NASA Carbon Dioxide Reduction Technology Approaches

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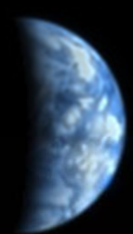


NASA Weekend Workshop on CO_2 Manufacturing
June 28-29, 2014

Agenda

- How does NASA use CO_2 for Exploration?
- NASA Missions and Design Drivers
- *ISS* CO_2 Reduction
- NASA-Funded CO_2 Reduction Technology Development
- Other CO_2 Reduction Approaches Considered
- Where next?

How does NASA use CO_2?

- Life Support Systems
  - Metabolic CO_2 produced by crew during respiration
  - O_2 recovery is critical for long-duration missions where O_2 resupply is logistically unfeasible
- *In Situ* Resource Utilization (ISRU)
  - CO_2 obtained from Martian atmosphere
  - O_2 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 O_2 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 CO_2 Reduction

- Sabatier-based CO_2 Reduction
- Developed by Hamilton Sundstrand

$$CO_2 + 4H_2 \leftrightarrow 2H_2O + CH_4$$

- Water electrolyzed to provide O_2 to the crew, H_2 recycled back to Sabatier
- Methane vented as waste product
- <50% O_2 recovery

AR Rack on ISS

NASA-Funded Development

- Life Support Systems
  - Sabatier Post-Processing for 90% O_2 Recovery
  - Bosch for 100% O_2 Recovery
- ISRU
  - CO_2/Water Co-Electrolysis to stockpile O_2
  - Sabatier to stockpile CH_4

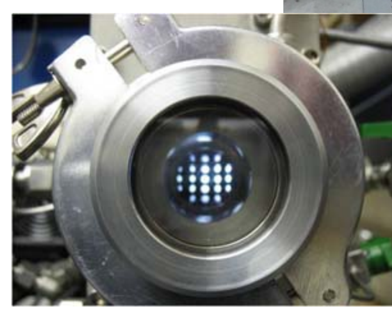
LSS: Sabatier Post-Processing

- Plasma Pyrolysis Assembly (PPA)
  - Microwave-generated plasma
  - Primary Reaction:

    $$2CH_4 \rightarrow 3H_2 + C_2H_2$$

  - Can produce C_2H_6, C_2H_4, C_2H_2, or C(s)
  - Challenges
    - High power requirement (~2.5kW)
    - Unwanted C formation
    - H_2 Purification for recycle
  - Potential 90% O_2 recovery

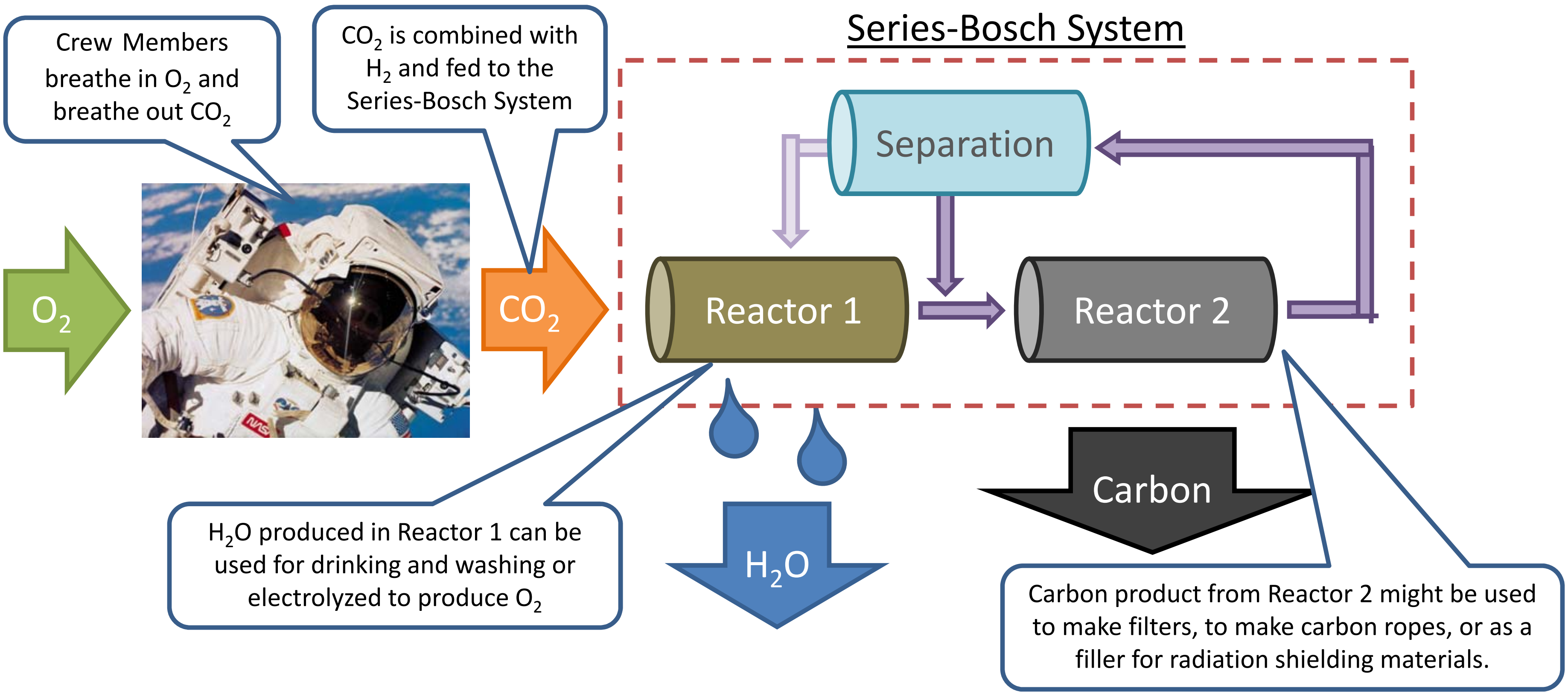
3rd Gen PPA



PPA Plasma

LSS: Bosch

- Bosch Process



LSS: Bosch

- Chemistry

RWGS: $CO_2 + H_2 \rightarrow H_2O + CO$

Carbon Formation:
$$\left\{\begin{array}{l} 2CO \rightarrow CO_2 + C(s) \\ CO + H_2 \rightarrow H_2O + C(s) \end{array}\right.$$

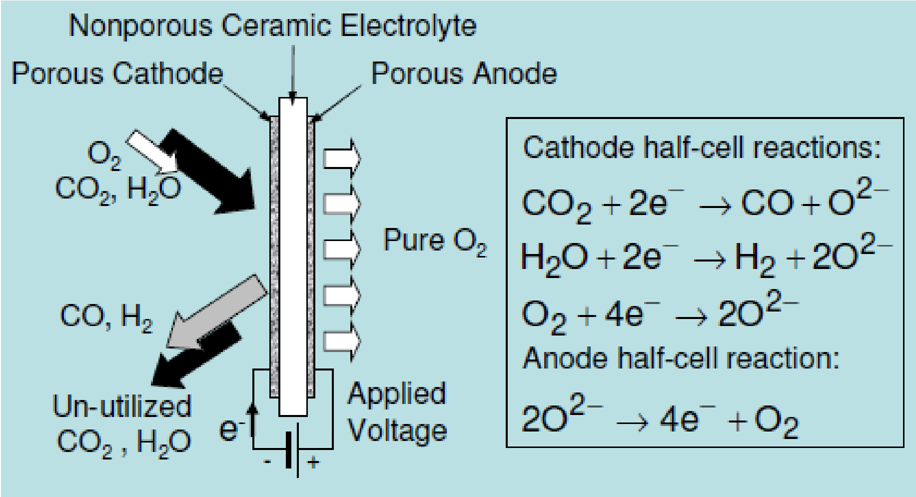
$$CO_2 + 2H_2 \rightarrow 2H_2O + C(s)$$

- Challenges
  - Power Consumption
    - High Temperature Reactions
  - Catalyst Resupply
  - Volume/Mass
- Potential 100% O_2 Recovery

1980's Bosch System

ISRU: Co-Electrolysis

- Solid Oxide Electrolysis
  - Co-electrolysis of water and CO_2
  - Directly produces O_2



- 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

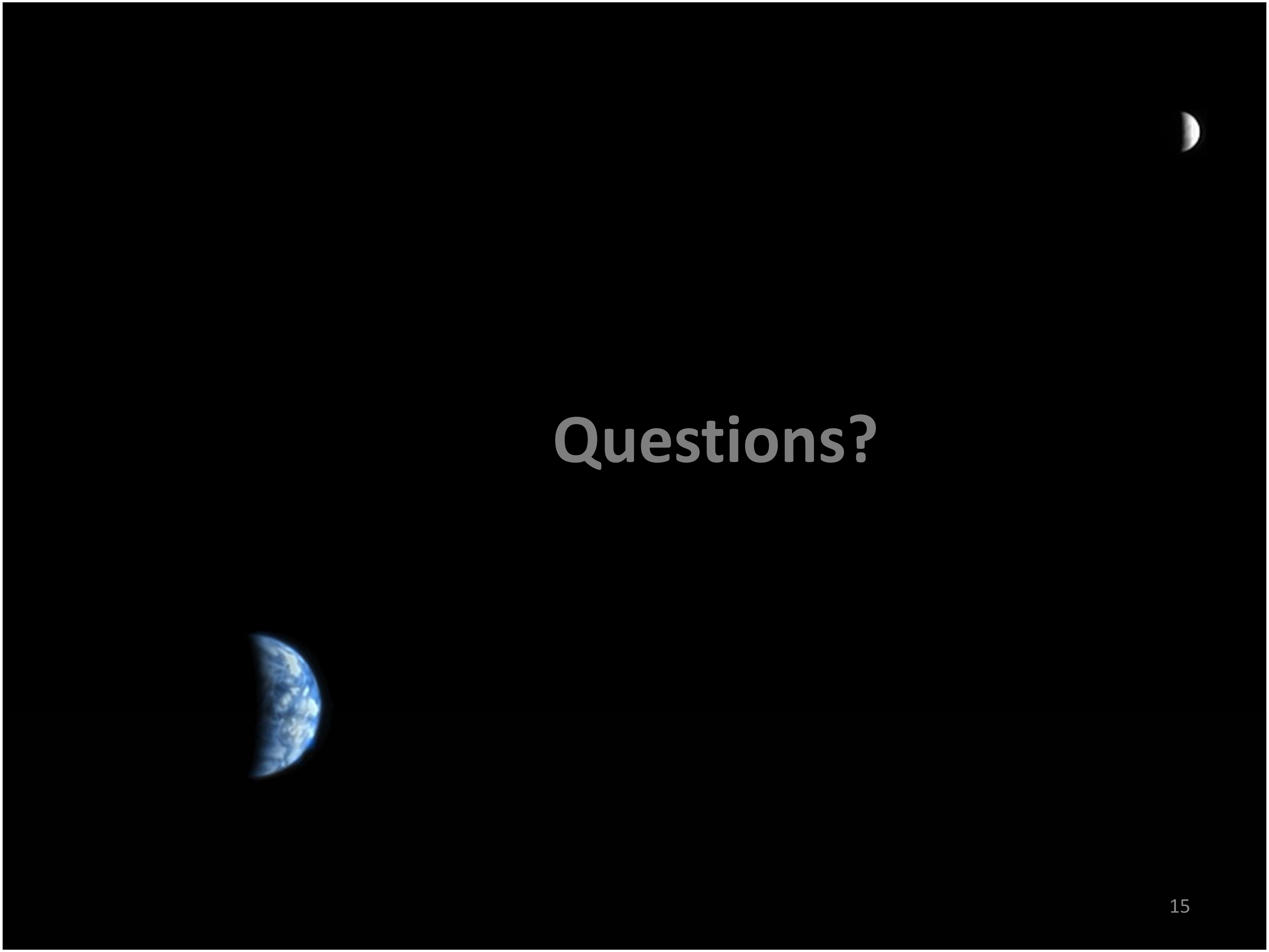
- Challenges
  - CO_2 Capture from atmosphere
  - Resistance to regolith fines
  - H_2 for reaction must be launched from Earth
  - Pressurization of CH_4

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

Where Next?

- 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?

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