

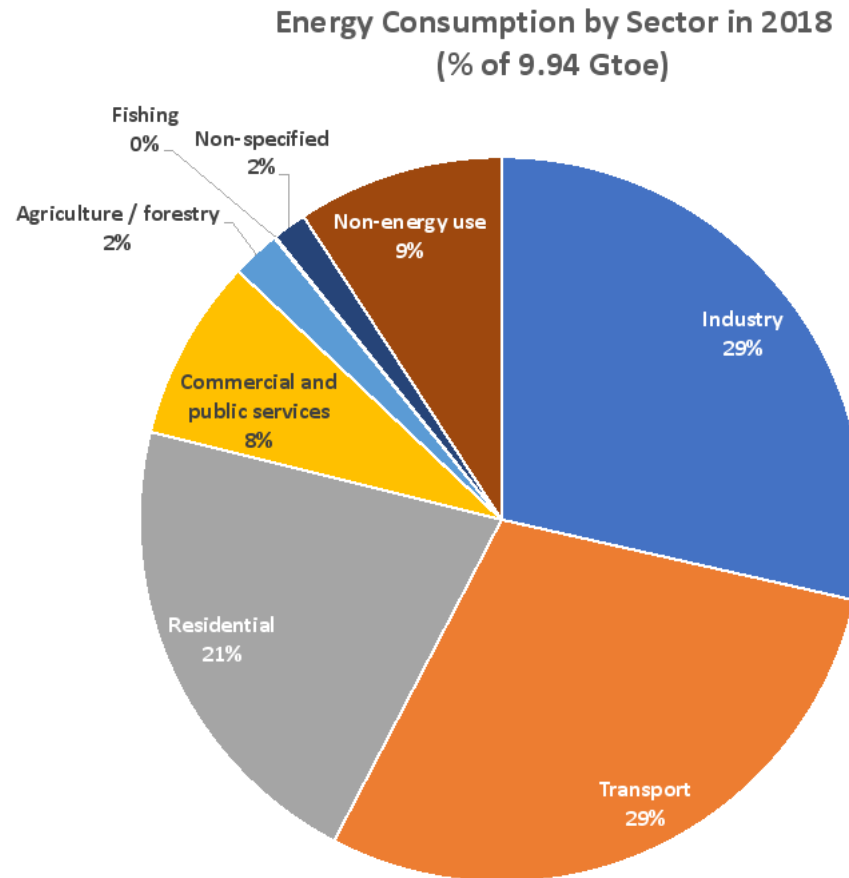
Hydrogen Compatible Materials Workshop

December 2 & 3, 2020

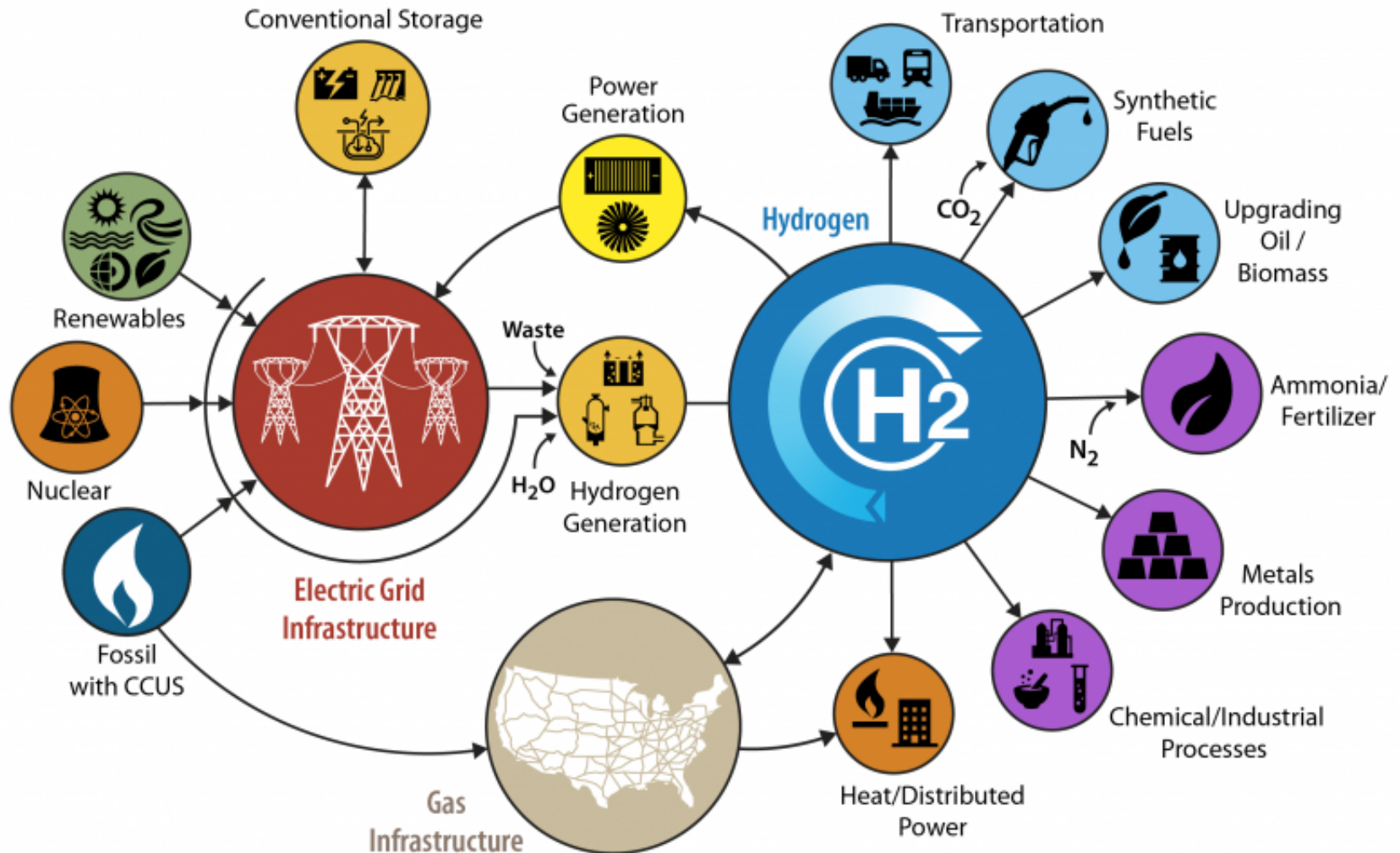
Jonathan Zimmerman
Hydrogen and Fuel Cells Program Manager
Sandia National Laboratories

The world's energy needs have never been larger

- Largest consumption sectors are transportation, industry and residential

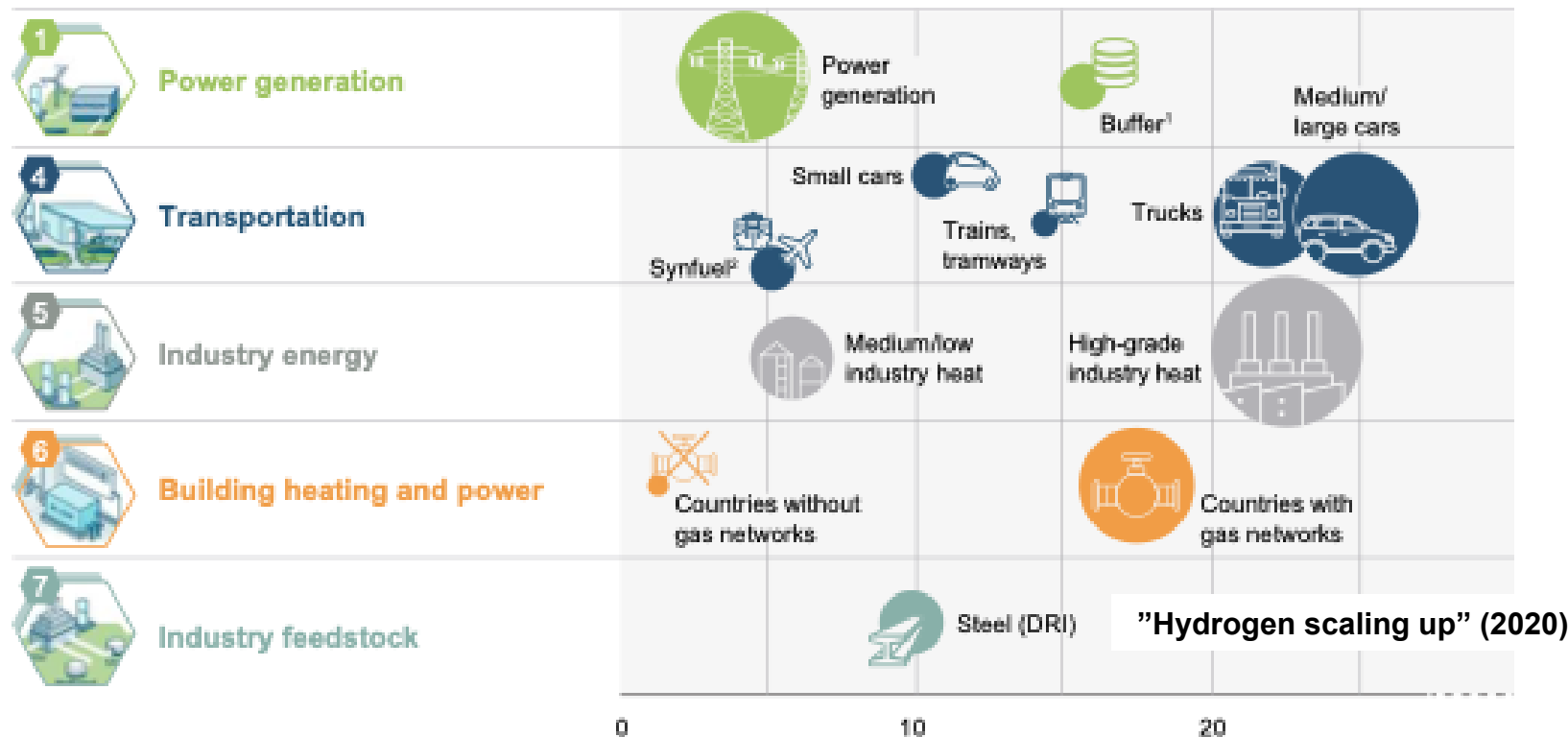


Hydrogen's potential is understood through the H₂@Scale concept – a vision for hydrogen energy



Roadmaps have identified opportunities and barriers for hydrogen deployment across technologies

- USDRIVE Technical Team Roadmaps for H₂ Production, Delivery, Storage, C&S (2017)
- **Hydrogen scaling up**, Hydrogen Council (2017)
- **Renewable Hydrogen Production: Roadmap for California**, UC-Irvine (2020)
- **Path to hydrogen competitiveness: A cost perspective**, Hydrogen Council (2020)
- **Road Map to a US Hydrogen Economy**, McKinsey & Company, FCHEA, EPRI++ (2020)
- **Hydrogen Strategy: Enabling a Low-Carbon Economy**, DOE-Fossil Energy (2020)



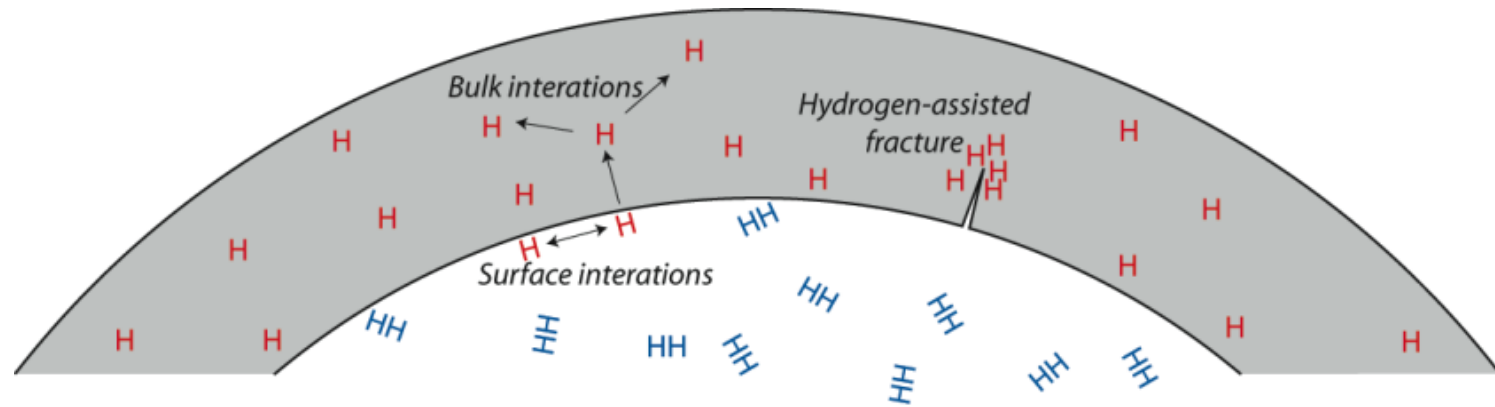


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- Themes on materials
 - Codes and standards that specify material requirements and testing procedures
 - Materials with resistance to hydrogen-induced fracture, fatigue and damage to avoid leakage
 - Manufacturing of specialized materials and components
 - Low-cost
 - Adaptable to heavy-duty applications and industrial uses

Materials and Hydrogen Compatibility

- Technical challenges are present in Production, Delivery (transportation & distribution), Storage, and Application of Hydrogen



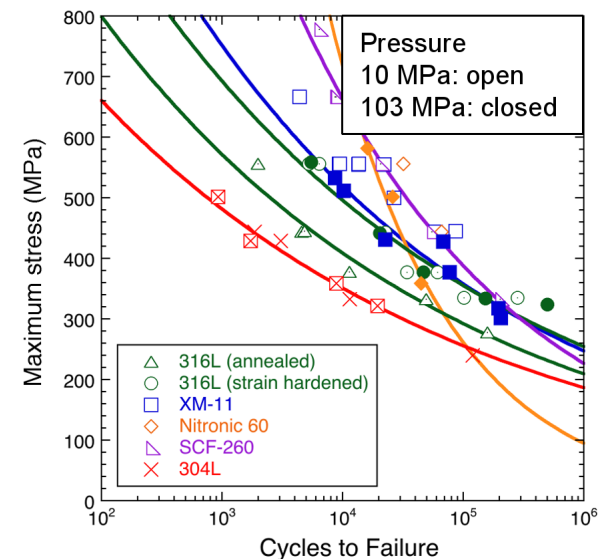
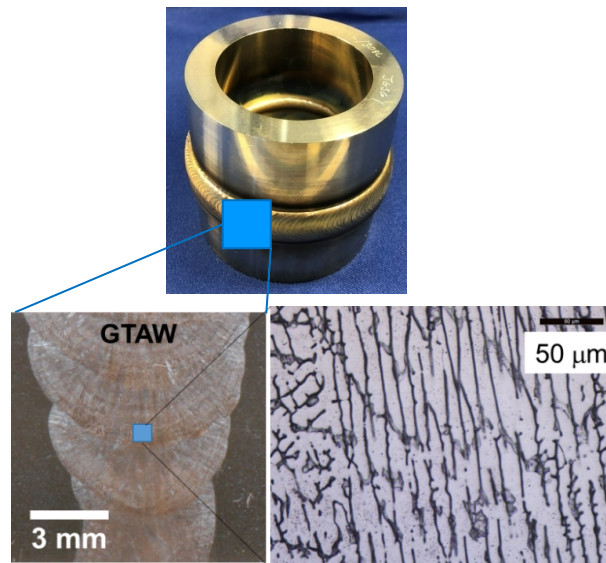
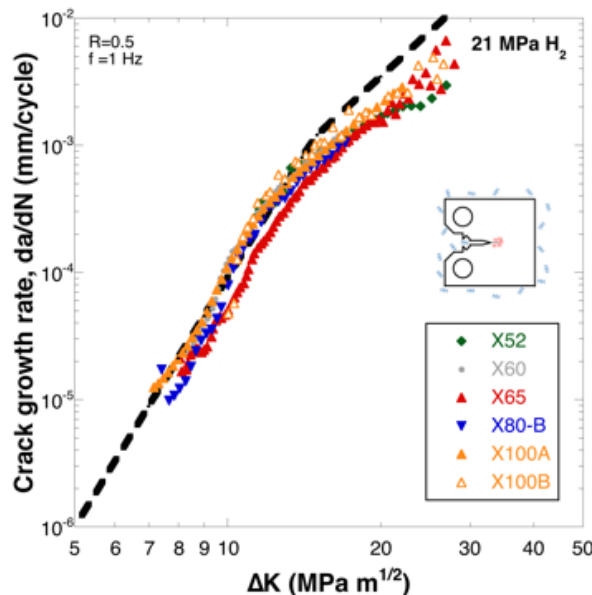
Rupture of hydrogen-containing metal tanks



Damage in polymer O-Rings after hydrogen gas exposure

Materials and Hydrogen Compatibility

- Concern over hydrogen effects has revealed knowledge gaps:
 - NG pipeline performance for fatigue and fracture resistance
 - Design requirements and operating conditions to avoid leakage at connection points (e.g. joints, valves, welds)
 - Manufacturing of materials and components with increased hydrogen resistance
 - Codes and safety standards that address variations of hydrogen use





Vision for Sandia's Hydrogen Research

- Focus on foundational-to-applied research uncovering the science of materials for hydrogen production, delivery, storage and use.
- Use our research to inform the safe, reliable use of hydrogen fuel cell technology.
- Partner with industry, codes & standards organizations, and international institutes and participate in demonstration applications to get scientific findings in the hands of practitioners.



HydroGEN
Advanced Water Splitting Materials



HyMARC
Hydrogen Materials Advanced Research Consortium



H-Mat
Hydrogen
Materials
Compatibility
Consortium

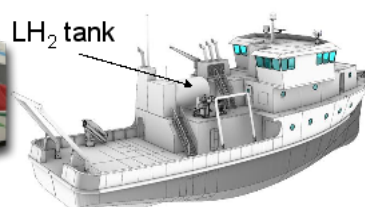
SM



HyRAM
HYDROGEN RISK ASSESSMENT MODELS

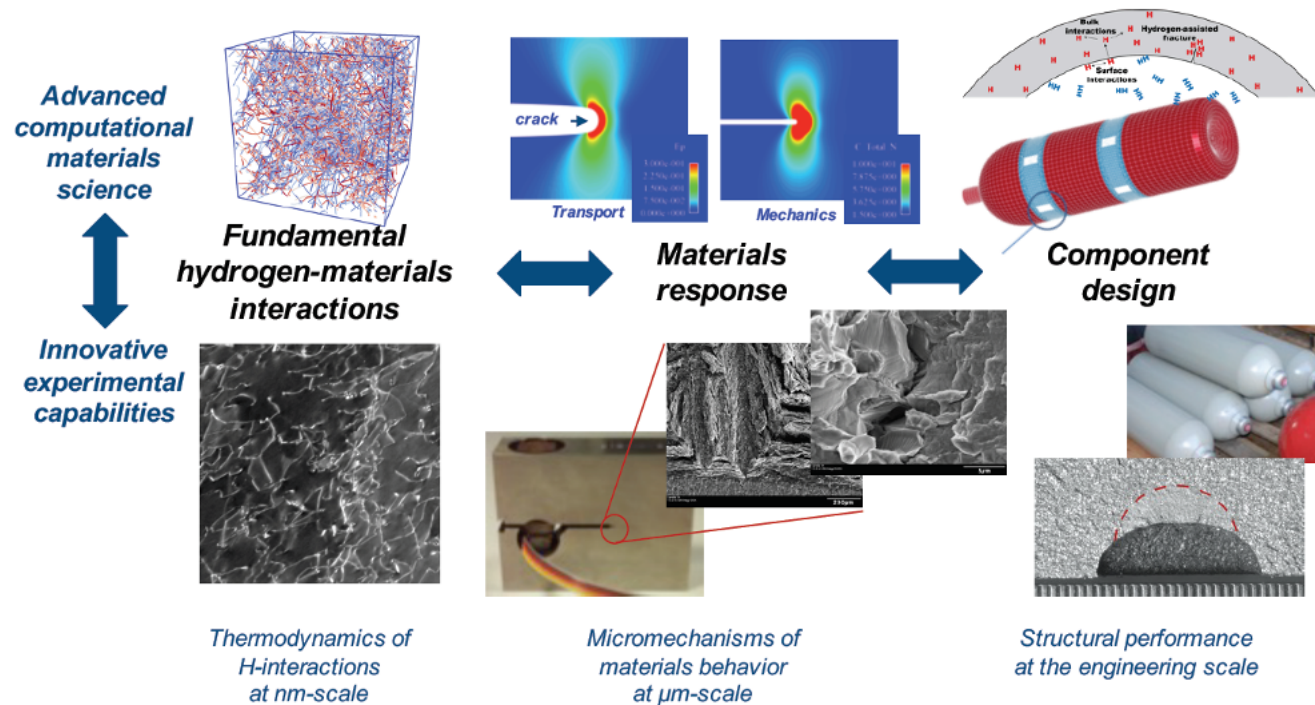


LH₂ tank



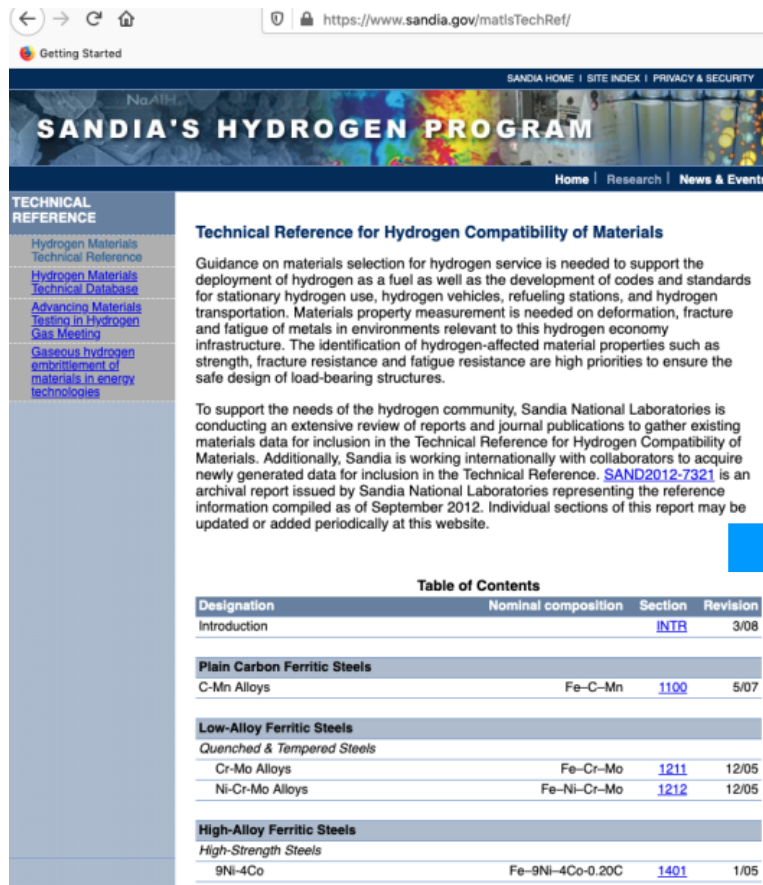
Vision for Hydrogen Compatible Materials Research

- State-of-the-art methods and tools to assess hydrogen compatibility of materials by uncovering the mechanisms responsible for hydrogen-materials interactions
- Use this understanding and these methods to inform science-based strategies to design the microstructure of metals with improved resistance to hydrogen degradation



Outcomes from previous workshops

- 2003: Hydrogen Materials Compatibility Workshop
 - Defined content for a Technical Reference for Materials Compatibility with Hydrogen, including materials, applications, operating conditions and data



SANDIA'S HYDROGEN PROGRAM

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TECHNICAL REFERENCE

- Hydrogen Materials Technical Reference
- Hydrogen Materials Technical Database
- Advancing Materials Testing in Hydrogen Gas Meeting
- Gaseous hydrogen embrittlement of materials in energy technologies

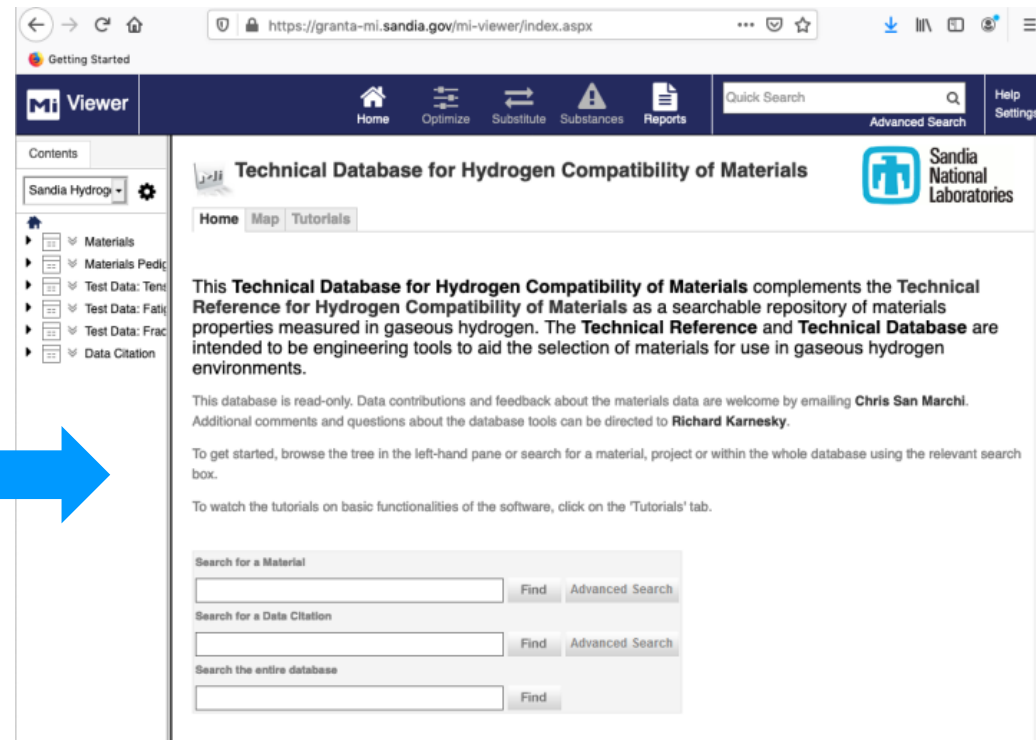
Technical Reference for Hydrogen Compatibility of Materials

Guidance on materials selection for hydrogen service is needed to support the deployment of hydrogen as a fuel as well as the development of codes and standards for stationary hydrogen use, hydrogen vehicles, refueling stations, and hydrogen transportation. Materials property measurement is needed on deformation, fracture and fatigue of metals in environments relevant to this hydrogen economy infrastructure. The identification of hydrogen-affected material properties such as strength, fracture resistance and fatigue resistance are high priorities to ensure the safe design of load-bearing structures.

To support the needs of the hydrogen community, Sandia National Laboratories is conducting an extensive review of reports and journal publications to gather existing materials data for inclusion in the Technical Reference for Hydrogen Compatibility of Materials. Additionally, Sandia is working internationally with collaborators to acquire newly generated data for inclusion in the Technical Reference. SAND2012-7321 is an archival report issued by Sandia National Laboratories representing the reference information compiled as of September 2012. Individual sections of this report may be updated or added periodically at this website.

Table of Contents

Designation	Nominal composition	Section	Revision
Introduction		INTR	3/08
Plain Carbon Ferritic Steels			
C-Mn Alloys	Fe-C-Mn	1100	5/07
Low-Alloy Ferritic Steels			
<i>Quenched & Tempered Steels</i>			
Cr-Mo Alloys	Fe-Cr-Mo	1211	12/05
Ni-Cr-Mo Alloys	Fe-Ni-Cr-Mo	1212	12/05
High-Alloy Ferritic Steels			
<i>High-Strength Steels</i>			
9Ni-4Co	Fe-9Ni-4Co-0.20C	1401	1/05



Viewer

Home | Optimize | Substitute | Substances | Reports

Quick Search [] Advanced Search [] Help Settings []

Technical Database for Hydrogen Compatibility of Materials

Home | Map | Tutorials

Contents

- Sandia Hydrog...
- Materials
- Materials Pedic...
- Test Data: Tens...
- Test Data: Fatig...
- Test Data: Frac...
- Data Citation

This Technical Database for Hydrogen Compatibility of Materials complements the Technical Reference for Hydrogen Compatibility of Materials as a searchable repository of materials properties measured in gaseous hydrogen. The Technical Reference and Technical Database are intended to be engineering tools to aid the selection of materials for use in gaseous hydrogen environments.

This database is read-only. Data contributions and feedback about the materials data are welcome by emailing **Chris San Marchi**. Additional comments and questions about the database tools can be directed to **Richard Karnesky**.

To get started, browse the tree in the left-hand pane or search for a material, project or within the whole database using the relevant search box.

To watch the tutorials on basic functionalities of the software, click on the 'Tutorials' tab.

Search for a Material

[] Find Advanced Search

Search for a Data Citation

[] Find Advanced Search

Search the entire database

[] Find



Outcomes from previous workshops

- 2010: Hydrogen Compatible Materials Workshop
 - Identified highest-priority technical issues and international partnerships needed to address gaps in Data and Phenomenology, Technology Development and Codes and Standards:
 1. Structural metal fatigue properties in high-pressure hydrogen gas and testing protocols for materials evaluation.
 2. An open-source database structured for hydrogen containment component designers.
 3. Properties and effects of welds, leveraging institutions having specialized high-pressure testing capabilities and industry to supply samples.
 4. High-strength, low-cost materials for long-life hydrogen service, through collaboration with universities and material manufacturers.



Outcomes from previous workshops

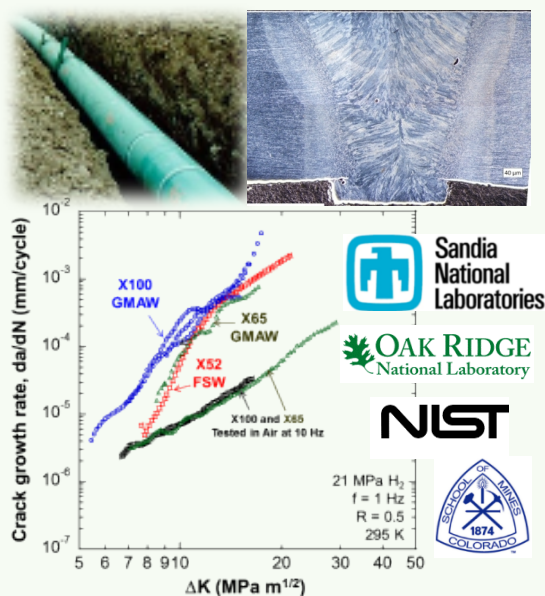
- 2012: Polymer and Composite Materials Used in Hydrogen Service
 - Information-sharing meeting on the use of polymer and composite materials in hydrogen applications
- Information gaps identified in topical areas:
 - Thermal performance at service conditions
 - Impact of thermal excursions
 - Minimizing gas permeation and absorption into polymers
 - Polymer characterization tests considering significant material variability
 - Characterization and performance of seals and O-rings
 - Liner buckling in pressure systems
 - Low cost composite material systems



Impacts since those workshops...

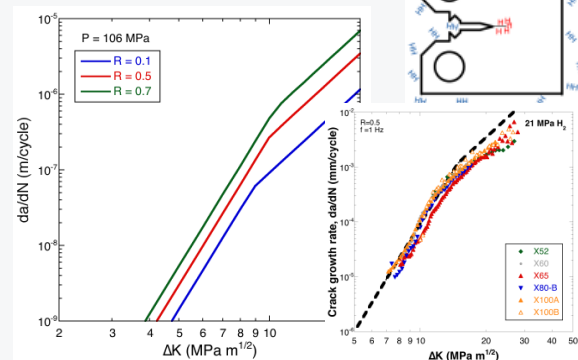
Scientific Basis for High-Strength Steels for Reduced Cost Pipelines

Provided the scientific basis to enable the deployment of high-strength steels for hydrogen pipelines that facilitate cost reduction through reduced material thicknesses.



Design Curves for predicting in-H₂ fatigue response of Pressure Vessel Steels

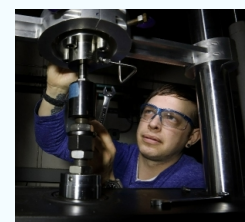
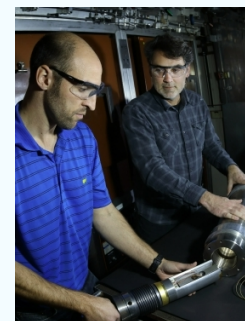
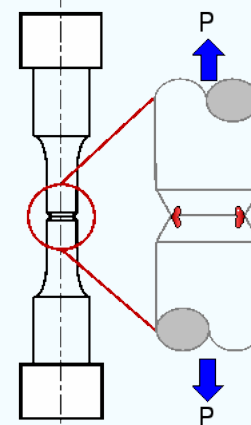
Critical assessment of fatigue data and consideration of the physical behavior of hydrogen enabled the establishment of a “master” design curve for fatigue in ferritic steels significantly reducing the cost of materials qualification



$$\frac{da}{dN} = C \left[\frac{1 + C_H R}{1 - R} \right] \Delta K^m \left(\frac{f}{f_{ref}} \right)^{1/2}$$

Codes & Standards for Hydrogen-Materials Compatibility

Led an international team to develop test methods and acceptance criteria for material qualification in the vehicle application for SAE J2579, Appendix B



2019: Hydrogen Materials Compatibility (H-Mat) Consortium formed to address HCM science questions

Metals

Task M1

High-strength ferritic steel microstructures



Task M2

High-strength aluminum alloys



Task M3

Transferability of damage and crack nucleation



Task M4

Microstructure of austenitic stainless steels



Task C1

Materials for cryogenic hydrogen service



Polymers

Task P1

Mechanisms of degradation



Task P2

Multiscale modeling



Task P3

Hydrogen-resistant polymeric formulations





Workshop Purpose and Desired Outcomes

- H-Mat aspires to expand its understanding of HCM needs for heat and power, manufacturing and other industrial uses, building on lessons learned in transportation.
- We also want to ensure that our work continues to address open questions in hydrogen-powered transportation of concern to this community.
- Our objectives for this workshop are to:
 - Increase industry awareness of H-Mat R&D
 - Assess current technologies in HCM for high-pressure gaseous hydrogen and liquid hydrogen use
 - Identify and prioritize unaddressed HCM challenges that inhibit deployment of hydrogen technology
 - Brainstorm collaborative models to enable projects to provide advances and enable technology transfer to end-use stakeholders.



All times listed are Pacific Standard Time [PST]

Day 1 – December 2, 2020

- 6–6:30 am – Welcome, select introductions, workshop purpose
- 6:30–7:15 am – Orientation of H-Mat consortium and current activities
- 7:15–7:45 am – Discussion on framing questions
- 7:45–8 am – Break
- 8–9:30 am – Panel-led brainstorming session on **transportation**
- 8–8:30 am – Panel answers to framing questions (3 panelists, 10 min. each)
- 8:30–9:30 am – Group brainstorming on R&D gaps
- 9:30–10 am – Day 1 review (including R&D gaps identified) and outline of Day 2 agenda

Day 2 – December 3, 2020

- 6–6:30 am – Special presentation
- 6:30–8 am – Panel-led brainstorming session on **heat and power**
- 6:30–7 am – Panel answers to framing questions (3 panelists, 10 min. each)
- 7–8 am – Group brainstorming on R&D gaps
- 8–8:15 am – Break
- 8:15–9:45 am – Panel-led brainstorming session on **industrial uses**
- 8:15–8:45 am – Panel answers to framing questions (3 panelists, 10 min. each)
- 8:45–9:45 am – Group brainstorming on R&D gaps
- 9:45–10:15 am – Day 2 review (including R&D gaps identified) and next steps



Workshop Topics for Panel-Led Discussion

Transportation

- *Panelists:* **Matthias Kuntz** - Bosch, **Amy Ryan** – Toyota
- *Moderators:* **Charles (Will) James** – SRNL, **Brian Kagay** – SNL

Heat and Power

- *Panelists:* **John Scheibel** – EPRI, **Kang Xu** – Linde, **Hemanth Satish** - PRCI/TC Energy
- *Moderators:* **Zhili Feng** – ORNL, **Joseph Ronevich** - SNL

Industrial Uses

- *Panelists:* **Anders Werme** – ArcelorMittal, **Gerhard Schiroky** – Swagelok,
Neeraj Thirumalai – ExxonMobil
- *Moderators:* **Kevin Simmons** – PNNL, **Christopher San Marchi** - SNL



Teams Best Practices and Workshop Ground Rules



Please mute your microphone when not speaking



Use “raise hand” function with questions or comments



Chat box can be also used for questions or comments



Session is being recorded (for purpose of writing workshop report ONLY)



Thank You to Workshop Team Members

- Christopher San Marchi
- Joseph Ronevich
- Jesse Bonfeld
- Carrie Burchard
- Gina Reyes
- Tylyn Turner
- Janine Donnelly
- Joseph Horton
- Trina O'Donohue West
- Rebecca Askew
- Christopher Moen
- Sarah Allendorf



Hydrogen Compatible Materials Workshop

- Brian Kagay
- Rob Wheeler
- Rakish Shrestha

