situ is critical for long-duration missions, especially human Mars missions where logistic resupply will be delayed. The capability also enables growth in exploration and science with the ability to make new tools based on lessons learned, and recover from failures quicker. Taken as a whole, the ability should also be able to reduce mass launched from Earth for long-duration and sustained human presence on the Moon.	**X**		**X**			
Lunar Resource Utilization	**mLRU10**	Produce products from lunar resources that can be used for missions to other destinations, to enable and support future exploration.	Produce products from lunar resources that can be used for missions to other exploration destinations. This includes production of propellants, life support and other consumables, spare parts, and other products and materials associated with space exploration to destinations other than the Moon. To utilize the materials that are produced will also require the ability to transport, store, and transfer materials from staging locations.	Producing products from lunar resources that can be used for future exploration missions will support these missions. This reduces the amount of material that must be brought from Earth in support of missions to exploration destinations other than the Moon and reduces the effort and cost that would have been associated with transporting material from Earth to cis-lunar space. This will improve productivity (value per unit cost) associated with activities in space.	**X**					

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilizatio	Economic Expansion	Global Partnerships	Public Engagement
Lunar Resource Utilization	**mLRU11**	Produce energy from lunar and cis-lunar resources to provide Earth with another energy source.	Establish one or more alternative energy sources for Earth based on lunar resouces. Potential energy sources include Helium-3 mining for use in fusion reactors on Earth and supplying materials and components for assembly and operation of space solar power satellites in cis-lunar space and beamed power from the lunar surface.	Utilizing energy produced on the Moon can reduce Earth's reliance on fossil fuels (including petroleum, coal and natural gas) and the associated emission of greenhouse gases and other pollutants on Earth. This can improve productivity (value per unit cost) associated with activities on the lunar surface; improve the economic sustainability of lunar activities; support permanent human presence and settlement on the Moon; and reduce the cost of lunar activities. This activity may encourage investment in space infrastructures by private institutions and others to generate wealth on Earth and on the Moon.				**X**		

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	**Scientific Knowledge**	**Human Civilization**	**Economic Expansion**	**Global Partnerships**	**Public Engagement**
Historic Preservation	**mHISP1**	Create international lunar heritage sites to protect the record of early human lunar activity.	Create lunar heritage sites at important historical locations on the Moon, such as the Apollo landing sites. Ensure that these sites are preserved in a way that they can be appreciated in the future.	Man's first contact with the Moon is an important part of the global history of humankind. Designating these sites as international lunar heritage sites would protect the record of early human lunar activity and preserve our common history.				**X**		**X**
Historic Preservation	**mHISP2**	Preserve an archive of life on Earth on the Moon to safeguard mankind's biological, historical, cultural, and knowledge base against catastrophic loss.	Preserve an archive of life on Earth on the Moon. This archive could include an agricultural cultivar bank, a data back-up site, which would include historical, cultural, and other data, and other archives of life on Earth.	Having an off-site back-up of the material of terrestrial life and the data produced by it would safeguard mankind's biological, historical, cultural, and knowledge base against catastrophic loss. In the event of a catastropic planetary event on Earth, the remains of civilization could potentially reconstruct society as it was before the disaster.				**X**		
Historic Preservation	**mHISP3**	Preserve regions of the Moon in their natural state to protect them from developing lunar activities.	Preserve regions of the Moon in their natural state. Maintain regions of the Moon for future scientific, cultural, recreation, and other uses.	Preserving regions of the Moon can protect them from the growing encroachment of lunar activities. Having areas such as these, which are relatively free of contamination from lunar activities, will enable scientific investigations without confounding influences and will preserve a pure lunar environment for humans to experience and enjoy.		**X**	**X**			**X**

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Development of Lunar Commerce	**mC1**	Engage the commercial sector throughout lunar strategy development to embed them in all current and future aspects of lunar activities.	Engage the commercial sector throughout strategy development and planning, both generally and specifically for commercial involvement.	Engaging the commercial communiy in strategy development will ensure that commercial interests are considered early on in the planning phases, such that commercial activities have a place in future lunar activities. Overall, this could increase commercial sector participation in lunar activities. Having increased commercial sector participation could also promote innovative thinking in some aspects of lunar activities.	**X**		**X**	**X**		
Development of Lunar Commerce	**mC2**	Identify and enable commercial markets, based on lunar activities, to broaden the scope and value of lunar activities.	Identify commercial markets for lunar activities by developing profitable lunar products for Earth and space use. Enable markets to form around these products by identifying market demand and price points. Collaborations between industry, government, and/or academia could lead to the development of new products and markets.	Identifying, investigating, and discussing potential lunar markets may stimulte private and venture capital investment in these commercial activities. If these activities generate wealth, they will stimulate further lunar activity investment and development.				**X**		
Development of Lunar Commerce	**mC3**	Create a strategy for permanently transferring government lunar assets to private industry to enable the shift of public resources toward the next exploration destinations and enhance commercial involvement on the Moon.	Create a strategy for permanently transferring government lunar assets, such as physical facilities, associated infrastructure, and the related operational considerations (physical, logistical, legal transfer), to the private sector. As these assets are transferred, there will need to be sufficient commercial or scientific reasons for living on Moon, such that it remains an attractive destination for private firms to utilize the government assets and invest further.	Having an "exit strategy" for transfer of assets out of government control will more easily free up public resources toward the next exploration destinations. Transferring assets to the private sector creates an "entrance strategy" for commercial involvement on the Moon. If properly managed, transfer of assets could stimulate further commercial investment in lunar activities.	**X**		**X**	**X**		

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Development of Lunar Commerce	**mC4**	Engage multiple communities in developing new operating procedures to challenge the status quo of how governments do business.	Engage the commercial, enthusiast, and other non-government communities early in the process of developing standard operating procedures for exploration. Consider other business models to enhance the benefits of involvement in exploration.	Non-traditional communities could challenge the status quo of how governments do business. This process will consider multiple viewpoints in the decision-making process, hopefully developing innovative methodologies that improve efficiency.				**X**		
Development of Lunar Commerce	**mC5**	Explore new methods of collaboration between and among industry, government, and academic entities, to maximize the benefits that each can bring to each other.	Actively explore new collaboration methods among different partners in space activities. Promote creative business and collaboration approaches, such as the creation of public-private partnerships, special international industry structures, and the revival of a NACA-type model for space agencies' roles with respect to industry.	New and innovative ways of doing business may yield true partnerships in which all parties play a significan role and benefit from the others' involvement. For example, with certain public-private partnership models, private investors will be more likely to contribute, thus lowering public funding requirements, because of the cooperation of the government.				**X**	**X**	
Development of Lunar Commerce	**mC6**	Provide non-monetary government assistance to industry to enable broader commercial involvement in exploration.	Provide non-monetary government assistance to industry actors interested in pursuing lunar activities. Specific examples include governments providing "free rides" or secondary payloads on expensive launch vehicles, leasing government assets to industry for commercial use, favorable finance and insurance regulations, and pursuing expensive research and development in cooperation with industry.	Government assistance can help remove barriers of entry for industry, enabling broader private and venture capital investment in commerical exploration activities. Broder commercial involvement can create new wealth on Earth and provide programmatic stability for government space programs.				**X**		
Development of Lunar Commerce	**mC7**	Resolve legal issues associated with lunar activities to reduce the perceived risk of private sector investment in lunar activities.	Resolve, as appropriate and possible, legal issues associated with lunar activites. Specific examples of legal issues that could have a detrimental effect on industry as a whole include liability and real and intellectual property rights.	Resolving legal issues could reduce the perceived risk associated with private sector investment in exploration by clarifying the legal regime in which the private sector operates. This could encourage private and venture capital investment in these commercial exploration activities.				**X**		
Development of Lunar Commerce	**mC8**	Resolve regulatory issues associated with lunar activities to reduce the perceived risk of private sector investment in lunar activities.	Resolve regulatory issues, as appropriate and possible, associated lunar activities. Specific examples of regulatory issues include export control regulations, commercial zoning and other policies that might impede the development of commercial lunar activities.	Resolving regulatory issues could reduce the perceived risk associated with private sector investment in exploration by clarifying the regulatory regime in which the private sector operates. This could encourage private and venture capital investment in commercial exploration activities.			**X**	**X**		
Development of Lunar Commerce	**mC9**	Provide opportunities for governments to engage in long-term and alternative procurement commitments to enable the private sector to obtain investments for lunar activities.	Provide opportunities for governments to make advance purchase, long-term commitments (so-called "anchor tenancy") for future goods and services from industry. A specific example requiring anchor tenancy could be the development of large-scale infrastructure for exploration, similar to the development of the electrical-grid system on Earth. Other innovative acquisition practices (e.g. alternatives to "Cost-Plus" contracts) should be utilized and built upon.	Allowing governments to engage in long-term and/or alternative procurement commitments has the dual benefit of providing the government with goods and services at a lower cost and enabling the commercial sector by providing long-term or non-traditional contracts. This may allow the private sector to more easily obtain the venture capital necessary to initiate programs.			**X**	**X**		

Category	Objective ID Number	Name	Summary	Value	Themes Supported: Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Commercial Opportunities	**mCO1**	Utilize innovative commercial entertainment and media outlets to broadcast to the public high-bandwidth video, imagery, and other information, to generate revenue and engage the public.	Utilize innovative commercial media outlets, such as internet-based sources, cell phone broadcasts, etc. to broadcast information about lunar activities to the public. Traditional media sources such as print and television could be utilized as well. Commercial companies could advertise or run promotions centered around space activities. One idea integrating innovative entertainment is an IMAX movie based off of a fixed Earth-observing camera.	Media outlets can make money through advertising, sponsorship, and broadcast rights. Media can be used to generate public support for exploration by showing exciting things between major missions. Utilizing innovative media sources, in particular, may engage the younger segment of the population, who will be responsible for paying the taxes to support exploration for many years in the future.				**X**		**X**
Commercial Opportunities	**mCO2**	Develop interactive video games based on lunar exploration to generate revenue and engage the public.	Create age-targeted video games, aimed at the younger generation, grounded in the reality of space exploration, possibly using video and data generated by lunar activities. To make the products competitive with current video games, players must be able to interact with one another.	A company selling video games can make money through game sales and sponsorships. A popular video game could generate public support for exploration by showing people what exploration and development of the Moon could be like.				**X**		**X**
Commercial Opportunities	**mCO3**	Emplace items on the Moon that can be controlled remotely by the public on Earth to generate revenue.	Emplace a camera or a rover on the Moon that the public on Earth can operate from their home or school computers.	A company emplacing a public-access item on the Moon could make money through operation time sales and sponsorships. Allowing the public to operate the item would generate public support for exploration by allowing the public to take part directly in lunar activities and see exciting things in between major missions.				**X**		**X**
Commercial Opportunities	**mCO4**	Host entertainment events on the Moon to generate revenue.	Host entertainment events on the Moon that will generate general public interest. Ideas for events include micro-g human sports or a lunar rover race.	Lunar entertainment events can make money through advertising, ticket sales, sponsorships, and media rights. Broadcasting these events could also generate public support for exploration by showing the public exciting things between major missions.				**X**		**X**
Commercial Opportunities	**mCO5**	Sell tourist trips to the Moon to generate revenue.	Private companies can sell trips to and stays on the Moon, if individuals are willing to pay for a ticket. Provide fun recreational activities, such as lunar gymnastics, human powered flight, and other lunar sports, based around the unique lunar environment, to entertain the paying tourists.	Private companies can make money by selling tourist trips. A larger market for these trips may exist if interesting activities are provided for tourists during their stays. The public will be engaged by the idea that they too can go to space.			**X**	**X**		**X**
Commercial Opportunities	**mCO6**	Create a commercial astronaut corp to provide scientific, technical, and mission support to support lunar science and operations.	A commercial astronaut corp may consist of private individuals selected and specially-trained to perform duties on the lunar surface. A number of different contracting options could be conceived for this scenario. In one example, if a commercial firm was carrying out science objectives, they could simply sell the data or samples they return.	Having a commercial astronaut corp will reduce the amount of lunar activities government is involved in, potentially raising the overall amount of lunar activity. Transferring astronaut selection and training to the commercial sector may increase the number of individuals able to travel to the Moon by decreasing government involvement in the process. Commercial firms could take more risks, potentially performing the same tasks at a lower cost.	**X**	**X**	**X**	**X**		**X**

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Commercial Opportunities	**mCO7**	Purchase launch services to the Moon from the private sector.	Provide fast, reliable, and regularly scheduled transportation services between points in cis-lunar space. Government should work towards purchasing transportation services from the private sector as soon as they are available.	Purchasing launch services from the private sector could bolster the commercial launch industry. Commercial launches could move the industry towards lower launch costs, with cheaper access to orbit and beyond for new applications. Having multiple launch options creates launch vehicle redundancies, which mitigates risk.	X		X	X		
Commercial Opportunities	**mCO8**	Utilize the commercial sector to provide Position, Navigation, and Timing services on the Moon.	The commercial sector can provide a Position, Navigation, and Timing system (simliar to GPS or Galileo) for the Moon.	A commercial PNT sytem would provide guidance and navigation information for the Moon, while involving the commercial sector in an area with which they are already familiar and competent.			X	X		
Commercial Opportunities	**mCO9**	Utilize the commercial sector to provide information and communication services for lunar activities.	The commercial sector can provide information and communications services, such as an internet-like capabiity that can transmit and receieve of data in any form, as well as handle data securely and integrate into the terrestrial communications infrastructure.	Utilizing the commercial sector in the implementation of the lunar information and communications infrastructure could encourage commercial investment and tend toward a market and customer-driven information service which is scalable and agile to the demand. A commercial information infrastructure would involve the commercial sector in an area with which they are already familiar and competent.			X	X		
Commercial Opportunities	**mCO10**	Utilize the commercial sector to perform lunar resource utilization.	Utilize the commercial sector to perform lunar resource utilization activities, such as resource prospecting, mining, materials processing, manufacturing, construction and other services/products based on lunar resources. This includes the use of private enterprise for the performance of various activities in the vertical chain from resource-to-product. Construction services include the assembly of research settlements and other facilities and structures supporting research and commercial operation. Manufacturing higher-level capabilities through making or processing lunar raw materials into a finished product, especially by means of a large-scale industrial operation. Other services/products can include depots for transportation and life support, and power generation, storage, and delivery services.	Utilizing the commercial sector in lunar resource utilization reduces the number of activities governments are involved in and increases the participation of the commercial sector. Lunar resource utilization has value because mid- and long-term exploration and exploitation of the lunar surface will require structures and facilities that launch vehicles coming from Earth cannot carry. The provision of facilities and systems on the lunar surface that accomplish various aspects of the vertical chain from resource-to-product will greatly reduce the mass of materials and products that must be brought from Earth. Lunar resource utilization improves productivity (value per unit cost) associated with activities on the lunar surface and elsewhere in space where lunar resources are applied.			X	X		

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Commercial Opportunities	**mCO11**	Utilize the commercial sector and the public to design and execute an "open-source" mission, to engage these groups directly in lunar exploration.	Allow the commercial sector and the public to contribute directy and individually to mission design through an open-source architecture. An open-source architecture means that anyone can access system designs and improve them directly. See Red Hat and Linux as examples.	An open source mission would allow the public and commercial entities to become directly involved with mission operations without going through government bureaucracy. Open source missions have the potential to decrease costs, improve cycle times, and generate a higher quality product.				**X**		**X**
Commercial Opportunities	**mCO12**	Develop materials on the Moon to sell on the Moon and on Earth.	Take advantage of the unique lunar environment to develop and manufacture new materials. Sell these materials to support lunar activities and for Earth applications.	Commercial firms who develop new materials coulc make money by selling the product. This activity has additional value if it produces new materials.		**X**	**X**	**X**		
Commercial Opportunities	**mCO13**	Produce and sell power and propellant based on lunar resources.	Create power and propulsion based on lunar resources. Power and propulsion could come from mining of regolith, manufacturing of solar cells, or other sources. Sell the product for a variety of uses -- on the Moon, in cis-lunar space, in deep-space, and on Earth. An infrastructure will be required for power distribution.	Commercial firms that can produce and sell power and propellant based on lunar resources could create a new energy market based on the Moon. For specific applications, lunar resource-produced products can provide power for use on the Moon, allow satellites in LEO/GEO to be more easily refueled, enable further deep-space destinations for scientific hardware, and provide power for Earth use. This activity is ideal for the commercial sector because there could be a viable market that exists for these products.	**X**	**X**	**X**	**X**		
Commercial Opportunities	**mCO14**	Provide waste removal, recycling, and reuse services to maintain a clean lunar environment.	Remove, recycle, and reuse biological and mechanical waste generated from cis-lunar and lunar activities. Commercial waste manegement firms could provide these services.	The value of any lunar activity will be degraded by the presence of biological and mechanical pollution and waste. The outcome of any activity will be enhanced if the environment can be kept as pristine as possible.	**X**		**X**	**X**		

This spreadsheet represents the varied views of the many people and organizations with whom NASA has consulted individually over the past year. The information represented here is an important resource to the United States Government as we move forward to develop a strategy of lunar exploration, and, we hope, to other interested stakeholders. This information does not reflect United States Government support for particular objectives at this time. Nor does it reflect that domestic legislation and international agreements would be necessary to carry out many of the objectives. NASA looks forward to continuing to work with a wide group of stakeholders as the global community further develops these objectives.

Category	Objective ID Number	Name	Summary	Value	Themes Supported: Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Global Partnership	**mGP1**	Establish a global partnership framework to enable all interested parties (including non-space faring nations and private companies) to participate in lunar exploration.	A global framework, able to encompass both commercial and governmental involvement, should be established to coordinte the lunar activities of all interested parties. This framework should allow for (but may not require) coordination of roadmaps and missions, sharing of data, infrastructure and facilities, while maintaining autonomy (if desired) of participants.	A global partnership framework could enable increased participation in exploration, including government-government, government-commercial, and commercial-commercial coordination. Having an international cooperative framework could promote efficient and cost effective exploration that is stable over the long run, while promoting international peace. Fostering collaboration has the potential to increase the amount of lunar activity by increasing the total amount of financial and human resources available to the endeavor and increasing the level of public support. Finally, by allowing participants to maintain their autonomy within the overall program, each participant can establish their own goals, as best suit the needs of their stakeholders.	X	X	X		X	
Global Partnership	**mGP2**	Establish standards and common interface designs to enable interoperability of systems developed by a global community.	Use existing standards and establish new standards for information (such as data and communication), equipment, and interfaces. Standards should enable systems produced by different parties to be interoperable.	Standards and common interfaces will enable lunar stakeholders to share data, infrastructure and consumables, thereby enhancing the affordability, sustainability, and safety of lunar surface activities. Standardization will also allow suppliers to compete across emerging space commerce markets. One of the potential impacts to establishing standards is that it increases the barriers to entry for some participants.	X		X		X	
Global Partnership	**mGP3**	Establish a set of export control laws and regulations that will enhance effective global cooperation on lunar activities.	Review and amend national export control laws and regulations, as necessary and as possible, to allow for timely, flexible, and sustainable cooperation between nations conducting lunar activitites.	Export control laws and regulations that minimize barriers to cooperation on lunar activities can maximize the overall effectiveness of lunar exploration by enhancing, among other things, further sharing of financial, personnel, and technical resources.	X		X		X	
Global Partnership	**mGP4**	As necessary, establish appropriate legal mechanisms for lunar surface and orbital activities to enable commercial and governmental involvement.	Given the framework of the Outer Space Treaty, establish legal mechanisms to govern elements of lunar activity. Areas these mechanisms should cover include the possibility of zoning, terrestrial leasehold, easement, and tenant law to settle access, land use, and resource disputes; liability provisions to address personal injury and property damage, in a manner allowing the insurance industry to manage risk sustainability; clarifying intellectual property rights; and ensuring environmental protection of the Moon. These legal mechanisms could be an internationally agreed-upon "Rules of the Road," with or without some body to administer and govern elements of lunar activities.	Establishing appropriate lunar legal mechanisms before undertaking extensive activities on the Moon can prevent future disputes and damage, while encouraging greater activity. Broadly accepted legal mechanisms could protect the interests of all public and private participants and encourage investment in lunar activities by clarifying the legal environment in which participants operate.			X	X	X	

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Public Engagement & Inspiration	**mEOR1**	Provide education, communication, engagement, and outreach activities to assist in building general knowledge of, and ultimately support for, lunar exploration activities.	An integrated, long-range strategy to guide the space community's activities in education, communication, engagement and outreach will promote substantive understanding, increase working knowledge, foster dialogue and "ownership," and inspire the next generations of citizens to continue their support for lunar exploration.	The lunar exploration program will depend on at least two new generations of citizens and taxpayers to understand and support exploration activities. An integrated long-range strategy will build new support bases, and increase the existing base, while providing high quality education, communication, engagement, and outreach products to the public. Education and engagement will profit from integrated planning that will reduce programmatic outlays while maximizing oppportunities.						X
Public Engagement & Inspiration	**mEOR1.1**	Provide opportunities for the public to watch surface operations via video broadcast, to engage the public in lunar activities.	Provide opportunities for the public to watch surface operations. Video could be taken of many different lunar locations and activities, including landing sites, construction activities, and any other dynamic activity that may be of interest to the public. This objective could be implemented by having a space agency pay for a small micro-rover to film around interesting activities, while enabling a media source to utilize the film for public engagement purposes.	Providing opportunities for the public to watch surface operations will engage them in dynamic lunar activities that they will most likely be interested in. Broadcasting day to day operations could yield broad interest and intimate knowledge of exploration operations.				X		X
Public Engagement & Inspiration	**mEOR1.2**	Provide opportunities for the public to watch the human side of crew activities, to engage the public in lunar activities.	Provide opportunities for the public to follow the human side of crew activities on the Moon. This could involve putting cameras at various places inside the habitable environment. Acess can be controlled so as not to be too intrusive to daily crew lives.	Providing opportunities for the public to follow the human side of crew activities on the Moon will engage them in human and emotional stories related to lunar activities. The public is likely to become more engaged because of the humanization of the crews. Having a media entity capture and distribute the video could improve its distribution because the media is in the business of reaching the public.				X		X
Public Engagement & Inspiration	**mEOR1.3**	Provide opportunities for the public to operate equipment that is either part of the lunar mission, or simply emplaced for public outreach, to engage the public in lunar activities.	Create opportunities for direct public manipulation of small technologies on the lunar surface. Initially, public interaction can be achieved via a simple camera that is keyed to filter, buffer, and process internet inputs. As time goes on, the system can become more sophisticated to provide more opportunities to interact. Later, this can include the public being able to remotely command repetitive tasks that a participating crew member would need to do anyway, with protection mechanisms in place to ensure that the crew's needs are met. Students should be given special access to these activities.	Members of the public who will not have the opportunity to travel to the Moon will be able to participate directly in a lunar mission. Active involvement allows better public response, awareness, and support for the lunar activities.						X
Public Engagement & Inspiration	**mEOR1.4**	Provide opportunities for two-way interaction with people on the Moon, to engage the public in lunar activities.	Provide opportunities for the public, in particular students, to communicate with crews via electronic means and/or verbal interactions such as live interviews. Crews should be able to respond to selected messages from students and the general public. Wide distribution of the crew response will ensure maximum benefit.	Providing opportunities for the public to communicate with crews will provide a two-way interaction with the people on the Moon. Similar past activities have been successful at engaging the public. The additional value of communication with students supports educational objectives.						X

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Public Engagement & Inspiration	**mEOR1.5**	Distribute current space-related media content to new media outlets to engage the younger generation in space exploration.	Distribute highly engaging, "bite sized" space-related media to new media outlets. Provide web content, animations, and short video clips to internet sites such as Google Video, YouTube, Atom Films, and Shockwave.com.	Distributing space content to new media outlets will expose the younger generation to space exploration in venues they already visit. Engaging content can communicate that space exploration is interesting, engaging, end exciting. In particular, convey this message to the next generation of taxpayers so that they will support future exploration initiatives.						**X**
Public Engagement & Inspiration	**mEOR1.6**	Allocate space on government missions for outside payloads, selected to engage the public.	Allocate space on government missions for outside payloads. Solicit ideas for every mission so that a much broader thinking pool can be touched when looking for public engagement activities.	Including non-governmental public engagement payloads will increase the amount of public engagement that occurs as part of lunar exploration. By periodically soliciting ideas from a much larger community, more innovative ideas may arise to benefit broad segments of the public.				**X**		**X**
Public Engagement & Inspiration	**mEOR2**	Provide opportunities to educate students through direct and indirect participation in lunar activities, to engage students in the space program.	Engage students directly and indirectly in a variety of lunar activities. Initial activities can be simply developing an educational curricula focused on the Moon. Later activities will have students based on Earth but participating in an activity on the Moon - such as teleoperation of a rover or designing a science experiment to be conducted on the Moon. Over time, these activities will move toward direct student engagement in lunar activities, such as a Lunar Institute, based on the Moon, that would allow selected students and teachers to travel to and learn on the Moon.	Participation in lunar activities will engage students more fully in the space program. The opportunity to work directly with systems and crews living and working on the Moon will provide excitement that Earth-based curricula cannot match. Exciting and engaging these students will improve overall public support for the space program and motivate students to pursue science and technology fields in their education.						**X**
Public Engagement & Inspiration	**mEOR2.1**	Allocate time for crews to teach about lunar activities, to educate students.	Allocate time for crews to create and/or teach lessons about recent and ongoing daily activities on the Moon, from a scientific, engineering, or operational perspective. Either train astronauts to be educators, or fly educators and have them teach.	Having crews teach lessons directly from the Moon can educate students in a more exciting manner than Earth-based curricula. This activity capitalizes on prior programs that flew teachers on the US Shuttle and International Space Station.						**X**
Public Engagement & Inspiration	**mEOR2.2**	Allocate space on missions for university-built payloads, to engage students directly with exploration activities.	Allocate space on missions for university-built payloads. Create opportunities for students to conceive, develop, implement, and operate space systems that will be carried to the Moon.	Allowing university-built payloads to fly to the Moon will engage students directly in lunar activities. By focusing at the college level, the students participating in these projects will have the opportunity to gain useful real-life experience in designing and building space systems. Students who are engaged in this activity may become more interested in space, and thus pursue careers in the space sector.						**X**
Public Engagement & Inspiration	**mEOR3**	Extend awareness of space activities to diverse, non-traditional communities, utilizing non-traditional means, to enhance public engagement.	Extend awareness of space activities to non-traditional communities that are rarely reached directly by the space program. Involve musicians, artists, poets, story tellers, etc. in public outreach about space to try and reach the general public in a new way. Non-traditional methods have proved effective in formal and informal education settings as well.	Extending outreach to non-traditional communities using diverse methods may reach and engage a segment of the population not touched by traditional education and public outreach activities. Engagement activities could eventually expand the workforce by demonstrating the excitement of and reasons for space exploration to diverse communities.						**X**

Category	Objective ID Number	Name	Summary	Value	Themes Supported					
					Exploration Preparation	Scientific Knowledge	Human Civilization	Economic Expansion	Global Partnerships	Public Engagement
Public Engagement & Inspiration	**mEOR3.1**	Allocate time in the crew schedule to tell the daily lunar story to the world audience.	Allocate crew time to tell the daily lunar story to the public. Crews can convey the message verbally, via video or audio broadcasts, or in written form, via internet blogs or regular newspaper columns. Allow crews to be expressive, and to convey the emotional and human sides of the story as well. Crews could should be trained as storytellers and writers so as to present a more engaging story to the public.	Providing opportunities for crews to convey the daily lunar activites to the public in a storytelling manner, much like a diary of not just accomplishments, but emotions and opinions as well, will provide opportunities for very human identification between the public and the crew. Using new media sources, such as internet blogs, crews may reach a set of the population not touched by traditional education and public outreach activities.						**X**
Public Engagement & Inspiration	**mEOR4**	Demonstrate the value of lunar activities for Earth to increase support for lunar exploration.	Demonstrate the value of lunar activities by developing a coherent and compelling (and truthful) "story" about how activities on the Moon can provide benefits to Earth. This story may be framed and delivered differently to reach different stakeholders, so as to have the most impact on each. This story should clearly answer all of the questions as to why we are going to the Moon.	Demonstrating the value of lunar activities to the general public could generate support for exploration. People must hear, in a language they can understand, the value to these activities.						**X**
Public Engagement & Inspiration	**mEOR5**	Encourage public discourse about the rationale for and objectives of lunar exploration, to better craft policies and plans that will be supported by the public.	Invite public comment and opinion on exploration to hear the many different views with respect to exploration and the need for it, especially as it competes for public resources. Good knowledge of all the views, both for and against, can be used toward forming exploration policy that will satisfy a broader segment of the public.	Gathering and utilizing public input can help craft policies and plans that are more likely to be supported by the public. Public support for exploration is critical in maintaining political support for it in the long term.	**X**	**X**	**X**	**X**	**X**	**X**
Public Engagement & Inspiration	**mEOR6**	Carry out a mission for pure public engagement to generate public excitement about exploration.	Carry out a mission for pure public engagement. An idea for a small mission would be to send a small commercial payload to the Moon that will yield something of entertainment value (i.e. photographs or videos) that can be broadcast to the public. An idea for a medium-sized mission would be to emplace something on the Moon that could be seen from Earth by the naked eye. An idea for a larger mission would be to send a celebrity to the Moon and create a documentary to show their experience. Utilize advertising and sponsorship revenues to fund the mission.	A mission with the goal of pure public engagement could generate public support for exploration by showing exciting things between major missions. A mission funded privately could generate revenues through advertising and sponsorship opportunities.				**X**		**X**
Public Engagement & Inspiration	**mEOR7**	Engage non-governmental entities to provide resources and develop hardware and elements to support public engagement objectives.	Participating space agencies should actively engage the outside community to provide mission support and funding for the objectives that support public education, communication, engagement, and outreach.	Engaging the outside communinty allows participating space agencies to fundshare more of the lunar objectives. An additional benefit is that by engaging a broader group in public engagement, more innovative ideas will emerge, and the public will begin to see space exploration as an activity that is not purely government funded.				**X**		**X**
Public Engagement & Inspiration	**mEOR8**	Utilize existing pro-space and student organizations to galvanize public support about exploration.	Utilize exisisting grassroots pro-space organizations (clubs, student orginzations, etc.) to carry public engagement messages to the public. Support pro-space events, such as an "Armstrong Night," similar to existing events like "Yuri's Night."	Leverage existing organizations to access new communities of space enthusiasts, to communicate the exploration objectives and excite a broader spectrum of the population.						**X**