An Advanced Carbon Dioxide Removal and Reduction System

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Outline

Introduction

TDA's Advanced CO_2 Removal/Reduction System

- Anticipated Benefits

Summary of Experimental Results

- Sorbent Development
  - Multiple-cycle Testing
- Catalyst Testing
  - Representative Conditions

Adsorption and Regeneration System

- System Analysis
- TDA's System

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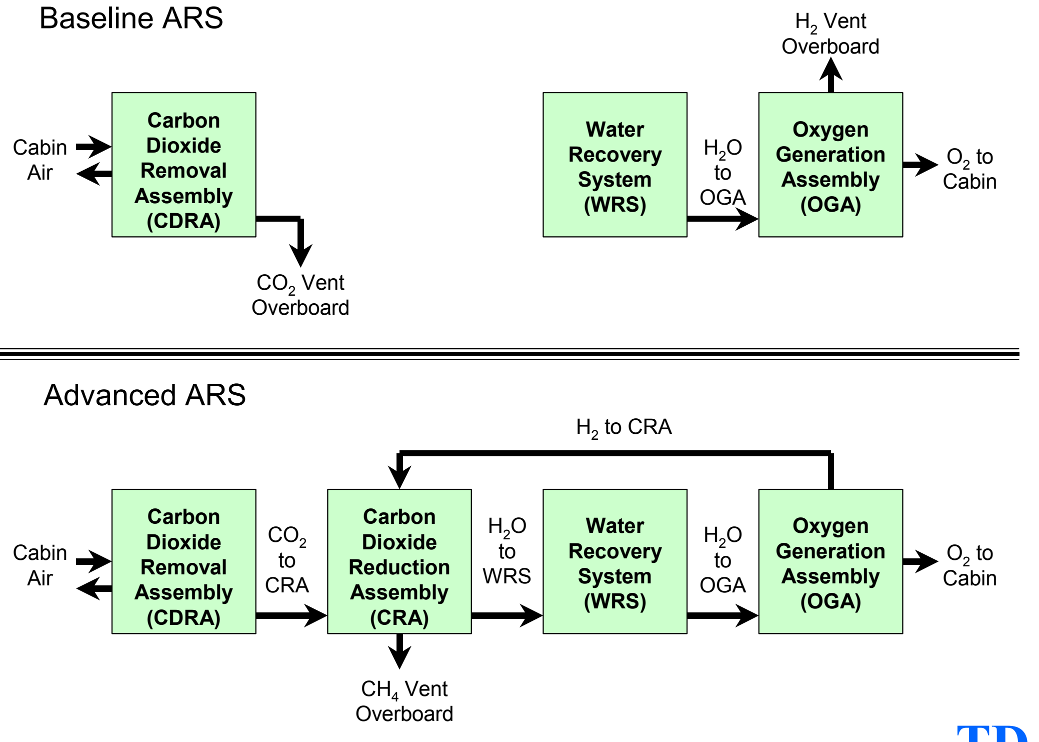
Introduction

An advanced ECLSS for long duration, manned space missions requires closure of all material loops

- Even for low orbit missions, reclamation of O_2 from CO_2 is essential



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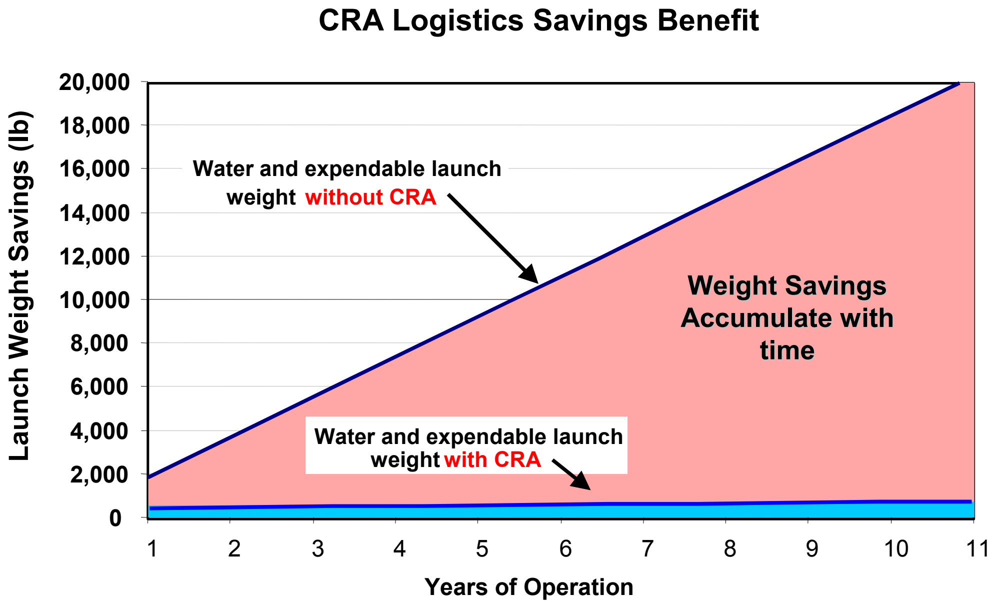
ISS Logistics Savings



"Advanced Life Support Risk Management for the Sabatier CO_2 Reduction Assembly", Telecon March 20, 2003

O_2 reclamation reduces mass required to meet crew oxygen and water needs

- Launch cost savings $22 M/year
- ISS Scientific Return: More crew time and payload capacity of scientific experiments

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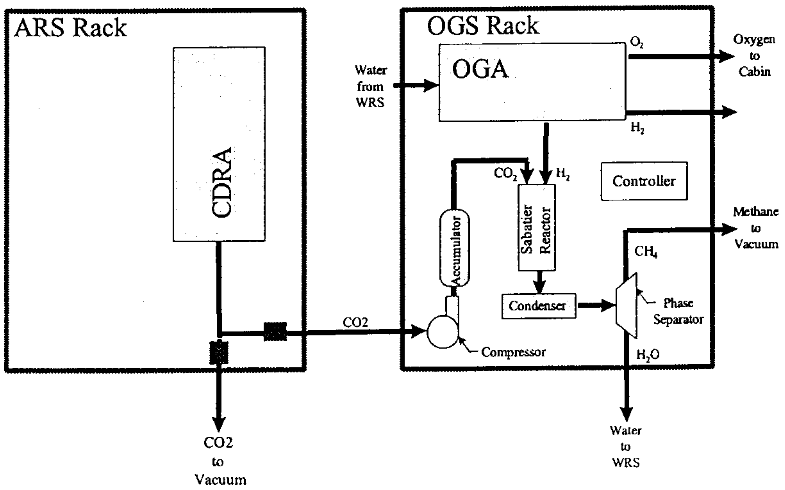
Challenge

Challenges in interfacing the CDRA and CRA

- Different operation sequences
  - CRA operates only during the day
  - CDRA operates day and night
- Different operation pressures
  - P_{CDRA}=<30 kPa (regeneration)
  - P_{CRA}=93-100 kPa

A pump/compressor and CO_2 storage tank as interface;

- High power consumption
- Large size
- Reliability issues with the mechanical moving parts
- Noise
- Complex System



- Jeng et al., (1999) "CO_2 Compressor Requirements for Integration of Space Station CO_2 Removal and CO_2 Reduction Assemblies"

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Research Objective

The objective is to provide an effective interface for CO_2 removal and reduction systems

A sorbent/catalyst combination controls cabin CO_2/H_2O level and carries out CO_2 reduction

Sorbent regeneration under hydrogen with a mild temperature swing

- Sorbent Regeneration } Endothermic
- Sabatier Reaction } Very Exothermic

$$CO_2 + 4\ H_2 = CH_4 + 2\ H_2O$$

System weight is minimized by

- Improving CO2 adsorption capacity:
- Reducing weight penalty associated with power generation, heat rejection and intermediate CO2 storage.

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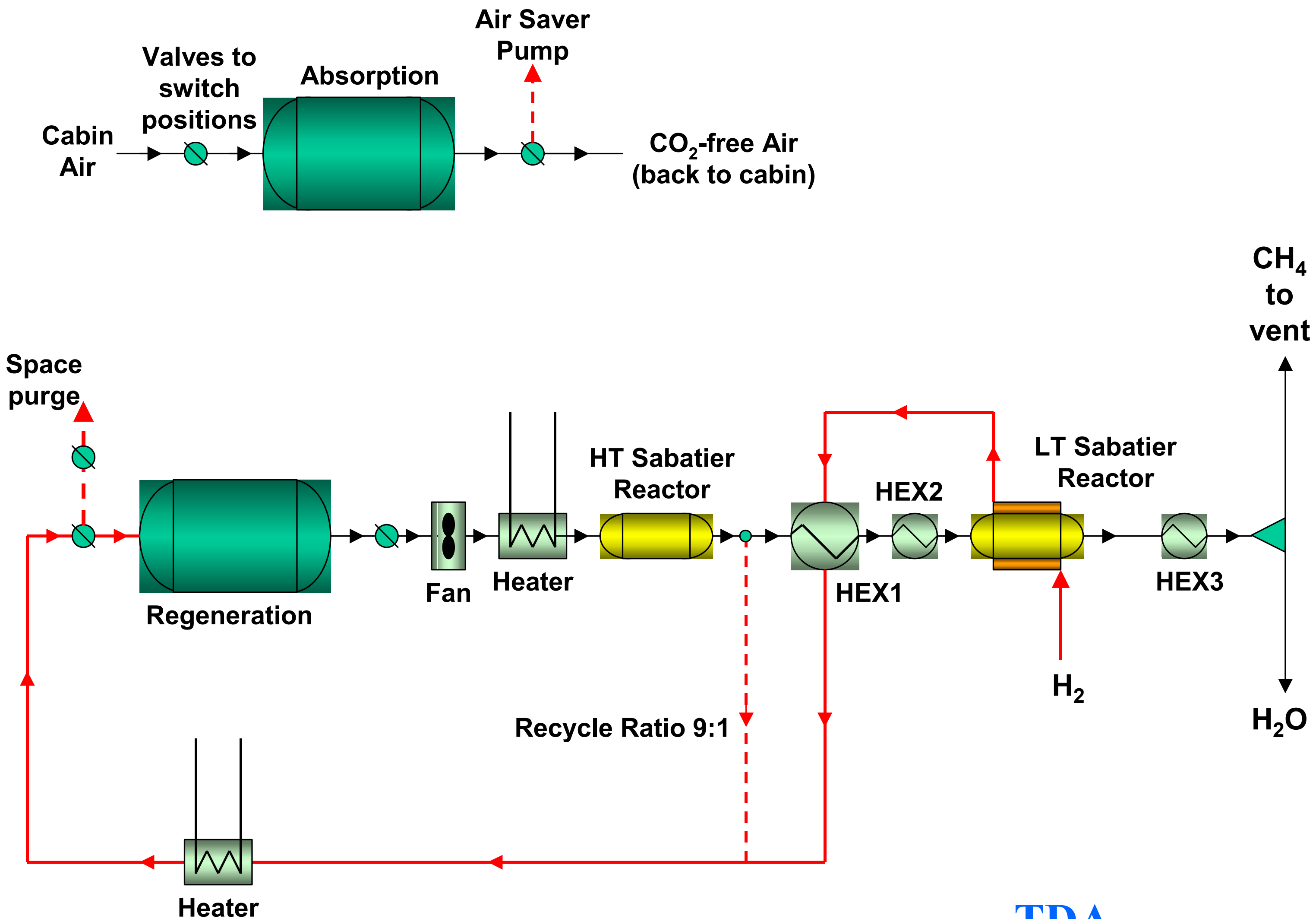
TDA's CO_2 Removal/Reduction System



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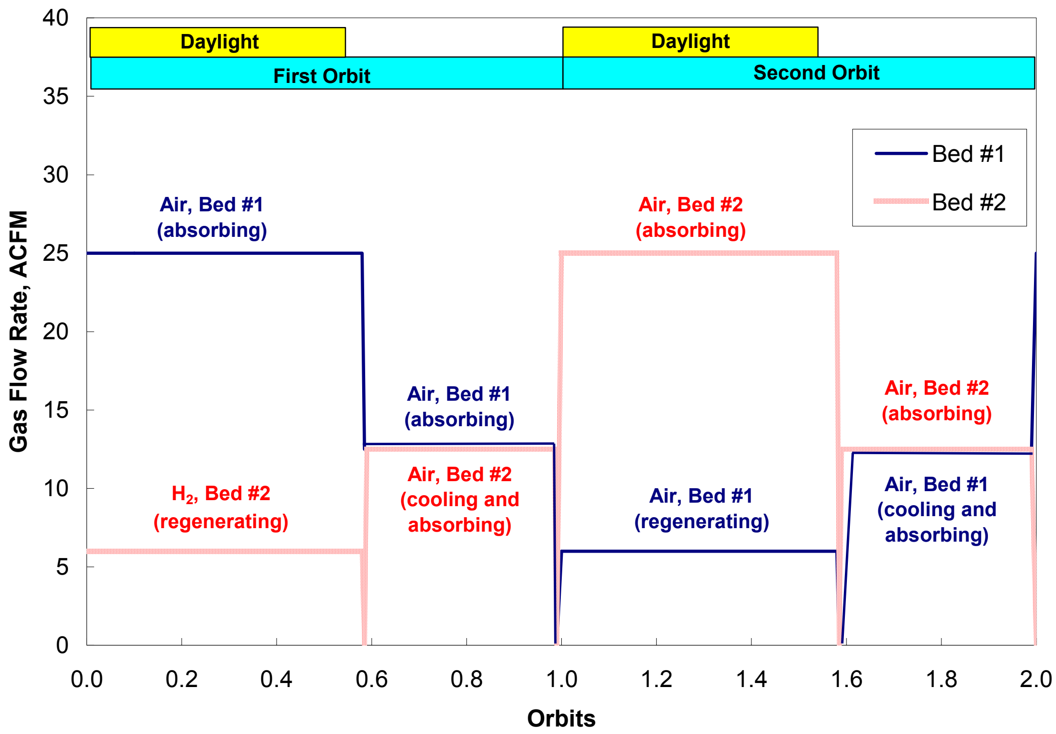
Bed Cycling Sequence

- Two orbits to cycle both beds
  - 90 minute orbits
  - 53 min day / 37 min night
- Beds purged of air before injecting H_2
- Beds purged of H_2 before adding air

180 minutes	duration for 2 orbits
120 minutes	absorption
4 minutes	air purge
50 minutes	reg. (during daylight)
6 minutes	H_2 purge



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Anticipated Benefits

Effective CO_2 Control

Eliminates the need to compress and store CO_2

- Savings in weight and volume
- Increase reliability

Effective utilization of the heat given off by the Sabatier reaction

- Exothermic Sabatier reaction provides part of the heat demand for sorbent regeneration
  - Minimizes power requirement
  - Minimized the need for heat rejection

Lightweight

The option of cabin humidity control

- Eliminates the need for condensing heat exchangers
- Water recovery in a sterile environment

The key need for the system is an effective CO_2 sorbent

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Sorbent Requirements

High CO_2 and H_2O absorption capacity

- To minimize canister size

Activity over a range of conditions

- Changing CO_2 and H_2O levels
- Temperature ranging from 18 to 75°C

Regenerable under mild conditions

- To conserve power

Maintain its capacity over hundreds of adsorption/regeneration cycles

- No spalling or structural deformations

Multiple-Cycle Test Reactor

Pyrex reactor

- Light reactor body weighs less than 30g with fittings

1.0 inch ID reactor size

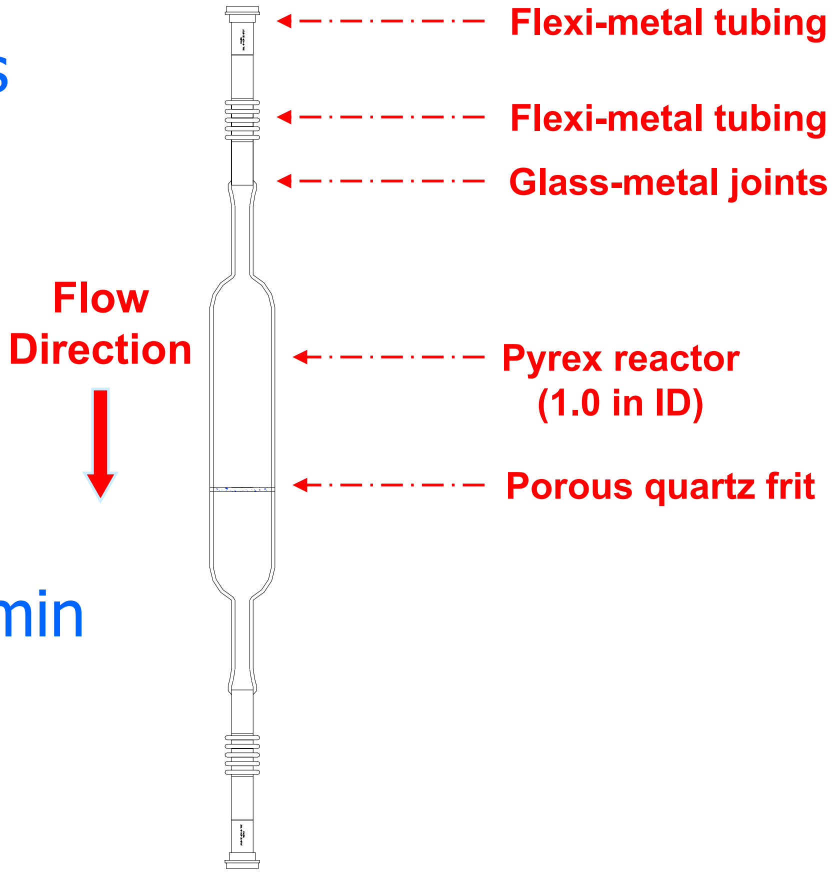
- Ability to test 1/16" pellets

Heating by heat tapes and fan aided cooling

- Minimizes the heating and cooling times to less than 15 min

Some heat losses

- Lower temperatures increase during absorption



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Multiple-Cycle Tests

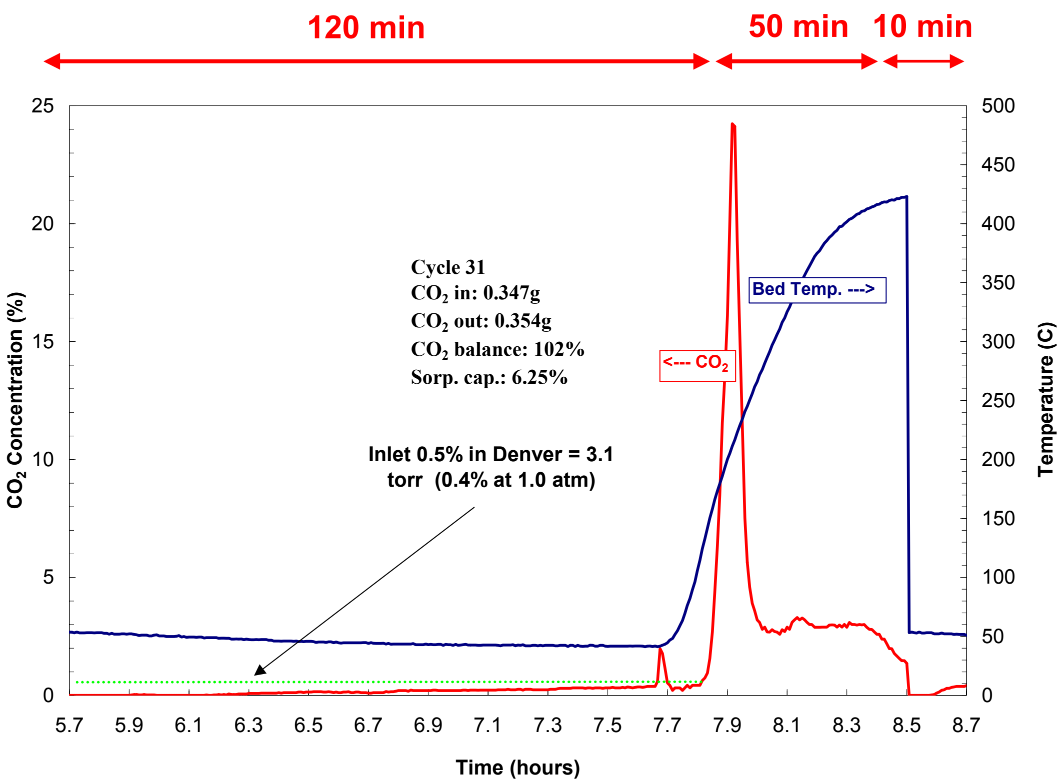
500 consecutive absorption and regeneration cycles

Absorption Conditions

- T = 25°C
- GHSV = 3,000 h-1
- CO_2 Conc. = 3.6 torr
- H_2O Conc. = 12.0 torr
- Duration = 120 min.

Regeneration Conditions

- T = 250 to 400°C
- GHSV = 800 h-1
- H_2 Conc. = 60% vol.
- H_2O Conc. = 40% vol.
- Duration = 50 min



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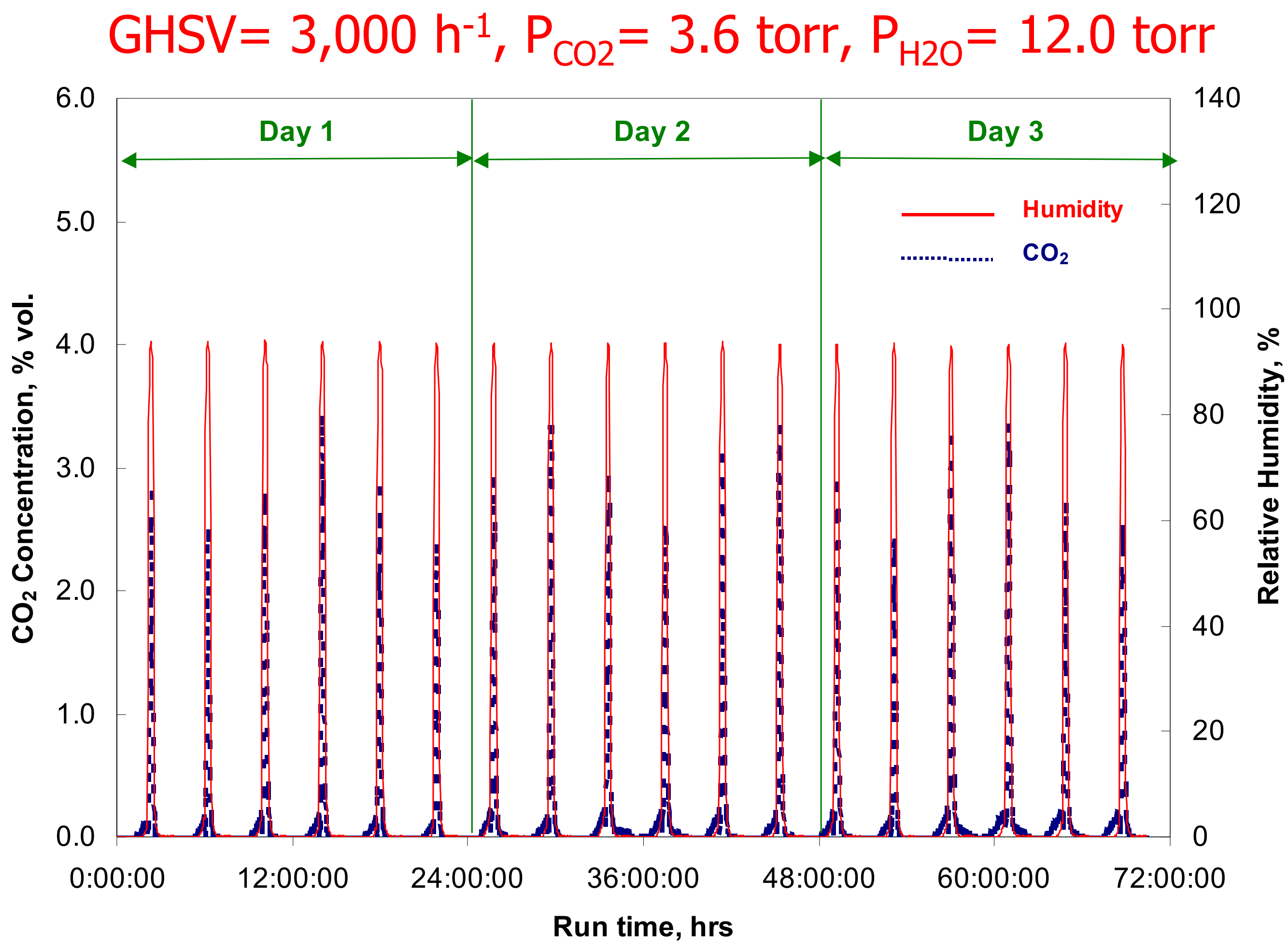
Typical Test Profile



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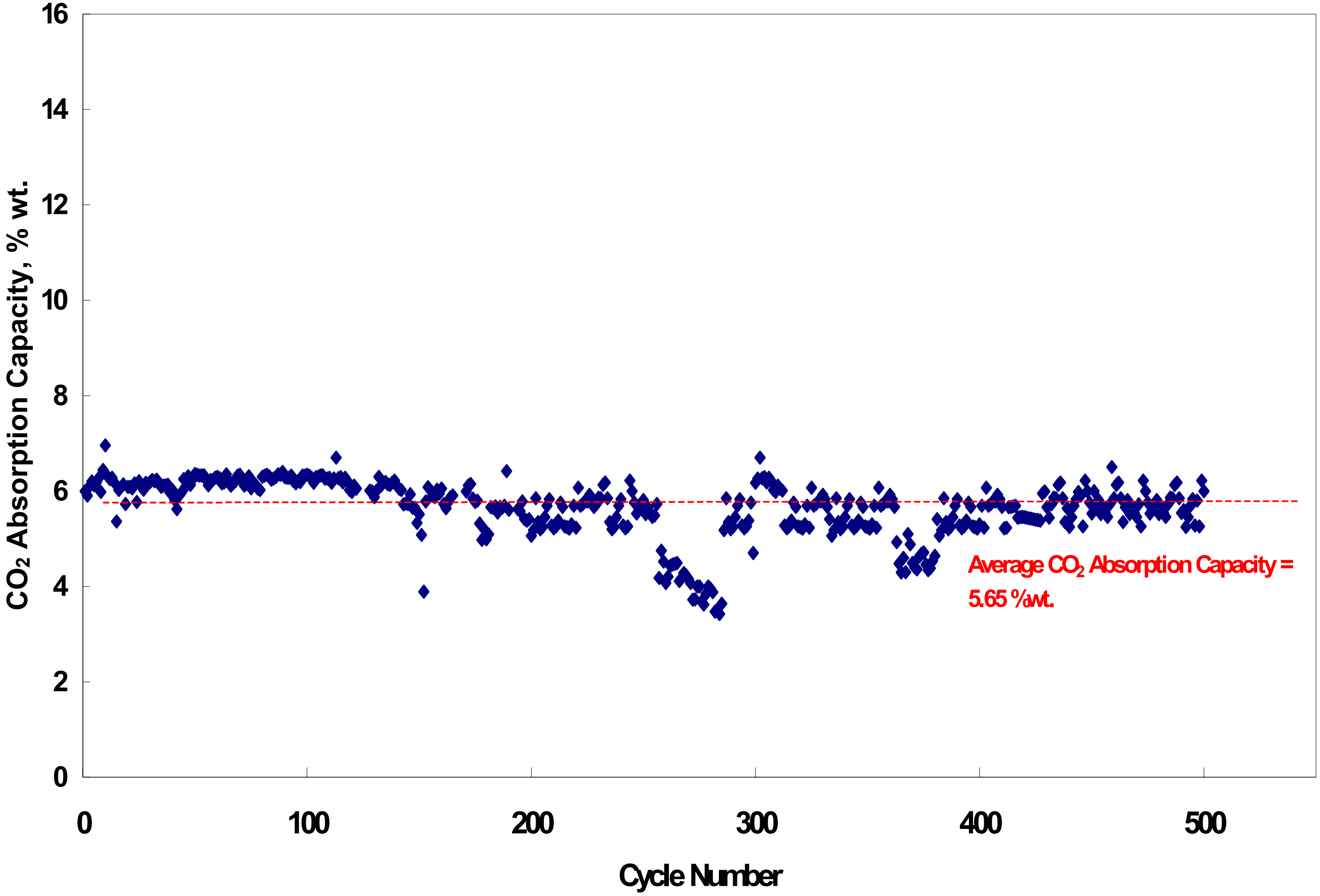
Multiple-Cycle Tests



- Sorbent maintains its CO2 and H2O absorption capacity for more than 500 cycles

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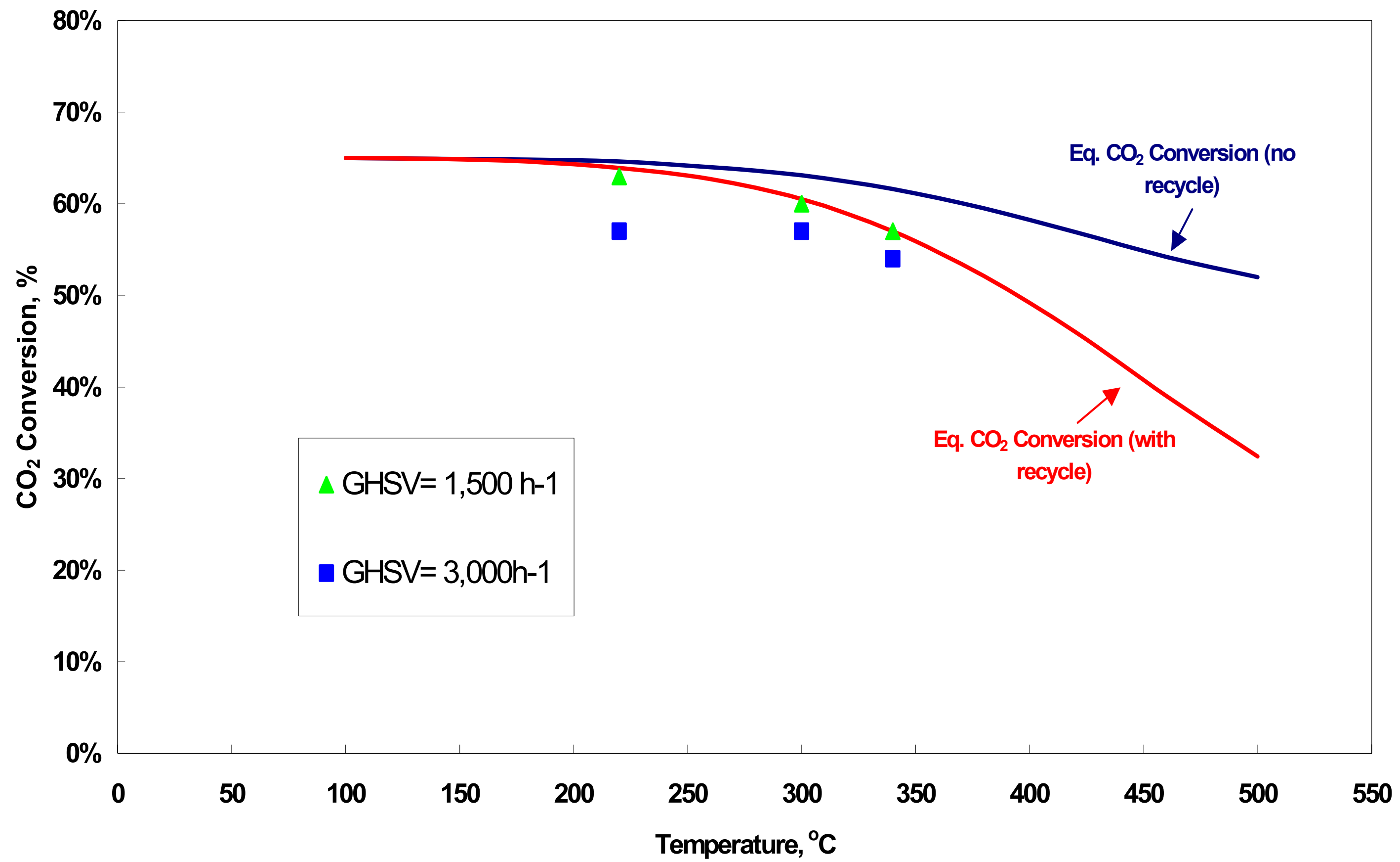
Catalyst Tests

The catalyst was tested using a simulated recycle flow. The following criteria were used:

- H_2/CO_2 = 2.6
- H_2O has two sources: the Sabaiter reaction (H_2O/CH_4 = 2.0), dictated by the reaction stoichiometry and the desorbed water from the sorbent (H_2O/CO_2 = 2.0), which we observed experimentally.

Components	% Vol.
H2O(g)	40%
H2(g)	40%
CH4(g)	6%
CO2(g)	14%
CO(g)	0%
Total	100%

Catalyst Test



- The catalyst achieved equilibrium conversion at the conditions of interest using a simulated recycle flow

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System Analysis

System Components

- Sorbent Beds
- Sabatier Reactor (HT and LT)
- Miscellaneous components
  - Heaters and heat exchangers
  - Air saver pump
  - Fan
  - Tubing and connections
  - Valves (check valves, gas selection valves, etc.)

Auxiliary Support Equipment

- Power Generation
- Heat Rejection

Overall Hardware Weight

Weight Breakdown of TDA's System (7.29 eq. Person)		
Sorbent Bed #1	41.21 lbs	18.71 kg
Sorbent Bed #2	41.21 lbs	18.71 kg
HT Sabatier Reactor	6.82 lbs	3.10 kg
LT Sabatier Reactor	4.28 lbs	1.94 kg
Heaters and Heat Exchangers	7.29 lbs	3.31 kg
Air Saver Pump	20.93 lbs	9.50 kg
Fan	11.00 lbs	4.99 kg
Water Separator	0.88 lbs	0.40 kg
Valves and connections	34.14 lbs	15.50 kg
Sensors	1.76 lb	0.80 kg
Electrical Harness	9.91 lb	4.50 kg
Plumbing	13.00 lb	5.90 kg
Electronics Cold Plate	10.57 lb	4.80 kg
Support Structure	34.05 lb	15.46 kg
Total Weight	**237.1 lb**	**107.6 kg**

The current Four Bed Molecular Sieve System+CRA system for 7.29 eq. persons weighs 299 kg

TDA's system offers the potential of reducing the weight of the system hardware by 63.5% (~191 kg)

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Weight Equivalency Associated with Power Generation and Heat Rejection

Weight Penalty due to Power Gen.	Watts	kg/kW	kg
Sorbent Bed Heating (W)	926	239*	221.4
H_2O desorption (W)	705	239	168.4
CO_2 desorption (W)	344	239	82.1
Gas heating (W)	102	239	24.4
Sabatier heat recovery (W)	-495	239	-118.2
Blower, controllers, valves	18	239	4.4
Air saver power (W)	35	239	8.3
Total Power (W)	**1635**		**390.7**

Weight Equivalency for Power Requirement = 390.7 kg

Total Heat Rejection Requirement	1740 W
Penalty Factor	324 kg/kW *
Weight Associated with Heat Rejection	**563.8 kg**

Weight Equivalency for Heat Rejection = 563.8 kg

*Advanced Life Support Baseline vs. Assumptions Document CTSD-AD-V484, JSC 47804, January 31, 2002

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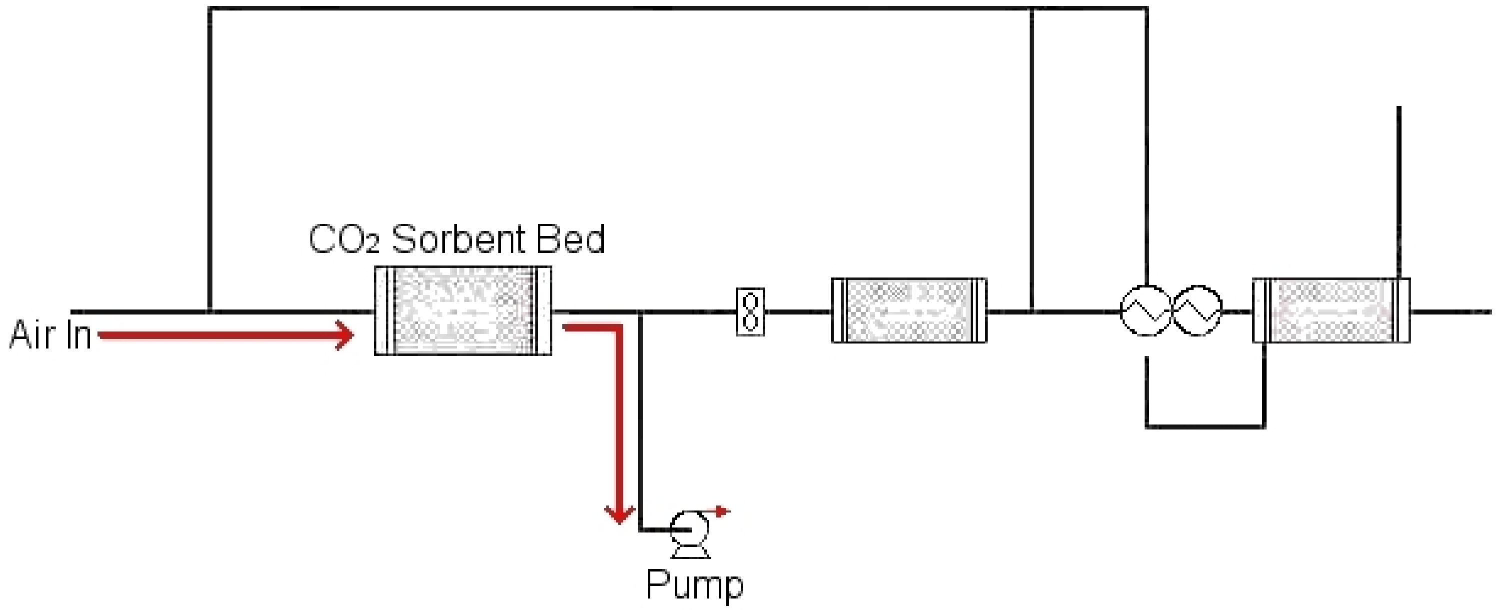
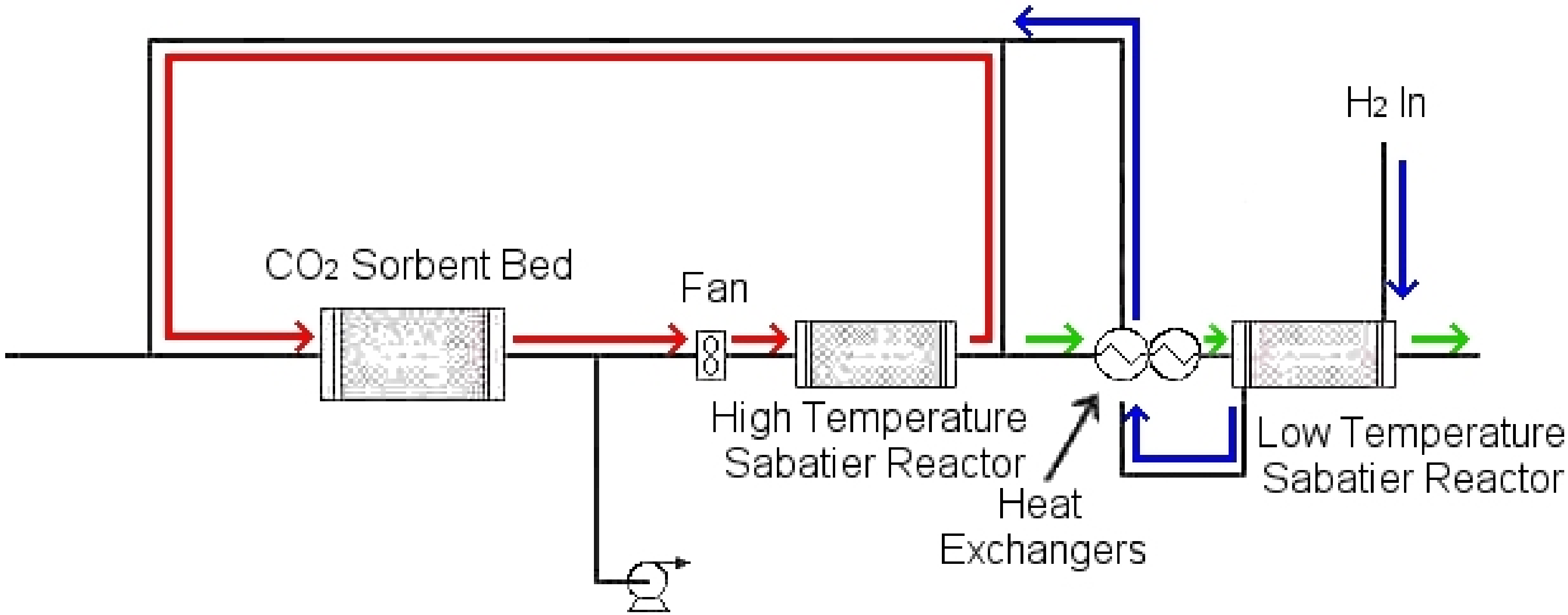
TDA's System: Absorption Cycle



- During the adsorption cycle, air is pulled into the CO2 sorbent bed and back out of the system. At the end of the cycle, any remaining air is removed using the pump

TDA's System Regeneration Cycle



- Hydrogen is added to the system and is heated using heat exchangers. The gas circulates round the loop, pushed by the fan. 1/10th of the gas is continuously removed (and replaced by the hydrogen inlet) through the low temperature Sabatier reactor.

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TDA's Test System

- TDA is in the process of completing the test system

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Conclusions

Technical Feasibility

- We developed a high capacity, regenerable sorbent for CO2 and H2O removal
- The sorbent maintained its activity for 500 consecutive cycles
- We demonstrated the operation of a Sabatier catalyst under simulated operation conditions, closely approaching to equilibrium in a high steam environment

TDA's Testing System

- TDA has designed a system to test the entire adsorption/regeneration cycle
- The testing apparatus is under construction

Acknowledgements

The funding from NASA Johnson Space Center is greatly acknowledged

JSC

- Fred Smith

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