Overview

Timeline
• Project start date Oct. 2003
• Project end date Sept. 2015
• Percent complete 50%

Barriers & Targets
• Barriers and targets addressed
  – Materials reference guide for design and installation
  – Hydrogen storage tank standards for portable, stationary and vehicular use
  – Insufficient technical data to revise standards

Budget
• Total project funding (to date)
  – DOE share: $3.8M
• FY08 Funding: $1.1M
• FY09 Funding: $0.9M
  (* R&D core, no IEA contracts)

Partners
• Interactions/Collaborations:
  – ASME, CSA, ISO
  – Swagelok, Fibatech
  – DOE Pipeline Working Group
  – HYDROGENIUS (AIST/Kyushu University, Japan)
Objectives

• Enable development and implementation of codes and standards for H$_2$ containment components
  – Evaluate data on mechanical properties of materials in H$_2$ gas
    • “Technical Reference on Hydrogen Compatibility of Materials”
  – Generate new benchmark data on high-priority materials
    • Pressure vessel steels, stainless steels
  – Establish procedures for reliable materials testing
    • Sustained-load cracking, fatigue crack propagation

• Participate directly in standards development
  – Structural design standards
    • ASME Article KD-10
  – Materials testing standards
    • Automotive components
Milestones

• Add/update chapters on stainless steels and precipitation-strengthened aluminum alloys in Technical Reference (FY08 Q4 and FY09 Q1; complete)

• Complete cracking threshold measurements on Ni-Cr-Mo pressure vessel steel (FY08 Q3; complete)

• Complete fatigue crack growth measurements on Ni-Cr-Mo vessel steel (FY08 Q4; in progress, expected FY09 Q3)

• Evaluate specimen designs for cracking threshold measurements of ferritic steels (FY09 Q2; complete)

• Compare fatigue crack growth data for stainless steels tested in H₂ gas vs H-precharged condition (FY09 Q2; in progress, expected FY09 Q4)

• Compare cracking threshold to fracture toughness measurements for vessel steels (FY09 Q3; complete)
Approach

• **Applied research**
  - Conduct materials testing to address voids in data base
    - Emphasize high $\text{H}_2$ gas pressures (>100 MPa)
    - Apply test methods in ASME Article KD-10 (i.e., fracture mechanics)
    - Prioritize hydrogen-assisted fatigue crack growth
  - Critically review data to assess test methods
    - Ensure laboratory testing reveals material response for component
    - Evaluate variables that affect materials test methods

• **Standards development activities**
  - Provide feedback on ASME Article KD-10 based on results from materials testing
  - Develop ideas for materials testing standards applied to automotive components
Technical Reference for Hydrogen Compatibility of Materials

- Additional/updated chapters in FY08-FY09
  - “Stabilized” austenitic stainless steels (i.e., 321 and 347)
  - Duplex stainless steels (updated with Sandia data)
  - Precipitation-strengthened aluminum (2xxx and 7xxx)

- Future chapters
  - Nickel alloys
    - Update chapters on ferritic steels with Sandia data

- www.ca.sandia.gov/matlsTechRef

Stakeholders (industry, SDOs, etc.) provide input on priority materials and receive completed products
Measurement of thresholds ($K_{TH}$) for Ni-Cr-Mo steels completed

- $K_{TH}$ measurements required in ASME Article KD-10
- Lower-strength variation of SA372 Gr. L may be attractive for thick-walled $H_2$ pressure vessels
Unexpected $K_{TH}$ trend may be influenced by specimen features

Long cracks (large $a/W$) result from high initial load ($K_0$)

$K_{TH}$ not independent of $K_0$

$K_{TH}$ values must represent reliable lower bounds to ensure safe design of $H_2$ containment vessels.
Modified specimen may yield lower $K_{TH}$ values

Chevron notch allows shorter initial crack lengths ($a_o$), leading to crack arrest further from back face.

Two test methods compared: 
“crack arrest” vs “crack initiation”

- Materials testing prescribed in ASME Article KD-10 (i.e., $K_{TH}$ measurements) appears non-conservative
- Results will be presented to ASME Project Team on Hydrogen Tanks
Fatigue crack growth measurements on vessel steel

Industry partner using fatigue data to design $H_2$ pressure vessel according to ASME Article KD-10
Fatigue crack growth measurements on stainless steel

Materials testing standards must address effect of load cycle frequency on fatigue cracking rates

Fatigue Crack Growth of Strain-Hardened 316 SS

Alloy D: 12% Ni
Alloy E: 13% Ni

~140 wppm hydrogen
Future Work

Remainder of FY09

• Add/update Technical Reference chapters on nickel-based alloys and ferritic steels (Q3 and Q4 milestones)
• Evaluate the effects of load cycle frequency on fatigue crack growth rate of ferritic steels in H₂ gas (Q3 milestone)
• Compare fatigue crack growth data for stainless steels tested in H₂ gas vs H-precharged condition (Q2 milestone in progress)
• Develop reliable methods for measuring fracture response of aluminum alloys in H₂ gas (Q4 milestone)
• Engage domestic and international stakeholders to develop standards for pressure manifold components (i.e., fittings, regulators, etc.)

FY10

• Update Technical Reference chapters with Sandia data
• Evaluate effects of load cycle wave form on fatigue testing in H₂ gas
• Develop high- and low-cycle fatigue test methods for manifold component materials in H₂ gas
Summary

• Completed measurement of cracking thresholds (K_{TH}) for Ni-Cr-Mo pressure vessel steels in high-pressure H\textsubscript{2} gas
  – K_{TH} measurements required in ASME Article KD-10

• “Crack arrest” test methods appear to yield non-conservative results compared to “crack initiation” test methods
  – Proposal to insert “crack initiation” test methods in Article KD-10 will be presented to ASME Project Team on Hydrogen Tanks
  – “Crack initiation” methods require test apparatus designed for dynamic loading of specimens in H\textsubscript{2} gas

• Demonstrated ability to measure fatigue crack growth of pressure vessel steels in high-pressure H\textsubscript{2} gas
  – Fatigue crack growth data in H\textsubscript{2} required in ASME Article KD-10
  – Test apparatus is one of few in U.S. or abroad for measuring fatigue crack growth in >100 MPa H\textsubscript{2} gas