



# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA) CENTENNIAL CHALLENGES PROGRAM (CCP) *Space Robotics Challenge Phase 2 (SRC2)* *Official Rules*

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## 1.0 REVISION TRACKING LOG

Section	Revision #	Description	Date
	0	Original Document	08/12/2019

## 2.0 ACRONYMS

- **CCP** - Centennial Challenges Program
- **ISRU** - In-Situ Resource Utilization
- **NASA** - National Aeronautics and Space Administration
- **SCH** - Space Center Houston
- **SRC** - Space Robotics Challenge
- **SRC2** - Space Robotics Challenge Phase 2



## **3.0 INTRODUCTION**

NASA has partnered with The Manned Space Flight Education Foundation, Inc. (henceforth referred to as Space Center Houston or SCH) to develop and execute Phase 2 of the Space Robotics Challenge (SRC2). The Space Robotics Challenge (SRC) is part of the NASA Centennial Challenges, which was initiated in 2005 to directly engage the public and seek innovation from diverse and non-traditional sources in the process of advanced technology development. NASA's Centennial Challenges program offers incentive prizes to generate revolutionary solutions to problems of interest to NASA and the nation. Awards are only made to competitors when the challenges are successfully met and can potentially provide those competitors with the opportunity to stimulate or create new business ventures.

As NASA moves forward with plans to support human exploration of the solar system, a critical need arises to supply basic materials such as oxygen (O<sub>2</sub>) and water (H<sub>2</sub>O), food, propellants, and other materials (radiation shielding, clothing, etc.). As humans venture farther from Earth and for greater periods of time, it becomes imperative to develop technologies and mission architectures that utilize local resources, such as those found in lunar regolith, to provide supplies needed for human exploration. In-situ resource utilization (ISRU) is an overall approach to support human exploration based upon utilization of resources derived from extraterrestrial bodies. (Source: <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150023468.pdf>)

NASA's vision of Phase 2 of the Space Robotics Challenge is seeking to foster the creation or advancement of autonomous capabilities of lunar surface robots. Future ISRU missions may occur on surfaces such as Earth's moon, and will likely need to operate autonomously for long periods of time before, during, and after the presence of astronauts. Robots that can successfully perform ISRU tasks with little to no human intervention are valuable due to both the communication latencies and limited bandwidth between these destinations and Earth. Additionally, NASA has unique constraints for robotic systems in space compared to terrestrial applications, namely the radiation and thermal environments encountered, which affect the processing and sensing capabilities available for robotic systems. It is also recognized that many of the robotic capabilities needed for future exploration missions could have highly valuable functionality for terrestrial robotic applications, such as disaster relief, exploration of difficult and/or dangerous terrains, and industrial plant maintenance and servicing.

The focus of SRC Phase 2 is on the ability of virtual robotic systems to perform a long-term fully-autonomous ISRU mission for the Moon. This challenge will require competitors to develop software that allows a team of virtual robots (i.e., virtual robotic team) to operate fully autonomously for a specified length of time. The Competition Rounds will be carried out in a robotic simulation format, using [Open Robotics'](#) Gazebo and Robot Operating System (ROS) platforms.

The challenge will consist of a Qualification Round and a Competition Round. Both rounds will require fully autonomous operations, such that competitors will not be able to interact with their virtual robotic teams during a challenge run. The Qualification Round will consist of three tasks, each to be completed individually, but not necessarily sequentially. The virtual robotic systems needed to complete these tasks will be provided to competitors. The tasks of the Qualification Round will consist of autonomously locating resources and objects in a simulated lunar world, extracting resources from the regolith, and navigating about the lunar simulation surface. Successful completion of these qualification tasks will provide confidence that competitors can reasonably attempt, or possibly complete, the Competition Round. The top 25 scoring teams will move on to the Competition Round. For the Competition Round, competitors will select their own virtual robotic team from a compiled list of different robot archetypes, while meeting a specified mass constraint for the overall robotic team. During the Competition Round, competitors' virtual robotic teams will locate various resources within the lunar regolith, excavate and collect resources,



transport the resources, and deposit the resources into a processing plant. Constraints will be introduced randomly, including maintenance issues, degradation of systems, and recharging needs. The top scoring competitors will win prizes as indicated in Section 4.0.

## **4.0 PRIZES**

A prize purse of up to \$1,000,000 USD will be awarded across two rounds of competition.

### **Qualifying Round - Awards:**

The Top 25 scoring competitors in the Qualification Round that meet or exceed a given threshold score, will be awarded prizes from a purse of \$375,000 USD.

**Only the Top 25 scoring competitors will be invited to compete in the Competition Round.**

Competitors will be able to win a maximum of \$15,000 USD. Should a competitor not complete all required tasks, but still be in the Top 25 scoring competitors, a percentage of the \$15,000 will be awarded based on the percentage of the trial that was completed.

### **Competition Round - Awards:**

The Top 10 scoring competitors in the Competition Round that meet or exceed a given threshold score, will be awarded prizes from a purse of \$625,000 USD.

First Place: \$185,000 USD

Second Place: \$125,000 USD

Third Place: \$75,000 USD

Fourth Place: \$50,000 USD

Fifth Place: \$40,000 USD

Sixth through Tenth Place: \$30,000 USD each



## **5.0 SCHEDULE**

<b>Date/Deadline</b>	<b>Event</b>
August 12, 2019 9:00 AM Central Time	Challenge Opens for Registration
December 20, 2019 5:00 PM Central Time	Challenge Registration Closes
January 15, 2020 by 5:00 PM Central Time	Packet of Robot Information Delivered to Competitors
March 16, 2020 9:00 AM Central Time	Qualification Round Opens
August 19, 2020 5:00 PM Central Time	Qualification Round Closes (simulation code due)
November 9, 2020 by 9:00 AM Central Time	Qualification Round Winners Announced
December 7, 2020 9:00 AM Central Time	Competition Round Opens
June 30, 2021 5:00 PM Central Time	Competition Round Closes (simulation code due) & Electronic Summary due
September 13, 2021	Winners Announced at Live Space Center Houston Event

## **6.0 ELIGIBILITY TO PARTICIPATE**

In order to participate in the Space Robotic Challenge, each individual, whether acting alone or as part of a Competitor Team must identify his/her nationality.

- No individual competitor shall be a citizen of a country on the NASA Export Control Program list of Designated Countries List Category II: Countries determined by the Department of State to support terrorism. The current list of designated countries can be found at <http://oior.hq.nasa.gov/nasaecp>. Please check the link for latest updates. This includes individuals with dual citizenship unless they are a U.S. citizen or a lawful permanent U.S. resident (green card holder).
- While China is not a Category II designated country, pursuant to Public Law 116-6, Section 530, NASA is prohibited from participating, collaborating, or coordinating bilaterally in any way with China or any Chinese-owned entity. Team members who are citizens of China but not affiliated with a Chinese entity may be permitted to participate on a Team.



- Subject to the conditions set forth herein, foreign nationals and foreign national teams can participate in the Challenge. However, they are not eligible for a cash prize, and must acknowledge acceptance of this by signing and submitting a Foreign Participant Acknowledgement Form.
- A competitor team-designated lead shall be responsible for both compliance with the rules (including prize eligibility rules) and the actions of all members of the team.

## **6.1 ELIGIBILITY FOR PRIZE**

In order to be eligible to win a prize:

1. **Individuals must be** U.S. citizens **OR** permanent residents of the United States, **AND** over the age of 18.
2. **Organizations must be** an entity incorporated in **AND** maintaining a primary place of business in the United States.
3. **Competitor Teams must be** comprised of otherwise eligible individuals or organizations, **AND** led by an otherwise eligible individual or organization.
4. **Team Leader must be** a U.S. citizen or permanent resident.

**A Team may include foreign nationals and be eligible to win prize money as long as** the foreign national signs and delivers a disclosure (separate form) wherein he/she discloses his/her citizenship and acknowledge that he/she is not eligible to win a prize from NASA, **AND**

- I. The foreign national is an employee of an otherwise eligible U.S. entity participating in the Challenge,
- II. The foreign national is an owner of such entity, so long as foreign citizens own less than 50% of the interests in the entity,
- III. The foreign national is a contractor under written contract to such entity, **OR**
- IV. The foreign national is a full time student, during the time of the Challenge, of an otherwise eligible entity which is an accredited institution of higher learning, **AND** the student is during the Challenge in the United States on a valid student visa and is otherwise in compliance with all local, state, and federal laws and regulations regarding the sale and export of technology.

Team Members must furnish proof of eligibility (including proof of citizenship or permanent resident status, for individuals, and proof of incorporation and primary place of business, for entities) which proof must be satisfactory to NASA in its sole discretion. A Team's failure to comply with any aspect of the eligibility requirements shall result in the Team being disqualified from winning a Prize from NASA.

U.S. government employees may enter the competition, or be members of prize-eligible teams, so long as they are not acting within the scope of their Federal employment, and they rely on no facilities, access, personnel, knowledge or other resources that are available to them as a result of their employment except for those resources available to all other participants on an equal basis.

U.S. government employees participating as individuals, or who submit applications on behalf of an otherwise eligible organization, will be responsible for ensuring that their participation in the Competition is



permitted by the rules and regulations relevant to their position and that they have obtained any authorization that may be required by virtue of their government position. Failure to do so may result in the disqualification of them individually or of the entity which they represent or in which they are involved.

Teams will be ineligible to win the Prize if any Team Member is a Federal entity or Federal employee acting within the scope of their employment. This includes any U.S. Government organization or organization principally or substantially funded by the Federal Government, including Federally Funded Research and Development Centers, Government-owned, contractor operated (GOCO) facilities, and University Affiliated Research Centers. No U.S. government funds may be used to participate in the Challenge. Any such entity or individual shall obtain prior written approval from their cognizant ethics officer that such participation does not violate federal personnel laws or applicable agency policy. A copy of this approval to participate in the Challenge shall promptly be provided to SCH.

Current employees, consultants, and students of Space Center Houston may only participate as Team Members when the Team is not competing for the Prize from NASA. Participation of such parties as Team Members on a Team will make a Team ineligible for any Prize award.

## **7.0 REGISTRATION**

All interested competitors must register for the Challenge by the deadline and meet the eligibility requirements in order to participate in the Challenge. Registration for the SRC takes place through the official challenge website [www.spaceroboticschallenge.com](http://www.spaceroboticschallenge.com). Section 5.0 documents the Challenge schedule which includes registration.

## **8.0 QUALIFICATION ROUND**

The Qualification Round will test competitors' abilities to virtually complete specific tasks that will be required during the Competition Round. Each task represents a capability needed to execute an autonomous ISRU mission. Competitors will develop software to enable an *a priori* robot to complete these tasks in a simulated lunar environment. Competitors will be provided with Gazebo simulation environments for development and testing, as well as ROS APIs to enable communication between the robots on the virtual robotic team. Provided Gazebo environments will be similar, but not identical to the competition environment. A few examples of differences might include the locations of the various resources and collection sites, the quantities of resources at each site, the location and type of lunar terrain, as well as the exact location of the home base. Details of the robotic system used for each task will be provided after registration opens.

For scoring runs of the Qualification Round, competitors will run their software to complete each task on their own local computer. Qualification runs will continue until time has lapsed for the run. The result of the run for each task will be uploaded at a given web location provided by the challenge website. More details about how to deliver the end result will be provided in the competition wiki site prior to the Qualification Round.



The 25 competitors with the highest scores will be required to submit their software to be run on the Challenge's host computer for verification.

## **8.1 QUALIFICATION ROUND TASKS AND SCORING**

The Qualification Round will be comprised of the following tasks. Each task will come with its own simulation environment. Tasks are completed individually, but are not required to be completed sequentially. More detailed instructions for these tasks will be provided after registration.

Resources important to ISRU processing on the lunar surface are listed below, and will be used for Qualification Round Tasks 1 and 2.

1. Water Ice (H<sub>2</sub>O)
2. Hydrogen (H<sub>2</sub>)
3. Carbon Dioxide (CO<sub>2</sub>)
4. Carbon Monoxide (CO)
5. Ammonia (NH<sub>3</sub>)
6. Hydrogen Sulfite (H<sub>2</sub>S)
7. Ethene/Ethylene (C<sub>2</sub>H<sub>4</sub>)
8. Methane (CH<sub>4</sub>)

### ● **Task 1: Resource localization**

- The goal of this task is to locate and identify as many resources as possible within the time constraints of the task.
- Competitors will develop software that allows a robotic system to search the lunar surface within a predefined area for resources. Resources will be located on or under the regolith surface within the area of discovery. Competitors will provide the locations and specific types of resources discovered in the lunar regolith. There will be a finite number of resource locations within the simulation environment. Resource locations shall be provided relative to the robot's starting location within the environment. Resource locations will be considered accurate if the position coordinates are within +/-2 meters of the actual simulated resource location.
  - Competitors will be provided with a prospecting robot equipped with sensors that allow for autonomous perception, as well as resource detection and identification.
  - Scoring metric:
    - 2 points for locating each resource location
  - Time constraint: 45 simulation minutes for this task

### ● **Task 2: Resource collection**

- The goal of this task is to excavate and collect as many resources as possible within the time constraints of the task.
- Location of the resources to be collected will be provided within the simulation. Resources should be expected to be at varying depths below the surface. Although there may be a trace of the resource at the surface, there may be resources deeper than the prospecting robot can detect. There will be a finite quantity of each resource within the simulation environment. Additionally, there will be a minimum quantity of resources that must be collected to receive points for this task. Resources will be considered "collected" if they are in the robotic haulers at the end of the task.
  - Competitors will be provided with a robotic excavator and multiple robotic haulers that are equipped with sensors that allow for autonomous perception.
  - Scoring metric:
    - 1 point for the minimum amount of each resource collected in a lighted area



- 1 point for each additional multiple of the minimum amount of resource collected in a lighted area
- 2 points for the minimum amount of each resource collected in a permanently shadowed region
  - 2 points for each additional multiple of the minimum amount of resource collected in a permanently shadowed region
- Time constraint: 45 simulation minutes for this task

● **Task 3: Self-localization**

- The goal of this task is to demonstrate self-localization of a robotic system.
- An *a priori* object will be placed in the simulation world, and a model template for that object will be provided. The location of that object must be reported, and the robot then must return to home base. The location provided will be considered accurate if the position coordinates are within +/-5 meters of the simulated *a priori* object location in the simulation environment. Additional points will be provided for aligning the robot with a specific target at home base. Fiducial markers will be provided to assist with alignment.
  - Competitors will be provided with a robot equipped with sensors that allow for autonomous perception.
  - Scoring metric:
    - 5 points for providing the accurate location of the *a priori* object
    - 5 points for getting back to home base
    - 3 additional points for correct alignment at home base
  - Time constraint: 45 simulation minutes for this task

In the event of a tie in the Qualification Round, the least amount of time to return to home base after locating the *a priori* object in Task 3 will be used as a tie-breaker.

## **8.2 QUALIFICATION ROUND DEVELOPMENT AND PRACTICE**

Competitors will be provided access to an online repository for downloading of practice simulation worlds and interface files. Competitors will have six months for software development of their challenge solutions. Suggested specifications for computers to run both the challenge software and the simulation software are listed in Section 10.0: Hardware and Software Specifications.

## **9.0 COMPETITION ROUND**

The purpose of the Competition Round is for the competitors' virtual robotic teams to complete a long-term autonomous ISRU mission in simulation. Competitors will develop software to enable their virtual robotic teams to perform this mission in a simulated lunar environment. As in the Qualification Round, competitors will be provided with Gazebo simulation environments for development and testing, as well as ROS APIs to enable communication between the robots on the virtual robotic team. Development/practice Gazebo environments will be similar, but not identical to the competition simulation environment.

For this round, competitors must select a virtual robotic team to complete the ISRU mission. Competitors will be provided a database of robotic systems and capabilities/specifications for each robot to determine the makeup of the robotic team they want to use in the competition. The database will provide in-depth



specifications and capabilities for each robot. All robots will contain a range of sensors, and it is up to competitors as to whether or not sensors are activated and used (sensors require additional power). Competitors will have a mass constraint they must meet for their robotic team. Forms will be provided to competitors for team selection and submittal to demonstrate their robot team does not exceed the mass constraint.

During the evaluation period, while the competitors' runs are being scored, there will be no interaction between competitors and their software, affording a fully autonomous mission scenario. Scoring logs will be provided to each competitor after the Competition Round is completed.

Competition runs will be managed on a field computer by the SRC2 challenge administrators. All competitors will upload their ROS software packages to the location provided by the challenge website. Competition runs will be initiated by a roslaunch file provided by each competitor. Details of time synchronization for launch files and Gazebo launches will be provided to competitors before the start of Qualification. Once the launch process begins, the only possibilities for a "restart" are if either the simulation or field computers stop functioning properly, or if an error by the SRC2 challenge administrators cause an issue. Competition runs will continue until time has lapsed for the run, or until competitors' virtual robotic teams find and collect all resources.

Each competitor will be allowed three scoring runs. The average score over these three scoring runs will be used for the final score. Competitors will be provided with their scores, and rosbag files containing all data collected from the challenge software and the simulation during each run, so that competitors have the option of playing-back their runs.

In order to qualify for prize money in the Competition Round, competitors are expected to submit an electronic summary containing their concept of operations, results, and lessons learned. A template will be provided in the Competitors' Packet, specifying the information desired by NASA, which can assist in eventually deploying competitors' software to future NASA missions.

## **9.1 COMPETITION ROUND TASKS AND SCORING**

The objective for the Competition Round is for the robotic ISRU team to gather as much valuable lunar regolith as possible, given long-term mission constraints. The simulated environment will assume the competitors' virtual robotic teams have landed on the lunar surface. Simulation worlds will recreate the lunar lighting as best as possible, and because some of the long-term ISRU tasks may take place in a permanently shadowed crater, competitors should expect their virtual robotic team to operate in the dark.

The Competition Round will consist of the Qualification Round tasks, but in a continuous mission, rather than independent tasks. During this round, robots will begin to degrade and require recharging and maintenance. Competitors will be provided means to repair certain degradations and failures. Resources will be hidden within the simulated environment, and should be expected to be at varying depths below the surface. Although there may be a trace of the resource at the surface, there may be resources deeper than the prospecting robot can originally detect before excavation has begun.

The long-term ISRU mission constituting the Competition Round will have a time constraint of 2 simulation hours. Competitors should note that Gazebo simulation time decreases with increased models in a world, and as such, large virtual robotic teams will likely decrease the speed at which the simulation will run. Each competitor will be allowed three runs for the final competition. All runs will be completed on the field computer (see Section 10).



Scoring will be based on points per unit of resource processed using a given processing plant. Partial resource units will be scored with partial points proportional to the amount of partial units.

<b>Scoring Opportunities for Competition Round</b>		
<b>Resource</b>	<b>Minimum Quantity</b>	<b>Points Per Unit*</b>
Water Ice/Gas (H <sub>2</sub> O)	60 kg	1 point/10 kg
Ethene/Ethylene (C <sub>2</sub> H <sub>4</sub> )	0 kg	20 point/kg
Methane (CH <sub>4</sub> )	0 kg	14 point/kg
Methanol (CH <sub>3</sub> OH)	0 kg	16 point/kg
Carbon Dioxide (CO <sub>2</sub> )	3 kg	3 point/kg
Ammonia (NH <sub>3</sub> )	4 kg	2 point/kg
Hydrogen Sulfite (H <sub>2</sub> S)	10 kg	1 point/2 kg
Sulfur Dioxide (SO <sub>2</sub> )	2 kg	1 point/kg

In the event of a tie, the following tie-breakers will be implemented:

<b>Tie-Breaker Criteria for Competition Round</b>	
<b>Order Sort</b>	<b>Criteria</b>
1st	Least combined mass of the virtual robotic team
2nd	Point value of resources in haulers at the conclusion of Competition Round
3rd	Number of resource types collected at the conclusion of Competition Round
4th	Number of original robotic team members still performing their intended function(s) at the conclusion of Competition Round

## **9.2 COMPETITION ROUND DEVELOPMENT AND PRACTICE**

Competitors will be provided access to an online repository for downloading of practice simulation worlds. Competitors will have seven months for software development of their challenge solutions.

Prior to the final Competition, Competitors will be required to participate in a dry-run of the Competition using the software and services to be used in the SRC2 Competition. The dry run will mimic conditions during the final competition, including the use of scoring plug-ins, random robot system degradations, and the use of competition hardware.



Suggested specifications for computers to run both the challenge software and the simulation software are listed in Section 10.0: Hardware and Software Specifications.

## **10.0 HARDWARE AND SOFTWARE SPECIFICATIONS**

Minimum System Requirements to run SRC P2 Simulation:

- An NVidia family GPU
- Intel i5 CPU or equivalent
- 8 GB of RAM
- 25GB of free disk space or more
- Ubuntu 18.04.2 LTS (Bionic Beaver)
- ROS Melodic Morenia
- Gazebo 9

## **11.0 FINAL SCORING**

Once each competitors' three scoring runs have been completed on the field computer, the average score of the three runs will be calculated, and all competitors' scores will be ranked highest to lowest. If a tie-breaker is required in order to have a discernible Top 10, the tie-breaker criteria (Section 9.1) will be applied.

Once the Top 10 is determined by score, and the timely receipt of the respective electronic summaries has been verified (See Section 5.0 and Section 9.0), the judges will view the Top 10 solutions in an effort to determine the integrity of the solutions and ensure no simulation "hacks" were used. If it is determined a "hack" of any kind was used, the competitor will earn a score of 0 (zero) for that scoring run. If necessary, the next highest scoring Team will be moved up into the Top 10. Once the scoring is complete, each Team Leader will be provided with their Competition Round score.

The Team Leader must submit any appeal in writing to the Ombudsman within one day of releasing competitors' scores and competition data logs to team leaders, and prior to prizes being awarded. All correspondence relating to an appeal will be conducted through the Ombudsman. An Ombudsman will act solely as the mediator between the Competitors and the Judging Panel if any appeals are raised. No Team members will approach the Judges with an appeal, or attempt to sway the Judges' decision. The Judges' decision of the appeal will be conveyed by the Ombudsman before the award of prizes and will be considered final.

## **12.0 MODIFICATIONS**

Competitors are invited to communicate directly with Space Center Houston using the SRC email address ([info@spaceroboticschallenge.com](mailto:info@spaceroboticschallenge.com)) regarding any rule that restricts their ability to demonstrate technical achievement and innovative solutions to space robotics.

Requests for rules clarifications should be sent to [info@spaceroboticschallenge.com](mailto:info@spaceroboticschallenge.com), and all questions and responses will be made public and shared with all competitors on the SRC website. To ensure



competitors' proprietary information is protected, competitors should indicate any confidential questions in the subject of the inquiry. SCH will hold confidential any questions that are designated as proprietary. SCH will also ensure that answers do not give any team an unfair advantage.

SCH and NASA Centennial Challenges reserve the right to alter the rules if deemed necessary. In addition, circumstances may arise that require adjustments to the Challenge timeline. Such adjustments of the challenge timeline is within the full discretion of SCH and NASA Centennial Challenges. Competitor Teams will be notified of any changes to the rules and/or timeline, and given the opportunity to voice concerns and/or request modifications. Final authority for all changes will rest with SCH.

