Cryocompressed Hydrogen Storage & Liquid Delivery

Jacob Leachman, Ph.D.
Assistant Professor
DOE H₂ Transmission & Delivery Workshop
2/26/2014

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

$^2$ REFPROP v. 9.1 NIST (2013)
Para, Normal, & Ortho Hydrogen

![Graph showing the isobaric heat capacity ($C_p$) and equilibrium mole fraction of ortho ($y_{ortho}$) versus temperature [K].](image)
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

² Ahluwalia, Hua, & Peng, DOE H2 Distribution & Transmission Workshop (2011)
Cryo Delivery Challenges

- **Cryo H₂ 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 H₂ Component Safety**
  - Lower cost and accelerated testing in LH₂ 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 H₂ TRL @ lower cost

• Solid H₂ Twin-Screw Extruder performance for US ITER ~ $67k
• Para-ortho conversion enhanced vapor cooled shielding ~ $66k
• 1\textsuperscript{st} dual-sinker magnetic levitation balance for cryogenic density & sorption ~ $100 k
• Genii UAV – 1\textsuperscript{st} LH₂ drone built by students ~ $30 k

Thank you!