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Hydrogen Purification and Recycling for an Integrated Oxygen Recovery System Architecture

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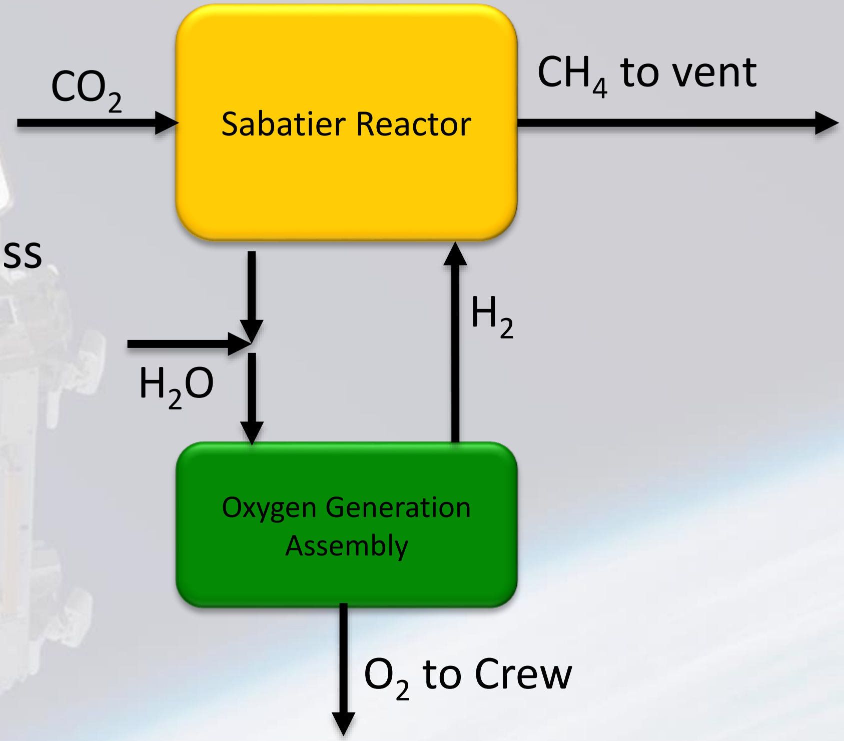
Overview

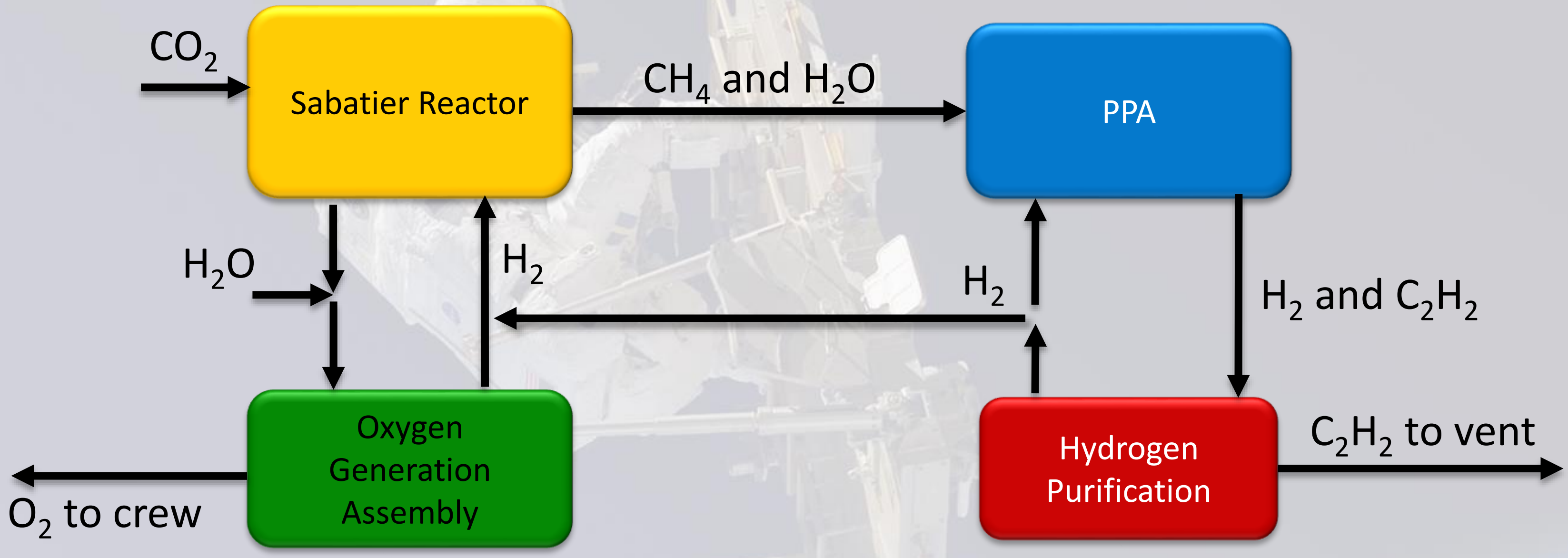
- Background
- Hardware
- Test Setup
- Results
- System Architectural Options
- Conclusion
- Acknowledgements

State-of-the-Art

- 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 ~54% of O_2 recovered from metabolic CO_2



Sabatier Plus Post-Processing



- ~91% O_2 recovery from CO_2 possible

PPA Technology Description

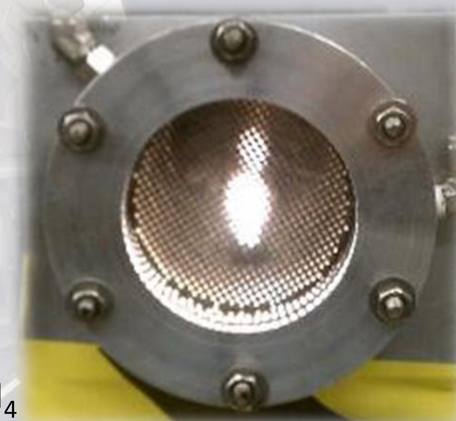
- Developed by UMPQUA Research Co.
- Methane converted to hydrogen and acetylene by partial pyrolysis in microwave generated plasma

- Targeted PPA Reaction:

  $2CH_4 \leftrightarrow 3H_2 + C_2H_2$

- 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	$CH_4 + H_2O \leftrightarrow CO + 3H_2$



H_2/CH_4 Plasma

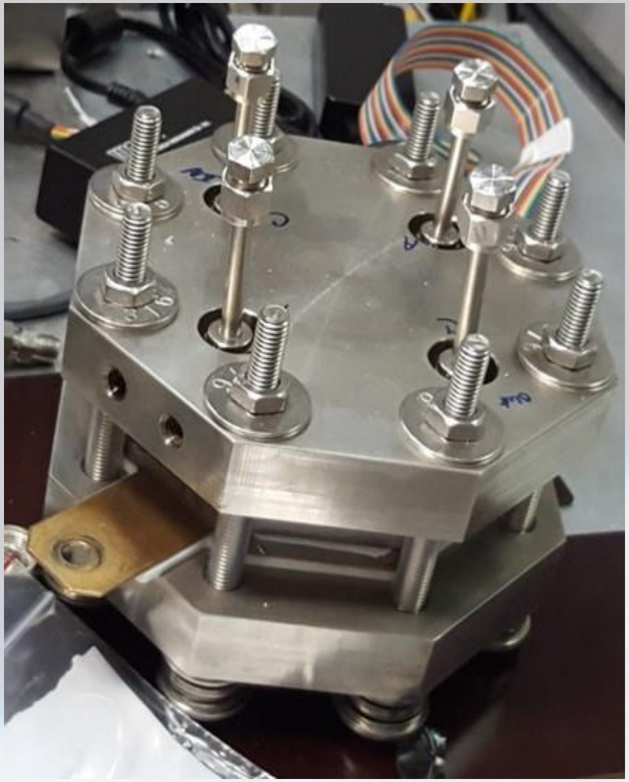
Plasma Pyrolysis Assembly

Metal Hydride Hardware

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

Electrochemical Hardware

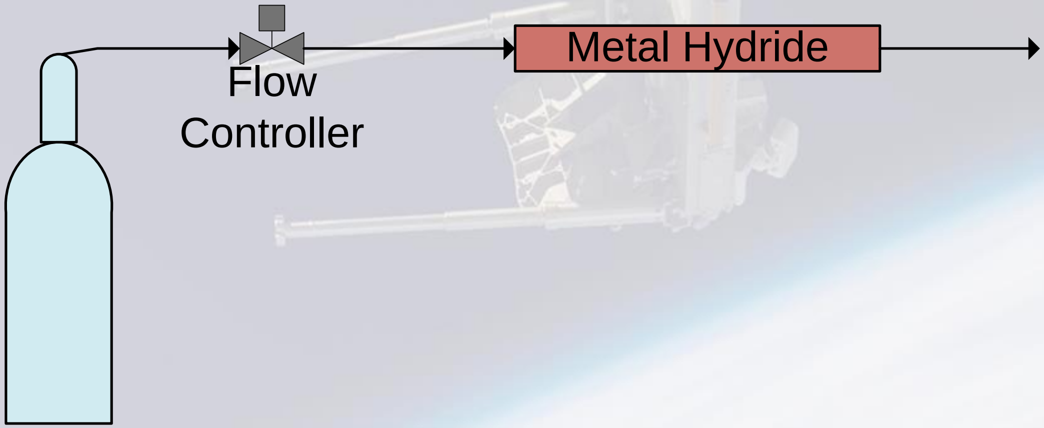
- Electrochemical hydrogen separation
  - H_2 electro-oxidized to protons and electrons
  - Protons are electro-reduced, recombined with electrons, in another chamber producing purified H_2
- Basic technology was well developed but not compatible with CO
  - CO would preferentially adsorb on catalytic electrodes and interfere with H_2 oxidation
- Sustainable Innovations developed electrolyte materials capable of operating above 150°C CO thermal desorption temperature
  - "Basic" and "Advanced" cell stacks delivered to MSFC



Sustainable Innovations Cell Stack

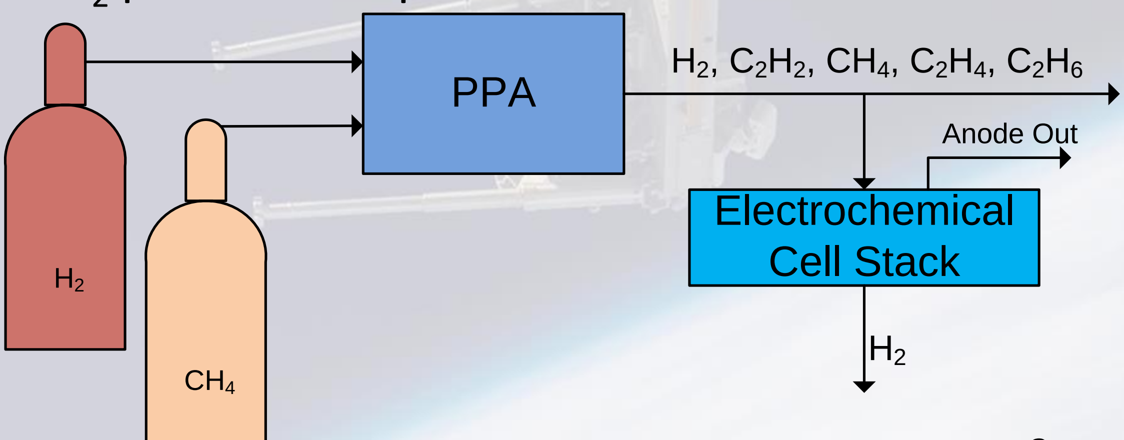
Test Configurations

- Stand alone
  - Metal hydride to verify safety
    - Literature indicated other metal hydrides had potential to cause violent acetylene decomposition or metal-carbide formation
  - Tested with gas mixture containing 7% C_2H_2, 1% CH_4, and 92% H_2
  - Tested in Marshall Space Flight Center's Component Development Area, usually used for rocket engine component testing



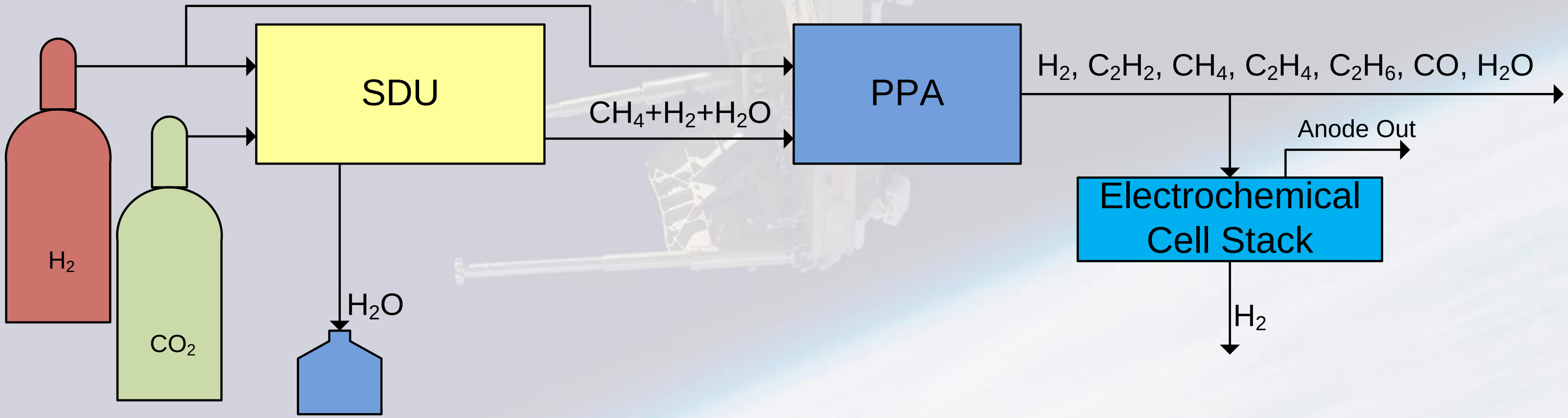
Test Configurations

- **PPA + H_2 Purification**
  - Cell stacks integrated with 2nd Gen. PPA
  - PPA operated with ultra-high purity H_2 and CH_4 bottles
  - 1 Crew Member processing rate
  - 4:1 ratio of H_2:CH_4
  - 52 torr
  - 550 W microwave power
- PPA products contained H_2, C_2H_2, unreacted CH_4, C_2H_4, and C_2H_6
- No CO
- 100 standard milliliters per minute (SmLPM) to cell stack
- Evaluated H_2 product and process effluent



Test Configurations

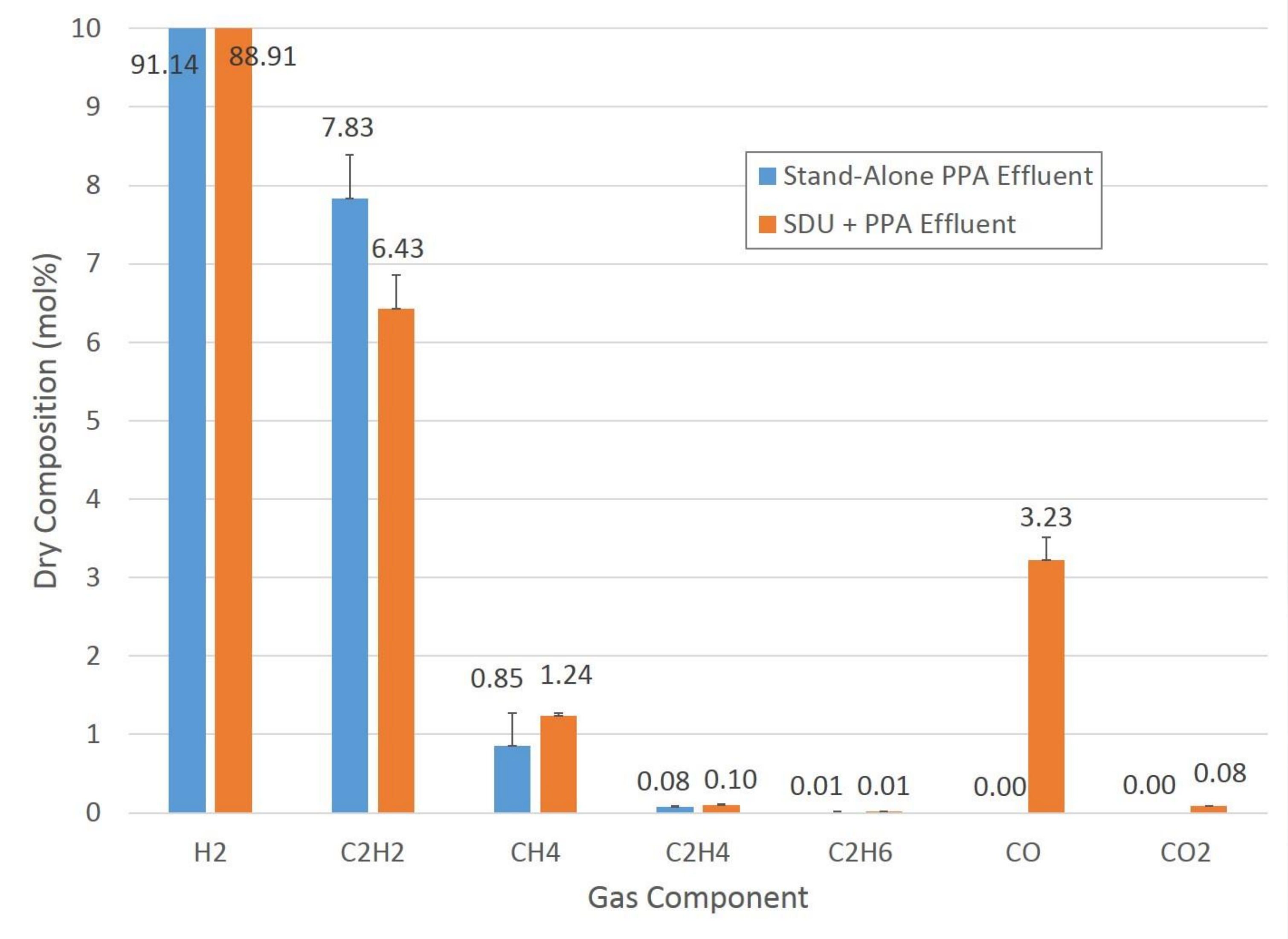
- **Sabatier Development Unit (SDU) + PPA + H_2 Purification**
  - Precision Combustion, Inc. SDU integrated upstream of PPA
  - SDU operated to produce 350 SmLPM CH_4 with no unreacted CO_2
  - Methane product containing 80 mol% hydrogen
  - Water vapor content dew point of 31°C
- PPA operated identically to PPA + H_2 testing
- PPA products contained all previously indicated components and CO and H_2O



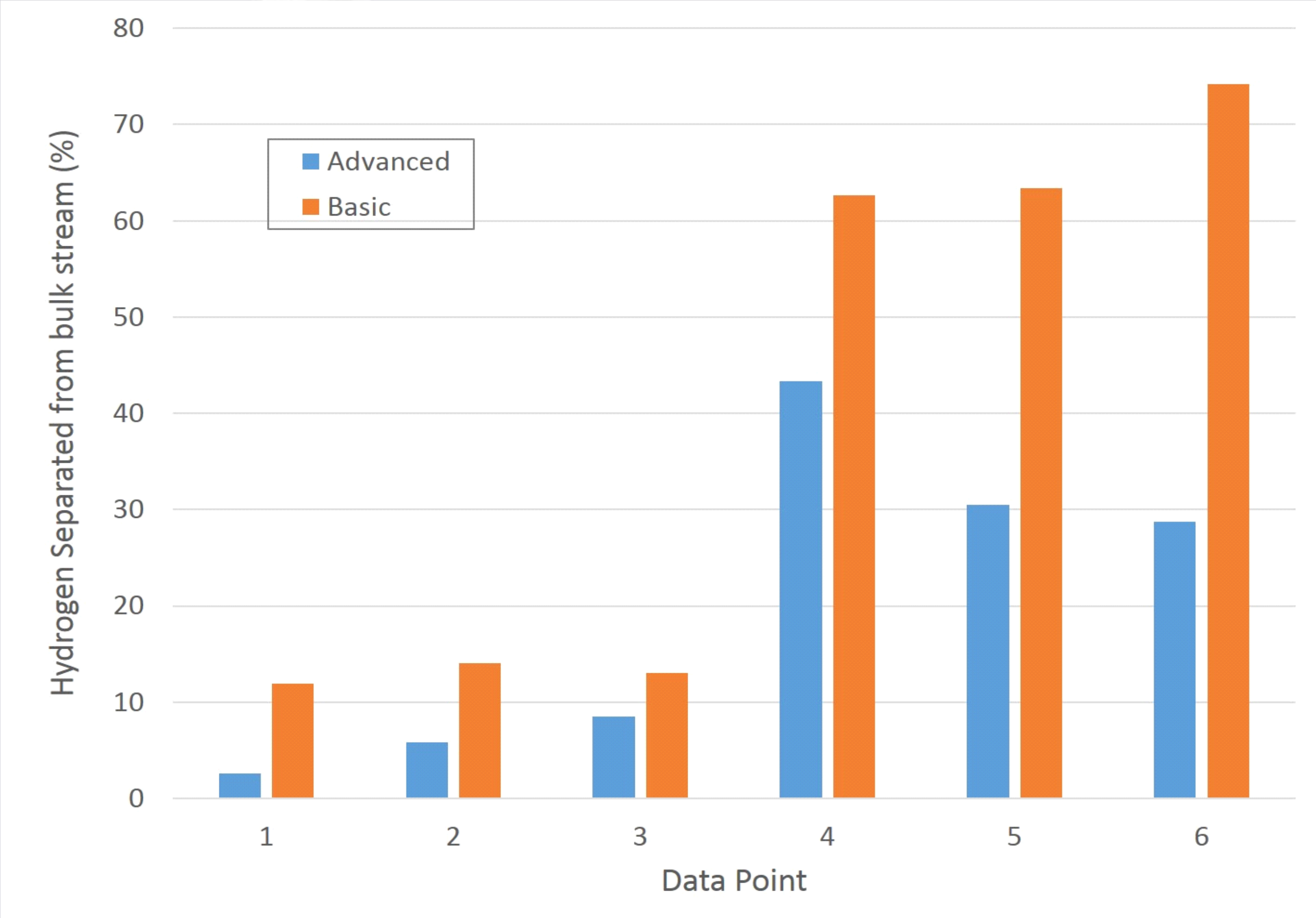
Metal Hydride Performance

- No measurable pressure or temperature difference between pure H_2 runs and acetylene mixed gas runs
- No safety risk under expected operating conditions

PPA effluent composition as a function of configuration



H_2 separation performance comparison between Basic and Advanced cell stacks

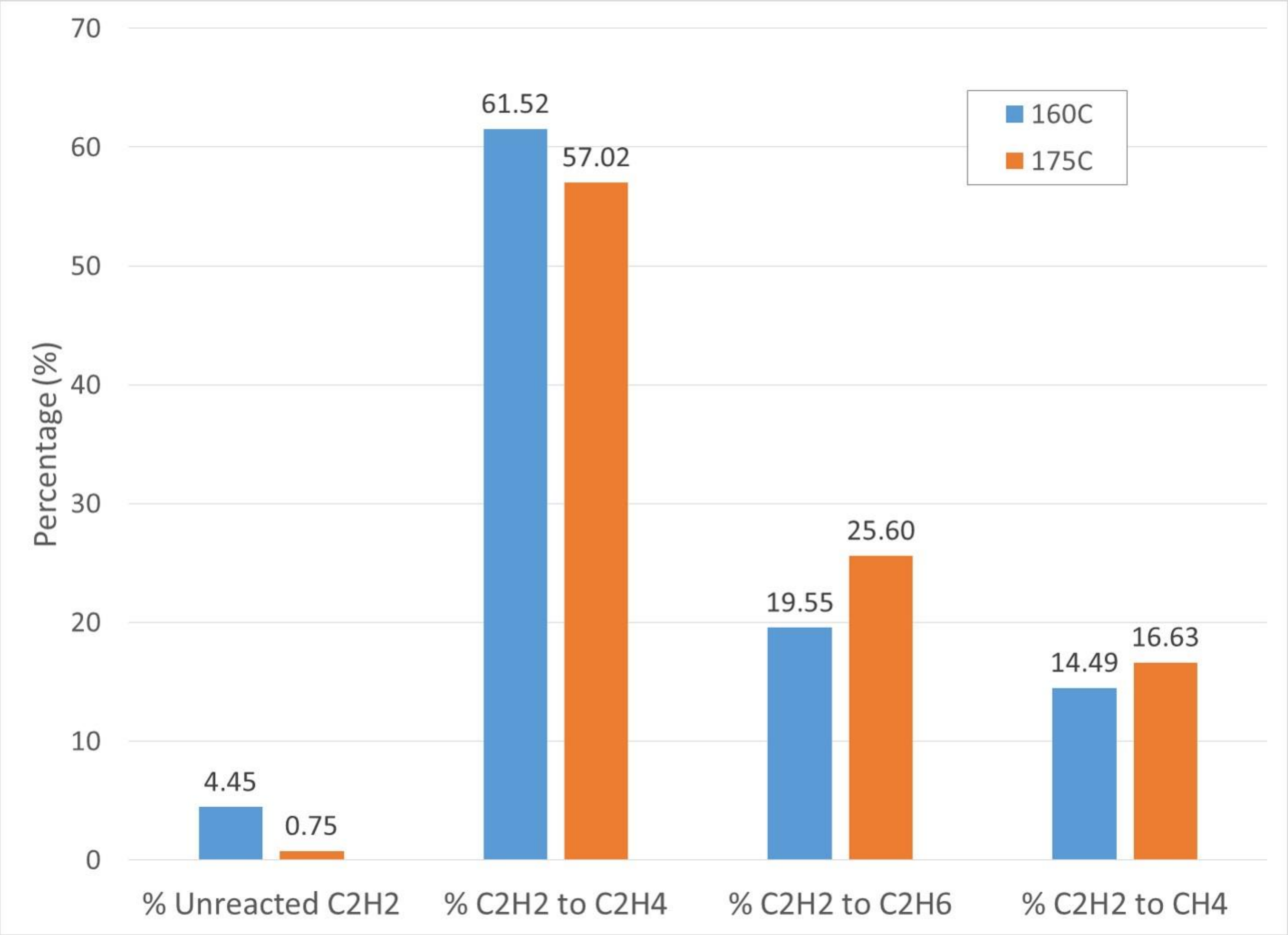


- Varied gas feed from PPA, stack temperature, inlet composition, and applied voltage
  - Conditions for each data point were identical
- **All recovered H_2 pure within measurable limits of µGC**

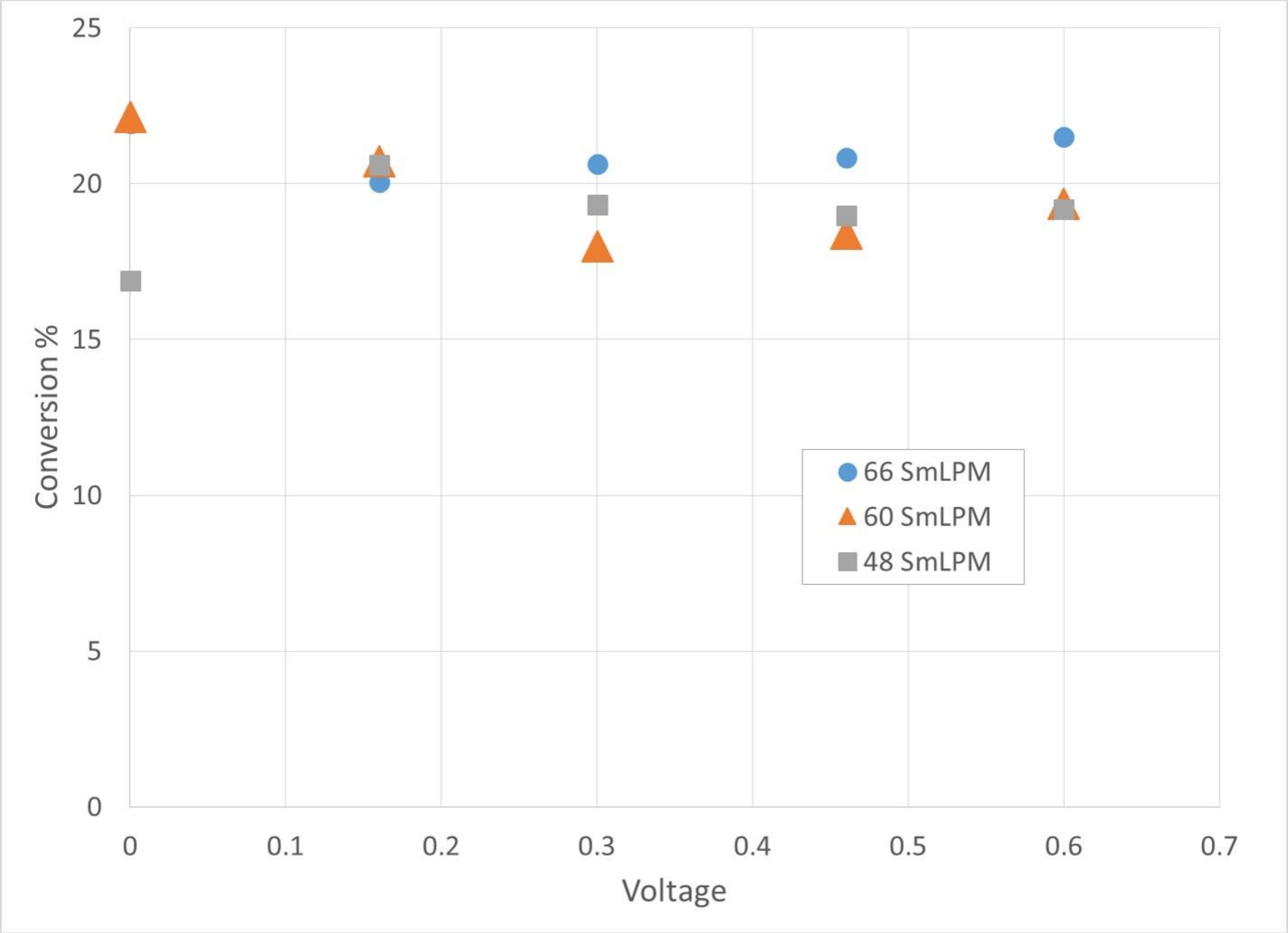
Hydrogenation

- Expected similar gas mix (minus H_2) leaving anode as entering
- High levels of C_2H_4 and C_2H_6 were observed with minimal or no C_2H_2
- Overall chemical equations:
  - CH_4 Conversion to Ethane $2CH_4 \leftrightarrow H_2 + C_2H_6$
  - CH_4 Conversion to Ethylene $2CH_4 \leftrightarrow 2H_2 + C_2H_4$
- Ethane Formation from CH_4 with free radical intermediates: $CH_4 + CH_4 \leftrightarrow CH_3{*} + CH_3{*} + H{*} + H{*} \leftrightarrow C_2H_6 + H_2$
  - CH_4 forms $CH_3{*}$ free radicals which then recombine to form C_2H_6
  - C_2H_6 is converted to C_2H_4 and C_2H_4 is converted to C_2H_2
  - Reverse reactions also occur providing a mechanism for C_2H_2 hydrogenation to the other hydrocarbons

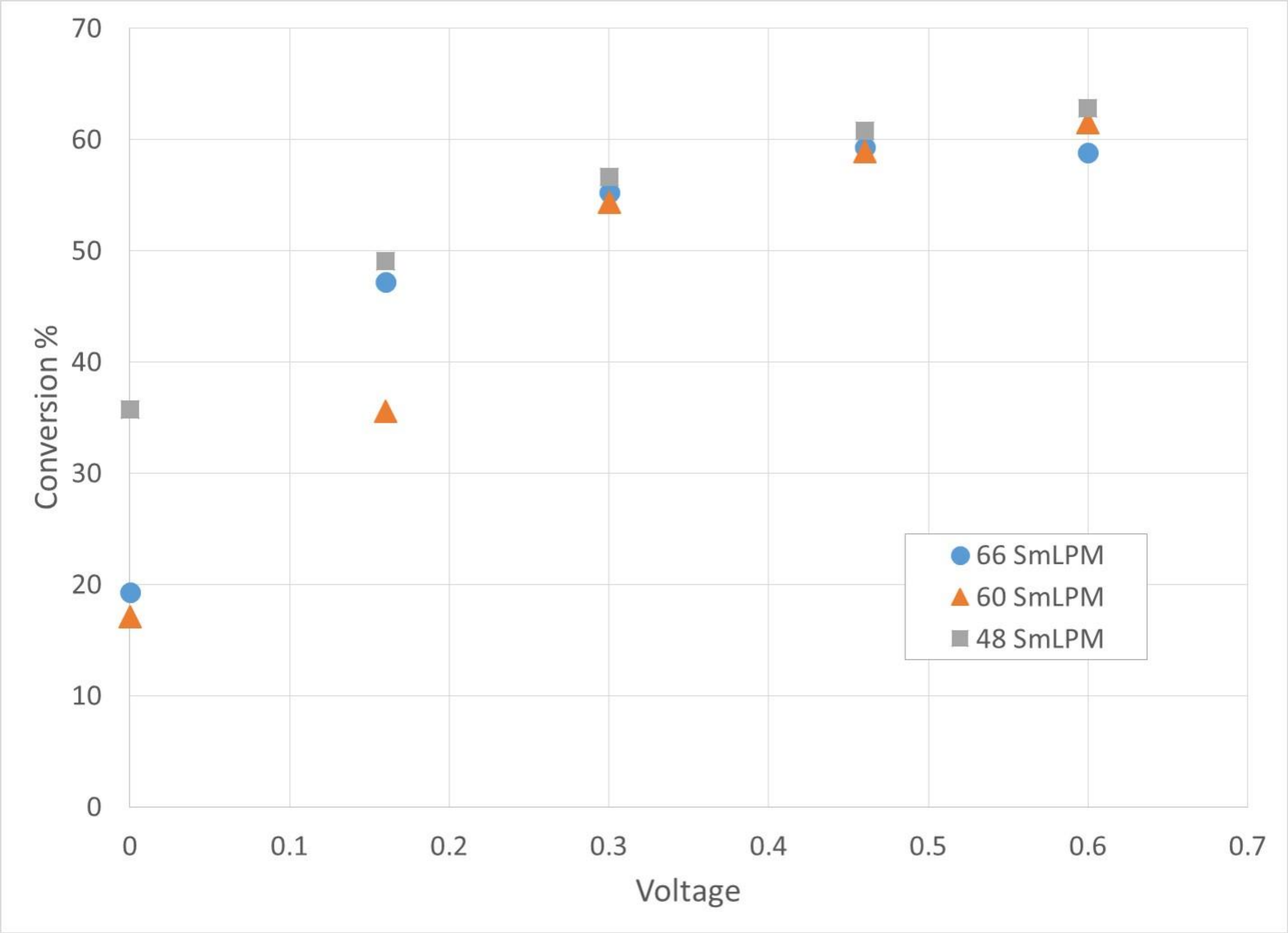
Effect of temperature on C_2H_2 hydrogenation, Advanced Cell Stack



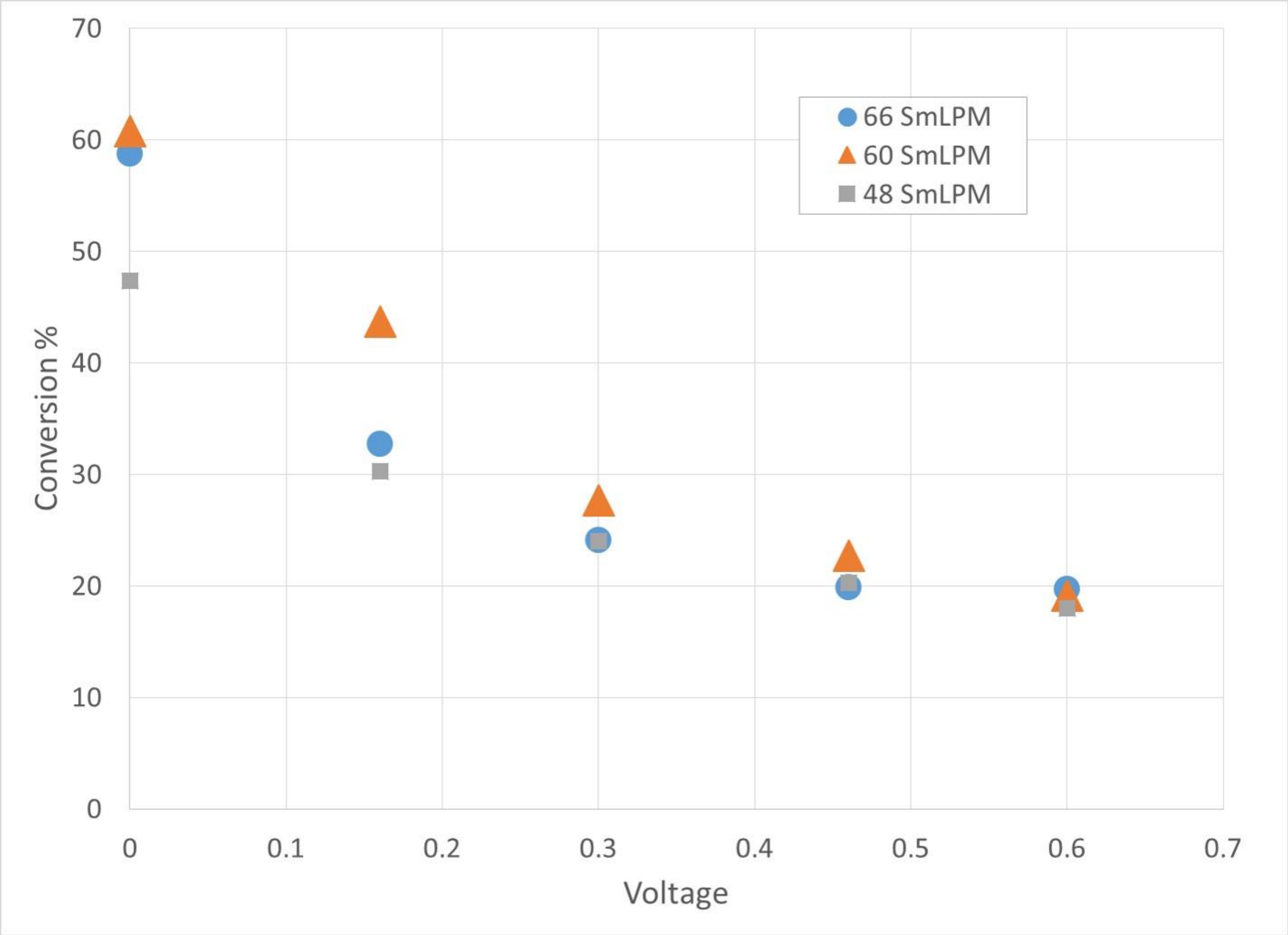
Acetylene conversion to methane in Advanced cell stack as a function of voltage and anode feed rate.



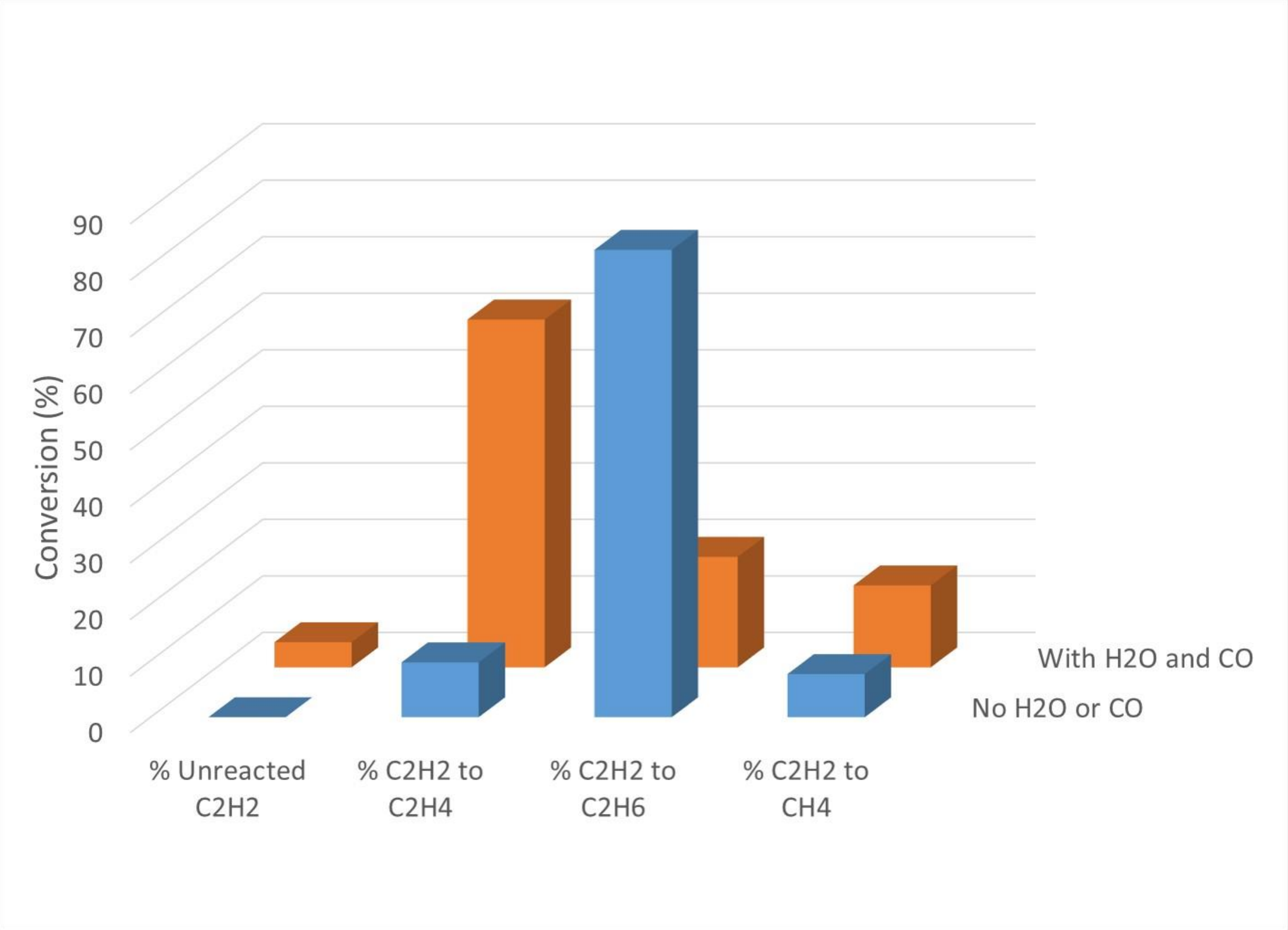
Acetylene conversion to ethylene in Advanced cell stack as a function of voltage and anode feed rate.



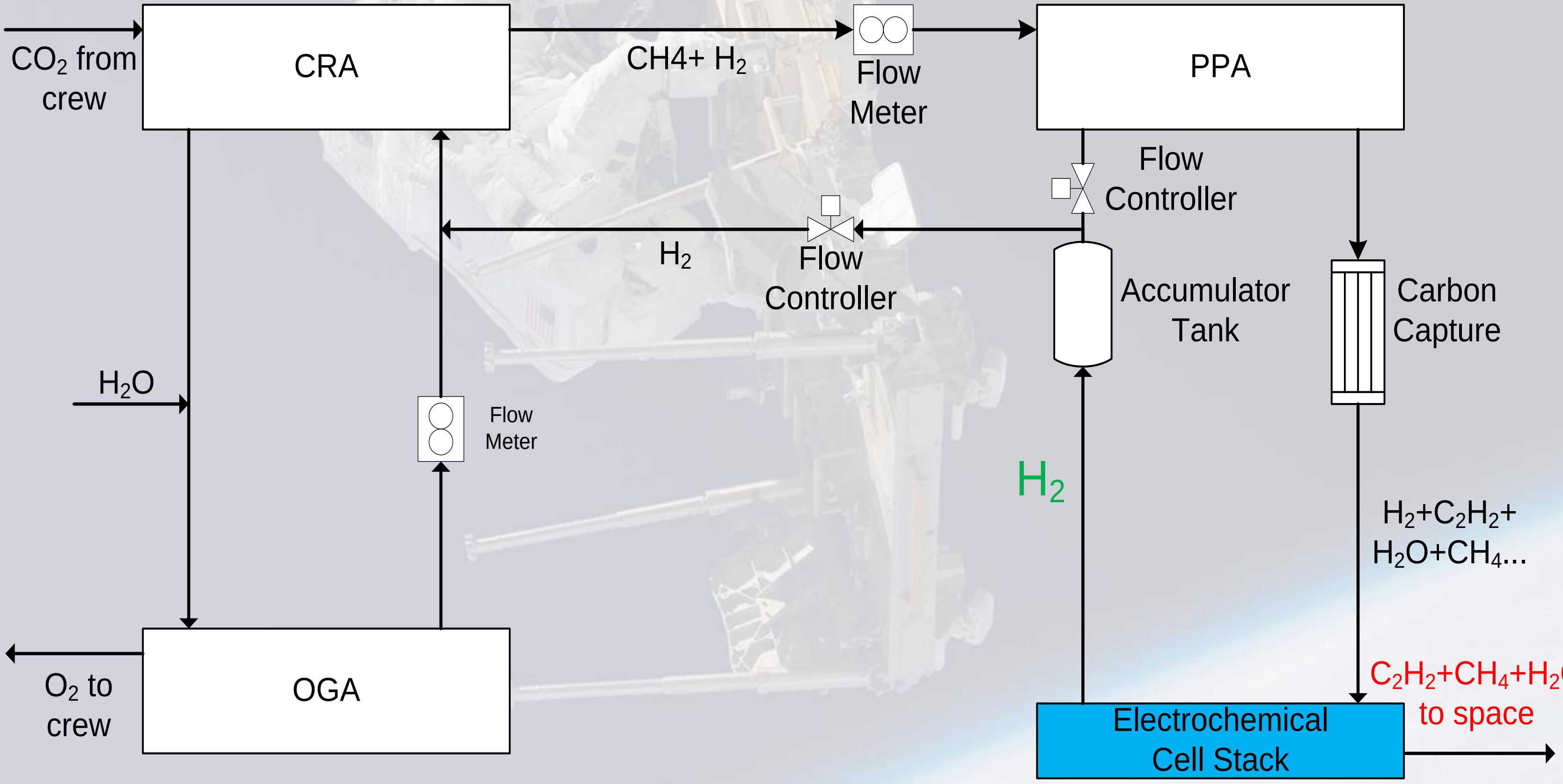
Acetylene conversion to ethane in Advanced cell stack as a function of voltage and anode feed rate.



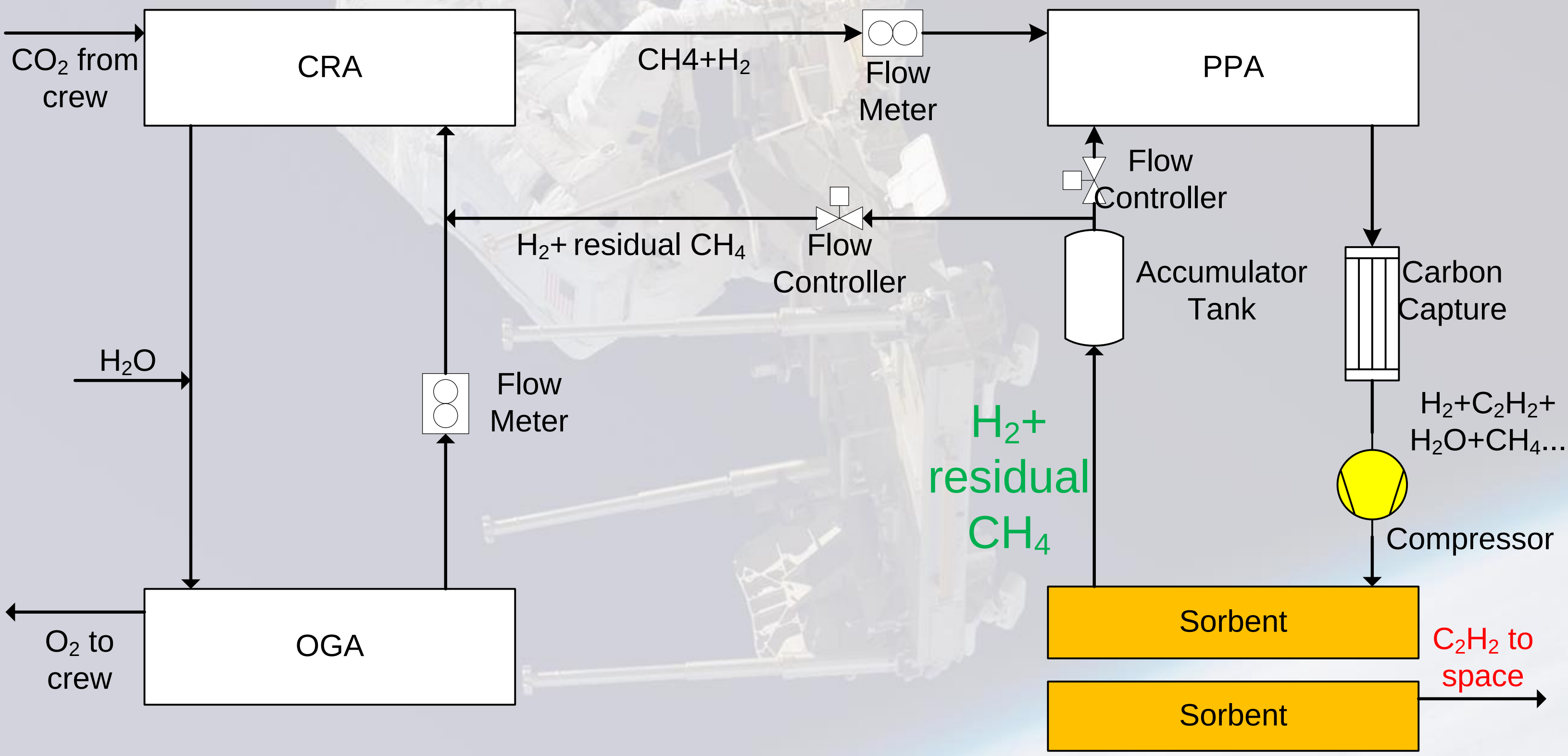
Effect of water vapor and CO on hydrogenation of C_2H_2.



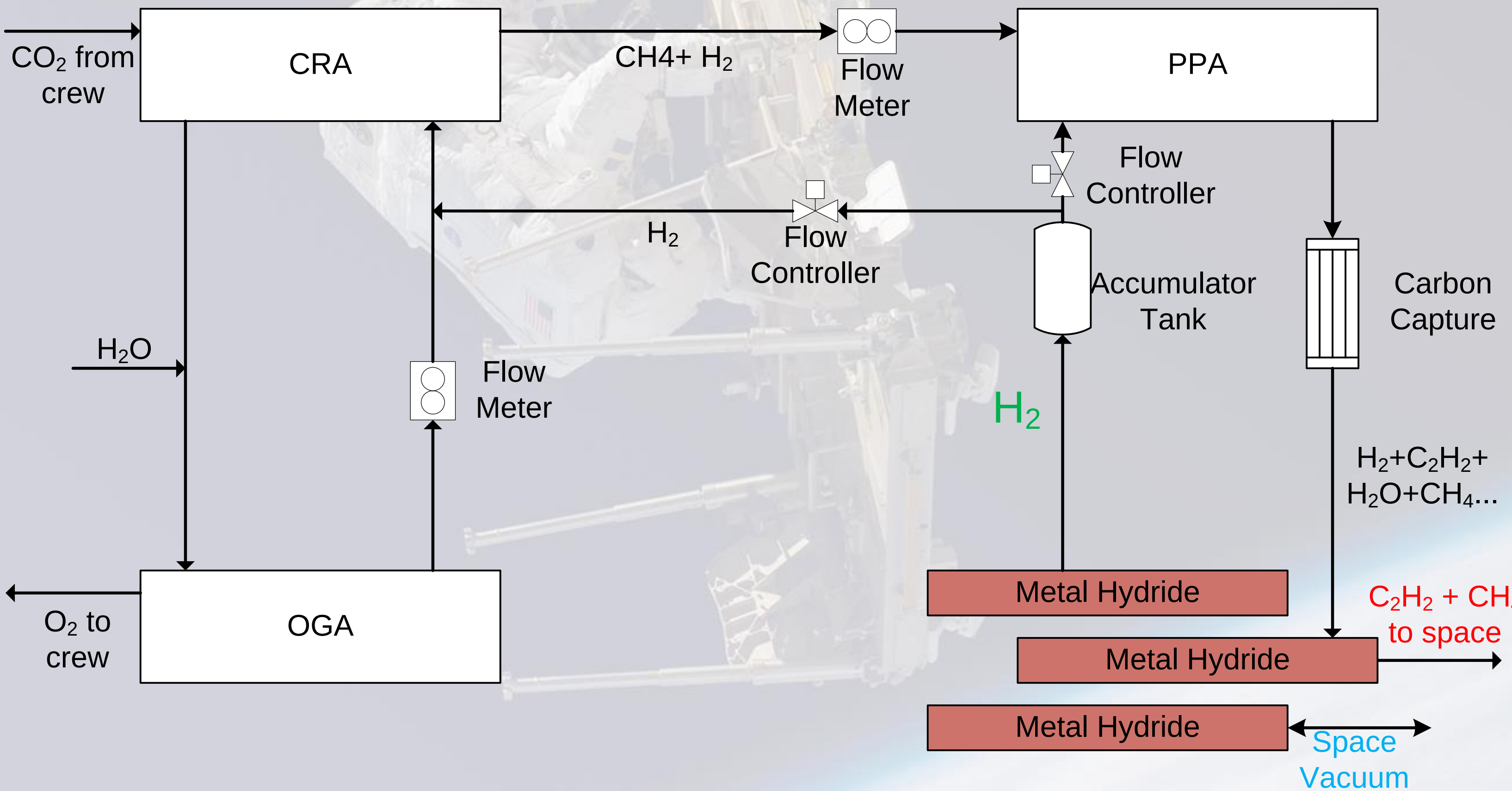
SI Cell Stack Architecture



Sorbent Architecture



Metal Hydride Architecture



Conclusion

- Effective acetylene separation technology is essential for Sabatier + PPA architecture
- Future work:
  - Reduce acetylene hydrogenation in cell stacks
  - Test UMPQUA sorbent based hydrogen separation system
  - Test metal hydride

Acknowledgements

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- …Questions?