Cryogenic Pressure Vessels: Progress and Plans

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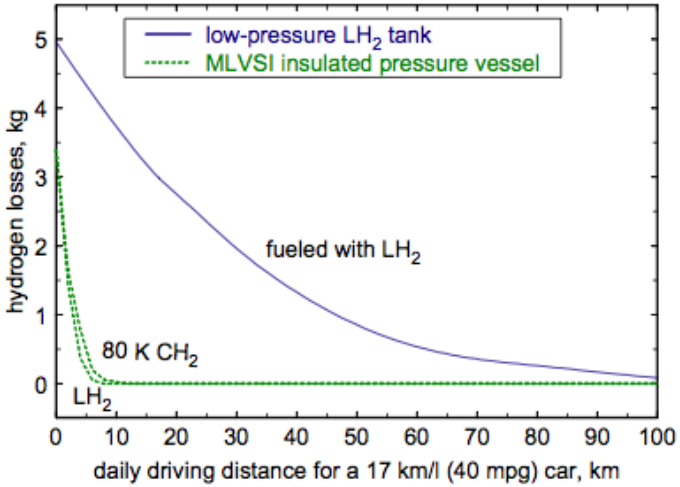
The cryogenic pressure vessel concept has evolved from thermodynamic analysis into manufacture and demonstration

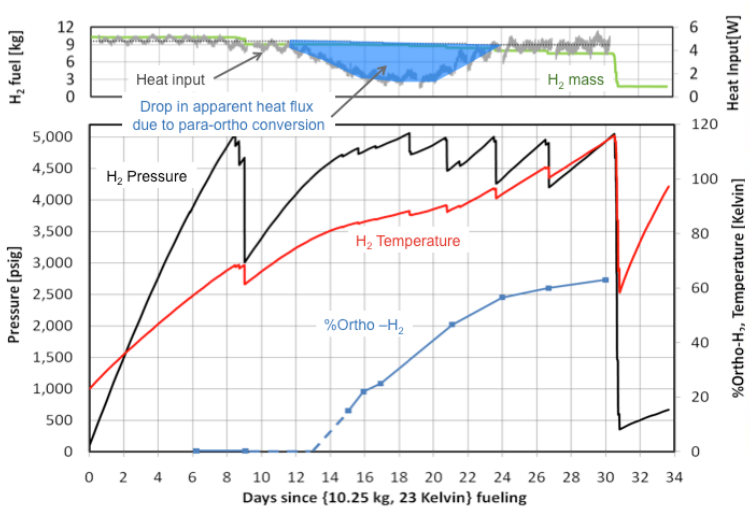


1998: thermodynamics

2000: DOT/ISO testing

2004: demonstration

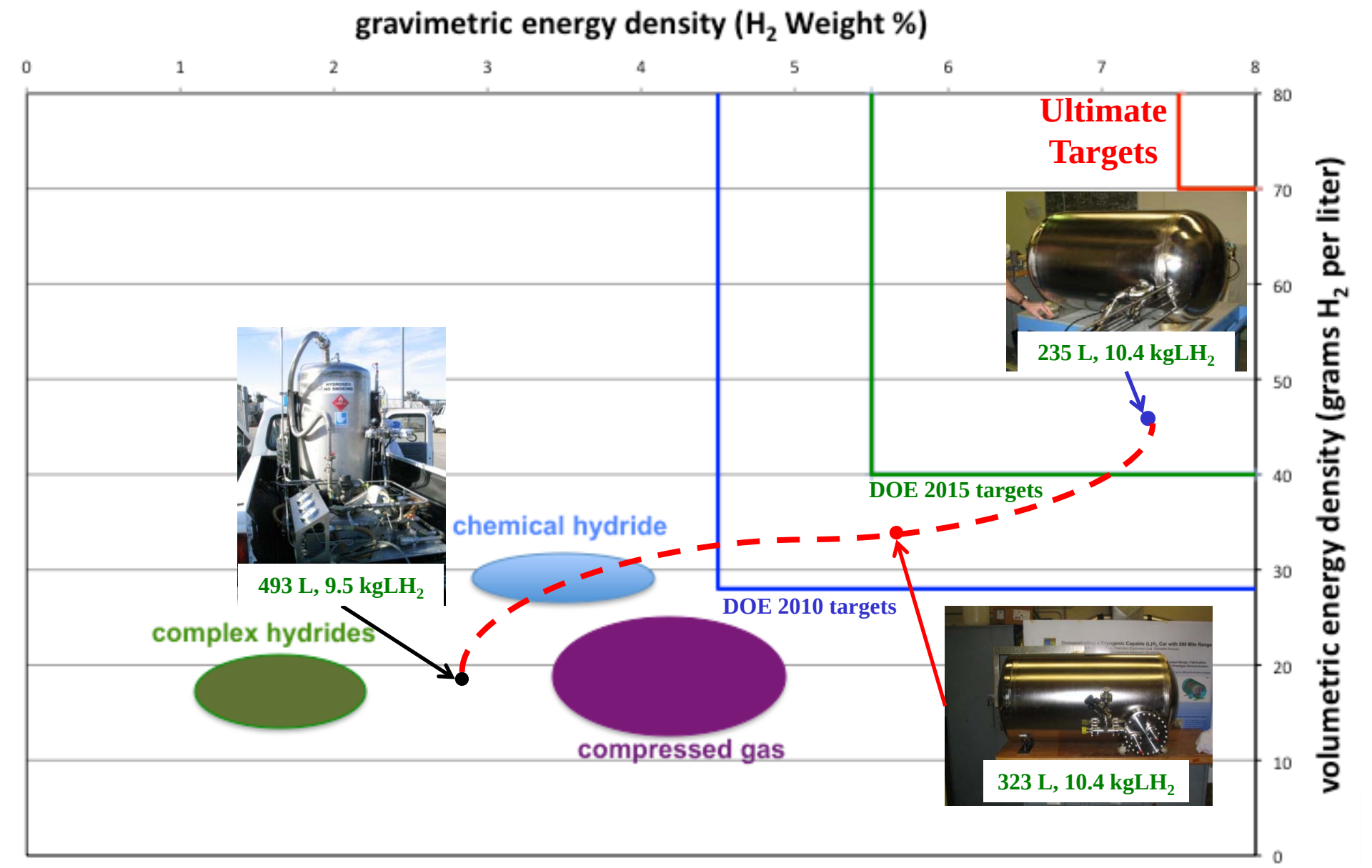
2007-2009: compact vessels



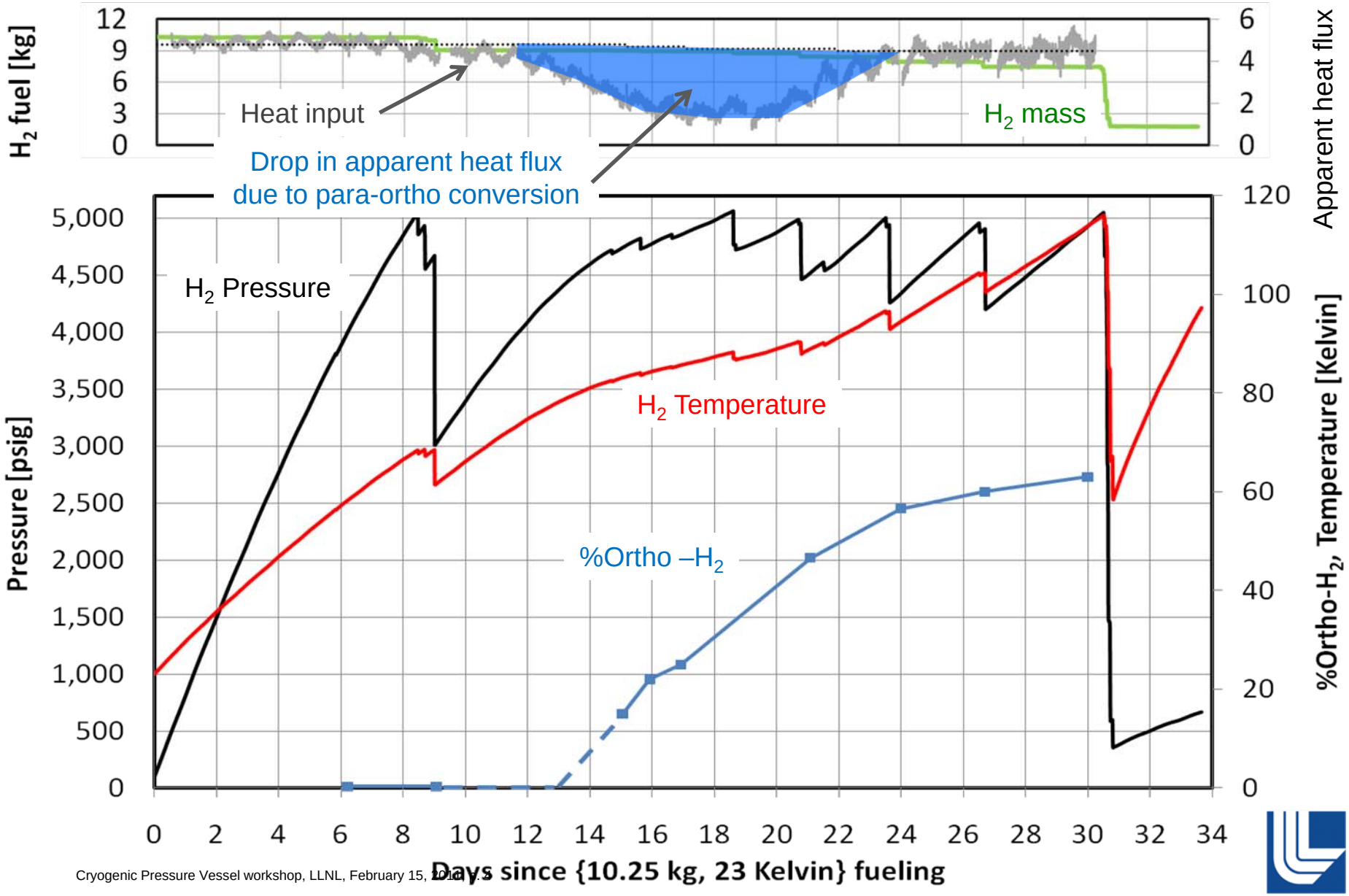
2010: *para-ortho* H_2 conversion

2011: LH_2 pump

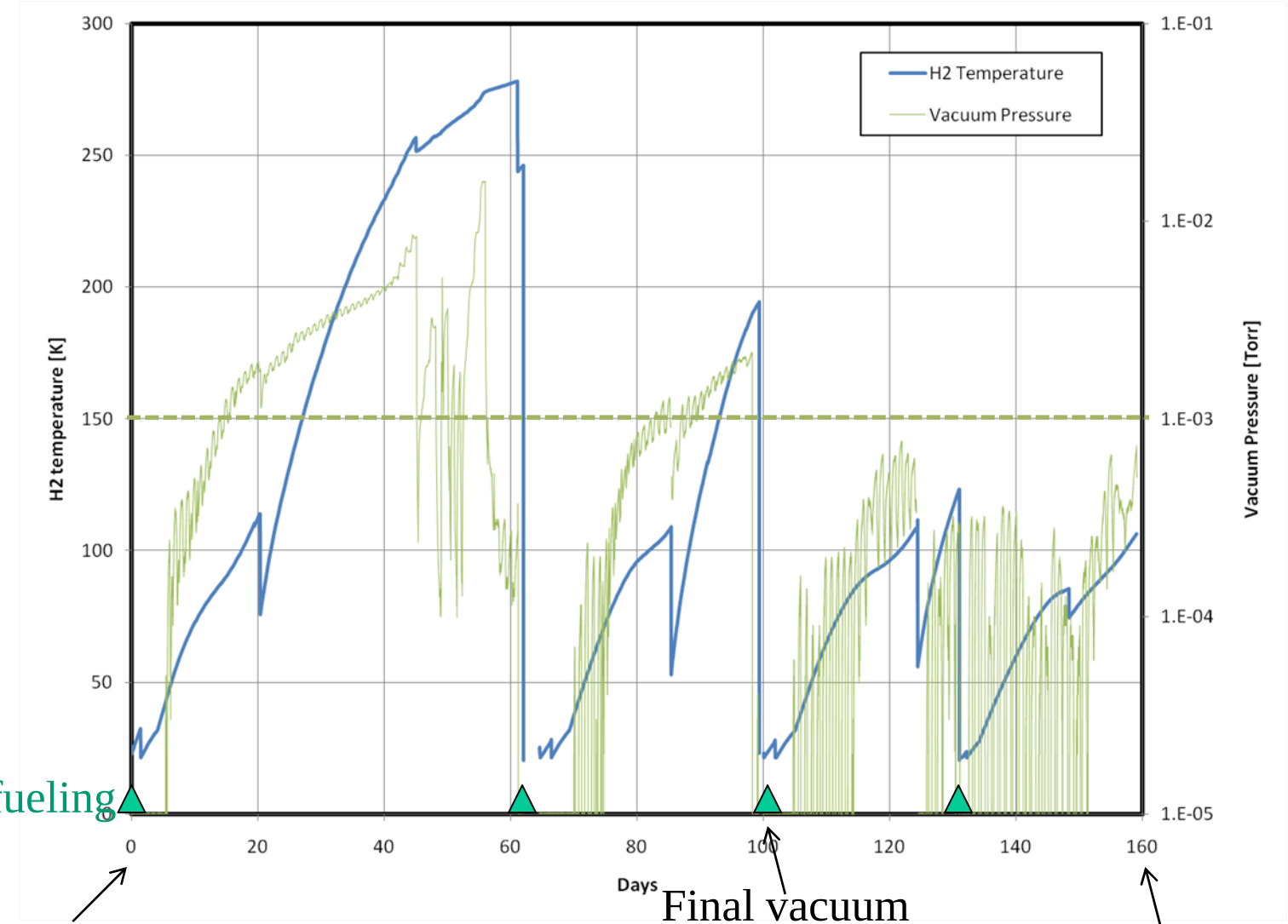
LLNL has refined three generations of cryogenic vessels *exceeding* 2015 storage targets fueled with 70g/L liquid H_2



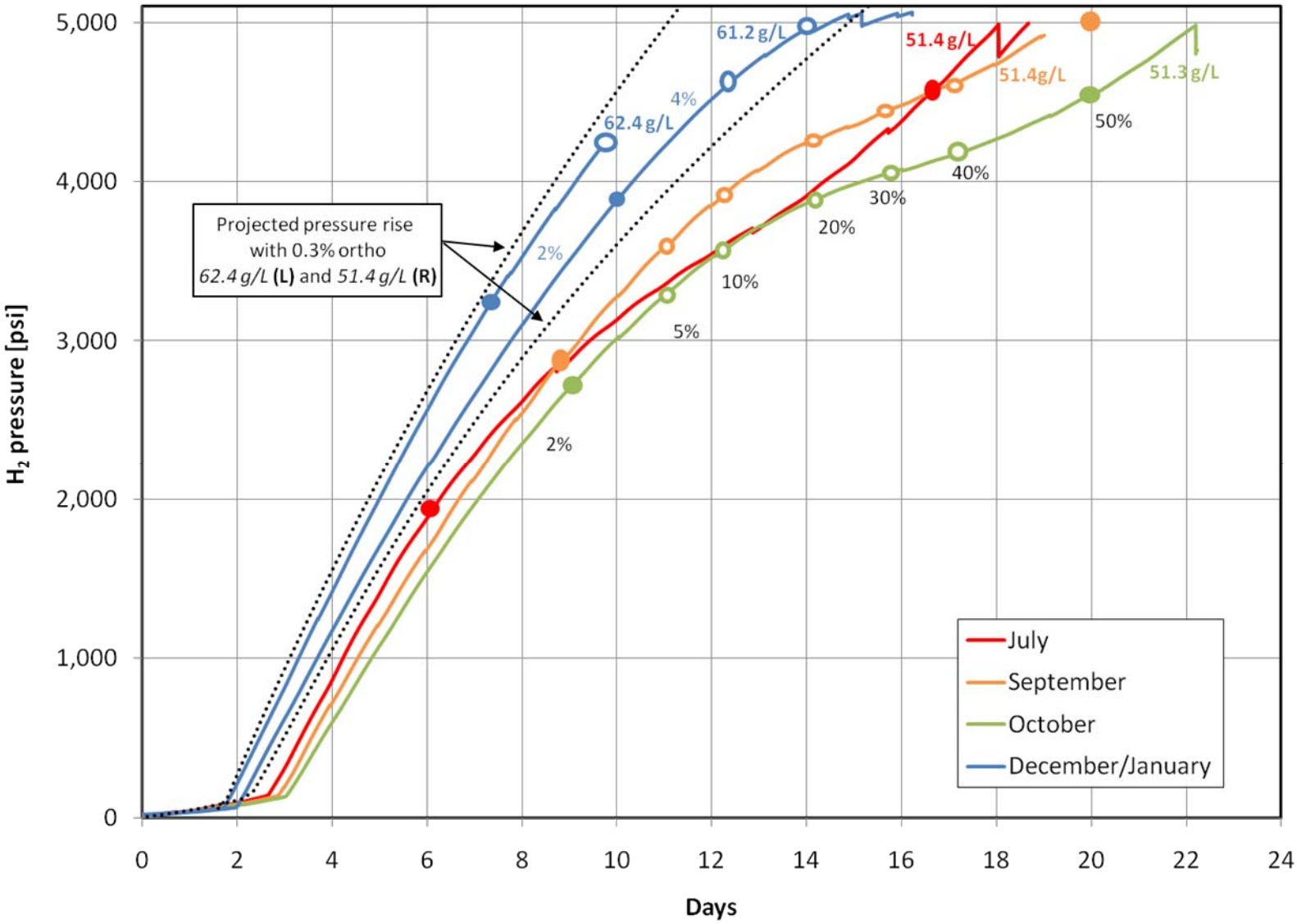
In a month long dormancy experiment, *para-ortho* conversion reduced heat transfer by half between days 12 and 24



Experimental tests have been run over a wide range of conditions (temperature, density, vacuum quality)



Para-ortho conversion became significant at ~75 K and extended dormancy by ~5 days for 70-90% full 151 L vessel



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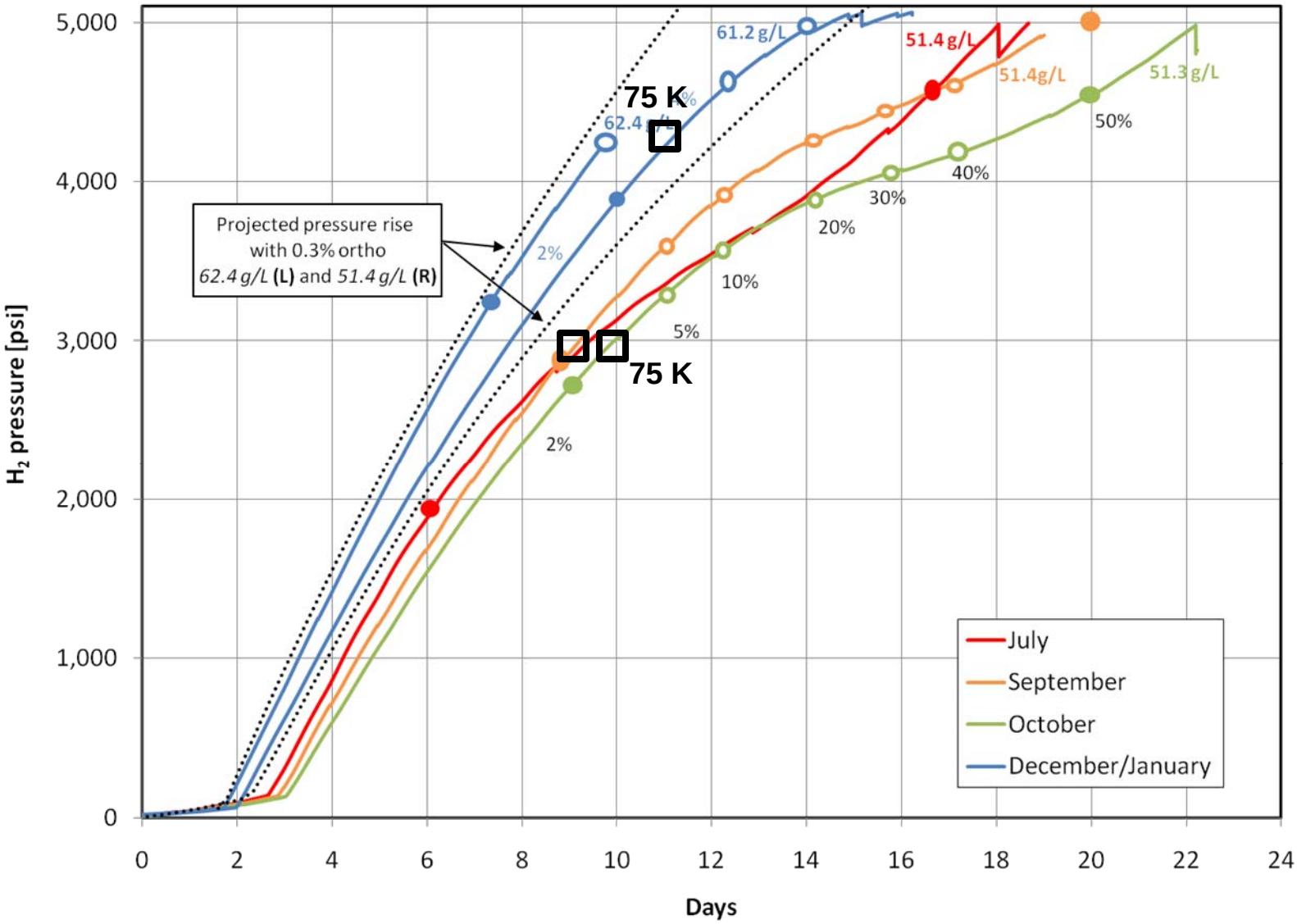
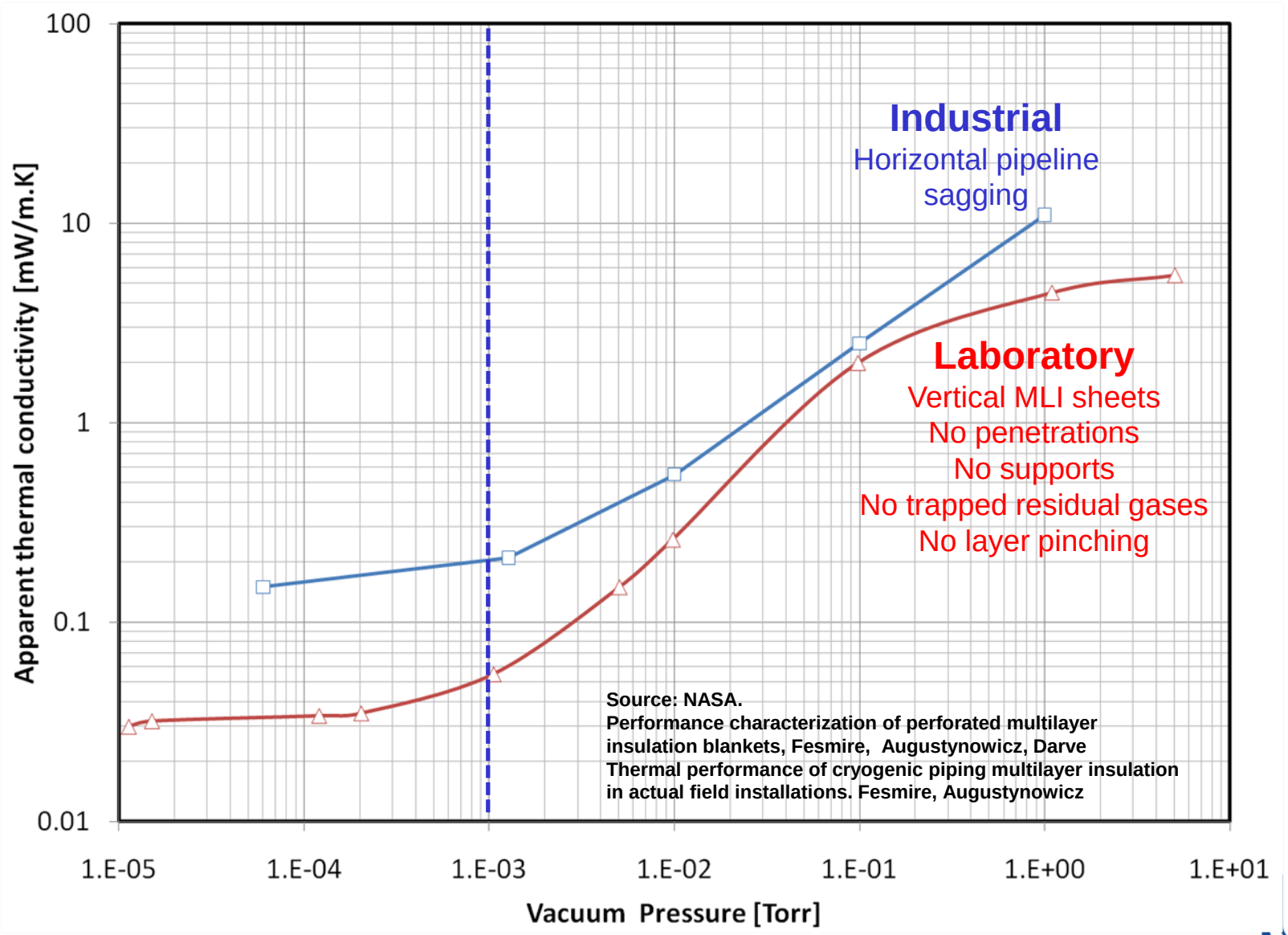
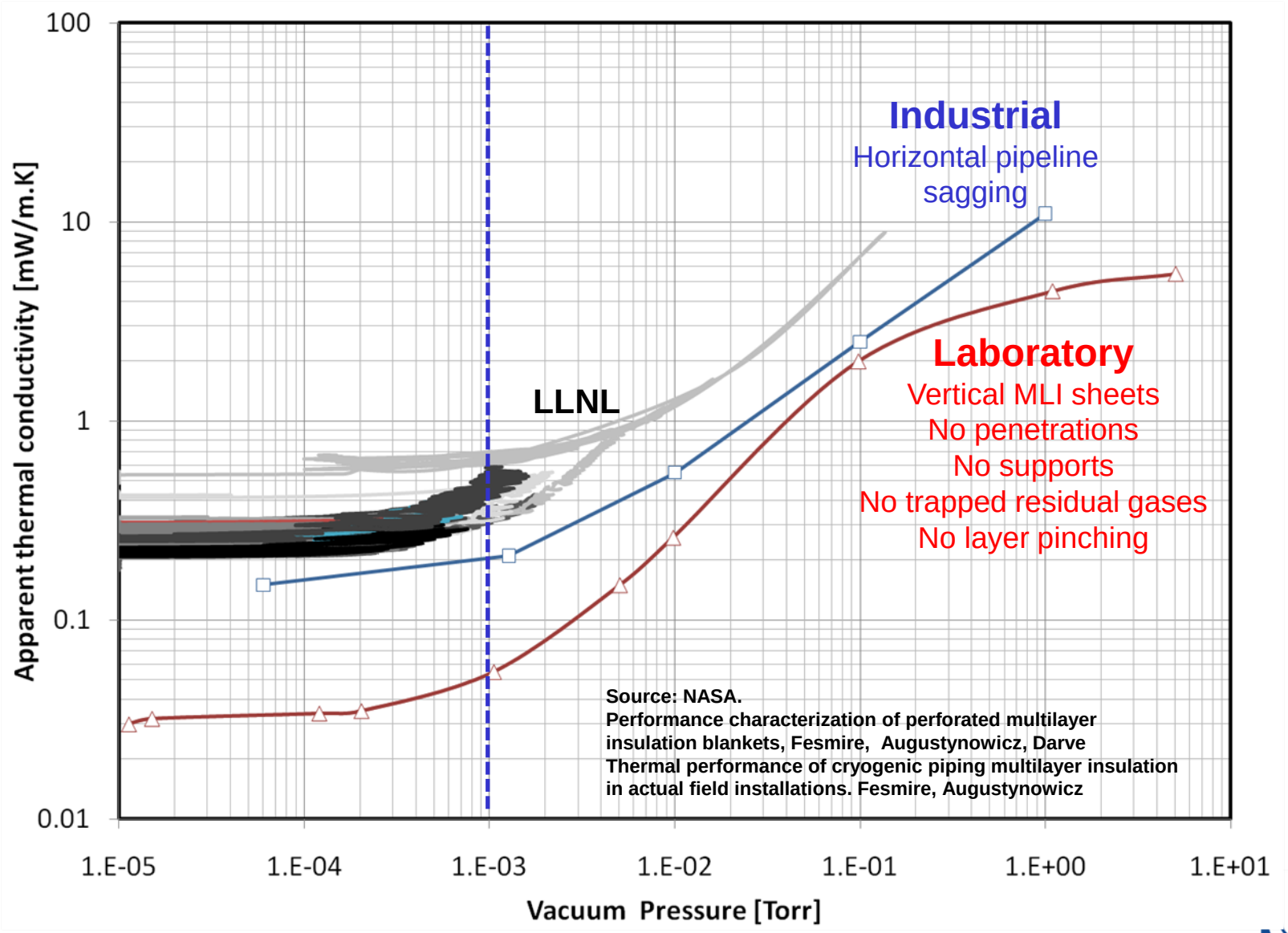


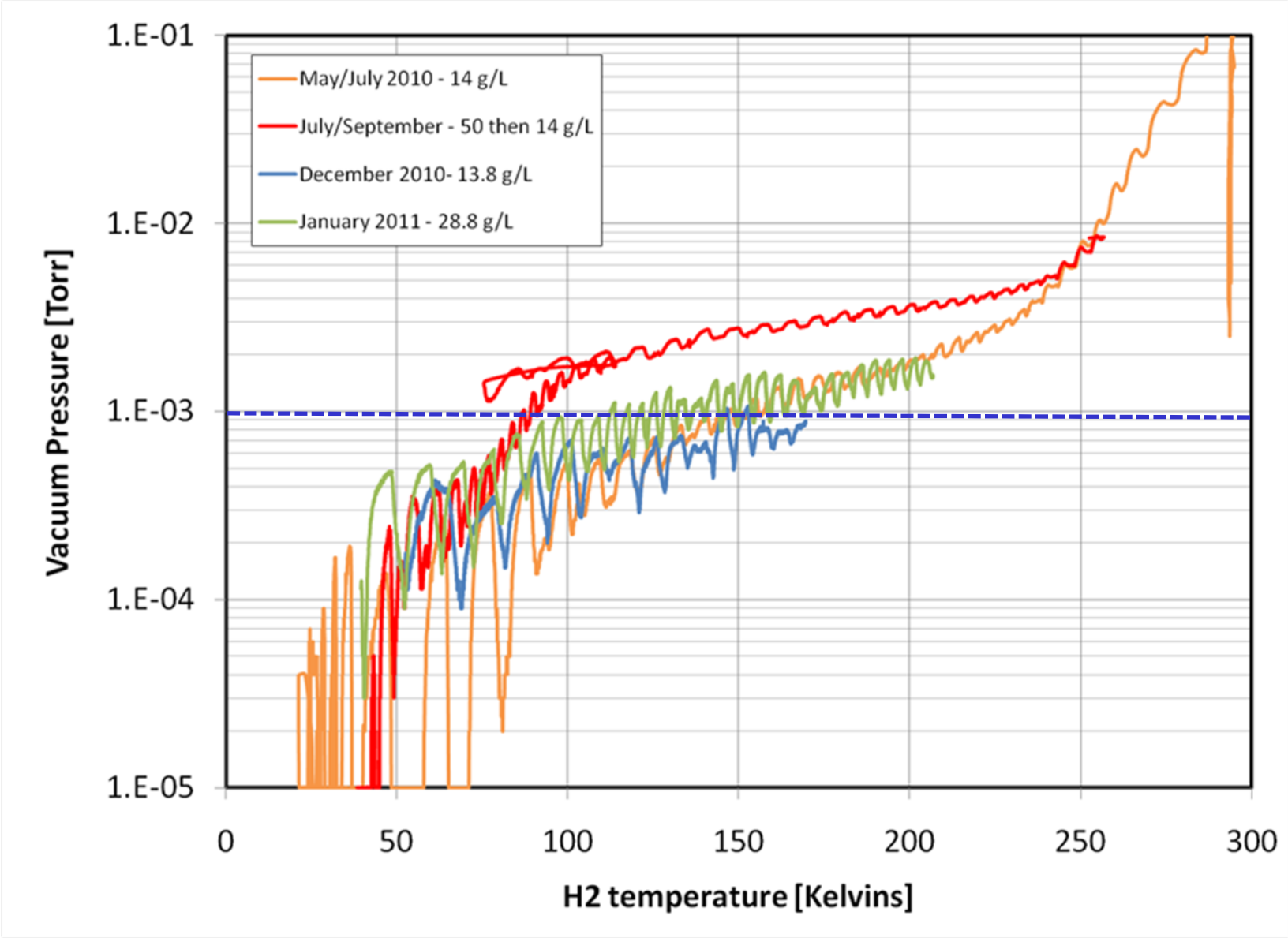
In both industrial and laboratory environments, low heat transfer requires < 1 mTorr vacuum quality



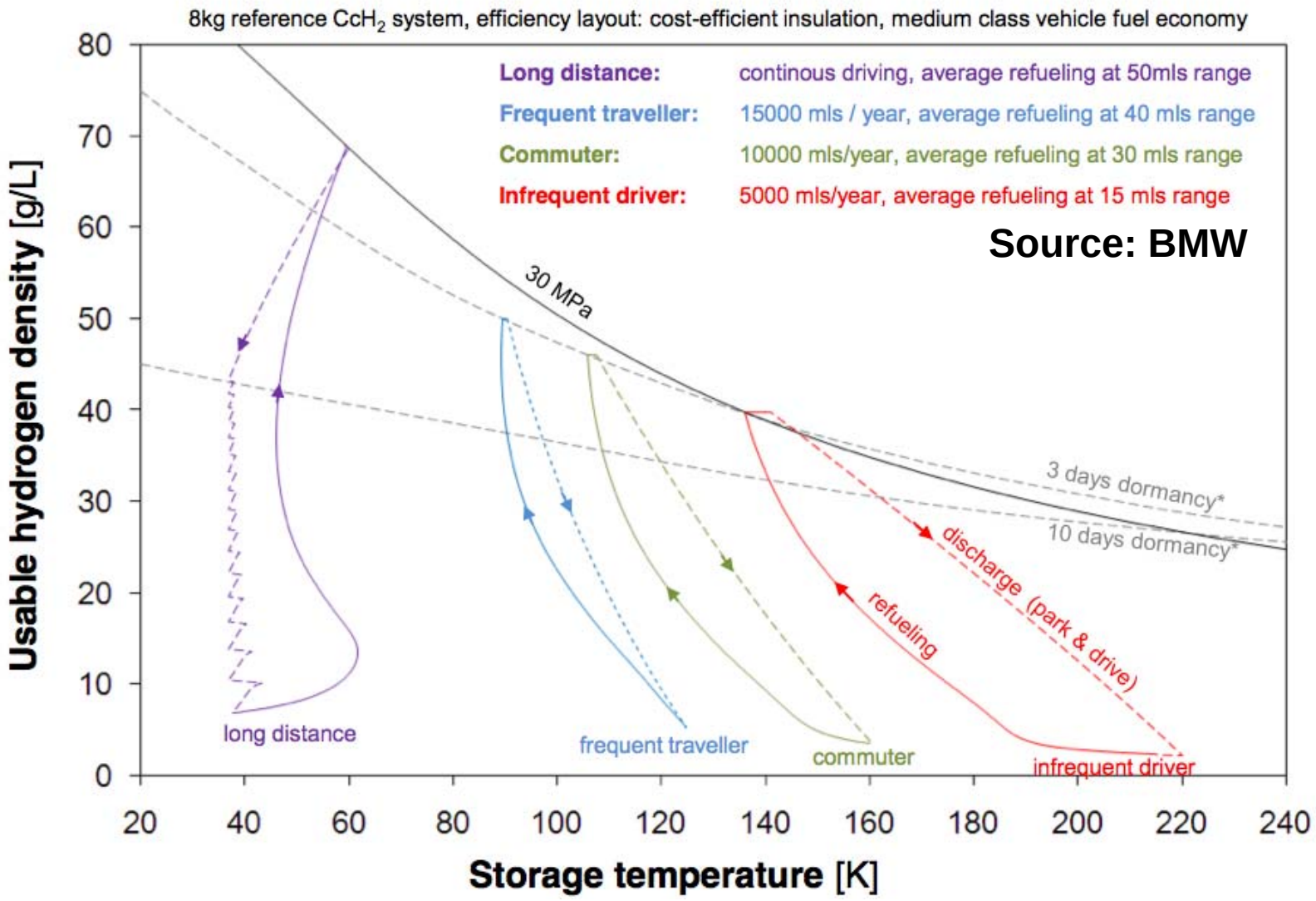
LLNL insulation performance follows the same trend



Experiments show viable indicated vacuum levels up to ~150 K for 4 months



Most cryogenic vessels may remain colder than 150 K due to expansion work during hydrogen extraction



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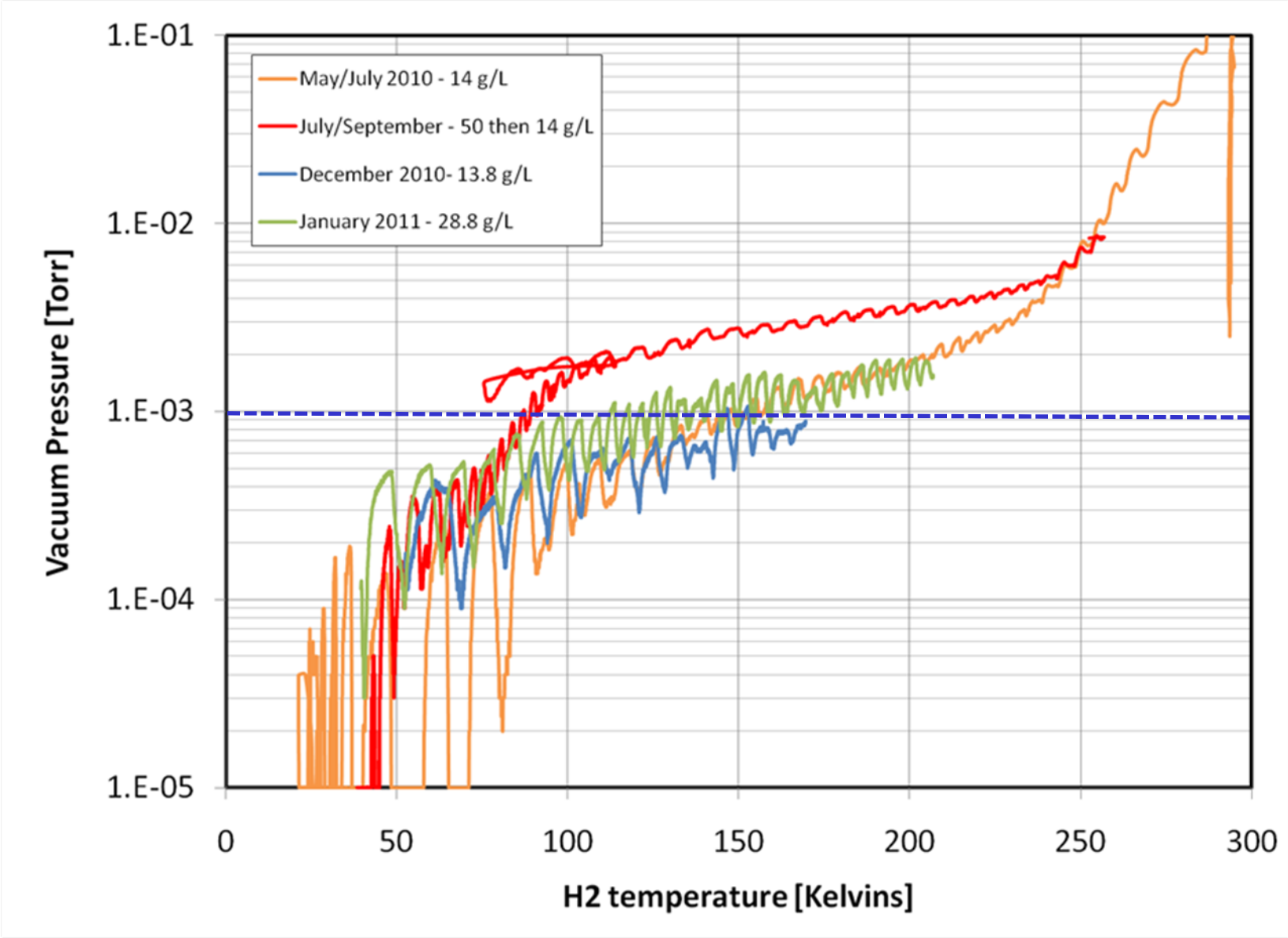
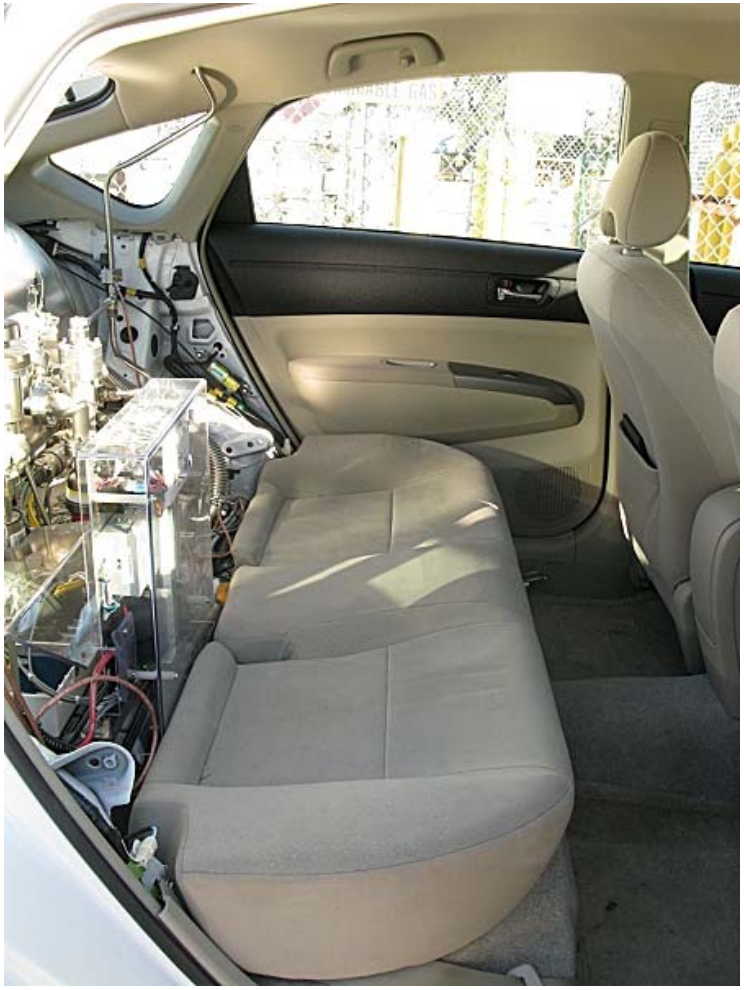


LH_2 pump will enable rapid high density refueling even for initially warm and/or pressurized vessels

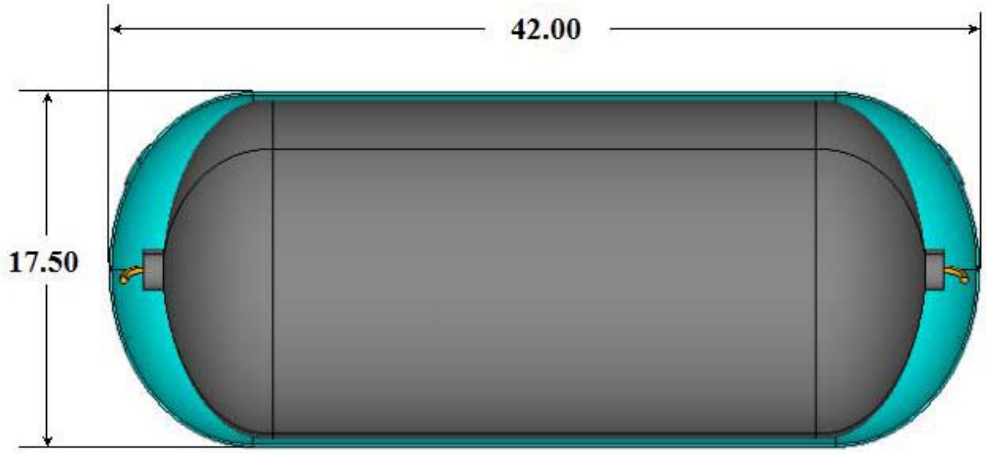
BMW cryogenic high-pressure pump

- ***A high pressure (up to 880 bar) LH_2 pump*** **offers rapid single phase refueling without boil-off**
- ***Single flow refueling*** **can be reliable and cost effective**
- ***Pump expected ~12 months after contract*****, possibly 2/12**
- ***Contract is now in procurement.*** **To be finalized within 1-2 months**
- ***LLNL is also responsible for basic services:*** **electricity, phone line, concrete pad, foundation**

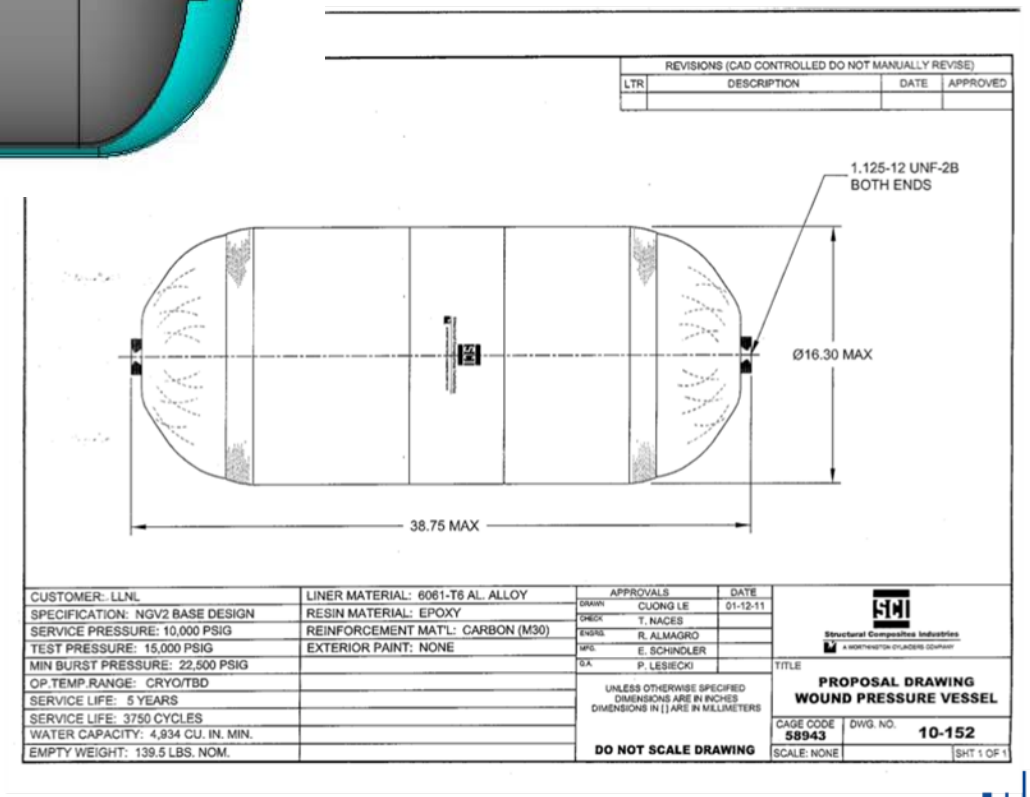
An 80 L 700 bar cryogenic vessel will be located forward of existing 151 L 350 bar vessel. Fueling both explores scale and transient vs. steady state refueling differences



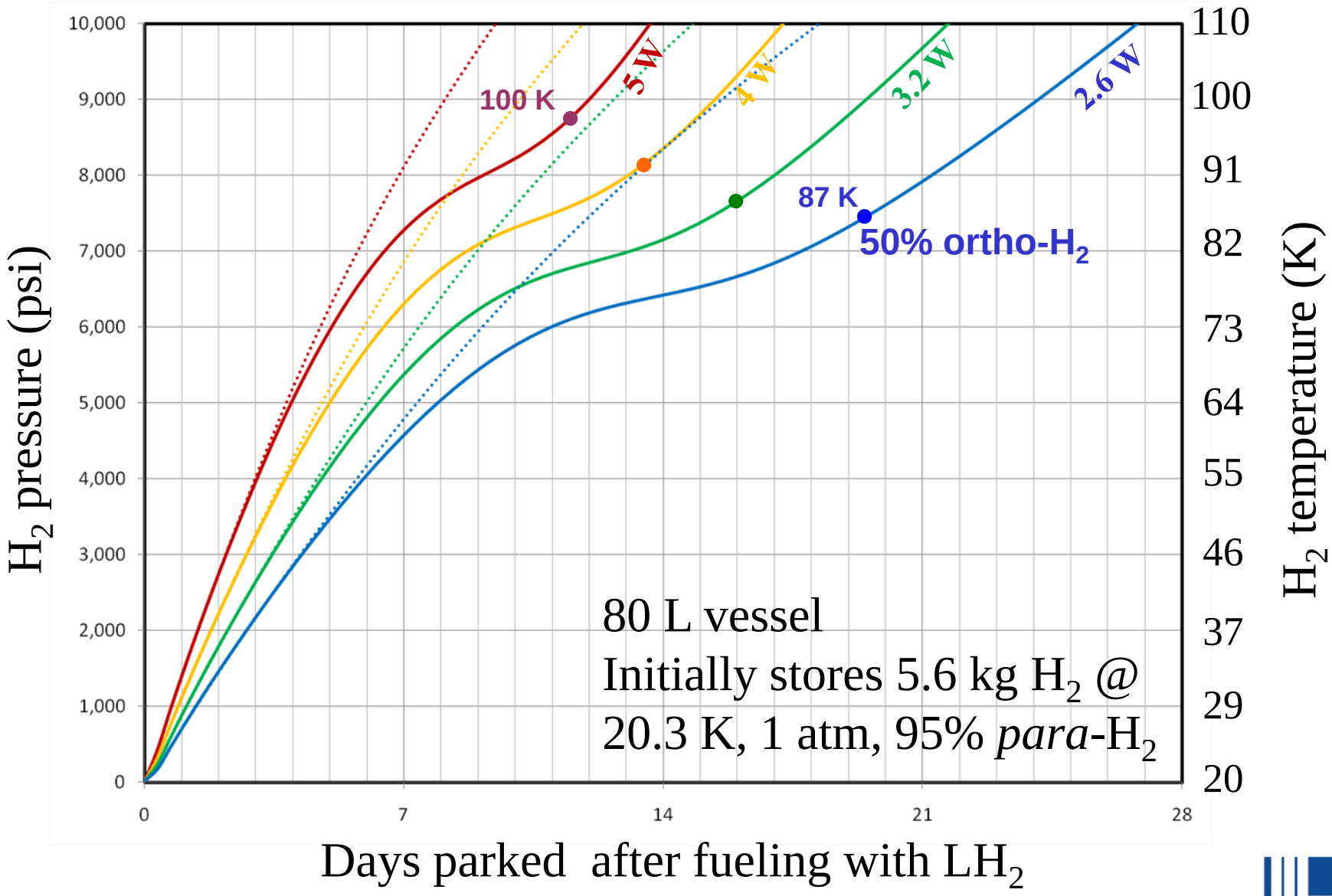
We project 55% volumetric efficiency for 80 L & 700 bar cryogenic vessel design with aspect ratio ~2.5



- *Capacity:* **5.6-7.4 kg (L)H_2 @ 1-700 bar**
- *Volume:* **153 liters (10 L accessories)**
- *Weight:* **90 kg total (15 kg accessories)**
- *3 mm aluminum vacuum jacket* **13 kg**
- *80 L capacity 700 bar vessel* **62 kg**



Fully capturing *para-ortho* conversion demands P > 5000 psi and/or vessel volume > 80 L



Summary: we will combine a high pressure LH_2 pump & lighter, smaller vessel with a comprehensive experimental strategy

- ***Rapid low loss refueling at higher density*** **up to 880 bar, 90 gH_2/L**
- ***Simpler high pressure operation*** **with *single* inlet/outlet line**
- ***Realistic (warm) refueling conditions:*** **partially full, <99% para H_2**
- ***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**
- ***Determine vacuum quality intrinsic to composite wall vessels***