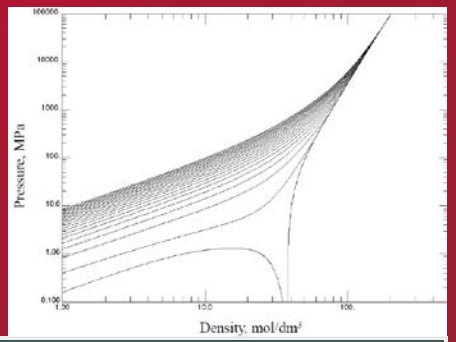
Cryocompressed Hydrogen Storage & Liquid Delivery

Jacob Leachman, Ph.D.
Assistant Professor

DOE H_2 Transmission & Delivery Workshop
2/26/2014



REFPROP
Reference Fluid Thermodynamic and Transport Properties

NIST Standard Reference Database 23, Version 9.1
DLL version number 9.1
E.W. Lemmon, M.L. Huber, and M.O. McLinden
Applied Chemicals and Materials Division

Hydrogen **Y**roperties for **P**nergy **E**search **R**

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

WASHINGTON STATE UNIVERSITY
World Class. Face to Face.

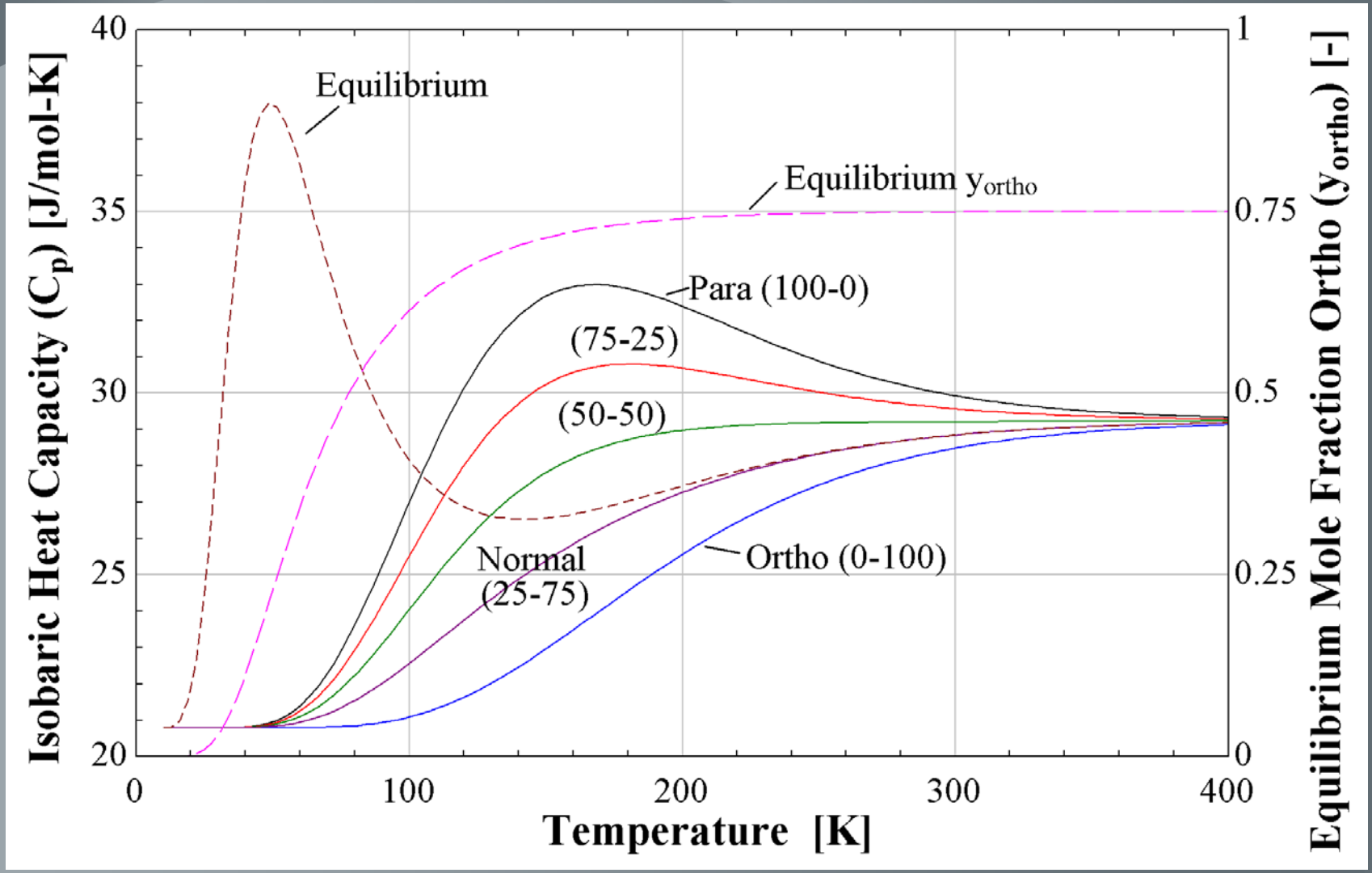
Why Cryogenic Hydrogen?

- *LH_2 tanker trucks delivered 80-90 % of total small merchant H_2 in 2010.[1]*
- *Cryo-H_2 densities are superior.[2]*
  - *LH_2 at NBP is 70.8 g/L*
  - *Cryocompressed at 440 bar and 30 K is 90 g/L*
  - *Gaseous at 700 bar and 295 K is 39.7 g/L*

- *Cryo-H_2 fill rates are substantially faster than gas.*
  - *No on-board cooling required*
- *Big downside: 30 % of usable energy lost to liquefaction.[1]*
  - *Liquefaction energy can be recouped via autogenous pressurization*
  - *Many cryo-challenges remain*

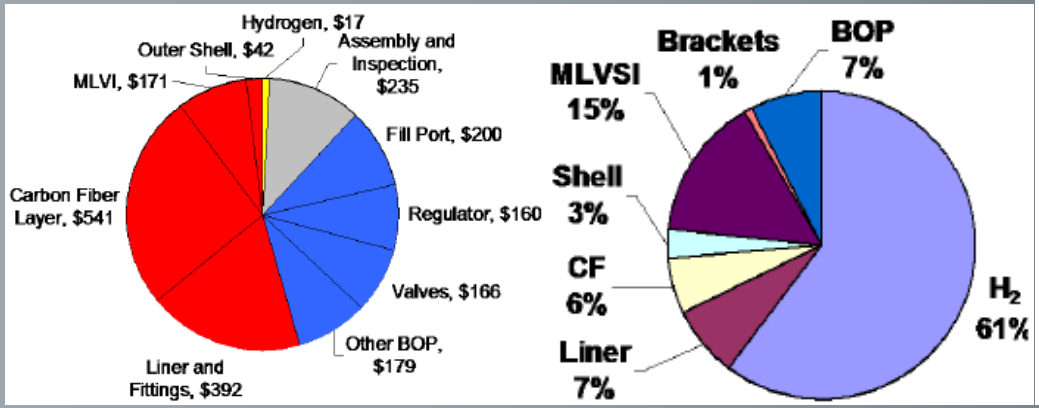
[1] *National Hydrogen Association, Hydrogen and Fuel Cells: The U.S. Market Report,* (2010)
[2] REFPROP v. 9.1 NIST (2013)

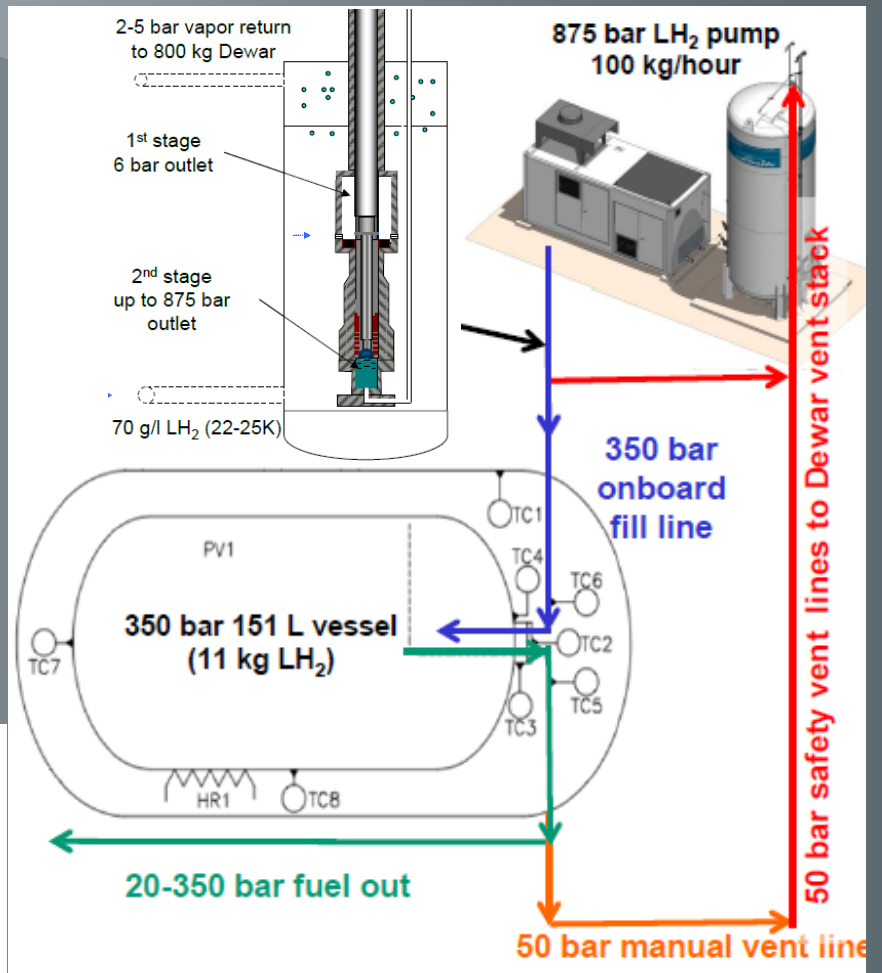
Para, Normal, & Ortho Hydrogen



Cryo Storage Challenges

- *Cryocompression pump demonstration to 875 bar underway.[1]*
  - *Linde & BMW partnering with LLNL*
- *Reducing Type 3-5 tank volume and cost.[2]*
  - *Novel ideas needed to improve carbon fiber synthesis, insulation, cold thermal mass, & liners*

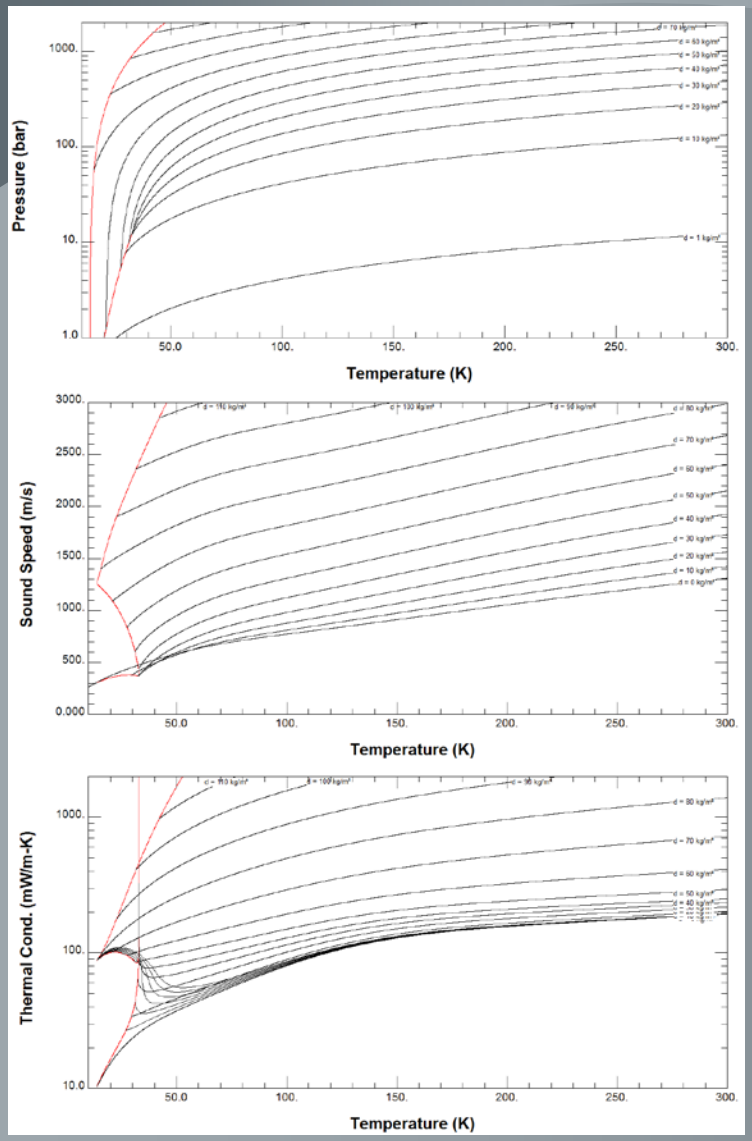




(above) Cryocompressed H_2 distribution concept.[1]
(left) 5.6 kg Cryocompressed H2 tank cost estimate.[2]
(center) 5.6 kg Cryocomp. tank volume distribution.[2]

[1] Aceves et al. "Rapid High Pressure LH2 Refueling for Maximum Range & Dormancy" DOE AMR (2013)
[2] Ahluwalia, Hua, & Peng, DOE H2 Distribution & Transmission Workshop (2011)

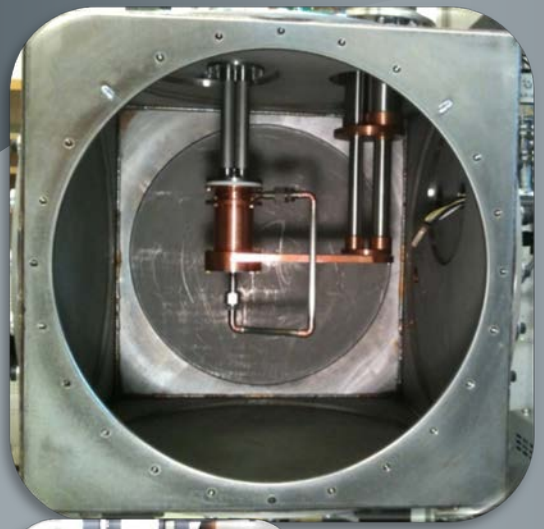
Cryo Delivery Challenges



- *Cryo H_2 Flow Metering*
  - *Bulk weighing is typical for mass gauging but not a long term solution*
  - *Accurate + low cost flow meters needed!*
  - *Ortho-para mixtures, very low viscosity and density confound traditional meters*
  - *Short property standards for cryo custody exchange needed (current >200 K)*
- *Cryo H_2 Component Safety*
  - *Lower cost and accelerated testing in LH_2 needed*
    - *Thermal and mechanical fatigue testing*
    - *High pressure and impact testing*
    - *Failure Modes & Effects Analysis (FMEA)*
- *Streamline Technology Readiness Level (TRL) advancement to reduce cost*

[1] REFPROP v. 9.1 NIST (2013)

Current Research: Advancing H_2 TRL @ lower cost



- *Solid H_2 Twin-Screw Extruder performance for US ITER ~ $67k*
- *Para-ortho conversion enhanced vapor cooled shielding ~ $66k*
- *1st dual-sinker magnetic levitation balance for cryogenic density & sorption ~ $100 k*
- *Genii UAV – 1st LH_2 drone built by students ~ $30 k*

Thank you!