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

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

Overview

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- Hydrogen purification
  - Metal Hydrides
- Objectives
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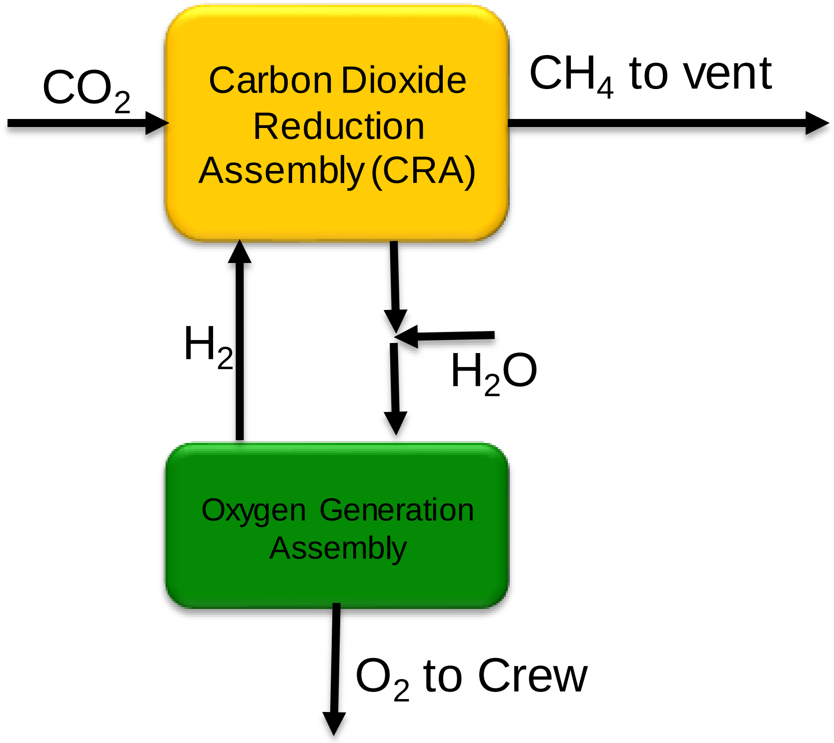
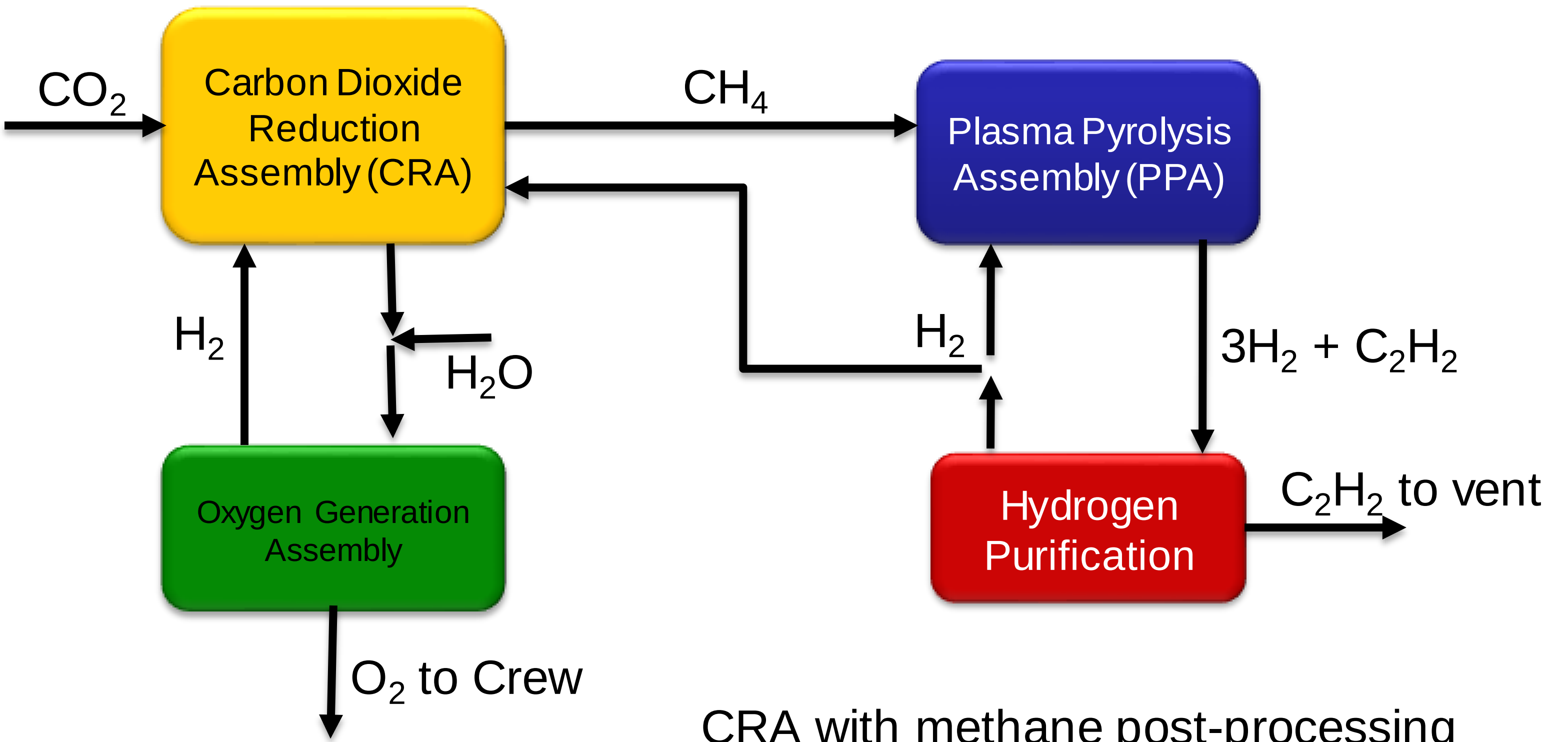
State-of-the-Art

- 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
  - $M + \frac{1}{2}xH_2 \leftrightarrow MH_x + \text{heat}$
- 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

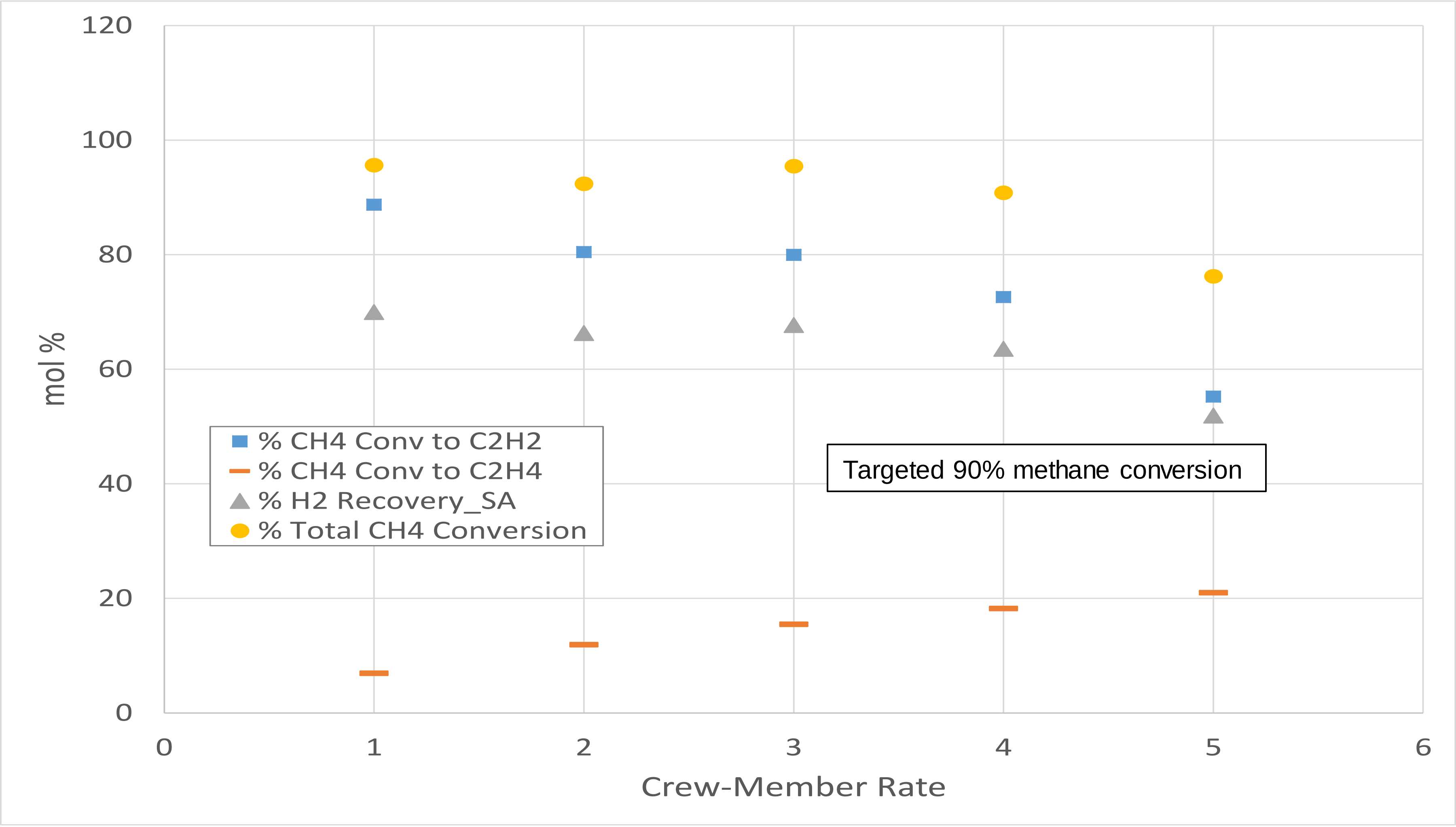
Method: PPA Stand-Alone

- 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

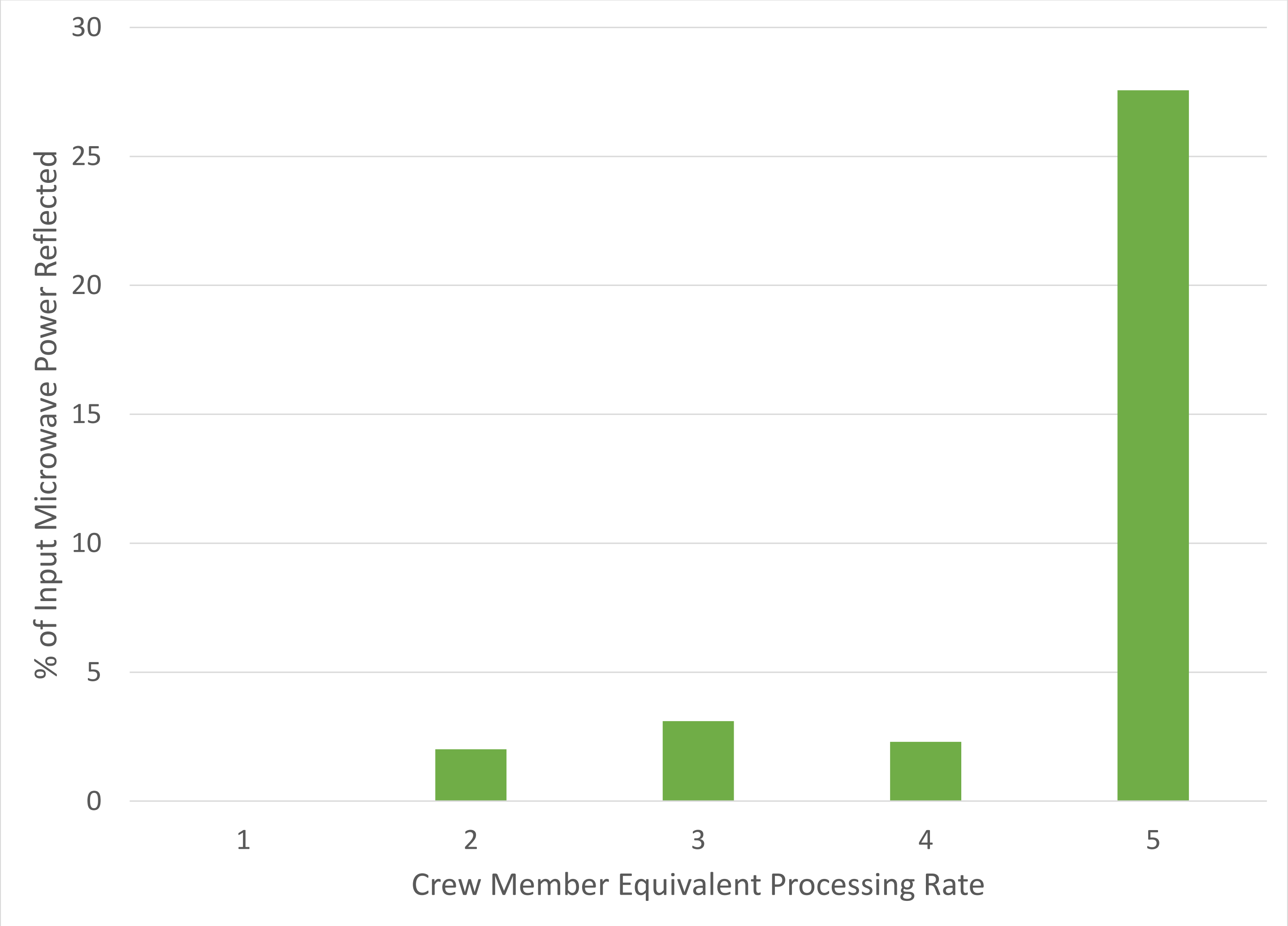
Method: PPA Integrated

- 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

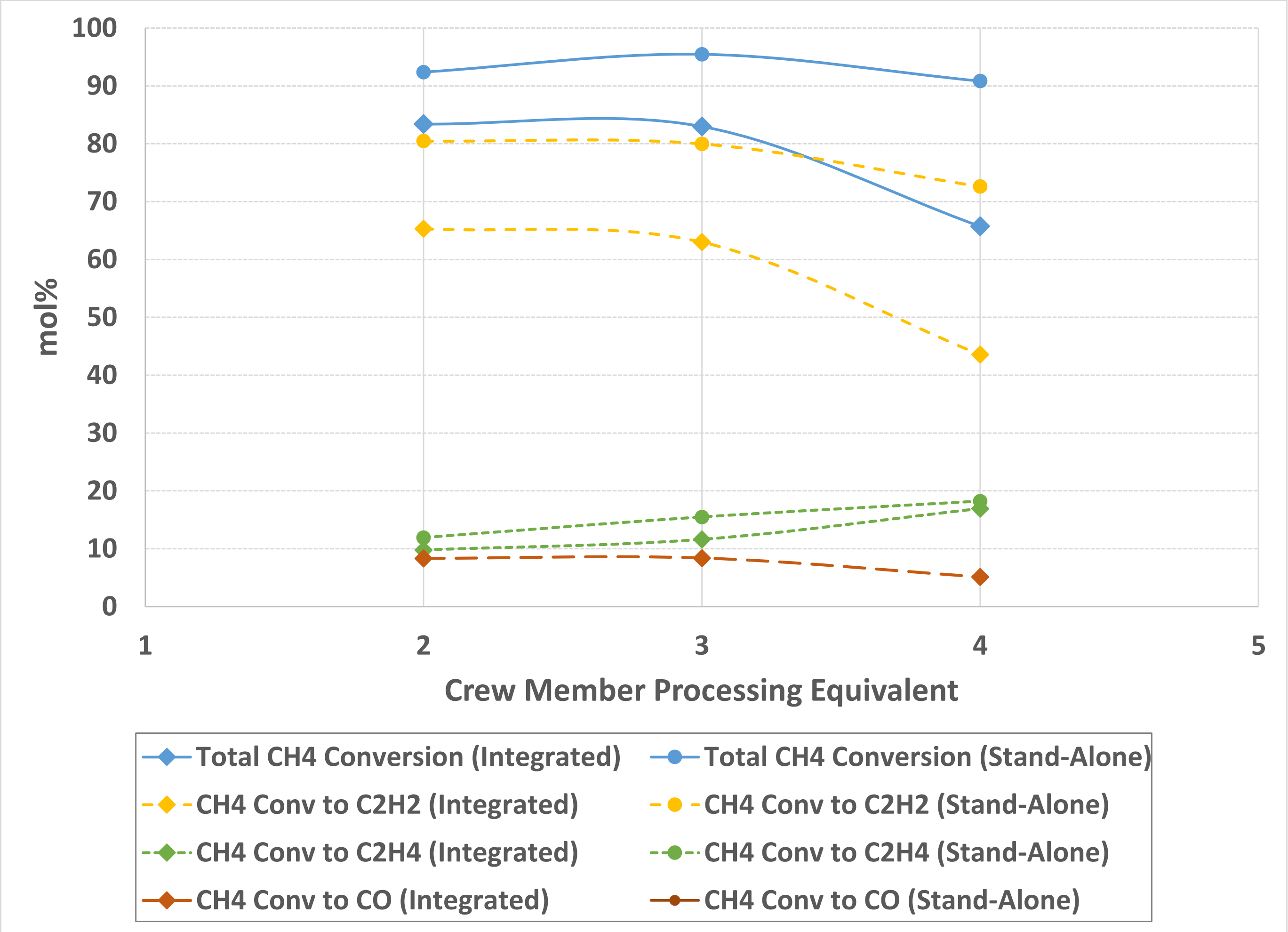
Results: Stand-Alone



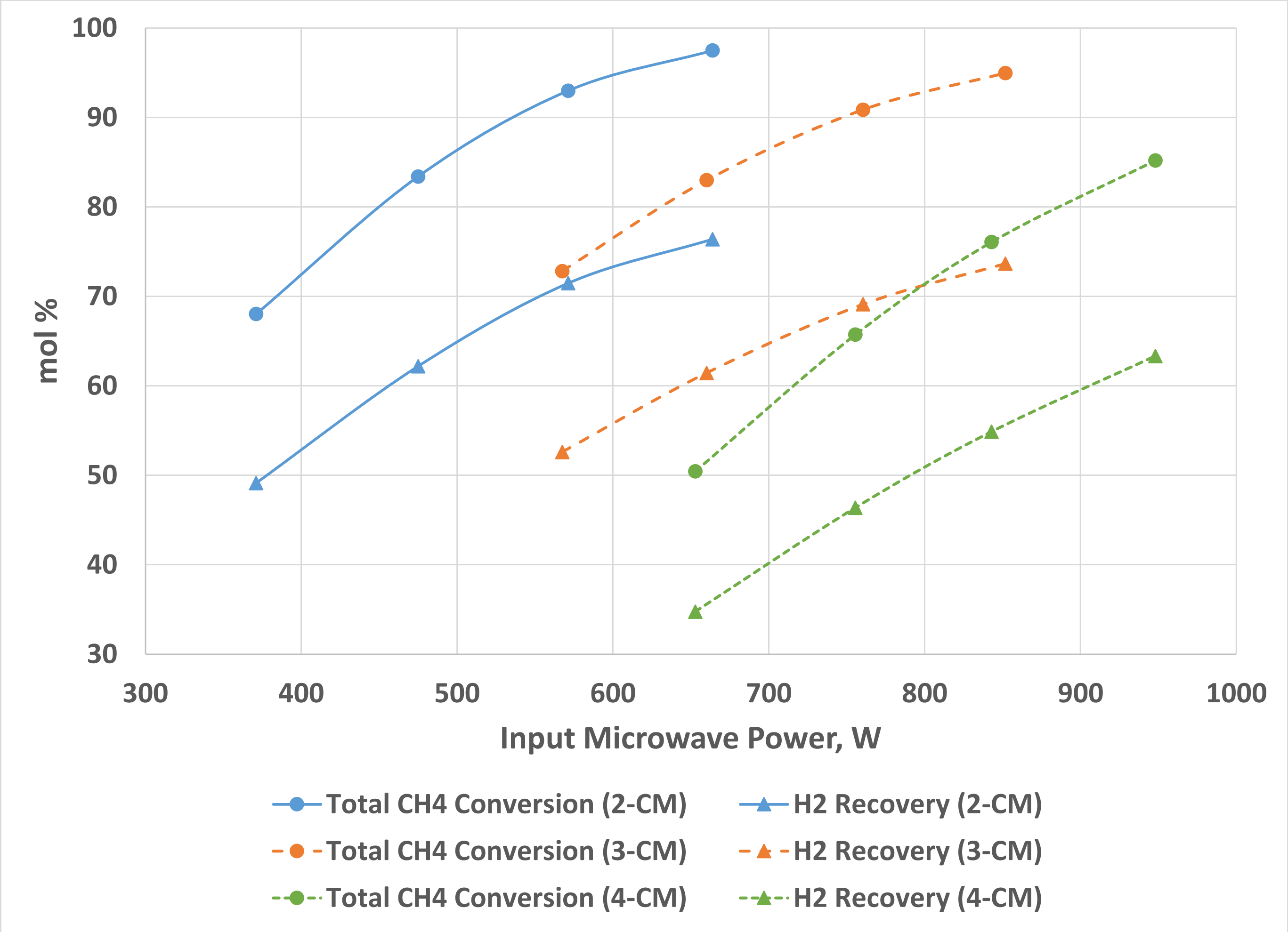
Results: Stand-Alone



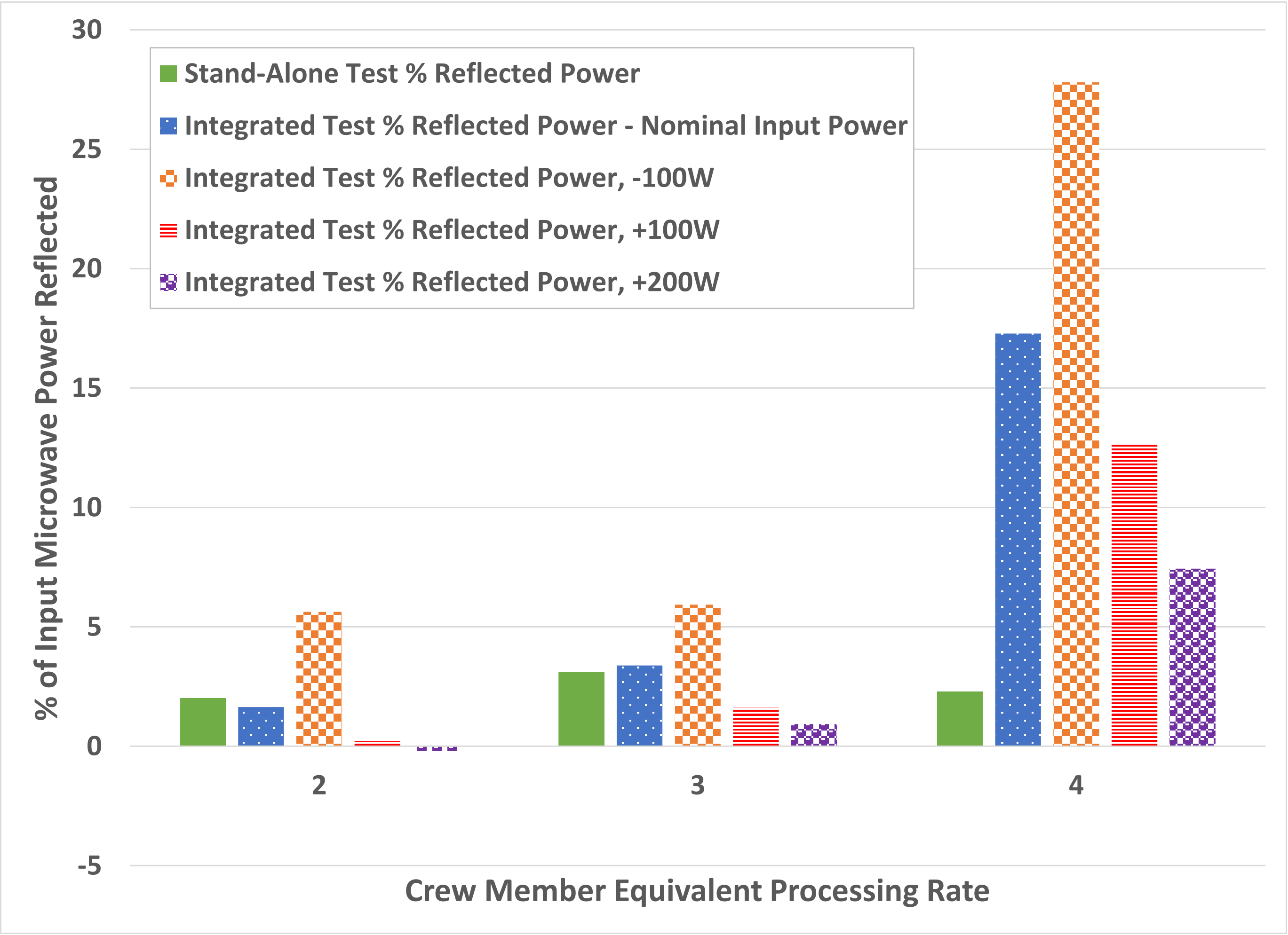
Results: Stand Alone vs. Integrated



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

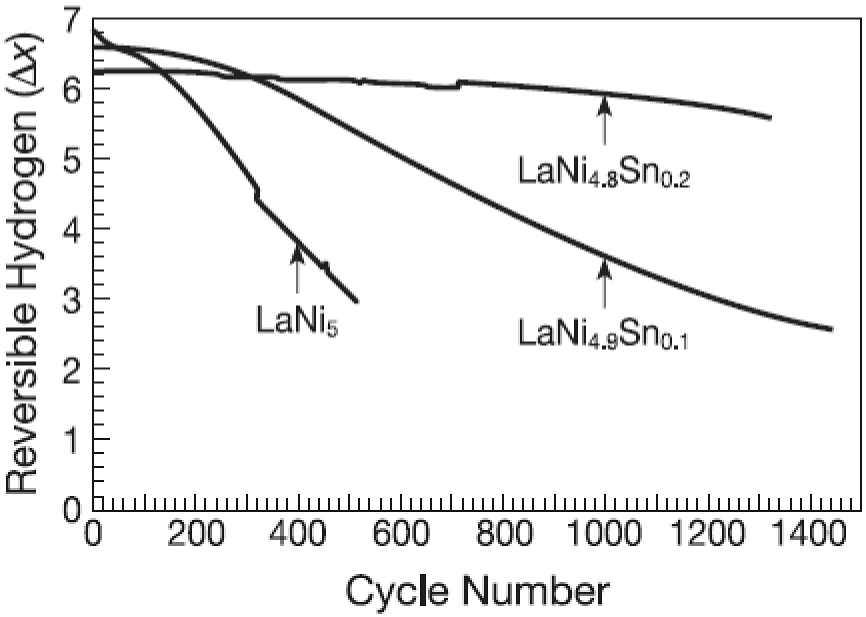


Figure 2. Effect of Sn substitution on the reversible hydrogen-storage capacity of $LaNi_{5-x}Sn_x$ hydrides after cycling between 295 K and 510 K.

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?