

Thermophysical Properties of Hydrogen as an Energy Carrier

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Presentation Outline

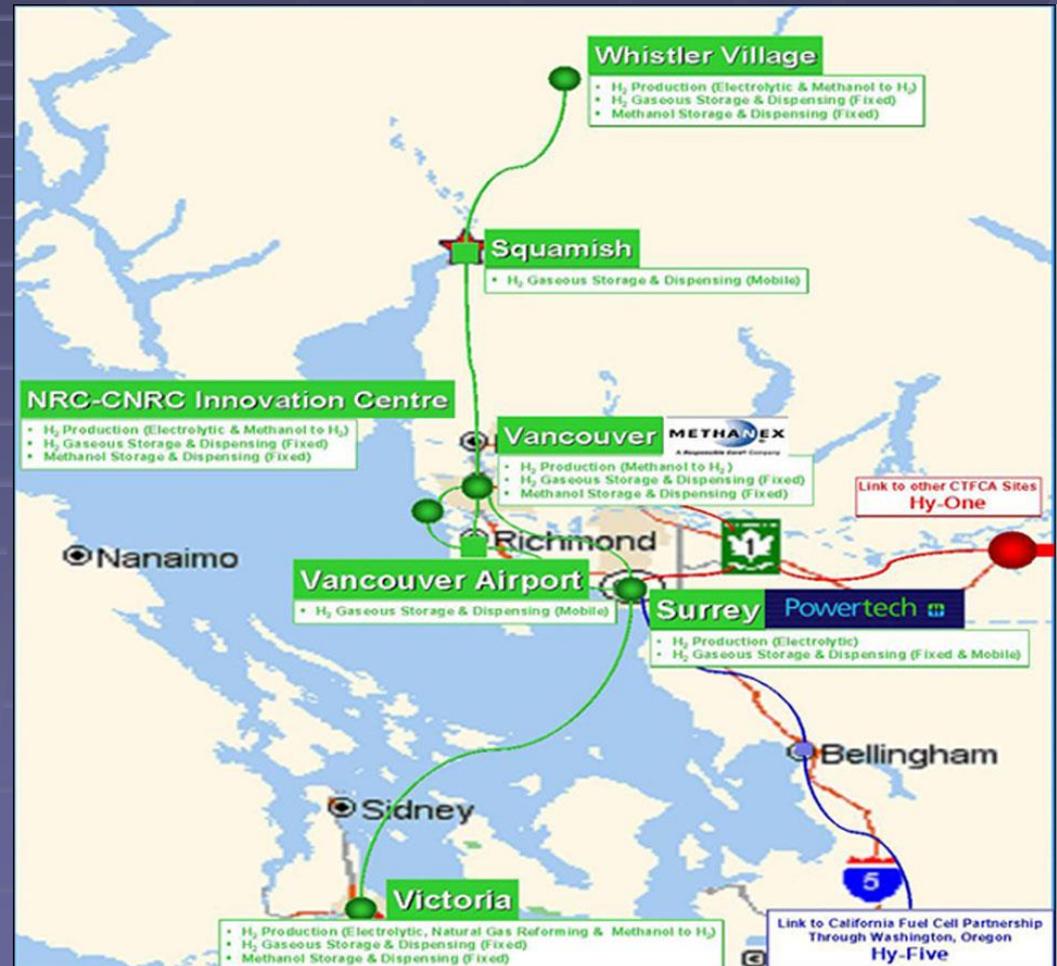
- Our energy future
- Hydrogen production, storage, and use
- Role of thermophysical properties in design
- Status of current property data and formulations
- Future research

Our Energy Future

- World energy demand increasing in China, India and other developing countries
- Middle Eastern countries controlling the supply of oil
- Gasoline prices at the pump -- \$3.00 per gallon or more
- President Bush's 2003 Hydrogen Fuel Initiative
 - \$289.5 million requested for FY 2007

Hydrogen Implementation

- Vancouver Hydrogen highway infrastructure
 - In operation by 2010 Winter Olympics



Hydrogen Implementation

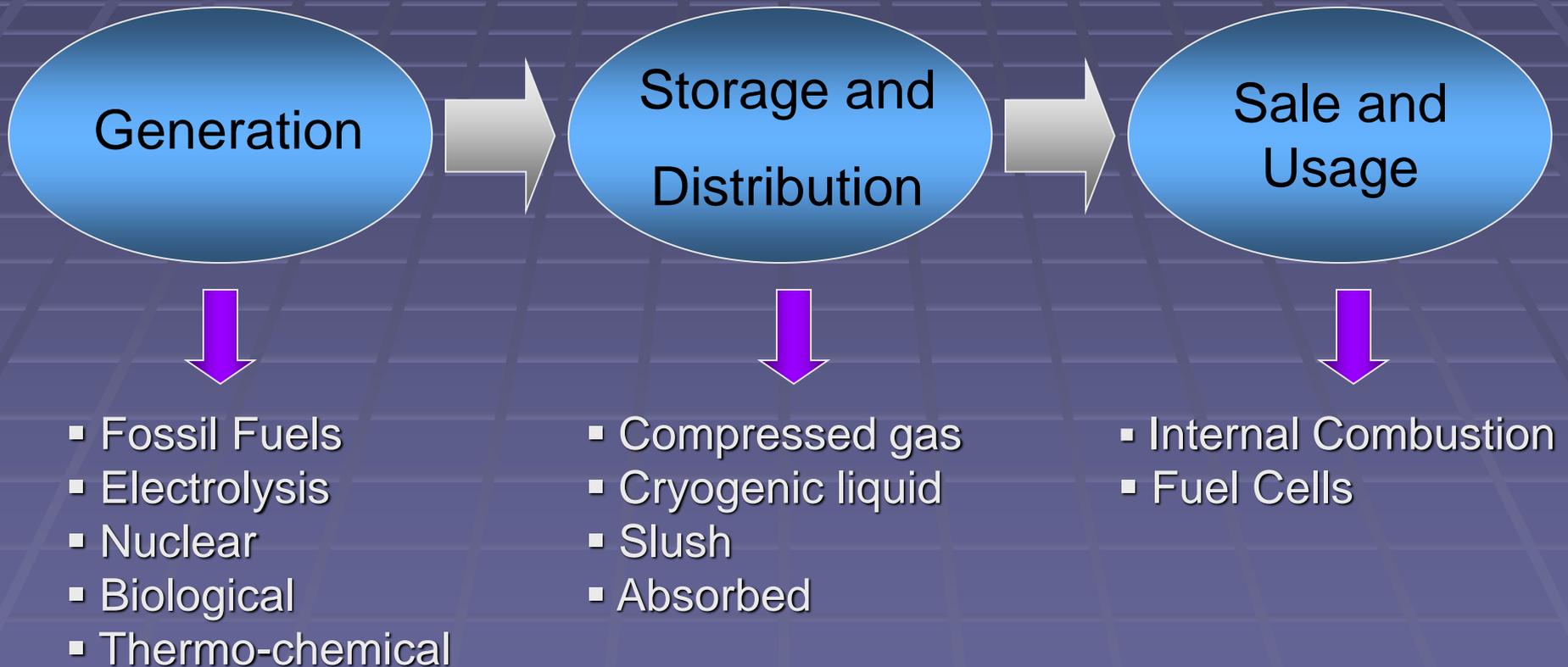
- California Hydrogen highway infrastructure
 - 13 existing stations
 - 170 stations in operation by 2010
 - Over 60 cars in operation



What's Hydrogen?

- Most abundant element in the Universe
 - 75% of all mass, 90% of all atoms
- Colorless, odorless, tasteless gas
- Diatomic molecule
- An energy carrier or fuel
- Does not exist in pure form on earth

The Hydrogen Supply



Supplier and Consumer Questions

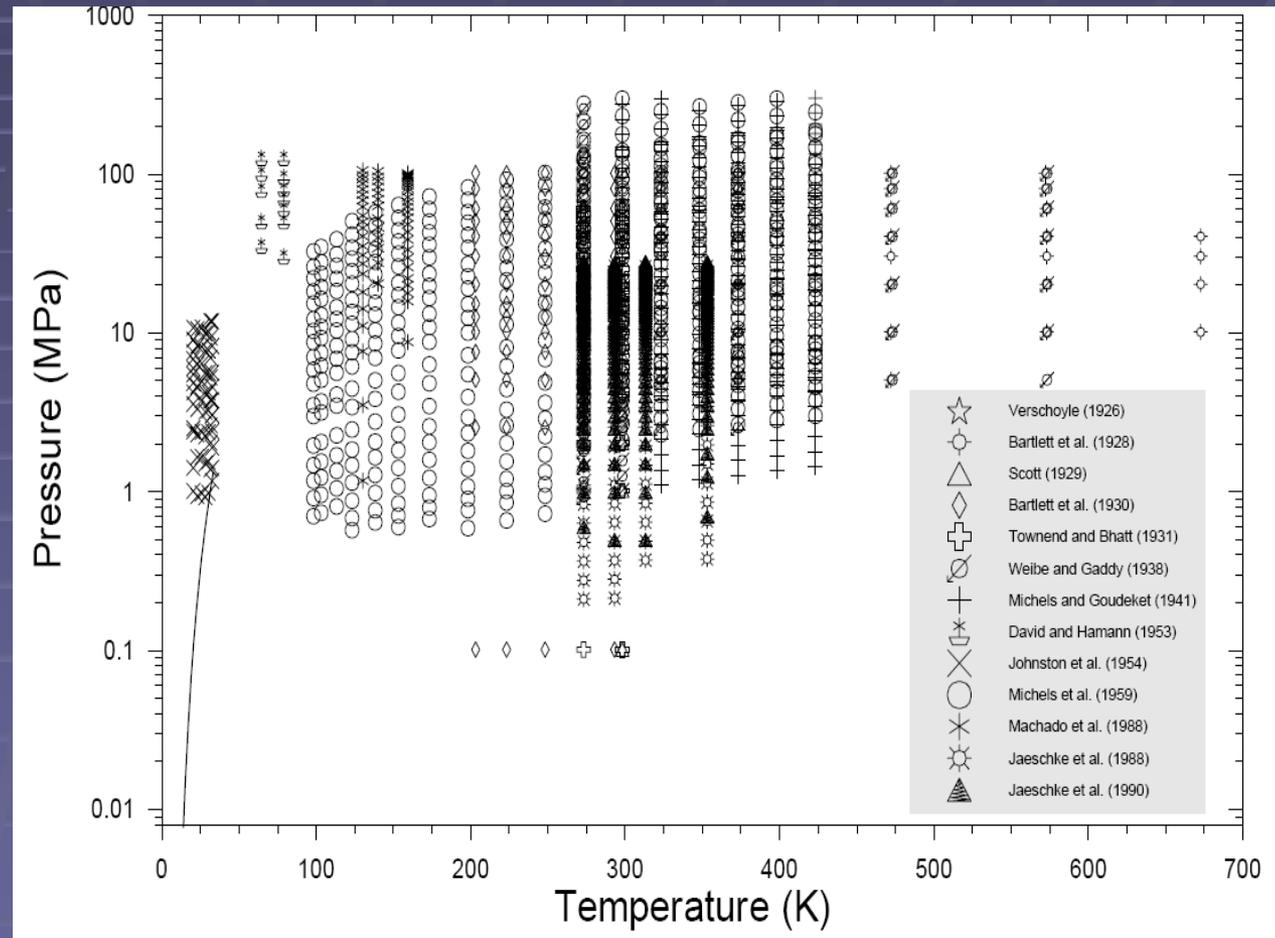
- Safety?
- Efficiency?
- Costs of buying and selling?
- Answer: Well designed systems.

Design of Hydrogen Systems

- Require accurate properties of hydrogen
- Custom experimental measurements not practical
- All thermodynamic properties from an Equation of State (EOS)
- All transport properties from a separate formulation
- EOS and transport formulations model published experimental data

EOS Formulation

- EOS are created by fitting experimental data
- Data maps show existing experimental data
- Temperature scales must be updated
- Equations are limited by the range and accuracy of experimental data

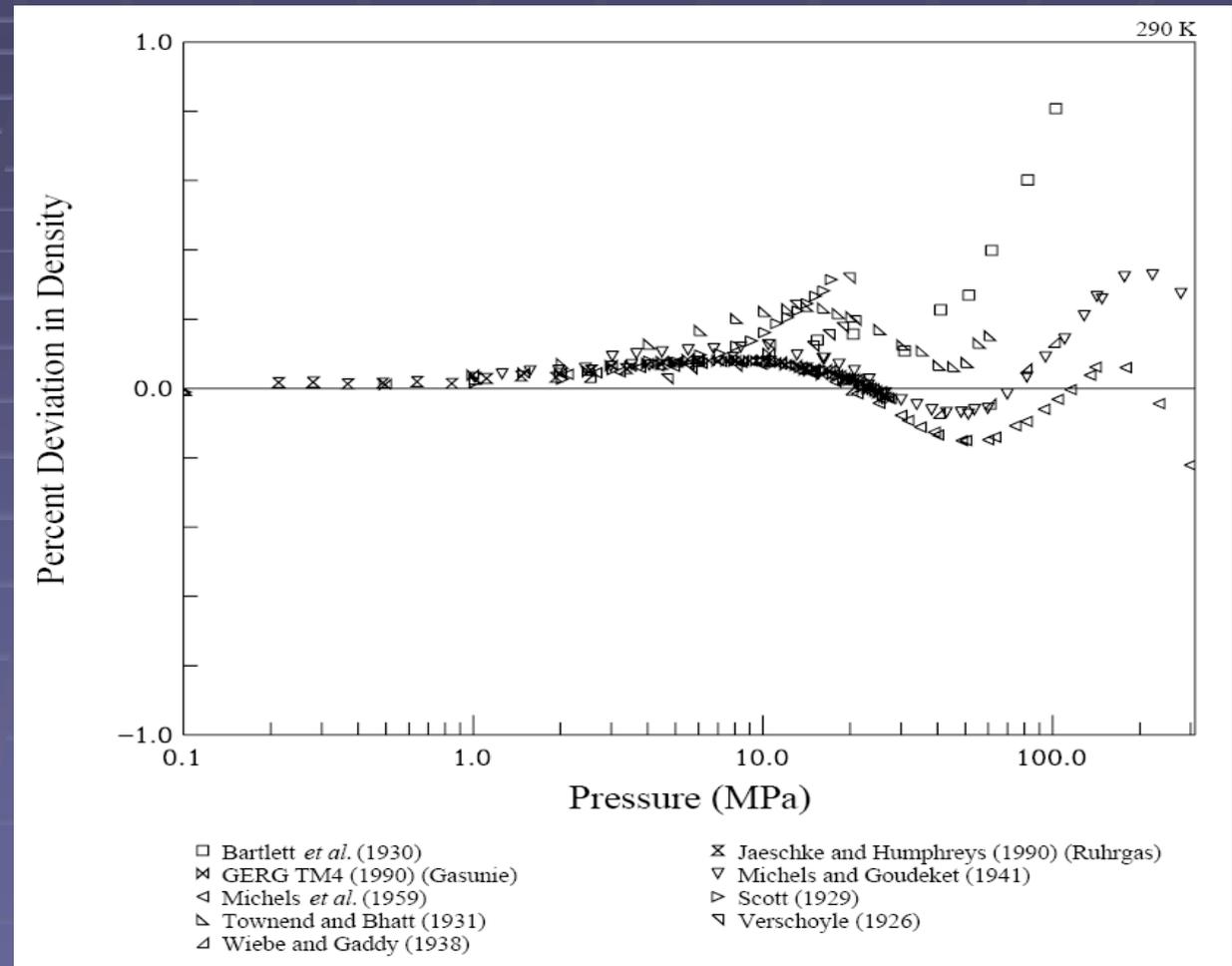


Normal Hydrogen Data Map P-v-T

EOS Formulation

- Deviation plots compare EOS to experimental data
- Deviations represent flaws in the EOS
- Uncertainty based on EOS deviations from experimental data

$$\% \text{ deviation in density} = 100 * (\rho_{\text{data}} - \rho_{\text{calc}}) / \rho_{\text{data}}$$



Normal Hydrogen Deviation Plot

Standard Hydrogen EOS Accuracies

- Hydrogen standard EOS from 1982
- Methane standard EOS from 1991 has better accuracies

<u>Property</u>	<u>Estimated Uncertainty in Normal Hydrogen and Methane EOS</u>			
	<u>Liquid H₂</u>	<u>Vapor H₂</u>	<u>Supercritical H₂</u>	<u>Methane</u>
Density	0.1%	0.25%	0.2%	0.03-0.07%
Heat Capacity	3%	3%	3%	<1%
Speed of Sound	2%	1%	1%	0.03-0.3%
Viscosity	4-15%	4-15%	4-15%	0.5-2%
Thermal Conductivity	1-10%	1-10%	1-10%	2-10%

Importance of Accuracy

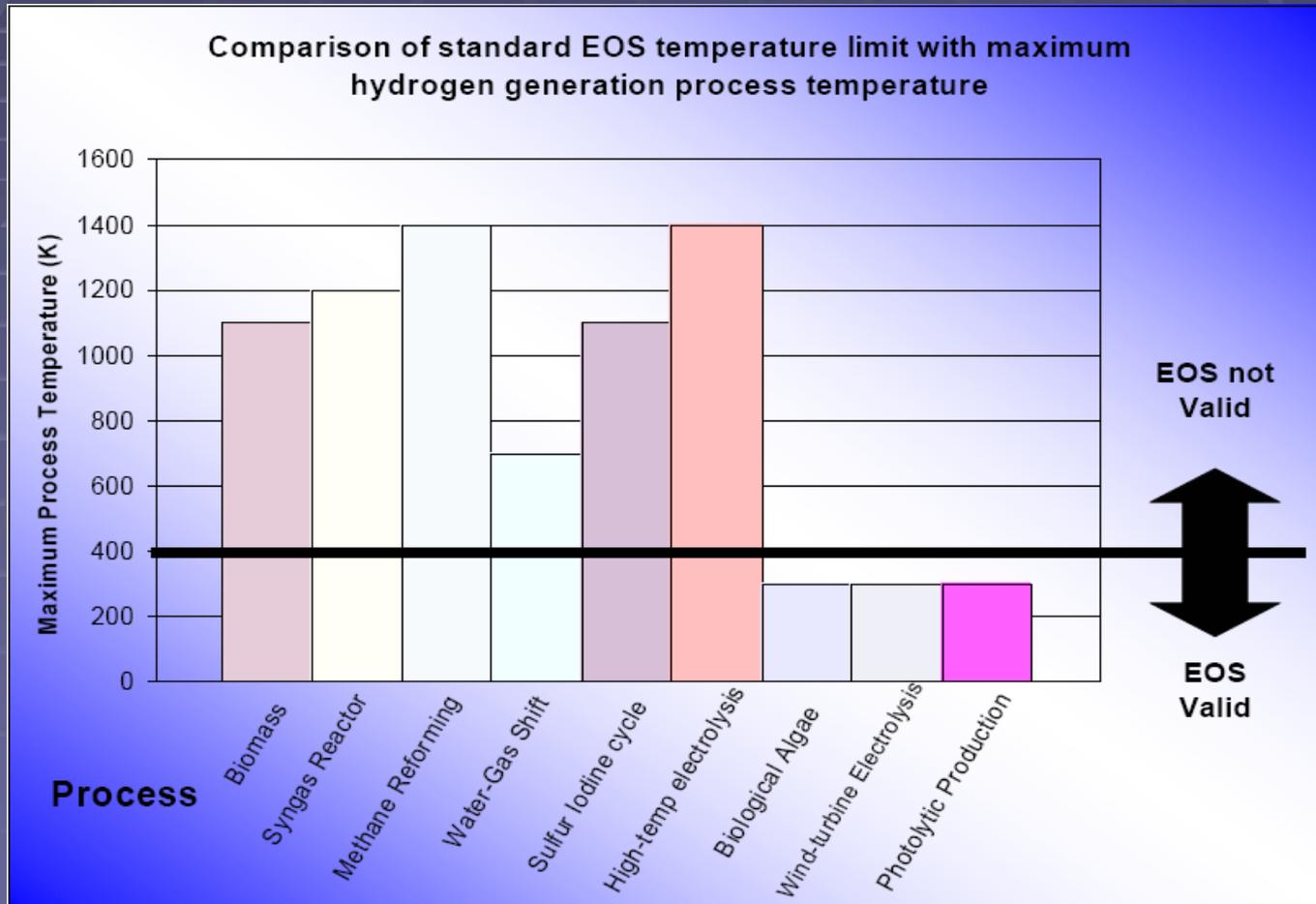
- U.S. used 440 million gallons of gasoline daily in 2004
 - 1 gallon of gasoline \approx 1 kg of hydrogen
 - Gasoline \$2.50 per gallon and fluctuating
 - 0.2% uncertainty in density calculation
 - \$2.2 million discrepancy in gross product sale every day

$(440 \text{ million gallons of gas}) * \$2.50 = \$1.1 \text{ billion}$

$(\$1.1 \text{ billion}) * (.002) = \underline{\underline{\$2.2 \text{ million discrepancy}}}$

Standard Hydrogen EOS Limits

- Upper temperature limit of 400 K



Hydrogen: 2 different molecules

Molecular Hydrogen – H₂



orthohydrogen

higher energy state
cannot exist in pure form

Normal
3 : 1

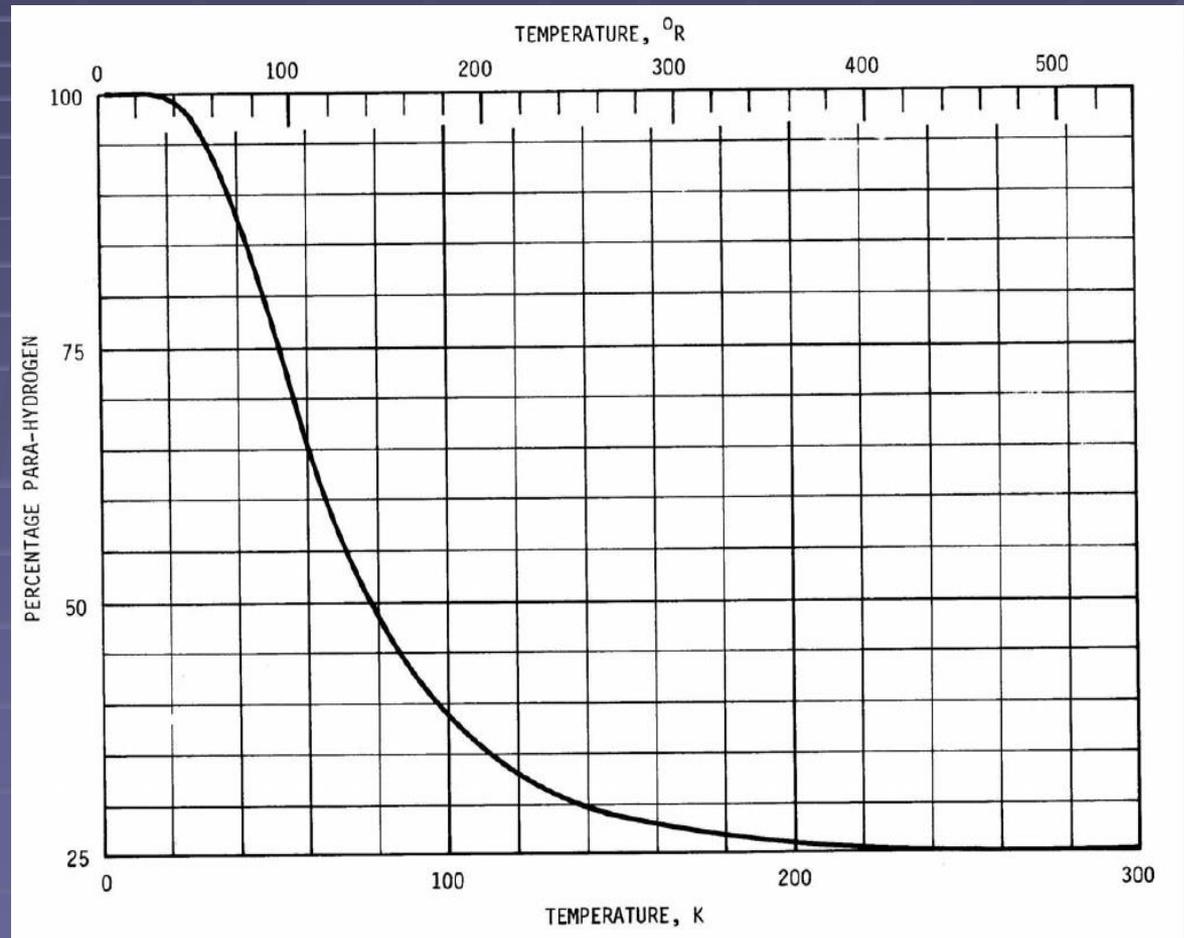


parahydrogen

lower energy state
can exist in pure form

Equilibrium Hydrogen

- Percentage of parahydrogen in equilibrium mixture
- Predicted by quantum mechanics and statistics

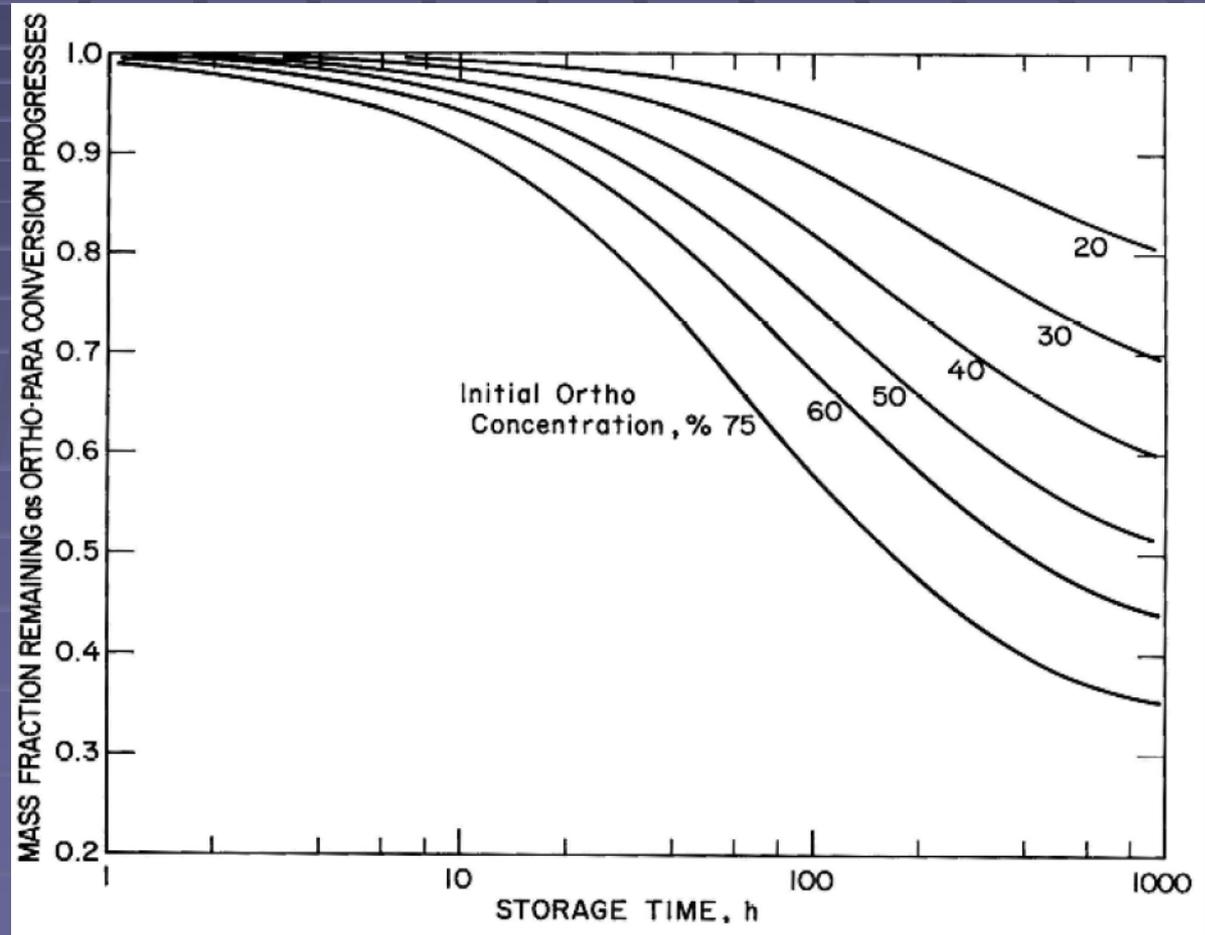


Modeling the Hydrogen Forms

- The different forms have different thermophysical properties
 - Ideal gas behavior predicts differences
- Two different EOS exist
 - Parahydrogen EOS (pure fluid)
 - Normal hydrogen EOS (treats normal hydrogen mixture as pure fluid)
- No mixture EOS exists for parahydrogen and orthohydrogen

Storage Behavior

- Conversion between forms causes energy change
- Energy change greater than the latent heat of vaporization



CATS Research

- Survey of published hydrogen properties
 - Over 200 hydrogen property papers identified
- Status of standard formulations for both thermodynamic and transport properties
- An orthohydrogen EOS
 - Mix orthohydrogen with parahydrogen
- Updated property formulations

Conclusions

- Accuracy of hydrogen EOS must be increased
- New hydrogen EOS must be accurate at high and cryogenic temperatures
- Hydrogen mixture EOS must be created

Questions?



Source: General Motors Corporation