Plasma Methane Pyrolysis for Spacecraft Oxygen Loop Closure

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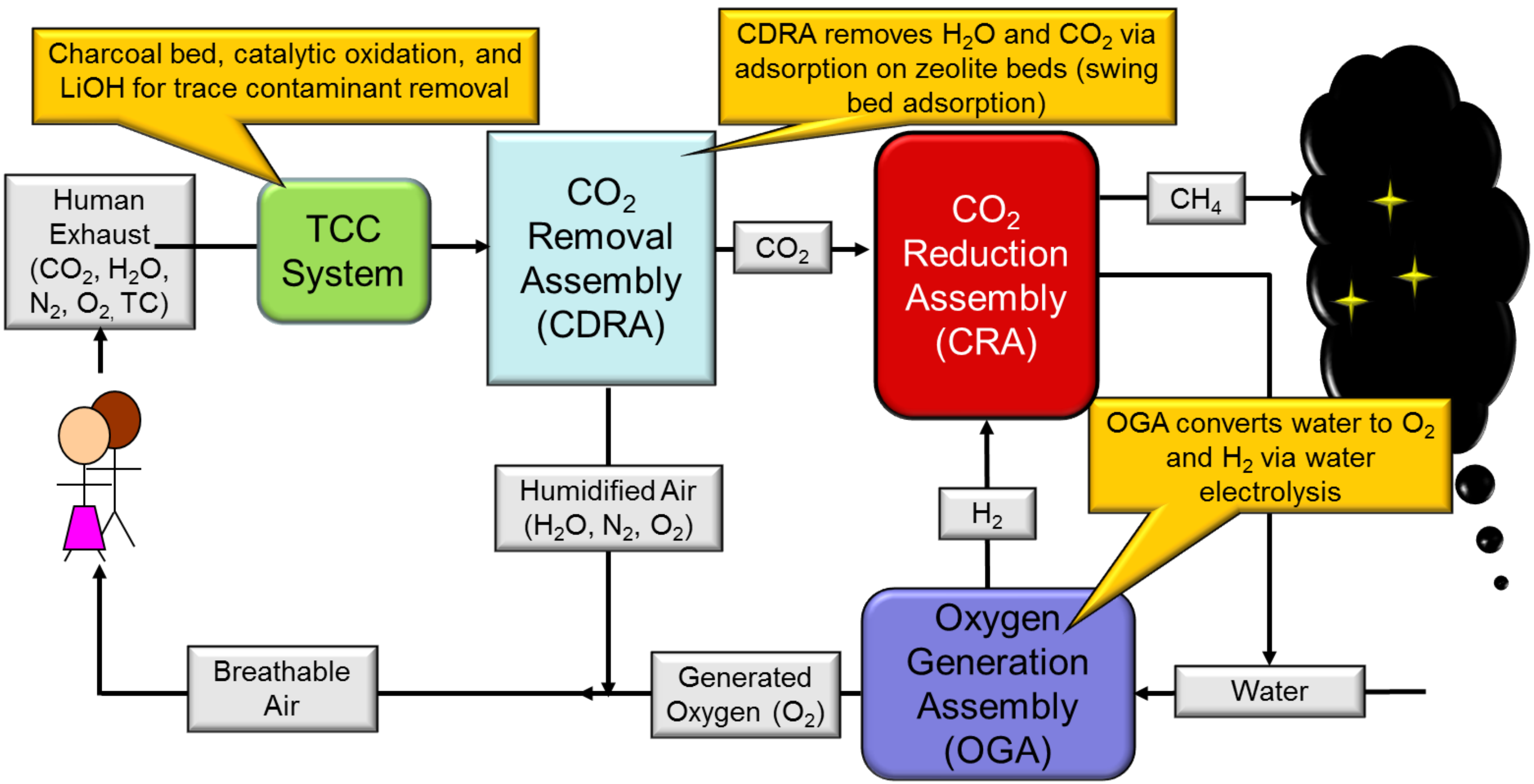
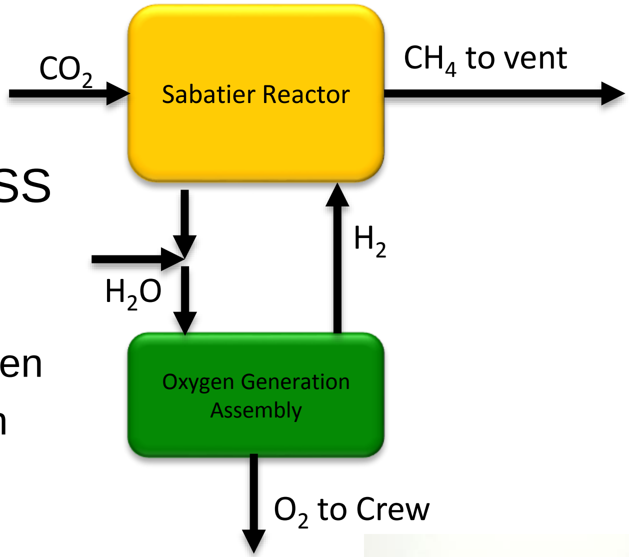
Overview

- International Space Station Life Support System Background
- Methane Post-Processing
- Plasma Pyrolysis Assembly
- Plasma Pyrolysis Assembly Challenges
- Future Work
- Conclusion

Life Support System on International Space Station (ISS)



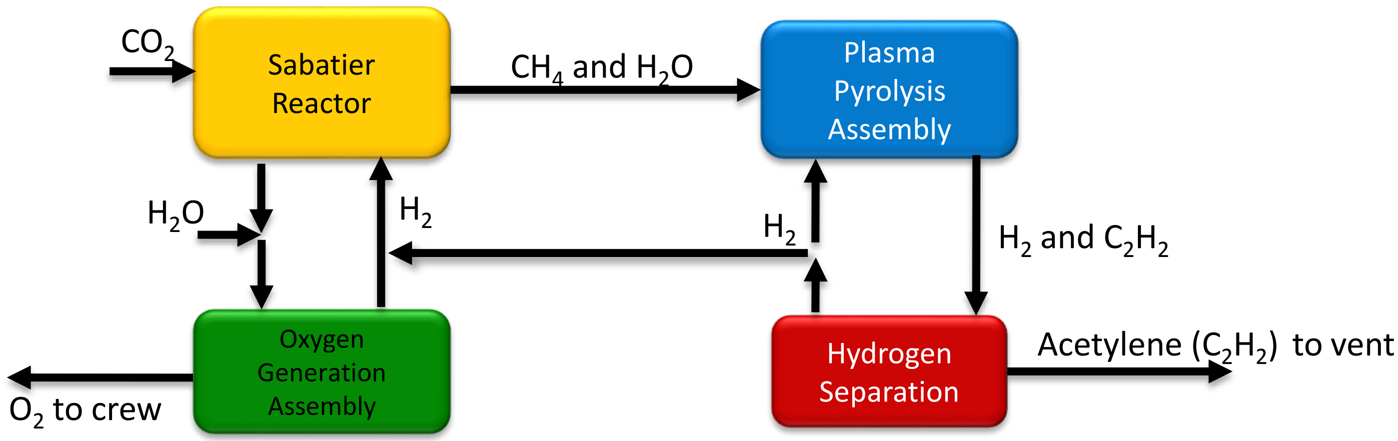
ISS Oxygen Recovery



- State-of-the-art O_2 Recovery on ISS utilizes a Sabatier Reactor
  - $CO_2 + 4H_2 \rightarrow 2H_2O + CH_4$
  - Water product electrolyzed for oxygen
  - Methane product vented resulting in loss of hydrogen reactant
  - Theoretical recovery of **~50%** of O_2 recovered from metabolic CO_2
- **To make long duration missions feasible O_2 recovery must be increased**

Hamilton Sabatier Development Unit

Sabatier with Methane Post-Processing



- O_2 recovery architecture incorporating Plasma Pyrolysis technology for methane post-processing
  - H_2 recovered from CH_4 and sent to Sabatier to recover additional O_2 from CO_2
    - ~50% with Sabatier based O_2 recovery
    - Potentially >86% total O_2 recovery with PPA

Plasma Pyrolysis Assembly

- Plasma Pyrolysis Assembly (PPA) was developed under a Small Business Innovation Research (SBIR) Grant with UMPQUA Research Company
  - First Generation Reactor delivered May, 2009
    - Proof of Concept
    - Operated at ½ Crew Member (CM) Rate
  - Third Generation delivered October, 2013
    - Capable of 5 CM processing rate, nominal 4 CM

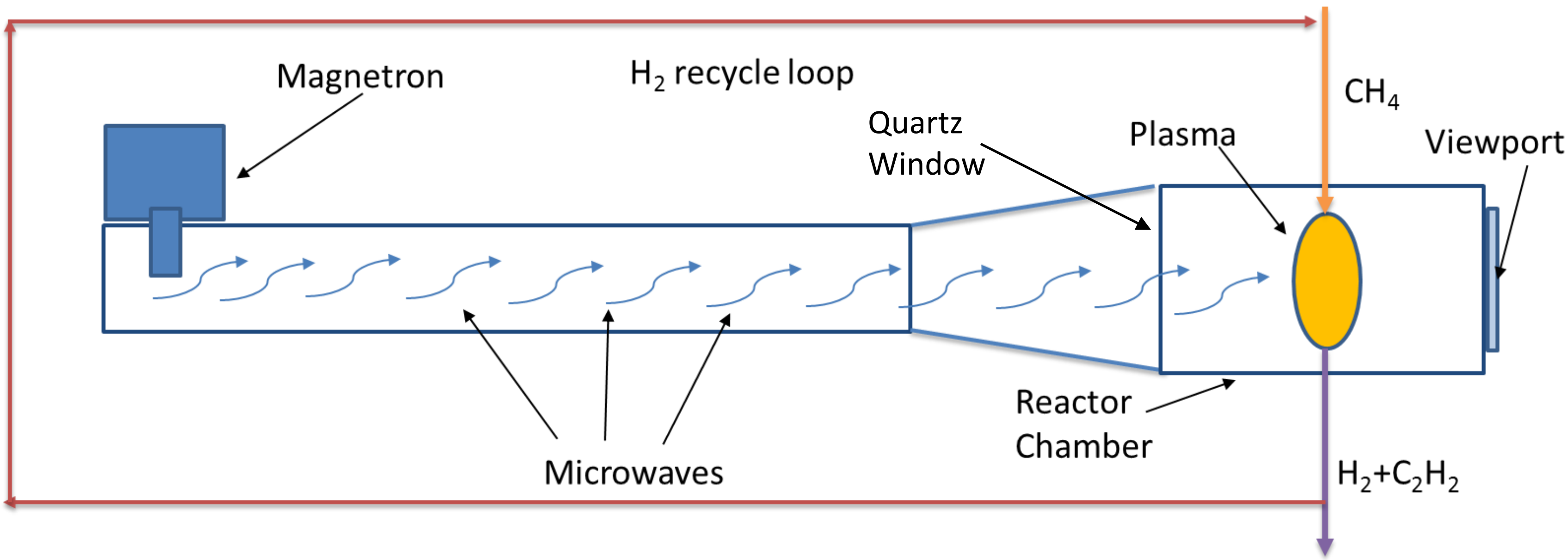
- Methane converted to hydrogen and acetylene by partial pyrolysis in microwave generated plasma

- Targeted PPA Reaction:

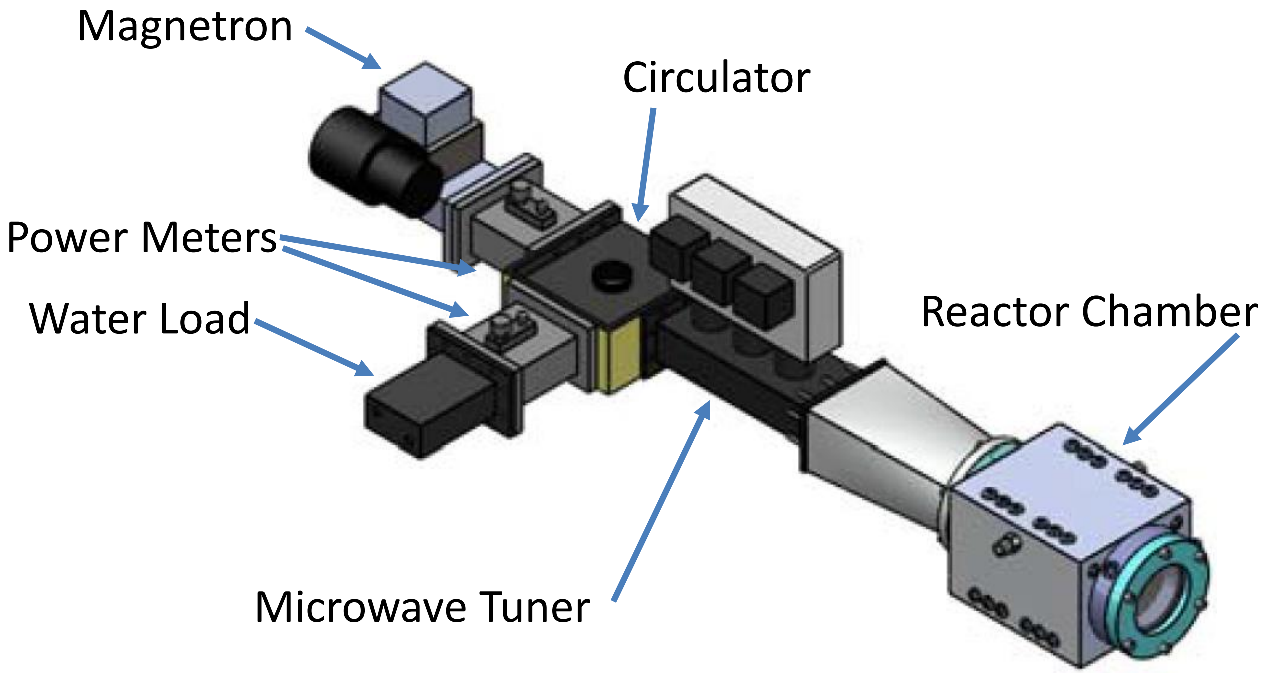
$$2CH_4 \leftrightarrow 3H_2 + C_2H_2$$

First Gen. PPA

PPA Reactor and Microwave System



PPA Reactor and Microwave System, Cont.

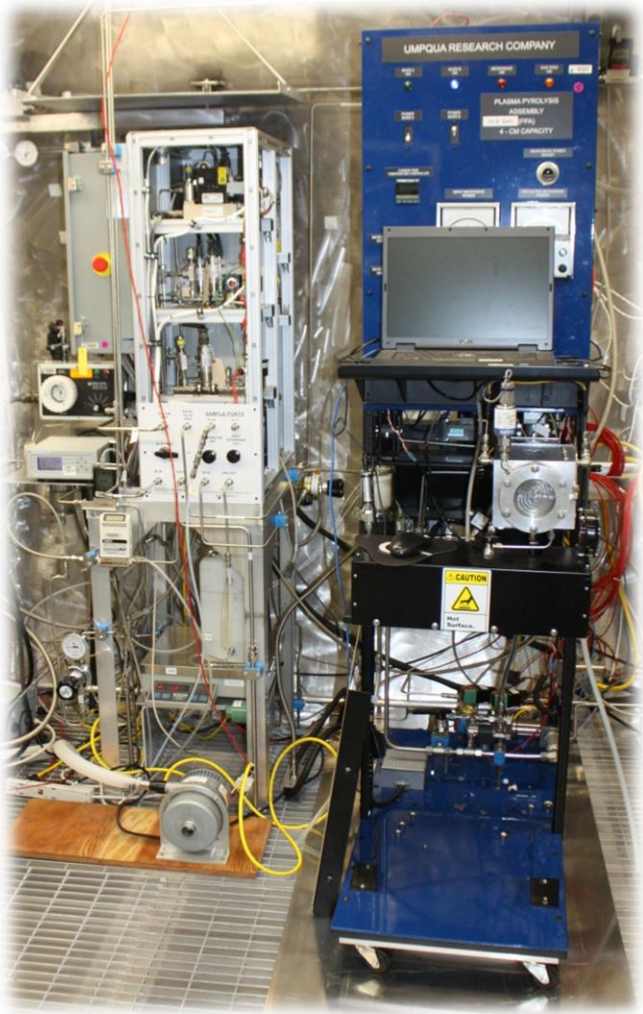


H_2/CH_4
Plasma

- Nominal reactor operation:
  - 110 torr reactor pressure
  - 4:1, Hydrogen:Methane
  - 800 W input microwave power for 4 CM

PPA Testing

- 3rd Gen. PPA integrated into MSFC Environmental-Chamber
  - Stand alone and integrated operation with Sabatier Development Unit characterized
    - Results reported in proceedings from International Conference on Environmental Systems



3rd Gen PPA and SDU in E-Chamber

PPA Microwave Challenges

- Magnetron based microwave generation requires high voltage power supply
  – Off the shelf power supplies are not suitable for space flight
- Solid state microwave generators were not available at appropriate power levels until recently
  – Sub-scale testing of solid state microwave generation with 2^{nd} Gen PPA shows promise
  – Currently working to procure full scale solid state microwave generator

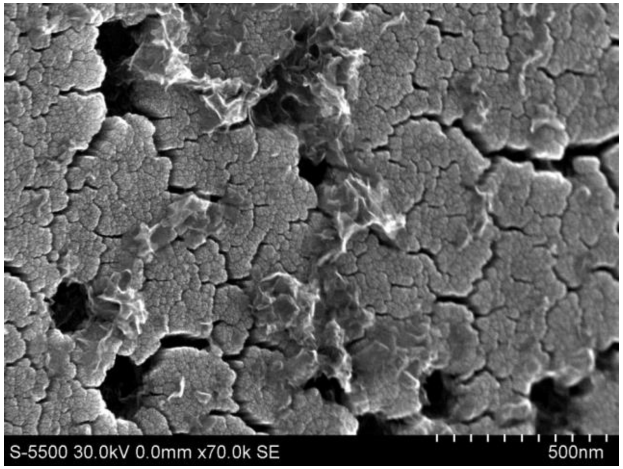
PPA Carbon Formation Challenges

- Targeted PPA Reaction:

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

- Other reactions:

CH_4 Conversion to Ethane	$2CH_4 \leftrightarrow H_2 + C_2H_6$
CH_4 Conversion to Ethylene	$2CH_4 \leftrightarrow 2H_2 + C_2H_4$
CH_4 Conversion to Solid C	$CH_4 \leftrightarrow 2H_2 + C(s)$
CO Production	$C(s) + H_2O \leftrightarrow CO + H_2$
CO Production	$CH_4 + H_2O \leftrightarrow CO + 3H_2$

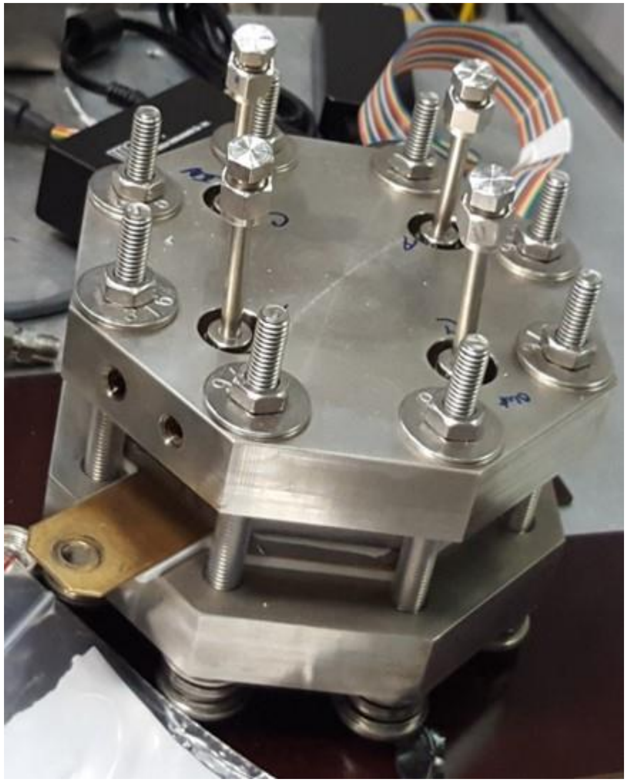


Secondary electron beam image (25° tilt) of carbon on filter

- Carbon produced is very fine, graphene-like, and extremely penetrating
- Carbon trap technology must last mission duration (~1000 days) with minimal resupply

PPA Hydrogen Separation Challenges

- To prevent fouling Sabatier catalyst acetylene (C_2H_2) must be removed from gas stream before H_2 can be recycled
- Unusual nature of C_2H_2 makes this separation challenging
  - Unstable and explosive at 29 psia
  - Forms explosive compounds with copper, silver, etc.
  - Prone to canalization and hydrogenation
- Current work focuses on development of electrochemical hydrogen separation



Electrochemical
Cell Stack

PPA Future Work

- Currently building up to an integrated test in MSFC E-Chamber demonstrating operation with PPA, Sabatier Development Unit, Oxygen Generation Assembly, and Electrochemical Hydrogen Separation
- Investigating solid state microwave generation and finding a supplier for flight magnetron power supply
- Working to refine hydrogen separation
- Developing effective carbon management system
- Planning for flight demonstration on the International Space Station

Conclusion

- Increased oxygen recovery is essential for human deep space exploration
- Methane post-processing with the Plasma Pyrolysis Assembly is currently the most well developed technology to increase oxygen recovery beyond the state-of-the-art
- PPA technology has been well demonstrated
- Current development focuses on component development for a robust system architecture