NATIONAL AERONAUTICS AND SPACE ADMINISTRATION {NASA}

CENTENNIAL CHALLENGES PROGRAM

CO_2 Conversion Challenge Competition Rules

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1.0 REVISIONS TRACKING LOG

Section	Revision #	Description	Date
	0	Original Document	8/16/2018

2.0 DEFINITION OF TERMS

1.1 CO_2 – Carbon Dioxide. A colorless gas with a density about 60% higher than that of dry air. Carbon dioxide consists of a carbon atom covalently double bonded to two oxygen atoms. It occurs naturally in Earth's atmosphere as a trace gas, and makes up the majority of the atmosphere of Mars.

1.2 Centennial Challenges Program – A NASA program that was initiated to use prizes to generate revolutionary and innovative solutions to problems of interest to NASA and the nation. The program seeks innovations from diverse and non-traditional sources and engages the public in the process of advanced technology development.

1.3Independent Laboratory – A laboratory outside of NASA that will provide independent verification and testing to confirm attainment of the Challenge specifications.

1.4 Judging Panel – A panel of personnel selected from among NASA, academic, and industry researchers and subject matter experts who specialize in the topic area and who will judge Challenge entries but are not competing in the Challenge.

3.0 CHALLENGE BACKGROUND

Future planetary habitats on Mars will require a high degree of self-sufficiency. This requires a concerted effort to both effectively recycle supplies brought from Earth and use local resources such as CO_2, water and regolith to manufacture mission-relevant products. Human life support and habitation systems will treat wastewater to make drinking water, recover oxygen from CO_2, convert solid wastes to useable products, grow food, and specially design equipment and packaging to allow reuse in alternate forms. In addition, *In-situ* Resource Utilization (ISRU) techniques will use available local materials to generate substantial quantities of products to supply life support needs, propellants and building materials, and support other In-SpaceManufacturing (ISM) activities.

Many of these required mission products such as food, nutrients, medicines, plastics, fuels, and adhesives are organic, and are comprised mostly of carbon, hydrogen, oxygen and nitrogen molecules. These molecules are readily available within the Martian atmosphere (CO_2, N_2) and surface water (H_2O), and could be used as the feedstock to produce an array of desired products. While some products will be most efficiently made using physicochemical methods or photosynthetic organisms such as plants and algae, many products may best be produced using heterotrophic (organic substrate utilizing) microbial production systems. Terrestrially, commercial heterotrophic bioreactor systems utilize fast growing microbes combined with high concentrations of readily metabolized organic substrates, such as sugars, to enable very rapid rates of bio-product generation.

The type of organic substrate used strongly affects the efficiency of the microbial system. For example, while an organism may be able to use simple organic compounds such as formate (1- carbon) and acetate (2-carbon), these "low-energy" substrates will typically result in poor growth. In order to maximize the rate of growth and reduce system size and mass, organic substrates that are rich in energy and carbon, such as sugars, are needed. Sugars such as D-Glucose, a six-carbon sugar that is used by a wide variety of model heterotrophic microbes, is typically the preferred organic substrate for commercial terrestrial microbial production systems and experimentation. There are a wide range of other compounds, such as less complex sugars and glycerol that could also support relatively rapid rates of growth.

To effectively employ microbial bio-manufacturing platforms on planetary bodies such as Mars, it is vital that the carbon substrates be made on-site using local materials. However, generating complex compounds like glucose on Mars presents an array of challenges. While sugar-based substrates are inexpensively made in bulk on Earth from plant biomass, this approach is currently not feasible in space. Alternatively, current physicochemical processes such as photo/electrochemical and thermal catalytic systems are able to make smaller organic compounds such as methane, formate, acetate and some alcohols from CO_2; however, these systems have not been developed to make more complex organic molecules, such as sugars, primarily because of difficult technical challenges combined with the low cost of obtaining sugars from alternate methods on Earth. Novel research and development is required to create the physicochemical systems required to directly make more complex molecules from CO_2 in space environments. It is hoped that advancements in the generation of suitable microbial substrates will spur interest in making complex organic compounds from CO_2 that could also serve as feedstock molecules in traditional terrestrial chemical synthesis and manufacturing operations.

The CO_2 Conversion Challenge is devoted to fostering the development of CO_2 conversion systems that can effectively produce singular or multiple molecular compounds identified as desired microbial manufacturing ingredients and/or that provide a significant advancement of physicochemical CO_2 conversion for the production of useful molecules.

4.0 CHALLENGE OBJECTIVE

The overall objective of this challenge is to demonstrate a solely physicochemical (no biological processing) process/system that uses CO_2 as the only carbon source to produce selected carbon-based molecular compounds. The compounds of interest are provided in Table 1, with an associated preference factor between 0 and 10, with D-glucose being the most preferred. The source CO_2 and hydrogen can be supplied from a commercially available pure gas (i.e., tanked CO_2 and H_2), or verifiably obtained from an alternate source (e.g., H_2 from water electrolysis). To increase the potential for use in space missions, scalable, low mass/power/volume systems are sought. Likewise, the ability to make target compounds at high efficiency and specificity, and with minimal contaminants and/or toxic by-products, is preferred.

Table 1. Challenge target compounds and associated preference factor.

Challenge Compound	Preference Factor
D-Glucose	10
Other 6-carbon sugars (hexoses)	7
5-carbon sugars (pentoses)	5
4-carbon sugars (tetroses)	3
3-carbon sugars (trioses)	2
Glycerol	2

5.0 CHALLENGE RULES AND REQUIREMENTS

NASA envisions this competition having two phases with a total prize purse of up to $1 million. Phase 1 (the current phase) is the Concept Phase with a prize purse of up to $250,000.The initiation of Phase 2, a Demonstration Challenge with a prize purse of up to $750,000, is contingent on the emergence of promising submissions in Phase 1 that demonstrate a viable approach to achieve the Challenge goals. The official rules for Phase 2 will be released prior to the opening of Phase 2.

Phase 1 (Concept Phase) rules

- **Team Registration** – All teams must register by the given deadline to participate in the Challenge
- **Concept Submission-** Prior to the submittal deadline, competitors are required to provide a preliminary design schematic and description of the physicochemical conversion system they could construct to demonstrate the production of selected carbon-based molecular compounds. To be eligible for the prize, the Concept must indicate a viable path to success. The Concept is to be supported by rationale obtained from basic and/or applied research, and will include all of the following:
    - Description of the major hardware components of the physicochemical conversion system
    - Description of the CO_2 conversion process the system uses and its chemistry, including any consumable chemicals, catalysts, etc.
    - List of targeted compounds and their characteristics (concentration, solid/liquid, pH, and any other applicable information). The system should be able to make at least one compound on Table 1, understanding that systems that can produce the more favored compounds will be ranked higher
    - The projected system mass/energy/size, and anticipated CO_2-to-product(s) conversion efficiency and production rate
    - Any preliminary laboratory data that support the design and operation of the proposed CO_2 conversion process

- A list of assumptions and supporting calculations

NOTE: The system should be scaled such that, at a minimum, it generates sufficient product within a continuous 7 hour period to allow analytical characterization/verification using conventional analytical methods.

6.0 PHASE 1 EVALUATION OF SUBMISSIONS

- In addition to providing a Concept as described above, each team will be required to present its prototype design and to discuss any data from preliminary laboratory testing (if available) with a judging panel during a webinar. In addition, each team will be required to submit a short video to introduce their team, discuss qualifications, available facilities, and approach. Judges will evaluate the inputs supplied by the teams and determine an overall ranking of all submissions. The challenge submittal period officially ends six months after registration is opened.
- Up to five (5) awards of $50,000 each will be made to the top competitors with the highest judges' scores for demonstrating a viable approach to achieve the Challenge goals.
- The judging panel's evaluation of the submissions will be based on the following scoring criteria:
  - **Factor 1.) Scientific/Technical Merit (25%):** Do the specific objectives, approaches and plans for developing and verifying the innovation demonstrate a clear understanding of the problem and the current state-of-the-art? Does the Concept clearly and thoroughly present the requested information needed to adequately evaluate the effort?
  - **Factor 2.) Feasibility of Proposed System (25%):** Does the Concept present a compelling case that the proposed technology is a clearly innovative and feasible technical approach to meet the Challenge success criteria? Does the team clearly understand the risks and address them in their Concept?
  - **Factor 3.) Applicability of Proposed System for Space Missions (25%):** Do the anticipated characteristics of the proposed technology support its potential use in future space exploration missions? Do the system attributes address the general need for efficiency, low mass/power/volume, and scalability?
  - **Factor 4.) System Fabrication and Test Plans (25%):** Does the team provide a clear pathway for the future fabrication and testing of the proposed technology? Do the participants demonstrate the necessary technical capabilities and experience, and have access to the necessary instrumentation, facilities, and other resources required to successfully build and test the proposed system?

- Additional details on the Submission Review process and Scoring can be found on the official challenge site at www.co2conversionchallenge.org/#scoring.

7.0 ELIGIBILITY TO WIN PRIZE MONEY

NASA welcomes applications from individuals, teams, and organization or entities that have a recognized legal existence and structure under applicable law (State, Federal or Country) and that are in good standing in the jurisdiction under which they are organized with the following restrictions:

1. **Individuals** **<u>must be</u>** U.S. citizens or permanent residents of the United States and **<u>must be</u>**18 years of age or older.
2. **Organizations** **<u>must be</u>** an entity incorporated in and maintaining a primary place of business in the United States.
3. **Teams** **<u>must be</u>** comprised of otherwise eligible individuals or organizations, and led by an otherwise eligible individual or organization.
4. **Teams** **<u>must</u>** conduct their demonstration work in facilities based in the United States, to include AK, HI and U.S. territories.

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.

Foreign citizens <u>may only participate</u> through an eligible US entity as:

- (i) An employee of such entity
- (ii) A full-time student of such entity, if the entity is a university or other accredited institution of higher learning,
- (iii) An owner of such entity, so long as foreign citizens own less than 50% of the interests in the entity, **OR**
- (iv) A contractor under written contract to such entity.

No Team Member shall be a citizen of a country on the NASA Export Control Program list of designated countries in Category II, Countries determined by the Department of State to support terrorism. The current list of designated countries can be found at http://oiir.hq.nasa.gov/nasaecp/. As of July 12, 2018, only 4 countries are in category II (Iran, North Korea, Sudan, and Syria). Please check the link for latest updates.

A team-designated team lead shall be responsible for the actions of and compliance with the rules, including prize eligibility rules, by all members of his or her team.