2025 Human Lander Competition (HuLC)
Q&A Session Summary Document

November 7, 2024
2:00 – 3:30 PM ET
Watch the recording on YouTube.

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Note: Highlighted questions were covered during the Q&A Session on November 7th, 2024.

Responses in Purple are transcribed live answers.

The Human Lander Challenge is sponsored by the National Aeronautics & Space Administration's (NASA's) Human Landing System Program and managed by the National Institute of Aerospace.

Live Context for the 2025 Theme: Advanced Cryogenics

Section begins in recording at [12:25]

Juan Valenzuela (JV): This is the 2nd year of NASA's Human Lander Challenge, and the chosen theme is Advanced Cryogenics. That's basically all of the suite of technologies that have been developed over the last, I want to say, 30 to 40 years at this point. The goal of which is to try to maintain cryogenic liquids, liquid hydrogen, liquid oxygen, and liquid methane, and primarily keep them in their cryogenic state while for a long duration period of time on orbit. Currently, NASA's Human Landing System (HLS) program has baselined cryogenic landers as the kind of the primary vehicle to return astronauts to the Moon, so there's been a huge emphasis of further developing these suites of cryogenic fluid management technologies and implement them onto a vehicle for the upcoming Artemis 3, 4 and 5 missions.

Esther Lee (EL): We're really looking forward to engaging all the students and seeing their creative minds come up with some potential solutions to help tackle some of the tough problems that we at NASA are also facing.

Technical Questions Received in Advance

1. **What makes cryogenics so important this year compared to the last Human Lander Challenge?**
   - Cryogenic Fluid Management (CFM) is a term used to describe a suite of technologies that store, transfer, and measure ultra-cold fluids—such as liquid hydrogen, liquid oxygen, and liquid methane. Cryogens (supercold fluids that must be maintained well below standard room temperature to remain in a liquid state) will almost certainly be beneficial, if not required, for any human landing system. Cryogenic propellants (e.g. hydrogen or methane) in combination with liquid oxygen provide some of the highest specific impulse performance of any chemical propulsion systems. Furthermore, oxygen is required for life support. Also, many of these elements may be extractable from the Lunar or Martian surface, making future in-situ acquisition a viable option. Cryogenic storage of these fluids is currently the only known practical way of efficiently storing them at reasonably high density.

2. **For "On-Orbit" transfer, are we to assume that the scope is transfer between a spacecraft/lander and a large fuel depot/barge (Like Gateway)?**
   - You can make a high-level assumption that you are transferring propellant from one spacecraft to another, like from a propellant storage vehicle to a lander or other spacecraft. Note that Gateway as currently envisioned does not carry cryogenic propellant storage for refill of another spacecraft. You can read more about the Human Landing System (HLS) architecture here NASA's Human Landing Systems Development.

3. **[15:18] When it specifies "large amounts of fuel", what numerical amount or order of magnitude are we talking? Is this a choice that our team can make itself?**
   - High level HLS requirements are available to the public that specify the mass of cargo or people required to be delivered to and returned from the lunar surface. Additionally, analysis is available that specifies the delta-V required to transfer from low-Earth orbit (LEO), to near-rectilinear halo orbit (NRHO), NRHO to low Lunar orbit (LLO), and LLO to the surface (and back). There are mathematical methods to estimate the amount of propellant (both fuel and oxidizer) this would require, along with high level estimates of other system masses (structures, power, thermal, etc.). Your team's choice should be supported by appropriate analysis to show that it makes sense in the context of the HLS

mission. Do research, reference your sources, make appropriate and well documented assumptions, and justify your approach.

- **Resources that might be helpful include:**
  - Mass Estimation: [NASA CR-172061]
  - Lander Architecture: https://dspace.mit.edu/handle/1721.1/133978
  - HLS Requirements: https://sam.gov/opp/f3f8689858d6fc2c7f91e6533235f6e7/view (see attachment F, HLS-RQMT-001)
- **Victoria O'Leary (VO):** When NASA talks about "fuel" in this context, they really want you to talk about *propellant*.
- **JV:** We do have a lot of resources out there available that could give you kind of a first order sizing of the amount of propellants that we're talking about here. There's a preliminary kind of requirement for the amount of payload that needs to be delivered to the lunar surface. The delta-V maneuvers are easily available online. The In-Space Propulsion (ISP)/thrust for both Raptor, on the SpaceX side, and the BE7 engine, on the Blue Origin side, are pretty easily available. That as well as how many engines there are per Lander, will give you a really good sense of thrust capabilities those two vehicles are going to have. The way both companies have baselined them should give you a rough estimation on the amount of propellant that will be necessary to execute the missions. Both companies have baseline what they call a Propellant Aggregation, meaning that's almost like a bit of like a gas station in LEO, so to speak, where multiple refueling missions will need to occur in order to fill what either what is the propellant depot to adequately fill the depot with enough propellant to then transfer the propellant from the depot to the specified Lander in order with the necessary propellant to actually execute the HLS mission. To give you a rough order, we are talking multiple, multiple tons of hydrogen, oxygen and methane.

4. [18:30] What is the measurement of "acceptable leakage"?

- Current state of the art flight valves of appropriate size for landers have leakages on the order of 1,000 sccm. Targets could be reduced by at least two orders of magnitude.
- **JV:** If you focus on the way either NASA or other launch vehicle companies have designed their vehicles, they're not really meant to hold cryogenic propellant for longer than, in some cases, a couple minutes. The longest that's ever been achieved is a couple hours, approximately 7 to 9 hours. That wasn't really a mission; that was more of a stretch objective secondary payload, so that was more of a more in the science experiments range. In order to meet the necessary long duration requirements, that leak rate needs to come down by, at least, two orders of magnitude. It would, at least, need to be less than the incoming heat leak into the propellants which causes them to boil off and evaporate. That will encompass the entire three to four months. That is the baseline of the HLS missions.

5. What is our power allocation (volts, watts, amps, etc.)? What are the main objectives of NASA HuLC in terms of power generation and management?

- This depends on what you're proposing, where it is, and what your power source would be. Do research, reference your sources, and justify your approach. As with any space application, lower size, weight, and power requirements are preferred. If a proposing team has a good idea that requires considerable electrical power (e.g., many kilowatts or megawatts) they should address where this power might come from, as well as the impact of this power source on the overall viability of their concept.

6. Are there limits beyond the prime power allocation?

- See TQ5.

7. **Are there computational limits, such as processing speed or data storage? Is there an Electrical Interface Control Document (EICD)?**
    - There are no identifiable requirements related to computational limits, however, reasonable assessments should be made based on the state of the art for space computers. Do research, reference your sources, and justify your approach.

8. **[19:59] What are the current CFM Challenges for the HLS in terms of structural supports? Inner to Outer Tank? Outer Tank to lander? Multi-Layer Insulation (MLI) Penetration?**
    - Most flight tanks will not have an inner/outer tank configuration, simply a single wall (insulated) tank that attaches to the vehicle structure. Structural supports between the cold cryogenic tank and warm vehicle structure must be sufficient to support tank and internal fluid mass during periods of high acceleration (1-g ground testing and pre-launch, launch thrust, orbital maneuvering and landing engine thrust). These structural penetrations through the tank insulation can often be the largest source of parasitic heat addition to the tank, resulting in excessive boil-off rates or other fluid management problems.
    - **JV:** As far as the inner and outer tanks, there's really no inner and outer tanks. Some of those are mostly driven by launch loads. You may be talking about a concept that is not really feasible for a kind of launch vehicle or like a payload size vehicle, especially when you're trying to carry this much magnitude of propellant from one point to another. Some of that seems to be falling more on the structural side. Conventional tanks, the way launch vehicles are, are second stage launch vehicles that are being built as structural supports. That is a pretty big issue that we're going to tackle. These launch vehicles do not really care about kind of conductivity and are trying to eliminate the conductivity that goes into the propellant. As far as multilayer insulation, that is essential. That is a huge part of what we call our passive CFM approach, a radiative insulator of some kind to help deal with either solar or Earth albedo radiation and lunar radiation.

9. **[21:55] Based on the gateway concept, should we expect the lander to be carrying fuel at launch, or receive all of it from Gateway?**
    - Both SpaceX and Blue Origin use a refueling architecture, but that does not preclude launch with cryogenic propellants onboard. These architectures do not refuel at Gateway.
    - **JV:** The baseline is multiple refueling campaigns in order to meet the propellant necessary for both SpaceX and Blue Origin Landers to execute the mission.

10. **[22:56] When the Proposal Guidelines document refers to "mission operational life of multiple months" at the bottom of page 4, what is the minimum design threshold for the number of expected performed cycles for the concept to be viable to NASA? What should the minimum operational lifetime be?**
    - HLS-RQMT-001 (Attachment F) requires an orbital loiter capability of at least 90 days in NRHO. This is in addition to any aggregation, transit and surface operations timelines (6.25 days – 33 days).

11. **[24:18] Will components be allowed maintenance intervals and, if so, how frequent and to what extent can the maintenance be performed?**
    - See HLS-RQMT-001 (Attachment F), HLS-SMA-0011 (pg. 48) and HLS-SMA-0028 (pg. 49). For sustained missions, the lander portion is allowed up to 24 hours of maintenance on orbit, but not on the lunar surface. Supporting spacecraft are likely to be uncrewed. A proposed solution that requires crewed or uncrewed maintenance should be appropriately justified and analyzed to consider impacts to other parts of the mission.
    - **JV:** There's not really a hard requirement for maintenance as mentioned. That alludes to that requirement for sustained missions that are only allowed up to 24 hours of maintenance. Consider

that on the broader scope, this is supposed to be a 3-4-month mission, and there's not that there's not that many opportunities for astronaut maintenance. Any decisions that you make in your proposals, I would not put that much emphasis on maintenance intervals.

12. **What is the minimum threshold of mass flow rate that an automated cryo-coupler will be expected to meet?**
    - Based on the answer from question 3 and a reasonable time frame, flow rates can be calculated.

13. **In the cislunar use of an automated cryo-coupler, is the component expected to be fully or partially automated or manually controlled?**
    - See HLS-RQMT-001 (Attachment F), HLS-SMA-0006 – Autonomous Systems (pg 44). Critical functions are expected to be autonomous. It may be wise to trade fully autonomous versus partly autonomous versus manually controlled and come up with pros and cons of each choice.

14. **In the cislunar or lunar deployment of an automated cryo-coupler, what is the range of expected travel distance to the connection point, and will this travel be automated or manual?**
    - There are no definitive answers for this question, a proposal should rather define the range of motion that is possible and that the solution can be scaled to. See the answer to question 13.

15. **Will an automated cryo-coupler be used for refueling in earth surface conditions as well as in lunar and cislunar conditions?**
    - It is possible, but not required, that any Earth based fueling coupler could be reused in lunar/cis-lunar conditions.

16. **We would like to know whether the system should continuously track the mass of the cryogenic propellant or take periodic measurements. If periodic tracking is sufficient, what frequency should the system be taking measurements?**
    - You tell us! A thorough literature review should uncover papers that have explored this concept from both angles. If you have an HLS cryogenics proposal that relates to propellant mass gauging, we look forward to receiving it.

17. **[25:48] What are good sources for fluid behavior and data in null gravity conditions, especially pertaining to cryogenic propellants with positive expulsion pressure systems applied to it?**
    - A thorough literature review should uncover papers that have explored this concept extensively.
    - **JV:** There's a lot of literature out there either through publicly available conferences, our own NASA and TRS (teleoperator retrieval system) that will try to deal with this, the zero-G fluid behaviors of cryogenic liquids.

18. **What is the gap analysis behind using pistons and what issues did NASA run into when using that type of system? We could not find any concrete details on the matter.**
    - If you have a cryogenics concept for HLS applications that uses pistons, then we would look forward to reading your proposal. Do research, reference your sources, and justify your approach. If you have a concept with minimal existing research, consider reaching out to subject matter experts in that field or using analogs for estimations.

19. **What are the minimum thermal insulation requirements for cryogenic night cycles?**
    - There are no program specific minimum thermal insulation requirements, these are somewhat vehicle dependent. However, a thorough literature review should uncover papers that have explored this concept extensively.

20. **What are the essential thermal insulation standards for cryogenic storage on the Moon, particularly during extended lunar nights?**
    - ASTM C740 describes cryogenic multilayer insulation, SLS-SPEC-159 (Cross-Program Design Specification for Natural Environments) describes the lunar environment. Additionally, a thorough literature review should uncover papers that have explored this concept extensively.

21. **[26:54] How long has cryogenics been used in space travel? (What is the track record of safety?)**
    - HLS would be the first time that cryogenic propellants have been stored for more than several hours on orbit or been transferred between tanks on different vehicles on orbit.
    - **JV:** This is the reason CFM is considered one of the highest risks for the HLS mission. As far as the track record of safety, that is, that is the reason it is one of the biggest risks. It's one of the biggest unknowns. One of the reasons this competition exists in the first place is to try to find new technologies that are able to mitigate that safety risk for the mission.

22. **How does the HuLC project focus on being eco-friendly, and what are the long-term effects on the environment?**
    - The 2025 HuLC Competition theme is cryogenics for HLS applications. Depending on your concept, you may need to address waste disposal. Otherwise, this topic would be outside of the scope for this challenge.

23. **[27:52] What strategies are competitors in the HuLC Human Lander Challenge employing to develop sustainable and resource-efficient landing systems that minimize fuel consumption and optimize power usage?**
    - If you have a concept for cryogenics for HLS applications that addresses this topic, you tell us! Proposals are due on March 3rd. We can't know what competing teams will propose until we receive submissions. However, you may want to do research on SpaceX's Starship and Blue Origin's Blue Moon lander to understand their strategies.
    - **JV:** We are open to all proposals! if you have any proposals to kind of minimize the propellant consumption of those 3 propellants (liquid hydrogen, liquid methane, and liquid oxygen), that is part of this year's Challenge.

24. **What are the key technological innovations that HuLC [cryogenics] brings to the table compared to traditional power systems?**
    - See TQ23.

25. **Can you explain the design architecture of [a particular vehicle] and its modular capabilities?**
    - There are many publicly available resources for this. We also have a wealth of resources available on the HuLC Resources webpage under "Recommended Reading," and we encourage you to search NTRS for more information that might relate specifically to your concept. The SpaceX and Blue Origin architectures are shown here. Do research, reference your sources, and justify your approach.

26. **What roles do machine learning models play in predicting and optimizing the performance of cryogenic cooling systems?**
    - Machine learning models are only as good as the data used to train them – given the limited in-space data, machine learning models may initially struggle in certain areas. If areas have more data, then machine learning could be used in those areas.

27. **How does NASA plan to address thermal regulation challenges in HuLC systems, particularly in environments with rapid temperature fluctuations?**
    - We are looking for solutions from students and don't want to presupposition solutions.

28. **Are there any alternative fuel sources being explored for powering the HuLC system, aside from traditional methods, to enhance sustainability and efficiency?**
    - It's hard to get more sustainable and efficient than oxygen and hydrogen or even oxygen and methane, plus solar power.

29. **How can cryogenic technology be utilized to preserve biological samples during long-duration space missions?**
    - While there are rapid freezers on the Space Station that provide freezing of experimental biological samples for long term storage, this year's challenge is looking for cryogenics concepts **for HLS applications**. If your concept is for cryogenic preservation of biologic tissues AND directly related to this year's challenge theme / HLS, then you should do research and tell us what the answer is. Otherwise, this question is out of scope for the HuLC Competition.

30. **What is the optimal temperature for cryogenic preservation of biological tissues, and how is it maintained over time?**
    - See TQ29. This is likely out of scope for the 2025 HuLC Competition.
31. **Do you think full-body cryopreservation for future revival is scientifically viable, or is it more science fiction?**
    - The 2025 HuLC Competition is looking for cryogenics concepts for HLS applications. "Cryopreservation" is out of scope for this year's Challenge.

32. **How do phase transitions (solid to liquid, or gas to liquid) impact the materials used in cryogenic systems, and what materials best withstand these conditions?**
    - Phase transition (generally liquid to gas) affect the tanks by pressurizing them, common materials that can be used for tanks are stainless steel, aluminum, titanium, etc. AIAA-S-080 describes how tanks are to be made and tested to withstand these conditions.

33. **[28:57] Can computational models predict the behavior of gases and liquids at cryogenic temperatures?**
    - Computational models can predict the behavior of cryogenic fluids. Computational models are only as good as the physics that they have been verified to. The challenge is modeling the behavior of these fluids in zero-G. NASA has been working on multiple computational software packages to validate them and is also working to obtain the data to validate the models to. A thorough literature review should uncover papers that have explored this concept extensively.
    - **JV:** There are tons of literature reviews out there of people trying to do this exact problem with the necessary kind of the theoretical physics involved to try to come potentially develop these models. There are lot of the problems because we don't really have that much actual physical data to corroborate set computational models. A lot of those efforts have largely been either unvalidated or kind of yet to be validated, which is also one of the really big challenges that we have here.

34. **[29:50] How does microgravity affect cryogenics? How do scientists mitigate the effects of microgravity on cryogenics?**
    - Microgravity affects cryogenic fluids mainly by changing the forces that cause different fluid densities (or phases) to move in certain relative directions. For some general initial guidance: In the absence of gravity (or at very low gravity), fluid behavior and orientation is more strongly influenced by surface tension. Cryogenic fluids have very low contact angles with most solid materials, meaning they "like" to wet solid surfaces and will move towards orientations that minimize the free surface area (i.e. one or more spherical vapor bubbles will form). Thermal gradients also play a role, and liquid will tend to migrate towards colder regions of a tank, while vapor pockets form around zones

of heat leakage into the tank. This can be mitigated in multiple ways, and we look forward to seeing different proposals that suggest mitigations. Details are complicated, and proposers are encouraged to do a thorough literature search if interested in this topic.
  - **JV:** The biggest problem is determining the dominating force that is being applied onto the propellant itself when it's being stored on the ground. When it's here on Earth, it's incredibly easy. It's gravity; it will push it down. The liquid will sit at the bottom. It will stratify with heat leak, and you'll have a nice perfectly level surface. In microgravity, it is a complete toss up, especially when you're dealing with the large amounts of quantity that we're talking about. What is the primary force that will dominate where the liquid goes and how it behaves? Will there be any acceleration that is being imparted on the vehicle itself? Will there be any celestial forces, any celestial body forces, or any gravitational forces that are on the Moon that are exerted on the Moon when it's in LLO? Any gravitational forces that are exerted when it's in LEO are called Tidal Forces. There's also one of the primary mechanisms, surface tension. It's a balance of those forces and trying to understand and really model where the liquid is, how it's positioned. It's a big challenge.

35. **What is the main mechanism through which cryogenic leaks are occurring in the current systems? Connection points tolerance? Structural micro-cracks? Target acceptable leak rate?**
    - Cryogenic seals in valves and flanges are notorious leak sources. Virtually all normally compliant materials become hard and brittle at cryogenic temperatures. Considerable shrinkage of metals, as well as seal materials, at cryogenic temperatures also contributes to the leakage problem. Even pressure actuated Teflon seals (a common cryogenic seal) lose most of their compliance at cryogenic temperatures, resulting in the need for extremely smooth surface finishes and high contact forces to reliably achieve even marginally acceptable leakage rates for long term space applications.

36. **Is it possible to move a cryogenic liquid in the vacuum of space through the compression of a fuel storage bag? Would there be a way to minimize the space between walls of the fuel storage bag so that there is minimal sloshing?**
    - You tell us! If you have an HLS cryogenics proposal that relates to propellant transfer using compressible storage bags, we look forward to receiving it.

37. **If I used pressure to move cryogenic liquids in the vacuum of space, what would the maximum amount of pressure be before the liquid turns to a gas?**
    - Fluid properties can be best found using the National Institute of Standards and Technology's (NIST's) Thermophysical property webpage: Thermophysical Properties of Fluid Systems or REFPROP software.

38. **For the physical materials that will be used in creating a component, naturally occurring materials better or is human made/ lab made materials better in space like atmosphere?**
    - The source of the materials is not as important as the compatibility of the materials with cryogenic propellants such at liquid oxygen, methane, and hydrogen.

39. **What stage of the Artemis mission are cryogenics the hardest to maintain viable?**
    - Cryogenic propellant viability is really a question of how long you can keep the propellant in the right state (liquid or gas) at the right temperature / pressure. This is directly affected by the heating rates into the propellants, which vary based on the body you are orbiting and the position in the orbit (or on the surface). Artemis missions start on the Earth's surface, transit to LEO, then cross through Earth-Moon space to NRHO, then LLO, then the lunar surface (and back). Heating rates at these locations are available in the literature or via modeling software such as Thermal Desktop—and

don't forget to account for direct solar radiation, reflected solar radiation, and planetary body radiation. (Note: NASA does not endorse the use of any specific tools, but you can learn more about the use of thermal modeling and analysis tools here)

40. **Have we explored transporting the components for creating cryogenic fuel and then distilling it in space?**
    - Yes, this is currently being explored within NASA and many other partners and is known as In-Situ Resource Utilization (ISRU). However, for the short timelines required for the initial Artemis lunar landings, we are assuming that ISRU will not be available.

41. **[31:53] Is designing a testing apparatus to model a positive expulsion system an appropriate approach for this project?**
    - Depending on what is being proposed, a testing apparatus and physical model may be appropriate, viable, and beneficial. Keep in mind that it may be possible to demonstrate various aspects of cryogenic fluid management devices by using much easier-to-handle ambient fluids, even water.
    - **JV**: Yes, depending on how it is proposed. It could be perfectly appropriate, viable, and beneficial.

42. **What is the current estimated mass margin of the vehicles to be used during the Artemis Missions?**
    - ANSI/AIAA-S-120 defines mass margins that should be used at various levels of maturity for your design. We also encourage you to search NTRS (NASA STI Repository) for more information that might relate specifically to your concept.

43. **What sort of alignment systems are currently under consideration for the use of cryo-couplers?**
    - You tell us! If you have an HLS cryogenics proposal that relates to alignment systems for cryo-couplers, we look forward to receiving it.

44. **What is the desired mass flow rate of the coupler? What would be the total volume transferred?**
    - See TQ3 and TQ12.

45. **How does NASA plan to integrate advanced redundancy systems into the HuLC project to ensure mission-critical functionality during extreme environmental variability?**
    - HLS requirements are to be single fault tolerant to catastrophic events (See HLS-RQMT-001). You should address contingency plans for potential problems and/or redundancy system (if applicable) in your proposed solution, and tell us what you would do or how that would affect your concept.

46. **What innovations in energy storage and management are being explored to support the HuLC project's goal of sustainable long-term operations in space?**
    - You tell us! If you have an HLS cryogenics proposal that relates to energy storage and management that supports the HuLC project's goal of sustainable long-term operations in space, we would look forward to receiving it.

47. **[32:31] Should we design our system(s) for use only in-orbit only or both in-orbit and on the surface of a terrestrial body such as the Moon?**
    - This is up to you and dependent on your concept. Do research and justify your approach.
    - **JV**: It's part of the proposal, so it's up to you – it could be either/or. Depending on your design, there are systems that are optimal for use on the lunar surface, in NHRO, in LEO. If you want to focus on one element of the HLS mission (lunar surface/NHRO/LEO etc.), that's up to you – as long as you justify.

48. **Why is cryogenics considered so important for space exploration and missions? How does the use of cryogenic technology contribute to advancements in propulsion, spacecraft systems, and the long-term storage of resources in space?**
    - We've provided the answer to this question in various Challenge documents and resources. We recommend you read the 2025 HuLC Competition Guidelines Context & Challenge Description, watch Juan Valenzuela's 2025 HuLC Theme Context Video, and read through the HuLC Resources Recommended Reading.

Miscellaneous Questions Received in Advance

1. **What are the geometries of the propellant tanks to be used during the Artemis missions?**
    - Nearly every kind of tank geometry may be used for Artemis missions between the launch systems, spacecraft, and landers. There are publicly available images that should give an idea of what is proposed, along with textbooks and other historical records on what has been used in the past.

2. **How much space is there for hardware to be added around the tanks?**
    - See MQ1. You tell us! Do research, reference your sources, and justify your approach.

3. **Where would the docking ports on the Artemis landing craft be located?**
    - There are no requirements or limitations associated with where the docking ports can be located or Artemis landing craft as long as Astronauts can get out of them.

4. **Should we be using ASME standards for any part of our design project? If so, are there additional standards we need to be aware of?**
    - ASME standards are a good start, but there are specific standards called out in the HLS-RQMT-001 document in Appendix D.3 that are better suited for space systems. These include NASA, Military, AIAA, and other standards.
    -

5. **Is accessibility to certain microgravity modeling programs or simulations available to us and if so, how do we go about accessing it? Are you against us reaching out to NASA facilities for assistance?**
    - Neither NASA nor the National Institute of Aerospace (NIA) can facilitate partnerships for proposing teams. However, we recommend you check out NASA's Space Mission Design Tools and the NASA Software Catalog to see if there's public access to a tool that may accomplish your goals.

6. **If the issue of efficiently moving liquid fuel is correlated with the lack of gravity, why can't we bring an object large enough to have a relevant amount of gravitational impact on the fuel within the vacuum of space, or use the nearest space body?**
    - If you have a technically sound cryogenics application for HLS that would benefit from this recommendation, then you tell us how that would work. Do research, reference your sources, and justify your approach.

7. **[33:50] How will NASA assist teams in securing partnerships with commercial space entities or suppliers for component sourcing?**
    - Neither NASA nor NIA can facilitate partnerships for teams. Teams are also not expected to build with space qualified parts or materials. Prototypes are a highly valued but optional part of each team's work, so keep that in mind if your team chooses to build one.
    - **VO:** Prototypes are also not due at the Proposal Phase. If you are interested in creating a prototype and you've begun testing, feel free to include that information in your proposal. To earn some of the

optional bonus points in the evaluation rubric, that prototype would need to be presented both at the forum during your Presentation and during your Poster Session. For example, if you are testing an object in a vacuum chamber and you clearly can't bring the item and the vacuum chamber to the forum, having high quality video can definitely substitute for some of that physical presentation portion.

8. **Why does NASA want to go back to the Moon?**
   - We recommend you read more about NASA's Artemis Program.

9. **[35:52] What is the backup plan if something goes wrong during important parts of the project, such as technical difficulties or hurricane weather?**
   - You should build contingencies and extra time into your work plan. Make sure everyone within your team has a full contact list for each other, agrees on the contingency plan *and* their role within it, and has practiced the plan at least once. For example, if you plan to store and work within Google drive, make sure the owner of each document understands who needs access and understands what they need to do when a deadline for that document is approaching. Someone else should also know if and when it's their responsibility to download offline copies for record keeping/backups.

10. **How does the HuLC Human Lander Challenge address human factors, such as astronaut safety and comfort, during both descent and post-landing activities on planetary surfaces?**
    - This year's competition is focused on cryogenic applications. You should consider health and human and safety if it is relevant to your concept and tell us how you plan to address it.

11. **What is your contingency plan for if one of the Artemis shuttles malfunctions in between Earth and the Moon?**
    - If you're proposing a cryogenics application to address this, please let us know what your proposed concept and contingency plan is, reference your sources, and justify your approach. Otherwise, this question is out of scope for this competition.

12. **What materials have worked the best for long-term space operations? Is it better for cheap materials that just get by or expensive longer lasting materials?**
    - Do research, reference your sources, and justify your approach. We want you to tell us what the best options are for your proposed design.

13. **How will the insights gained from HuLC be applied to future lunar missions?**
    - We can't know the answer to this until after the 2025 HuLC Forum.

14. **What are the potential commercial applications of the technologies developed in the competition? What are the next steps for NASA's lunar exploration program, building upon the success of HuLC?**
    - Again, we can't know the answer to this until after the 2025 HuLC Forum. However, you can read more about NASA's Artemis Missions to understand what comes next.

15. **What role will lunar resources play in the HuLC project, and how will they be used to support infrastructure and human habitation on the Moon?**
    - See TQ42. You tell us, but know that ISRU is outside of the scope for this challenge given the timeline listed in the theme. Do research, reference your sources, and justify your approach.

16. **What issues have arisen in the past to ask for help in solving this issue that brains at NASA could not solve or could not implement?**

- HuLC is not the result of an issue or lack of implementation. Challenges like HuLC seek and value innovative, out-of-the-box thinking from student engineers, and hope to engage them as important partners in NASA's mission early in their careers. Through HuLC, college students help NASA's advancement of HLS technologies, concepts, and approaches. Improvements in these technology areas have the potential to revolutionize NASA's approach to space exploration, and contributions from the academic community are a valuable part of the journey to discovery.

17. **Under Pg. 9 in the Competition Guidelines Document, it states, "Proposals should include - "Realistic technology assumptions, including realistic NASA technology Readiness Level Definitions and justifications where appropriate." It is not clear what the document in the link explains about. How should we use it in our proposal?**
    - Ultimately, we want the teams to make realistic assumptions when evaluating their technology maturity. The NASA Technology Readiness Level (TRL) is one method to benchmark how mature the technology is. For example, if your concept is formulated without proof-of-concept, you are at TRL 1-2, if you have a component validated in a lab, then the technology is at TRL 3-4. We encourage you to read more about NASA Technology Readiness Levels (TRLs) at the following links to aid your proposal justification:
        - NASA Technology Readiness Assessment Best Practices Guide
        - NASA Technology Readiness Levels
        - Technology Readiness Level (TRL) as the foundation of Human Readiness Level (HRL)
        - TRL Unicorn Chart (Unofficial but Recommended Reading)

Programmatic Questions (NIA)

1. **[39:59] Are entrances into a specific category being judged solely against the requirements and/or competing concepts in the same category or concepts in all available categories? If we have a concept that solidly meets the requirements for multiple categories, can we present the same concept for multiple design categories?**
    - All proposals will be judged against each other. The categories are meant to help judges understand a little more about what your concept hopes to achieve, not separate proposals for selection. The proposal form has a checkbox selection for categories that allows multiple selections and has a section for "other." You do not need to submit your proposal more than once; select all that apply, or write-in your own category to tell us what cryogenics topic you're addressing.

2. **Do prototypes (physical prototypes that require hardware/experimental setups) need to be completed by the March 4 proposal submission deadline?**
    - No. Prototypes are optional, and finalist teams who design/build prototypes should plan to bring them to the onsite Forum in June to demonstrate during their presentation and the poster session.

3. **Does the proposal need to include experimental results, or working software/model/simulations?**
    - No. The proposal needs to include enough information to convince the judges that your proposed concept is credible and valuable and provides confidence that your team can successfully implement the work proposed.

4. **Are students on a visa in the US allowed to participate?**
    - Foreign Nationals (FNs) attending the proposing U.S.-based university can fully participate on a HuLC Team, and at most of the HuLC Forum event (with some exceptions) – including those on

student visas. We can never guarantee whether a FN will be granted access to any Forum events held onsite at a NASA facility. See PQ4 below.

5. **How can a team member of foreign nationality send a request for approval to come to the main HULC Forum in Alabama during the Final event? Are there any special exceptions?**
    - Please read the [HuLC Competition Guidelines, Eligibility: Foreign Students/Universities section]() for full information. Foreign Nationals (FNs) attending the proposing U.S.-based university can fully participate on a HuLC Team, and at the HuLC Forum if their team is selected as a finalist, with several notable exceptions:
        - Due to prohibitive restrictions and ever-changing NASA security regulations, foreign nationals may not be approved to attend culminating HuLC Forum events that take place on-site at a NASA Center (including tours). HuLC Program Staff will not know if Foreign Nationals are approved to attend events at a NASA Center until shortly before the Forum. If Foreign Nationals are approved to attend events on a NASA Center, they will need to provide current passport information via their Forum Registration, ~1.5 months prior to the Forum.
        - Neither NASA nor HuLC Program Staff can sponsor travel from foreign countries, and students of any nationality attending foreign universities are ineligible to participate.

6. **[41:58] Since the NOI is non-binding, can I add/remove/replace team members and mentors?**
    - Absolutely! You can make most changes without contacting us, but if your team leads or primary faculty advisor change, please send their updated name, email, and phone number to HuLC@nianet.org so we can update your team's contact information. Finalist teams should list all contributors on their final technical paper, even if they only assisted on the proposal.

7. **Is remote participation in the HuLC Forum via video conferencing allowed?**
    - No, there is not an option for HuLC teams to participate in the Forum virtually. However, the team presentations during the Forum will be livestreamed so finalist teams can invite family, friends and colleagues to watch remotely.
    - As a reminder, teams must send at least 2 students to attend and present at the in-person Forum. Teams may send up to 10 students to the Forum, and (space-permitting) there may be an option to send more than 10 students to the Forum with written approval from HuLC staff.
    - If your team is selected as a finalist and you plan to send more than 10 students, please reach out to HuLC@nianet.org with your request to receive approval prior to the registration deadline.

8. **Do writing expectations include passive third-person, or is first person also acceptable? Previous winners included first person.**
    - Either is acceptable, but please be consistent. Using last year's 1^{st} place winner's concept name as an example, you could say "The ARC-LIGHT project will do x, y, and z." Or, you could write "To accomplish the goals of ARC-LIGHT, we plan to do x, y, and z."

9. **[44:16] What are the expectations on behalf of the judges with respect to concept testing in terms of cryogenic and other performance thresholds?**
    - There are no direct expectations for teams to build prototypes or do testing, but it will almost always add credibility to your concept. You can read [papers from last year's finalists]() to learn more about what has been successful in the past or review the [proposal evaluation matrix]() to learn more about the scoring criteria.

10. **How high of a level do you expect our solution to be?**
    - You can [read papers from past finalists]() to learn more about the expectations for your work.

11. **What is the timeline that is expected for the delivery and testing of the lander system after the proposal get acceptance?**
    - The HuLC Competition is a student challenge seeking ideas in the form of technical papers and optional prototypes. There are no planned "next steps" for delivery and testing of a lander system.

12. **What results have the human lander challenge produced in the past?**
    - You can read [papers from last year's finalists]() to learn more about this.

13. **How does the HuLC Human Lander Challenge encourage innovation in the design of landers that can efficiently navigate and land on diverse planetary terrains, such as those on the Moon or Mars?**
    - The 2025 HuLC Competition seeks ideas for cryogenics applications for HLS. If your concept can relate to that, then you tell us! Otherwise, this may be out of scope for the challenge.

14. **How can the team make the data collection process easier and more accurate during tests?**
    - If your concept addresses cryogenics applications for HLS, then you tell us! Or, do some research and justify your approach.

15. **What are the key criteria and metrics used to evaluate participants' performance in the HuLC contests, and who comprises the judging panel? What are the criteria for selecting the finalists?**
    - Review the [2025 HuLC Competition Proposal Scoring Matrix](). This is how [our judges]() will evaluate the proposing teams.

16. **How does HuLC integrate with existing spacecraft systems?**
    - The HuLC Competition is a student challenge seeking ideas in the form of technical papers and optional prototypes. It does not inherently integrate with existing spacecraft systems, but your proposed concepts may need to address integration.

17. **How does the human lander challenge interact with other NASA mission components, like Gateway or rovers, to streamline astronaut operations and resource management? Will it be used in other applications?**
    - Challenges like HuLC seek and value innovative, out-of-the-box thinking from student engineers, and hope to engage them as important partners in NASA's mission early in their careers. Through HuLC, college students help NASA's advancement of HLS technologies, concepts, and approaches. Improvements in these technology areas have the potential to revolutionize NASA's approach to space exploration, and contributions from the academic community are a valuable part of the journey to discovery. We can't say if or how your concepts will interact with other NASA components.

18. **How does NASA plan on getting their funds reliably for future space operations considering they got their budget completely cut in the past?**
    - This question is out of scope for the HuLC Competition.

19. **[45:32] If we have any queries along the way, until the deadline, whom can we contact?**
    - If you have any additional questions, please reach out to the HuLC Program Team at HuLC@nianet.org and we will get a response for you from the appropriate person. All questions and their answers are ultimately posted to the HuLC FAQs webpage. We try our best to remove information that could give away a team's unique concept or design.
    - Please also be cognizant of weekends and holidays when sending your questions. Questions should be sent well in advance of the associated deadline to ensure a response is received with enough time for you to incorporate it into your work.

Questions Received Live During Q&A Session

1. **[38:04] Can you clarify the reference to "sustained missions" in TQ11? Was that referring to future missions within the Sustained Lunar Evolution segment? Can you clarify the six days transit and up to 33 days surface day at this additive?**
   - **JV:** There's a separate contract within the HLS program that deals with sustained missions called "Sustained Lunar Presence/Evolution." Those have been the baseline for Artemis 4, Artemis 6, and beyond. So, there are future missions that have been outlined as part of HLS to have a sustained lunar presence on the Moon that's beyond the 3-4-month timeline. That is Artemis 3 and 5. It's 90-day loiter + 66.5-day surface day + the time to travel between Earth and NHRO.

2. **[47:35] Can you give us more guidance about good literature sources? Can you tell us a bit more about the Gateway concept?**
   - **VO:** We do strongly recommend the NASA Technical Reports Server (NTRS). That is an incredible resource. AIAA also has a repository called AIAA Aerospace Research Central (ARC). Some of those papers require paid access, but many of them are free. If you're a student, reach out to your advisor, because they probably have access to technical repositories that your university pays for that you might not be aware of.
   - **JV:** Gateway can be found here.

3. **[49:28] What order of magnitude does NASA expect the propellant transfer operation to take hours, days, etc.?**
   - **JV:** State all of your assumptions for the minimum time that a vehicle is able to operate on orbit and any power requirements that are needed for that vehicle to be able to transfer some propellants or to be able to maintain to stay on orbit. If you're developing a novel concept for propellant to transfer, please state your given flow rates. Since it is multiple propellant aggregation, it's definitely not days, because of the scale of launching multiple propellant to be able to adequately fill the depot with enough propellant to execute the mission.

4. **[51:38] Is there a target amount of thermal leakage rate? For example, in an insulated cryogenic tank, how many watts of thermal leakage should we aim for in the design? We could make it extra good for a minimum thermal leakage, but it might cost too much and might not be feasible.**
   - **JV:** That's definitely part of the tradeoff. We have concepts here called Zero Boil Off, where *[paraphrased]* the goal is to have enough CFM systems that your cryo basically acts like a storable. That is one of the goals that the CFM program tends to focus on. If you would like to pursue that, you are fully free to explore that concept. If you'd like to minimize the boil off, you're also free to do that. It's really up to you, just as long as your assumptions and goals are clearly stated in the proposal, whether you want to achieve Zero Boil Off and try to keep the cryo, keep 100% of the cryo that's available to you, or to minimize boil off and size the vehicle accordingly to account for said boil off during the mission.

5. **[53:39] There are so many questions, and so many good ideas out there to play with. Do you have any suggestions on what track might be most interesting and useful to NASA?**
   - **JV:** That's one of the things we struggle with at NASA. Once you do the lit reviews, you'll find out that that there have been multiple ideas thrown out there to try to achieve what is considered a CFM technology. They run the gamut between conductive insulators, passive radiator, radiative

insulations, and active heat interceptors. All of them are good ideas. All of them are worth pursuing for the Artemis 3 and Artemis 5.

6. **[55:53] If we do the structural supports prompt, how many pounds should these structural supports be able to hold?**
   - **JV:** A good resource for that is a thorough literature review. There are resources out there that roughly estimate the mass of a launch vehicle and the payload requirements for astronaut habitats. A thorough literature review should give you a rough order of magnitude for the weight capacity of support structures.

7. **[56:47] What are some key criteria for a good cryogenic transfer process?**
   - **JV:** If we knew that, this competition wouldn't exist! We'll leave that up to you. All proposals are welcome.

8. **[57:27] Are there any compressed MLI studies or force dependent conduction through separator, like polyester fiber sheets or mesh materials? The only one I'm aware of is the NASA CR (contractor report) by Lockheed.**
   - **JV:** Sounds like you already know what you're talking about! There are studies that deal with the compressibility of multilayer insulation and the pros and cons depending on the design. So, if you compress them, that that will produce a thermal short and will lead to a conductivity heat leak that goes into the tanks. There are multiple MLI concepts that are being studied. If you have one in mind, please, please put it forward!

9. **[58:54] Is there any or to what extent is there freedom for student teams to modify with justification either the Starship HLS or the Blue Moon HLS design so that they can accommodate their CFM architecture better? Do you want there to be minimal changes and justified so that the technologies would be applicable for Artemis 3, 4, and 5?**
   - **EL:** Ideally, we'd like to see designs that are with minimal changes to the Lander which will make the integration easier.
   - **JV:** We're looking for proposals out there that can be executed and implemented into the HLS mission in a 3-5-year time period.

10. **[1:00:19] When we were doing through the literature review, we recognized that there were a lot of TRLS that were addressed to manage some of the issues that were brought up in the in the prompt. Is it OK to assume that some of these technologies would be in use or can be in use for our proposal or for our proposed solution, such as liquid vapor separation or being able to mitigate belt boil off during launch or things of that nature?**
    - **JV:** As long as that is assumed, you are completely welcome.
    - **VO:** Take a peek at the TRL information that we have on the Resources page, because as you're estimating if technology would be ready or available to you, you may want to take a peek and see if it would be ready or available to you based on those kinds of estimations.

11. **[1:12:54] What is the Forum experience like?**
    - **VO:** At our events, we try really hard to focus on networking as well as fun. We understand that everybody here will be working very hard up until that proposal deadline, and then 12 Finalist Teams will be joining us for the onsite Forum next June. We want to give you the absolute best opportunity to shine during the during the Forum. The day before the Forum starts, we'll host a networking event. The next day, we will begin with Team Presentations. Each team will have 25 minutes to present their concepts followed by a [20]-minute Q&A Session. Each day of presentations will have morning, lunch, and afternoon breaks, and a Poster Session for presenters. The Forum will not be open to the

public, but anyone can watch via livestream. On the last day of the Forum, participants will either be able to partake in a tour of NASA's Marshall Space Flight Center or the U.S. Space & Rocket Center. Then, we will host an Awards Ceremony Luncheon where the Forum Winners will be announced.

Other Questions

1. **Did any previous missions involve the use of cryogenic components and fluids that we could then use in application for this project?**
    - Yes, previous missions have used cryogenic technology. We have a wealth of resources available on the HuLC Resources webpage under "Recommended Reading," and we encourage you to search NTRS for more information that might relate specifically to your concept.

2. **Since the project will be implemented in 3-5 years, what will be done if a new problem or solution arises?**
    - You should address contingency plans for potential problems and new technology in your proposal and tell us what you would do or how that would affect your concept.

3. **What is considered to be "affordable enough to merit consideration for implementation?" What are the current cost estimates that NASA has for the development of these systems?**
    - You tell us! "Affordable" cost will vary depending on the proposed solution. Teams should propose innovative concepts that include realistic budgets for implementation. You are encouraged to do research and/or trade studies to justify your cost with the **impact** of the proposed solution. Affordability can be considered as a trade between cost and the impact of your solution, and it is the proposers' job to convince the judges that your design is worth its cost.