

# Rapid Low Loss Cryogenic H<sub>2</sub> Refueling

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**Project ID #  
PD074**

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# Overview

## Timeline

- Start date: **October 2009**
- End date: **10/2011\***
- Percent complete: **30%**

## Budget

- Total project funding
  - DOE: **\$1,300k**
- Funding for FY10:
  - **\$300k**
- Funding for FY11:
  - **\$1,000k**

## Barriers

- **J. Refueling site operations**

## Targets

- **2015 refueling efficiency**

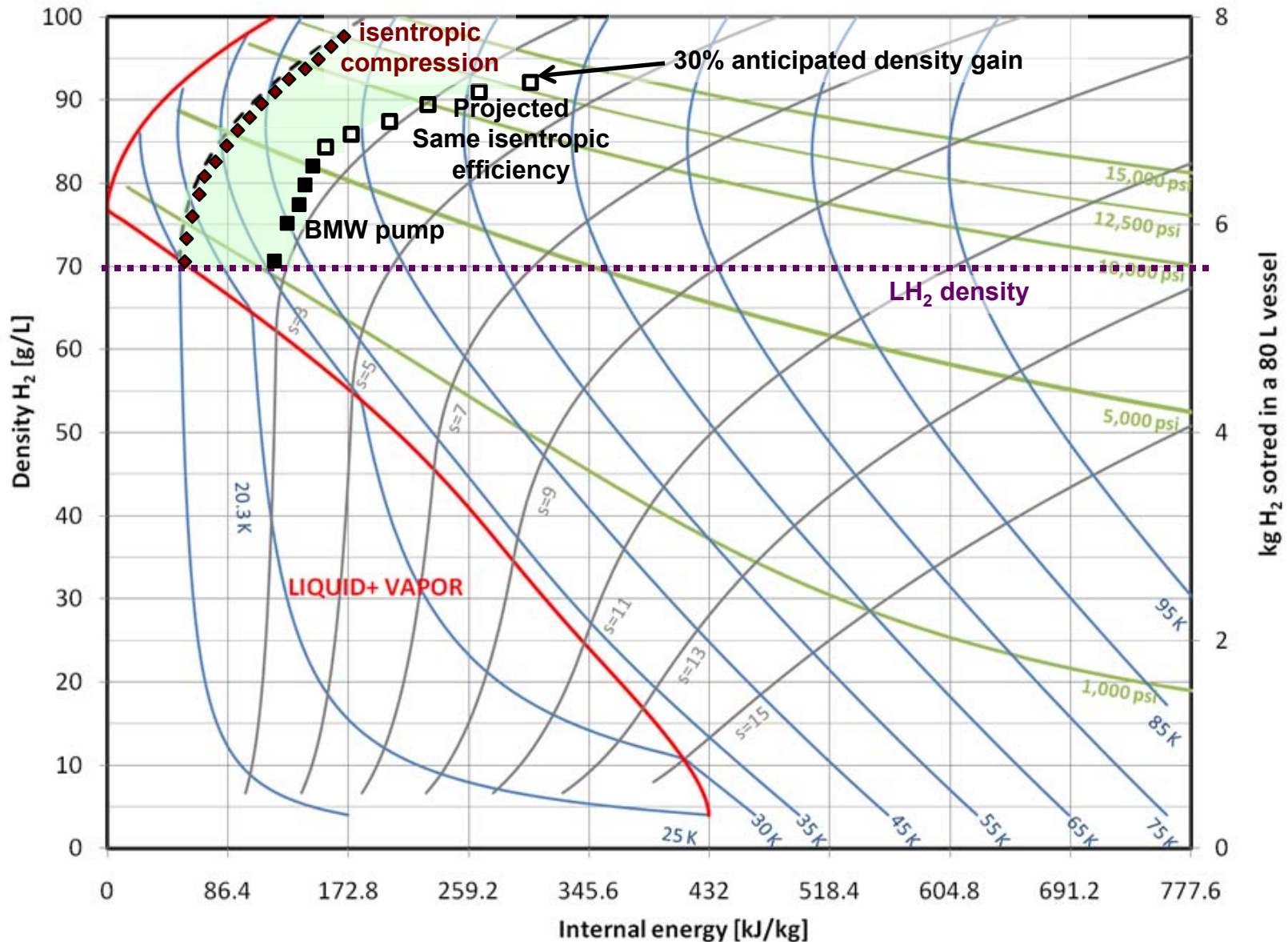
## Partners

- Collaborating with **Linde** and **BMW** to demonstrate practical refueling of cryogenic pressure vessels

\* Project continuation and direction determined annually by DOE



# Relevance: We believe onboard $H_2$ densities above 90 g/L are achievable, increasing hydrogen density by 30% over $LH_2$



# Approach: pressurize LH<sub>2</sub> for rapid refueling of cryogenic vessels with low evaporative losses and pumping power

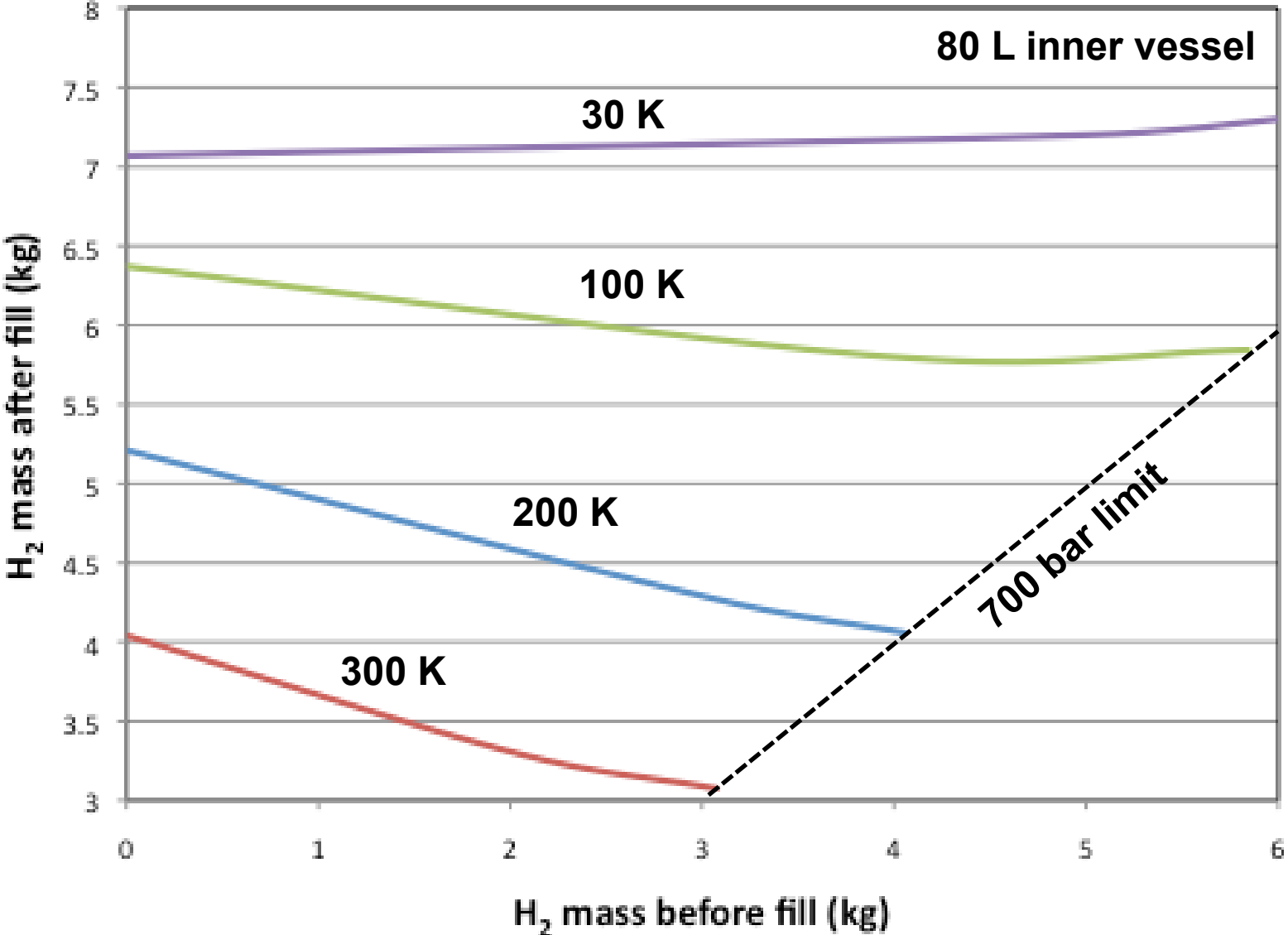


BMW high pressure cryogenic pump

- High LH<sub>2</sub> density minimizes pump power & compression heating
- Pumping power =  $\int \frac{dP}{\rho}$
- Compression heating =  $\frac{P}{\rho}$
- Pressurized LH<sub>2</sub> pump quickly fills even warm and/or pressurized vessels
- Recycled H<sub>2</sub> vapor from pump maintains stationary vessel pressure



# Test matrix: evaluate refuel vessel capacity as a function of initial conditions ( $\rho$ , $T$ of vessel in vehicle pulling into station)

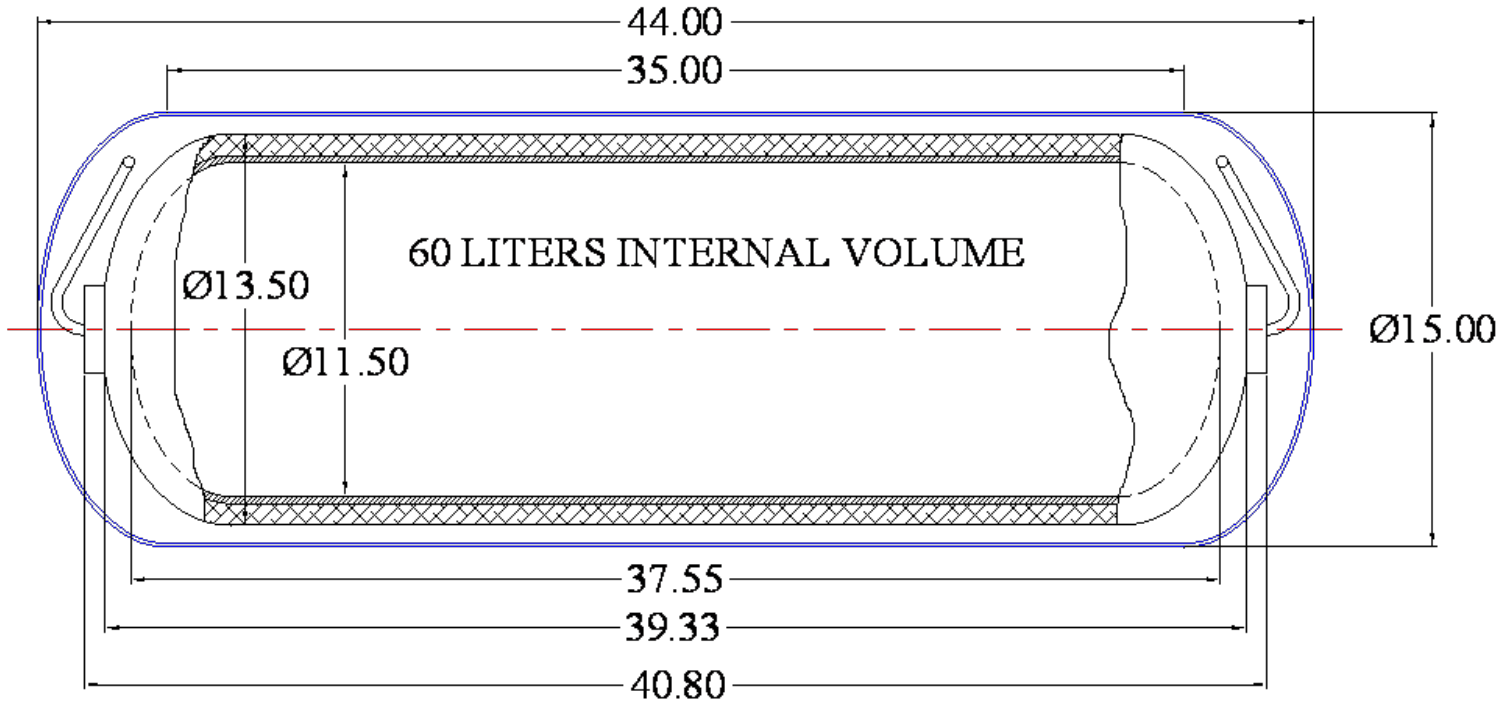


**A 60 L 700 bar cryogenic vessel will be located forward of existing 151 L 350 bar vessel. Fueling both explores scale and transient vs. steady state refueling differences**



# We project 51% volumetric efficiency for 60 L & 700 bar cryogenic vessel design with aspect ratio ~3

118.7 LITERS EXTERNAL VOLUME



- **Simpler high pressure operation with single inlet/outlet line**
- **Measure  $H_2$  temperature in addition to vessel, piping and jacket temperatures** by inserting silicon diodes in vessel
- **Second independent capacity measurement** by weighing vessel ideally *during* refueling
- **Aluminum jacket material** to improve weight, capacity measurement, and thermal uniformity



## Collaborations: We are working with two major companies in the field of cryogenic hydrogen storage and dispensing

- ***Linde:*** Extensive expertise on cryogenics and liquid hydrogen automotive systems. Supplier of high pressure cryogenic pump. Delivered first ever system to BMW last year. Planning a custom design for the experimental needs of LLNL.
- ***BMW:*** Long standing collaboration with LLNL through cryogenic pressure vessel technology CRADA. Demonstrating first prototype cryogenic pump technology. Contributing technical information and expertise.





**Future work: we will combine  
a high pressure LH<sub>2</sub> pump & lighter, smaller vessel  
with a comprehensive experimental strategy**

- ***Rapid low loss refueling at higher density*** up to 880 bar, 90 gH<sub>2</sub>/L
- ***Simpler high pressure operation*** with *single* inlet/outlet line
- ***Realistic (warm) refueling conditions:*** partially full, <99% para H<sub>2</sub>
- ***Measure H<sub>2</sub> temperature in addition to vessel, piping and jacket temperatures*** by inserting silicon diodes in vessel
- ***Second independent capacity measurement*** by weighing vessel ideally *during* refueling
- ***Aluminum jacket material*** to improve weight, capacity measurement, and thermal uniformity



# Summary: LLNL will measure real-time cryogenic refueling parameters (P,T) for actual scale (60 L) vessels under full range of drive-up conditions (20-300 K, 0-100% full)



## *700 bar cryogenic H<sub>2</sub> vessel*

- 75 kg system (Al vacuum jacket)
- 5+ kg usable H<sub>2</sub> capacity



## *880 bar LH<sub>2</sub> pump*

- Rapid single phase refueling
- Target fuel density 90+ gH<sub>2</sub>/L

