Rapid High Pressure LH_2 Refueling for Maximum Range and Dormancy

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Overview

Timeline

- Start date: October 2011
- End date: *
- Percent complete: 50%

Budget

- Total project funding
  - $2.4M
- Funding for FY13:
  - $0.7M

* Project continuation and yearly direction provided by DOE

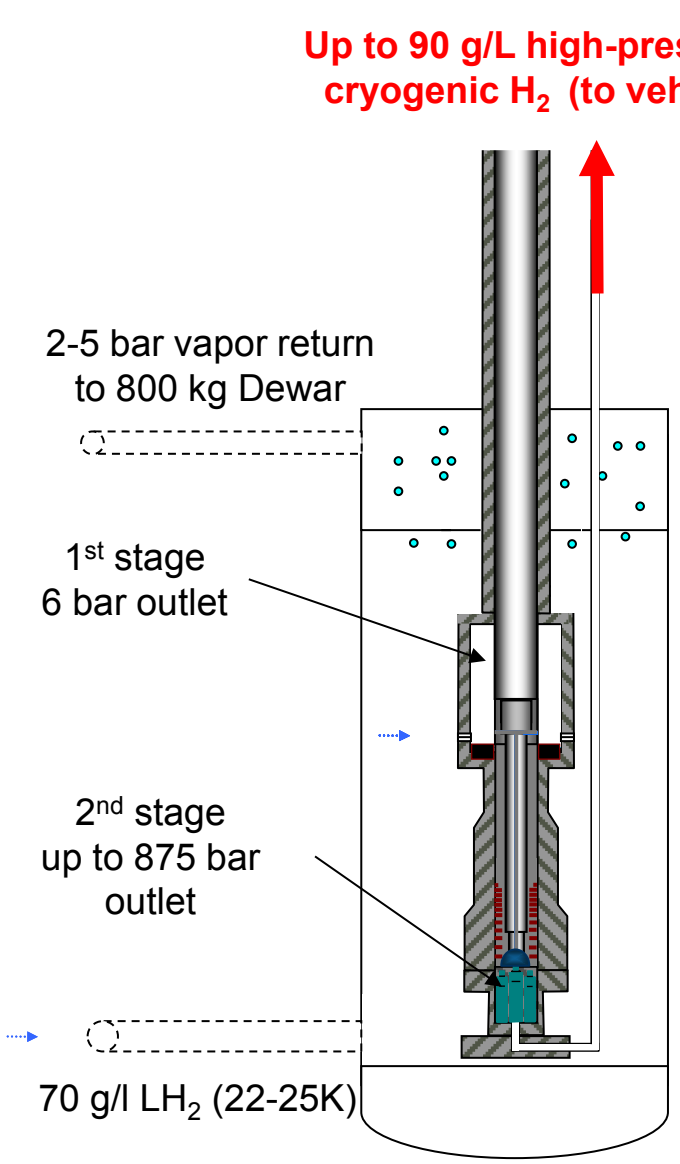
Barriers

- C. Reliability and cost of LH_2 pumping

Partners

- Linde 875 bar LH_2 pump supply, operation & maintenance
- BMW cryogenic H_2 auto usage patterns (refuel/drive/park)
- Spencer Composites custom cryogenic pressure vessel

Relevance: H_2 refueling is limited by onboard heating and power & capital at the station



High pressure LH_2 pump resolves refueling challenges due to upstream liquefaction and no onboard cooling

LH_2 pump provides rapid fueling

- Pump provides flow rate of 100 kgH_2/hour
- Refuel time decoupled from compression heating

Pressurized LH_2 refueling has high density and low power use

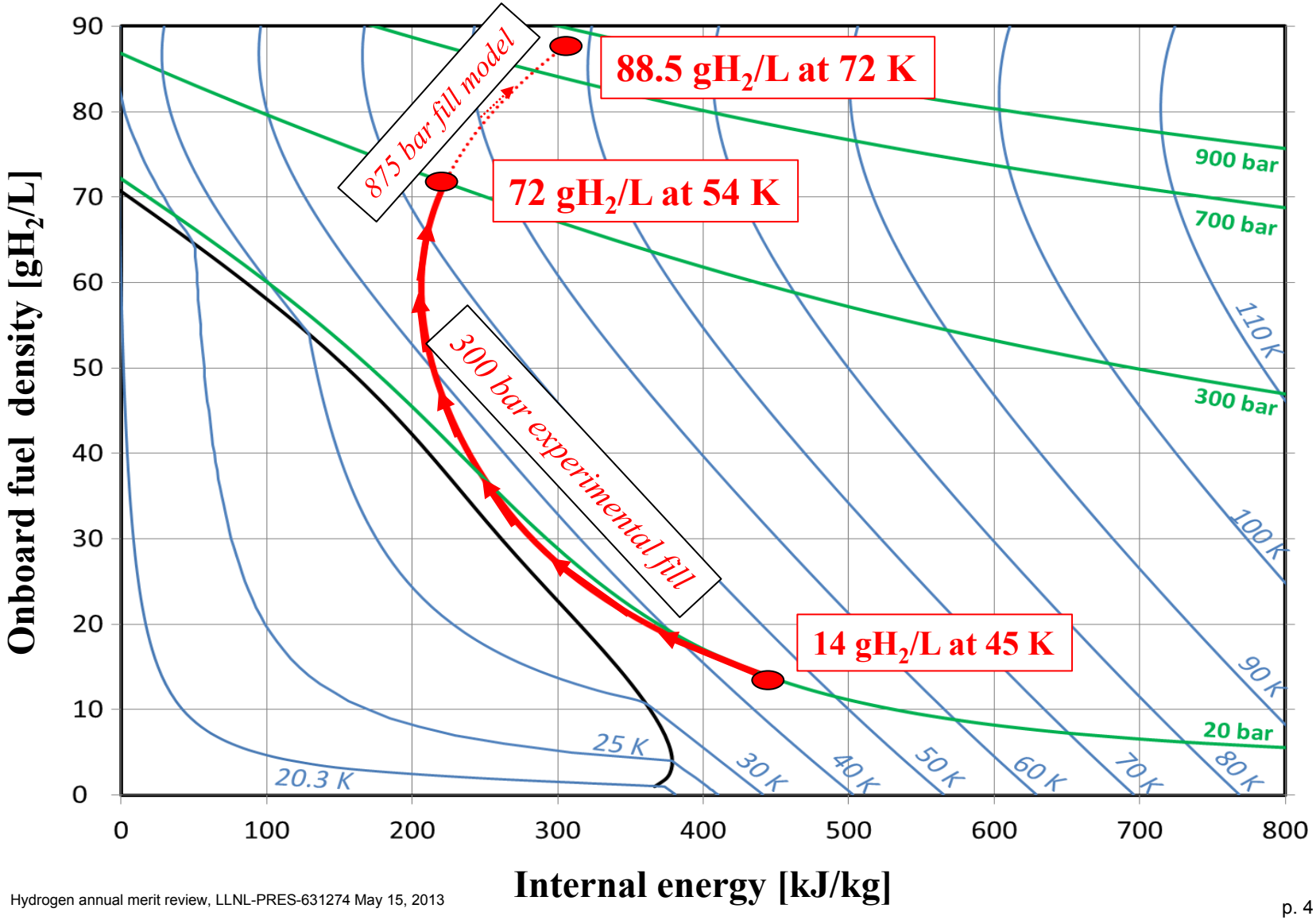
- The pump starts with high density LH_2
- Moderate compression (70 to 90 gH_2/L)

High pressure LH_2 pump makes cryogenic refueling practical

- H_2 (at up to 70 K) sent rapidly to cryogenic vessel
- Negligible impact on station boil-off (1-3% of fill)
- Refuel onboard system of any temperature
- Can refuel adsorbents or ambient storage

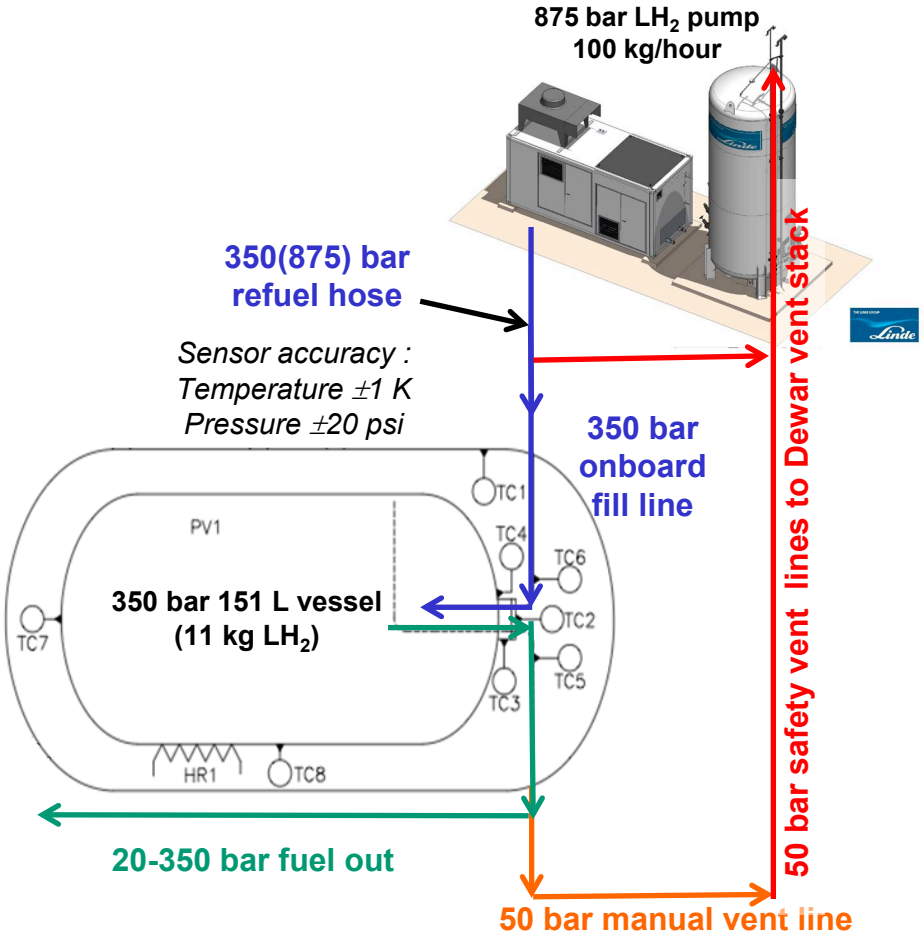
Relevance: LH_2 is compressible with very moderate heating

LLNL fill model predicts 88.5 gH_2/L onboard at 875 bar using 300 bar experimental data from BMW



Approach: Verify LH_2 pump performance up to 350 bar

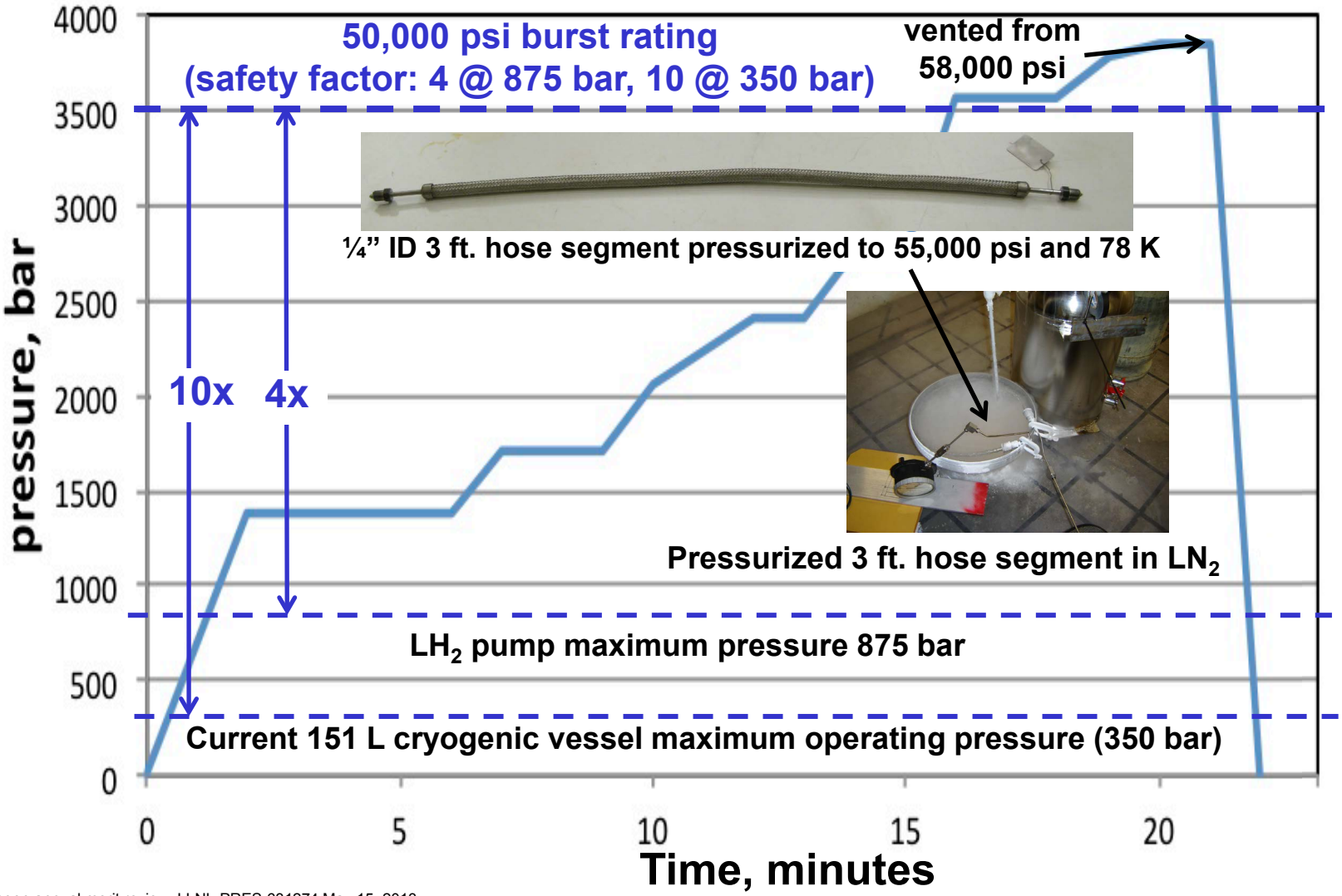
Determine 1) LH_2 fill time, 2) onboard density 3) refueling efficiency, and 4) Dewar boil-off



LLNL experimental system upgraded for 350 bar refueling and venting through Dewar stack

Technical accomplishment:
Successful test of high pressure cryogenic 3 ft hose segment

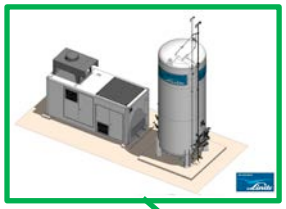
Enables rapid high pressure LH_2 refueling with safety factor of 4 to 10



Accomplishments: Site preparation

Electrical and civil work necessary for LH_2 pump & Dewar operation completed in 3 months

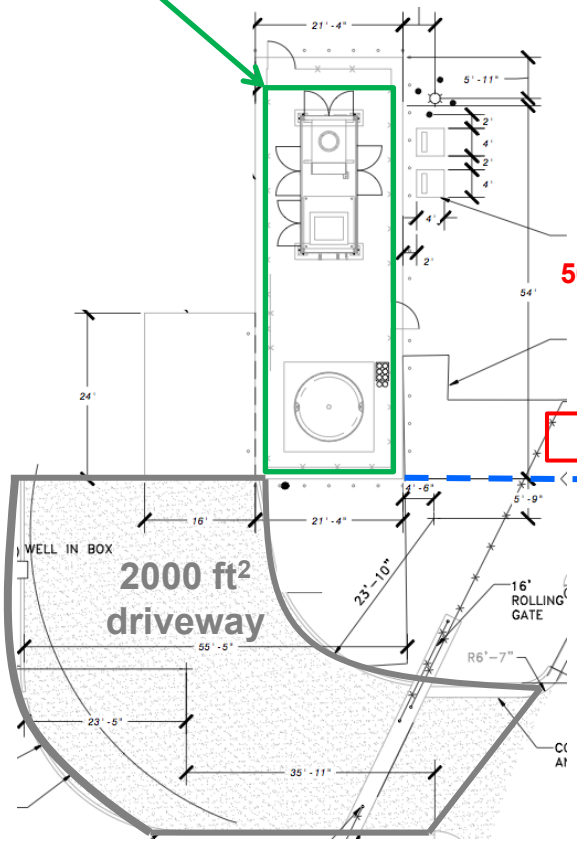
4/1 Raised pad forms



875 bar pump, 800 kg Dewar

3/20 Equipment pad preparation

4/3 LH_2 pump arrival

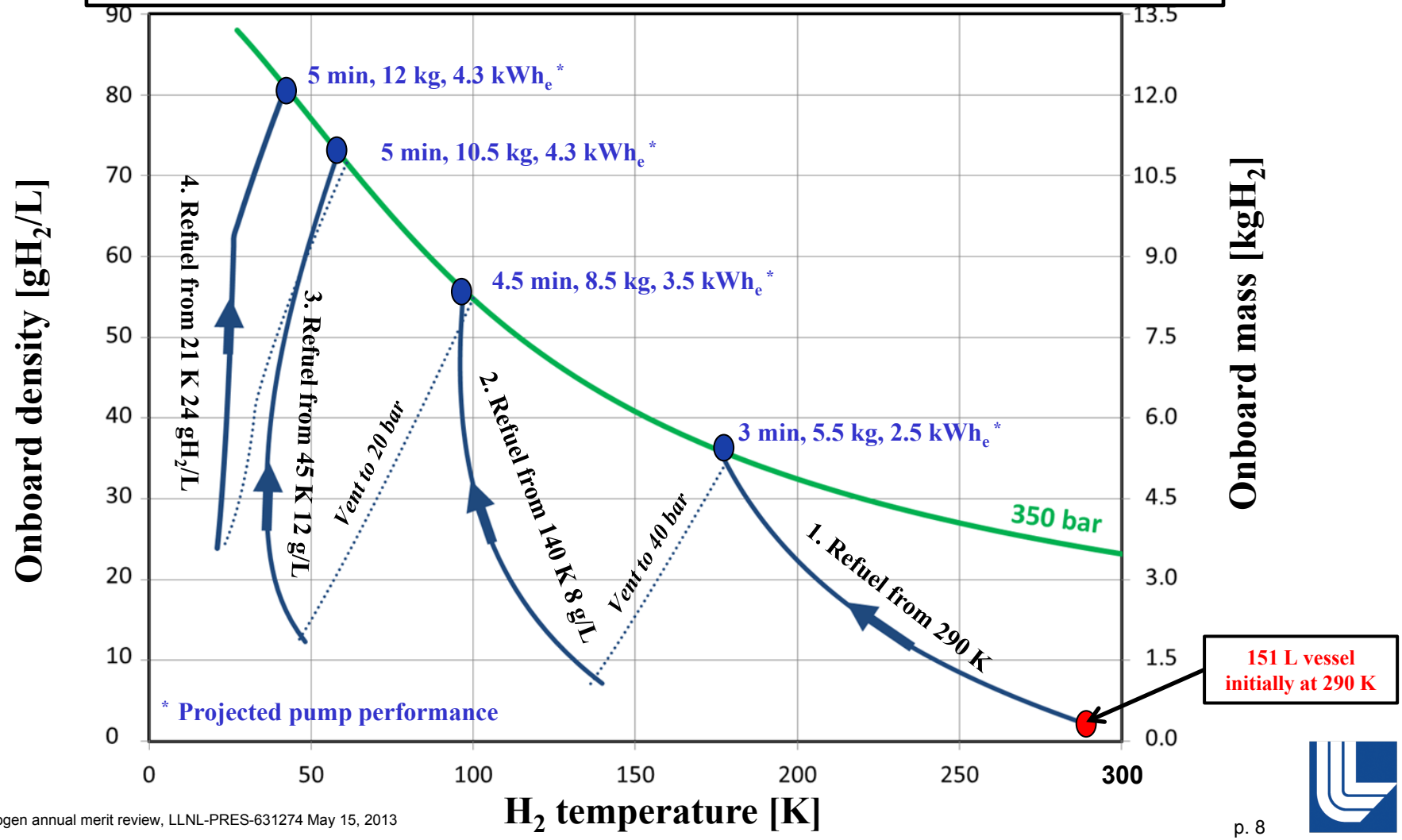


3/11 water/communication trench

3/6 asphalt and fence demolition, tree removal

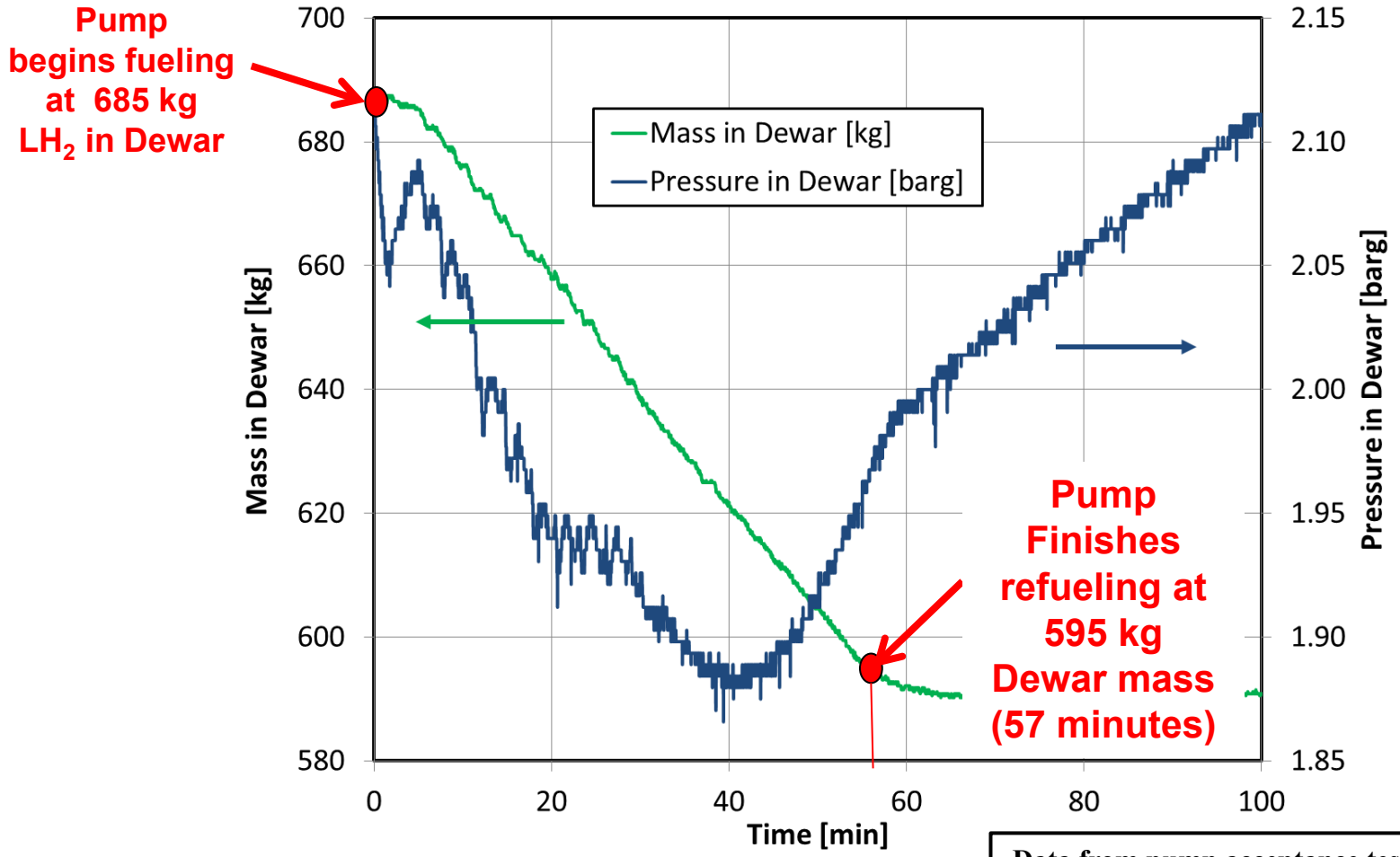
Planned FY13 work: Measure pump performance at 350 bar delivery (onboard refueling)

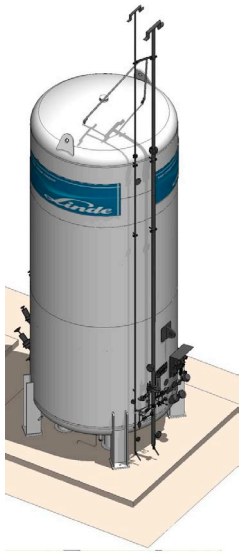
For a full range of initial vessel temperatures (20-300K), measure pressure, temperature and power during fueling, and calculate H_2 flow rate, electrical efficiency, & density



Planned FY13 work: Measure pump performance at 350 bar delivery (Dewar boil-off)

Inferring change in boil-off rate before and after pumping may be difficult because 1) signal to noise ratio is low 2) gas and liquid phases in Dewar are not in equilibrium





Data from pump acceptance test (10/15/2012, Linde, Germany)

Future proposed FY14 work: Characterize LH_2 pump to maximum pressure

Design and (over)build experimental apparatus for highly accurate, rapid response H_2 density measurements up to 875 bar

Comprehensive testing of LH_2 pump up to 875 bar within an outdoor pressure cell and/or onboard a vehicle

- **Independent measurements of temperature and density**
- **Cryogenic cycling capability if desired**
- **Determine key refueling variables vs. pressure and time**
  - **Refueling speed**
  - **Delivery temperature (isentropic efficiency[1])**
  - **Electrical efficiency[2]**

1. Ideal compression work/actual compression work, 2. kWh_e/kgH_2,

Collaboration with global leaders

- ***Linde:*** **World class cryogenics experience. Manufactures maximum efficiency LH_2 pump. Delivered first commercial system to BMW in 2009 (300 bar). Very cooperative, sharing detailed information throughout LH_2 pump development, construction and installation.**
- ***BMW:*** **Long standing collaboration with LLNL through cryogenic pressure vessel CRADA. Contributing technical information and expertise. Advancing cryogenic pressure vessel technology and preparing demonstration vehicles**
- ***Spencer Composites (Sacramento, CA)*****: Expertise in custom composite pressure vessel development. Collaborated with LLNL previously on cryogenic vessels for H_2 delivery**

Summary: 875 bar LH_2 pump can refuel onboard H_2 storage rapidly, efficiently, and to very high densities

- *H_2 fueling limited by onboard heating, forecourt power & capital*
- *LH_2 pumping offers fundamental thermodynamic advantages*: **maximum refueling density, lowest theoretical refueling work, refueling speed not limited by heating**
- *Pump installation under way, experimental vessel and refueling hose ready:* **LLNL and Linde will conduct first LH_2 pump shakedown test in two weeks.**
- *Planned experiments characterize key aspects of LH_2 pump:* ***H_2* flow rate, efficiency and boil-off**
- *Need higher pressure vessel (875 bar) to test full pump capability:* **flow rate, evaporation rate, maximum refuel density**

Supplemental slides

Main budget items are concrete pads and power lines. Construction began 1 March, equipment installation 22 April, driveway paving on 9 May, first refuel scheduled for 30 May

concept	Labor	Matl's	Total
Demolition (asphalt, fences)	**26**	**0**	**26**
300 ft. 13600 volt overhead power line	24	44	68
Low voltage work, grounding, panels	41	42	83
Pull cables and make terminations	50	0	50
480 Volt 500 kVA transformer	26	27	53
200 ft. data & communication line	5	2	7
Total electrical and power lines	**146**	**115**	**261**
40 4" Bollards	30	5	35
2000 ft^2 Concrete pads, curbs	54	15	69
150 ft. trenching and excavation	55	0	55
150 ft. water line and bib	14	2	16
50 ft. New fences & rolling gates	23	10	33
2000 ft^2 New roadway	39	12	51
Total civil work	**215**	**44**	**259**
Supervision	**40**	**0.0**	**40**
Total	**427**	**159**	**586**
Contingency			**75**
Total with contingency			**661**