Rapid Low Loss Cryogenic H_2 Refueling

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Project ID # PD074

This presentation does not contain any proprietary or confidential information

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**

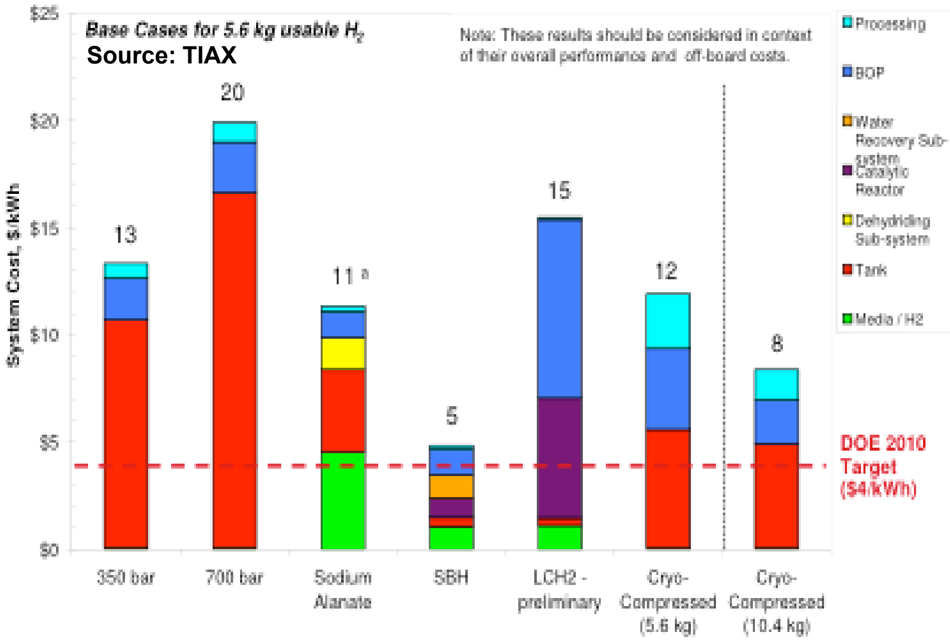
Targets

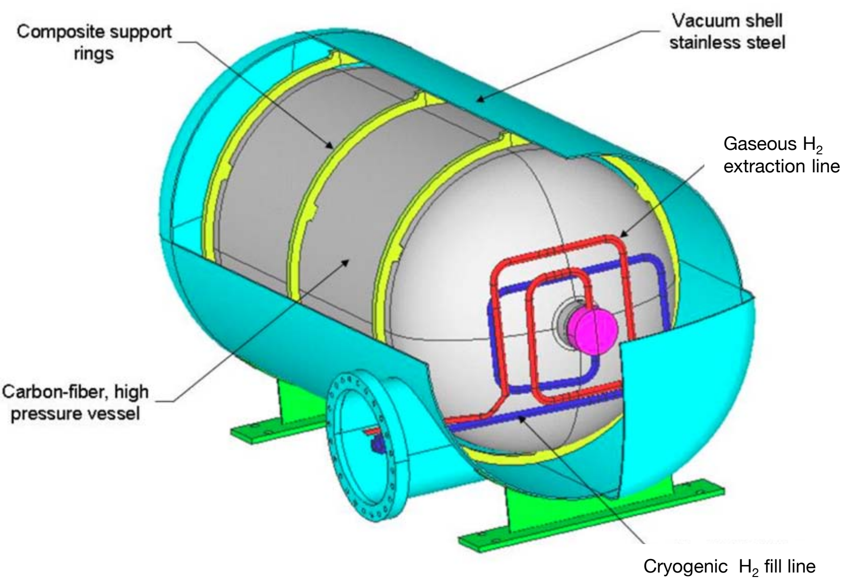
- **2015 refueling efficiency**

Partners

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

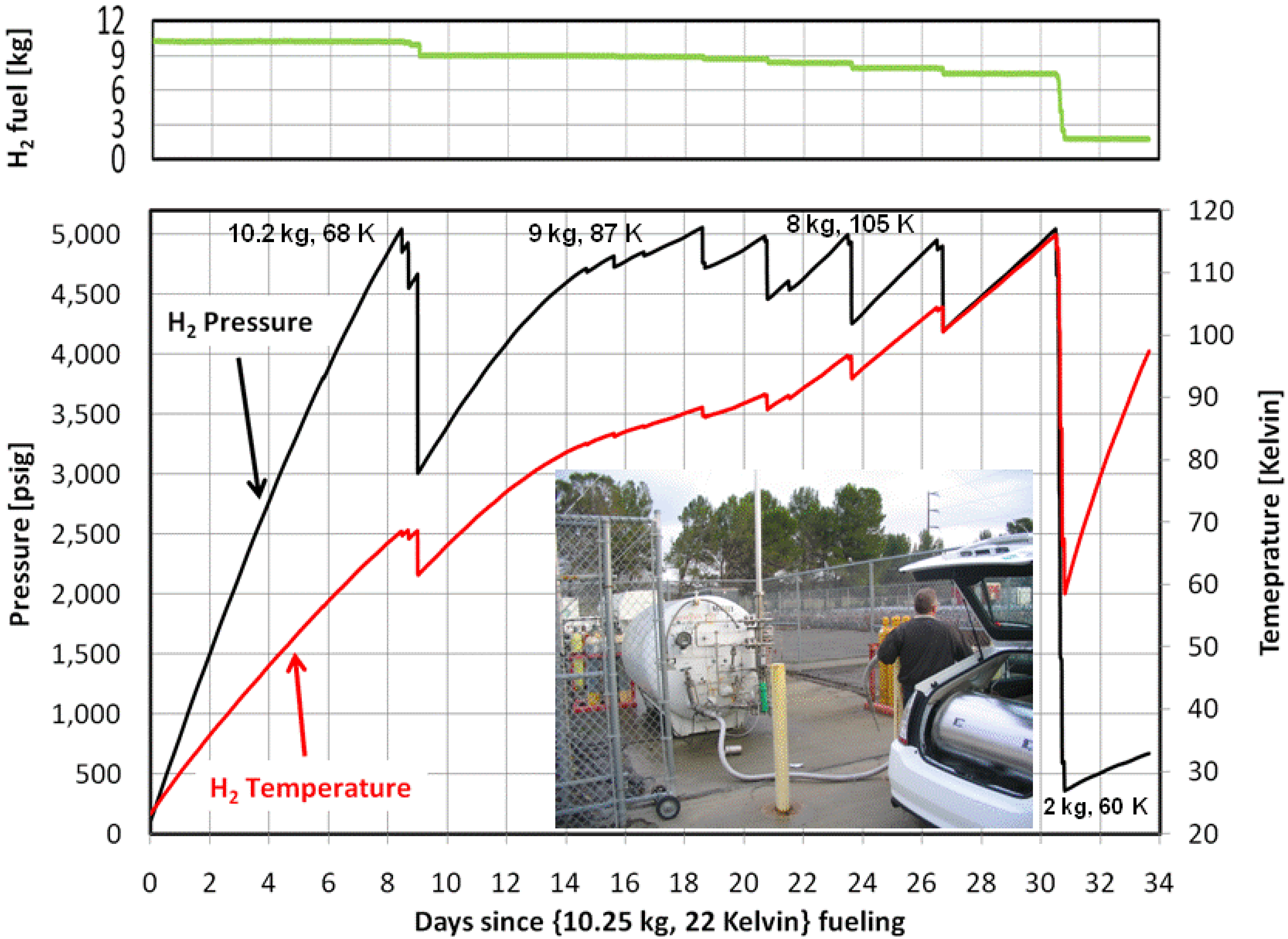
High density cryogenic hydrogen enables compact, lightweight, and cost effective storage





- ***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_2)**

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

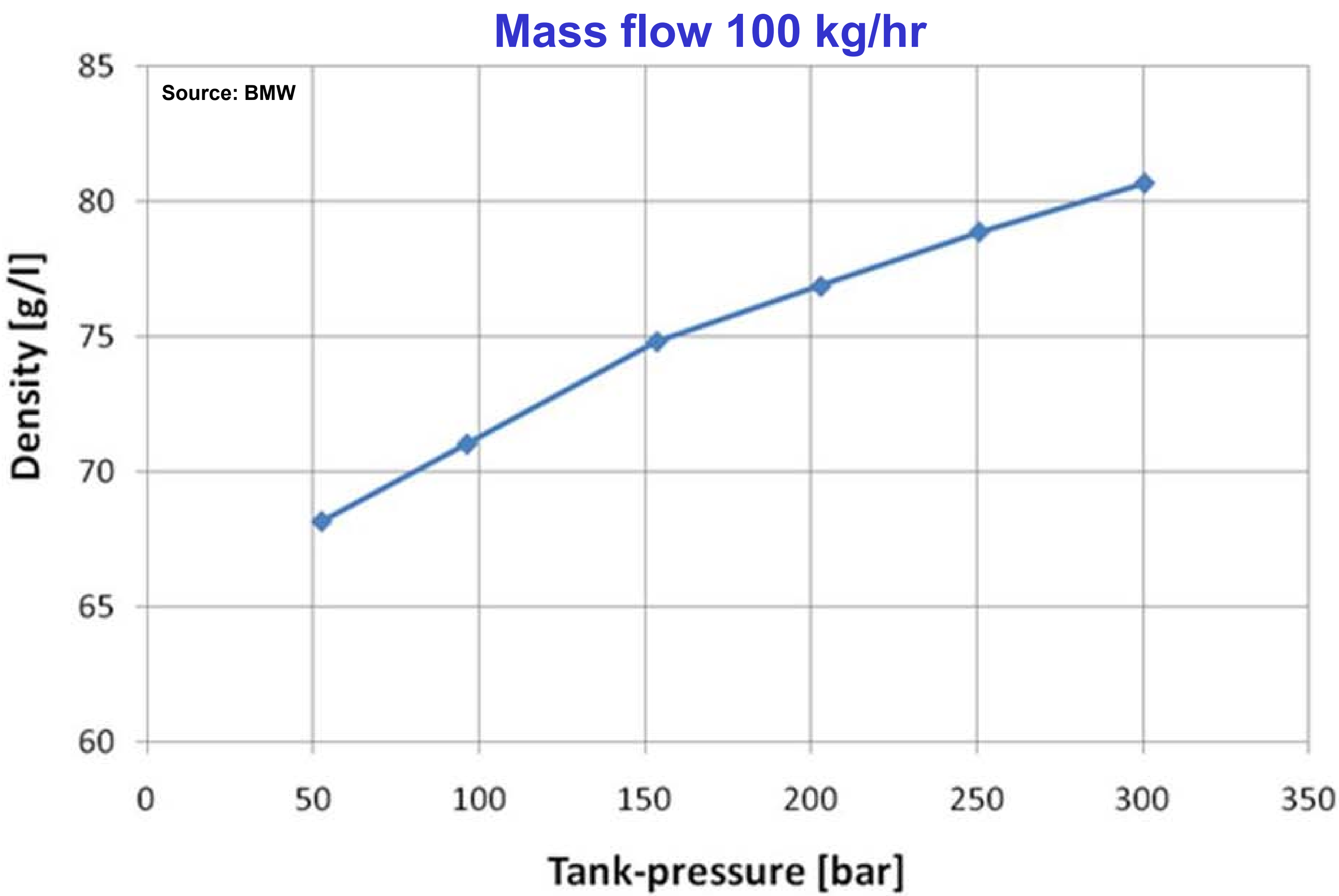


Approach: pressurize LH_2 for rapid refueling of cryogenic vessels with low evaporative losses and pumping power

BMW high pressure cryogenic pump

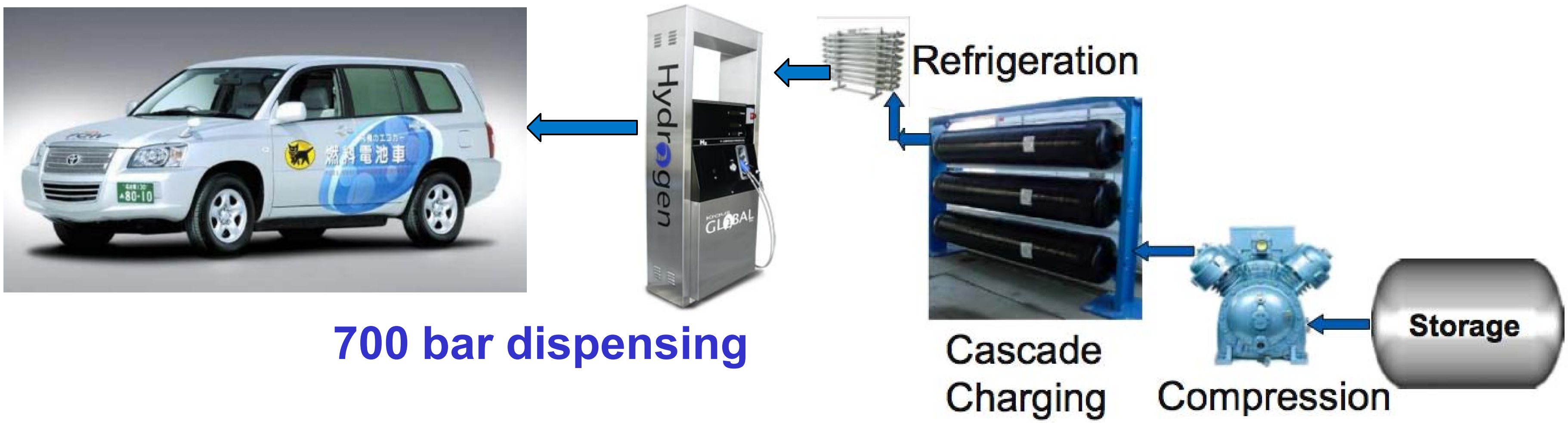
- High LH_2 density minimizes pump power & compression heating
- Pumping power = $\int \frac{dP}{\rho}$
- Compression heating = $\frac{P}{\rho}$
- Pressurized LH_2 pump quickly fills even warm and/or pressurized vessels
- Recycled H_2 vapor from pump maintains stationary vessel pressure

Pressurized LH_2 pump delivers high density hydrogen (>70 kgH_2/m^3) at rapid flow rates



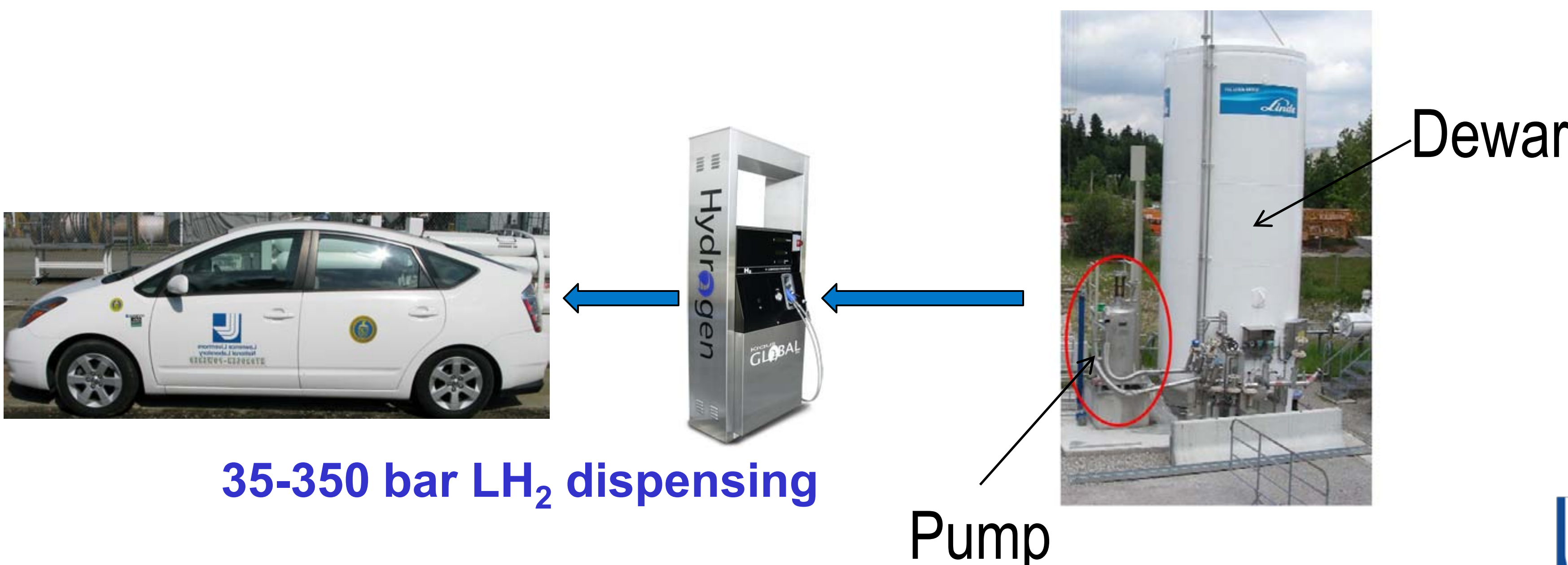
Room for improvement to even higher density via after-cooling of pressurized LH_2

Pressurized LH_2 refueling does not require compressor, cascade, or refrigerator; reducing station capital cost



700 bar dispensing

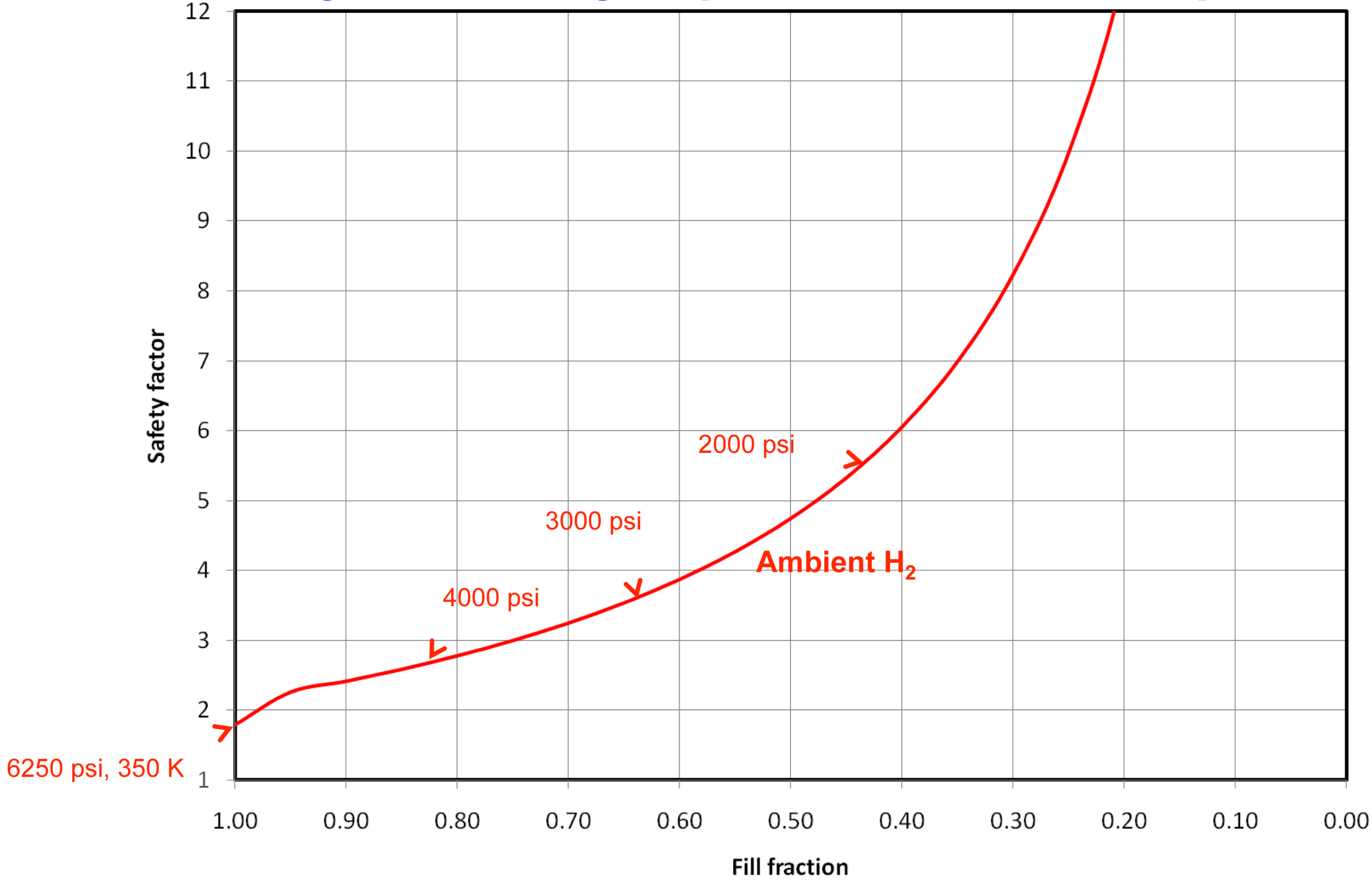
Source: Argonne National Laboratory



35-350 bar LH_2 dispensing

Hydrogen annual merit review, LLNL, June 9, 2010, p. 7

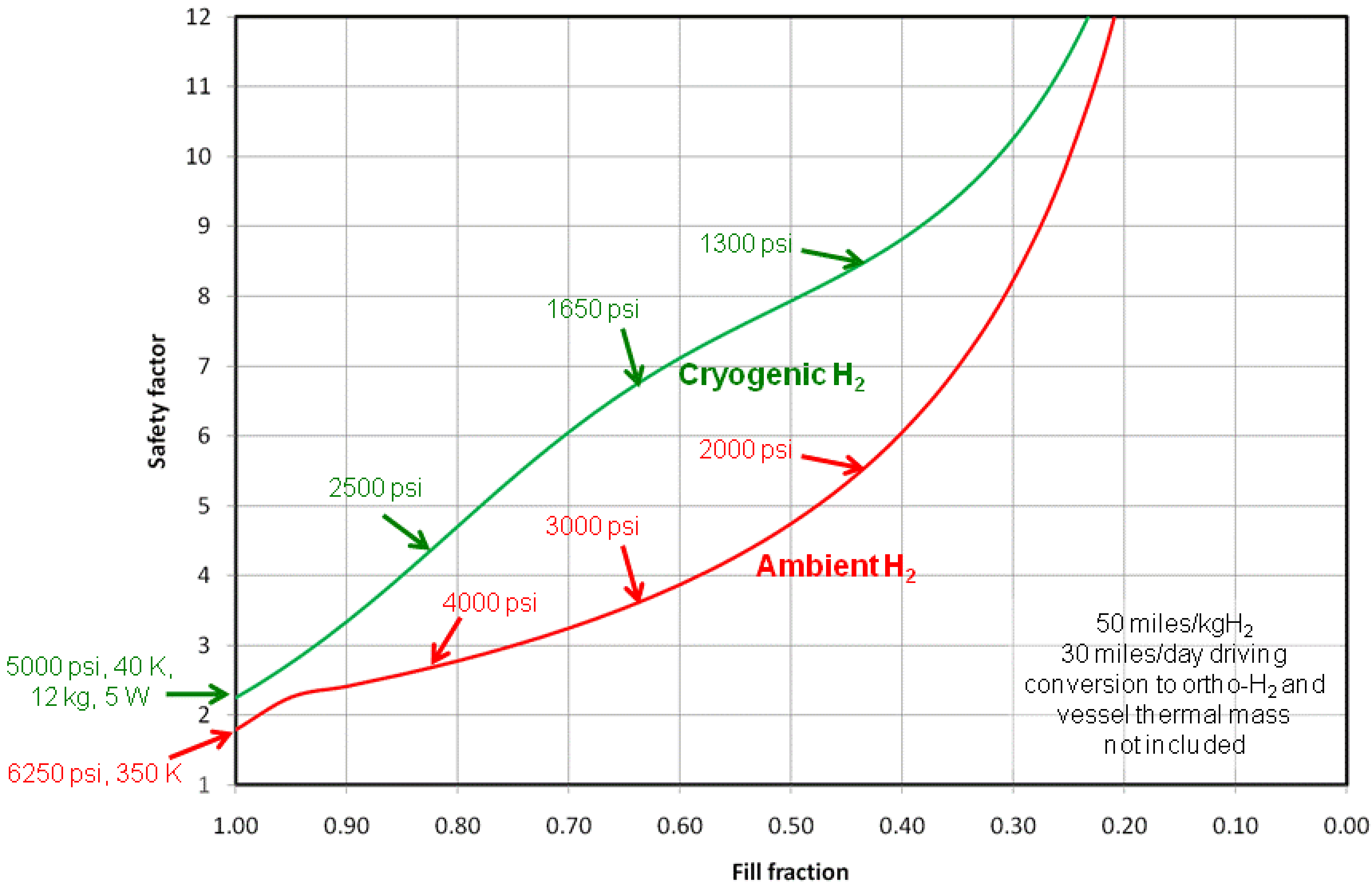
Ambient vessels store H_2 always at high temperatures safety factor only improves as vessel empties



- **Compressed gas vessels reach *maximum* pressure *every* refueling**

Hydrogen annual merit review, LLNL, June 9, 2010, p. 8

Even when filled to 80 kg/m^3, cryogenic pressure vessels depressurize quickly due to isentropic cooling



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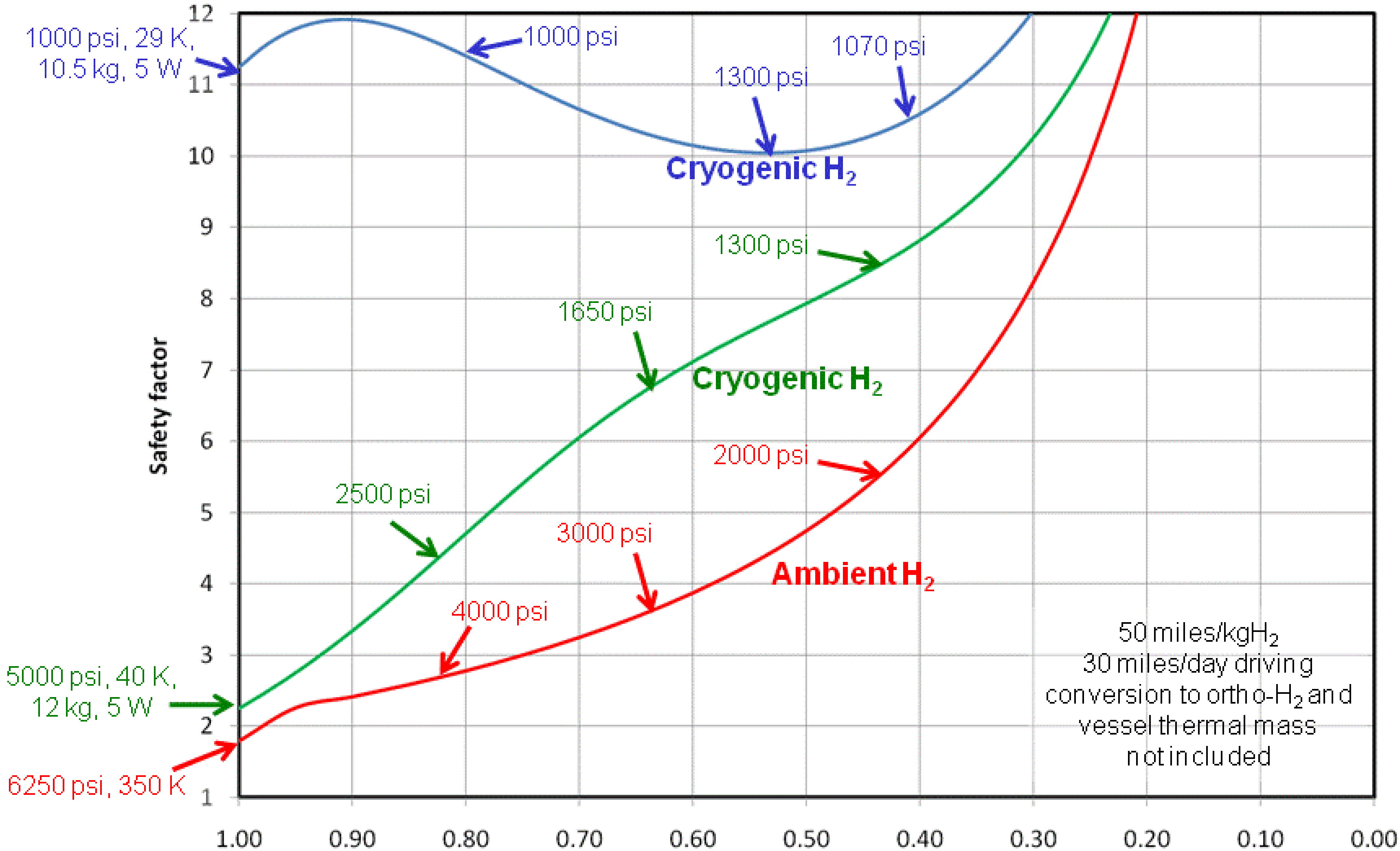
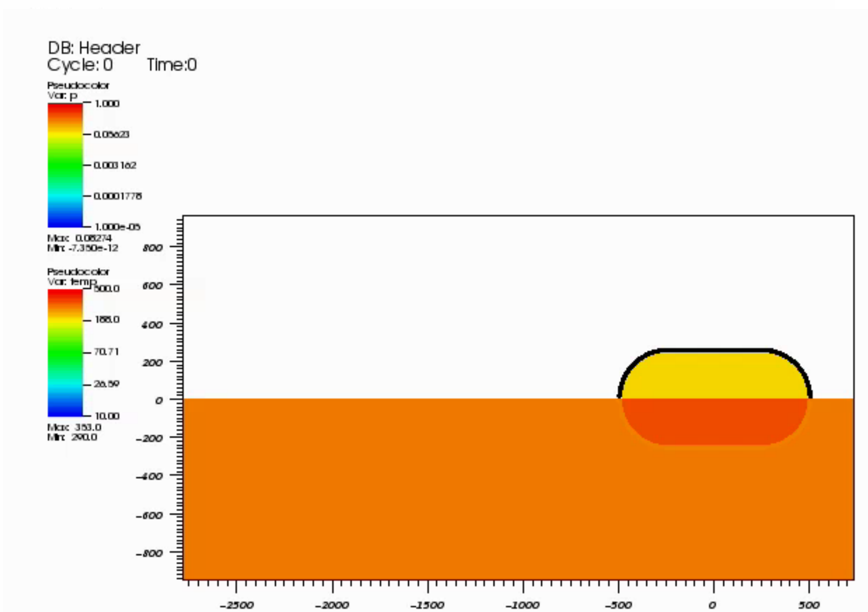
Refueling and on-road safety factors of cryogenic vessels can be very high with typical driving

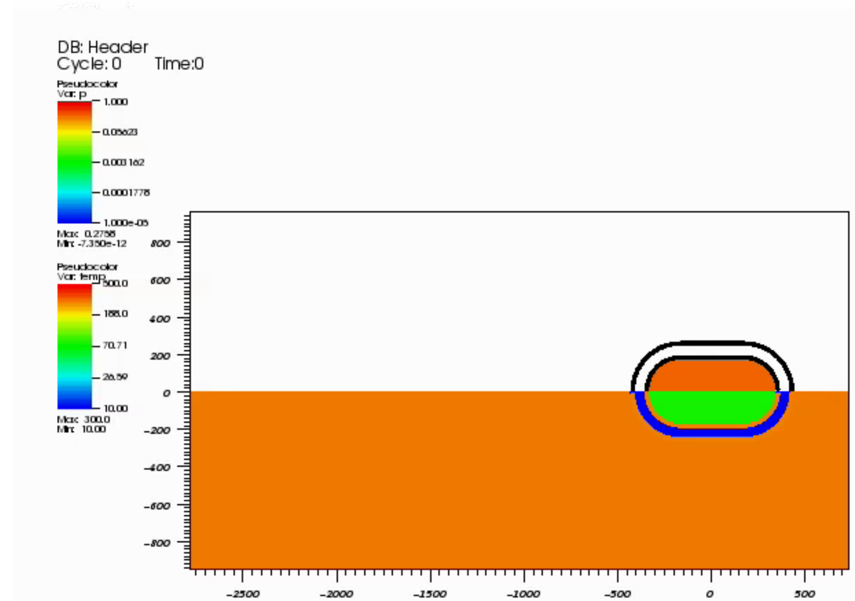


- *Refueling safety factor of 10+* **cold fill may not need maximum pressurization**
- *Potentially fewer maximum pressure cycles* **reduces liner fatigue**
- *On-road safety factor of 10+* **due to cooling from regularly driven vehicles**

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

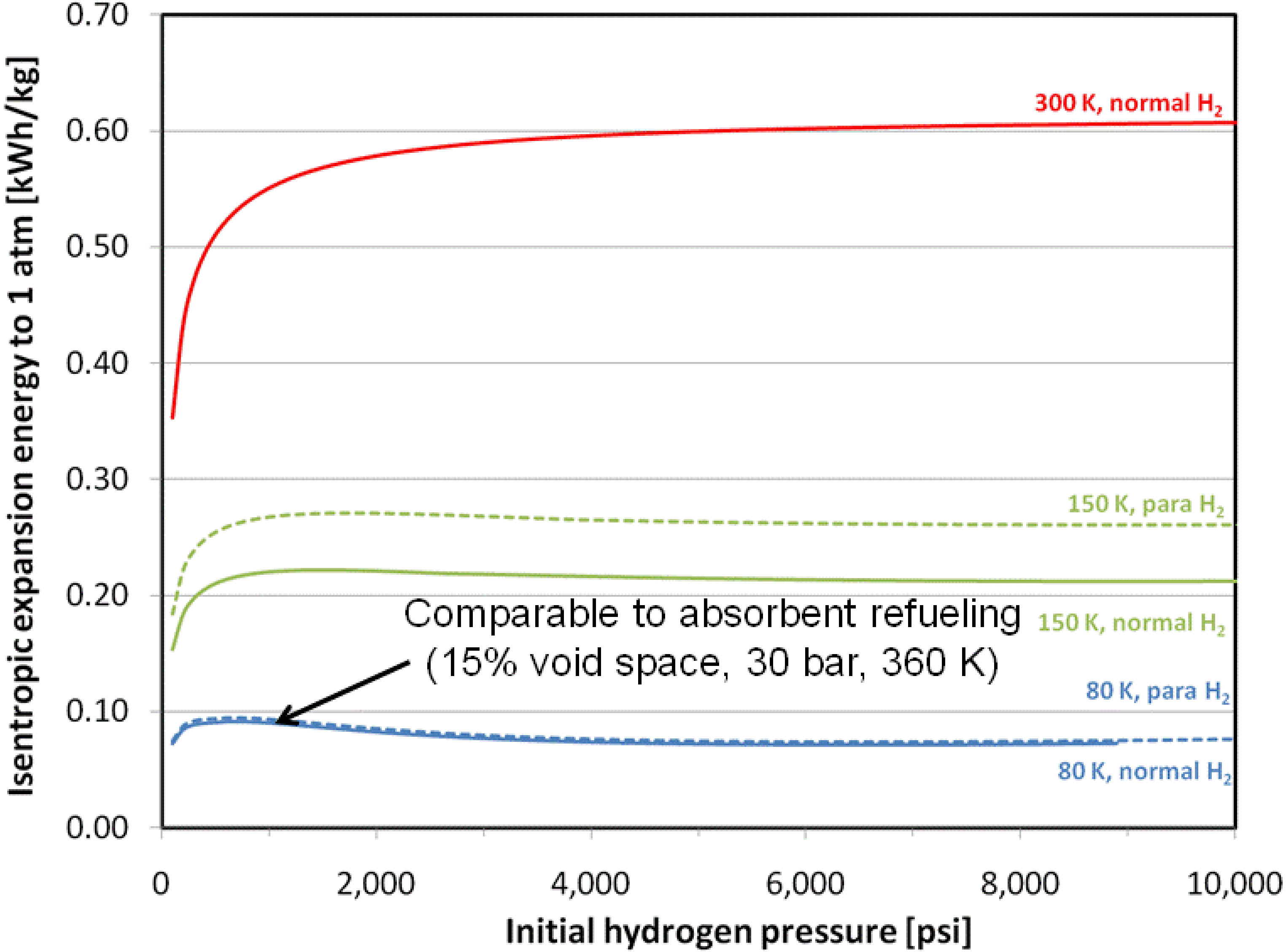


6 kg H_2, 12,500 psi, 350 K, ρ=40.5 kg/m^3



6 kg H_2, 2200 psi, 80 K, ρ=40.5 kg/m^3

Cryogenic operation substantially reduces expansion energy



H_2 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_2 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)**