Methane Post-Processing and Hydrogen Separation for Spacecraft Oxygen Loop Closure

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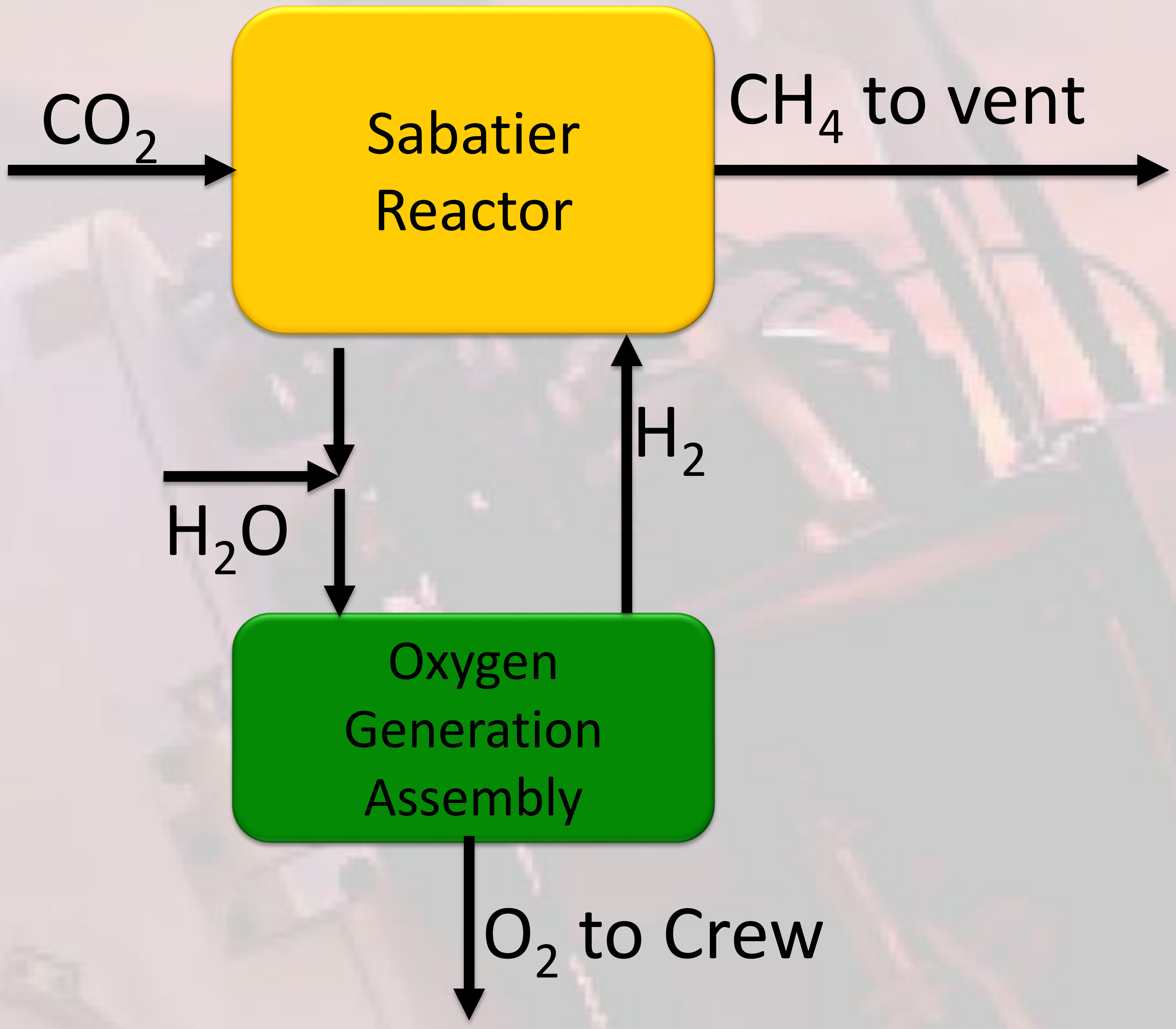
Overview

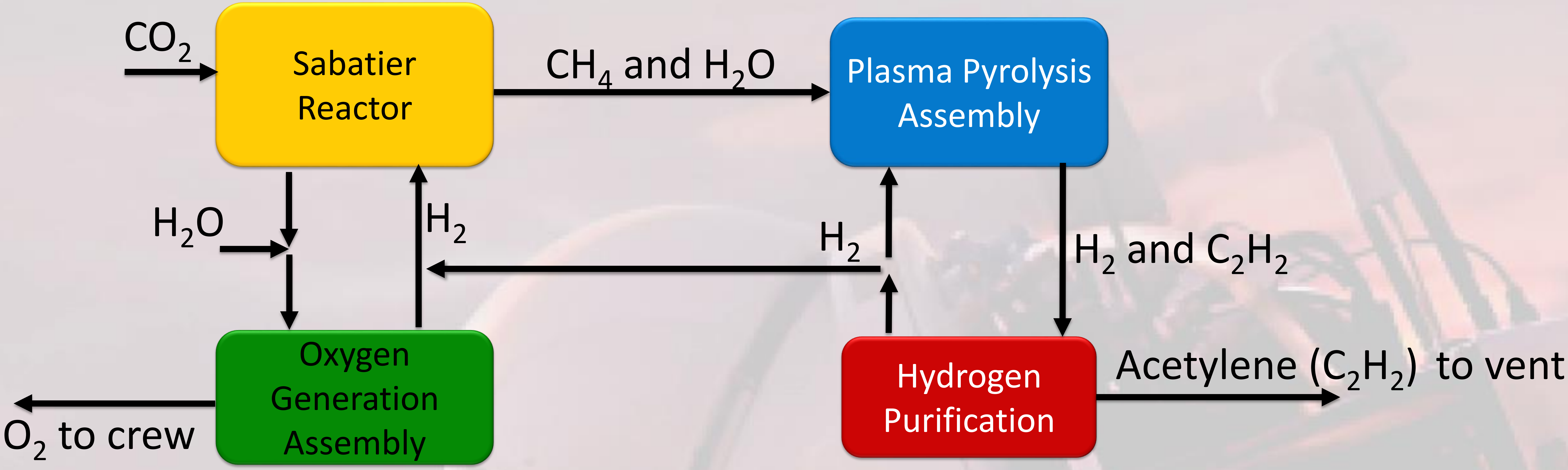
- Background
- Hardware
- Test Setup
- Methods
- Results
- System Architecture Discussion
- Conclusion
- Acknowledgements

O_2 Recovery on ISS

- Sabatier Reaction: $CO_2 + 4H_2 \rightarrow 2H_2O + CH_4$
- Water product electrolyzed for oxygen for crew
- Methane (CH_4) vented resulting in net loss of hydrogen limits oxygen recovery to ~50%



Sabatier Plus Post-Processing

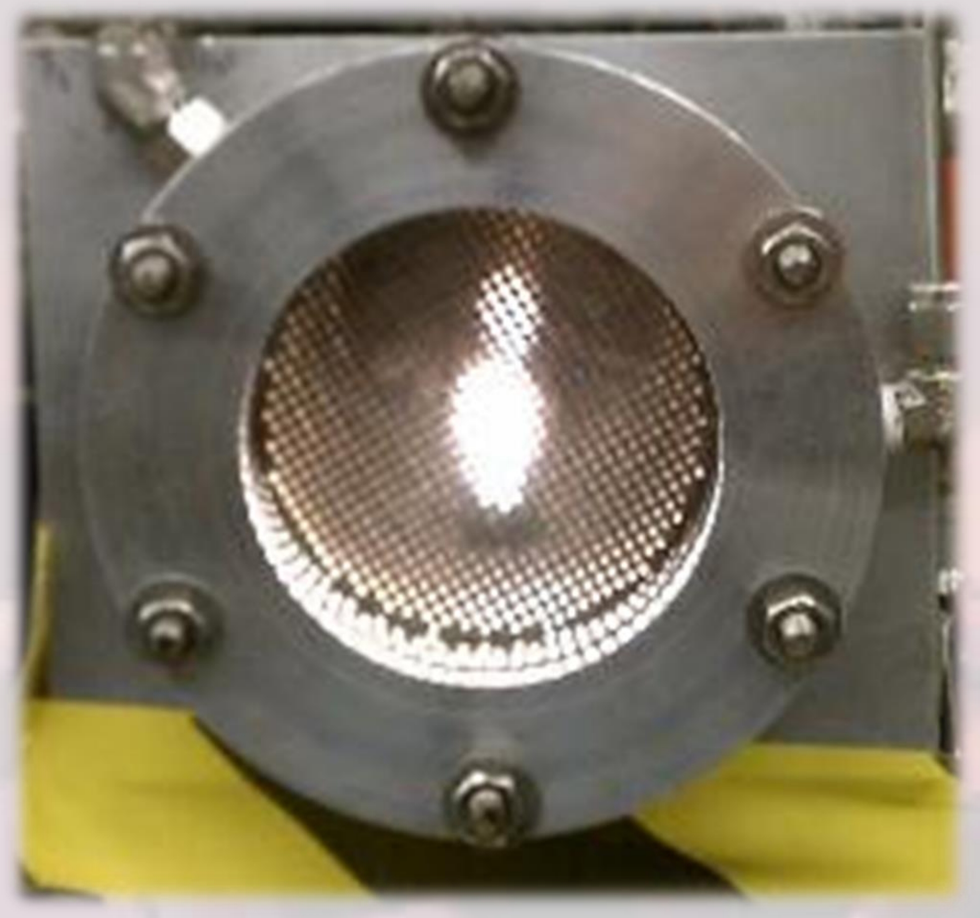


- O_2 recovery architecture incorporating Plasma Pyrolysis technology for methane post-processing
  - **H_2 recovered from CH_4 and sent to Sabatier to recover additional O_2 from CO_2**
    - 47% with SOA O_2 recovery
    - Potentially >86% total O_2 recovery with PPA

Plasma Pyrolysis Assembly (PPA)

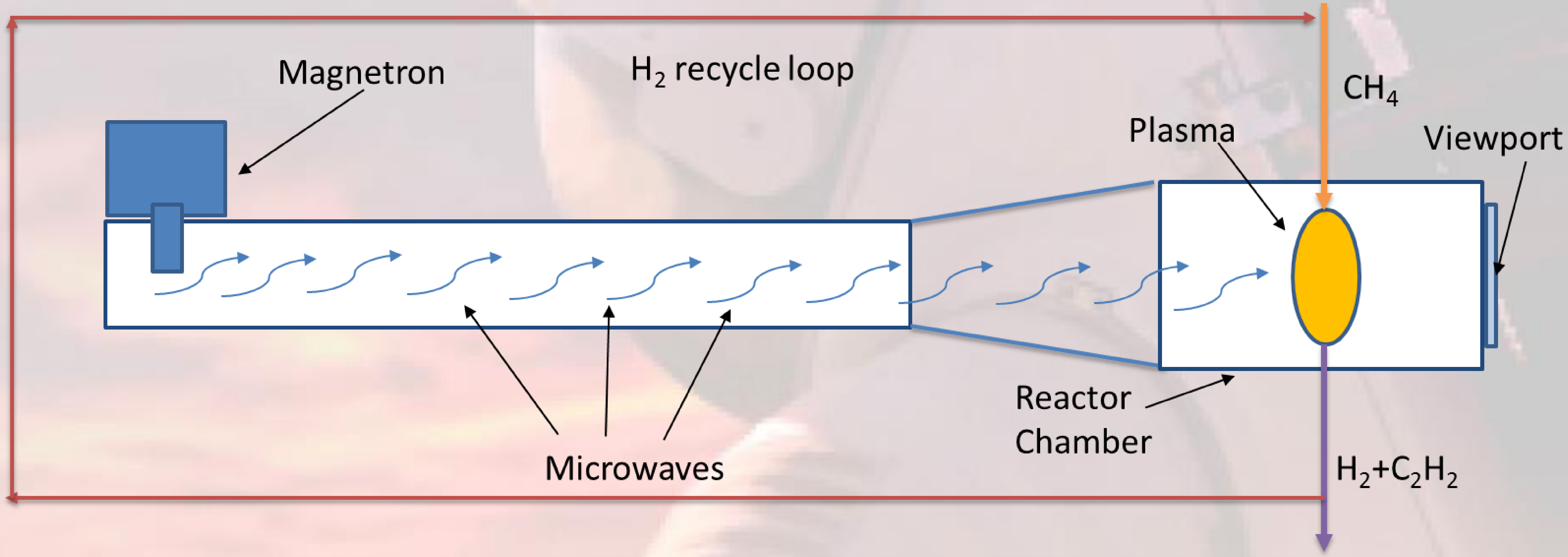
- Developed by UMPQUA Research Co.
- Methane converted to hydrogen and acetylene by partial pyrolysis in microwave generated plasma
- Targeted PPA Reaction:

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



H_2/CH_4 Plasma

Plasma Pyrolysis Assembly



Metal Hydride Hardware

- Hydrogen Components, Inc. Metal Hydride Canister
- $LaNi_{4.6}Sn_{0.4}$ metal hydride
- Designed for hydrogen storage

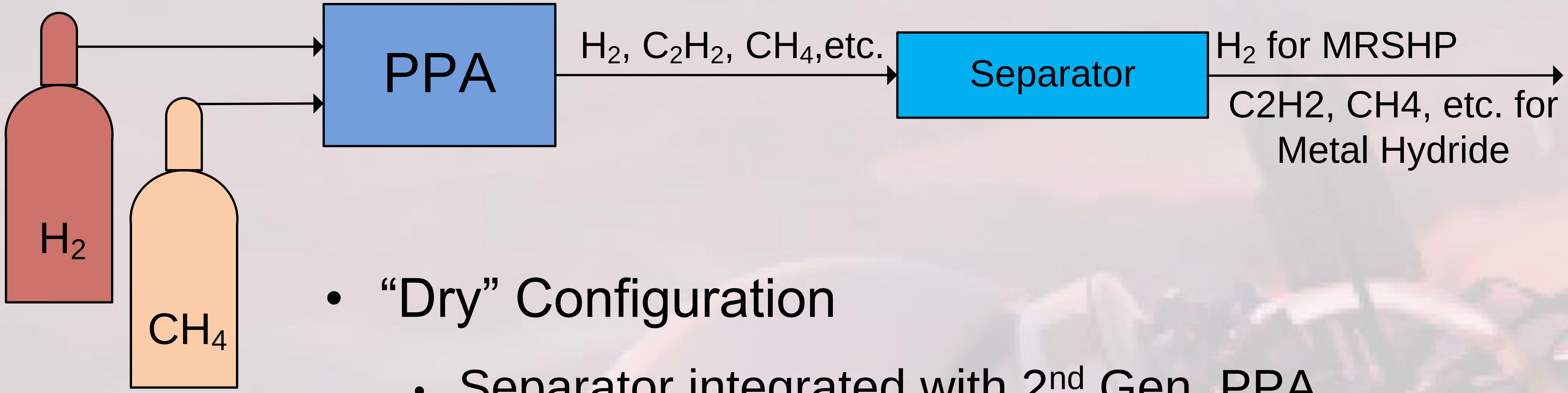
Hydrogen Components, Inc. Metal Hydride Canister

UMPQUA Microwave Regenerative Sorbent-based Hydrogen Purifier (MRSHP)

- MRSHP was the product of a Phase III Small Business Innovation Research (SBIR) development by UMPQUA Research Company
- Molecular Sieve 13X to carry out H_2 separation
- Thermal/vacuum desorption with heat provided by microwave power

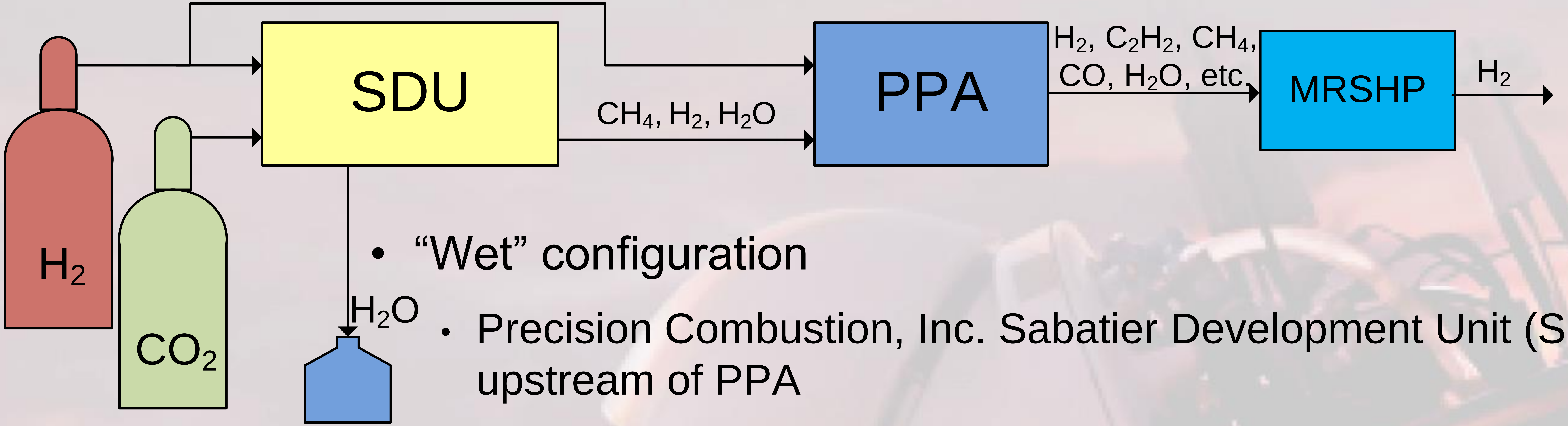
MRSHP

“Dry” Test Configuration



- “Dry” Configuration
  - Separator integrated with 2nd Gen. PPA
  - PPA operated from ultra-high purity H_2 and CH_4 bottles
  - 1 Crew Member processing rate
  - 4:1 tatio of H_2:CH_4
  - 52 torr reactor pressure
  - 550 W microwave power
  - Evaluated H_2 product and process effluent
- No water in separator feed stream

"Wet" Test Configuration



- "Wet" configuration
  - Precision Combustion, Inc. Sabatier Development Unit (SDU) upstream of PPA
  - SDU operated to produce 350 SmLPM CH_4 with minimal unreacted CO_2
  - Water vapor dewpoint of ~31°C
- PPA operated identically to Dry configuration
- PPA products contained all previously indicated compounds along with CO and H_2O

Metal Hydride – Method and Results

Test Parameters:

- Flow: from zero to 300 SmLPM
- Pressure: ~ 1 atm
- Temperature: 2 °C, room temp., 120 °C

Results:

- No effective capacity for H_2 at the conditions tested
  - Canisters are normally charged at 200 psig (13.6x the test pressure)
  - Likely that low pressure reduces driving force and reaction kinetics

MRSHP - Methods

Test Parameters:

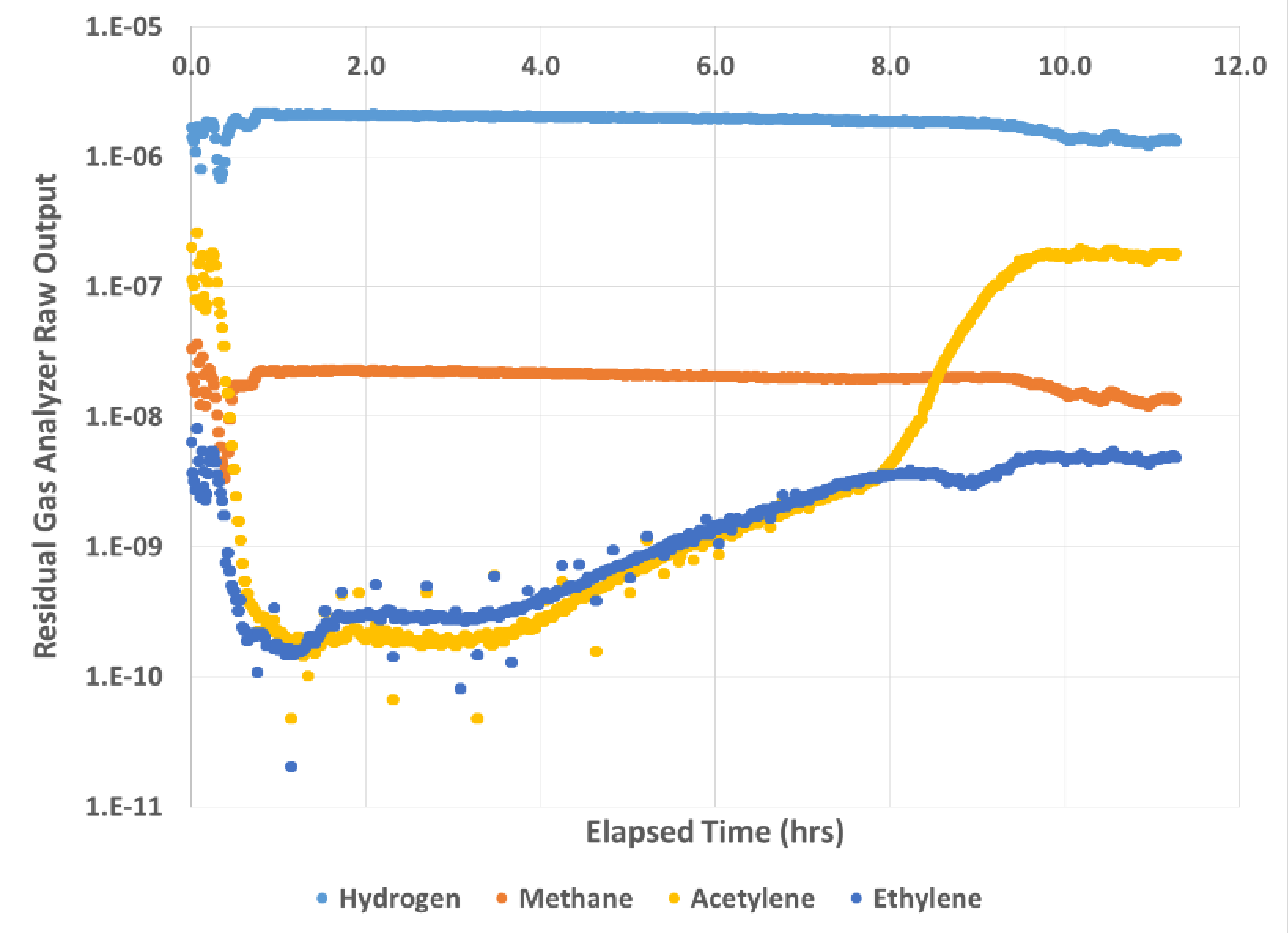
- Flow: One Crew Member rate
- Pressure: ~720 torr
- Temperature: room temp.
- Dry runs with PPA fed from high purity gas bottles
- Wet runs with PPA fed from PCI SDU

Desorption conditions following each adsorption cycle

Microwave Desorption #	Microwave Power Level (Watts)	Duration (Hours:Minutes)
1-Post Dry Adsorption	110	24:42
2-Post Dry Adsorption	135	16:2
3-Post Dry Adsorption	Varied	Long
1-Post Wet Adsorption	130	15:45
2-Post Wet Adsorption	130	15:00
3-Post Wet Adsorption	130	06:28
4-Post Wet Adsorption	130	06:45
5-Post Wet Adsorption	130	06:45

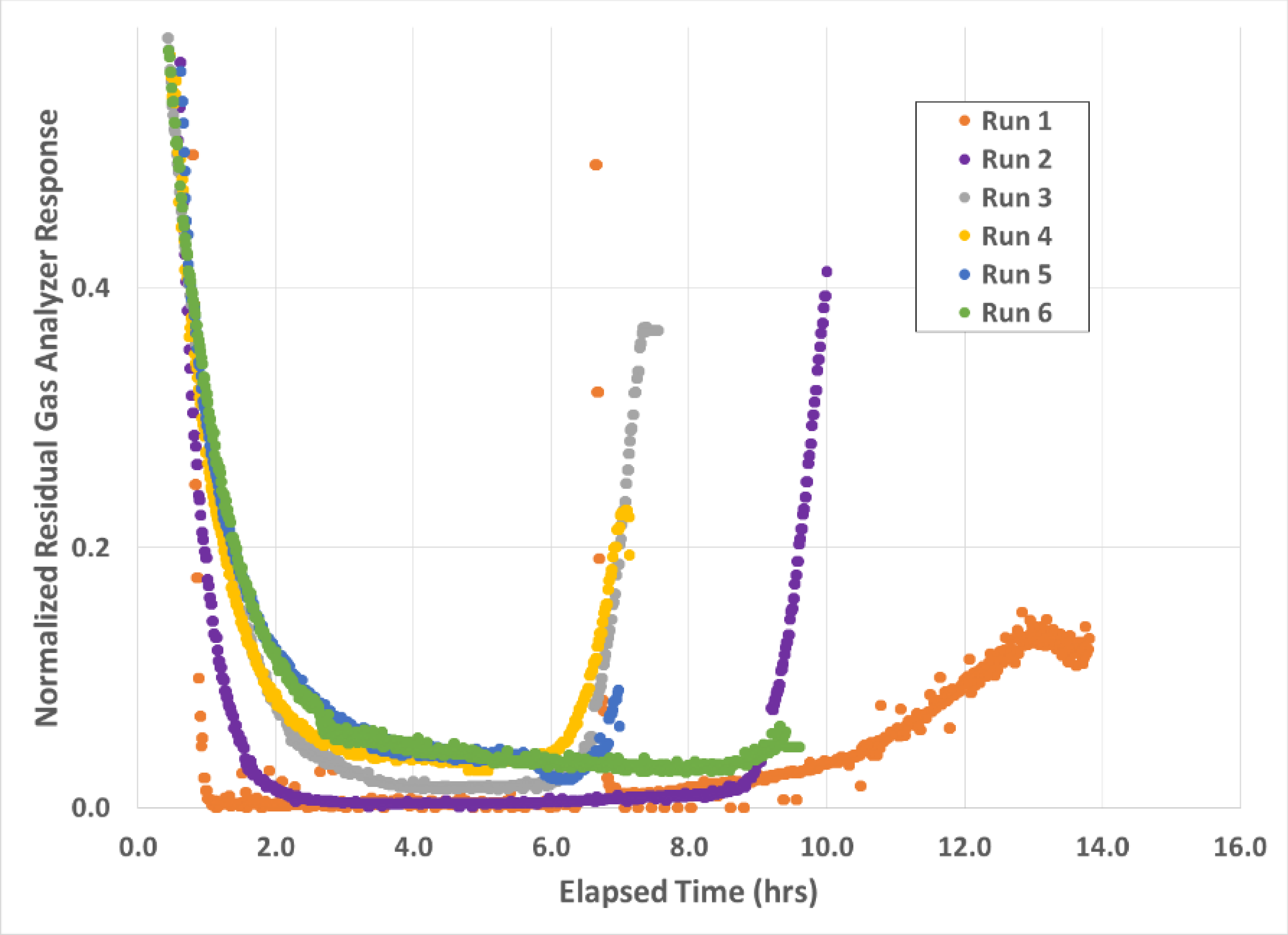
MRSHP - Results

- Third MRSHP Dry Adsorption Run, representative of all three dry runs



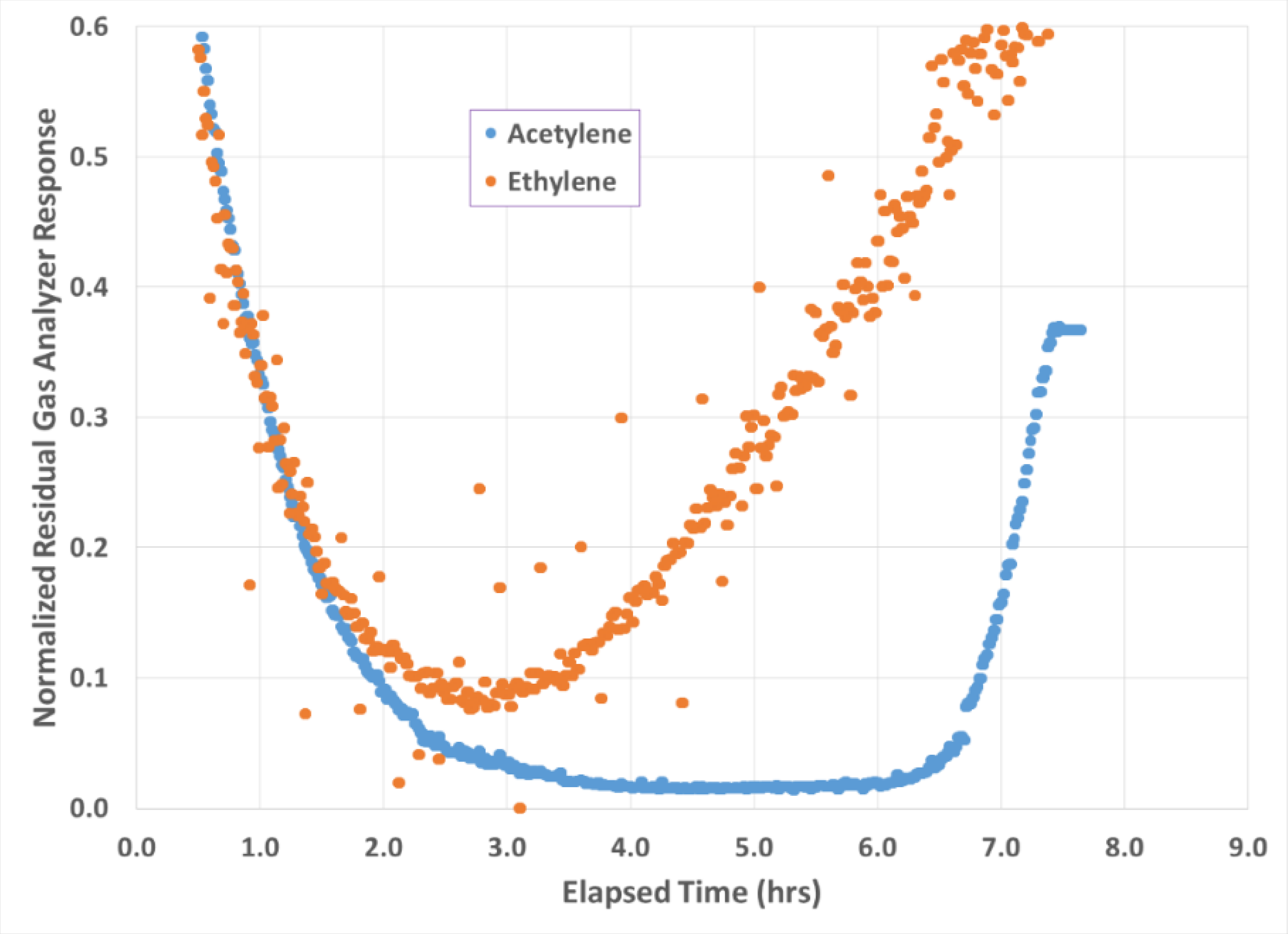
MRSHP - Results

- Combined acetylene adsorption breakthrough curves for Wet adsorption runs



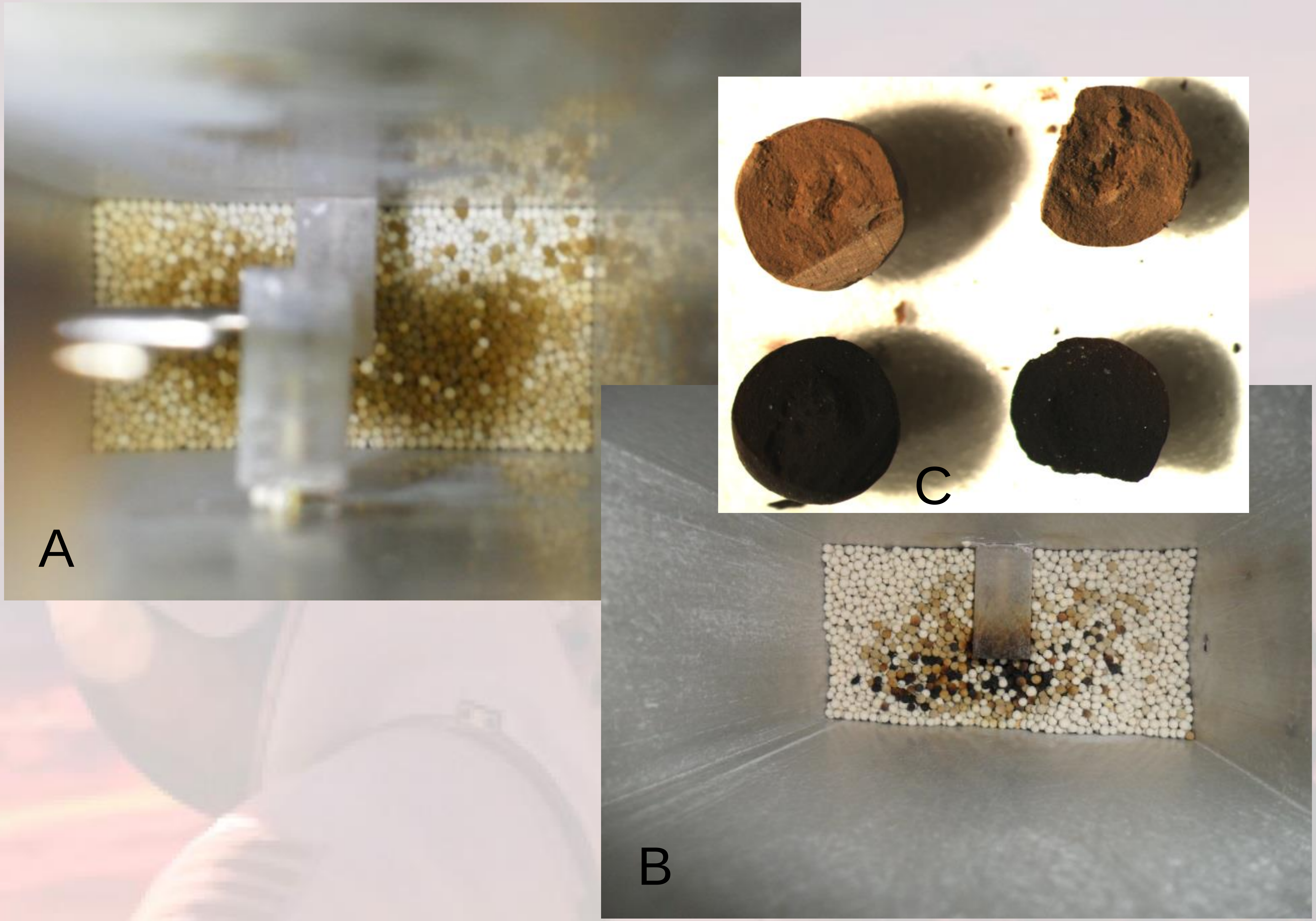
MRSHP - Results

- Wet adsorption run #4 contrasting ethylene and acetylene breakthrough curves

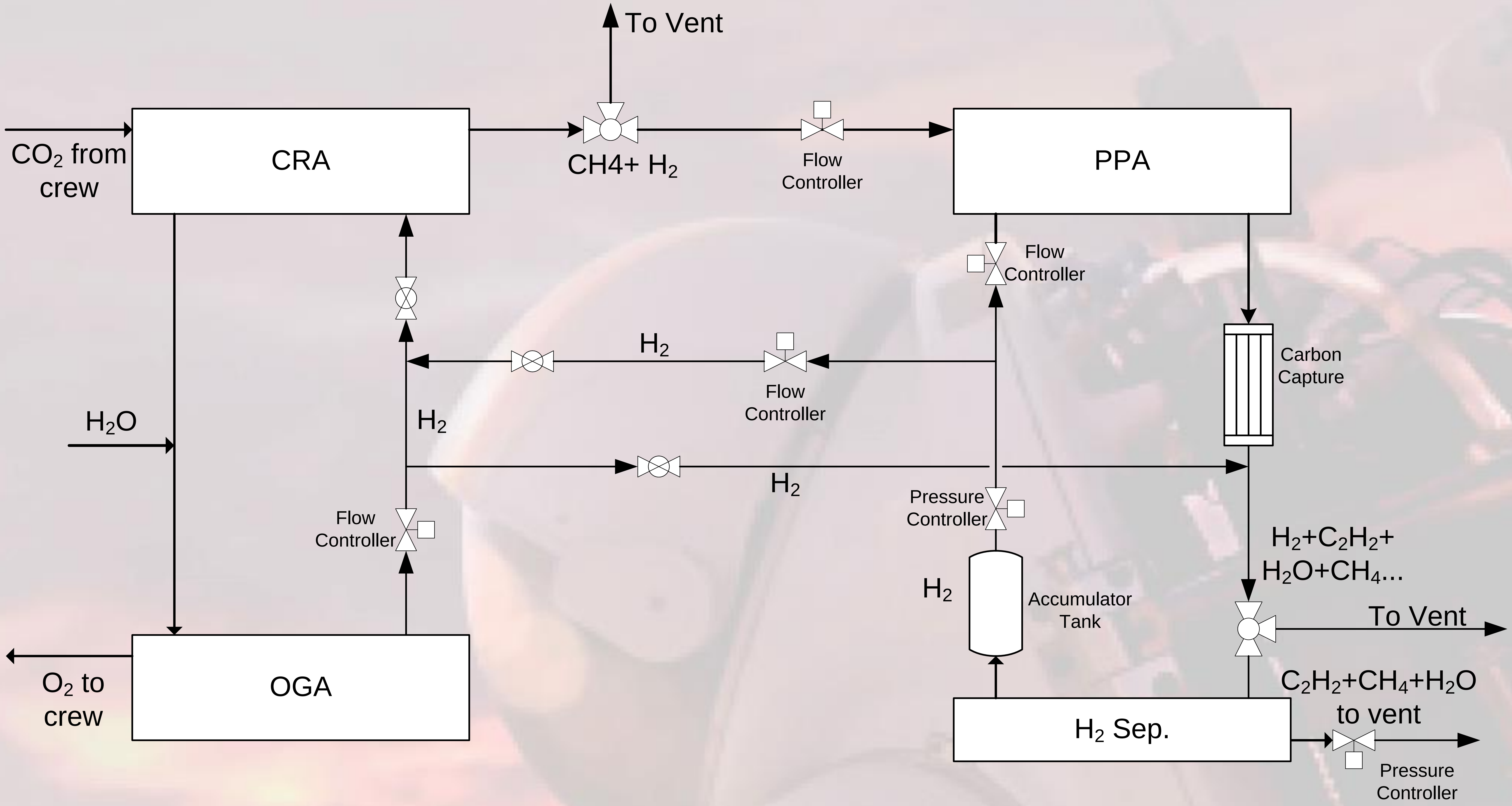


MRSHP – Results from Bed Disassembly

- 13X sorbent discoloration near microwave antennas noted during bed disassembly
  - Figures A and B are the view down the bed as it was unpacked
  - Figure C shows the cross section of two discolored sorbent beads



Proposed PPA System Architecture



- Proposed PPA system architecture utilizing electrochemical separation
  - Sorbent system would require desiccant and compressor

Conclusion

- Four hydrogen separation technologies (two Sustainable Innovations (SI) electrochemical cell stacks, the metal hydride, and the MRSHP) have been tested at MSFC since 2015
- Electrochemical cell stacks meet system requirements while simplifying system architecture and minimizing mass, power, and volume
- A fully integrated test with the PPA, OGA, and CRA, including a hydrogen recycle loop, is planned for 2017

Acknowledgements

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