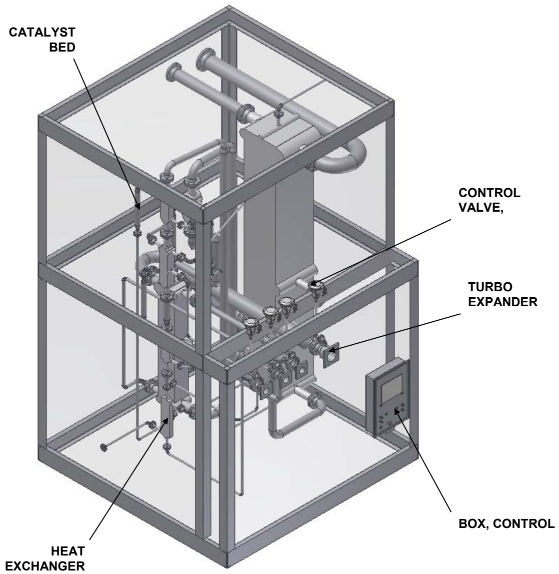
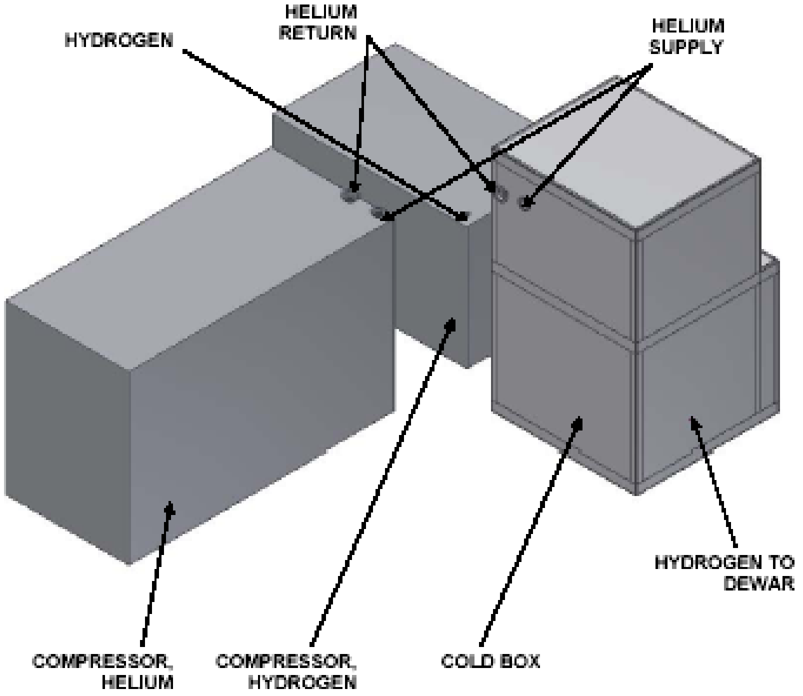
Innovative Hydrogen Liquefaction Cycle





Paul Dunn, Martin Shimko **Project # PD026** **2010 DOE Merit Review**

Gas Equipment Engineering Corporation **June 9, 2009**

H2 Liquefier Development Program

Timeline

Restart Date: Jan 2007
End Date: Sept 2011
Percent Complete: 75%

Budget

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

$161K Received in FY06
$394K Received in FY07
$587K Received in FY08
$475K Received in FY09
$288K Allocated for FY10

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 H2 Liquefaction Cycle That Significantly Increase Efficiencies Over Existing Technologies	Complete
➢ Identify, Design, and Test the Key Component – Continuous Catalytic Heat Exchanger	In-Process
➢ Design a 50,000 kg/day Plant Using Low/No Risk Development Components	Complete
➢ Document a Significant Reduction in the Total Cost of H2 Liquefaction at the 50,000 kg/day Production Level	Complete

Key Results From Earlier Project Work

Designed and Modeled a Once-Through, H2 Liquefaction Cycle

- **Independent He Reverse-Brayton Cooling Loops with Innovative Staging**
- **Catalytic Heat Exchangers**
- **H2 Wet Expander**

30% EFFICIENCY INCREASE OVER PRESENT LARGE SCALE H2 LIQUEFACTION PLANTS

- **From 30% TO 44% OF CARNOT, or**
- **From 9.7 kWh/kg to 7.4 kWh/kg**

SYSTEM "EQUIPMENT" COST ~40% OF H2A ESTIMATE

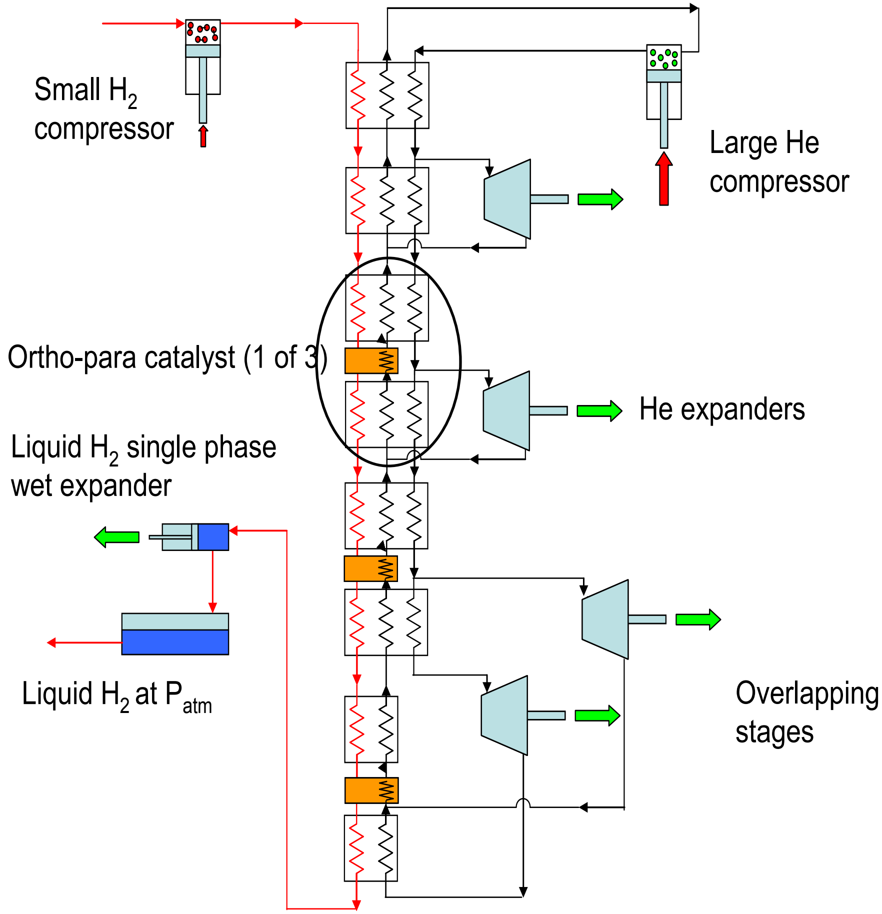
- **Largely Conventional Component Use**
- **Development Risk and Cost Uncertainty Minimized**

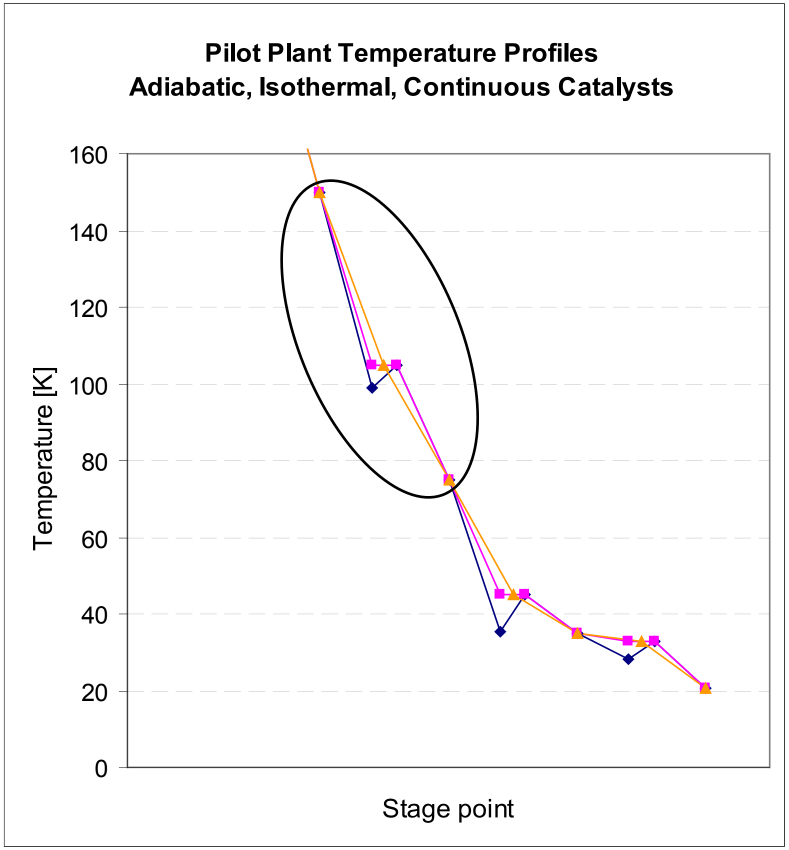
Continuous Catalytic Heat Exchangers Are The Key Undemonstrated System Component

Sub-Scale Pilot Plant Performance Example	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 Selected For Demonstration Testing

Once-Through, H2 Liquefaction Cycle





Selection Enables Cost Effective Testing at Cryogenic Temperatures Using LN2 Cooling

CHEX Testing Goals

- Perform Testing of CHEX at Cryogenic Temperatures
  - Produce a Para-Ortho Measurement Devise For These Temperatures (Completed)
- Build and Test Sub-Scale CHEX
  - Adiabatic Test Article
  - Continuous CHEX
- Validate Model Results
- Demonstrate Practical, Scalable CHEX Design

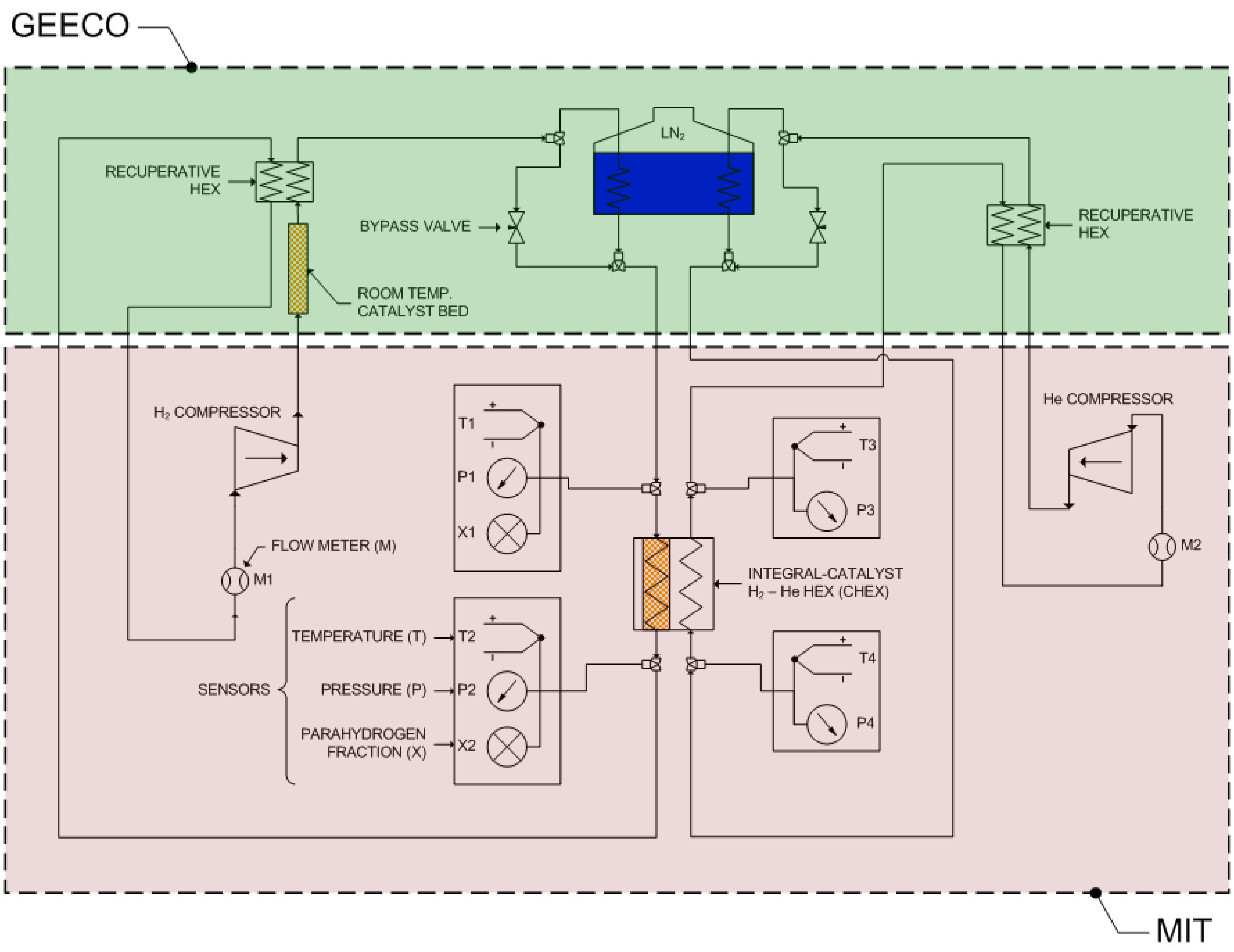
Remaining Project Schedule

<u>Remaining Tasks Revised to:</u>

- Complete the Catalytic Heat Exchanger Demonstration Testing
- Refine the Compressor Design for the 50,000 kg/day System
- Complete Component Development and Produce Full Pilot Plant Demonstration only if Future Funds Allocated

PROJECT TIME LINE	2010							
	May	June	July	Aug	Sept	Oct	Nov	Dec
Design CHEX (Heat Exchanger)	■	■						
Build Test Apparatusand Test Articles		■	■	■	■			
Test Adiabatic Test Article					■	■		
Refine Pilot Plant Design				■	■	■	■	
Test CHEX							■	■
Evaluate and Report								■

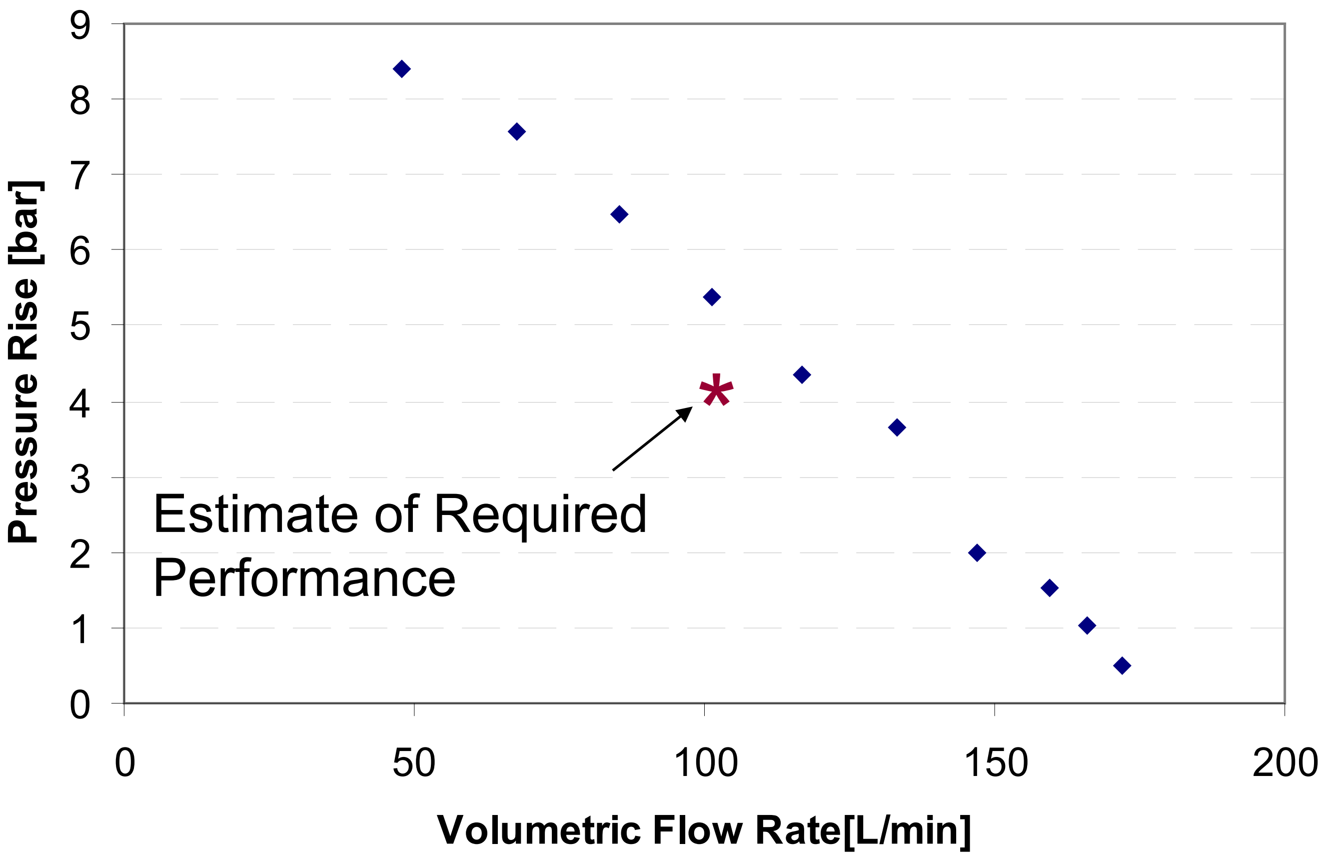
CHEX Test Apparatus



Key Results For Last Year

- Tests Verifying that the Selected Hydrogen and Helium Compressor Will Support the Planned Testing Was Completed
- The CHEX Test Article Configuration and Sizing Was Completed
- The Auxiliary Heat Exchangers for the Test Apparatus Were Designed
- The Test Article “Cold Box” was Designed

He Compressor Test Results



The CHEX Test Article Design Was Completed

Problems with parallel plates…

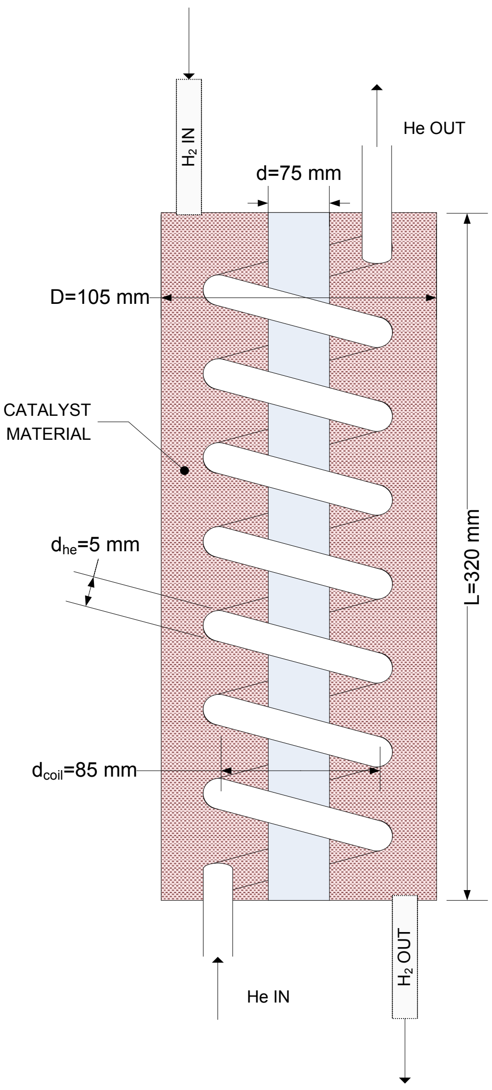
- Difficult to manufacture reliable seals between H2 and He passages
- Maldistribution due to variation in duct width
- Large flat surfaces with large ΔP
- Parallel pathways do not communicate with each other

Solution: Develop tubular design

- equal catalyst volume,
- stream-to-stream surface area, and
- helium stream cross-sectional area

Basic design

- Annular space filled with catalyst
- 8 parallel, helical counter-flow cooling passages (8-start helix)
- Characteristic dimension in catalyst approximately equal to parallel plate design



The Auxiliary Heat Exchangers for the Test Apparatus Were Sized

Sizing the Auxiliary Heat Exchangers

(recuperators for the independent H2 and He loops).

- Choose a desired HX effectiveness
- Calculate required NTU
- Choose an acceptable ΔP/P and determine L and D

Geometry:

Coiled concentric tubes (to fit Dewar)

Results :

<u>H2 Recuperator</u>

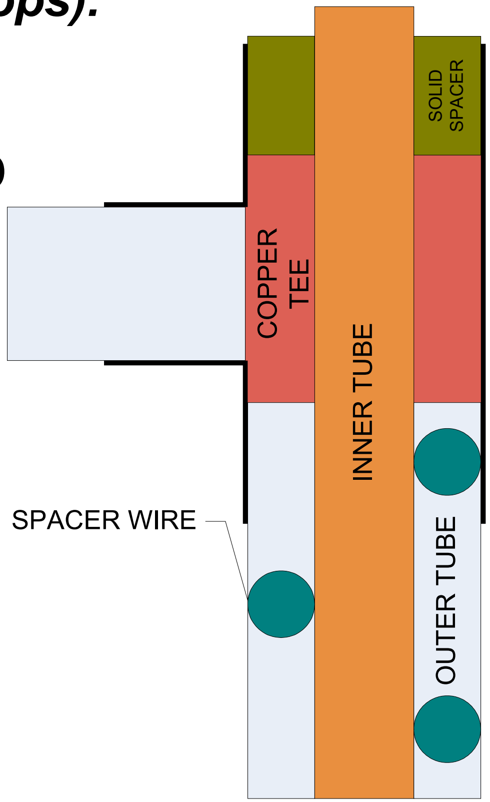
ε=0.85, NTU=4.96, UA=37.9 W/K, ΔP/P=0.01

Din=3.5 mm, Dout=5 mm, L=2.7 m

<u>He Recuperator</u>

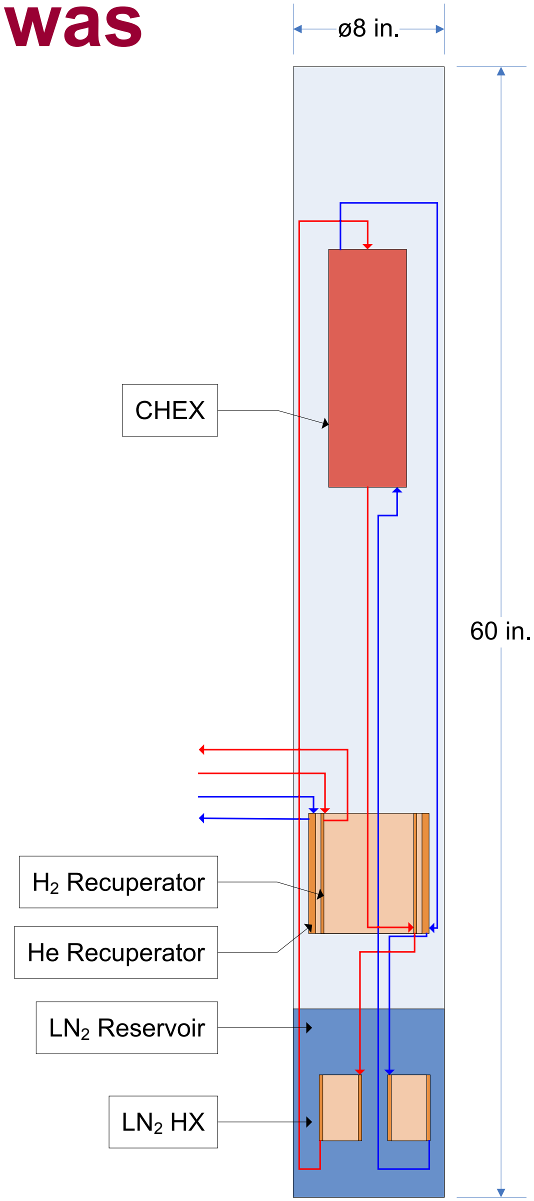
ε=0.75, NTU=3, UA=27.4 W/K, ΔP/P=0.05

Din= 7.4 mm, Dout=10.5 mm, L=3 m



The Test Article "Cold Box" was Designed

- ➢Use Existing Cryostat
- ➢Sized to Accept Cryogenic Recuperators and Heat Exchangers
- ➢Tubing and Instrumentation Will Pass Thru Cryostat Upper Lid



Plan For Remainder of 2009

- Q2 ’10
  - Finish Design and Build of Test Apparatus
  - Build Adiabatic Catalyst Bed
- Q3 ’10
  - Test Adiabatic Catalyst Bed
  - Design and Build CHEX
  - Identify Full Scale Compressor
- Q4 ’10
  - Test CHEX
  - Assess and Report