Next Generation Life Support (NGLS): Continuous Electrochemical Gas Separator Element

Game Changing Development Program | Space Technology Mission Directorate (STMD)

ABSTRACT

The purpose of this technology development task is to develop a new air purification system based on a liquid membrane, capable of purifying carbon dioxide from air in a far more compact and energy efficient system than what is currently possible. The approach relies on recent advances in supported liquid membranes, which allow the manufacture of mechanically stable, ultra-thin supported liquids that have permeability and selectivity for carbon dioxide over one order of magnitude greater than existing approaches. Most critically, because these membranes use a liquid as an active material, it is possible to electrochemically pump the carbon dioxide, making it viable to build an air purification system that uses no mechanical components such as compressors. Such an innovation has the potential to dramatically improve NASA's capabilities for human missions to Mars and other long-term space habitation applications.

ANTICIPATED BENEFITS

To NASA funded missions:

If successful and when mature, will provide an alternative carbon dioxide removal technology for existing spacecraft including the International Space Station and Orion.

To NASA unfunded & planned missions:

If successful and when mature, will provide an alternative carbon dioxide removal technology for future human exploration missions to a range of destinations beyond low Earth orbit (LEO), including cis-lunar space, near-Earth asteroids (NEAs), the moon, and Mars and its moons. If successful and when mature, may provide new carbon dioxide removal capability for the next generation portable life support systems (PLSS) for new space suits to be used during future human exploration missions to a range of destinations beyond low Earth orbit (LEO), including cis-lunar space, near-Earth asteroids (NEAs), the

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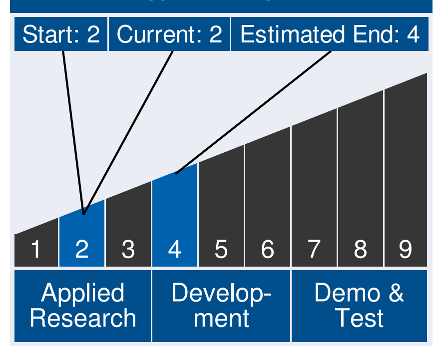
Technology Maturity



Management Team

Program Executive:

- Ryan Stephan

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moon, and Mars and its moons. May effectively work on Mars surface, where competing technologies based on pressure swing will not.

To other government agencies:

Submarine atmosphere purification (Department of Defense) Carbon doxide sequestration to prevent release into Earth's atmosphere (Department of Energy, Department of Transportation)

To the commercial space industry:

If successful and when mature, will provide an alternative carbon dioxide removal technology for future commercial human spacecraft.

DETAILED DESCRIPTION

Life support systems on human spacecraft are designed to provide a safe, habitable environment for the astronauts, and one of the most significant challenges is managing acceptable air quality. Carbon dioxide (CO2) is an important trace gas produced by human metabolism that must be actively removed from spacecraft cabin atmosphere. The Carbon Dioxide Removal Assembly (CDRA) currently on board the ISS performs the carbon dioxide (CO2) removal function as part of the on-board Atmosphere Revitalization System (ARS). It is considered the state-of-the-art for manned spacecraft cabins, but has two significant drawbacks: 1. The CDRA requires that air be dried prior to CO2 capture, and this costs energy – in fact, the system uses much energy drying the air than is required for capturing and releasing carbon dioxide. 2. The CDRA works in batch mode, requiring complicated valving and control to switch between sorbing and desorbing beds, while downstream CO2 processing systems can operate on a continuous stream of CO2. This adds unnecessary complexity, as well as a second parasitic energy loss. An ideal system would process CO2 continuously without any need for drying of the air, and without

Management Team *(cont.)*

Program Manager:
- Stephen Gaddis

Project Manager:
- Daniel Barta

Principal Investigator:
- David Olmeijer

Technology Areas

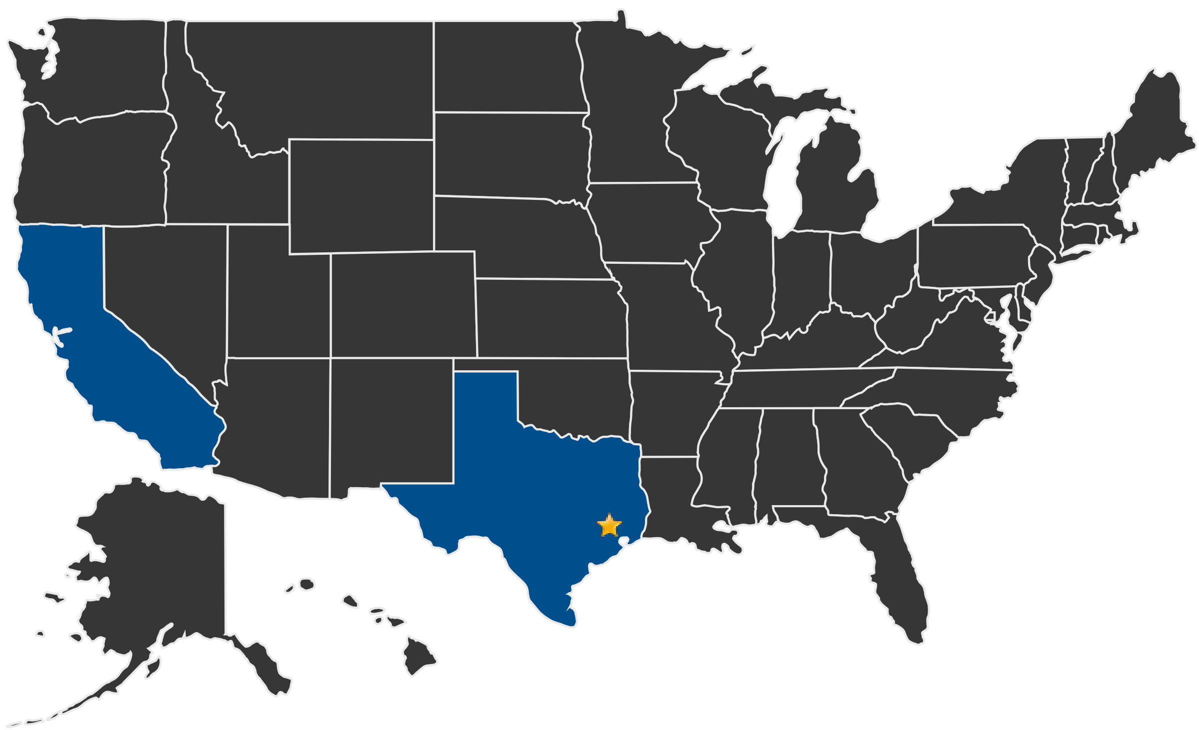
Primary Technology Area:
Human Exploration Destination Systems (TA 7)
└─ In-Situ Resource Utilization (TA 7.1)
  └─ Processing and Production (TA 7.1.3)
    └─ New Membranes for Gas Separation and Cleanup (TA 7.1.3.14)

Secondary Technology Area:
Human Health, Life Support, and Habitation Systems (TA 6)
└─ Environmental Control and Life Support Systems and Habitation Systems (TA 6.1)

Additional Technology Areas:
Human Exploration Destination Systems (TA 7)

any moving parts. Such a system would require a fraction of the size and weight of the CDRA while dropping the cost of CO2 capture by 5X or more. Such a technology would be enabling for future long term manned flight missions, such as a mission to Mars. This element is developing a new electrochemical membrane technology using patented innovations in electrolyte materials. Technology development began under a Phase I effort funded by the NASA Advanced Innovative Concepts Program. The prior Phase I effort demonstrated the functionality of the basic approach to CO2 separation, demonstrating CO2 removal using only electrical input using a film in a membrane configuration. Membrane synthesis and fabrication techniques were developed that allowed for the successful incorporation and retention of an electrochemically active carrier molecule using composite liquid membrane technology. This allowed for the successful demonstration of a continuous CO2 capture rate at 40% in a single step with no moving parts. A higher capture rate of 80% was demonstrated in a batch mode during this phase. The work gave promise that highly efficient, low energy separation of CO2 was possible using this technology, with the potential of operational energy savings as high as 80% compared with the state of the art, together with a weight and size footprint that could be as much as 75% smaller. The key enabling technology – composite liquid membrane materials – allow creation of a functional electrochemical membrane in a thin film form factor that enables this technology and application. This prior work, however, demonstrated CO2 from nitrogen gas only, not humidified air. It will be a technical challenge to prove the concept in representative cabin atmosphere containing moisture and oxygen. This Element, representing Phase II tasks, will focus on modifying the composite membrane system, evaluating active carrier molecules, ionic liquid solvents and membrane properties to operate the system efficiently in humid air. Reliability and performance of the system will be evaluated. Finally, a subscale system for a prototype air purifier will be designed. The effort will include increasing the size of the test cell and demonstrating long-term operation of the membranes under simulated cabin air (oxygen and nitrogen mixture with moisture), consistent with NASA requirements.

U.S. WORK LOCATIONS AND KEY PARTNERS



U.S. States With Work

Lead Center:
Johnson Space Center

Other Organizations Performing Work:

- ESIONIC CORP.

Contributing Partners:

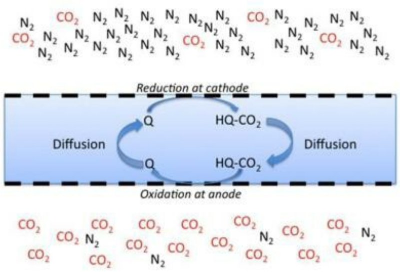
- HEOMD Advanced Exploration Systems

ELEMENT LIBRARY

Final Reports

- Solid State Air Purification System, NIAC Phase I Final Report
  - (http://www.nasa.gov/sites/default/files/files/Gellett_SolidStateAirPurification.pdf)

IMAGE GALLERY



CO2 is transported from a low concentration (cathode side) to a high concentration (anode side) by reaction with an electrochemically active carrier. CO2 is bound to a reduced form of the carrier, and is released when the carrier is oxidized.

DETAILS FOR TECHNOLOGY 1

Technology Title

Continuous Electrochemical Gas Separator

Technology Description

This technology is categorized as a hardware component or part for manned spaceflight

At the core of the Continuous Electrochemical Gas Separator (CEGS) is a new membrane technology that uses ultra-thin, mechanically stable liquid films for gas separation. Prior difficulties in stabilizing liquids as thin films with no evaporation or dewetting from its substrate were overcome with the invention of a "composite liquid" material, a film composed of non-volatile ionic liquid and polymer materials.

The principle behind electrochemical gas separation is that a concentration gradient of CO_2 can be created solely through electrical pumping, with no requirement for gas pressure to drive it. Electrochemical transport of CO_2 occurs when a carrier species (analogous to an amine in conventional CO_2 capture tower in the energy industry) reacts with the carbon dioxide when it is in its reduced form, but releases it when oxidized. Because the chemical reactions that underpin the process are specific to carbon dioxide, the process is highly selective for CO_2 over other gases. Separation is accomplished using electricity as the motive force, and applying the electricity only to the CO_2 and not to any other gas or material in the process. The process consists of four steps that occur on a continuous basis as the membrane is operated:

1. A CO_2 molecule approaches the electrochemical membrane where it reacts with a carrier such as a hydroquinone (HQ) to form a tight-binding pair.

2. This carrier-CO_2 pair diffuses to the permeate side of the membrane.

3. The carrier is oxidized to a form (Q) that has a far lower affinity for CO_2; the CO_2 is thereby released.

4. This inactivated carrier diffuses back to the feed side of the membrane where it is reduced to its active form (HQ), and will subsequently react with another CO_2 molecule.

Capabilities Provided

- Low power removal of carbon dioxide from cabin or space suit atmosphere.
- Continuous operation.
- Ability to operate without vacuum.
- Separation and concentration of carbon dioxide for closed loop resource recovery.
- Solid state (no moving parts).
- No pretreatment of gas stream is expected to be required.

Potential Applications

- Spacecraft cabin atmosphere revitalization
- To serve as space suit Portable Life Support System (PLSS) subsystem for CO_2 removal
- Submarine atmosphere purification (Department of Defense)
- Carbon doxide sequestration to prevent release into Earth's atmosphere (Department of Energy, Department of Transportation)

Performance Metrics

Metric	Unit	Quantity
Flux & Selectivity after 4 Weeks	% of Initial Value	80
Theoretical Energy Efficiency	kJ/mole CO2 captured	<100