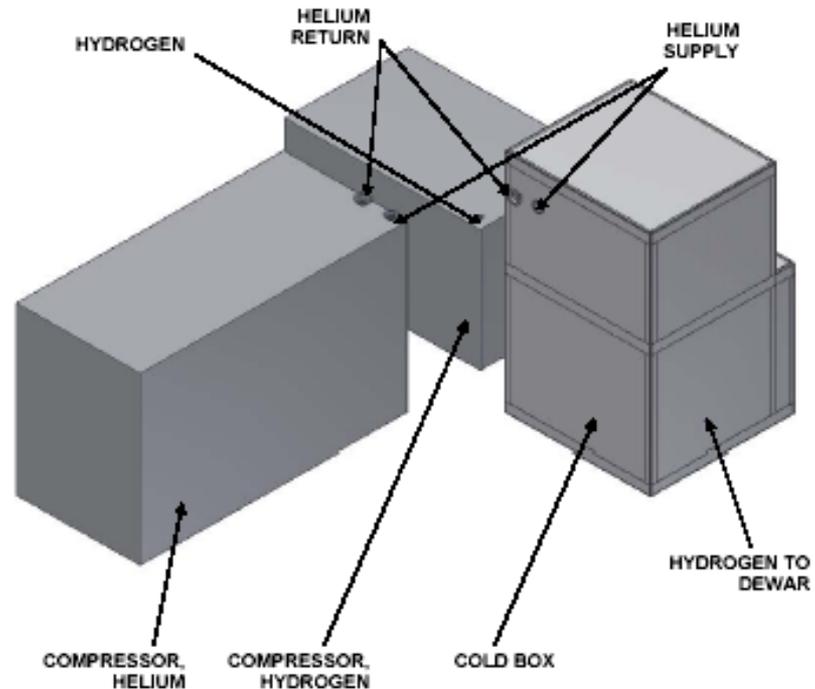
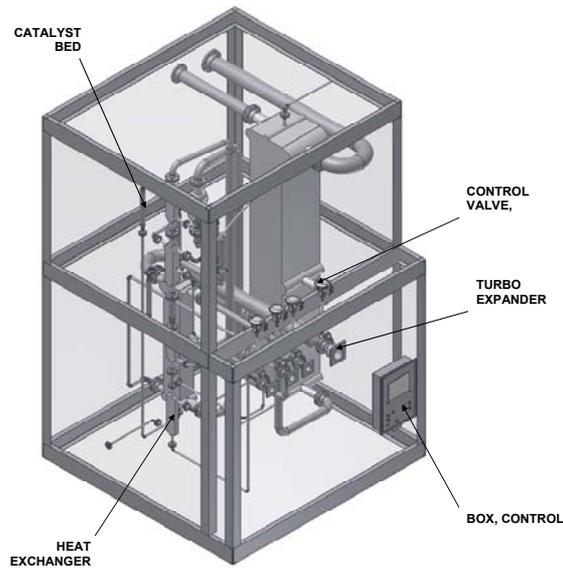




# Innovative Hydrogen Liquefaction Cycle



**Martin A Shimko    Project # pdp\_23\_shimko    2009 DOE Merit Review**  
**Gas Equipment Engineering Corporation    May 19, 2009**

This presentation does not contain any proprietary, confidential, or otherwise restricted information

# H2 Liquefier Development Program

## Timeline

Restart Date: Jan 2007

End Date: Sept 2011

Percent Complete: 40%

## 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

## Barrier Addressed

High Cost and Low Efficiency of  
Hydrogen Liquefaction

## 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 H<sub>2</sub> 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 H<sub>2</sub> Liquefaction at the 50,000 kg/day Production Level**





# Near-Term Project Schedule

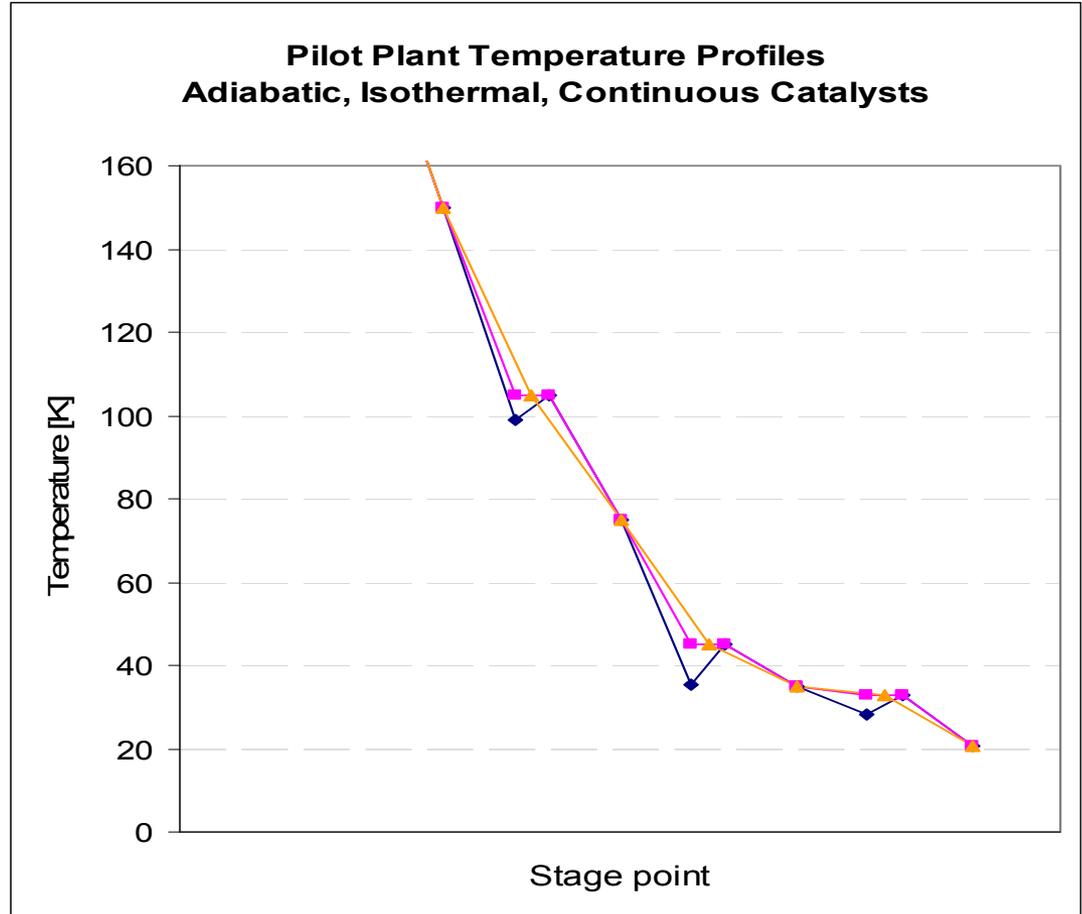
- Key Component To Develop Identified as Catalytic Heat Exchanger
- Complete Catalytic Heat Exchanger Fabrication and Testing by End of 2009

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

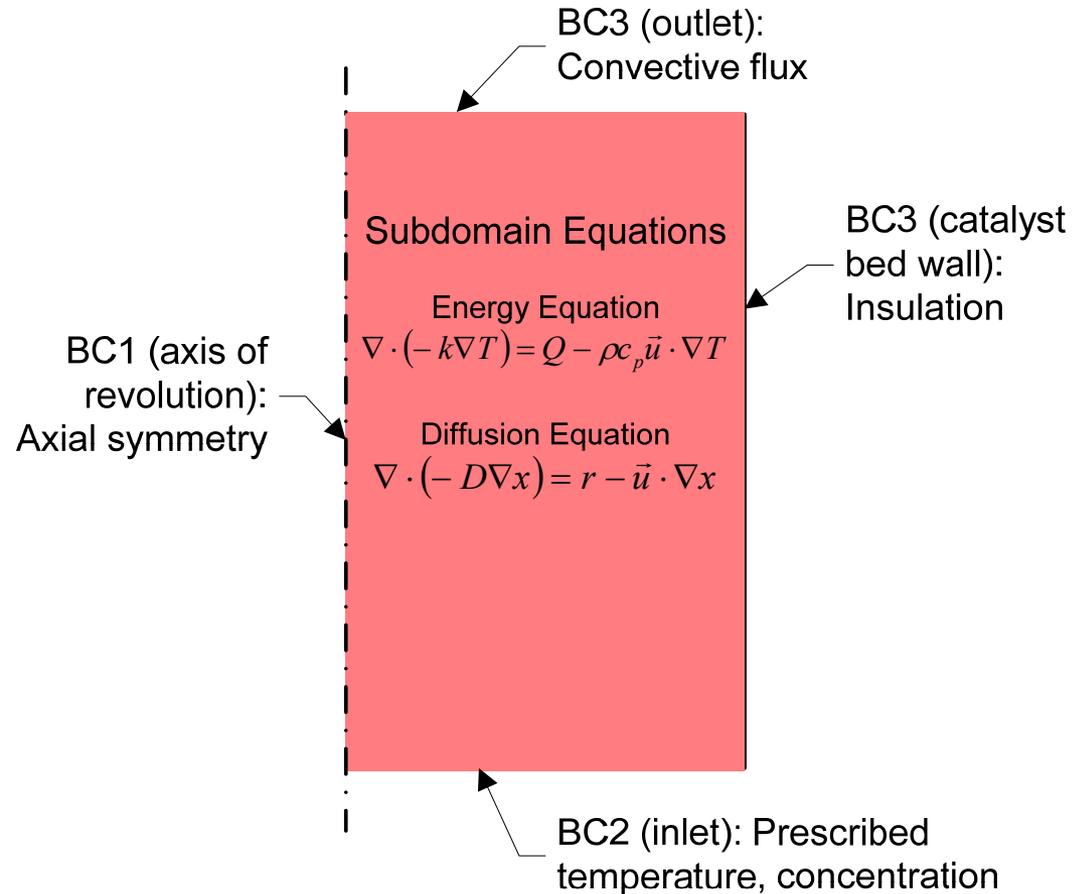
Pilot Plant Performance Simulation	$\eta$ cycle	W net (kWh/kg)
Adiabatic Catalyst Beds	19.76	19.69
Isothermal Catalyst Beds	22.14	17.57
Continuous Catalytic Heat Exchangers	23.33	16.67





# CHEX Simulation Program

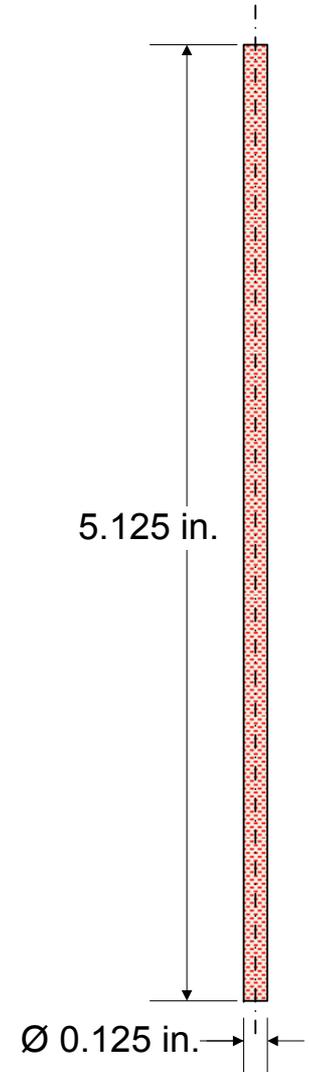
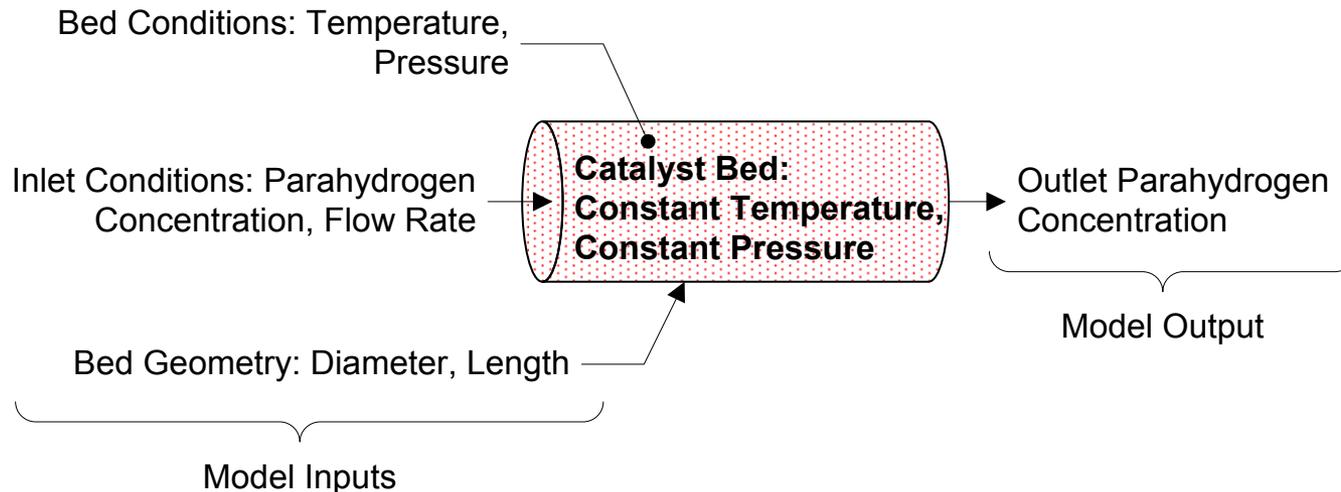
➤ **Developed a Numerical Model Using MATLAB and COMSOL Multiphysics**





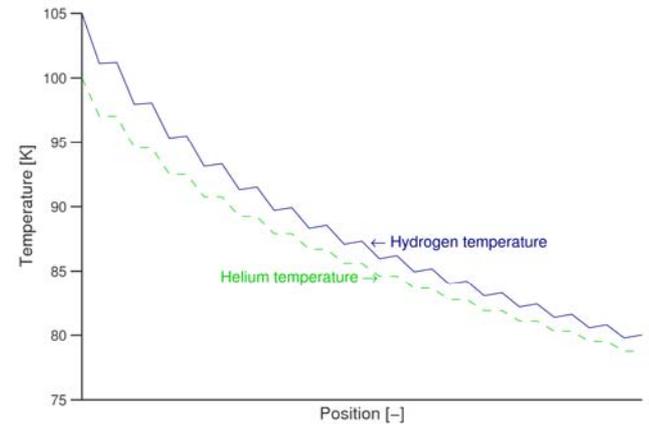
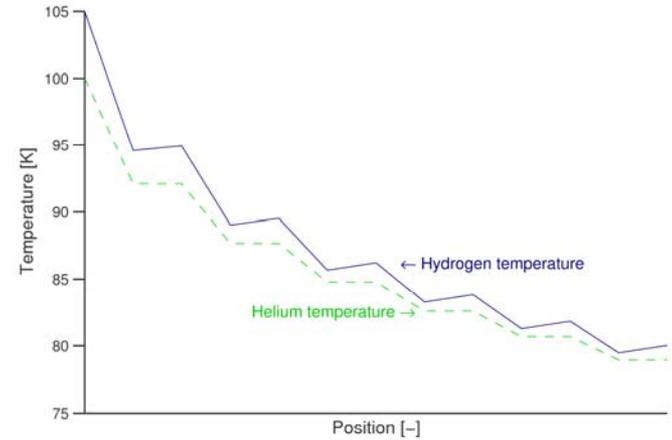
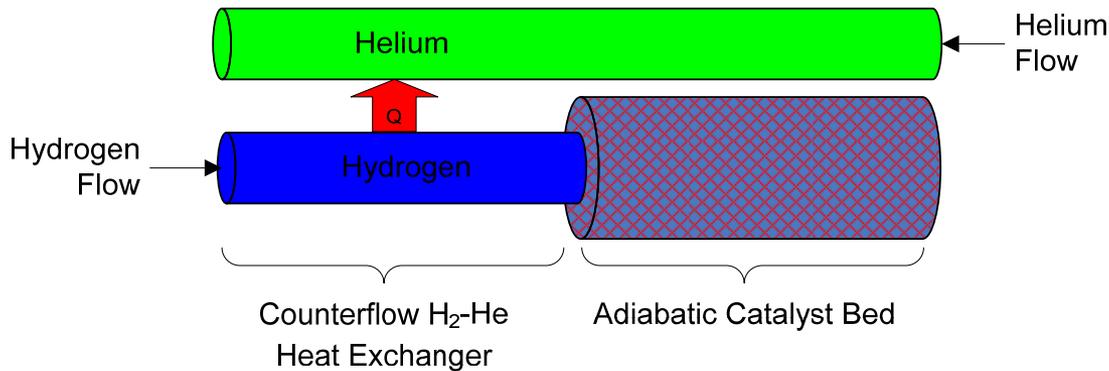
# CHEX Simulation Program

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



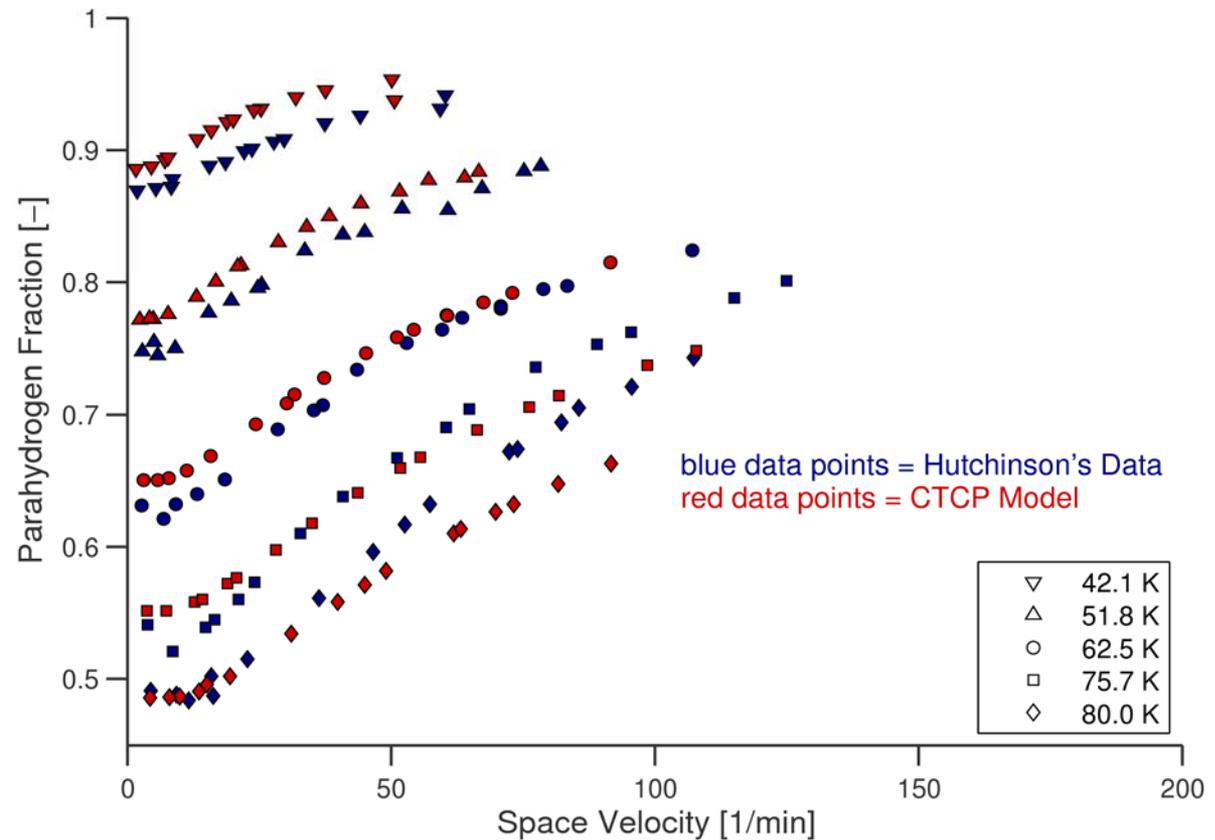
# CHEX Simulation Program

- “Satisfactory” Step Size Identified
- Results Show Pressure Independence

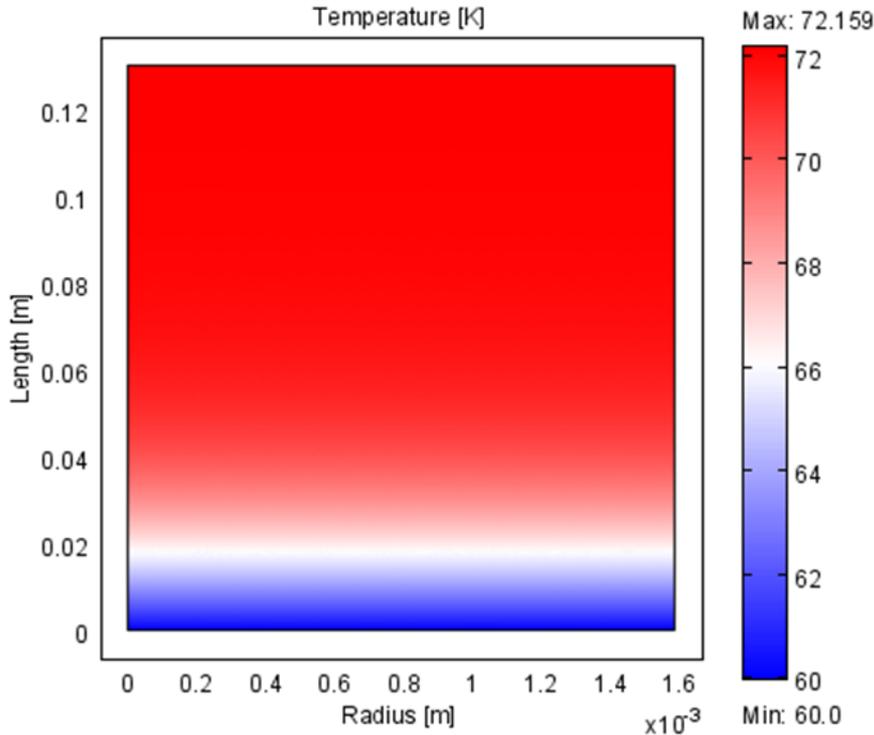


# CHEX Simulation Program

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

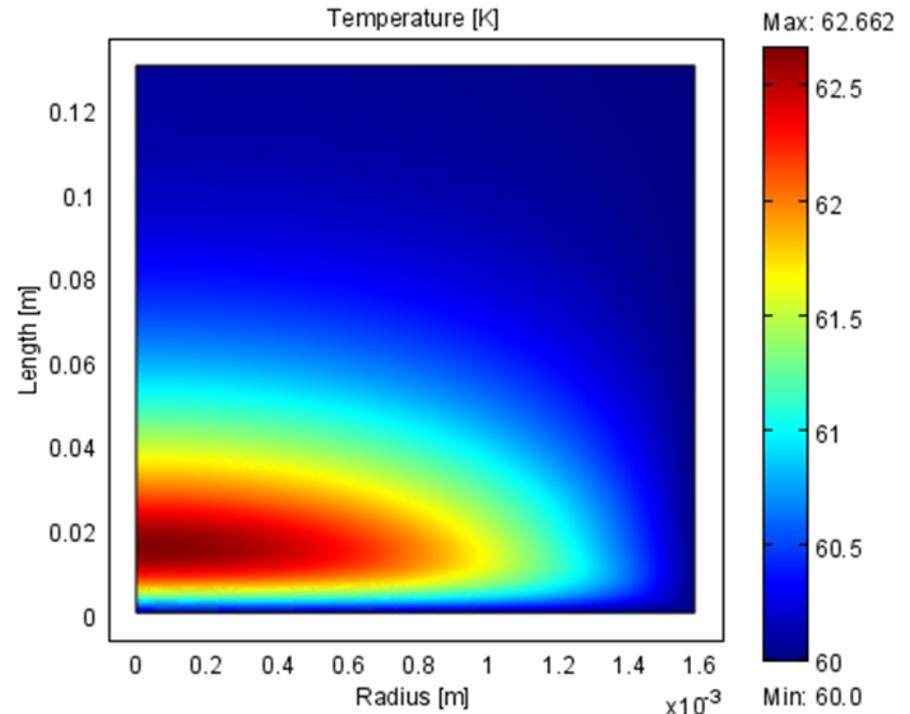


# CHEX Simulation Program Results



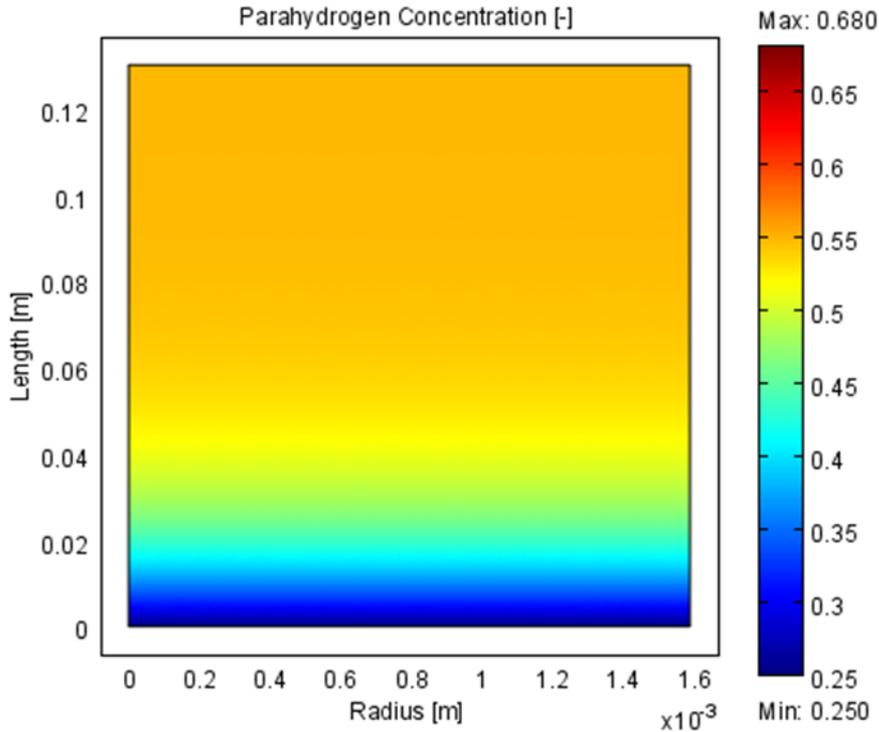
Constant Wall  
Temperature Bed

← Adiabatic Bed



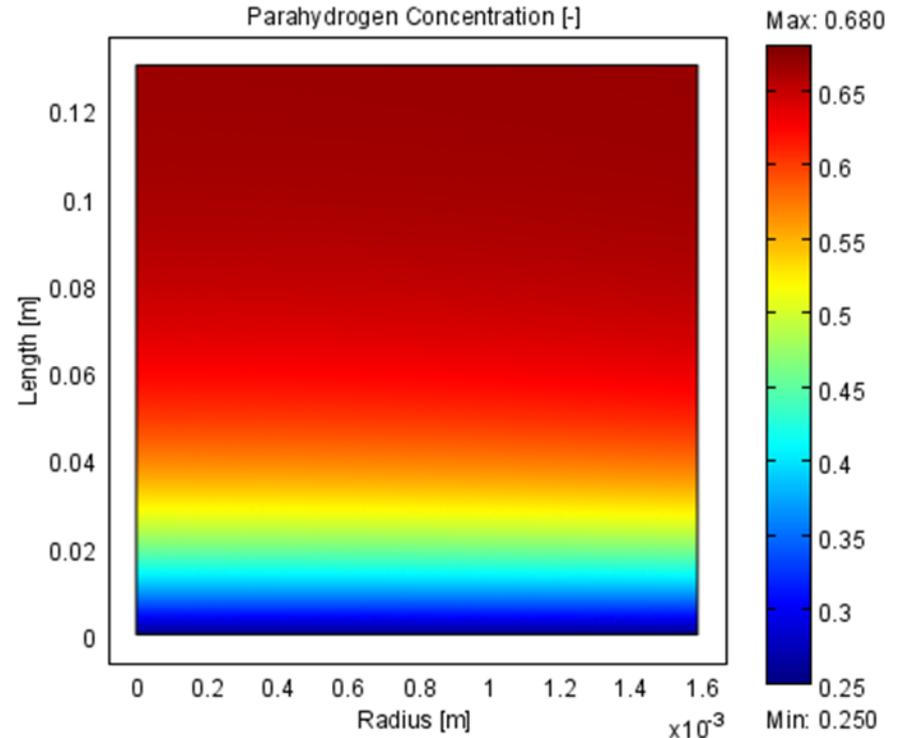


# CHEX Simulation Program Results



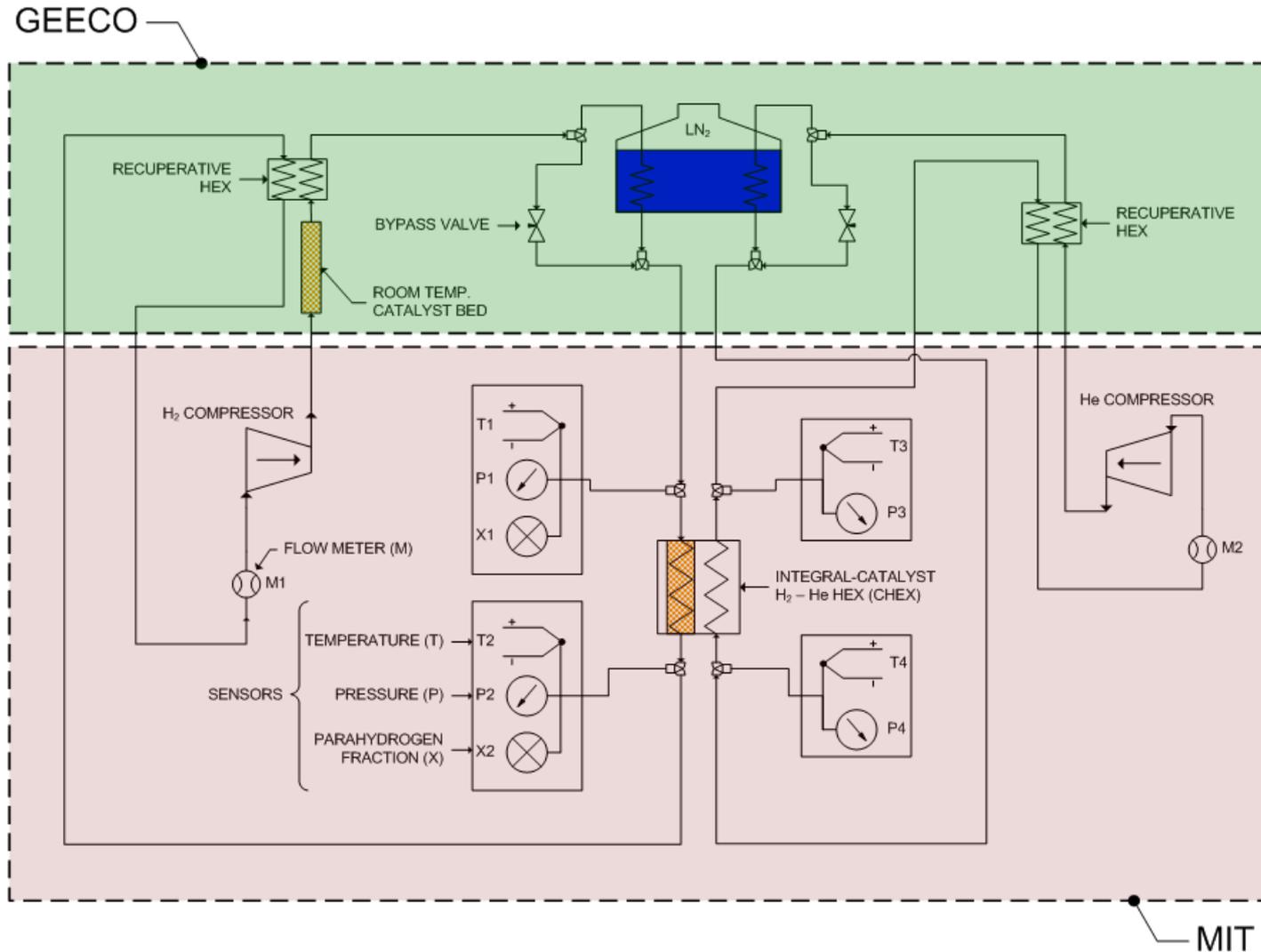
Constant Wall  
Temperature Bed

← Adiabatic Bed





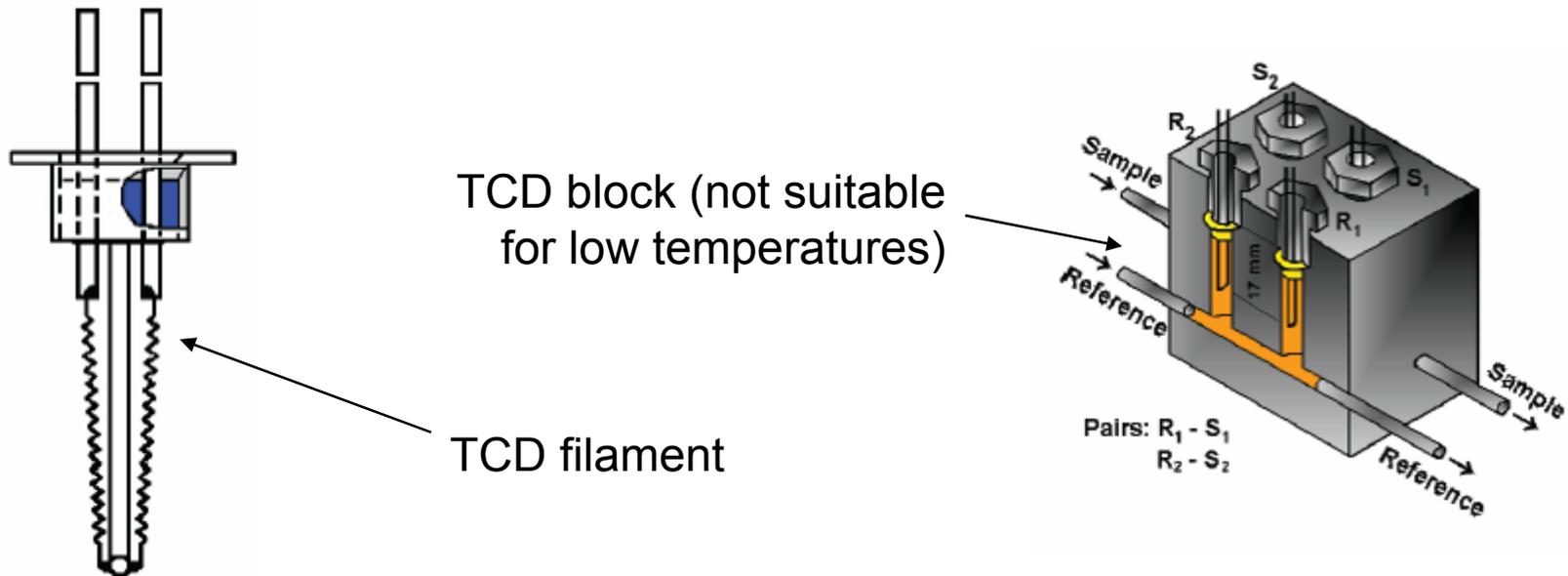
# CHEX Test Apparatus



# 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

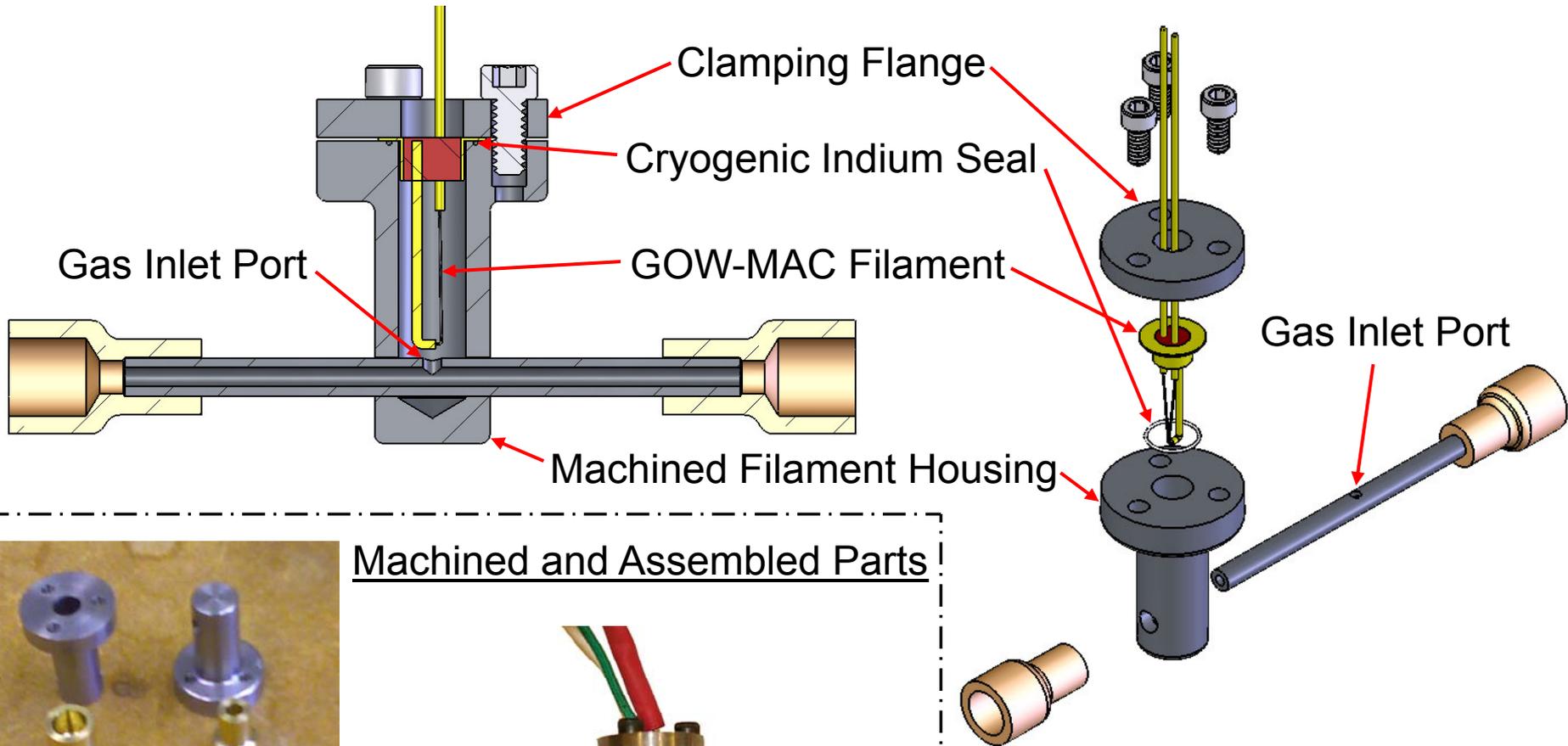
Commercially available TCD components made by GOW-MAC



# pH<sub>2</sub> Detector Assembly

Section View

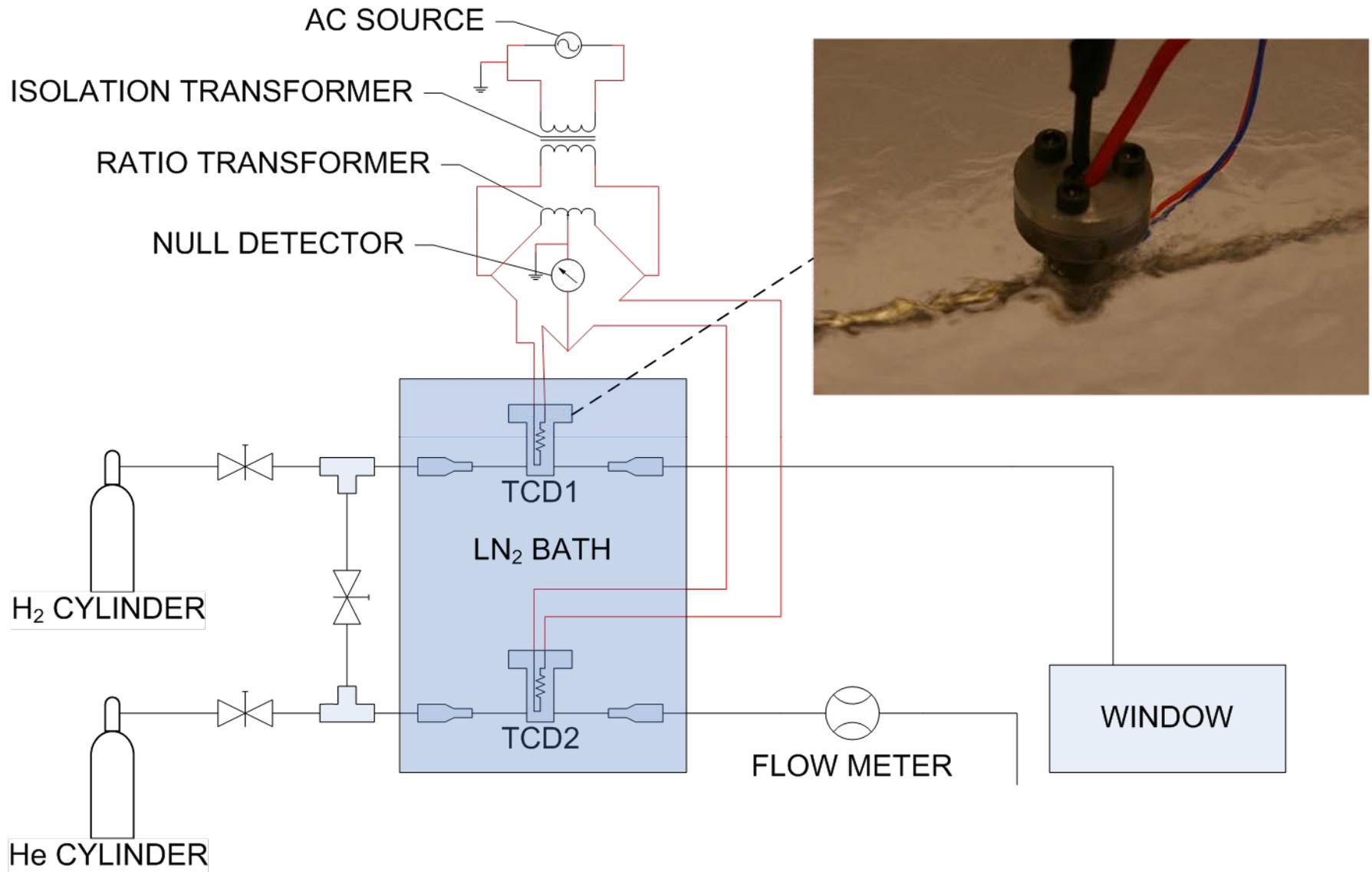
Exploded View



Machined and Assembled Parts

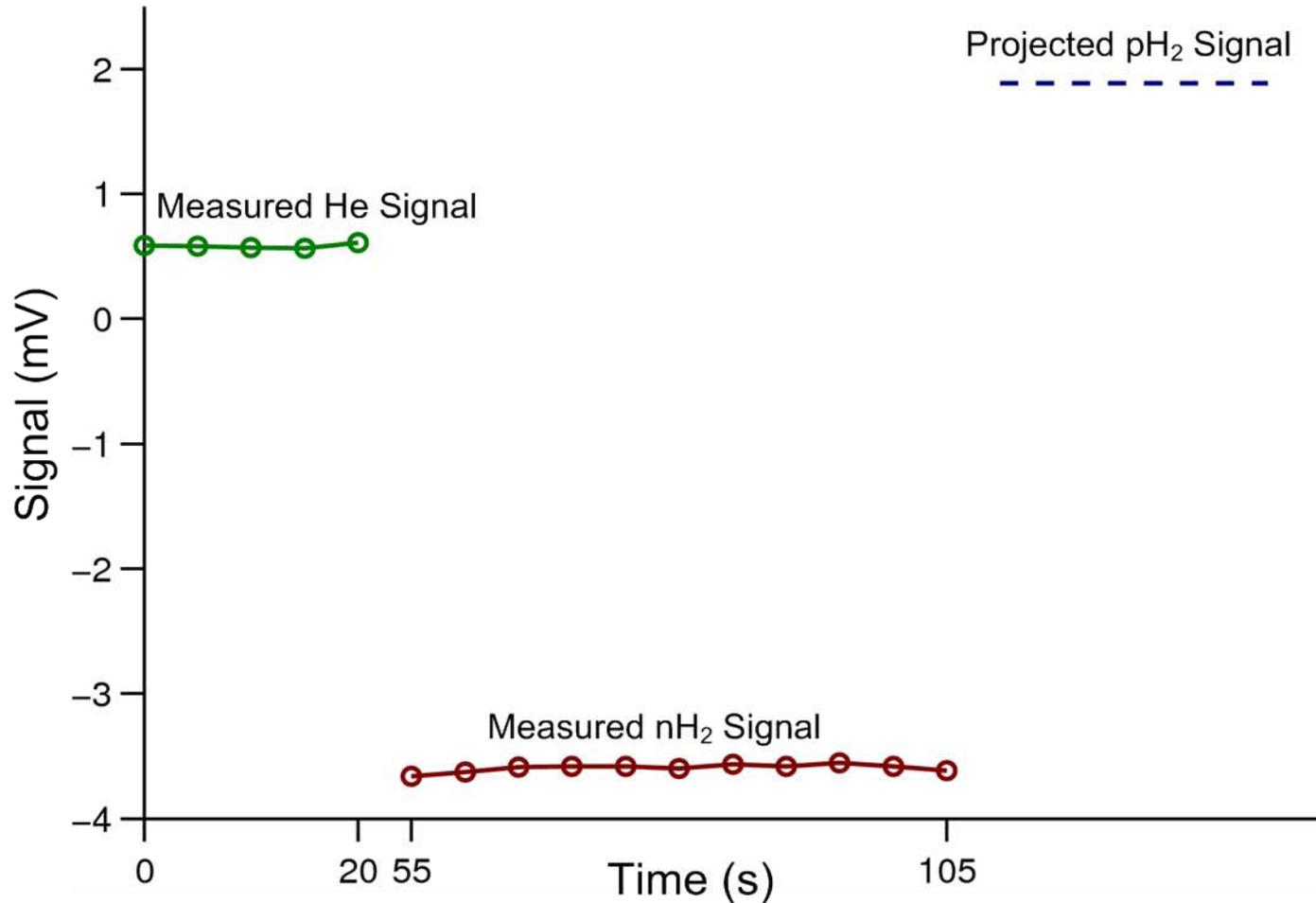


# AC Bridge $p\text{H}_2$ Measurement Configuration



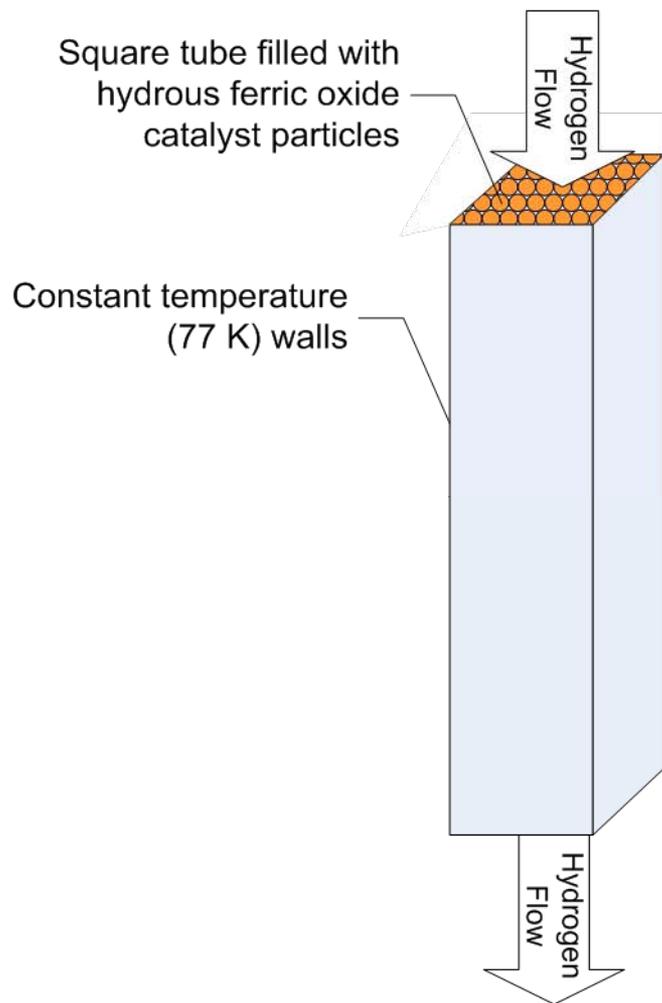
# Sample AC Bridge Results

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

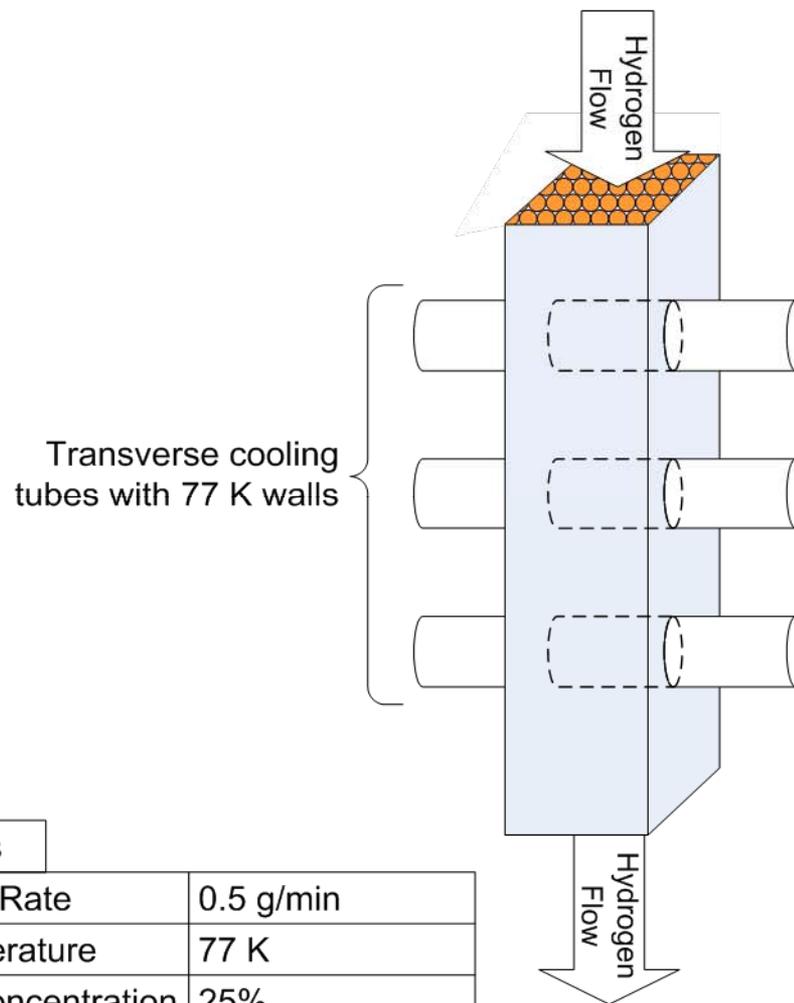


# 2D Packed Bed Models

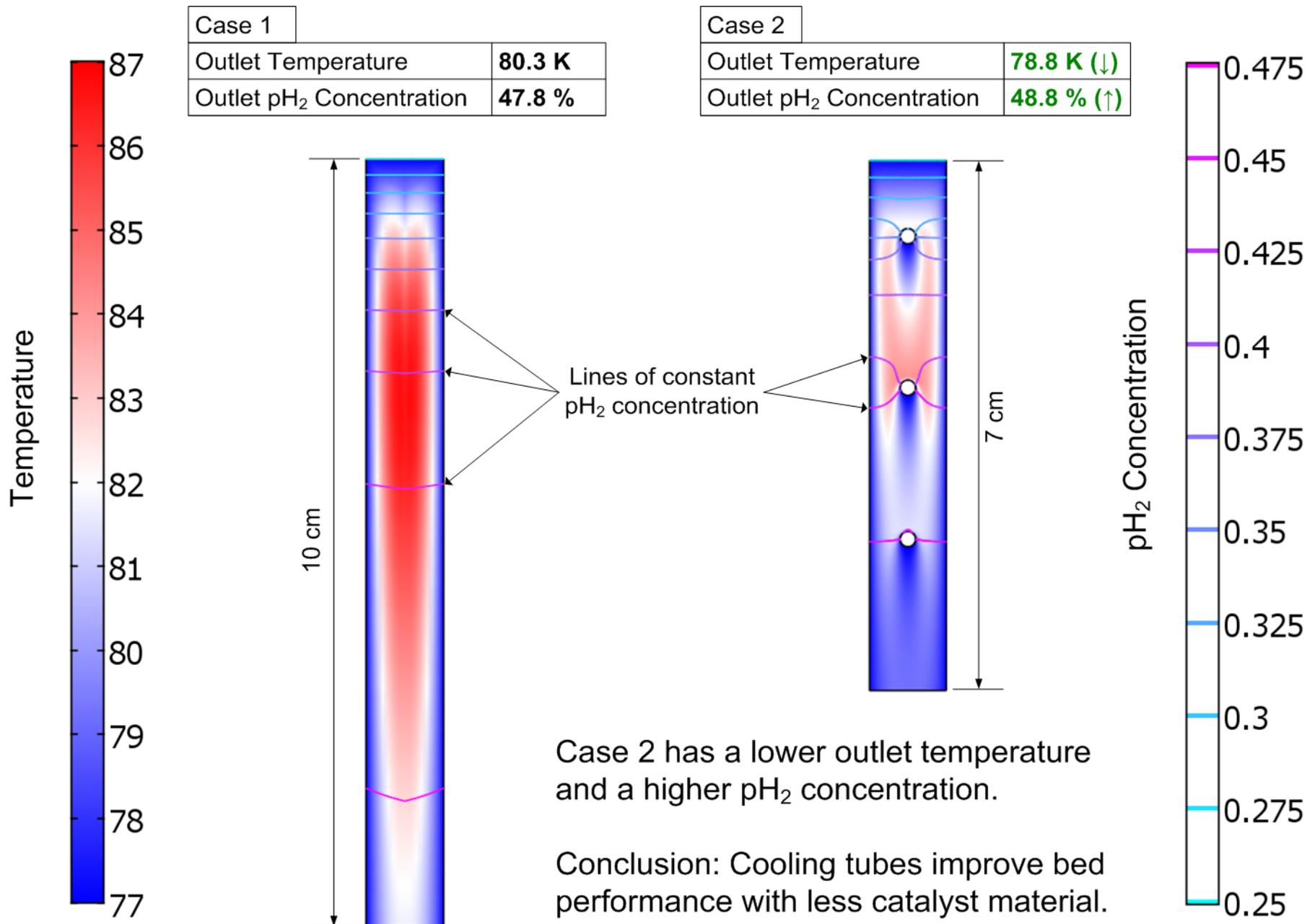
Case 1



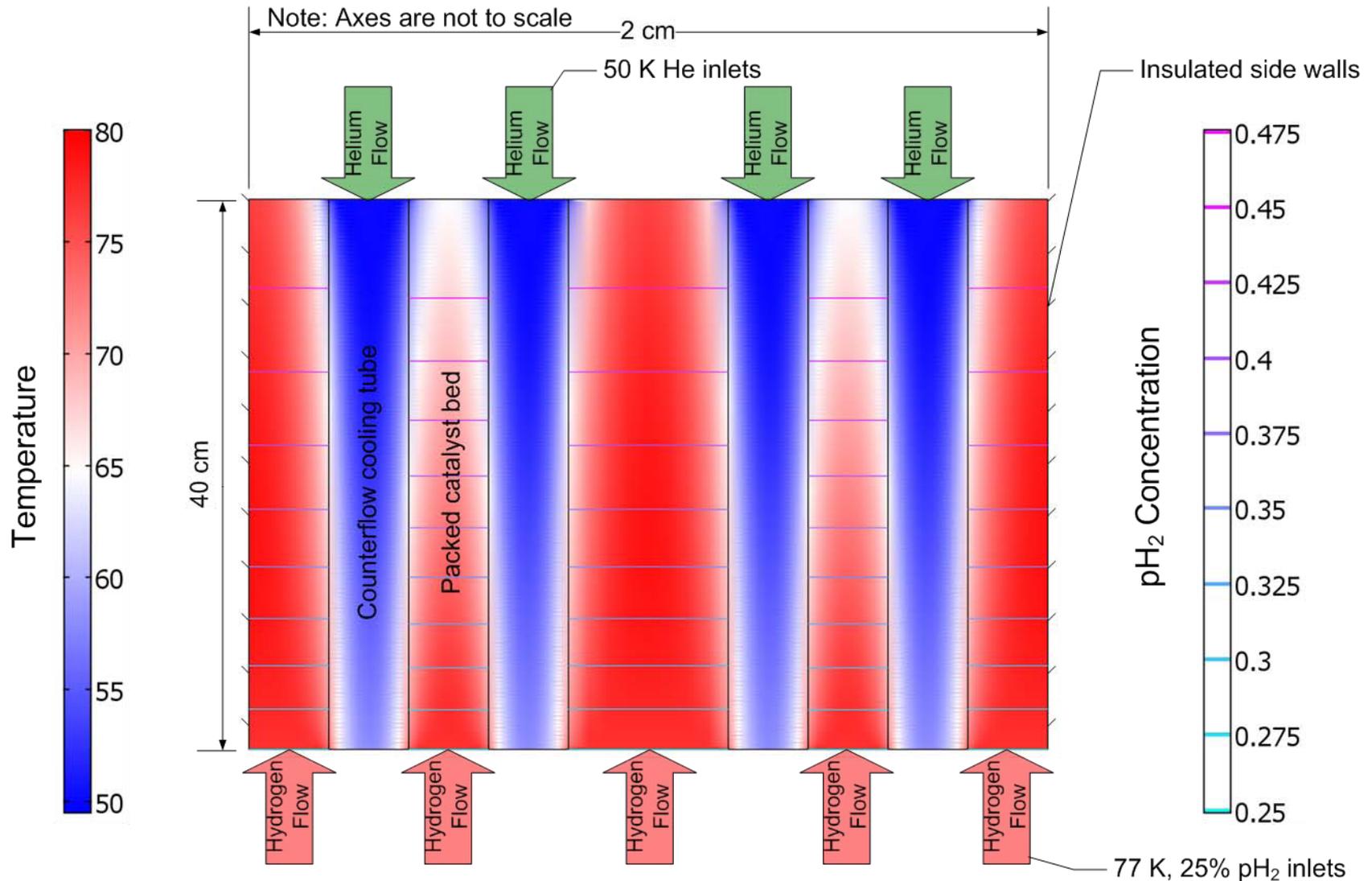
Case 2



Both Cases	
Mass Flow Rate	0.5 g/min
Inlet Temperature	77 K
Inlet $p_{H_2}$ Concentration	25%
Tube Cross Section	1 cm x 1 cm



# 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**