Increased Oxygen Recovery from Sabatier Systems Using Plasma Pyrolysis Technology and Metal Hydride Separation

Zach Greenwood, Morgan Abney, Jay Perry, Lee Miller, Roger Dahl, Neal Hadley, Spencer Wambolt, and Richard Wheeler

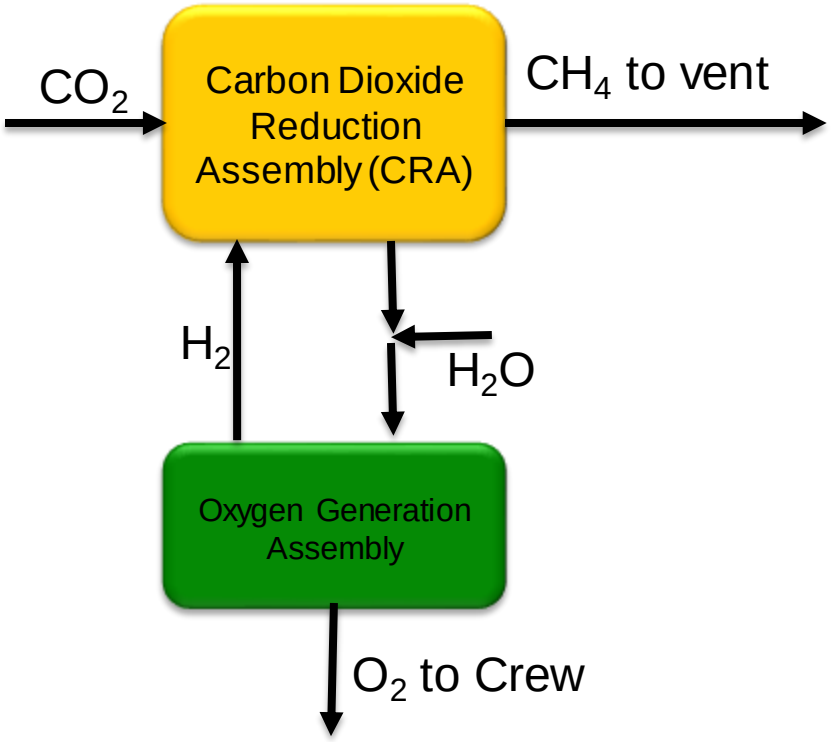
45rd International Conference on Environmental Systems
Bellevue, Washington
July 12-16, 2015

Overview

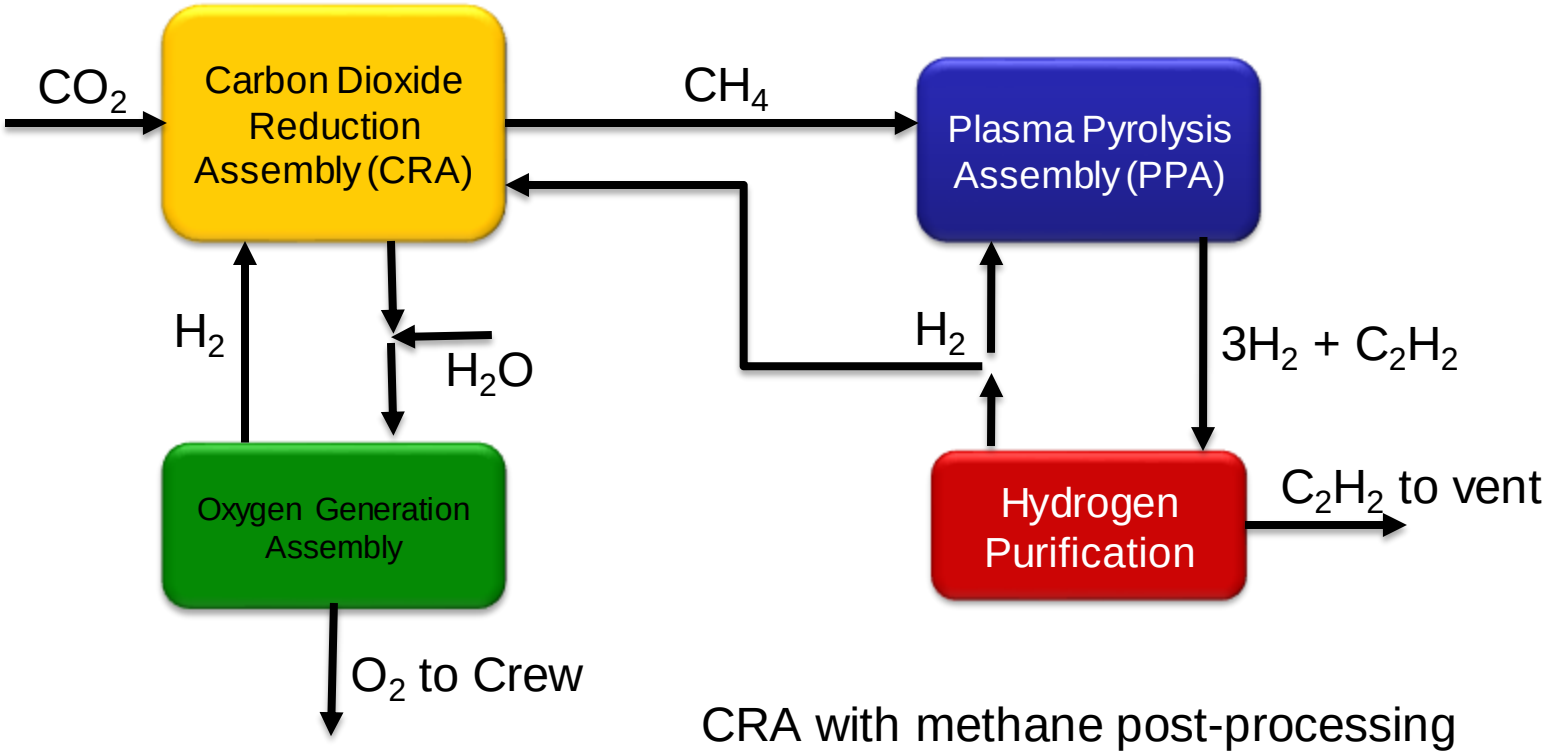
- Background
  - State-of-the-Art
  - Beyond State-of-the-Art
- PPA Technology Description
- Hydrogen purification
  - Metal Hydrides
- Objectives
- Method
- Results
- Conclusion
- Acknowledgements

State-of-the-Art

- Carbon Dioxide Reduction Assembly (CRA)= SOA ISS
  - $CO_2 + 4H_2 \rightarrow 2H_2O + CH_4$
  - Water product electrolyzed for oxygen
  - Methane product vented resulting in loss of hydrogen reactant
  - ~50% of O_2 recovered from metabolic CO_2



Beyond State-of-the-Art



CRA with methane post-processing recovers 75-90% of O_2 from metabolic CO_2

PPA Technology Description

- Methane converted to hydrogen and acetylene by partial pyrolysis in microwave generated plasma
  - $2CH_4 \rightarrow 3H_2 + C_2H_2$
- First Generation UMPQUA Microwave Plasma Methane Pyrolysis Assembly (PPA) delivered in May 2009
- 3nd Gen. PPA, capable of 4CM flow rates, delivered October 2013

H_2/CH_4 Plasma

3rd Gen PPA

PPA Technology Description

- 3rd Gen. PPA integrated with Sabatier Development Unit (SDU) in Exploration Test Chamber
- PPA gets CH_4 from Sabatier Development Unit (SDU) or bottles
  - H_2 and CO_2 from bottles

Hydrogen Purification

- Primary methods of interest
  - Sorbents
    - SBIR in work
  - Solid polymer electrolysis
    - SBIR in work
  - Metal hydrides
    - MSFC preliminary investigation
- For use with C_2H_2 must be below autoignition temp. (325°C) and exothermic decomposition pressure (200kPa)

Metal Hydrides

- Form when H_2 reacts with metal alloy to form chemical compound
  - $M + \frac{1}{2}xH_2 \leftrightarrow MH_x + heat$
- Reversible
  - La-Ni-Sn alloys present greatest cyclic durability and performance at PPA process conditions
- High volumetric packing density
  - Ex. $LaNi_5H_{6.7}$ hydride has a volumetric density of 7.6×10^{22} atoms H/ml which is nearly 81% greater than the liquid H_2 (4.2×10^{22} atoms H/ml.)

Hydrogen Science & Technology Fact Sheet, Savannah River National Laboratory, 2009.

Objectives

- Evaluate performance of 3rd Gen. PPA
  - Stand-alone
  - Integrated with SDU
- Investigate metal hydride hydrogen purification

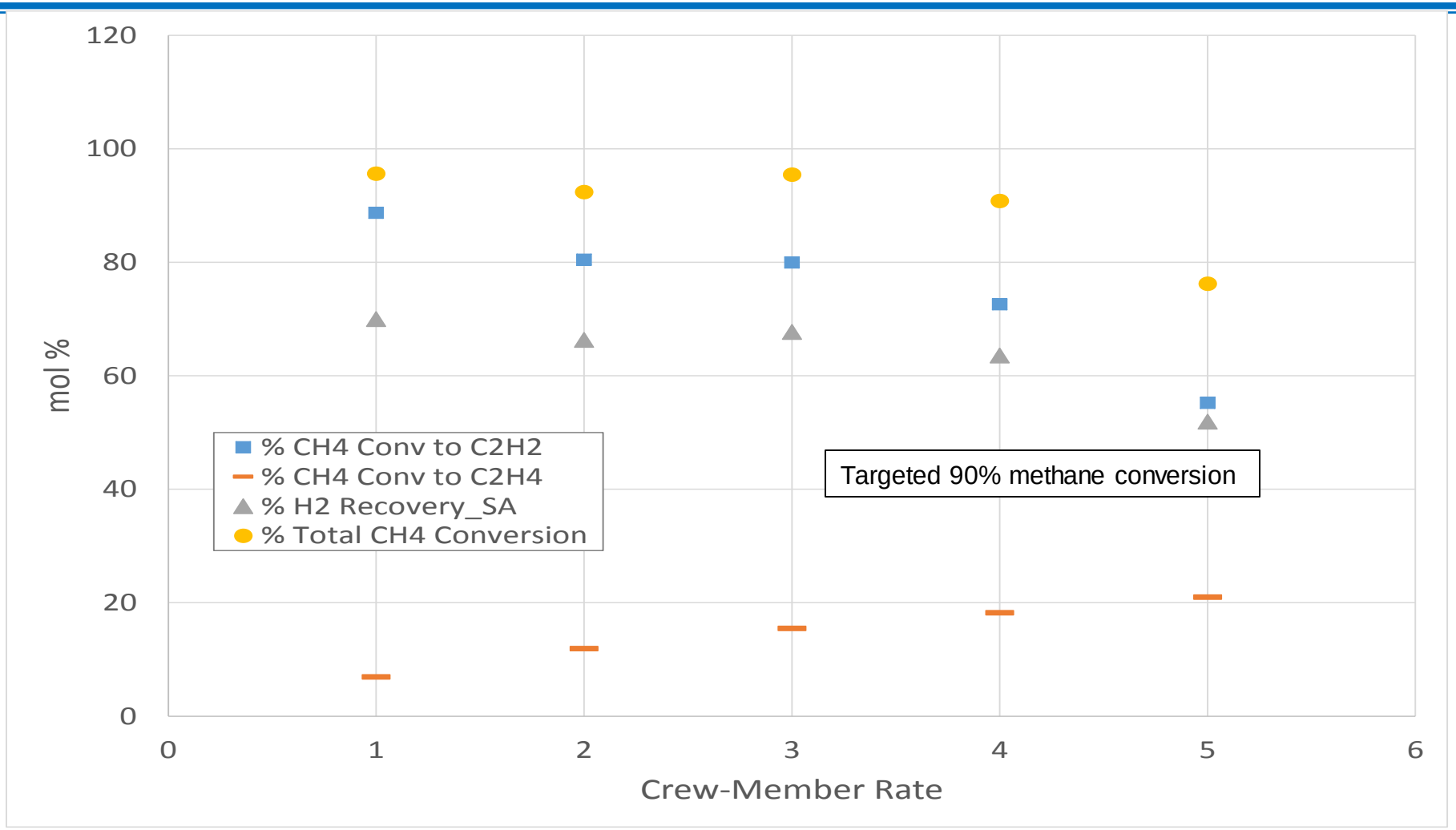
Method: PPA Stand-Alone

- Purpose: Verify performance consistent with UMPQUA's
- H_2 and CH_4 fed from ultra-high purity bottles
  - 4:1 ratio H_2:CH_4
- 1,2,3,4, and 5 crew member processing rates

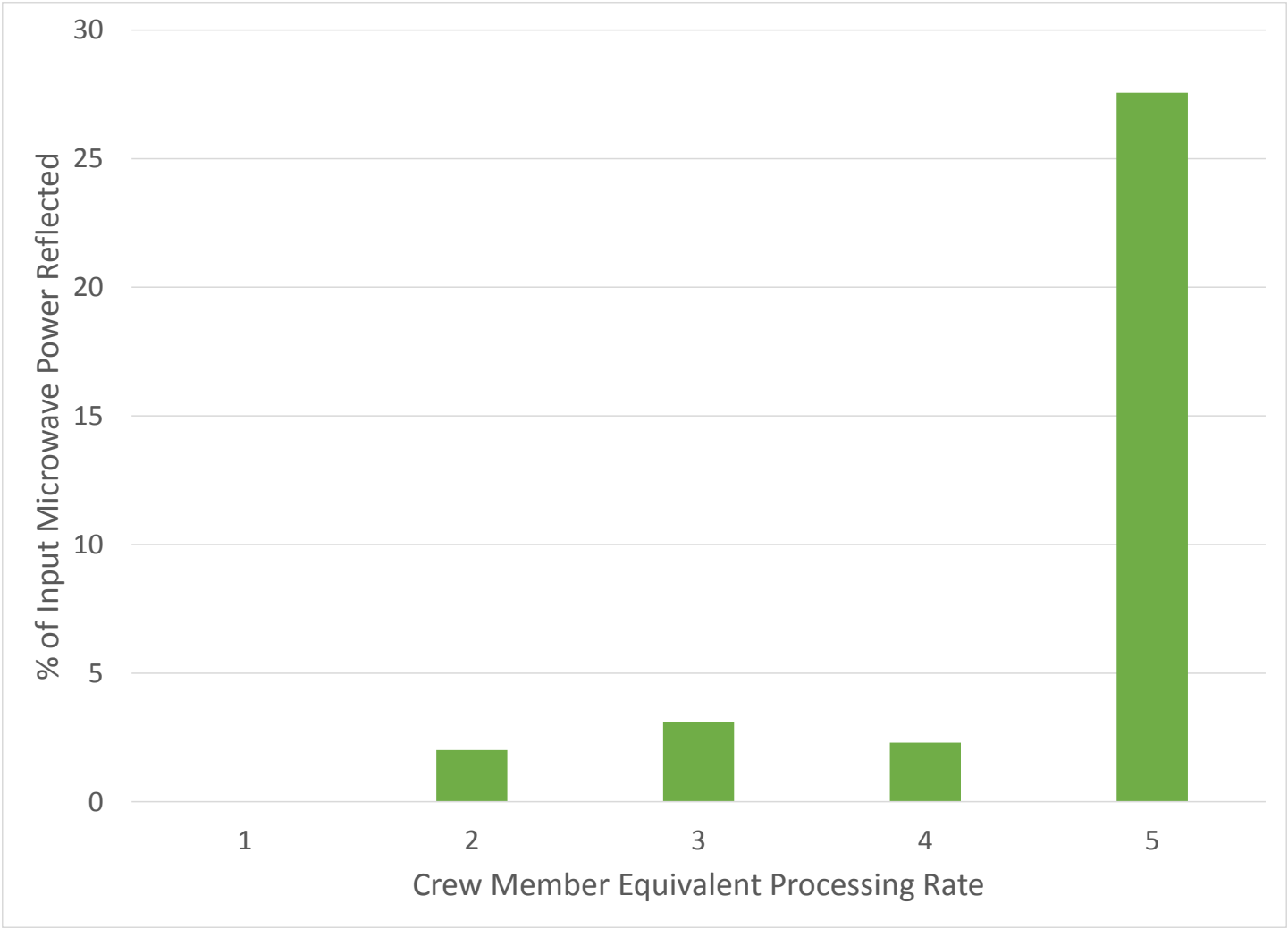
Method: PPA Integrated

- Purpose: Evaluate PPA performance with Sabatier Development Unit (SDU) CH_4 feed stream
- SDU operated at H_2:CO_2 ratio of 4.5:1
  - Ensured all CO_2 was reacted
  - H_2 in SDU product
  - H_2O in SDU product
- H_2 balance from bottles adjusted to maintain 4:1 ratio of H_2:CH_4
- 2,3, and 4 crew member processing rates

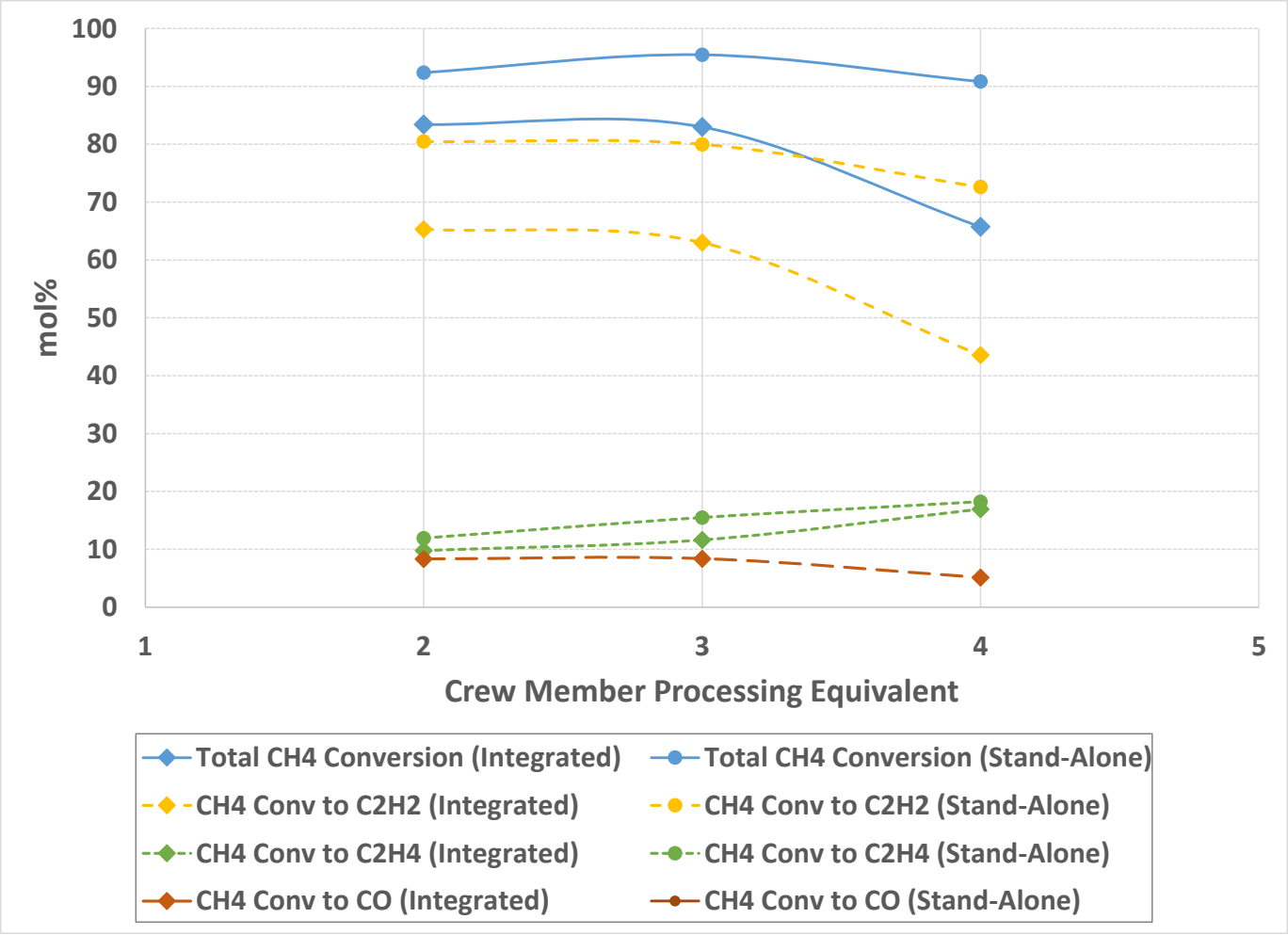
Results: Stand-Alone



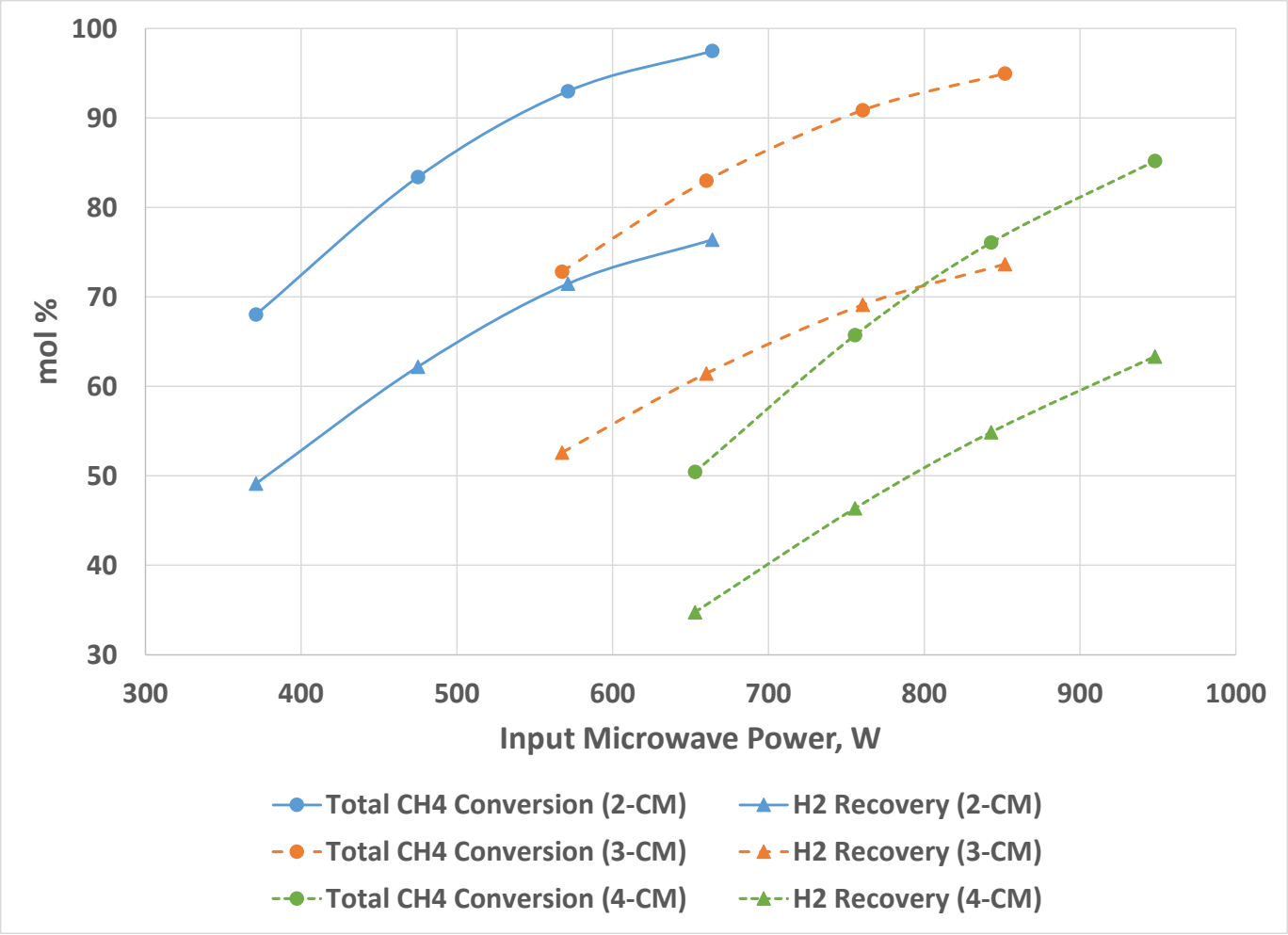
Results: Stand-Alone



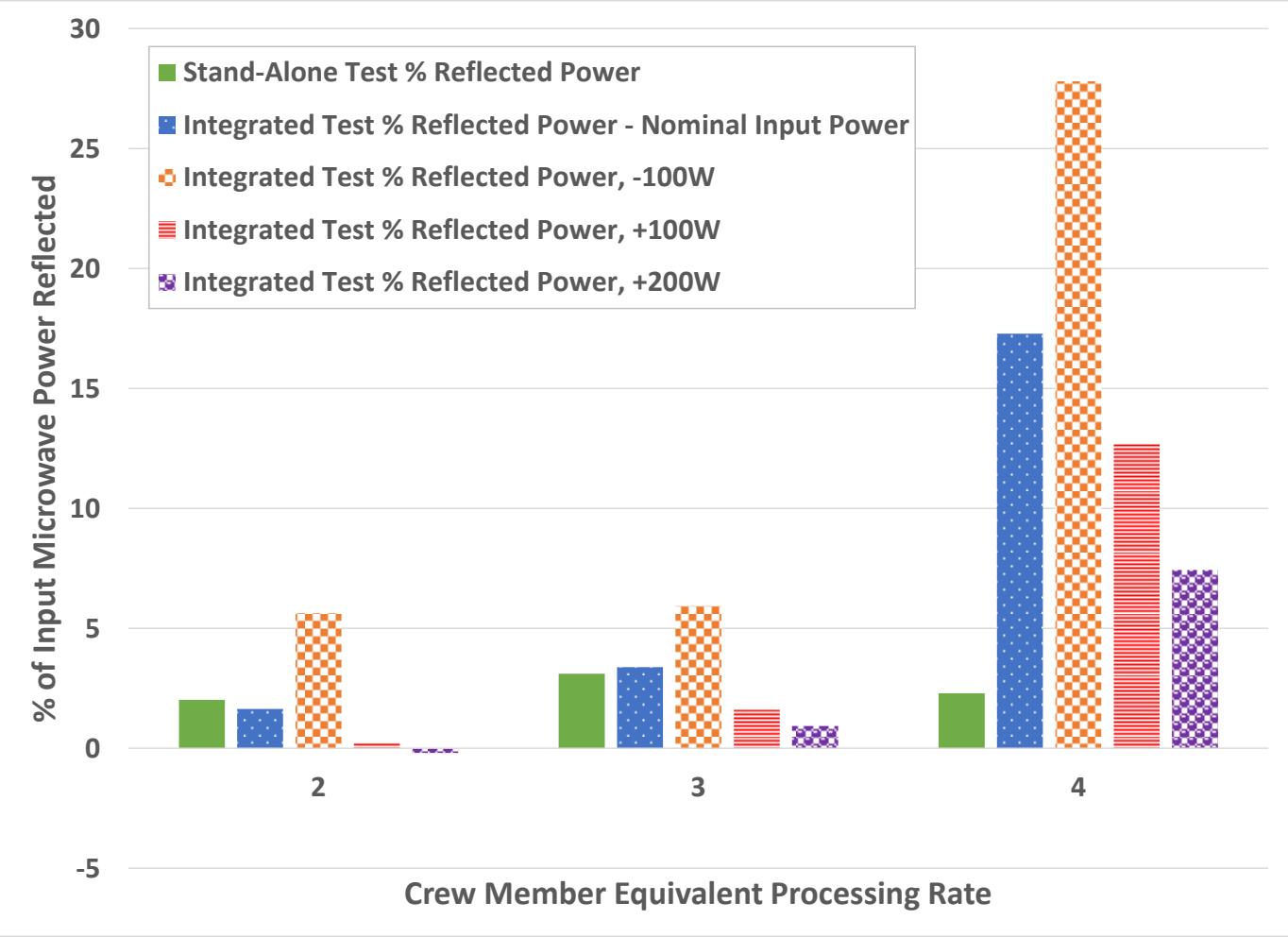
Results: Stand Alone vs. Integrated



Results: Integrated with SDU



Results: Integrated with SDU



Results: Metal Hydrides

- $LaNi_{4.8}Sn_{0.2}$ alloy
  - >1.2 weight percent reversible hydrogen capacity
  - High cyclic durability
  - Adsorption-desorption pressure and temperature compatible with PPA process conditions
- 2.6 kg needed for one hour operation
- Three bed system mass ~10kg w/ 20% structure
- Absorption at 10 °C desorption at 25 °C

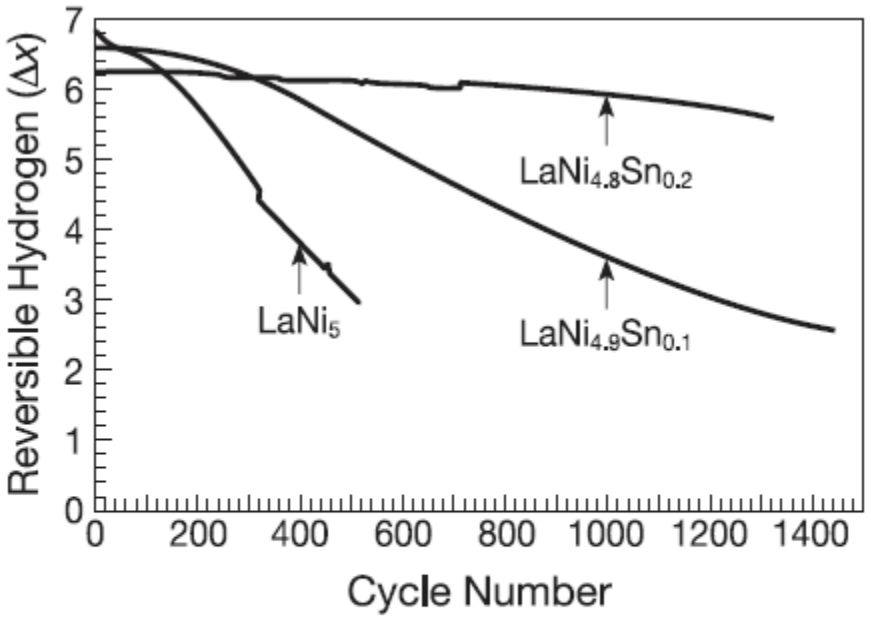


Figure 2. Effect of Sn substitution on the reversible hydrogen-storage capacity of $LaNi_{5-x}Sn_x$ hydrides after cycling between 295 K and 510 K.

Bowman & Fultz, *Metal Hydrides I*, MRS Bulletin, 2002.

Conclusion

- PPA met targeted 90% CH_4 conversion in stand-alone operation
- Integrated operation showed less than targeted CH_4 conversion and H_2 recovery
  - Significant CO production resulted in decreased performance
  - Investigating performance improvements through microwave power adjustment and tuning
- Metal hydride separation system very viable for PPA application

- Advanced Exploration Systems Advanced Resource Recovery and Environmental Monitoring
- Jacobs Engineering
  - Tom Williams
  - Kenny Bodkin
  - Heath Mullins

Questions?