An Advanced Carbon Dioxide Removal/Reduction System

Dr. Gökhan O. Alptekin
Dr. Robert Copeland
Ms. Rita Dubovik
Ms. Yevgenia Gershanovich

International Conference of Environmental Systems

Vancouver, BC
July 9, 2003

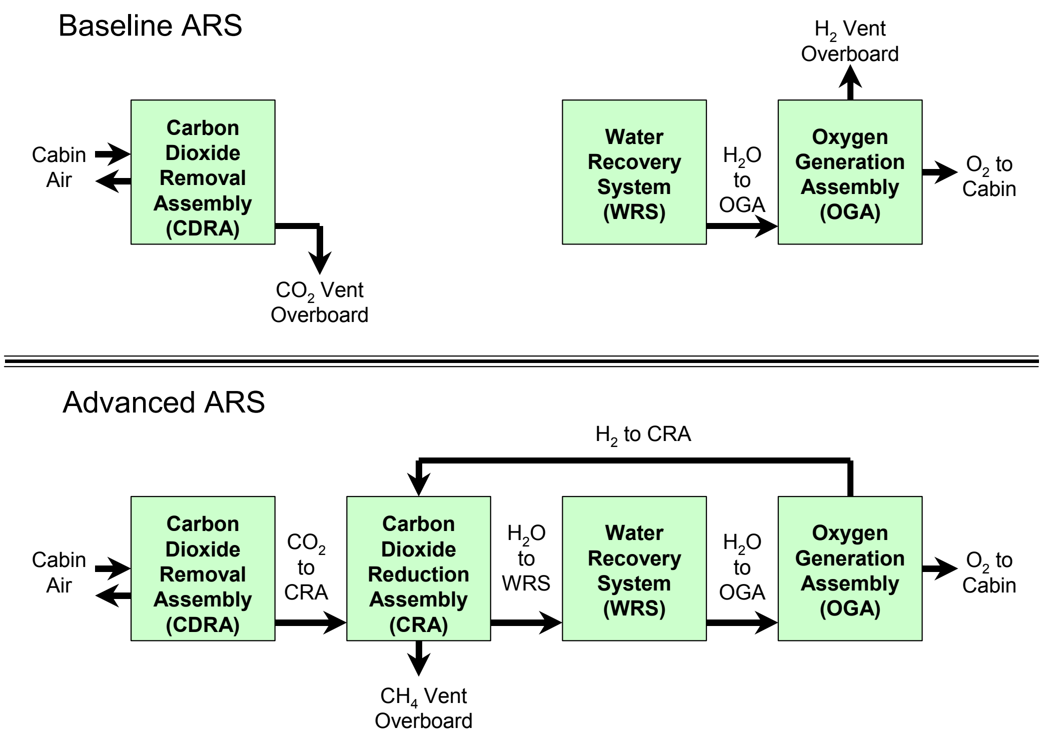
TDA Research Inc. • Wheat Ridge, CO 80033 • www.tda.com

Outline

- **Introduction**
- **TDA's Advanced CO_2 Removal/Reduction System**
  - Anticipated Benefits
- **Summary of Experimental Results**
  - Sorbent Development
    - Adiabatic Experiments
    - Multiple-cycle Testing
  - Catalyst Testing
- **Preliminary System Analysis**

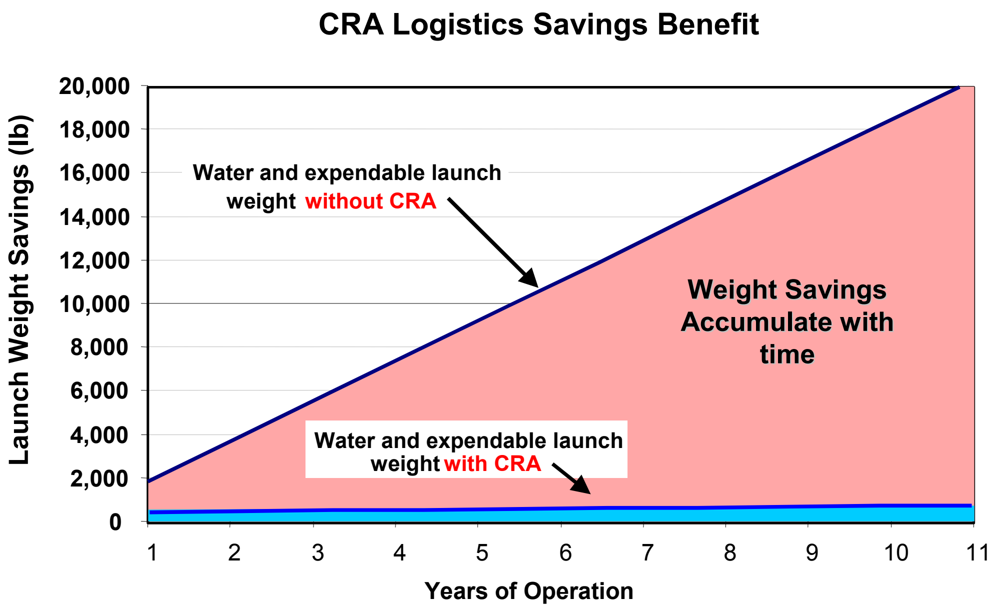
Introduction

- **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



TDA Research

ISS Logistics Savings



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

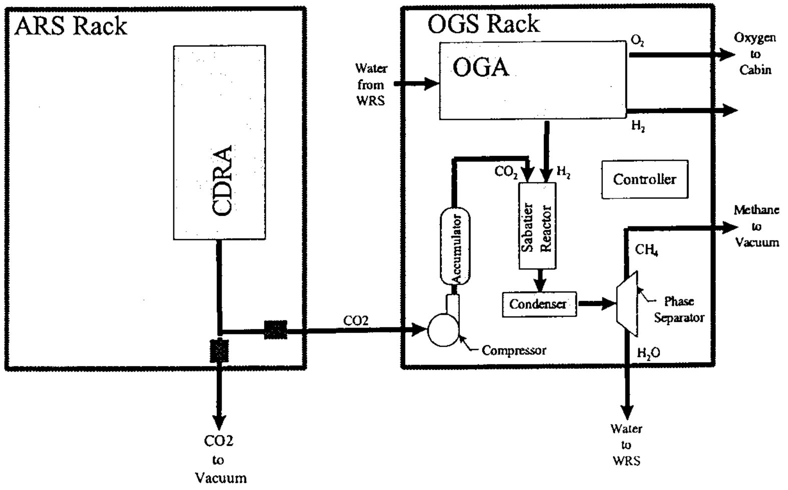
- O_2 reclamation reduces mass required to meet crew oxygen and water needs
  - Launch cost savings $22 M/year
  - ISS Scientific Return: More crew time and payload capacity for scientific experiments

TDA Research

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 mechanically 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"**

TDA Research

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**

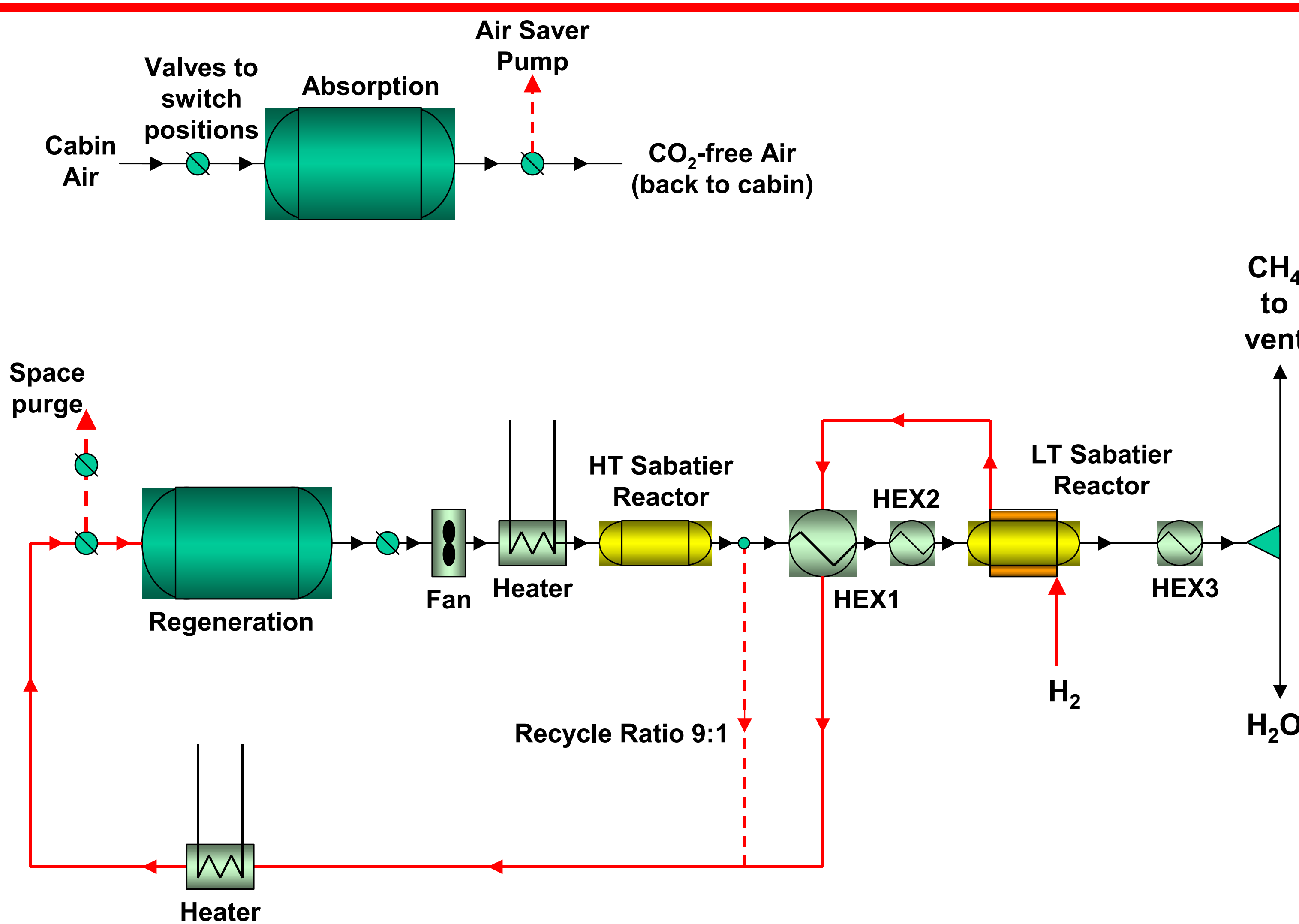
  Sorbent Regeneration } **Endothermic**

  Sabatier Reaction

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

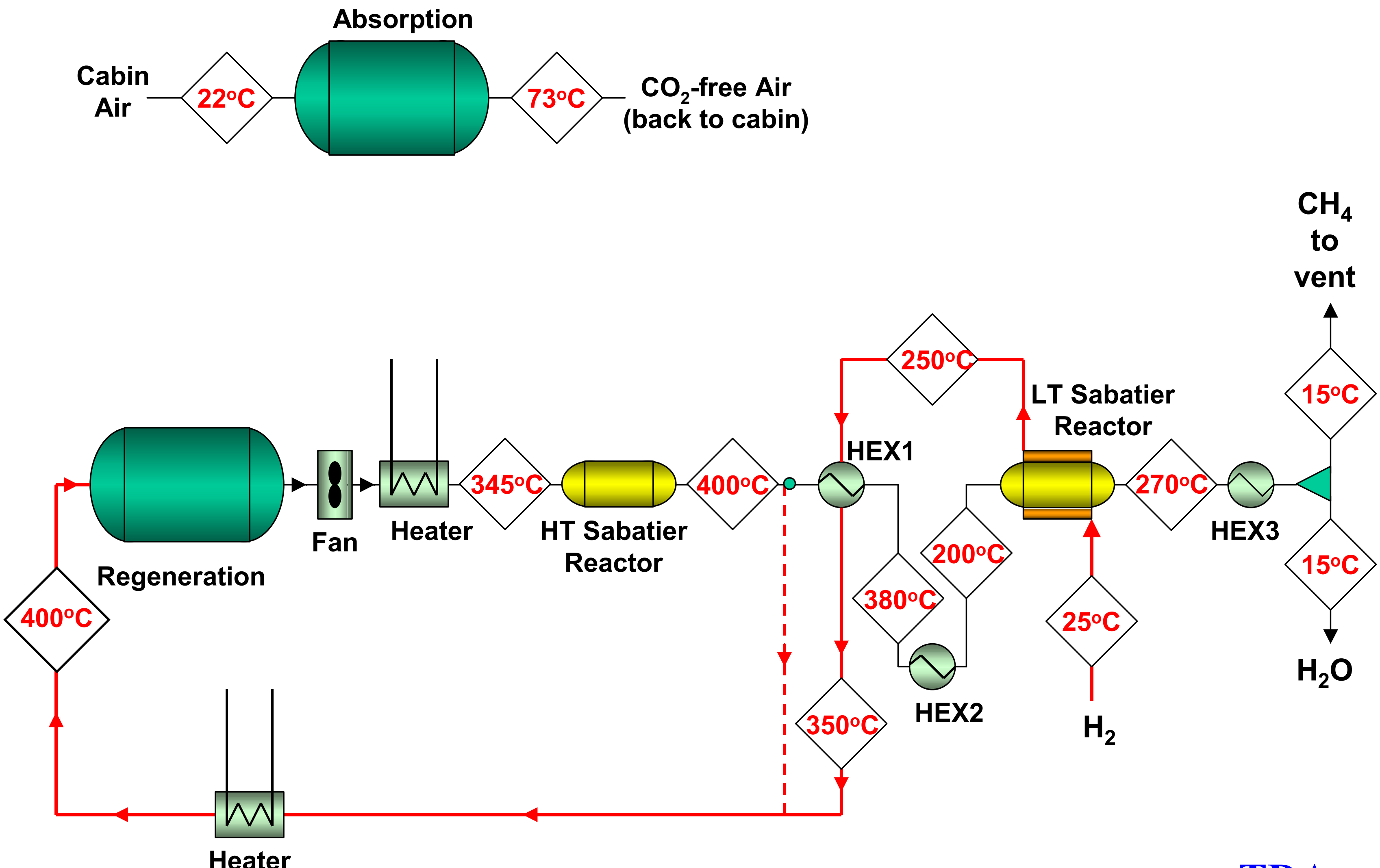
  } **Very exothermic**
- **System weight is minimized by**
  - improving CO_2 absorption capacity
  - reducing weight penalty associated with power generation and heat rejection

TDA's CO_2 Removal/Reduction System



TDA Research

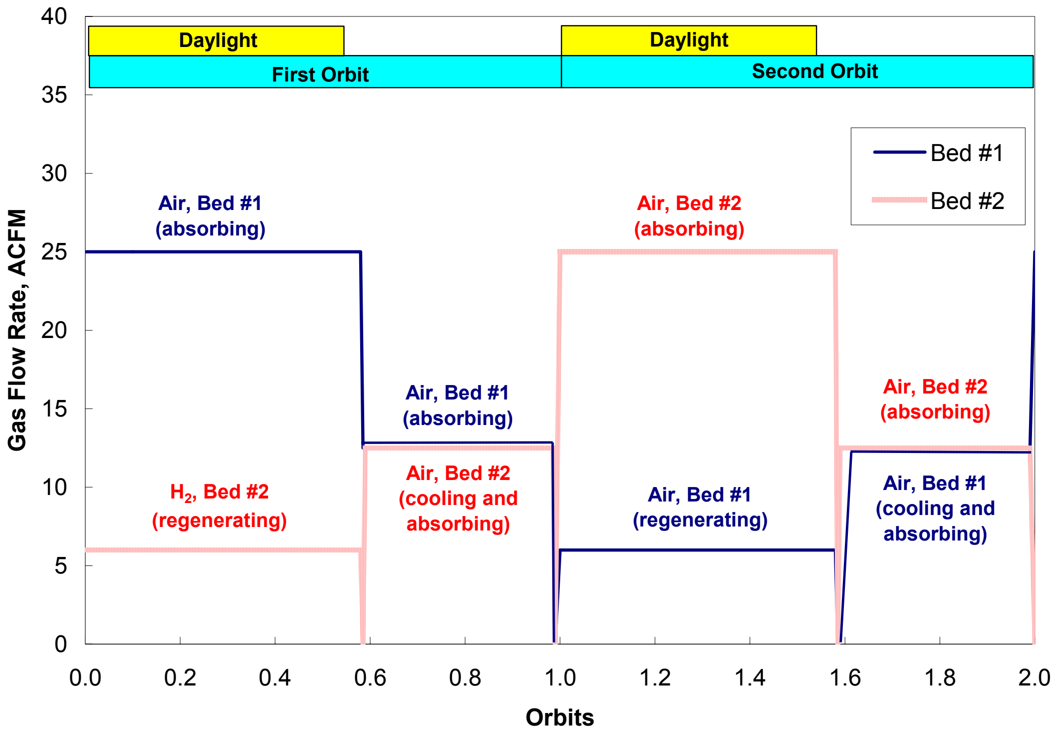
Stream Temperatures



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



TDA Research

Anticipated Benefits

- **Effective CO_2 control**
- **Eliminates the need to compress and store CO_2**
  - Savings in weight and volume
  - Increased 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
    - Minimizes 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**

Sorbent Requirements

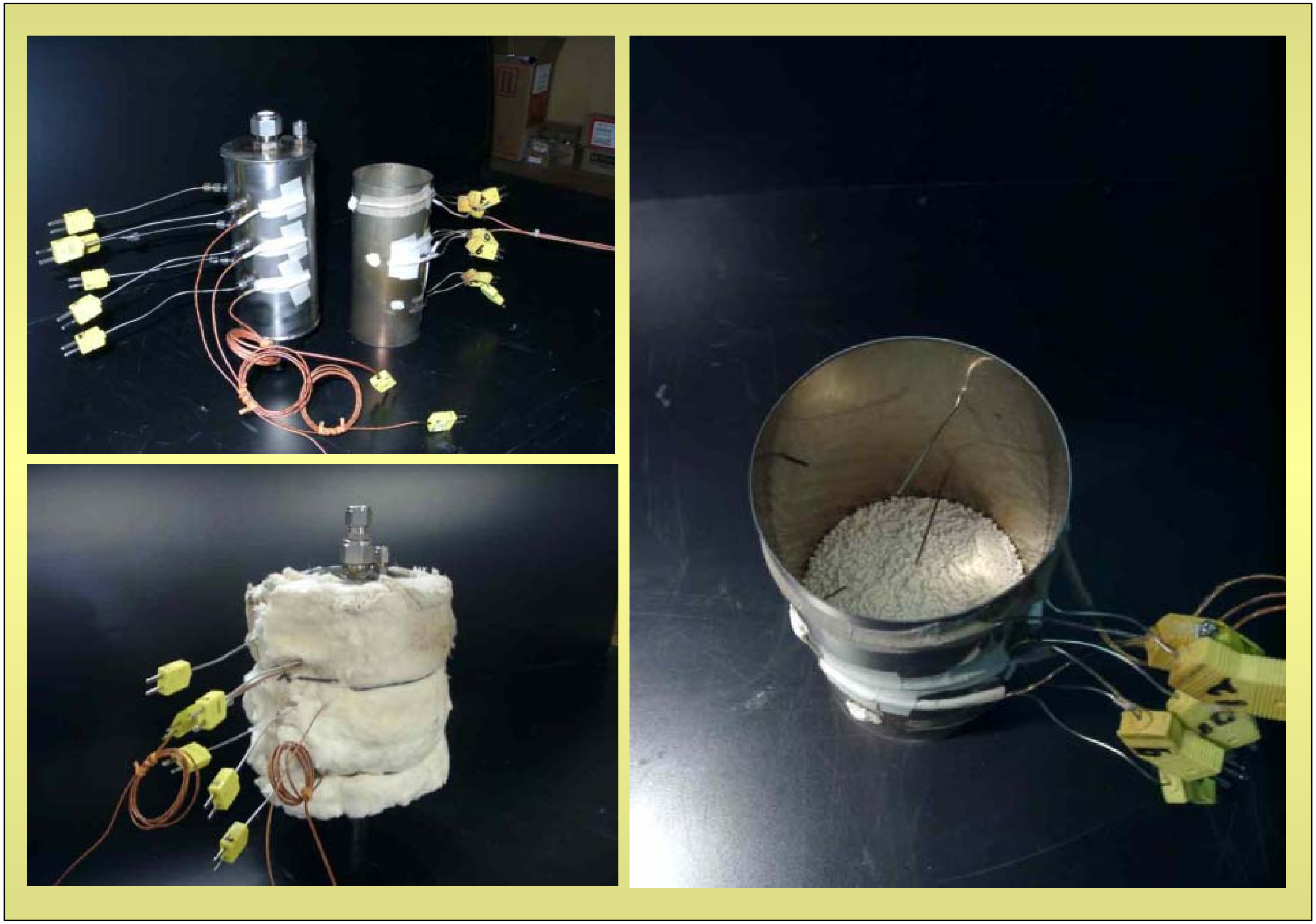
- **High CO_2 and H_2O absorption capacity**
  - To minimize canister size
- **Activity over a range of conditions**
  - Changing CO_2 and H_2O levels
  - Temperatures ranging from 18 to 75^oC
- **Regenerable under mild conditions**
  - To conserve power
- **Maintain its capacity over hundreds of absorption/regeneration cycles**
  - No spalling or structural deformations

Adiabatic Reactor Specifications

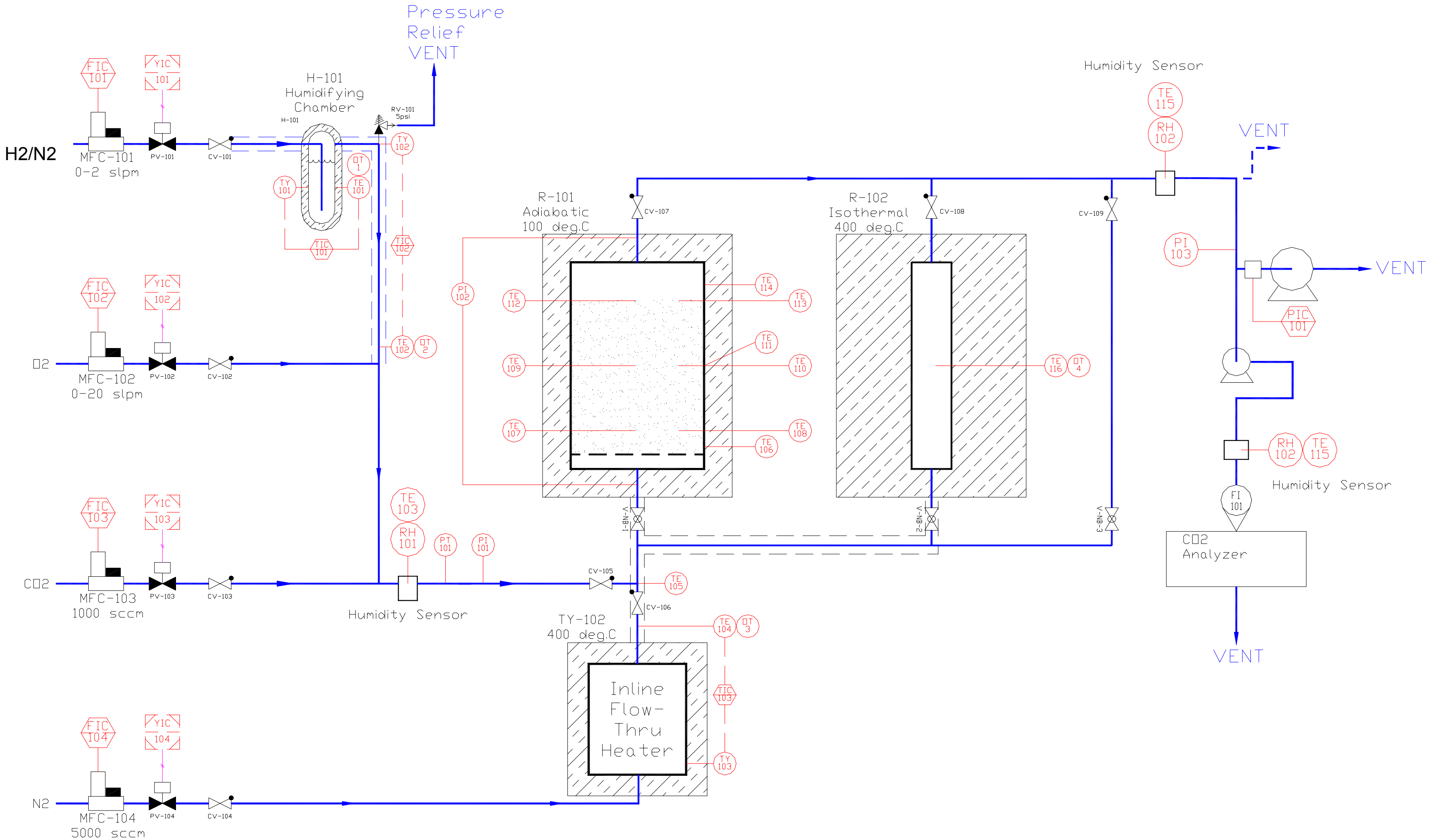
- **Thin-wall (0.014”) SS316 reactor**
  - Reactor body weighs less than 50g
  - Holds 300 cc or ~250g sorbent as 1/16” pellets
- **2.0” external insulation**
  - Minimum heat leaks
- **Axial and radial temperature monitoring**
- **External gas heater for regeneration**
  - Ability to operate at 250 to 425^{o}C range
- **On-line monitoring for CO_2 and H_2O**
- **Low pressure operation capability**

TDA Research

Adiabatic Reactor

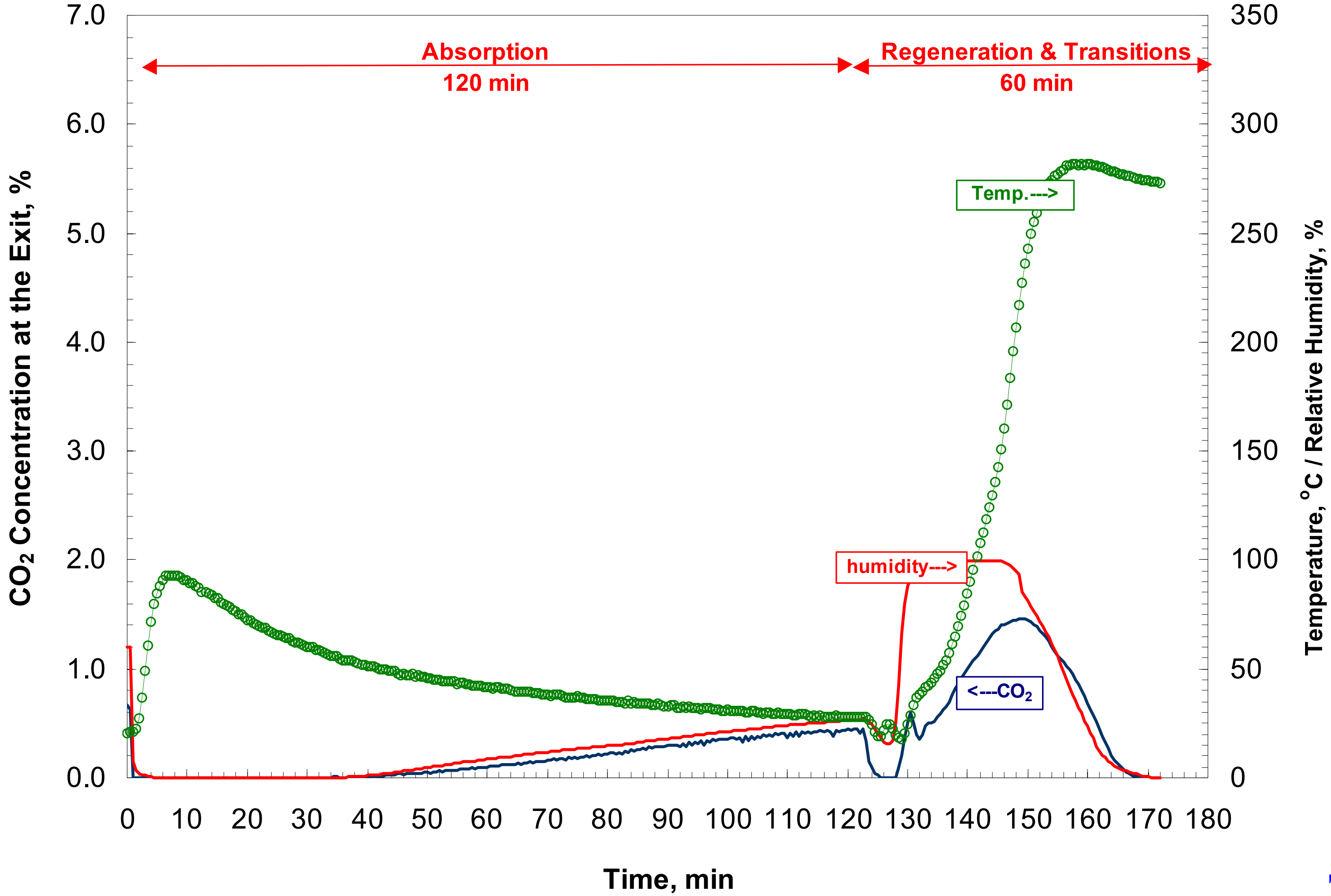


P&ID of the Adiabatic Test Unit



TDA Research

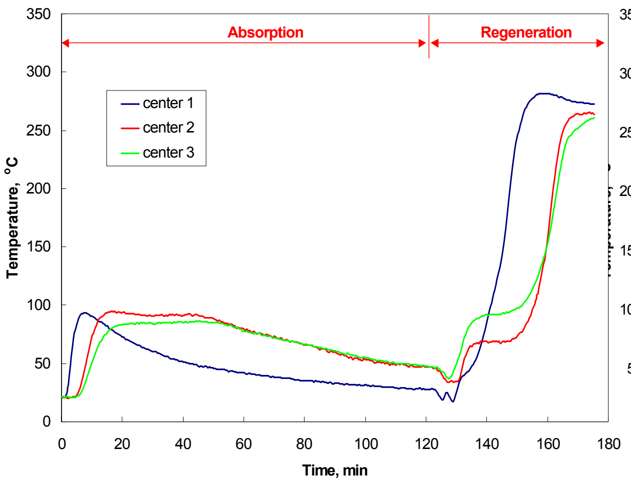
Typical Adiabatic Test Profile



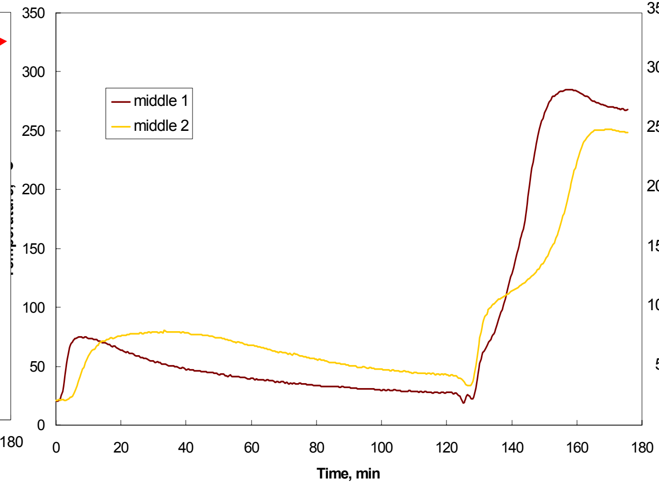
TDA
Research

Temperature Profiles

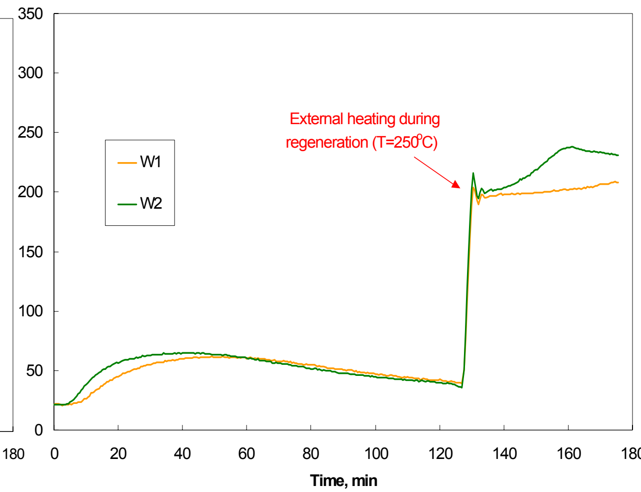
Center



Middle



Wall



- Due to the reaction exotherm, we observed bed temperatures exceeding 80°C during the absorption
- Sorbent effectively removed CO_2 and water vapor at these high temperatures

TDA Research

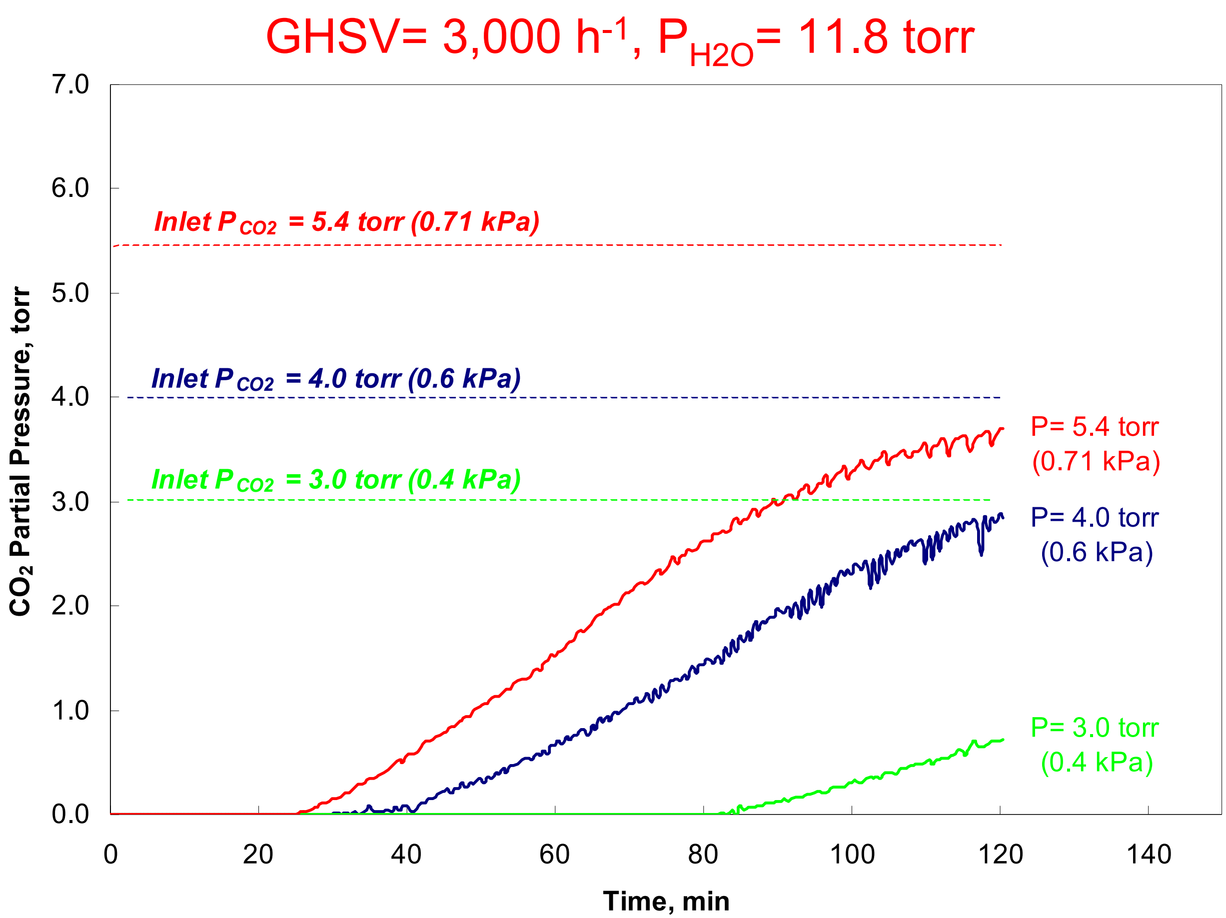
Mission Assumptions

- **7.29 person equivalent**
  - 0.668 lb/h CO_2 removal
  - 0.623 lb/h H_2O removal (2.28 mol H_2O/mol CO_2)

Parameter	Units	lower	nominal	upper
Carbon Dioxide Generated	kg/CM-d	0.466 (1)	0.998 (2)	2.241 (1)
Oxygen Consumed	kg/CM-d	0.385 (1)	0.835 (2)	1.852 (1)
p(CO2) for Crew [3]	kPa	0.031 (2)	0.4 (3)	0.71 (2)
p(CO_2) for Plants [35]	kPa	0.04 (4)	0.12 (5)	TBD
p(O_2) for Crew	kPa	17.76 (3)	19.5 □ 23.1 (2)	23.1 (2)
Total Cabin Pressure	kPa	59.2	70.3 (3)	101.3 (2)
Temperature	°C	18.5 (2)	22.0 (2)	26.8 (2)
Relative Humidity	%	25 (6)	60 (6)	75 (6)

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

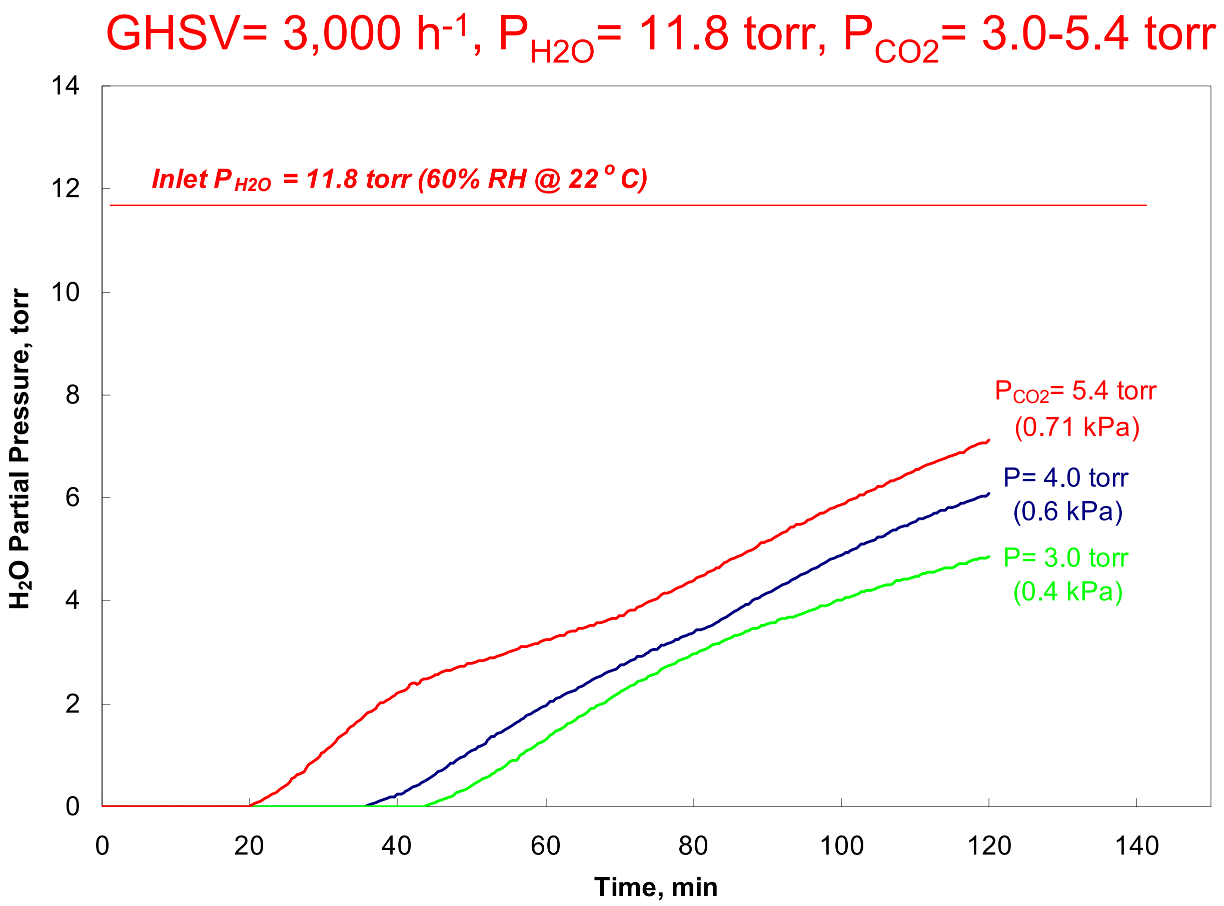
Effect of CO_2 Partial Pressure



- CO_2 absorption capacity of the sorbent can be up to 9% wt.

TDA Research

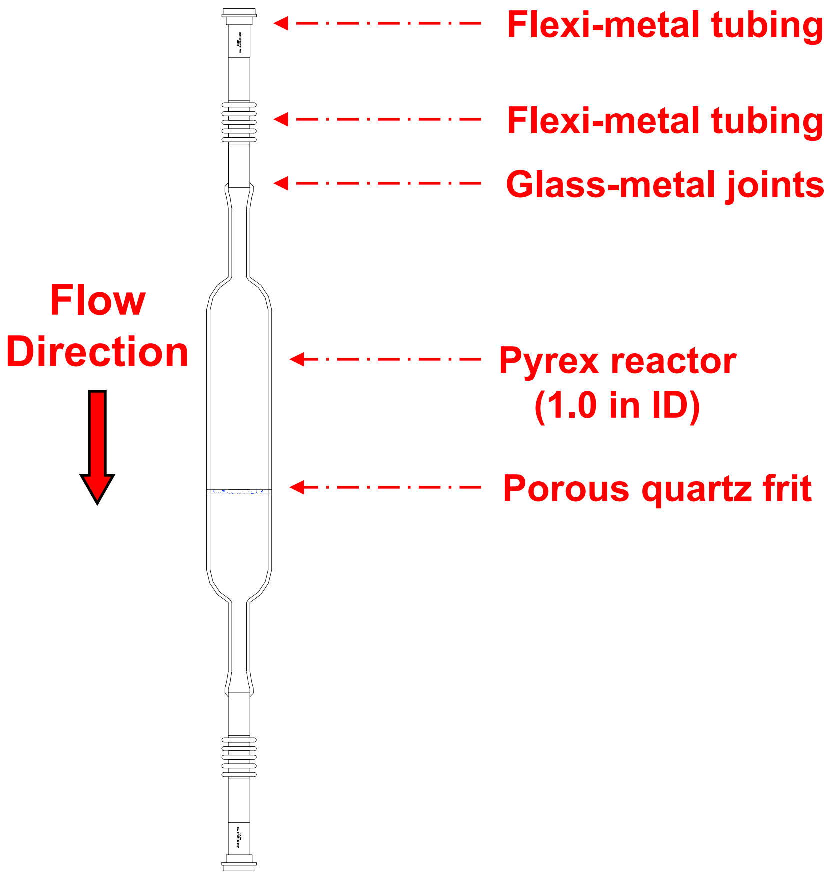
H_2O Removal Performance



- Water absorption capacity of the sorbent can be up to 11% wt.

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 minutes
- **Some heat losses**
  - Lower temperature increase during absorption results



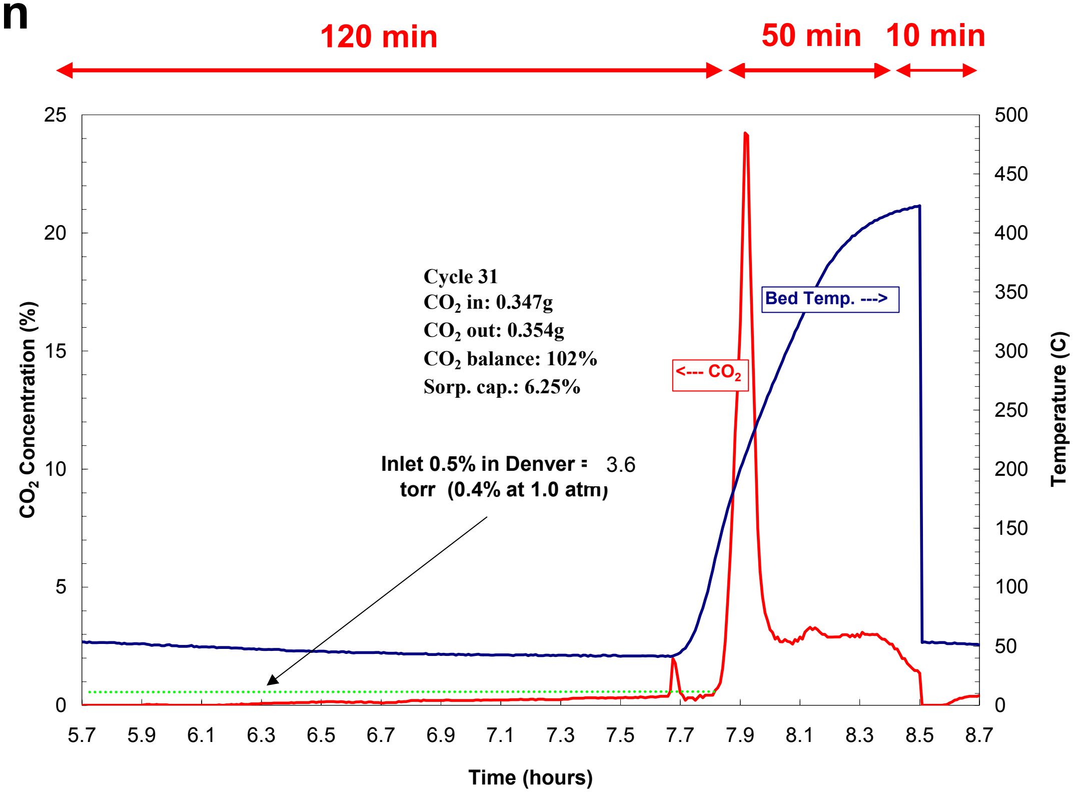
TDA Research

Multiple-Cycle Tests

- **500 consecutive absorption and regeneration cycles are targeted**

- **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

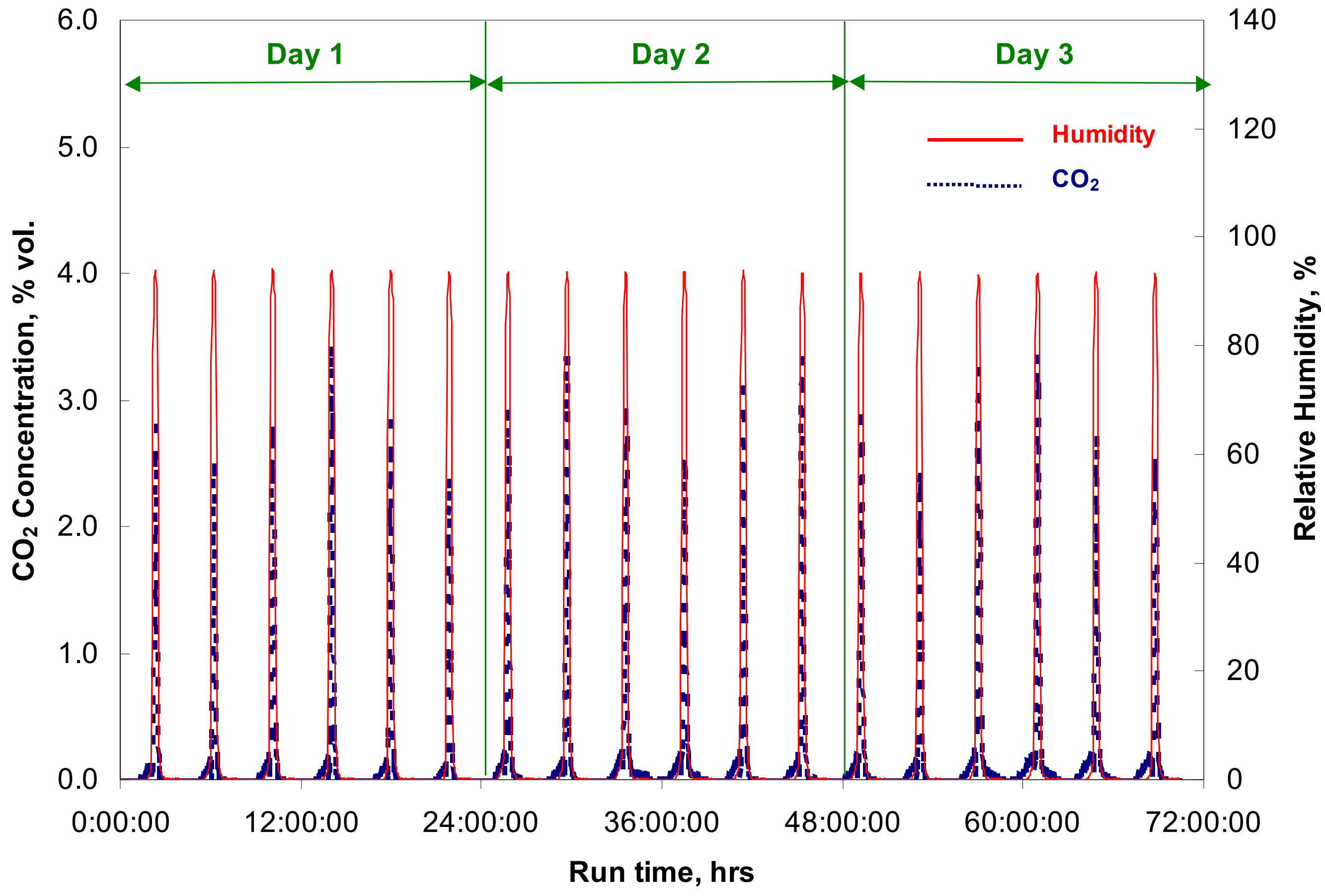
- **Regeneration Conditions**
  - T= 250 to 400°C
  - GHSV= 800 h^{-1}
  - H_2 Conc.= 60% vol.
  - H_2O Conc.= 40% vol.
  - Duration = 50 min



TDA Research

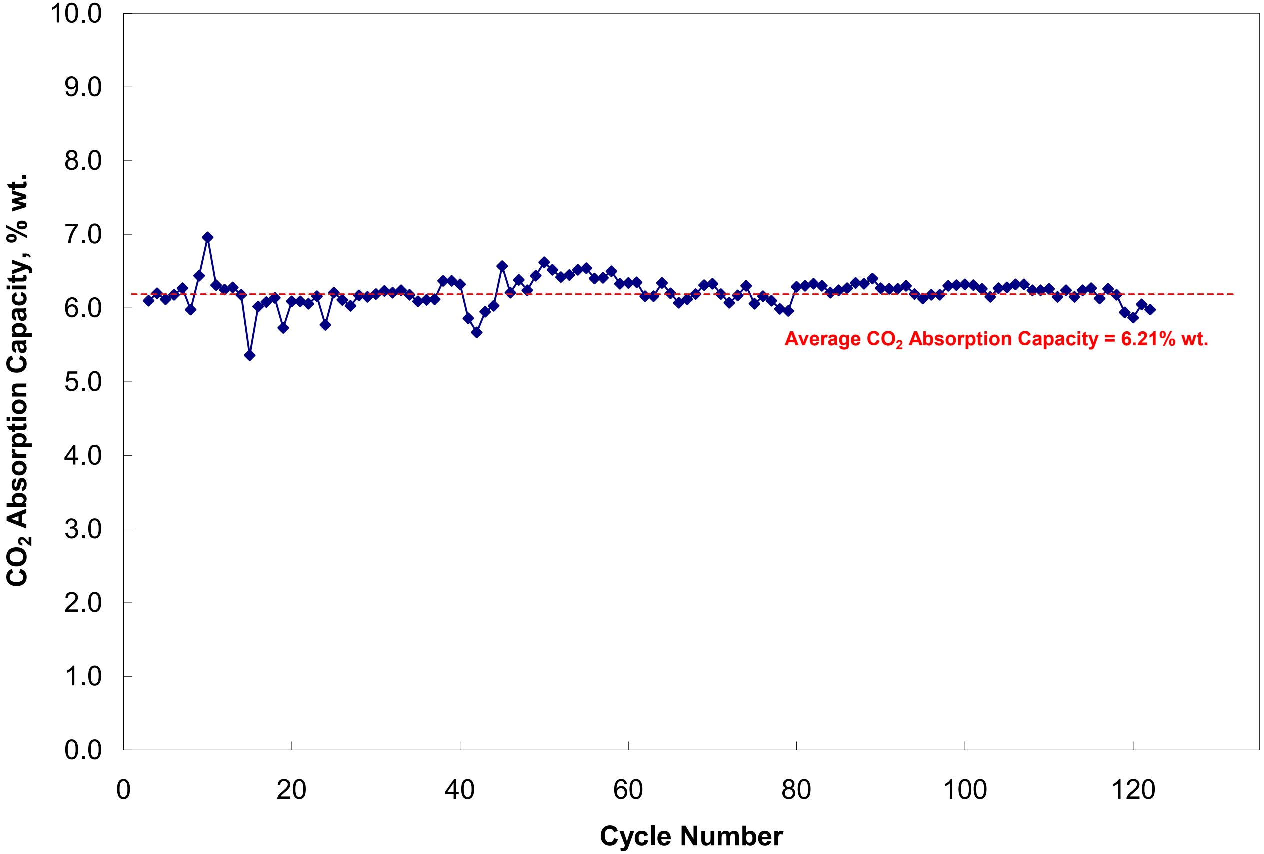
Typical Test Profile

GHSV= 3,000 h^{-1}, P_{CO2}= 3.6 torr, P_{H2O}= 12.0 torr



TDA Research

Multiple-Cycle Tests

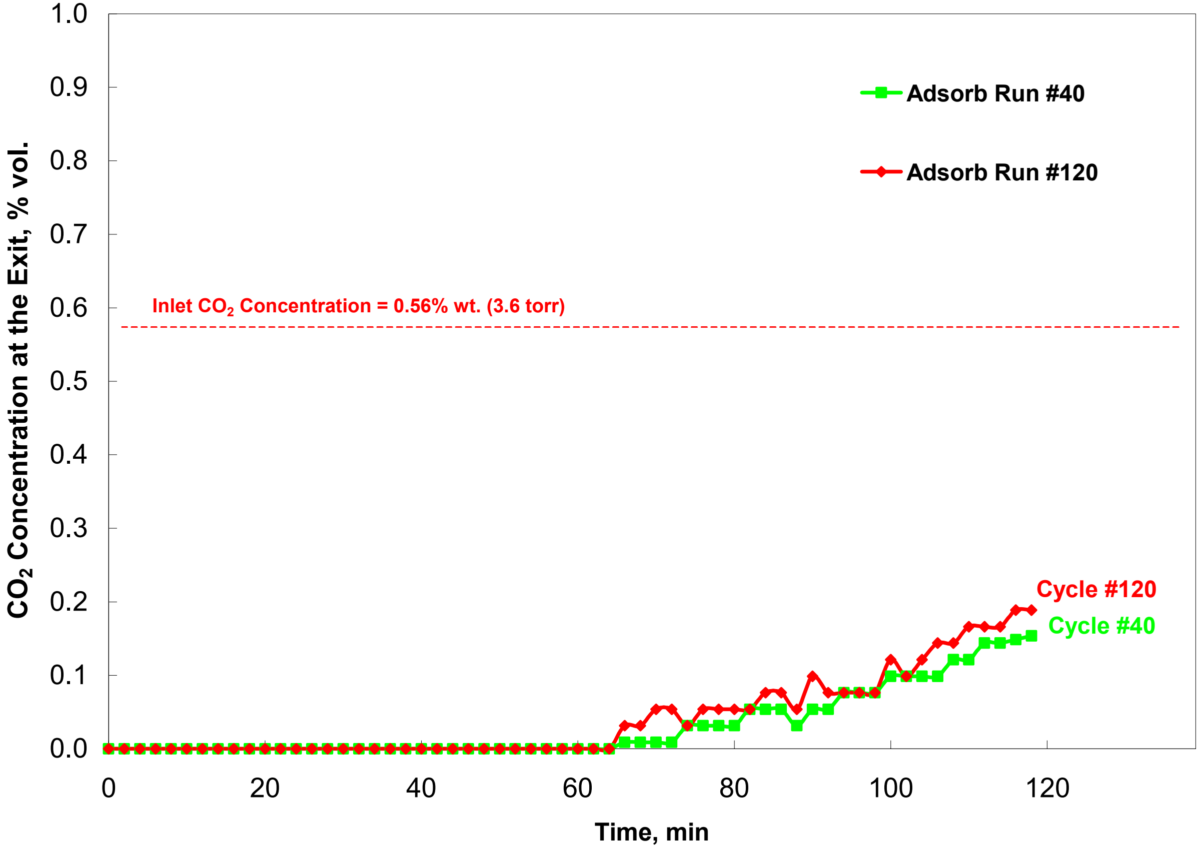


- **Sorbent maintains its CO_2 and H_2O absorption capacity for more than 120 cycles**

TDA Research

CO_2 Breakthrough Profiles

GHSV (STP)= 3,000 h^{-1}, P_{CO2}= 3.6 torr, P_{H2O}= 12.0 torr



TDA Research

Sabatier Equilibrium with Added Water

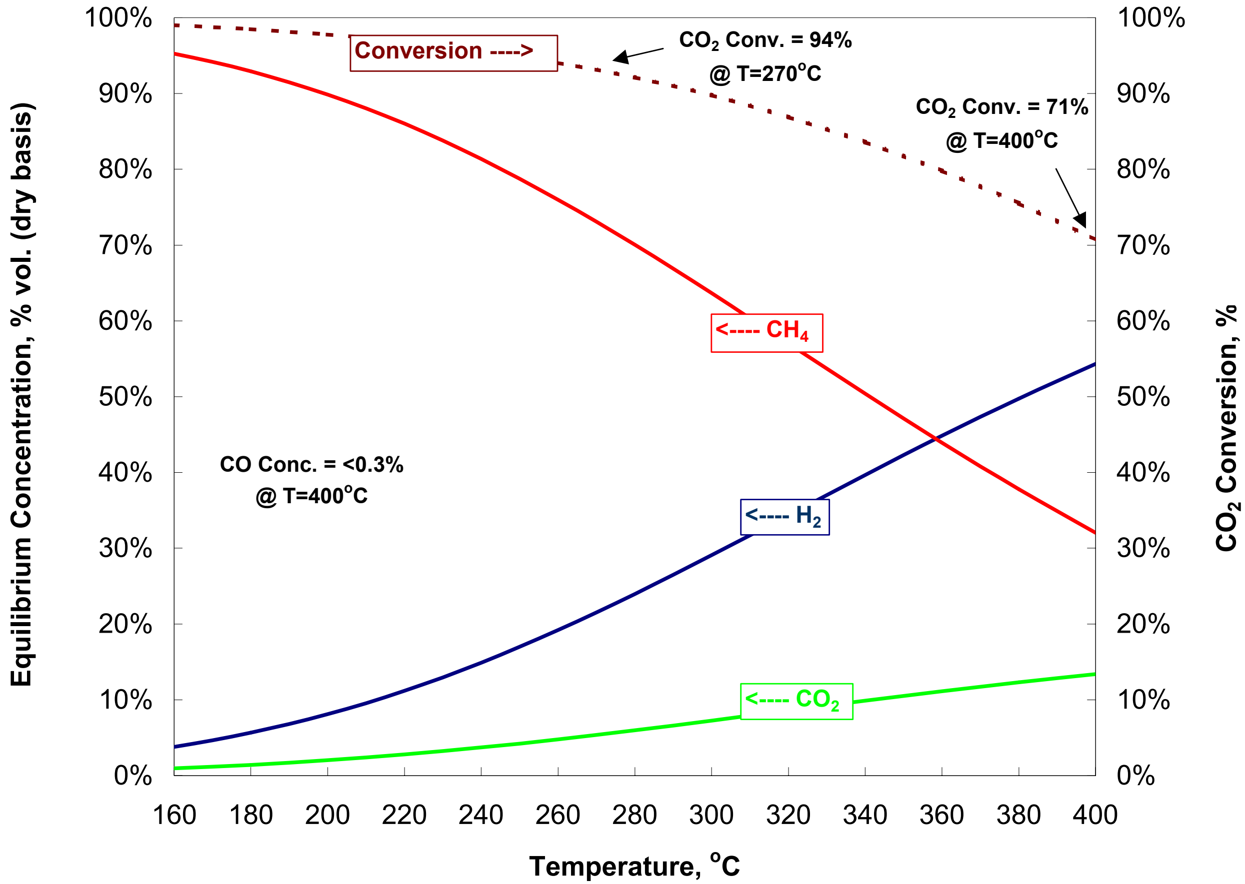
P= 0.9 atm

Inlet Gas Concentration	
CO2	1.0
H2	4.0
H2O	2.5

CO_2 Conversion = 71% @ T= 400°C

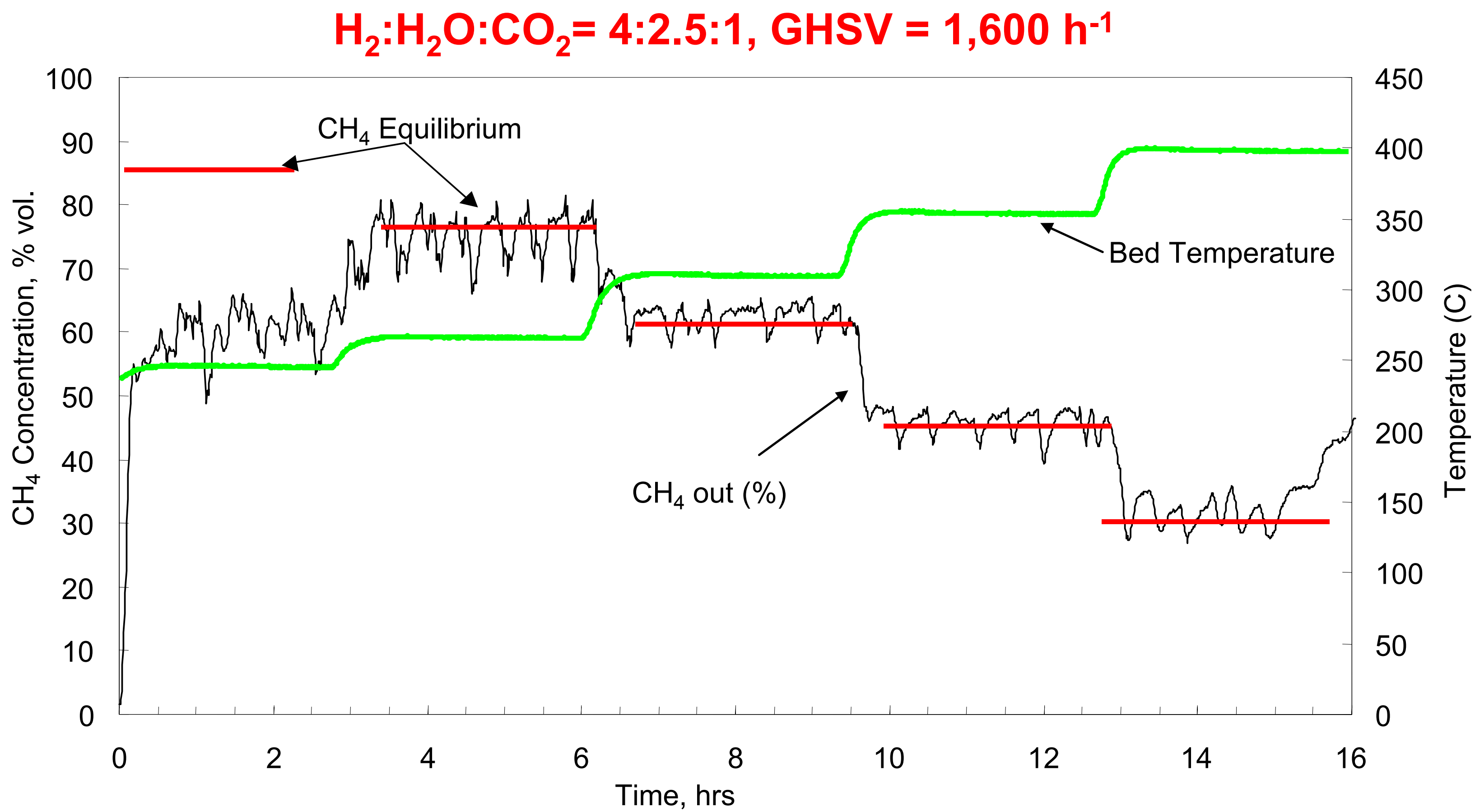
CO_2 Conversion = 94% @ T= 270°C

CO_2 Conversion =96.5% @ T= 270°C (with no added water)



TDA Research

Catalyst Performance with Added Water



- Catalyst achieves equilibrium CO_2 conversion at the operation temperature of low temperature (270°C) and high temperature (400°C) Sabatier reactors

TDA
Research

System Analysis

- **System Components**
  - Sorbent Beds
  - Sabatier Reactors (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

- 4BMS+CRA system for 7.29 eq. person weighs 299 kg
- TDA's system offers the potential of reducing the weight of the system hardware by 63.5% (~191 kg)

TDA Research

Weight Equivalency for 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

TDA Research

Conclusions

- **Technical Feasibility**
  - We developed a high capacity, regenerable sorbent for CO_2 and H_2O removal
  - The sorbent maintained its activity for 120+ consecutive cycles
  - We demonstrated the operation of a Sabatier catalyst under simulated operation conditions, closely approaching to equilibrium in a high steam environment
- **Implications**
  - TDA's system has the potential of reducing the hardware weight by 63.5% (191 kg) and overall system weight by 26% (375.4 kg)

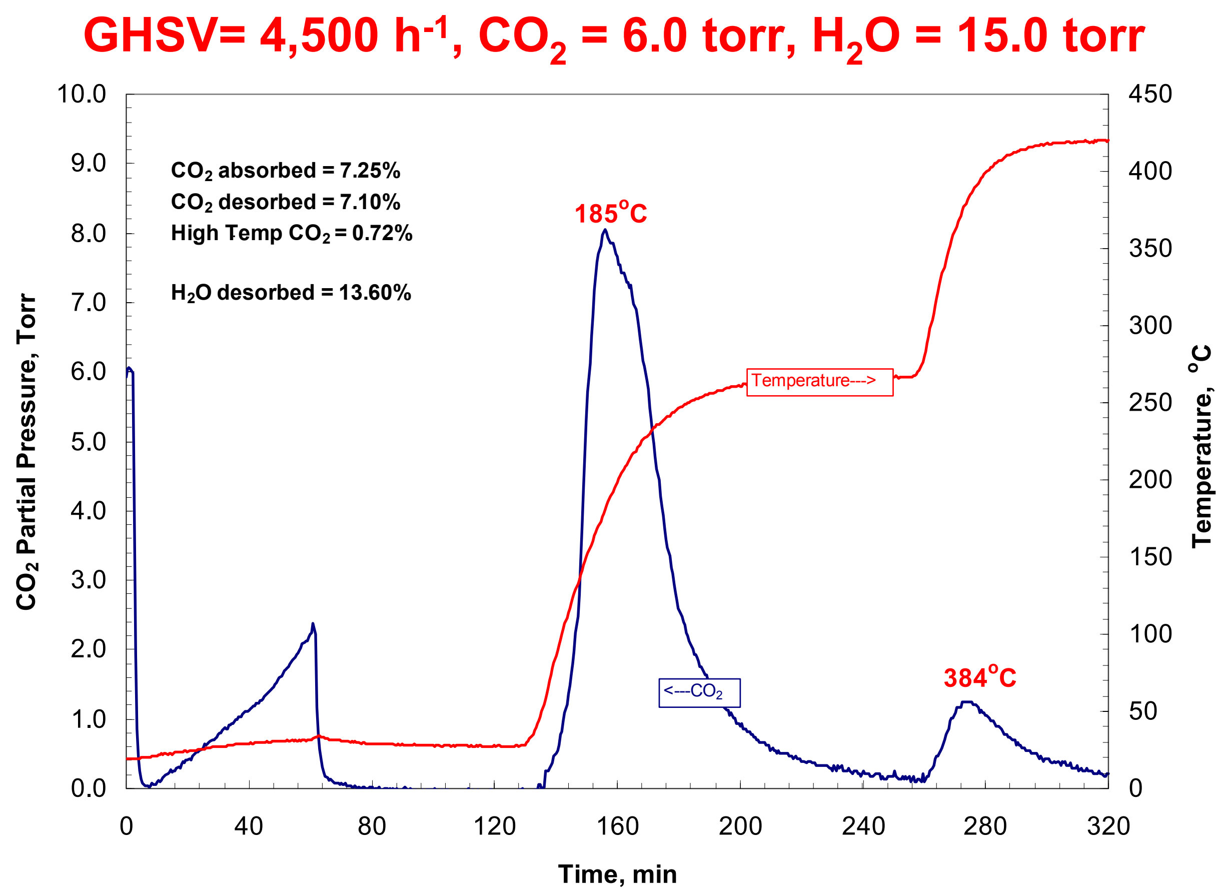
	TDA's System	4BMS+CRA
Weight of System Hardware (kg)	107.6	299.0
Weight Equiv. for Power Requirement (kg)	390.7	364.5
Weight Equiv. for Heat Rejection (kg)	563.8	774.0
Total Weight Impact	1062.1	1437.5

TDA Research

Acknowledgements

- **The funding from NASA Johnson Space Center is greatly acknowledged**
- **JSC**
  - Fred Smith, COTR
- **TDA Research, Inc**
  - Dr. Robert Copeland
  - Margarita Dubovik
  - Jania Gershanovich

Low Temperature Regeneration



- TPD studies indicate that low temperature (250-300°C) regeneration of the sorbent is possible

TDA Research