NASA Carbon Dioxide Reduction Technology Approaches

Morgan B. Abney
Environmental Control and Life Support Systems
NASA Marshall Space Flight Center

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Agenda

• How does NASA use CO₂ for Exploration?
• NASA Missions and Design Drivers
• ISS CO₂ Reduction
• NASA-Funded CO₂ Reduction Technology Development
• Other CO₂ Reduction Approaches Considered
• Where next?
How does NASA use CO₂?

• **Life Support Systems**
  – Metabolic CO₂ produced by crew during respiration
  – O₂ recovery is critical for long-duration missions where O₂ resupply is logistically unfeasible

• **In Situ Resource Utilization (ISRU)**
  – CO₂ obtained from Martian atmosphere
  – O₂ may be produced to support the crew or stockpiled for surface launch
  – Other materials may be produced (e.g. methane)
NASA Missions

• Low Earth Orbit (ISS)
  – Long Duration (years)
  – Resupply from Earth logistically feasible – but used as testbed for future missions beyond LEO

• Surface Missions
  – Long Duration (years)
  – Lunar or Martian Surface
  – Mars Transit

• Resource Recovery
  – Oxygen recovery
  – Hydrogen recovery
  – Carbon recovery?
Design Drivers

• Life Support Design Considerations:
  – Maximize O₂ recovery
  – Ensure technology is highly robust and reliable
  – Minimize mass/volume/power
  – Make compatible with habitat
  – Microgravity compatible
  – Planetary Protection

• ISRU Design Considerations:
  – Scale necessary to be useful
  – Identify technology that produces useable products
  – Minimize consumables or materials necessary from Earth
  – Regolith fines
  – Planetary Protection
ISS CO₂ Reduction

- Sabatier-based CO₂ Reduction
- Developed by Hamilton Sundstrand

\[
\text{CO}_2 + 4\text{H}_2 \leftrightarrow 2\text{H}_2\text{O} + \text{CH}_4
\]

- Water electrolyzed to provide O₂ to the crew, H₂ recycled back to Sabatier
- Methane vented as waste product
- <50% O₂ recovery

AR Rack on ISS
• Life Support Systems
  – Sabatier Post-Processing for 90% O₂ Recovery
  – Bosch for 100% O₂ Recovery

• ISRU
  – CO₂/Water Co-Electrolysis to stockpile O₂
  – Sabatier to stockpile CH₄
• Plasma Pyrolysis Assembly (PPA)
  – Microwave-generated plasma
  – Primary Reaction:
    \[ 2\text{CH}_4 \rightarrow 3\text{H}_2 + \text{C}_2\text{H}_2 \]
  – Can produce \( \text{C}_2\text{H}_6, \text{C}_2\text{H}_4, \text{C}_2\text{H}_2, \text{or C}(s) \)
  – Challenges
    • High power requirement (~2.5 kW)
    • Unwanted C formation
    • \( \text{H}_2 \) Purification for recycle
  – Potential 90% \( \text{O}_2 \) recovery
• Bosch Process

Crew Members breathe in \( \text{O}_2 \) and breathe out \( \text{CO}_2 \)

\( \text{CO}_2 \) is combined with \( \text{H}_2 \) and fed to the Series-Bosch System

\( \text{H}_2\text{O} \) produced in Reactor 1 can be used for drinking and washing or electrolyzed to produce \( \text{O}_2 \)

Carbon product from Reactor 2 might be used to make filters, to make carbon ropes, or as a filler for radiation shielding materials.
LSS: Bosch

• Chemistry

\[
\begin{align*}
\text{CO}_2 + \text{H}_2 & \rightarrow \text{H}_2\text{O} + \text{CO} \\
2\text{CO} & \rightarrow \text{CO}_2 + \text{C(s)} \\
\text{CO} + \text{H}_2 & \rightarrow \text{H}_2\text{O} + \text{C(s)} \\
\text{CO}_2 + 2\text{H}_2 & \rightarrow 2\text{H}_2\text{O} + \text{C(s)}
\end{align*}
\]

• Challenges
  – Power Consumption
    • High Temperature Reactions
  – Catalyst Resupply
  – Volume/Mass

• Potential 100% O\textsubscript{2} Recovery
• Solid Oxide Electrolysis
  – Co-electrolysis of water and CO₂
  – Directly produces O₂

• Challenges
  – High temperatures limits ability to thermally cycle and maintain seals
  – Launch mass required to launch water needed for co-electrolysis

• Variable Oxygen recovery
ISRU: Sabatier

• Same technology approach as ISS CO$_2$ Reduction

• Challenges
  – CO$_2$ Capture from atmosphere
  – Resistance to regolith fines
  – H$_2$ for reaction must be launched from Earth
  – Pressurization of CH$_4$
Other Approaches Considered

- Direct CO$_2$ decomposition (to solid carbon and O$_2$)
- CO$_2$ conversion to alcohols
- CO$_2$ conversion to sugars – precursors to food
- CO$_2$ conversion to various hydrocarbons for fuels
- CO$_2$ conversion to CH$_4$ $\rightarrow$ conversion to DLC for tooling or refurbishment
• Mission specific
  – Dependent on duration
  – Dependent on available resources (*in situ* or from Earth)
  – Martian surface missions = any number of useable materials or chemicals are of interest
Questions?
Morgan B. Abney, Ph.D.
National Aeronautics and Space Administration
Marshall Space Flight Center
Bldg 4755, Room 403-7
MSFC, AL 35812

morgan.b.abney@nasa.gov
Office Phone: +1 256 961 4758
Mobile Phone: +1 256 541 8534
Fax: +1 256 961 0737