

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

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This presentation does not contain any proprietary or confidential information

**Project ID #  
PD074**



# Overview

## Timeline

- Start date: **October 2009**
- End date: **September 2011**
- Percent complete: **10%**

## Budget

- Total project funding
  - DOE: **\$300k**
- Funding for FY09:
  - **\$0**
- Funding for FY10:
  - **\$300k**

## Barriers

- **J. Refueling site operations**

## Targets

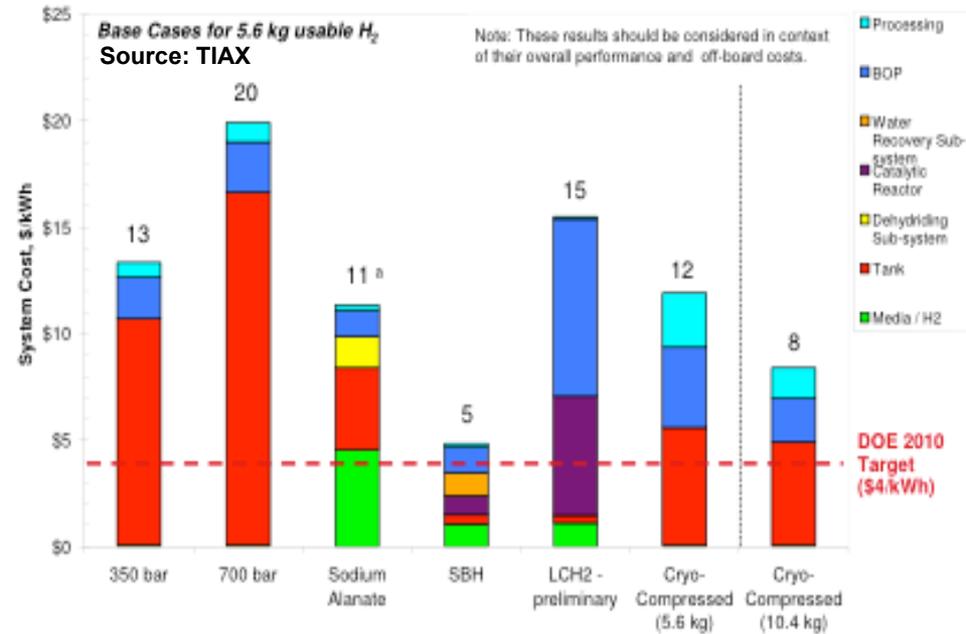
- **2015 refueling efficiency**

## Partners

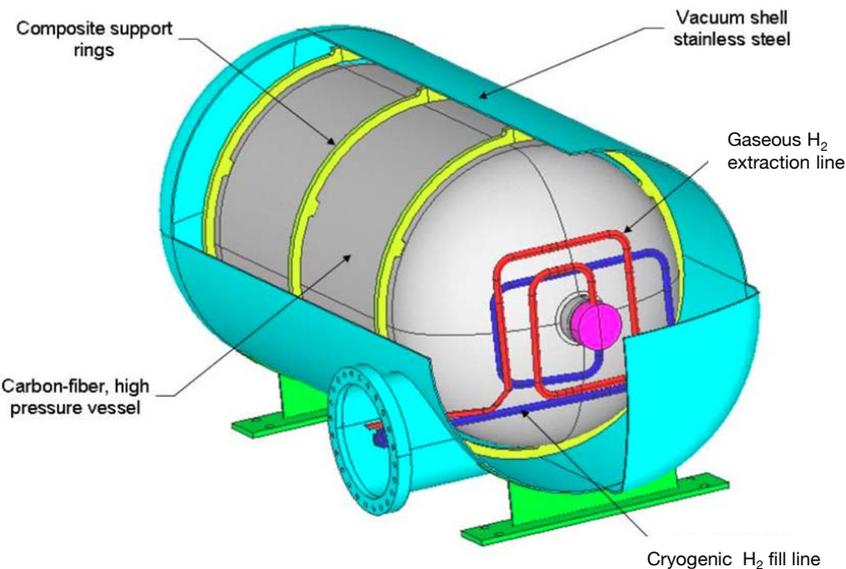
- Collaborating with **Linde** and **BMW** to demonstrate practical refueling of cryogenic pressure vessels



# High density cryogenic hydrogen enables compact, lightweight, and cost effective storage



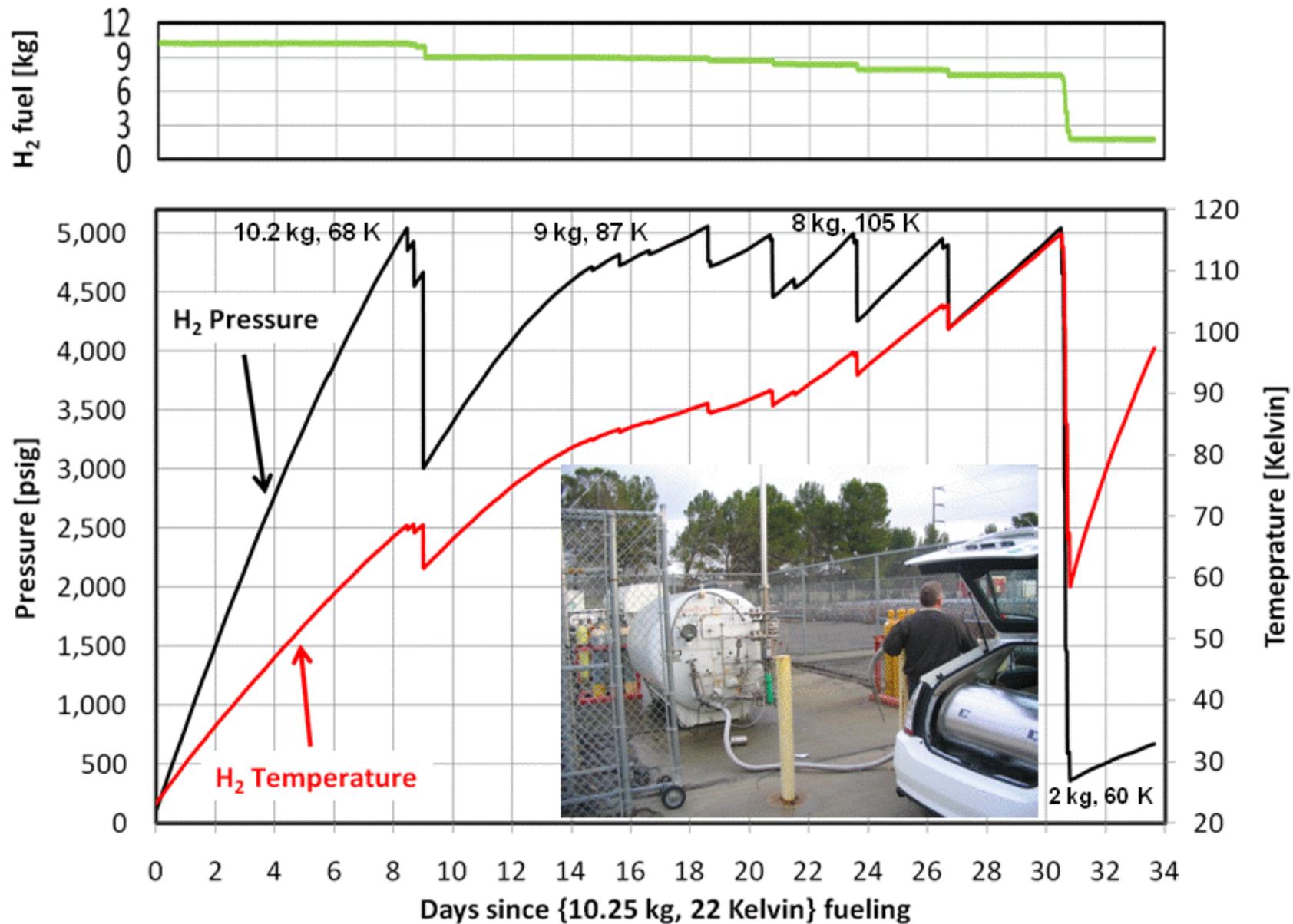
- **Cost effective:** Cryogenic vessels use 2-4x less carbon fiber. Substantial cost reduction with high capacity.



- **Compact:** 235 L system holds 151 L fuel (10.3-10.7 kg H<sub>2</sub>)



# Relevance: reducing or eliminating onboard evaporative losses results in vessel warming requiring pressurized refueling



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

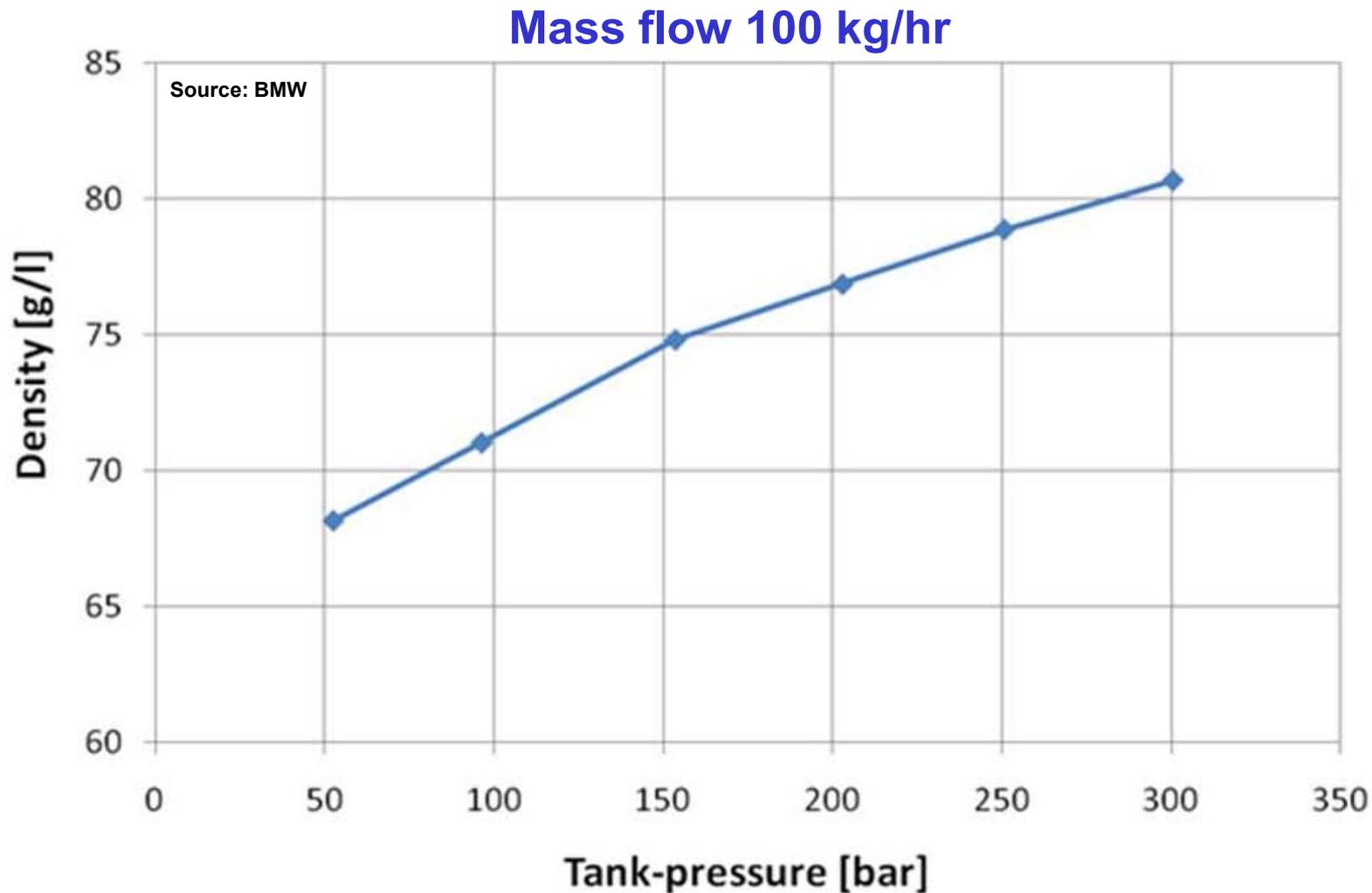


- High LH<sub>2</sub> density minimizes pump power & compression heating
- Pumping power =  $\int \frac{dP}{\rho}$
- Compression heating =  $\frac{P}{\rho}$
- Pressurized LH<sub>2</sub> pump quickly fills even warm and/or pressurized vessels
- Recycled H<sub>2</sub> vapor from pump maintains stationary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

BMW high pressure cryogenic pump



# Pressurized LH<sub>2</sub> pump delivers high density hydrogen (>70 kgH<sub>2</sub>/m<sup>3</sup>) at rapid flow rates



Room for improvement to even higher density  
via after-cooling of pressurized LH<sub>2</sub>



# Pressurized LH<sub>2</sub> refueling does not require compressor, cascade, or refrigerator; reducing station capital cost



700 bar dispensing



Refrigeration



Cascade Charging



Compression



Storage

Source: Argonne National Laboratory



35-350 bar LH<sub>2</sub> dispensing

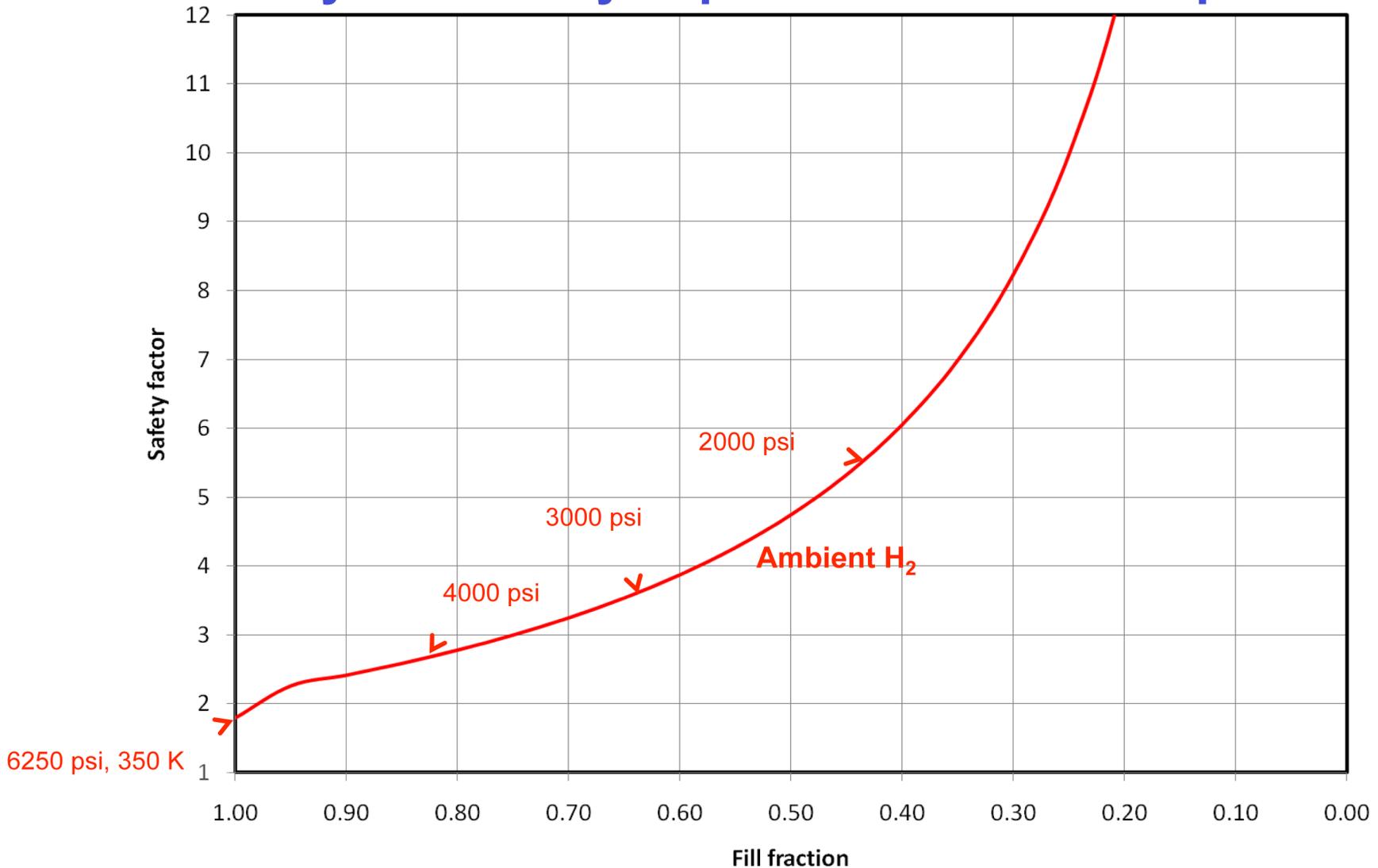


Dewar

Pump



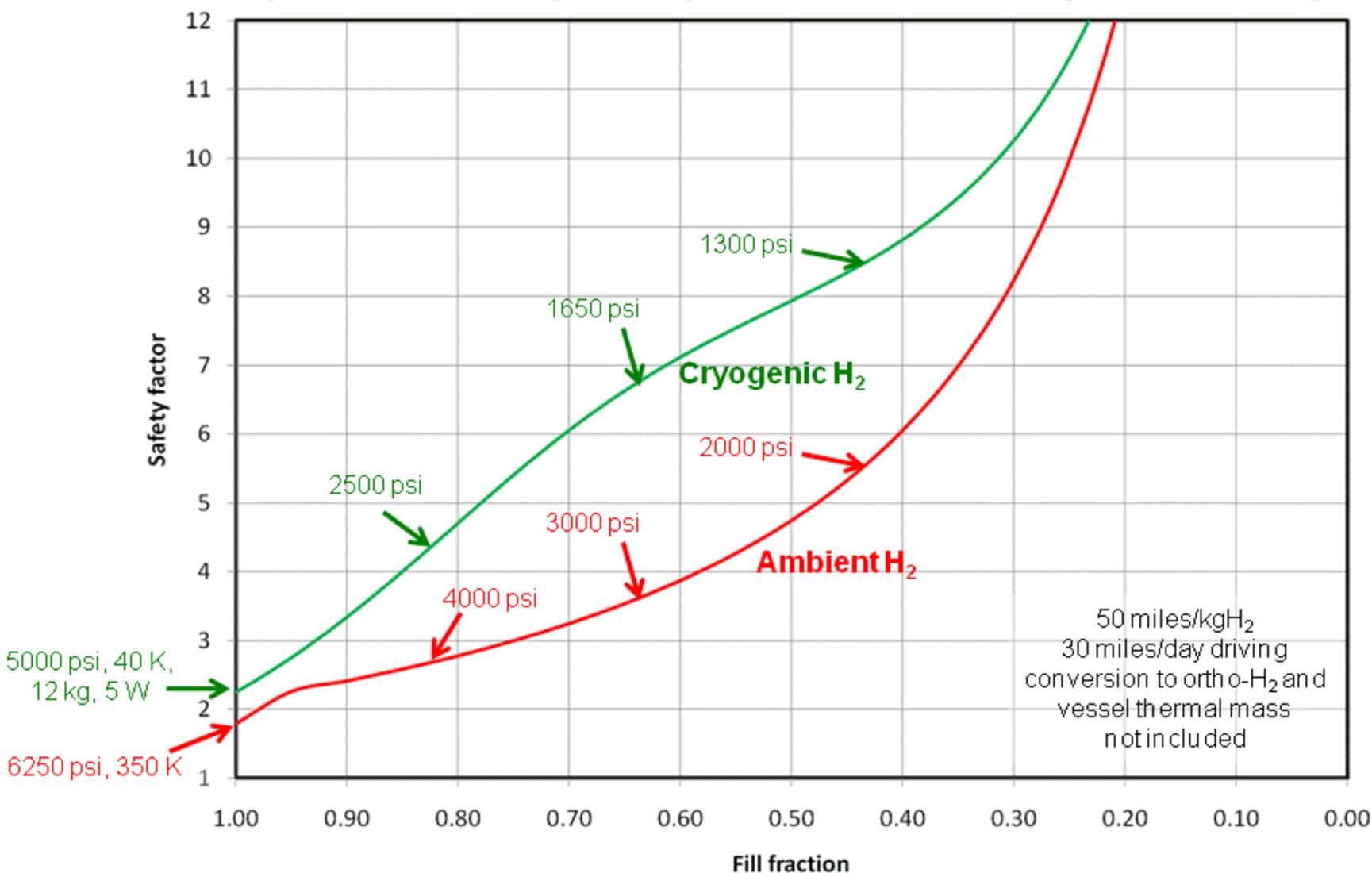
# Ambient vessels store H<sub>2</sub> always at high temperatures safety factor only improves as vessel empties



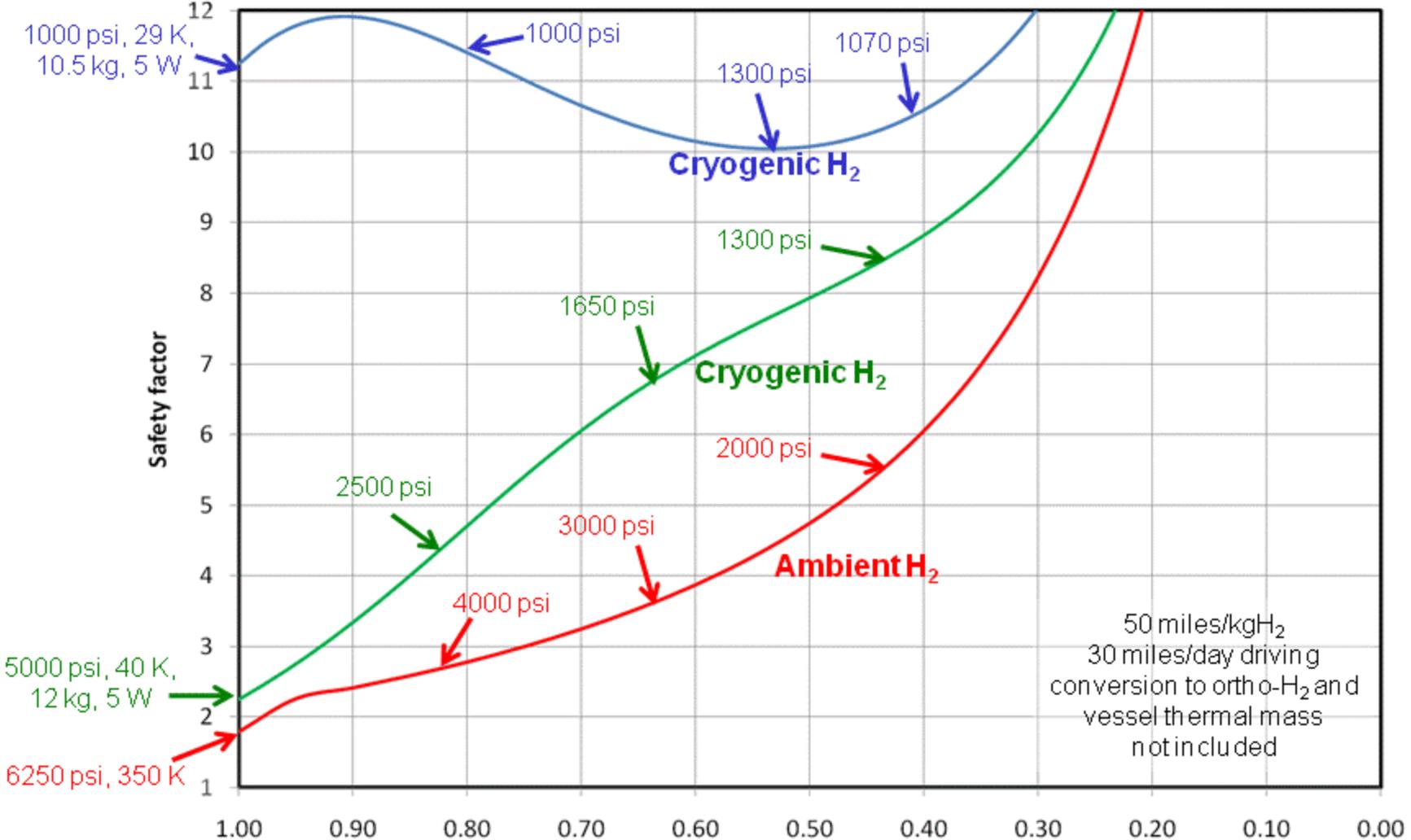
- Compressed gas vessels reach *maximum* pressure every refueling



# Even when filled to $80 \text{ kg/m}^3$ , cryogenic pressure vessels depressurize quickly due to isentropic cooling

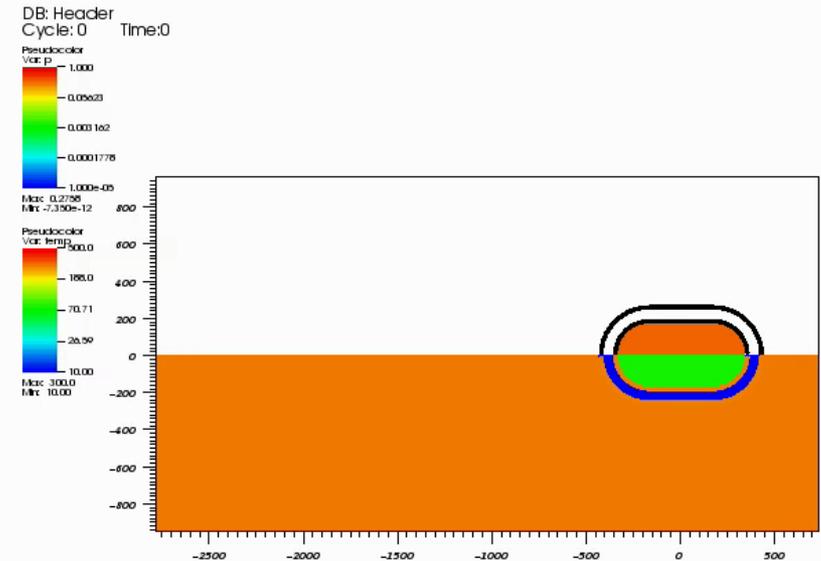
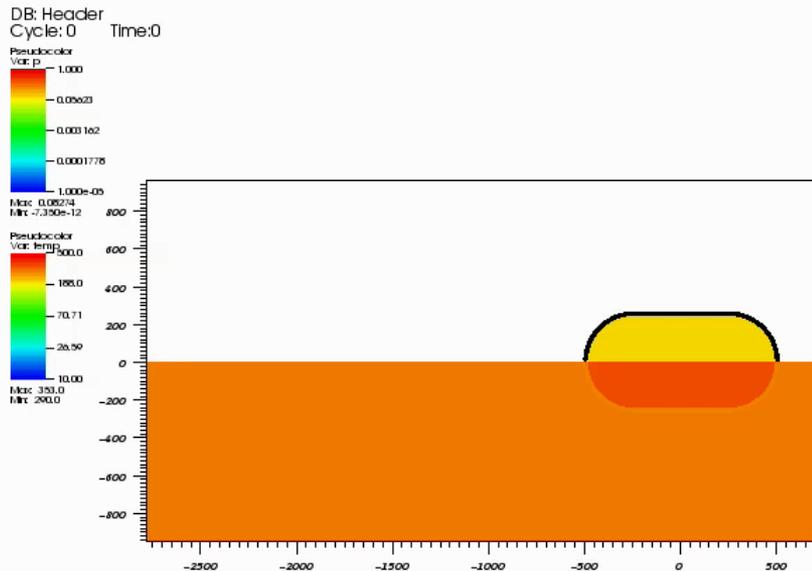


# Refueling and on-road safety factors of cryogenic vessels can be very high with typical driving



- **Refueling safety factor of 10+** cold fill may not need maximum pressurization
- **Potentially fewer maximum pressure cycles** reduces liner fatigue
- **On-road safety factor of 10+** due to cooling from regularly driven vehicles

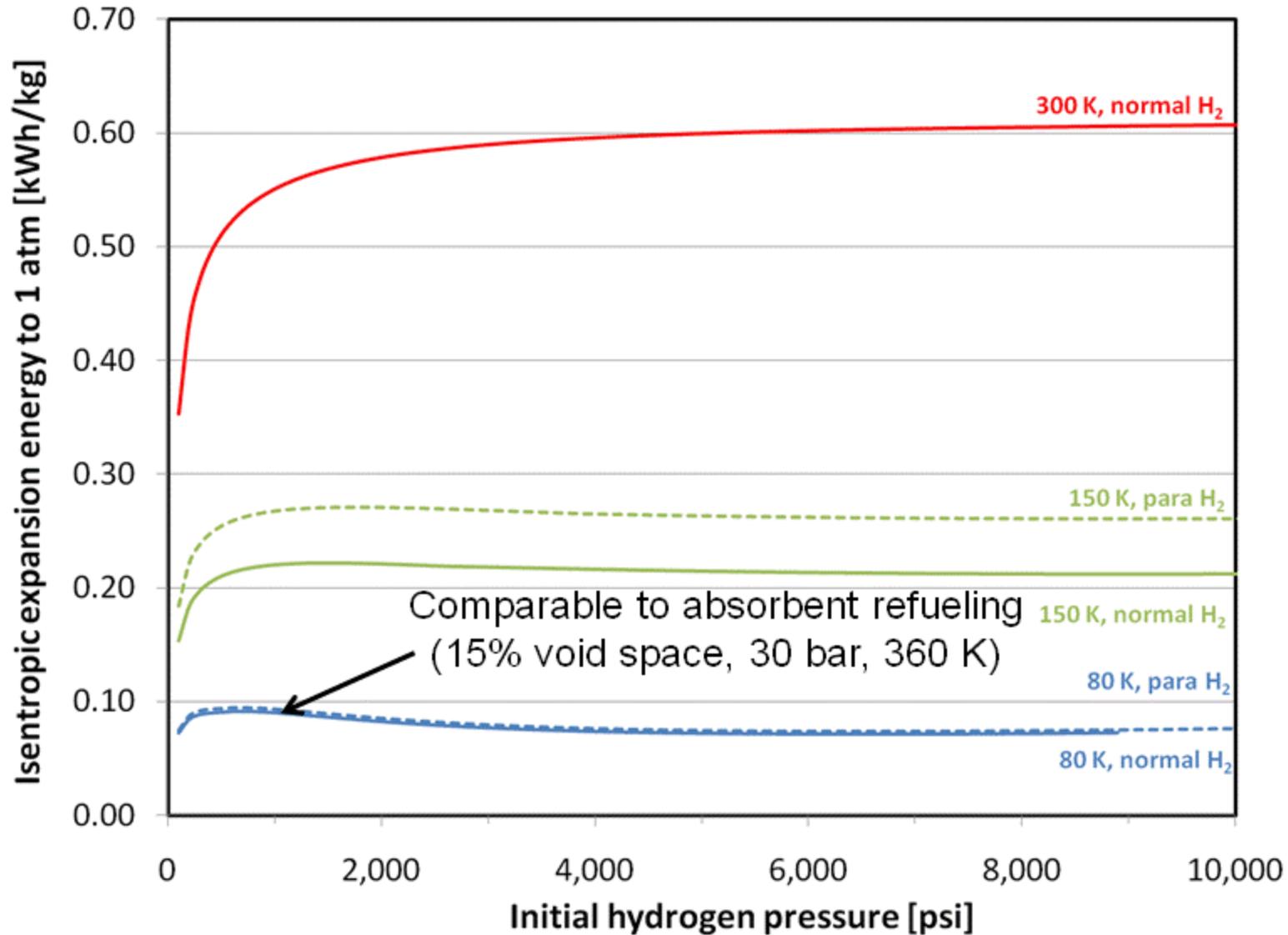
# Steel vacuum jacket offers an inert vessel environment, strong secondary protection, and expansion volume



6 kg H<sub>2</sub>, 12,500 psi, 350 K,  $\rho=40.5 \text{ kg/m}^3$

6 kg H<sub>2</sub>, 2200 psi, 80 K,  $\rho=40.5 \text{ kg/m}^3$

# Cryogenic operation substantially reduces expansion energy



**H<sub>2</sub> temperature, not pressure,  
controls theoretical maximum burst energy**



# **Future work: we will acquire a cryogenic pump and demonstrate pressurized cryogenic refueling**

- **Purchase and install a pressurized cryogenic pump**
- **Demonstrate rapid refueling of (even warm) cryogenic pressure vessels with low evaporative losses**
- **Explore effect of higher pressure on evaporative losses, refueling speed and maximum vessel capacity**



## 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.



# Summary: We look forward to demonstrating practical cryogenic pressure refueling with low evaporative losses

- ***Rapid, low loss refueling*** of cryogenic vessels is possible through pressurized LH<sub>2</sub> dispensing
- ***Reduce station cost*** by avoiding compressor, cascade, and refrigerator
- ***Improved safety*** of cryogenic pressure vessels is expected from fundamental thermodynamics: cryogenic operation minimizes expansion energy and maximizes safety factor (>10 under typical operating conditions)

