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NASA Centennial Challenge

Night Rover Challenge: Final Public Comment Rules

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SECTION 1: OVERVIEW

The objective of the Night Rover Challenge is to foster innovations in energy storage technology. Specifically, this challenge asks teams to create an energy storage system that can provide the power required for a lunar rover to remain continuously operational throughout multiple lunar cycles (one cycle = 29.5 days = 708 hours) meeting system requirements and a power profile provided by NASA.

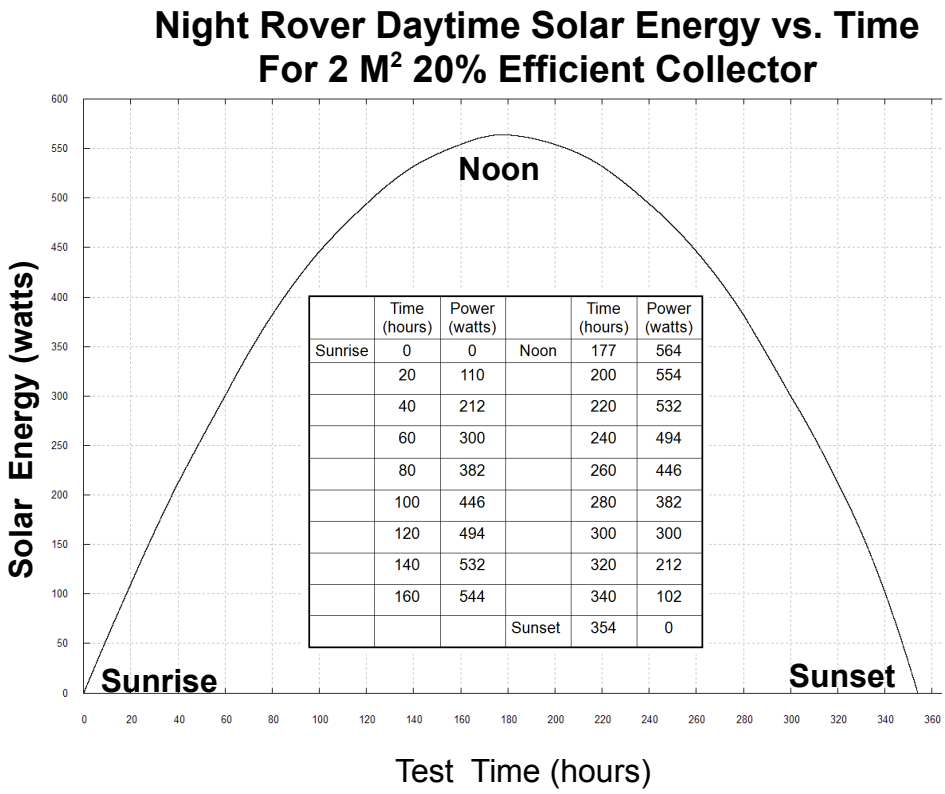
Phase I Trials of the Night Rover Challenge will be conducted at ambient temperature and pressure conditions. Rules and requirements for Phase I are detailed in this document.

Phase 1 competition awards will be provided to the teams that meet the minimum system requirements and score the highest based on the judging rubric listed in section 8. The final interpretation of all rules is at the discretion of the Technical Committee. All amendments to the rules will be posted for public comment at least two weeks prior to being finalized.

NASA plans to conduct Phase II Trials at lunar thermal and pressure conditions, after successful demonstration of an energy storage system meeting the Phase I Trial requirements. Initial plans for the Phase 2 competition are included in Appendix A for informational purposes only. Complete rules and registration requirements for Phase II will be released at a later date.

SECTION 2: DEFINITIONS & ASSUMPTIONS

1. Lunar Night = 354 hours
2. Lunar Day = 354 hours
3. Lunar Cycle = Lunar Day + Lunar Night = 708 hours
4. Simulated Solar Panel Efficiency = 20%
5. Simulated Solar Panel Area = 2 square meters
6. Simulated Solar Panel Operating Voltage = 15VDC (the input voltage to the energy storage system, based on Mars Rover designs) +/- 0.1VDC.
7. Simulated Rover Operating Voltages = 15VDC (the output voltage from the energy storage system, based on Mars Rover designs) +/- 0.1VDC.
8. Energy Storage System (ESS) = all parts, pieces, and components necessary to successfully and safely store energy from the simulated solar panels and deliver power to the simulated rover operations breakout box. Components included in the Energy Storage System begin with and include the pigtail connector to the power supply and end with and include the pigtail connector to the breakout box creating the power draw. This includes a Cat 5 Ethernet Connector for health/status monitoring as described in Section 6. This also includes all components contained within an imaginary box meeting the volume requirement in Section 3.2.
9. ESS Setting and Mounts = Mounts of test units shall be accomplished by a four-leg bolt-down using angle iron to be defined by the team and facility managers. Mounts will not be included in the system weight.
10. Solar Energy Profile = the amount of energy provided to the energy storage system from the simulated solar panel power for charging the energy storage system. This is zero watts during the lunar night and variable during the lunar day based on the sun angle (time of day). The rules are based upon a 20% efficiency of the simulated 2 square meter area solar panels creating a solar energy profile during the daytime following the graph below (nighttime solar energy is always equal to zero):

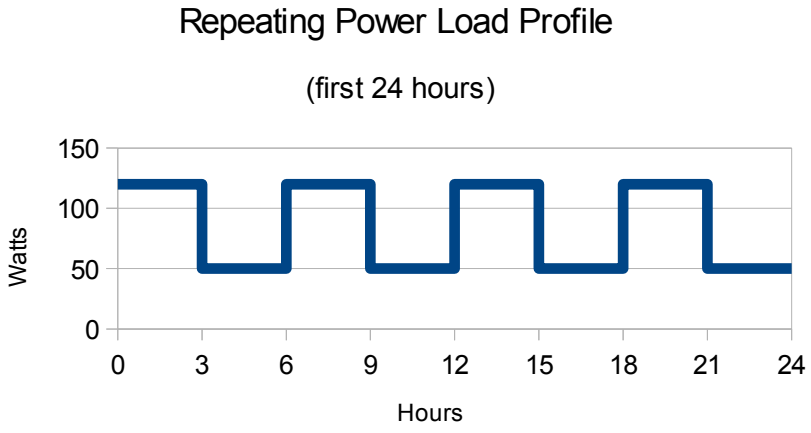


	Time (hours)	Power (watts)		Time (hours)	Power (watts)
Sunrise	0	0	Noon	177	564
	20	110		200	554
	40	212		220	532
	60	300		240	494
	80	382		260	446
	100	446		280	382
	120	494		300	300
	140	532		320	212
	160	544		340	102
			Sunset	354	0

11. Power Load Profile = a variable power draw will be required over the course of the competition trials to simulate the different operational modes of a lunar rover. This power profile will follow a 6 hour repeating cycle averaging 85W throughout the lunar day and night:

    3 hours @ 120 watts = 360 watt-hr Communications and Roving

    3 hours @ 50 watts = 150 watt-hr Communications and Science



    Teams should note that this power profile does NOT include any power loss due to inefficiencies in their system, or power required for thermal control of their system. The Power load must be delivered as an output to the competition measurement sensors.

12. All electrical components including the storage and energy management system are to be electrically isolated or floating from its support frame.

SECTION 3: ENERGY STORAGE SYSTEM

3.1 Disallowed Technologies - Since a primary goal of this competition is to develop processes and technologies that could be implemented in a lunar environment, the energy storage system shall not employ fundamental physical processes, technologies, gases, fluids, or consumables that would not function in the lunar environment. Any teams using physical processes requiring Earth-like conditions must provide to the judges their own corroborated evidence that they have a self-contained system that could be operated in a lunar environment. Specifically disallowed technologies include anything that cannot be self-contained to operate in the lunar environment including:

1. Sensors that rely on the earth's magnetic field
2. Ultrasonic or other sound-based sensors
3. Earth-based or earth orbit-based radio aids
4. Open circuit pneumatics
5. Air-breathing systems
6. Class 1, 3, 4, 5, 6, or 7 hazardous materials are prohibited.
7. Components that outgas at > 0.2 standard liters per minute (SLPM). If the system outgases at higher rates than this, they will be disqualified.
8. All nuclear energy storage systems are not allowed.

3.2 Energy Storage System Requirements

1. Must have a mass of no more than 100.0 kilograms.
2. Must have a volume of no more than 1.0 cubic meter, with a maximum of 2.0 meter length in any direction.
3. Must provide a 6 foot cable pigtail input connector to receive power from the simulated solar panels meeting the voltage listed in Section 2.
4. Must provide a 6 foot cable pigtail output connector to allow for connection of the Power load breakout box provided by the Night Rover management.
5. Must provide a Cat 5 Ethernet connector for health status monitoring.
6. Must provide thermocouple pigtails (type T) to interface to the facility monitoring system for any safety required temperature, and 1/4 inch Swagelock VCR (or equivalent) fitting for any safety required measurement. The facility will provide necessary transducers. Additional specified connectors will be defined individually with each team through review of the registration packet.
7. Must provide appropriately sized Swagelock VCR (or equivalent) vent connections if system will outgas into the test facility. Required connections will be defined through review of the team's registration packet.
8. Must be independently weighable according to requirements in Section 2.
9. Must not use any disallowed technologies listed above in 3.1
10. Must comply with all safety requirements listed in Section 6.

SECTION 4: POWER SUPPLY & LOAD

4.1 Power Supply – The power supply will simulate a 2 square meter solar panel at 20% efficiency as stated in Section 2 #11. The power will be provided to the energy storage system using the simulated solar panel operating voltage specified in Section 2 #6. The system will be connected to the power supply through a 6 foot cable with a pigtail connection to the facility.

4.2 Power Load – The energy storage system will be subject to a variable Power Load as defined in Section 2 #11. The energy storage system must deliver the power at the voltage specified in Section 2 #7. The system will be connected to the power load through a 6 foot cable with a pigtail connection to the facility.

SECTION 5: COMPETITION TRIALS

5.1 Overview

The Phase 1 Competition Trials will be run over two lunar cycles (708 hours or 29.5 days per cycle) at ambient temperature and pressure of the competition facility. An additional Phase 2 Competition will be conducted at a future, yet to be determined date to test how well energy storage systems could operate in lunar environmental conditions (low temperature and low pressure). Details of the Phase 2 competition will be provided at a later date.

5.2 Facilities

Competition trials will be conducted at NASA's Glenn Research Center (GRC) Plumbrook Station located in Sandusky, Ohio. All systems must be delivered to the Plumbrook Station. Eligible systems will be housed in one, access controlled testing facility at Plumbrook Station. The facility will provide additional safety barriers or equipment to protect each team's storage system, personnel, and the facility itself, from damage due to failure of any system throughout the trial. However, the team will be required to provide the safety equipment identified and agreed upon in the accepted registration packet.

5.3 Pre-trial Compliance Review

The Technical Committee will conduct a final compliance review prior to the start of the trials. All systems must be judged favorably in this compliance review to be eligible to compete in the trial.

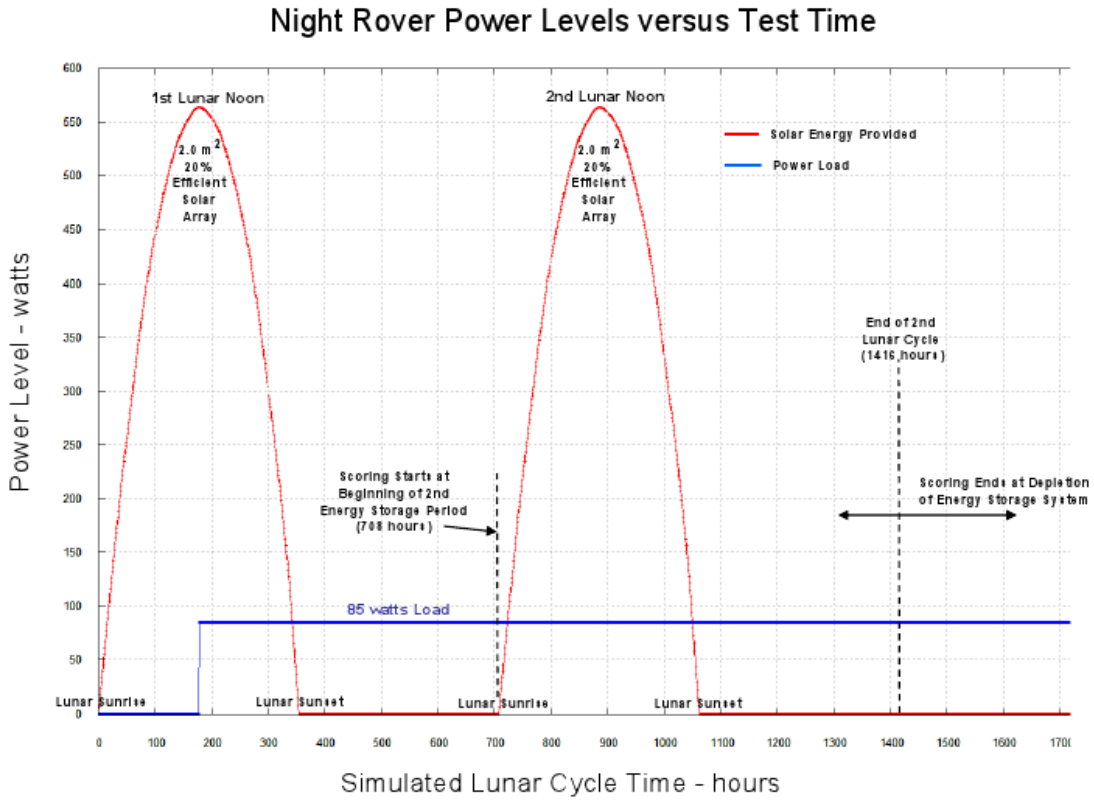
Technical Committee members will work with the team members to verify compliance to the rules and that all safety procedures noted in the teams Registration Packet have been followed. Each team is responsible for handling their energy storage system at all times during the setup of the trials. The NRC management and Glenn Research Center staff will only interact with the system to install it in the test facility and make necessary measurements. The team is responsible for ensuring that all systems are properly connected.

To be eligible to compete in the trial, teams must receive a favorable review on the following items prior to beginning the trial:

1. Registration Packet: teams must have completed all registration materials listed in Section 7, and received a favorable review on the registration packet from the Technical Committee. Teams must have all safety materials and personnel described in their registration packet present at Plumbrook station and be available to setup their system at the start of the trial. Any changes to the documents must be provided to and accepted by the Technical Committee in advance of the Trials. Teams may be disqualified if any materials, safety equipment, or personnel described in their accepted registration packet are not present for the trial setup. Additional team members not required for the trials are allowed, but must be included and specified as such in the registration packet.
2. Criteria Validation: teams will have their energy storage system evaluated by the Technical Committee to ensure compliance with all requirements including materials used, mass restrictions, volume restrictions, physical dimensions, and use of restricted technologies. Teams will be disqualified if any restrictions from the conditions provided in these rules are broken.
3. Participation: teams must have at least 1 member present at the start of the trial to ensure proper connection to the power supply and power draw systems.

5.4 Phase 1 Competition Trial Procedures

1. Teams must deliver their energy storage system, and all required safety equipment to the trial location at least 4 days prior to the start date of the trial (T-4). (Shipping & delivery details will be provided to the team upon being accepted into the trials.)
2. The day following the delivery of the energy storage systems (T-3) the Technical Committee (TC) will host a joint orientation session for all teams. Following the orientation, TC members will begin testing energy storage systems for their compliance review. During the compliance review, all systems will be weighed and check for safety systems as noted in the teams registration packet. After each team's system has been reviewed, the TC members will accompany the team in connecting their system to the power supply and draw.
3. After all teams have been connected to the power supply and draw by a team member, the trial facility will conduct a test run of all systems (T-2). During this test run teams will assess the performance of their system and upon completion of the test, teams will be able to adjust their system to ensure proper connections and monitoring sensors are operational. This test run will include:
   (a) a 6 hour charge at lunar noon conditions,
   (b) a 6 hour load period following the power load profile outlined in Section 2.
   (c) a one and a half day review and update period for teams to adjust their systems.
4. After the test run and system adjustments, systems shall be discharged to a minimum operating condition of 15V and 3.3A. All systems will then be considered in impound with no further team access allowed (T-1).



The figure above notes the trial period from T+0 until the end of the two lunar cycles (T+60)

5. At the start of the trial (T+0), power supplies and power draws to all energy storage systems will be turned on at the same time. The trial will begin at lunar sunrise and conclude at the end of the second lunar night. The power load profile will begin at the first lunar noon so that the first lunar period of daytime (sunrise to noon) will be used to charge the systems with no power load. At the first lunar noon, the power draw profile will begin.
6. After the trial has begun systems will be monitored remotely via the Internet. Monitoring will be conducted and logged by the Night Rover Judging panel, but will also be available to each team through the NRC website. The information made available to the public will include the input current/voltage provided to each system and the delivered output power provided from the systems.
7. At the end of the trial (T+60), the energy storage systems will be discharged to full depletion, i.e. to the point where the system can no longer meet the power demand outlined in Section 2 for the Lunar Night. This full depletion discharge shall establish the total energy content of the system. The total energy content is measured from the beginning of the second lunar cycle, to the point of full depletion and this shall be the value used in assessing the specific energy (Watt-hr/kg) of the system for the prize tiers as well as the total energy content of the system for judging purposes in the weighted

scoring criteria of Section 8: Judging. At the completion of this discharge, all power supplies and draws will be shut down, and teams will be allowed to enter the impound area.

8. For the purpose of this competition, the total energy capacity will be considered complete at the point where the system can no longer provide the power profile.
9. Following the closing of the trial (T+60), the Technical Committee will review total energy outputs and host a recognition ceremony to announce Phase 1 results.
10. Teams must return to the Plumbrook Station a minimum of 1 day before the recognition ceremony to support the removal of their systems and prepare for the ceremony.

5.6 Failures and Petitions to Resume Trials

Once the trial has begun, the teams will not be able to interact with their system in any way, or restart the trial for any reason. If a unit fails, it will be isolated individually from the power sources and loads providing no other units were damaged due to the failure. If other units were compromised as a result of the failure from another unit, then the trial would be suspended to allow for inspection and repairs. The Night Rover Challenge management would then determine when the trial is to be restarted. The Night Rover Challenge management will work with teams to ensure that all materials are properly setup prior to the challenge, but it is the teams' responsibility to ensure their system is ready for operations.

SECTION 6: SAFETY

Each team will undergo two safety reviews to be eligible for the competition trials (registration review, and final compliance review). To receive favorable reviews, the team must provide safety procedures and hazards analysis with mitigations and countermeasures for the setup, operation and removal of their energy storage system including the power supply and power draw connections.

6.1 Registration Review

Teams must complete a registration packet as defined below in Section 7. The Technical Committee will review this registration packet to see that appropriate safety measures are included in their trial procedures. This packet must be submitted before the final registration deadline cited in Section 9.

6.2 Compliance Review

Prior to the trial, each team will review their system and procedures with the Technical Committee as outlined in the trial procedures in Section 5. Teams must demonstrate all safety procedures and equipment to protect team members and judges, and shield other energy storage systems from harm during the duration of the trials. Safety procedures must include appropriate sensors to monitor the system to see if it is approaching a dangerous failure state. Any applicable systems must include overcharge and discharge protection.

6.3 Trial Safety

In the event that there is a failure of a system that could endanger other energy storage systems (such as extreme overheating), the managers at Plumbrook Station will shut down that system. In the team's Registration Packet, the team and Technical Committee will agree upon critical shutdown conditions.

Safety and system status monitors will be implemented with remote access capabilities via Cat 5 Ethernet connection as outlined in Section 3. Additional Safety requirements include:

1. The teams shall develop and provide a hazards analysis to define power supply and draw unit hazards as well as mitigations and countermeasures for these hazards. The teams shall also provide hardware that will safeguard the unit from damaging other units or personnel in the event of a catastrophic failure.
2. The test facility will provide electrical isolation switches and fusing that will isolate the power supply and draw in case of over current or hazardous conditions.
3. The facility shall monitor the charge and discharge cycles and provide equipment and loads to conduct this monitoring effort.
4. The facility will provide a server for test team remote access of the recorded charge and discharge data.
5. The facility will provide a Cat 5 connector to provide access to the team's health monitor equipment.

SECTION 7: REGISTRATION REQUIREMENTS

To be eligible for the competition trials and final awards, each team must complete the following:

1. Sign, and submit the Team Agreement by the registration deadline.
2. Submit the registration fee by the registration deadline ($3000 early registration, $5000 regular registration).
3. Complete, sign, and submit the Registration Packet including:
    a. Energy Storage System description – explain (1) the general storage system operations including all physical processes, (2) expected storage capabilities, and (3) a Material Safety Data Sheet for all materials including the physical description of all materials used, their expected mass, volume, and dimensions.
    b. Safety Procedures for ambient temperature prototype trial – explain any possible safety concerns and procedures used to mitigate them. Safety procedures must include hazards analysis with mitigations and countermeasures, safety for all individuals who interact with the energy storage system as well as protecting any other energy storage systems from harm caused by the team's system. The team must include documentation for access and status interpretation of data your system will provide.

Registration Packet reviews will be completed within one month of being submitted. If the team is not given a favorable judgment by the review committee, the team will be able to revise and resubmit the packet anytime before the registration deadline. Teams shall not receive a favorable review if the Technical Committee does not have adequate information on the operations of the system, or safety procedures. After the final registration deadline, no further requests to participate will be allowed.

SECTION 8: JUDGING

Teams will be judged on a combination of technical metrics including system mass, volume, and total energy content. Teams must sustain the energy draw required to meet the power profiles listed in Section 2 throughout the trial to be eligible for an award. The teams meeting these criteria with the highest scores based on the rubric below will be the winners of the awards.

Criteria Weighting:

Criteria	Range	Normalized Range
Total Energy Storage System Mass	100.0 to 0 kg	0 to 60
Total Energy Storage System Volume	1.0 to 0 cubic meter	0 to 20
Total Energy Content	30,000.0 to 50,000.0 Watt-hrs	0 to 20

In other words:

1. Total Energy Storage System Mass: for each 5.0kg below 100.0kg, the team receives 3points.
2. Total Energy Storage System Volume: for each 0.05 cubic meters below 1.00 cubic meter the team receives 1 point
3. Total Energy Content: for each 1,000.0 Watt-hrs above 30,000.0 total Watt-hrs, the team receives 1 point up to a maximum of 20 points.

Normalized score equivalents:

- System Mass:
  - 100.0 kg = 0 points
  - 79.9 – 75.0 kg = 15 points
  - 54.9 – 50.0 kg = 30 points
  - 29.9 – 25.0 kg = 45 points
  - 4.9 – 0.0 kg = 60 points
- System Volume:
  - 1.00 cubic meter = 0 points
  - .799 – 0.75 cubic meters = 5 points
  - .549 – 0.50 cubic meters = 10 points
  - .299 – 0.25 cubic meters = 15 points

- 0.0 cubic meters = 20 points

- Total Energy Content
  - 30,000 Wh = 0 points
  - >35,000.0 Wh = 5 points
  - >40,000.0 Wh = 10 points
  - >45,000.0 Wh = 15 points
  - >50,000.0 Wh = 20 points

Example 1:

A 420 Watt-hr/kg energy storage system that has energy content of 42,000 Wh, a weight of 100 kg, and a volume of 1 cubic meter, the following score would result:

Normalized Mass = 0

Normalized Volume = 0

Normalized Energy Content = 12

Final Score = 0 + 0 + 12 = 12

Example 2:

A 1000 Watt-hr/kg energy storage system that has a total energy content of 50,000 wh, a weight of 50kg, and a volume of 0.5 cubic meters, the following score would result:

Normalized Mass = 30

Normalized Volume = 10

Normalized Energy Content = 20

Final Score = 30 + 10 + 20 = 60

Tie Breaking of Equal Final Scores:

In the event two or more teams have the same highest final score based on the weighted scoring equation, the winner will be the team with the lowest mass. In the event they have equal mass, the winner will be the team with the smallest volume. In the event that teams have equal weight and volume, the team with the highest energy content will be the winner.

SECTION 9: TIMELINE

1.	Final Rules Released	Month 1 (February 2013)
2.	Registration Opens	Month 2 (March 2013)
3.	Early Registration Closes	Month 7 (Midnight PST, July 26, 2013)
4.	Regular Registration Closes	Month 10 (Midnight PST, October 25, 2013)
5.	Final List of Competing Teams Announced	Month 12 (December 1, 2013)
6.	Energy Systems Delivered to Phase 1 Trials	Month 13 (January 20, 2014) (T-4)
7.	Compliance Reviews & Team Workshops	Month 13 (January 21, 2014) (T-3)
8.	Trial Test Run	Month 13 (January 22, 2014 (T-2)
9.	System Adjustments	Month 13 (January 23-24, 2014 (T-1 to T+0)
10.	Trial Begins	Month 13 (January 24 evening, 2014) (T+0)
11.	Trial Concludes	Month 15 (March 24, 2014) (T+60)
12.	Energy System Draw Down Begins	Month 15 (March 24, 2014)
13.	Judges Review & Recognition Ceremony	Month 16 (April 4, 2014)
14.	Cleantech Open Global Recognition Ceremony	Month 23 (Nov 2014)

SECTION 10: ELIGIBILITY, AWARDS & DISQUALIFICATION

10.1 Eligibility to Compete

Team eligibility requirements are described in the Team Agreement. If teams meet the eligibility requirements in the Team Agreement, they must also complete these milestones to participate in the competition trials:

1. Receive a favorable review on the registration packet.
2. Receive a favorable review on the compliance review prior to the trial.

10.2 Awards

1. All awards will be announced at the ceremony following the trial. Teams must have at least one member (or a designated representative) attend the award ceremony to receive the award.
2. Phase 1 Competition Awards: three levels of awards will be possible*:

   Level 1: greater than 300 Watt-hr/kg - (1st place $500K; 2nd place $100K; 3rd place $50K)**

   Level 2: greater than 400 Watt-hr/kg - (1st place $750K; 2nd place $200K; 3rd place $100K)

   Level 3: greater than 500 Watt-hr/kg - (1st place $1,000K; 2nd place $300K; 3rd place $200K)

* The Levels for awards' specific energy (Watt-hr/kg) thresholds are rounded to the nearest hundred and intended to establish the prize tier range only. The energy storage system MUST provide enough energy to meet the required power draw profile throughout all required lunar cycles, regardless of the energy storage system's specific energy (Watt-hr/kg). For example, a 400 Watt-hr/kg system that is undersized will not have sufficient energy to meet the power draw profile over the complete lunar night, and therefore will not be eligible for any award.

**Lower level awards will ONLY be available if no teams reach a higher level. If one team achieves greater than 500 Watt-hr/kg, only 1st, 2nd, and 3rd place for Level 3 qualified teams will be available. If no teams achieve Level 3, then level 2 awards will be provided to eligible 1st, 2nd, and 3rd places for that level. If no teams achieve Level 2, then 1st, 2nd, and 3rd place awards will be available for Level 1.

In the event that more than one team meets the requirements for their level, the team's energy storage systems will be ranked according to the weighted scoring criteria in Section 8, Judging.

10.3 Disqualification

Disqualification of a team will be conducted by review of the full judging panel, and will only be acted upon if a majority vote (greater than 50%) of the judges deems the team's system to have failed to meet one or more of the requirements set forth in this rules document or the Team Agreement. Teams can be disqualified at any point during the process of the competition.

APPENDIX A: PHASE 2 COMPETITION DRAFT INFORMATION

NOTE – this appendix is for informational purposes only and is not to be considered official rules for the Phase 2 competition. Official rules and timeline for the Phase 2 competition will be provided at a future date. Participation in Phase 2 is not required to compete or win the phase 1 competition.

Overview:

In addition to the Night Rover Challenge's Phase 1 competition, NASA plans to create an additional competition to further test energy storage systems in lunar conditions. This has not yet been approved by NASA and will only be conducted upon successful internal review by NASA officials.

It is the goal of this competition to identify energy storage systems that can perform the best under lunar conditions. The Phase II Awards will be provided on a best-to-perform basis, rather than meeting specific energy targets.

Competition Environmental Conditions.

1. Temperature = -177 deg Celsius is the minimum the test chamber will reach at the simulated lunar night time and a maximum temperature at Lunar noon of 25C. (Note this is not the actual lunar temperature, but is used in this trial because of the facility limitations; thermal management technologies exist to dissipate the higher heat load, and energy storage systems will not be required to operate at higher temperatures).
2. Pressure = <10^-4 Torr

Competition Trial Procedures:

1. Temperature test – the first part of this competition will bring the energy storage systems down to the low temperature. Energy Storage Systems that are able to operate under this condition will be able to continue to the second part of the Trial.
2. Vacuum test – the energy storage systems that successfully pass the low temperature test will be taken into a vacuum chamber and will be subject to both low temperature and low pressure conditions. The teams that perform the best (above a predefined baseline) will be awarded the competition prizes.

The Phase II competition will be held at the same test facility used for the Phase I competition. Any energy storage system that did not successfully complete or participate in the Phase I trials will be subject to Phase I testing prior to Phase II testing.

APPENDIX B: ENERGY STORAGE SYSTEM SPEC SHEET

Energy Storage System Specifications	
Max Weight	100.0kg
Max Volume	1.0 cubic meter
Maximum Length	2.0m
Cycle Life	2 cycles (708hrs each), 25^{0}C
Calendar Life	Not restricted
Cell Chemistry	Not restricted
Number of Cells/Modules	Flexible
Data Interfaces	Cat 5 ethernet connector,
BMS	- CAN Bus (system must connect to facilty monitors by Cat 5 ethernet connector) - BMS will detect problems and isolate the test article as outlined in the accepted registration packet from the team.
Electrical Interface	6 foot pigtail input & output connectors
Thermal Interface	thermocouple pigtails (type T),
Venting	1/4 inch Swagelock VCR and connectors
Voltage range	15 +/- 0.1 VDC
Usable Energy	30.09 kWh at 25^{0}C, BOL to EOL
Energy Density (Pack Level)	Level 1 > 300wh/kg Level 2 > 400wh/kg Level 3 > 500wh/kg
Temperature of operation	15 to 25^{0}C
Heating / Cooling	Must be provided by the team and are considered part of the system mass. No external heating/cooling is allowed.
Max peak discharge power	120W for 3 hour
Max peak charge power	564 W
Power duration	14 days/cycle
Safety	- “A Sample” prototype qualified for 2 lunar cycles. - Facility includes isolation contactors/disconnects. - Team must provide monitoring data service disconnects - no fire/no explosions during trials or storage
Liability	$1,000,000 insurance policy
Environmental Restrictions	- Sensors that rely on the earth’s magnetic field - Ultrasonic or other sound-based sensors - Earth-based or earth orbit-based radio aids - Open circuit pneumatics - Air-breathing systems - Class 1, 3, 4, 5, 6, or 7 hazardous materials - Outgasing at > 0.2 standard liters per minute (SLPM). - Nuclear energy storage systems
Total Power Measurements	- Facility will record voltages, currents, and power delivered of power supply and load.