NASA STTR 2022 Phase I Solicitation

T7.05 Climate Enhancing Resource Utilization

Lead Center: GRC

Participating Center(s): ARC, KSC, MSFC

Scope Title
Sustainable Atmospheric Carbon Dioxide Extraction and Transformation

Scope Description

Component and subsystem technologies are sought to demonstrate sustainable, energy-efficient extraction of carbon dioxide (CO$_2$) from a defined planetary or habitable atmosphere fully integrated with CO$_2$ transformation into one or more stable products such as manufacturing feed stock polymers or readily storable, noncryogenic propellants or fuels. This scope is intended to incentivize revolutionary, dual-use technologies that may lead to reduced dependence of sustainable space exploration activity on terrestrial supplies of carbon-containing resources and lead to products with commercial promise for repurposing terrestrial atmospheric CO$_2$. At the core of this scope is a requirement for integrated technology solutions that dramatically reduce mass, volume, and end-to-end energy consumption of highly integrated CO$_2$ collection and transformation.

Proposals must specifically and clearly describe: (1) physical and/or chemical processes to be implemented for CO$_2$ collection and transformation, including reference to the current state of the art; (2) specific engineering approaches to be used in dramatically reducing mass, volume, and end-to-end energy consumption per mass of product carbon content mass; (3) validated performance estimates of high-cycle utilization of any sorption, catalytic, or other unconsumed materials used in the CO$_2$ collection or transformation processes; (4) suitability or adaptability of the proposed CO$_2$ capture approach for operation in various ambient CO$_2$ mixture and partial pressure environments (i.e., ambient Mars atmosphere to ambient Earth atmosphere conditions); (5) substantiated estimates of the mass conversion efficiency of ingested carbon to product carbon; and (6) estimated total end-to-end energy consumption per unit mass of product carbon.

The scope specifically excludes: (1) evolutionary improvements in mature CO$_2$ collection technologies that do not provide large reductions in mass, volume, and end-to-end energy consumption; (2) CO$_2$ collection approaches that employ CO$_2$ absorbing materials that require frequent replenishment or replacement (e.g., greater than 50% reduction in absorption efficiency after 500 cycles); (3) technologies considered as life support systems including air revitalization, water processing, or waste processing; (4) biological or biology-based components or subsystems of any kind; and (5) CO$_2$ transformation products that are not readily stored at approximately Earth-ambient conditions such as cryogenic propellants.

Expected TRL or TRL Range at completion of the Project:

3 to 5
Primary Technology Taxonomy:
Level 1: TX 07 Exploration Destination Systems
Level 2: TX 07.1 In-Situ Resource Utilization

Desired Deliverables of Phase I and Phase II:
- Prototype
- Research
- Analysis

Desired Deliverables Description:
Phase I deliverable is defined as a detailed feasibility study that clearly defines the specific technical innovation and estimated performance of CO₂ collection and transformation into products, identifying critical development risks anticipated in a Phase II effort. Technology feasibility evaluation should address the scope proposal elements including: (1) process descriptions; (2) results of engineered mass, volume, and energy consumption efficiency designs; (3) cyclic performance of participating unconsumed process materials; (4) adaptability to different atmospheric CO₂ mixtures and partial pressures; (5) ingested atmosphere throughput and carbon conversion efficiency to product carbon, and (6) estimated total end-to-end energy consumption per unit mass of product carbon. Phase I feasibility deliverables should include laboratory test results that demonstrate the performance of unit processes, components, or subsystems against these metrics.

Phase II deliverables are to include matured feasibility analysis provided in Phase I, and matured laboratory prototype components or subsystems integrated into an end-to-end CO₂ collection and transformation prototype system, including design drawings. Component, subsystem, and integrated system performance test data is a specific deliverable and must include: (1) cyclic performance; (2) ingested atmosphere throughput and carbon conversion efficiency to product carbon; (3) evaluated properties of products; and (4) the results of engineered mass, volume, and energy consumption efficiency designs including measured end-to-end energy consumption per unit mass of product carbon. Analysis deliverables for Phase II should address a credible path toward maturation of the technology and approaches to scaling the technologies to larger processing capacities.

State of the Art and Critical Gaps:
This topic is intended to solicit innovative technologies with clear dual use: (1) adoption by NASA for infusion into long-term mission capabilities enabling mission scale in situ resource utilization (ISRU) use of the Martian atmosphere and (2) commercialization and the potential formation of a terrestrial industry to meet potentially significant future demand for terrestrial atmospheric CO₂ extraction and repurposing. Additionally, if or as a viable industry associated with terrestrial applications of these technologies emerges, commercial competition may continue to drive innovation and contribute over the long term to improved NASA mission capability. Early-stage innovations in this topic are anticipated from teams of small businesses and research institutions, which can demonstrate feasibility and readiness for accelerated maturation.

Well-developed and mature technologies for atmospheric CO₂ capture have been flown and operated on NASA spacecraft, based on phase change (freezing) of ambient gas; accepting the power requirements and efficiency levels of both the refrigeration and heating devices in a freeze/thaw-based collection cycle. NASA operational collection of CO₂ from habitable atmospheres is performed using flow-through beds of sorption materials driven to saturation followed by either desorption processes or discarding of the sorption material and the collected CO₂. Similarly, CO₂ processing based on electrochemical reduction of CO₂ into carbon monoxide (CO) has been flown demonstrating production of oxygen from atmospheric sources. However, the collected carbon is a disposable byproduct. Significantly, these systems are not developed nor optimized for recovery and repurposing of considerable process heat drawn from spacecraft power sources, nor for repurposing of the collected carbon.
Recent literature suggests emerging laboratory research of both efficient CO\textsubscript{2} capture and repurposing processes is occurring and may be well positioned for development into components and subsystems suitable for longer-term infusion by NASA into ISRU systems and an emerging terrestrial industry.

**Relevance / Science Traceability:**

The quantification of resources on Mars suitable for the local production of a variety of mission consumables, manufactured products, and other mission support materials has become much better understood through recent in situ measurements and introductory technology demonstrations. Evolving mission scenarios for expanded robotic and human exploration of Mars uniformly depend on the utilization of these resources to dramatically reduce the cost and risks associated with these exploration goals. In order to reduce the broad goal of utilizing the CO\textsubscript{2} of the Martian atmosphere as a source of both carbon and oxygen to practical, full-scale reality, substantial improvements in system mass, volume, and power requirements are needed. This solicitation is intended to incentivize these innovations in the service of future NASA missions.

Additionally, there is a growing recognition of the planetwide consequences of accumulating CO\textsubscript{2} in the terrestrial atmosphere. Technologies that advance NASA's Mars ISRU aspirations may be created with the necessary energy efficiencies to support scaling up to terrestrial industrial capacity large enough to begin to reduce or reverse atmospheric CO\textsubscript{2} accumulation.

**References:**
