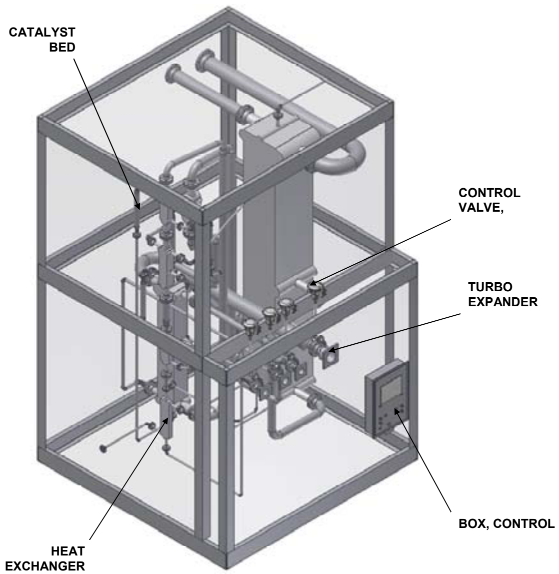
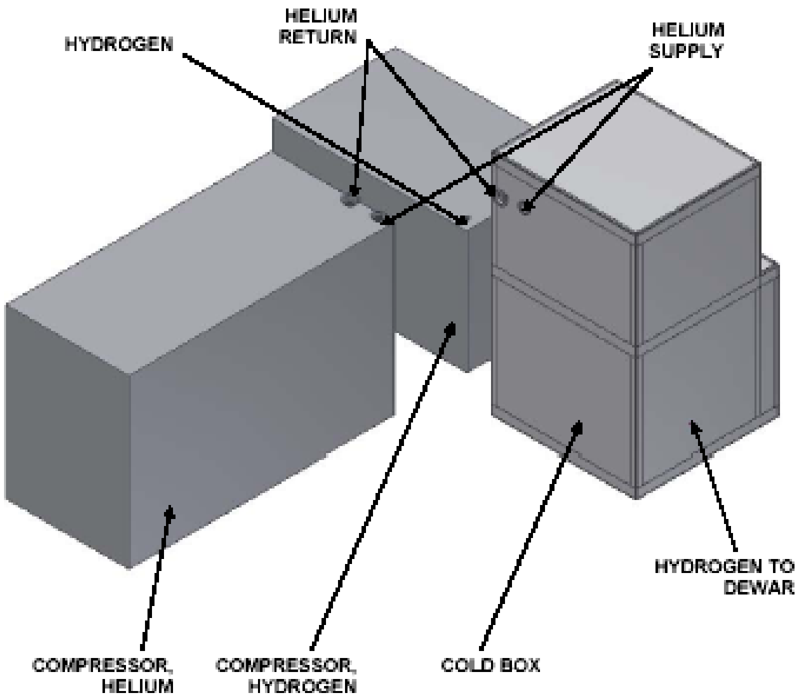
Innovative Hydrogen Liquefaction Cycle





Martin A Shimko **Project # pdp_23_shimko**

Gas Equipment Engineering Corporation

2009 DOE Merit Review

May 19, 2009

H2 Liquefier Development Program

Timeline

Restart Date: Jan 2007
End Date: Sept 2011
Percent Complete: 40%

Barrier Addressed

High Cost and Low Efficiency of Hydrogen Liquefaction

Budget

Project Funding:	$2.52M
DOE:	$2.00M
Contractor:	$0.52M

$161K Received in FY06
$394K Received in FY07
$587K Spent for FY08
$113K Remaining for FY09

Partners

GEECO:	*Detailed Design*
	Liquefier Fabrication
	System Testing
Avalence:	*System Integration*
MIT:	*Cycle Design*
	Catalytic HXC Design
R&D Dynamic:	*TBX Design and Fab*

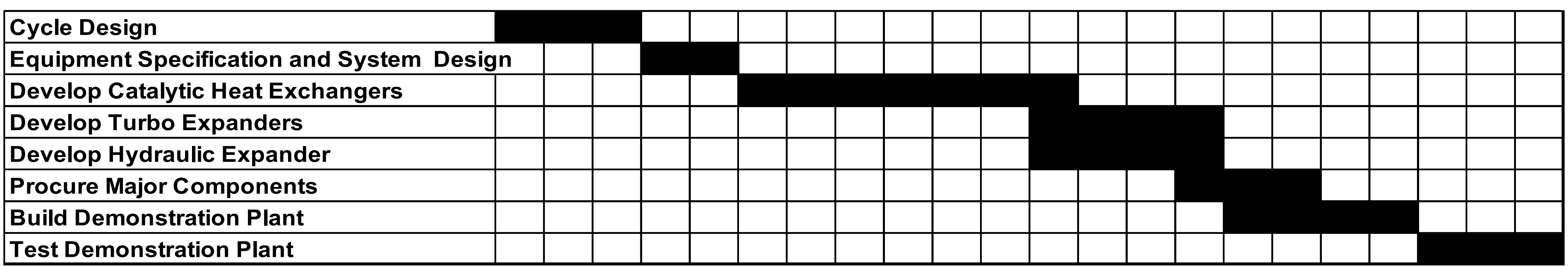
Refined Project Objectives

- Design a Practical H2 Liquefaction Cycle That Significantly Increase Efficiencies Over Existing Technologies
- Produce a small-scale (100 – 500 kg/day) hardware demonstration of a hydrogen liquefaction plant
- Use Low/No Risk Development Components That Scale to 50,000 kg/day Plant Size
- Document a Significant Reduction in the Total Cost of H2 Liquefaction at the 50,000 kg/day Production Level

Overall Project Schedule

Revised to:

- Reflect Project Restart in Jan ’07
- Limited Component Development and Demonstration Phase Consistent with FY ’08 Funding
- Focus is on The Catalytic Heat Exchanger Development
- Complete Component Development and Produce Full Pilot Plant Demonstration if Future Funds Allocated



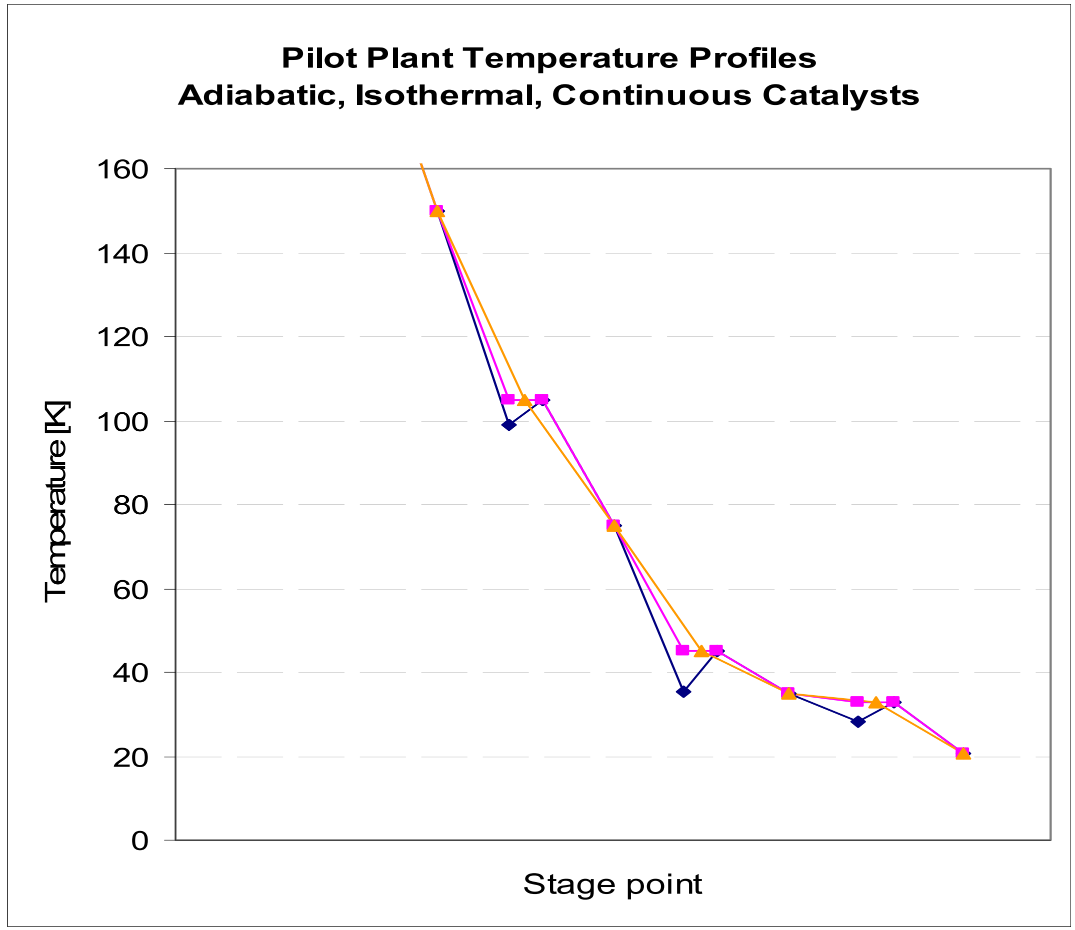
Near-Term Project Schedule

- ➢Key Component To Develop Identified as Catalytic Heat Exchanger
- ➢Complete Catalytic Heat Exchanger Fabrication and Testing by End of 2009

PROJECT TIME LINE	2008							2009											
	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Catalyst Investigation	■	■	■	■															
CHEX Numerical Modeling		■	■	■	■	■	■	■	■	■									
Design Test Apparatus				■	■	■	■	■	■	■	■	■							
Para/Ortho Measurement Devise					■	■	■	■	■	■									
Design CHEX (Heat Exchanger)									■	■	■								
Build Test Apparatus											■	■	■	■					
Test Adiabatic Test Article															■	■			
Refine Pilot Plant Design											■	■	■	■	■	■	■		
Test CHEX																	■	■	
Evaluate and Report																■	■	■	■

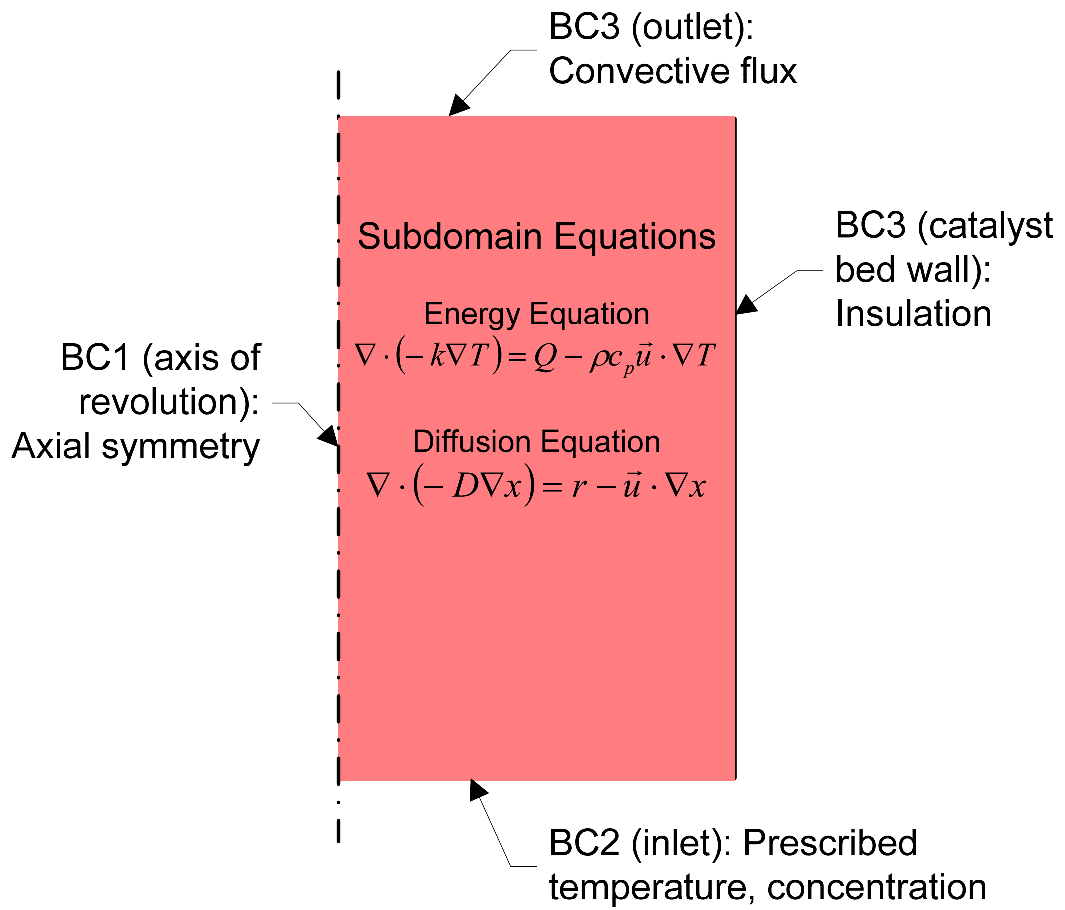
Catalyst Characteristic's Effect on Temperature Profile and Efficiency

Pilot Plant Performance Simuation	η cycle	W net (kWh/kg)
Adiabatic Catalyst Beds	19.76	19.69
Isothermal Catalyst Beds	22.14	17.57
Continuous Catalytic Heat Exchangers	23.33	16.67



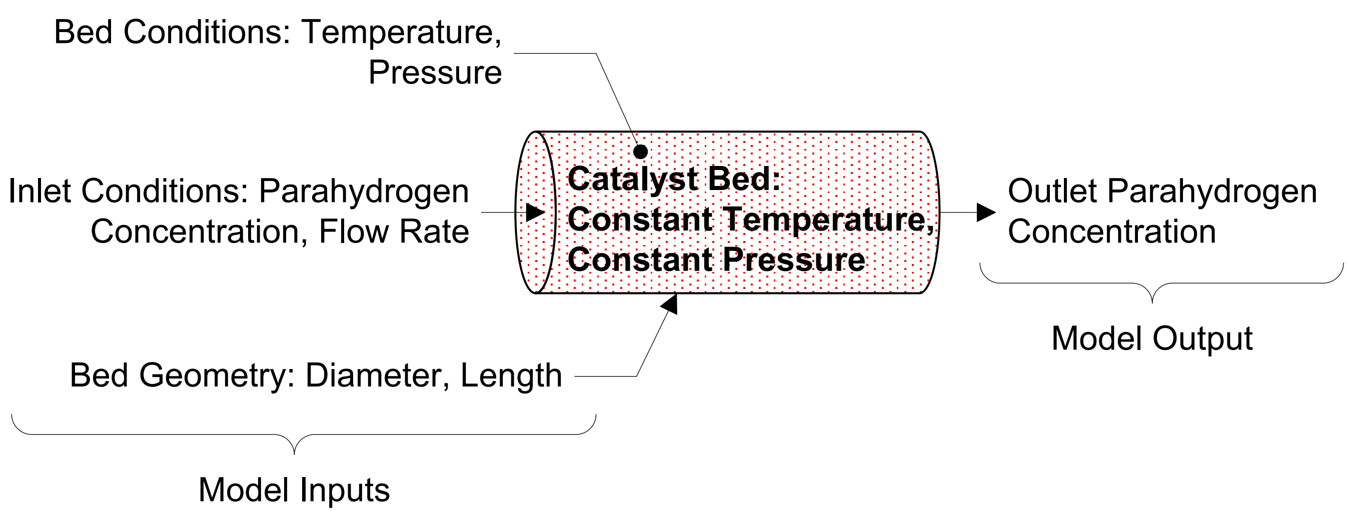
CHEX Simulation Program

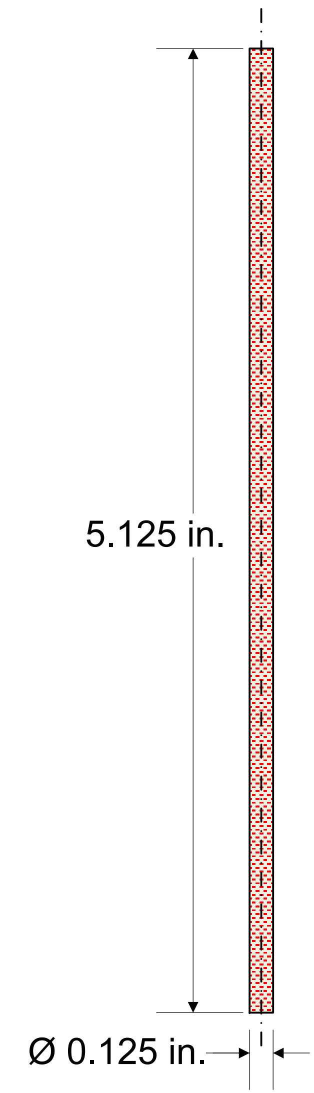
- **Developed a Numerical Model Using MATLAB and COMSOL Multiphysics**



CHEX Simulation Program

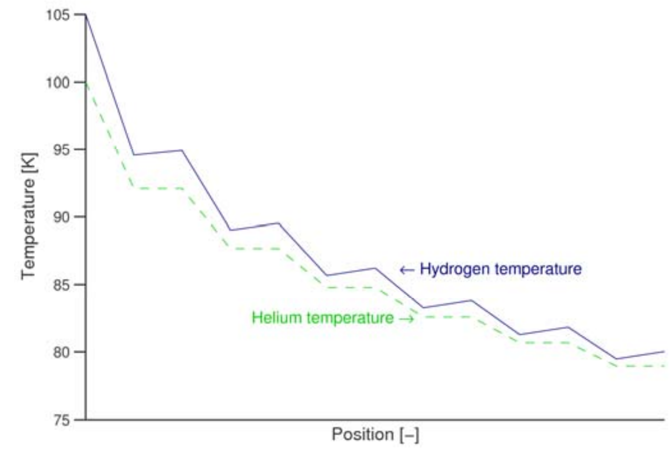
- Model Breaks Length Into Steps of Catalytic Conversion and Heat Exchange
- "Typical" Heat Exchanger (Shell and Tube" Dimensions Used

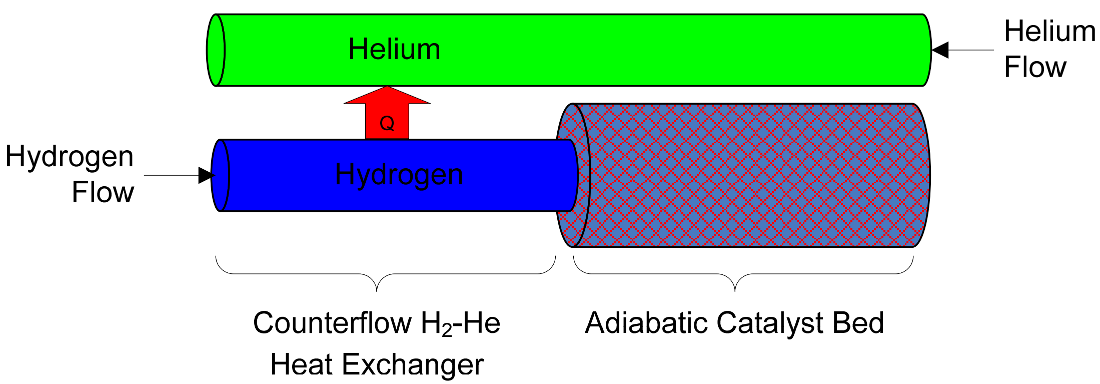


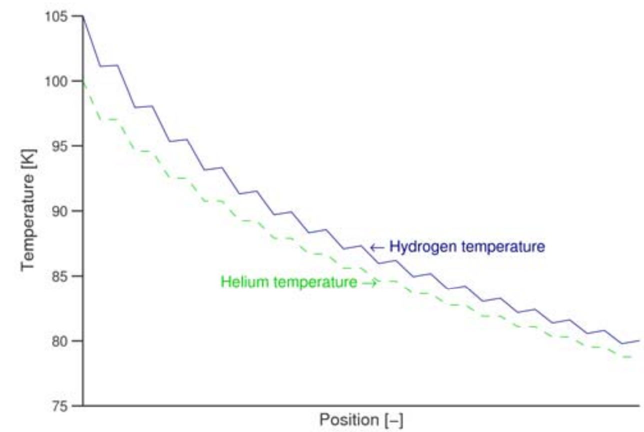


CHEX Simulation Program

- "Satisfactory" Step Size Identified
- Results Show Pressure Independence

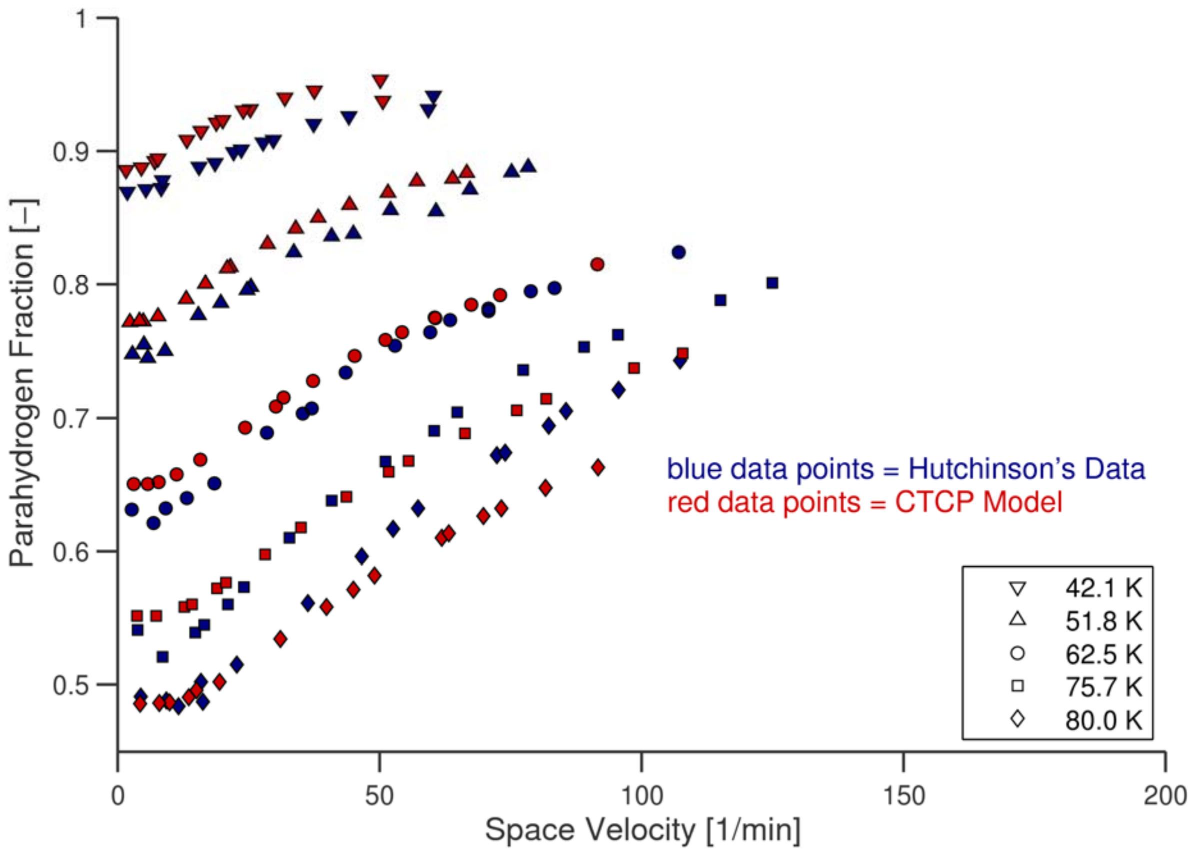




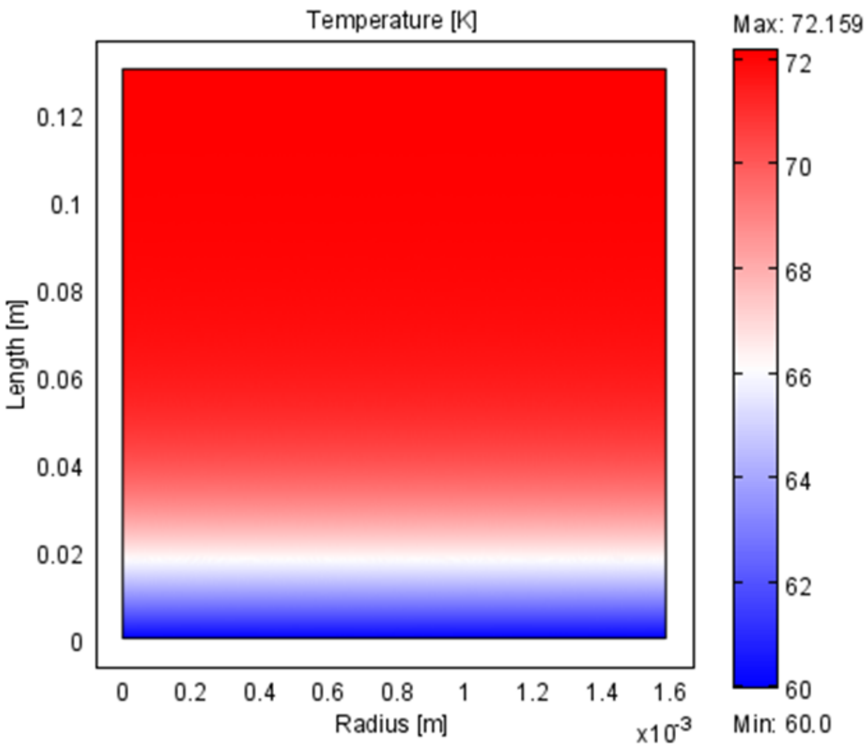


CHEX Simulation Program

- ➢ Validated Against Testing by Hutchinson
- ➢ Original Testing was Performed Examining Para to Ortho Transition (cold to warm)
- ➢ Adiabatic Catalyst Bed

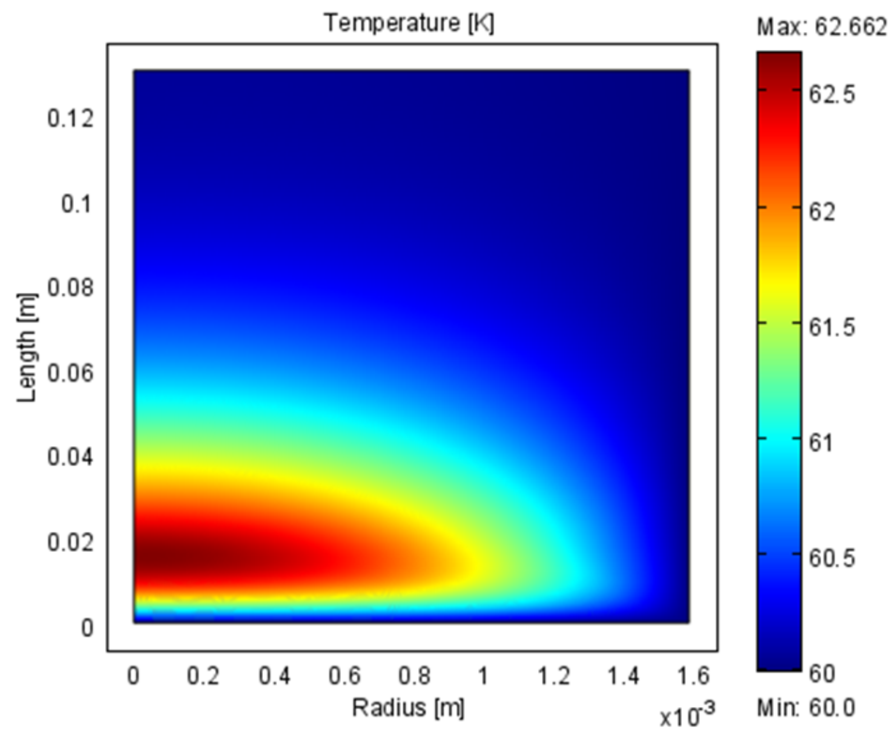


CHEX Simulation Program Results

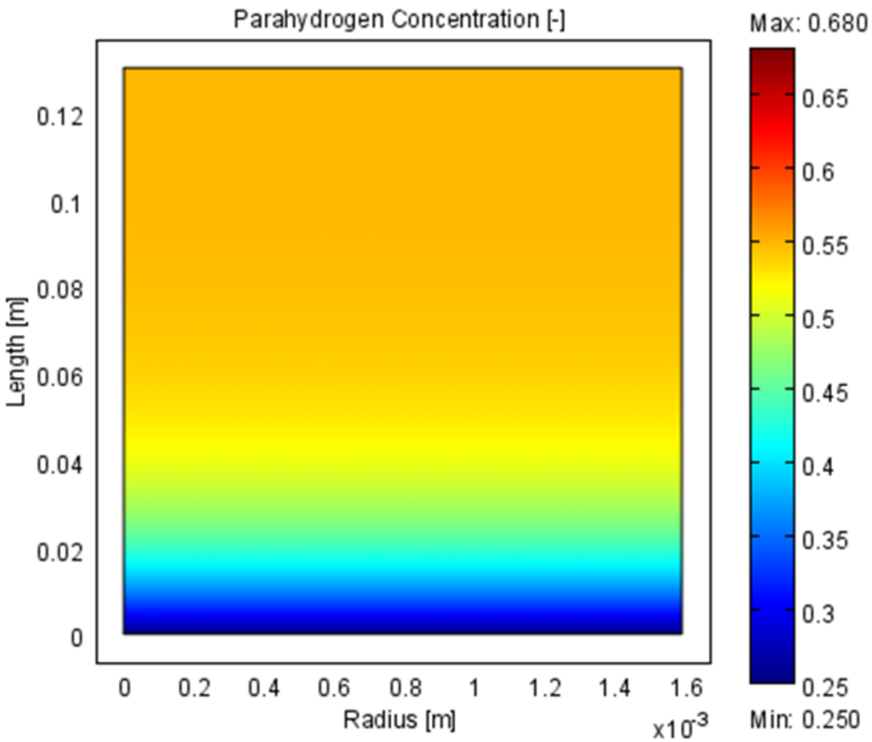


← Adiabatic Bed

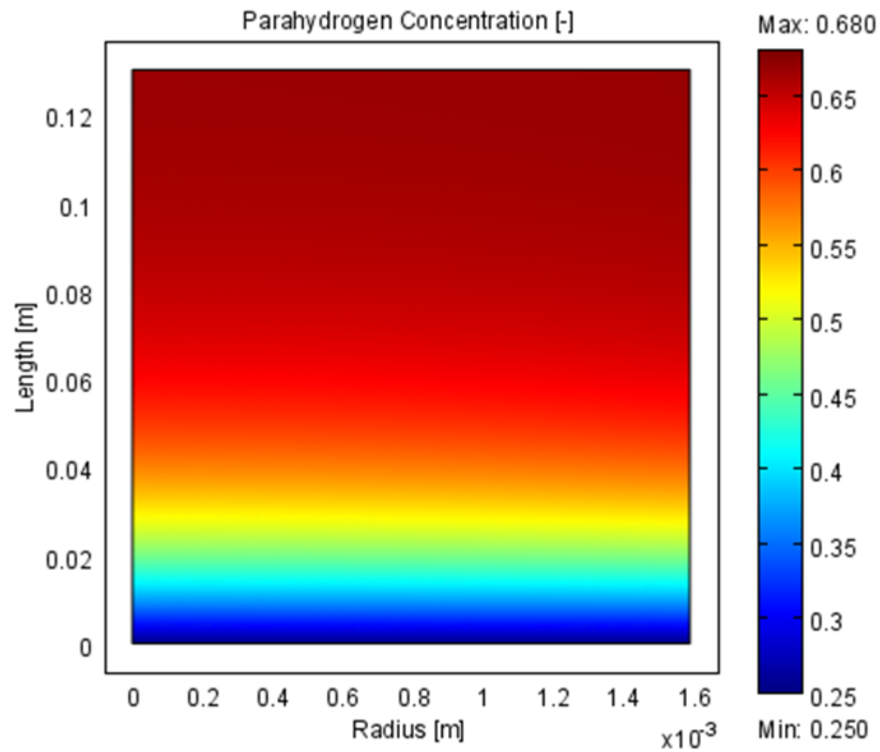
Constant Wall Temperature Bed →



CHEX Simulation Program Results

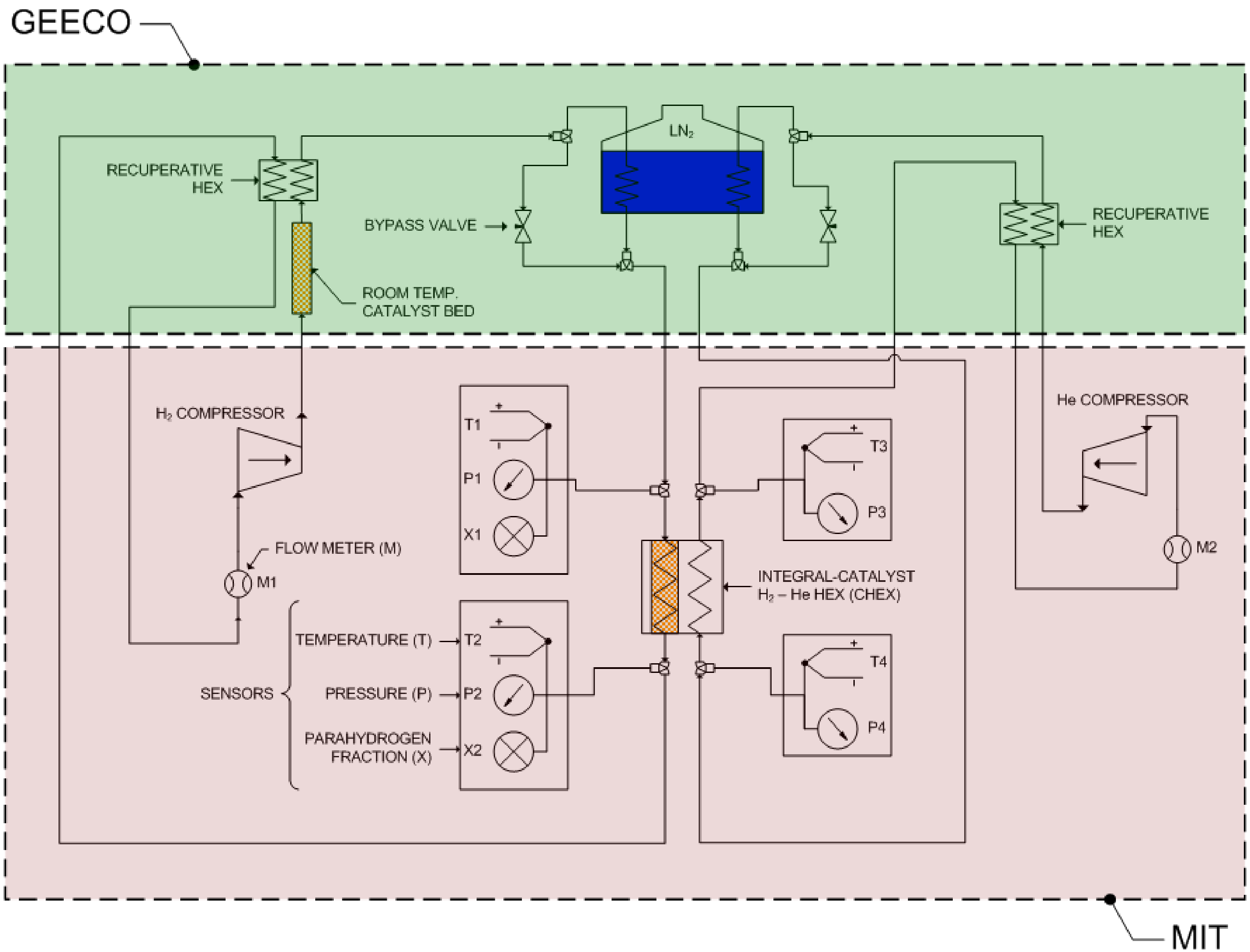


← Adiabatic Bed



Constant Wall Temperature Bed →

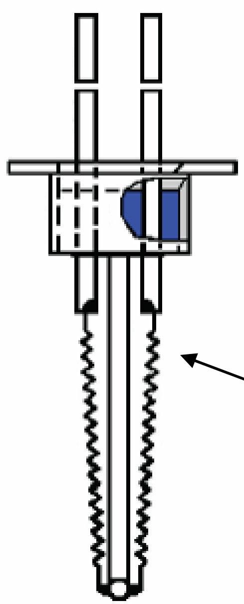
CHEX Test Apparatus



Development of pH_2 Detector

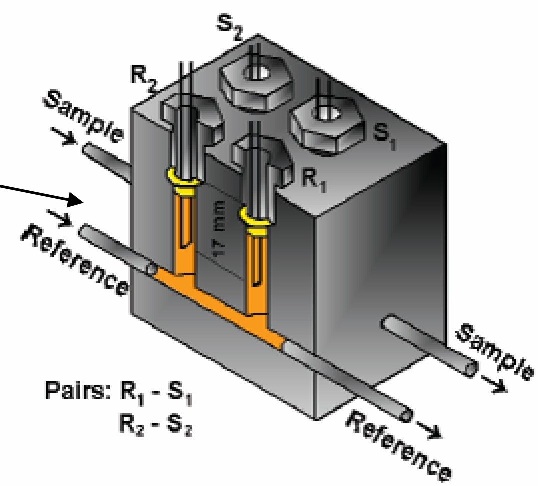
- pH_2 detectors are not commercially available
- pH_2 concentration can be deduced from thermal conductivity measurement
- Commercial thermal conductivity detectors (TCDs) are not designed for use at LN_2 temperature

Commercially available TCD components made by GOW-MAC



TCD filament

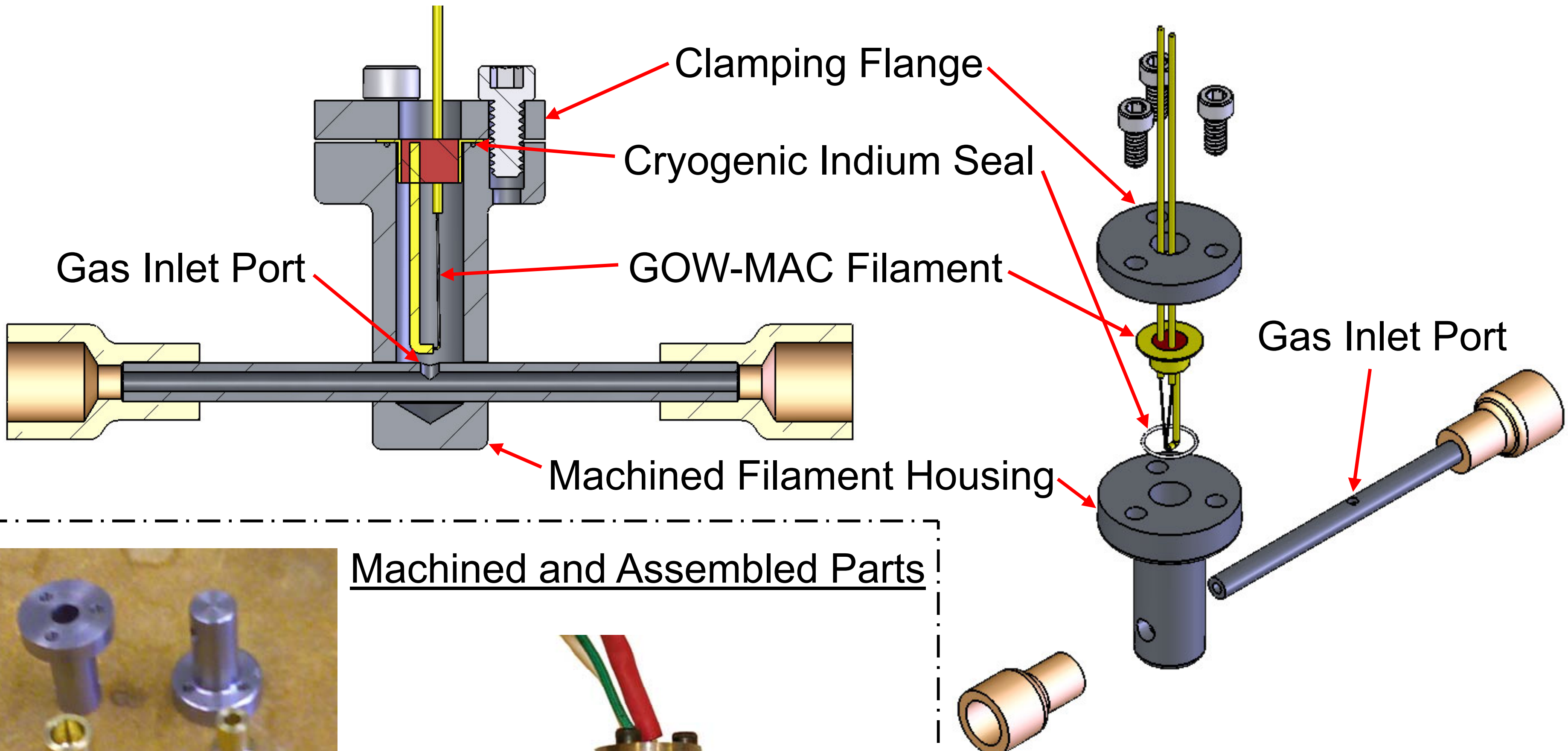
TCD block (not suitable for low temperatures)



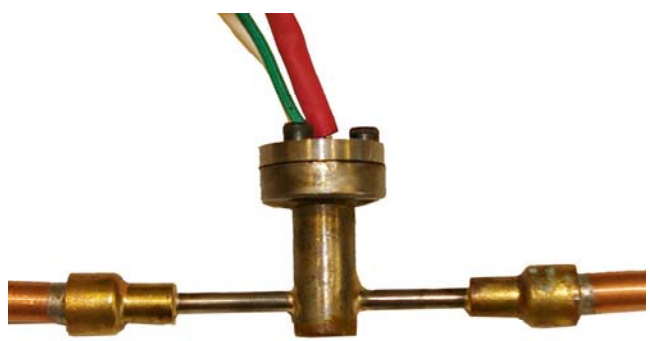
pH_2 Detector Assembly

Section View

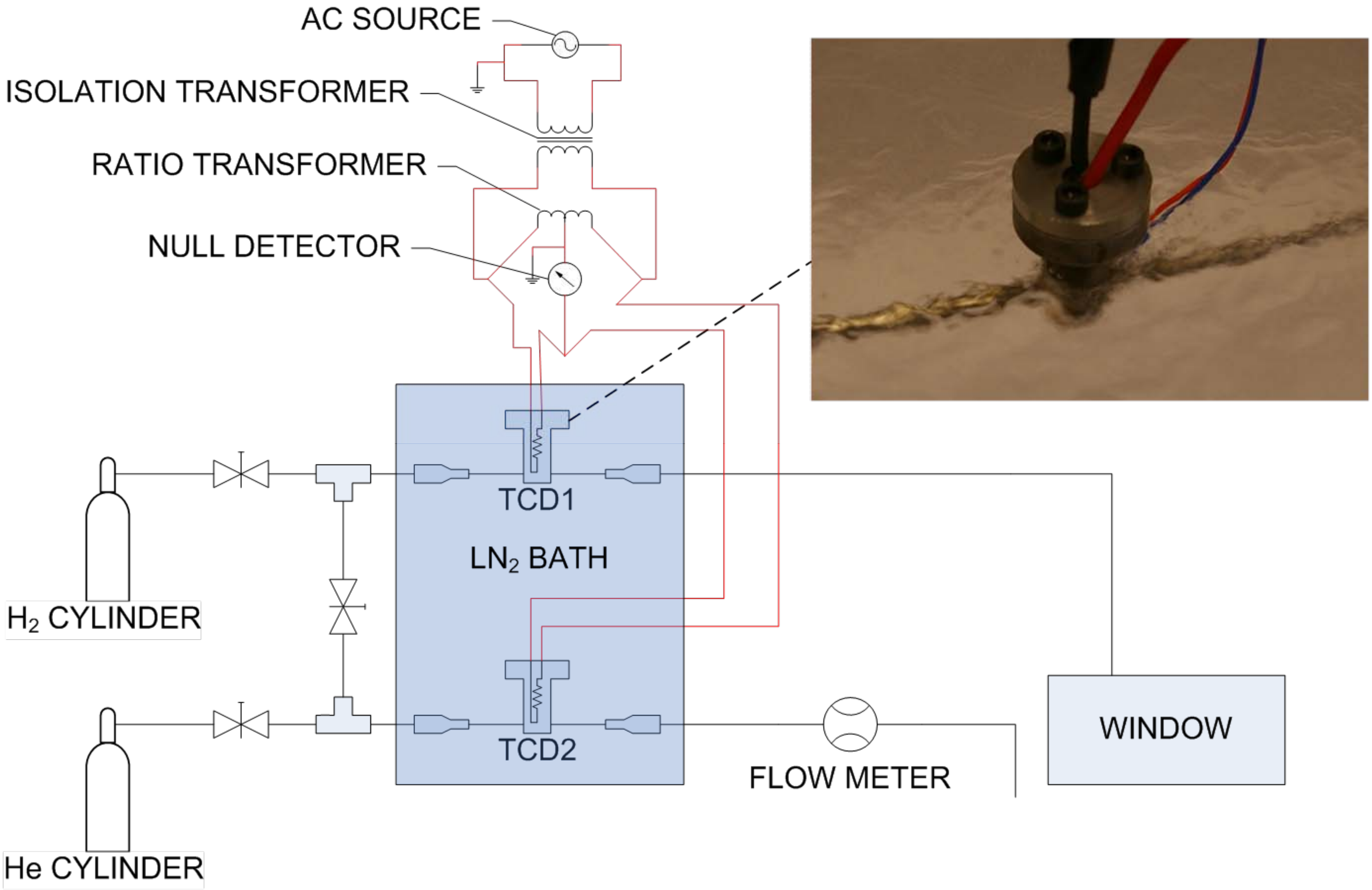
Exploded View



Machined and Assembled Parts

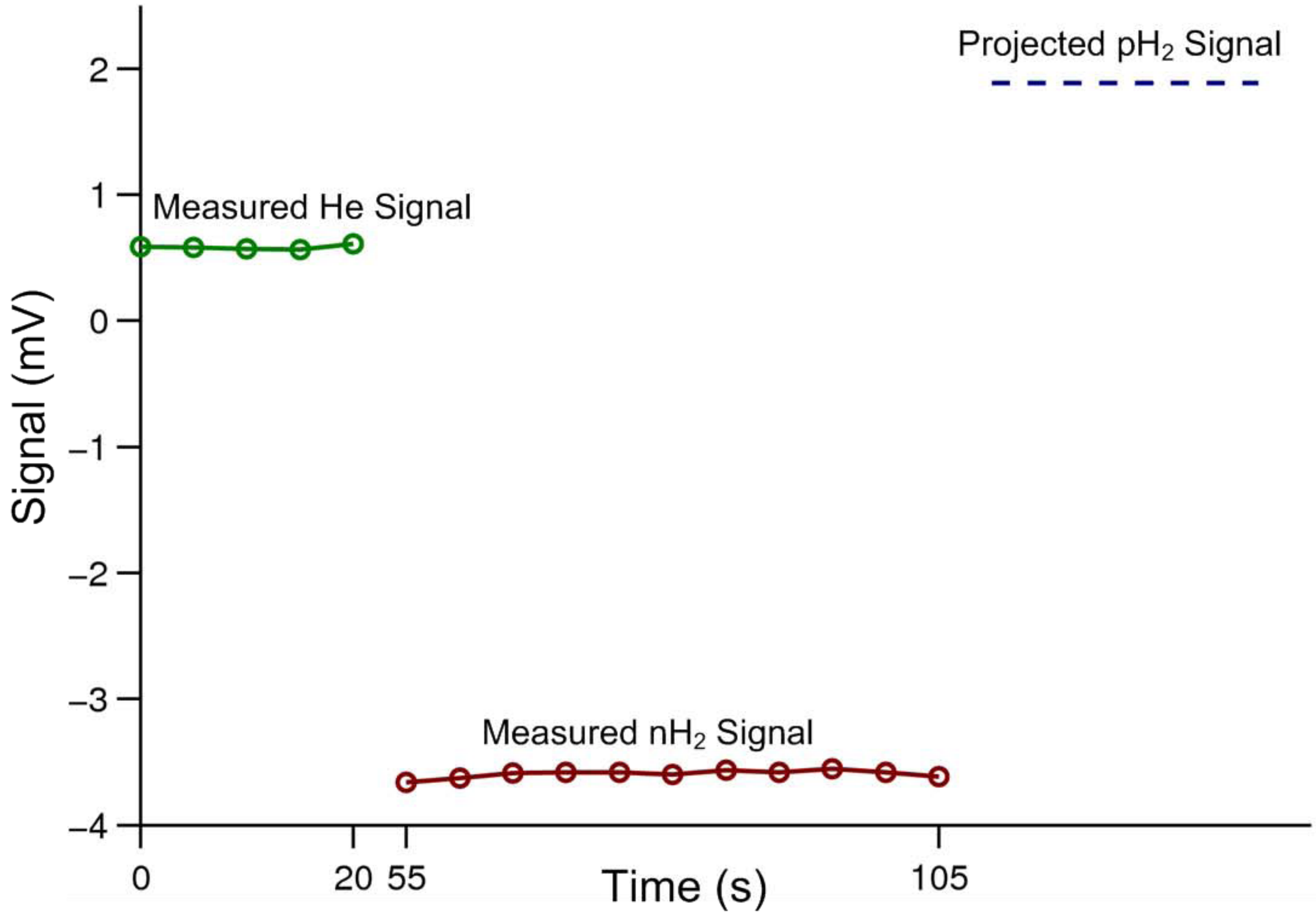


AC Bridge pH_2 Measurement Configuration

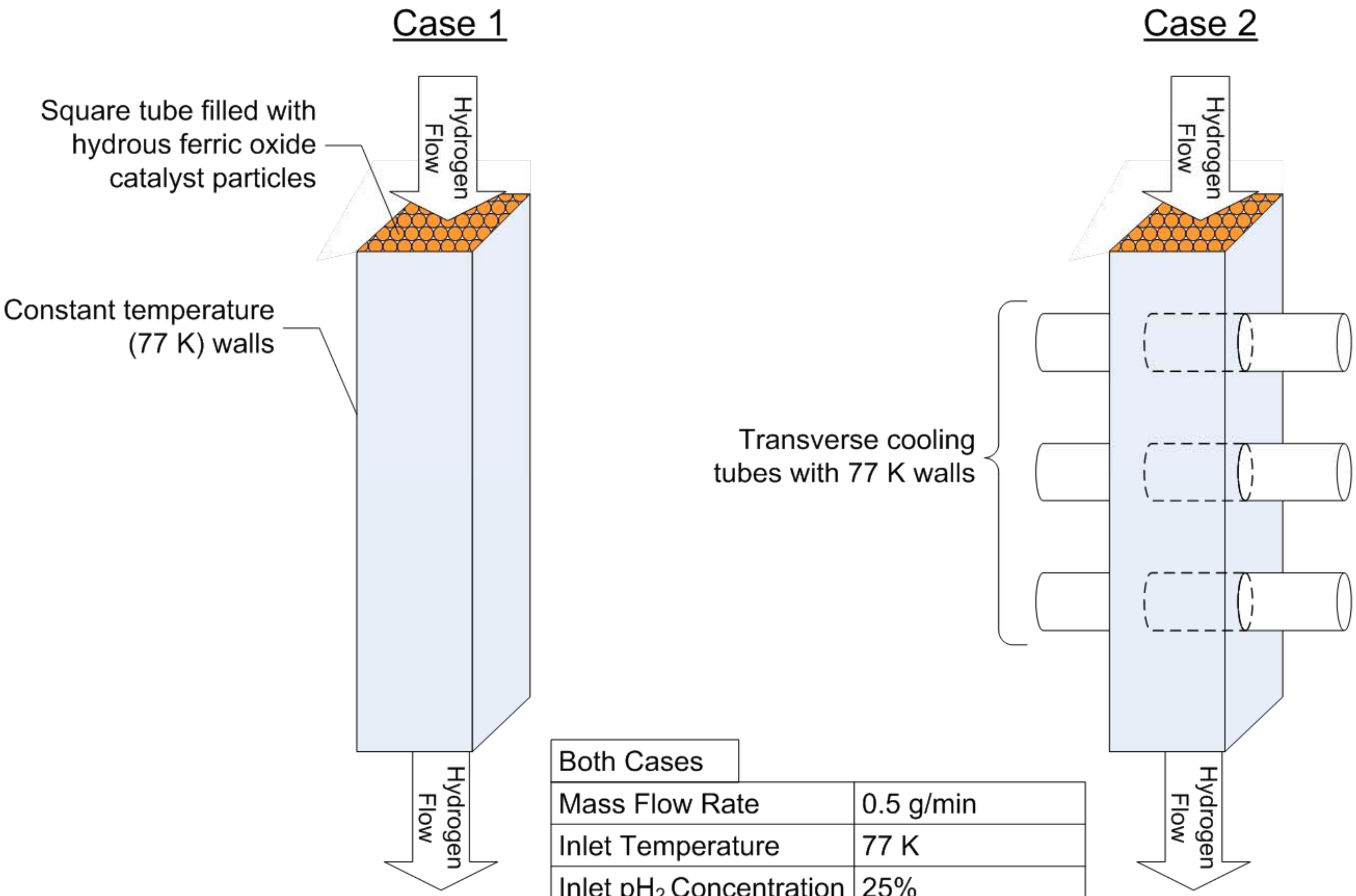


Sample AC Bridge Results

Initial measurements indicate that the pH_2 concentration can be resolved to 0.35%



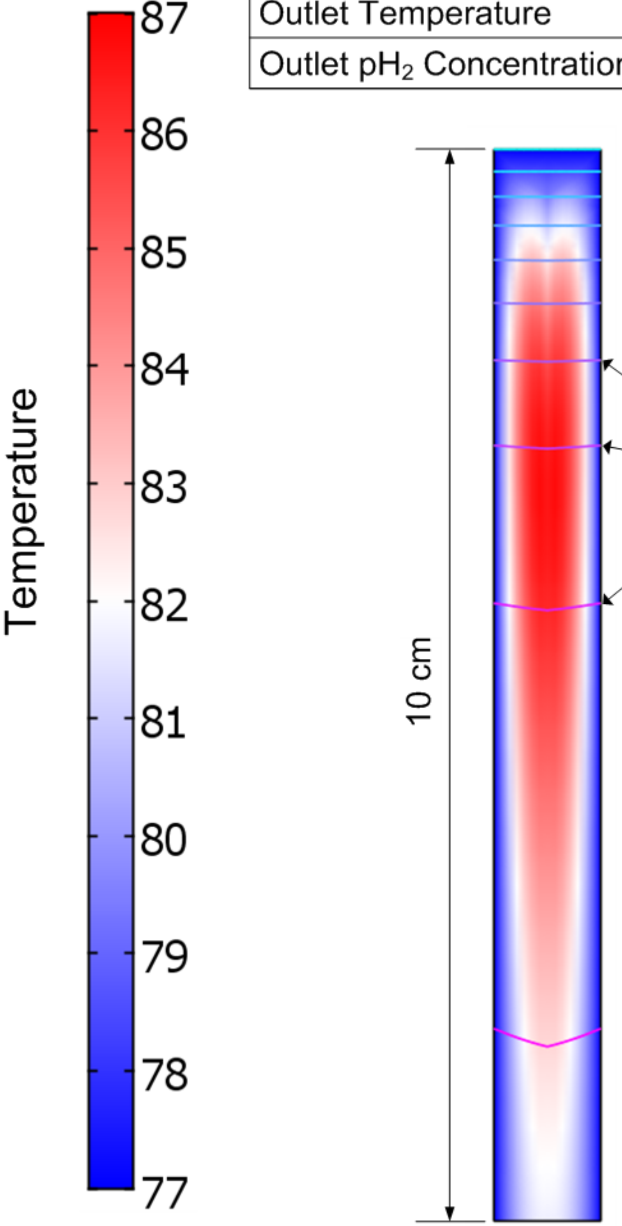
2D Packed Bed Models

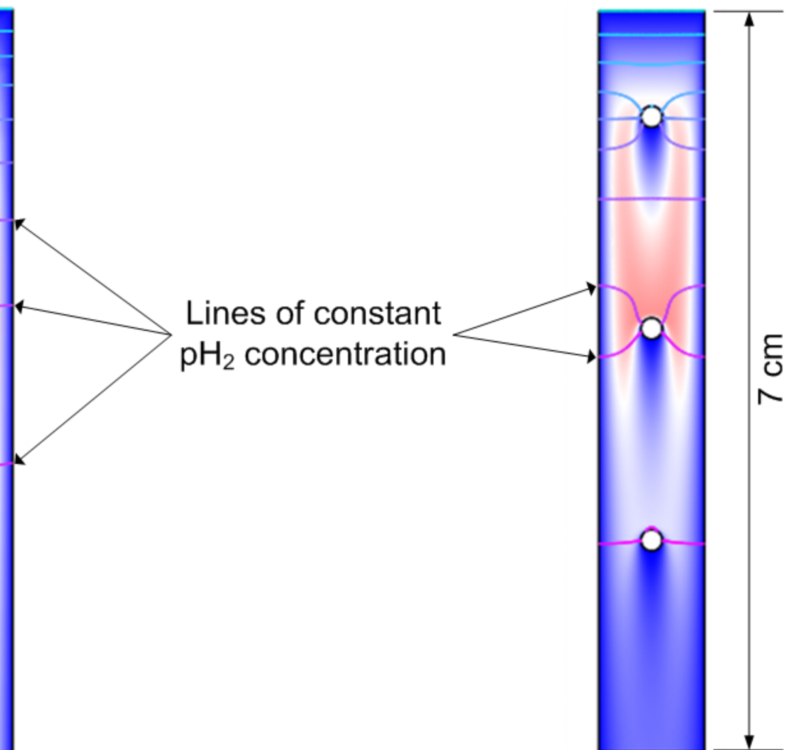


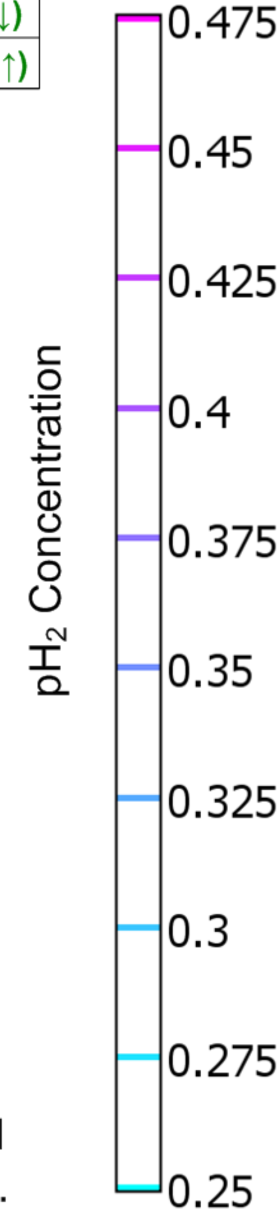
Both Cases	
Mass Flow Rate	0.5 g/min
Inlet Temperature	77 K
Inlet pH_2 Concentration	25%
Tube Cross Section	1 cm x 1 cm

Case 1	
Outlet Temperature	**80.3 K**
Outlet pH_2 Concentration	**47.8 %**

Case 2	
Outlet Temperature	**78.8 K (↓)**
Outlet pH_2 Concentration	**48.8 % (↑)**



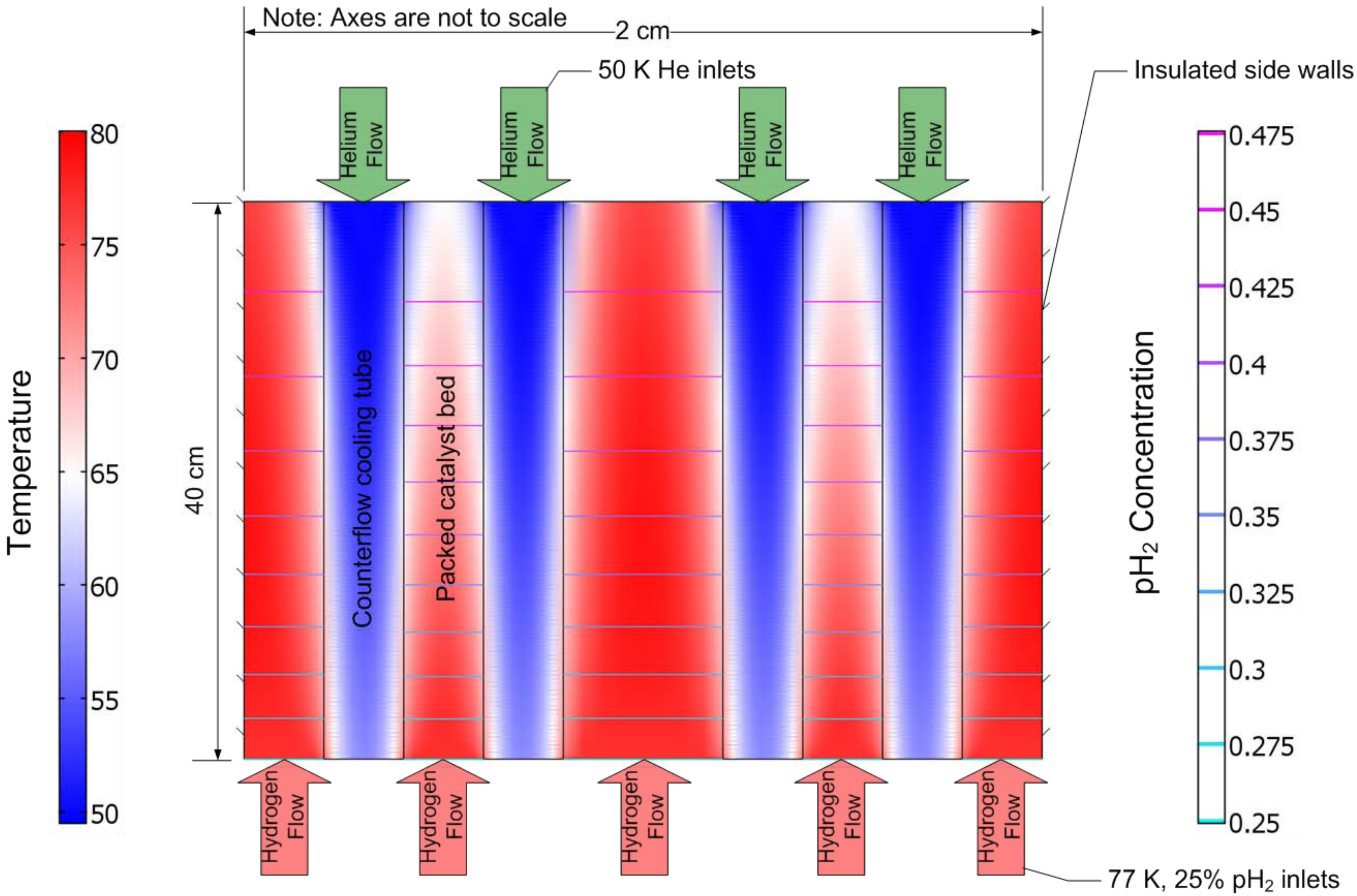




Case 2 has a lower outlet temperature and a higher pH_2 concentration.

Conclusion: Cooling tubes improve bed performance with less catalyst material.

2D Counterflow Packed Bed Model



With an appropriate cooling configuration, the CHEX apparatus effectively catalyzes the o-p conversion in a small space

Key Results For Last Year

- Completed Development and Validated Accuracy of CHEX Numerical Model
- Finished Design of CHEX Article Test Apparatus
- Sensor for Measuring para/ortho Make-Up Fabricated and Performance Verified
- Model Shows That Typical Heat Exchanger Channel Dimensions are Satisfactory for Pressure Drop, Heat Exchange, and Catalyst Reaction Rate Criteria

Plan For Remainder of 2009

- Q2 ’09
  - Finish Design and Build of Test Apparatus
  - Build Adiabatic Catalyst Bed
  - Design CHEX
- Q3 ’09
  - Test Adiabatic Catalyst Bed
  - Build CHEX
- Q4 ’09
  - Test CHEX
  - Assess and Report