Sandia National Laboratories

H_2FC Hydrogen and Fuel Cells Program

Hydrogen Compatible Materials Workshop

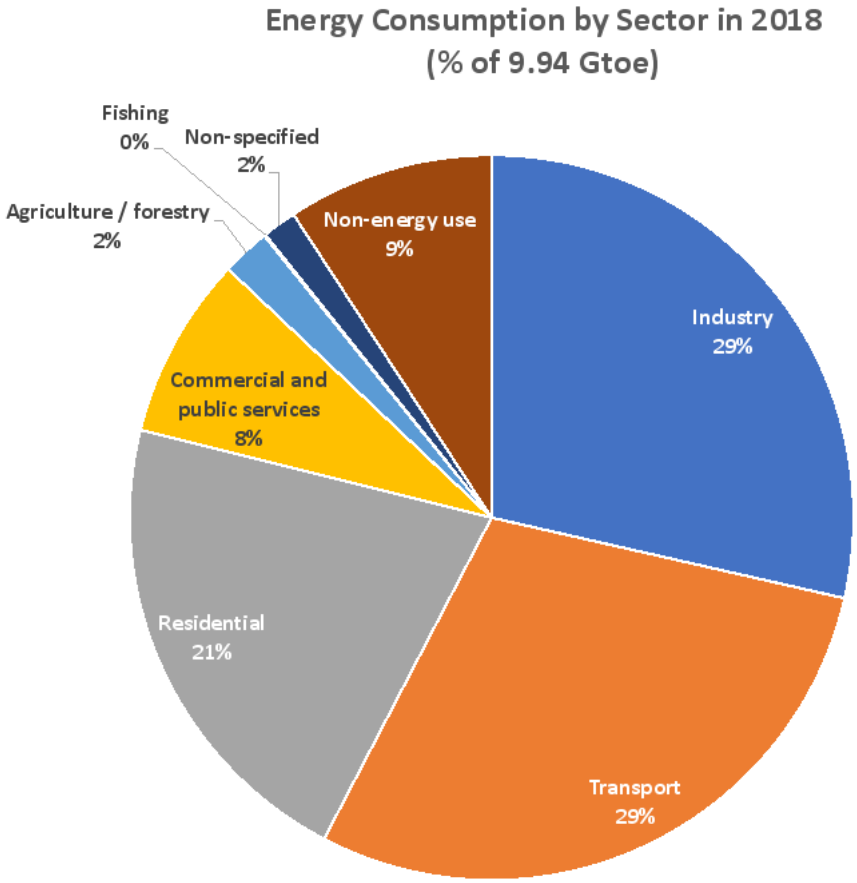
December 2 & 3, 2020

Jonathan Zimmerman
Hydrogen and Fuel Cells Program Manager
Sandia National Laboratories

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

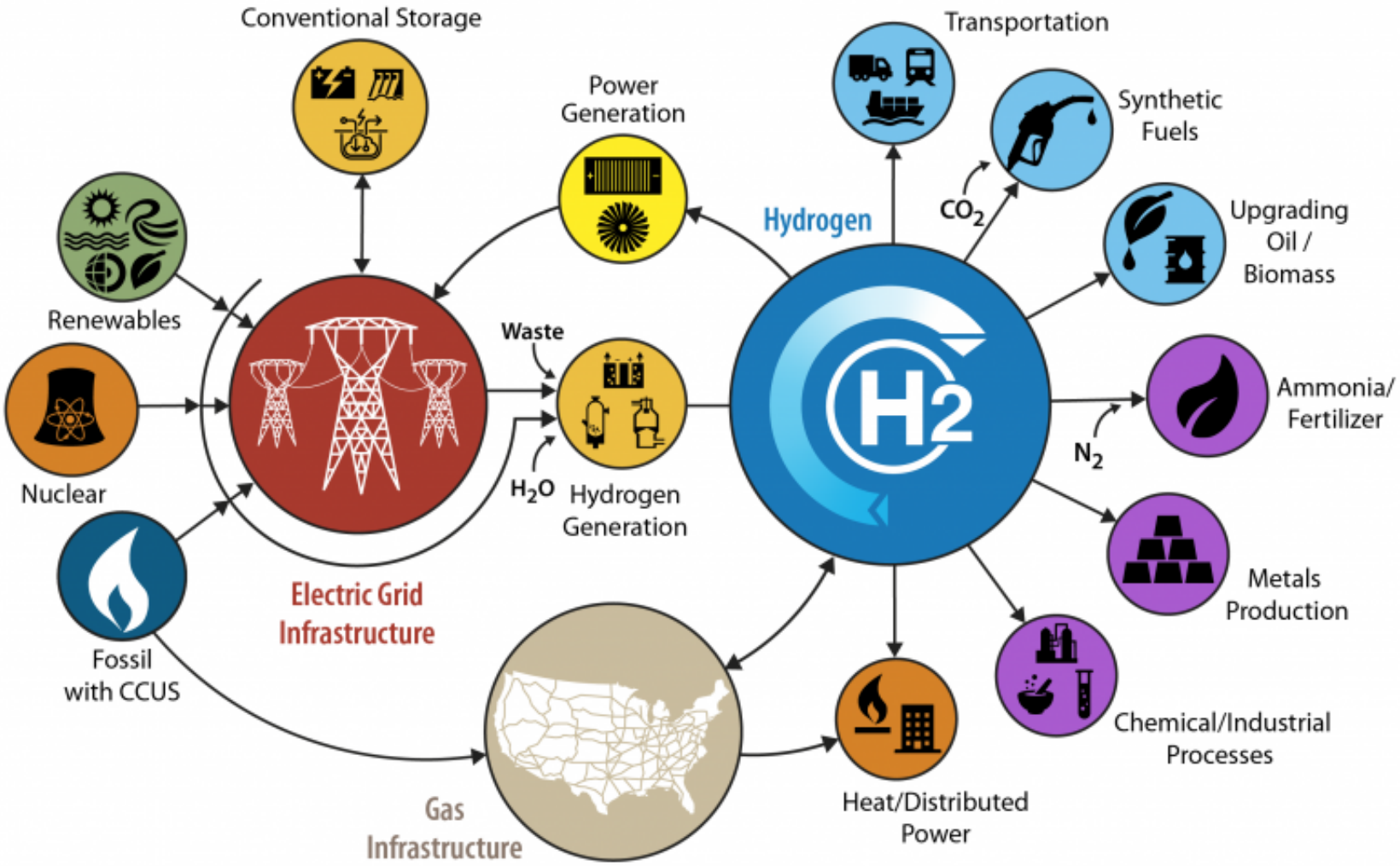
The world's energy needs have never been larger

- Largest consumption sectors are transportation, industry and residential



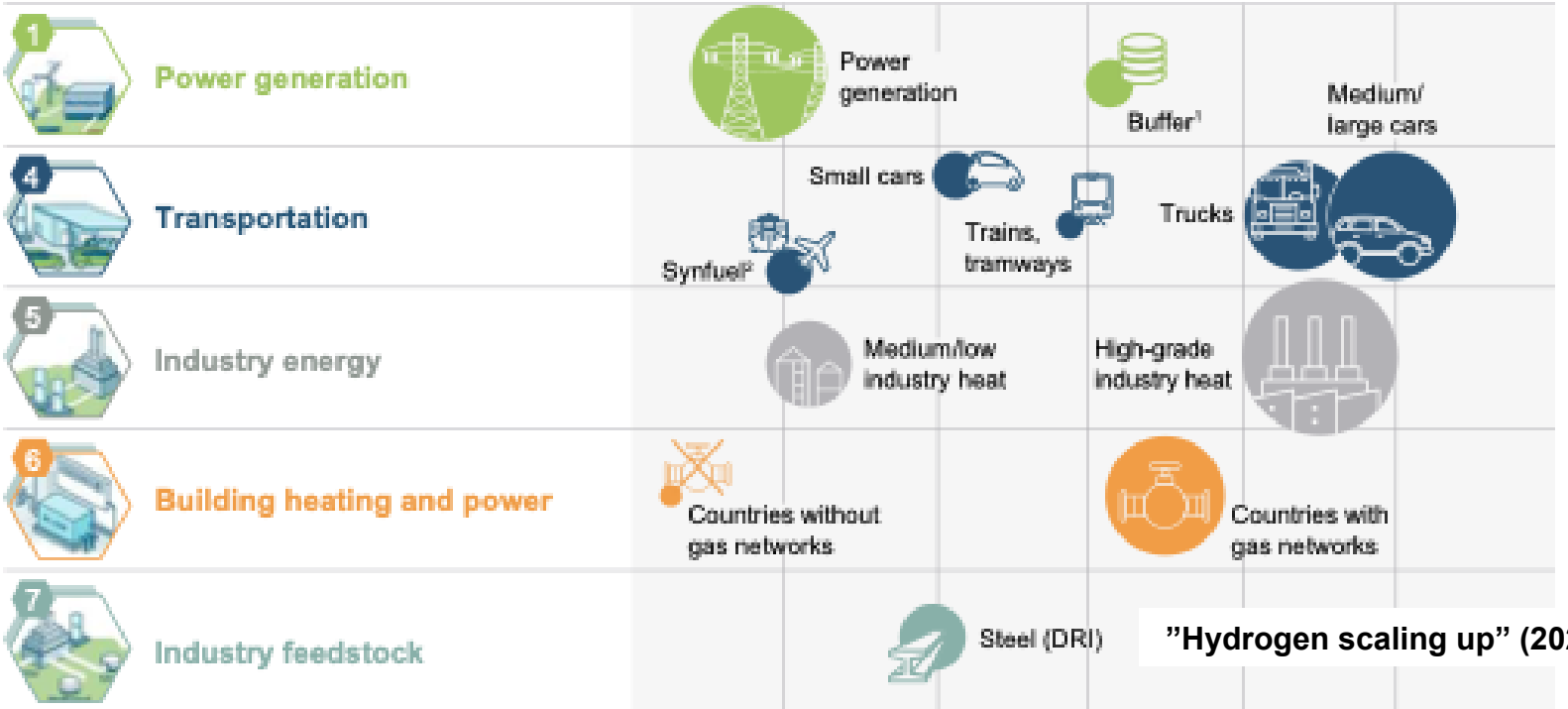
https://www.iea.org/data-and-statistics

Hydrogen's potential is understood through the H_2@Scale concept – a vision for hydrogen energy



Roadmaps have identified opportunities and barriers for hydrogen deployment across technologies

— USDRIVE Technical Team Roadmaps for H_2 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)



"Hydrogen scaling up" (2020)

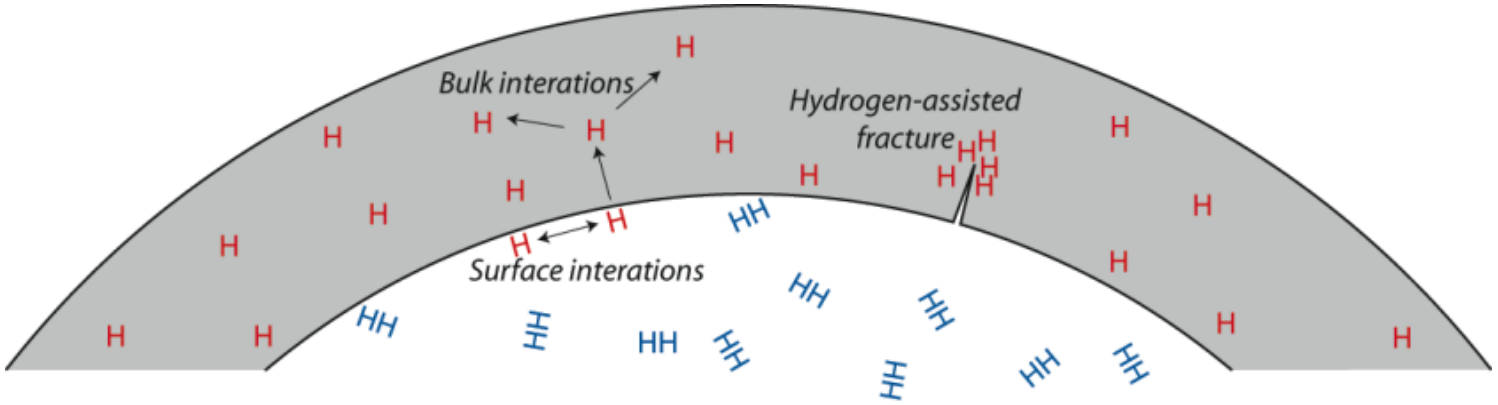
Roadmaps have identified opportunities and barriers for hydrogen deployment across technologies

— USDRIVE Technical Team Roadmaps for H_2 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)

- 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

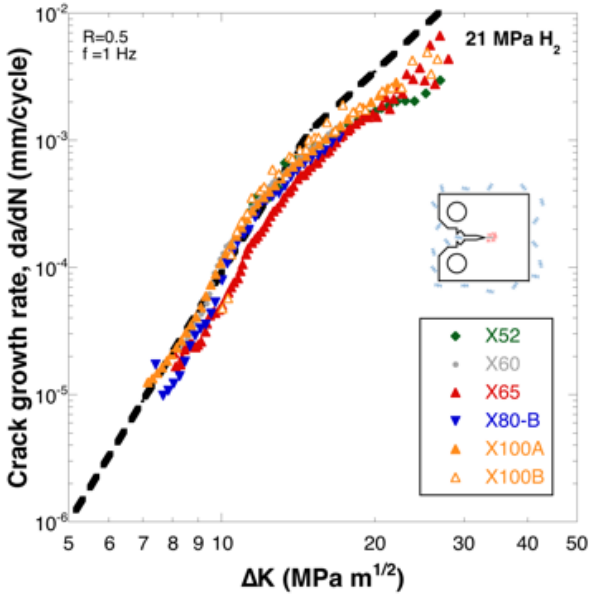


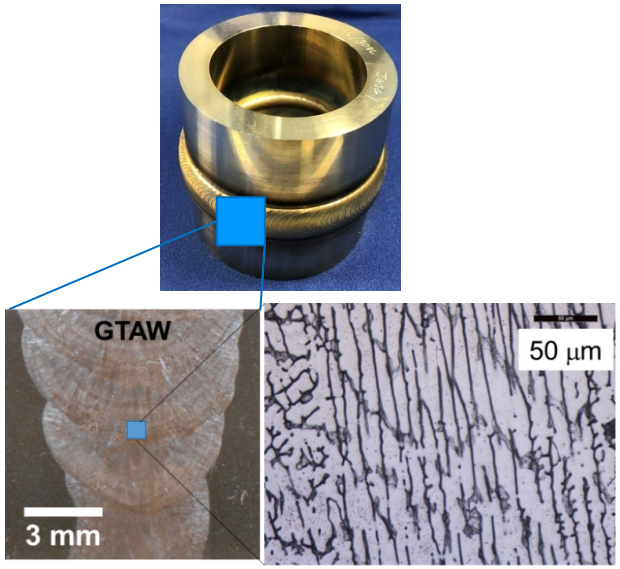
Rupture of hydrogen-containing metal tanks

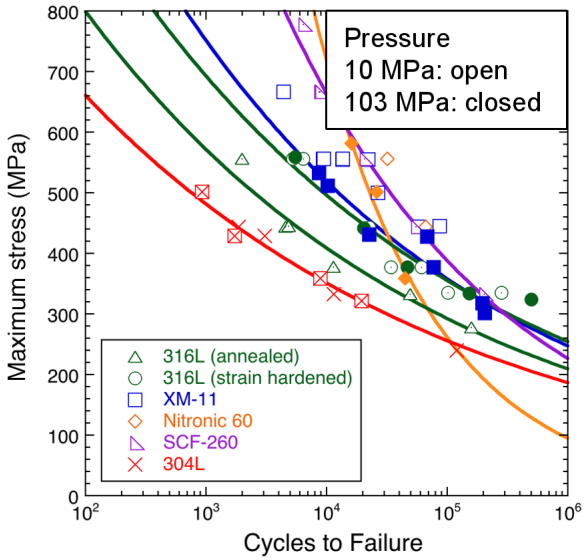
Damage in polymer O-Rings after hydrogen gas exposure

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

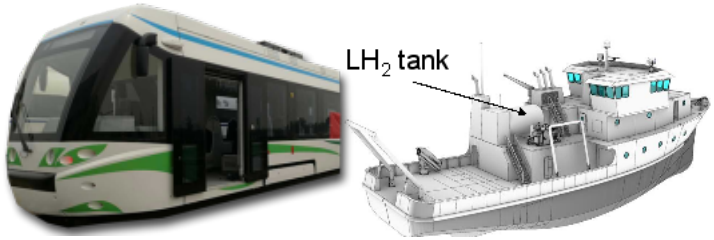
- Focus on foundational-to-applied research uncovering the science of materials for hydrogen production, delivery, storage and use.
- Use our research to inform the safe, reliable use of hydrogen fuel cell technology.
- Partner with industry, codes & standards organizations, and international institutes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

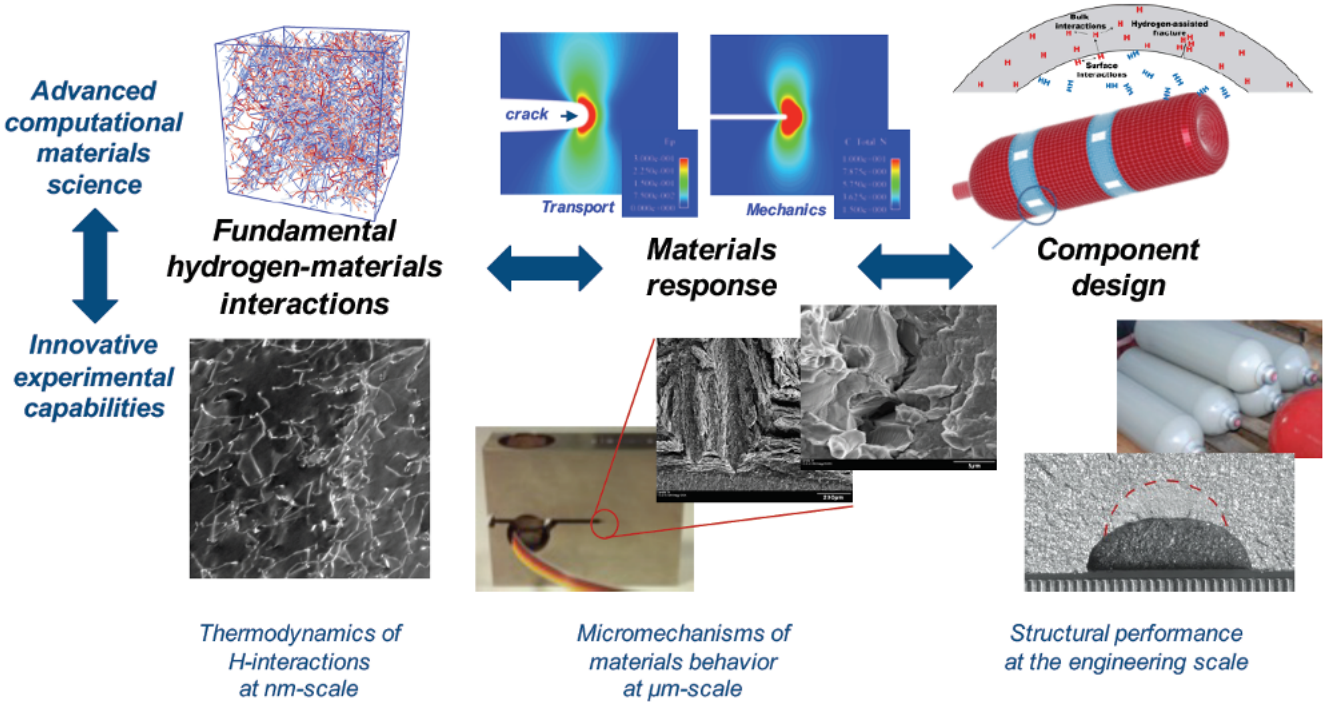
H-Mat℠
Hydrogen Materials Compatibility Consortium

HyRAM
HYDROGEN RISK ASSESSMENT MODELS



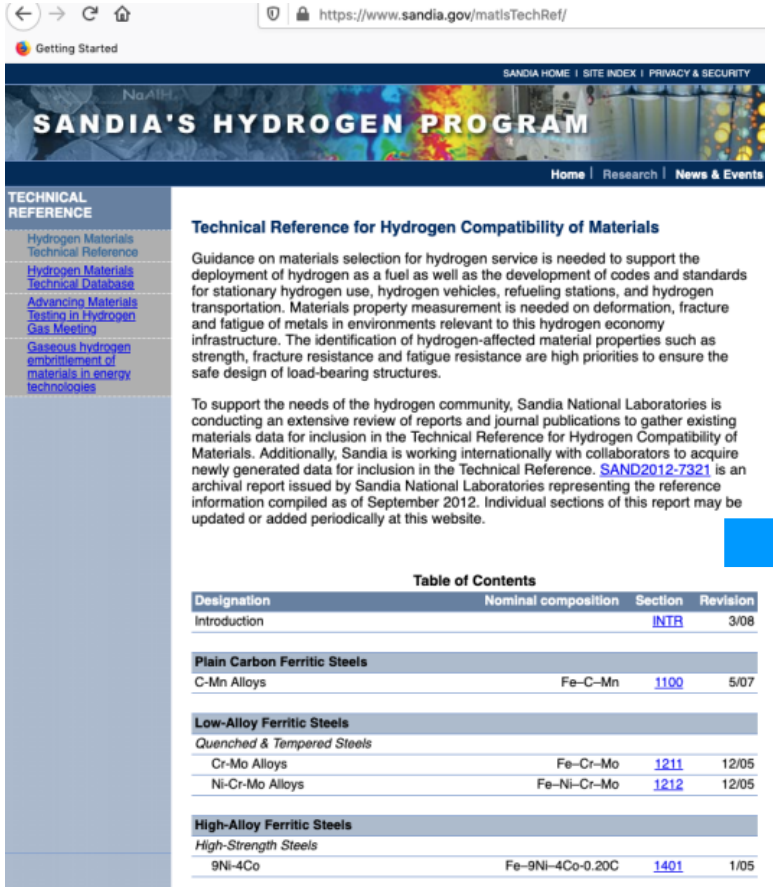
Vision for Hydrogen Compatible Materials Research

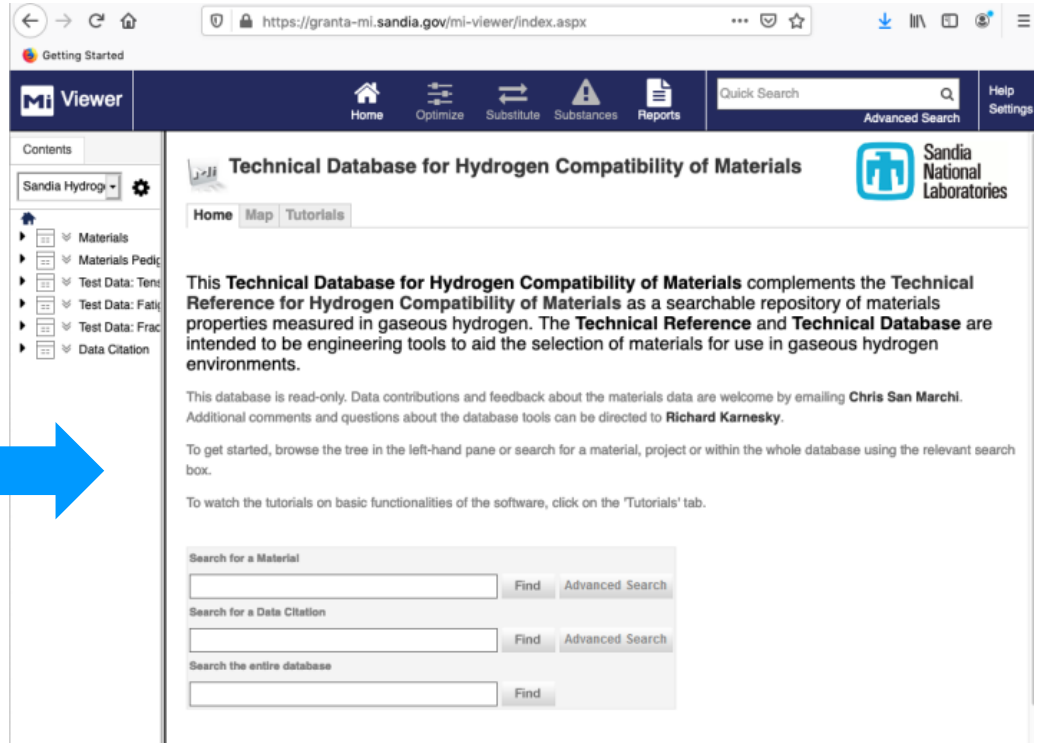
- State-of-the-art methods and tools to assess hydrogen compatibility of materials by uncovering the mechanisms responsible for hydrogen-materials interactions
- Use this understanding and these methods to inform science-based strategies to design the microstructure of metals with improved resistance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





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.

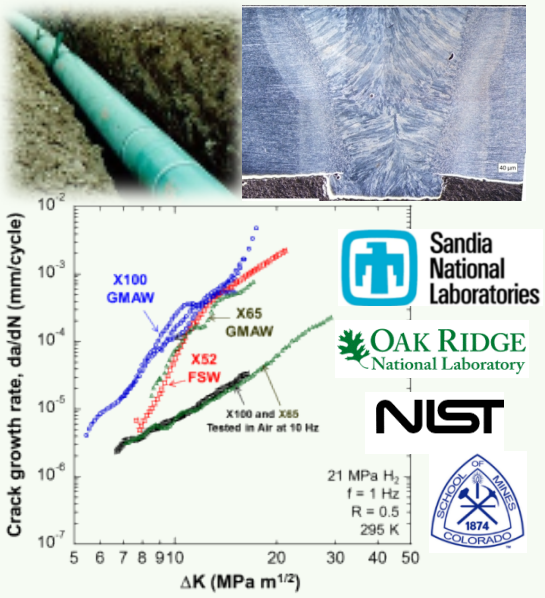
Outcomes from previous workshops

- 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…

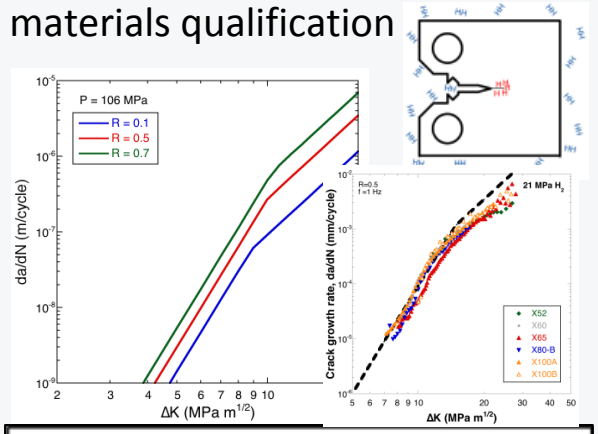
Scientific Basis for High-Strength Steels for Reduced Cost Pipelines

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-H_2 fatigue response of Pressure Vessel Steels

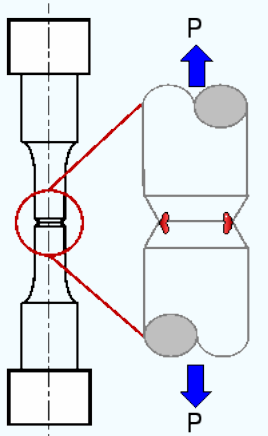
Critical assessment of fatigue data and consideration of the physical behavior of hydrogen enabled the establishment of a "master" design curve for fatigue in ferritic steels significantly reducing the cost of materials qualification

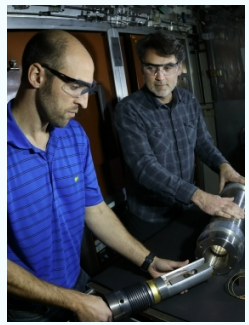


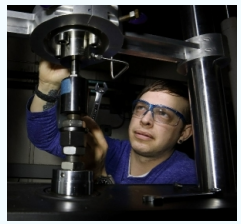
$$\frac{da}{dN} = C\left[\frac{1+C_H R}{1-R}\right]\Delta K^m \left(\frac{f}{f_{ref}}\right)^{1/2}$$

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







SAE INTERNATIONAL®

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.

Workshop Agenda

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

- Brian Kagay
- Rob Wheeler
- Rakish Shrestha


AND NOW A WORD
FROM OUR
SPONSOR