PNNL Capabilities for H₂ Safety, H₂ – Polymer Compatibility, and Grid Simulation

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PNNL at a Glance

Intellectual property and startups

- Average ONE INVENTION per day
- Average ONE PATENT per week
- 822+ LICENSES since 1970s
- 170+ BUSINESSES started with PNNL IP or executives

FY16:
- $920 MILLION in R&D expenditures
- 4,400 STAFF
- 100 R&D 100 AWARDS
- 83 Tech transfer AWARDS
PNNL’s Signature Capabilities
Capabilities Highlighted in this Presentation

• Hydrogen Safety Panel

• Hydrogen Polymer Materials Compatibility

• Grid Simulation
Hydrogen Safety Resources

**HYDROGEN Safety Panel**
- Identify safety-related technical data gaps
- Review safety plans and project designs
- Perform safety evaluation site visits
- Provide technical oversight for other program areas

**HYDROGEN Tools**
- Hydrogen Tools web portal (http://h2tools.org)
- Hydrogen Lessons Learned
- Hydrogen Best Practices

**HYDROGEN Emergency Response Training Resources**
- Online awareness training
- Operations-level classroom/hands-on training
- National hydrogen and fuel cell emergency response training resource
Hydrogen Safety Panel

Hydrogen Safety Panel… Supporting energy security by enabling the safe and timely transition to hydrogen and fuel cell technologies

- Nationally recognized expert resource for hydrogen safety
- Formed in 2003
- 400+ years of experience
- Participated in 320 hydrogen projects (474 safety reviews) covering vehicle fueling stations, stationary and portable power, industrial truck fueling, transportation applications and R&D activities
- Produces technical white papers and industry guides to address gaps and support infrastructure deployment

Current Hydrogen Safety Panel Membership

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
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<tr>
<td>Nick Barilo, Manager</td>
<td>PNNL</td>
</tr>
<tr>
<td>Richard Kallman, Chair</td>
<td>City of Santa Fe Springs, CA</td>
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<tr>
<td>Eric Binder</td>
<td>Santa Monica Fire Department</td>
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<tr>
<td>Ken Boyce</td>
<td>UL LLC</td>
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<td>David Farese</td>
<td>Air Products and Chemicals</td>
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<td>Donald Frikken</td>
<td>Becht Engineering</td>
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<td>Livio Gambone</td>
<td>CSA</td>
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<tr>
<td>Aaron Harris</td>
<td>Air Liquide</td>
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<tr>
<td>Chris LaFleur</td>
<td>Sandia National Laboratories</td>
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<tr>
<td>Miguel Maes</td>
<td>NASA-JSC White Sands Test Facility</td>
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<tr>
<td>Steve Mathison</td>
<td>Honda Motor Company</td>
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<tr>
<td>Larry Moulthrop</td>
<td>Proton OnSite</td>
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<tr>
<td>Glenn Scheffler</td>
<td>GWS Solutions of Tolland</td>
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<td>Tom Witte</td>
<td>Witte Engineered Gases</td>
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<td>Robert Zalosh</td>
<td>Firexplo</td>
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http://www.h2tools.org/hsp

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Hydrogen Safety Panel

The Panel is a unique resource and can be a valuable asset for supporting the safe commercial rollout of fuel cell vehicles, stationary applications and the supporting infrastructure.

Can Provide Support to:
- Other federal agencies
- State agencies, code officials, and permitting authorities
- Private industry and commercial installers

Types of Activities:
- Design and document reviews
- Participation in or review risk assessments
- Site reviews

Safety is paramount - its the first question we get asked in California when we go into local communities. If anything, we need to figure out how to expand the Safety Panel's reach. The reviews from the Panel have already shown benefit to the state - its a crucial, trusted 3rd party resource. – 2015 DOE AMR Reviewer Comment

Photo courtesy of the California Fuel Cell Partnership
First Responder Training Resources

► National Goal
- Support the successful implementation of hydrogen and fuel cell technologies by providing technically accurate hydrogen safety and emergency response information to first responder

► Integrated Activities
- Online, awareness-level training (http://hydrogen.pnl.gov/FirstResponders/)
- Classroom and hands-on operations-level training
- National training resource (enabling trainers) (http://h2tools.org/fr/nt)

A properly trained first responder community is critical to the successful introduction of hydrogen fuel cell applications and their transformation in how we use energy.
H₂ – Polymer Compatibility Capabilities

- In situ tribometry
  - Friction and wear testing in H₂ atmosphere (38 MPa)
- X-Ray micro CT for internal damage
- H₂ impact on materials before and after hydrogen exposure to look for correlations with other tests
  - Hardness changes – directly after exposure and 1 week after
  - Swelling – directly after exposure and 1 week after
  - Sensible with free volume and diffusion considerations
- Materials characterization
  - Dynamic mechanical analysis
  - DSC- Differential scanning calorimetry
  - Thermogravimetric analysis (TGA)
  - Density
  - Thermal desorption spectroscopy
    - Diffusion calculations
Overview of PNNL’s Unique In Situ Tribometer

Overview of Tribometer

- Linear reciprocating adapted from ASTM G133
- Normal load (using weights) presses steel ball into moving sample
- Frictional force and vertical wear depth profiles measured in situ
- Pressures up to 5,000 psi hydrogen
- Ambient air and high pressure argon tests run for comparison
Cold Materials Test Capability

To investigate materials compatibility at cold temperatures, PNNL has expanded our cold temperature capability:

- Mechanical test frame capable of -129°C up to 315°C for all materials
- IR camera for thermal imaging and evaluation of advanced physical insulation for cold gas operation
Ex Situ Polymer Testing: Hydrogen saturated cryogenic tests

- PNNL can do ex-situ testing at cryogenic temperatures of samples at cryogenic temperatures
  - 60 hour 100% hydrogen soak at 5,000 psi
  - Rapidly chill with LN2 – traps hydrogen
  - Test in LN2 bath

Example Poly samples in hydrogen autoclave

High pressure hydrogen autoclave

Poly samples in LN2
Stress Rupture Testing Capabilities

- ASTM D2343 method
- 12 polymer, carbon or glass strands test at once
- Control temperature and humidity
PNNL GRID R&D: Over 25 Years of Impact

1990
- Aug '96 blackout: 7.5M consumers, 10 western states
- Developed Wide Area Measurement System (WAMS)
- Lead contributor to WAMS

2000
- Developed GridFriendly™ Controller Technology
- Joined CERTS, helped frame foundation for reliability

2005
- Key technical role in blackout reviews: '96 PMU forensics, '03 need for situational awareness
- Leadership role in DOE NASPI initiative
- Developed GridWise concept
- Founding member of GridWise Alliance
- Electricity Infrastructure Ops: GridWise & Facility Demo -- 30% improvement in operator response

2010
- Landmark Olympic Peninsula Demo: Transactive Cntl > 10% savings, 15% peak reduction
- GLD validates DR options for NRECA
- GLD validates VVO for AEP

2015
- DOE launches NASPI
- DOE launches GridWise Alliance MOU
- EIM review for NWPP shaping PNW
- SGIG Cyber require./reviews
- Future Power Grid Initiative
- Smart Grid Systems Reports
- WECC balancing area study guides strategy

ARRA Co-Fund
- Install Regulation Forecaster at CALISO
- SGDP Demos – First regional TC signal, first PUC TC rate approval
- Phasor & AMI Equipment Installs
- 10 Smart Grid Demos + 6 Storage Demos

PNNL INDUSTRY IMPACTS

- GLD validates DR options for NRECA
- GLD validates VVO for AEP
- Deploy Mode Meter at WECC WISP
PNNL’s Electric Infrastructure Research Agenda

**Transmission Reliability** – Seeing and operating the grid at the interconnection level in real-time

**Grid Analytics** - Leveraging high-performance computing and new algorithms to provide real-time situational awareness and models for prediction and response

**Distribution Systems and Demand Response** – Making demand an active tool in managing grid efficiency and reliability.

**Stationary Energy Storage** – Defining the location, technical performance, and required cost of storage; developing new materials and system fabrication approaches to meet requirements

**Cyber Security and Interoperability** – Developing tools and standards for secure, two-way communication and data exchange
Systems Engineering Building – Dedicated to the Power GRID

- 24,000 ft²
- 3 Control Centers
- 70+ staff
- Live / historical Grid feed
- Simulate Grid
- State of the Art industry software
Our Approach: Enabling demand response to be an active tool for increasing grid efficiency and reliability. Key elements include:

- **Smart grid simulation and analyses**
  - GridLAB-D™
  - Microgrids
  - Smart Grid System Report
- **Demand response**
  - Pioneer in “transactive control,” demand response demonstrations
  - Smart appliances/Grid-Friendly Appliance Controller
- **Grid architecture and standards** (interoperability)
  - GridWise Architectural Council leadership
- **Integration of PHEVs**
  - Smart Charger Controller
  - Grid impact analyses

**GridLAB-D™**
First-of-its-kind distribution system simulation and analysis tool

**Smart Grid System Report**
Leadership on behalf of DOE on reports to Congress
Our approach: Improve power system performance and transmission reliability by extracting greater value from grid measurements and data. Key elements include:

- DOE’s lead for the North American Synchrophasor Initiative (NASPI) – joint effort with the North American Electric Reliability Council (NERC) and industry
- Planning models validation using measurement-based analysis
- Decision support tools for operators
- EIOC – providing utilities, vendors and researchers access to real-time grid data for testing in realistic operations environment

Ensure a reliable U.S. power system by leveraging new data streams that provide wide-area visualization, monitoring and control.
PNNL Cyber Activities (partial list)

- Cybersecurity Risk Information Sharing Program (CRISP)
  - PNNL + ANL + DOE
  - 28 utilities and growing
- National Electric Grid Cyber Exercise
  - PNNL supporting the GridEx III design
  - GridEx III includes working with NERC, the ES-ISAC, DOE OE, INL, and electric utilities, and other participating government agencies
Mission
We transform the world through courageous discovery and innovation.

Vision
PNNL science and technology inspires and enables the world to live prosperously, safely and securely.
Hydrogen Tools

A Transformative Step Towards Hydrogen Adoption

- CENTRALIZED LOCATION
  organizes current H₂ resources in one robust location—including many proven tools, with plans for adding future content

- FOCUSED CONTENT
  tailored to the specialized needs of H₂ user groups

- RESPONSIVE DESIGN
  enables H₂ safety work across both desktop and mobile devices

- TRUSTED COMMUNITIES
  fostered through social networking around H₂ subject matter expertise

- EXPANDABLE FORMAT
  built with frequently requested features factoring sets in mind

http://h2tools.org

> Credible and reliable safety information from a trustworthy source
EMSL: The Environmental Molecular Sciences Laboratory – DOE User Facility

- National scientific user facility
- Sponsored by DOE Office of Biological and Environmental Research
- World-class research; integrated experimental & computational resources

Key capabilities:
- Supercomputer
- Mass spectrometry
- NMR spectrometry
- Surface science tools

http://www.emsl.pnl.gov/emslweb/
EMSL Characterization Equipment

- Mass Spectroscopy
- NMR and EPR
- Spectroscopy
- Environmental TEM (modified)
- In-situ TEM (modified)
- Cascade super computer (3.4 petaflops) and Aurora 15.8 petabyte storage
EMSL Equipment Example: In-situ TEM an Environmental TEM

In-situ liquid cell for battery study; a new cell can be designed for electrocatalysts study.

Environmental TEM
EMSL Equipment Example: Aberration corrected Environmental TEM

- Differential pumping aperture for a gas pressure of up to 20 Torr around the specimen
- Heating to temperature 1200 °C

Environmental: H₂, O₂, CO, CO₂, CH₄, etc.
EMSL Equipment Example: Aberration Corrected E-TEM: Atomic Restructuring of Pt–Co Nanoparticles

Atomic-scale reaction dynamics of a single $\text{Pt}_{0.5}\text{Co}_{0.5}$ nanoparticle in an oxidizing environment (0.1 mbar $\text{O}_2$, 250 °C)

TEM of a Co-Pt nanoparticle during oxidation in 100 mTorr $\text{O}_2$ environment at 250 °C. Co segregates from the Co-Pt alloy nanoparticle and forms CoO islands around the nanoparticle.