Active Project (2015 - 2016)

Self-Cleaning Boudouard Reactor for Full Oxygen Recovery from CO2 Project

Center Innovation Fund: KSC CIF Program | Space Technology Mission Directorate (STMD)

ABSTRACT

Oxygen recovery from respiratory CO2 is an important aspect of human spaceflight. Methods exist to sequester the CO2, but production of oxygen needs further development. The current ISS Carbon Dioxide Reduction System (CRS) uses the Sabatier reaction to produce water (and ultimately breathing air). Oxygen recovery is limited to 50% because half of the hydrogen used in the Sabatier reactor is lost as methane, which is vented overboard. The Bosch reaction is the only real alternative to the Sabatier reaction, but in the last reaction in the cycle (Boudouard) the resulting carbon buildup will eventually foul the nickel or iron catalyst, reducing reactor life and increasing consumables. To minimize this fouling, find a use for this waste product, and increase efficiency, we propose testing various self-cleaning catalyst designs in an existing MSFC Boudouard reaction test bed and to determine which one is the most reliable in conversion and lack of fouling. Challenges include mechanical reliability of the cleaning method and maintaining high conversion efficiency with lower catalyst surface area. The above chemical reactions are well understood, but planned implementations are novel (TRL 2) and haven't been investigated at any level.

ANTICIPATED BENEFITS

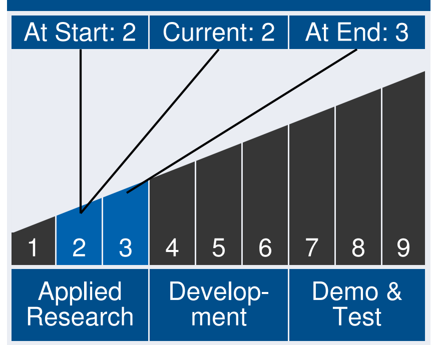
To NASA funded missions:

The current ISS oxygen recovery method utilizes the Sabatier process which is only 50% efficient due to limits on H2 availability. This means that for a full crew over 3 kg of water/day are used in making oxygen that isn't recovered from CO2. At current launch prices this costs **$100,000/day.**

By producing a self-cleaning Boudouard reactor the single greatest challenge of the Bosch process is resolved and the full

Table of Contents

Technology Maturity



Management Team

Project Manager:
- Nancy Zeitlin

Continued on following page.

oxygen recovery of the system can be realized. The decrease in consumable requirements will be significant for the ISS and enabling for BEO exploration missions. In addition, oxygen production is a limiting factor in ISS population and a system such as this can help improve that number.

To NASA unfunded & planned missions:

For BEO exploration missions, in-space resupply is virtually impossible so nearly 100% oxygen recovery is essential to reduce the Initial Mass in Low Earth Orbit (IMLEO). The graphite/carbon nanotube "soot" product could have applications in air or water purification filters and as a filler for 3D printing.

To the commercial space industry:

Crewed commercial and international spacecraft would benefit from this enhancement of full oxygen recovery from respiratory CO2, greatly reducing consumables and resupply costs.

To the nation:

Full oxygen recovery on spacecraft would save the nation millions of dollars in launch costs and assist in enabling exploration missions that would be hindered by less efficient processes.

DETAILED DESCRIPTION

Using our experience with similar chemical reactions in ISRU (in situ resource utilization), we plan to build a number of Boudouard reactors with different cleaning methods built in (such as a "wire-brush" catalyst, "spring" catalyst, or an ultrasonic water recycle loop) for testing on a Marshall Space Flight Center test stand that simulates upstream conversion of CO2 to CO from a reverse water gas shift (RWGS) reactor for simplicity. The synthetic CO stream (which may contain H2 to enhance the reaction) the Boudouard reactor will convert it to

Management Team *(cont.)*

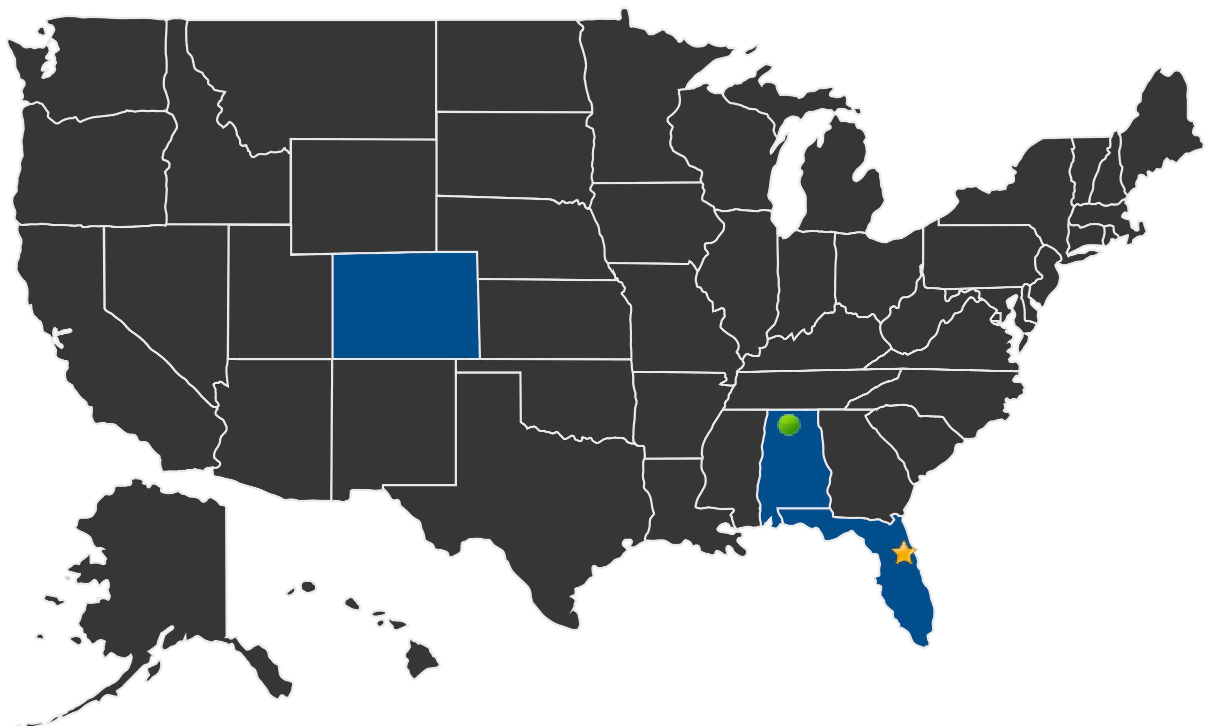
Principal Investigator:
- Anthony Muscatello

Technology Areas

Primary Technology Area:
Human Health, Life Support, and Habitation Systems (TA 6)
└─ Human Exploration Destination Systems (TA 7)

CO_2 and carbon fines. The gases will be analyzed with GC and mass flow meters. Peak performance as well as continuous performance after multiple regenerations will be documented to determine reactor performance. The goal is to arrive at a reactor and catalyst design which reduces or eliminates consumables with this reaction (extra catalyst or reactor swaps) which currently is 0.05g/g oxygen recovered and would be competitive if it can be reduced by 80% or greater.

U.S. LOCATIONS WORKING ON THIS PROJECT



U.S. States With Work

Lead Center:
Kennedy Space Center

Supporting Centers:

- Marshall Space Flight Center

Other Organizations Performing Work:

- Pioneer Astronautics (Lakewood, CO)

Contributing Partners:

- None
- None
- None

PROJECT LIBRARY

Presentations

- Two-Step Bosch Process Diagram
  - (https://techport.nasa.gov:443/file/16567)

DETAILS FOR TECHNOLOGY 1

Technology Title

Self-Cleaning Boudouard Reactor for Full Oxygen Recovery from CO2

Technology Description

This technology is categorized as a hardware subsystem for manned spaceflight

The initial step in the Bosch reaction ($CO_2 + 2 H_2 \Rightarrow 2 H_2O + C$) is the Reverse Water Gas Shift (RWGS) ($CO_2 + H_2 \Rightarrow CO + H_2O$) which produces carbon monoxide. The water is electrolyzed to make the oxygen product and hydrogen, which is recycled. The next step is the disproportionation of CO into carbon and CO2 ($2 CO \Rightarrow C + CO_2$). The carbon is disposed and the CO2 is sent back to the RWGS. Combined, these reactions recover 100% of the oxygen in CO2. Self-cleaning Boudouard catalysts would continuously remove the carbon, greatly extending the lifetime of the reactor compared to current technology based on steel wool, which eventually clogs the reactor.

Capabilities Provided

Self-cleaning Boudouard reactors would enable 100% recovery of oxygen in respiratory CO2 on spacecraft while using reactors that would have much greater lifetimes than current technology. Testing is needed to prove this concept works. Based on current technology at MSFC, estimates indicate that our designs are feasible with regard to the surface area of the self-cleaning Boudouard catalyst.

Potential Applications

In addition to oxygen recovery on crewed NASA and commercial spacecraft, the same technology would be useful for the production of oxygen from the carbon monoxide on the Moon and from the carbon dioxide on Mars. Air and water filters for spacecraft could use the elemental carbon produced in the process. The carbon may also be useful as a filler for 3D printing of spacecraft parts.

Performance Metrics

Metric	Unit	Quantity
Reduce Boudouard reactor consumables to 20% of 0.05g/g oxygen recovered.		