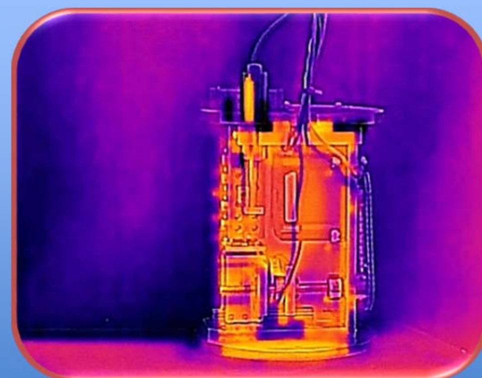
PNNL Capabilities for H_2 Safety, H_2 – Polymer Compatibility, and Grid Simulation



Jamie Holladay
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PNNL at a Glance

FY16:
$920 MILLION
in R&D expenditures

FY16:
4,400 STAFF

100
R&D 100
AWARDS

83
Tech transfer
AWARDS

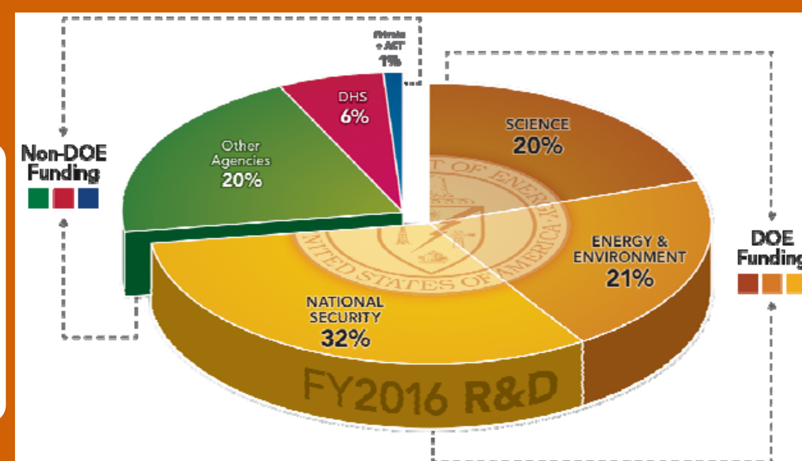
Intellectual property and startups

Average
ONE INVENTION
per day

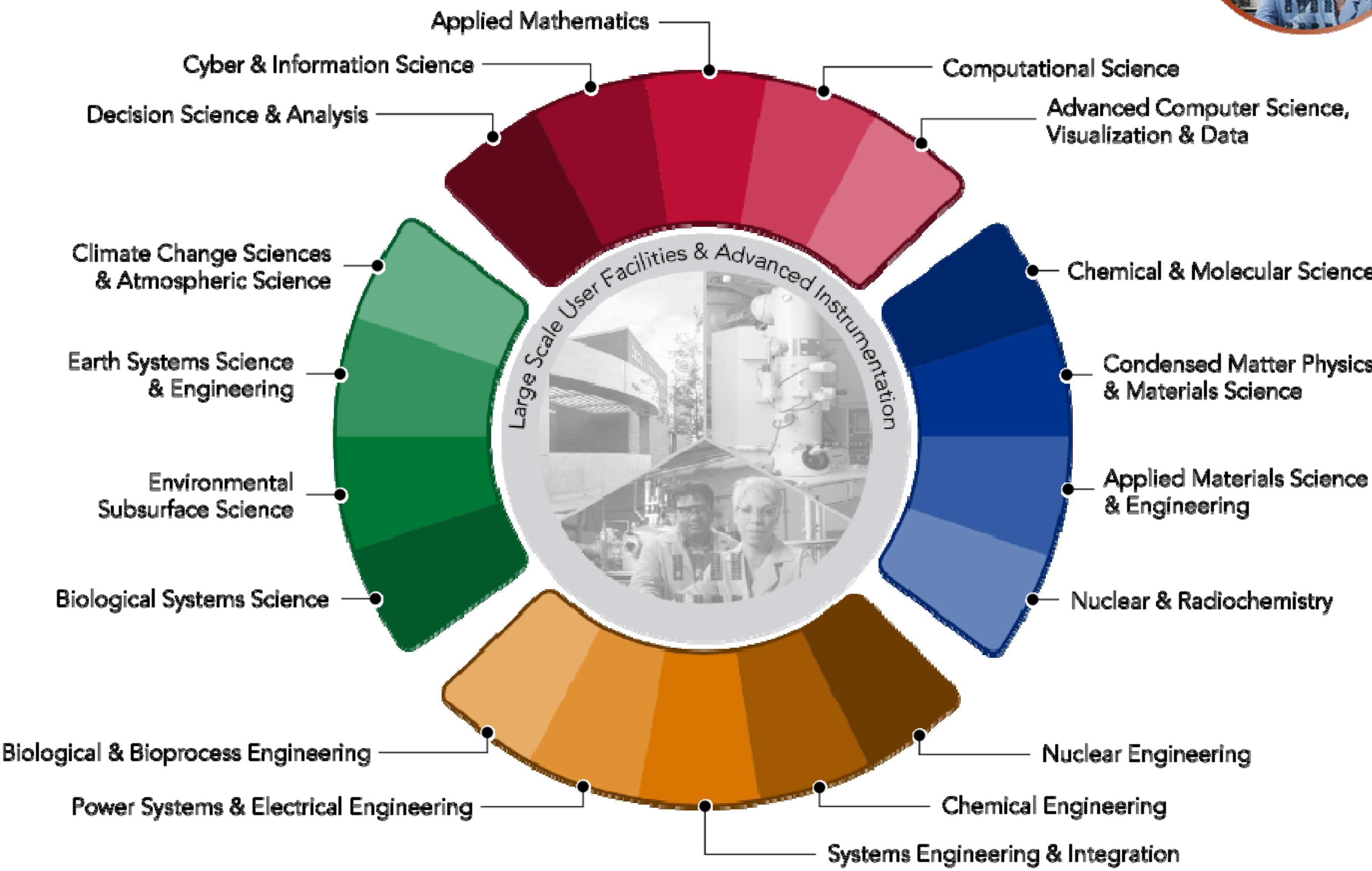
Average
ONE PATENT
per week

822+
LICENSES
since 1970s

170+
BUSINESSES
started with
PNNL IP
or executives



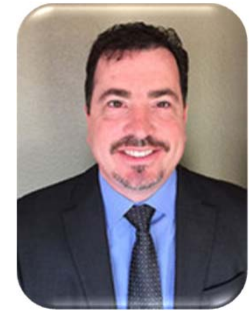
PNNL's Signature Capabilities



Capabilities Highlighted in this Presentation

- Hydrogen Safety Panel
- Hydrogen Polymer Materials Compatibility
- Grid Simulation

Hydrogen Safety Resources



Nick Barilo

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

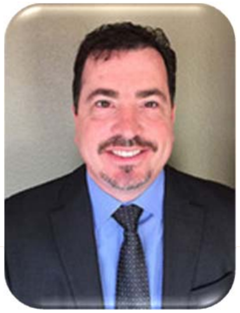
HYDROGEN
Tools

- 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


Nick Barilo

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

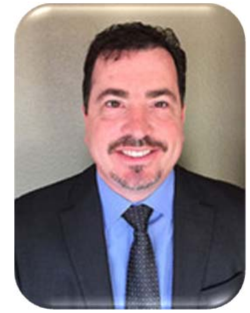
- Nationally recognized expert resource for hydrogen safety
- Formed in 2003
- 400+ years of experience
- Participated in 320 hydrogen projects (474 safety reviews) covering vehicle fueling stations, stationary and portable power, combined heat and power, industrial truck fueling, transportation applications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

Current Hydrogen Safety Panel Membership

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

http://www.h2tools.org/hsp

Hydrogen Safety Panel



Nick Barilo

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

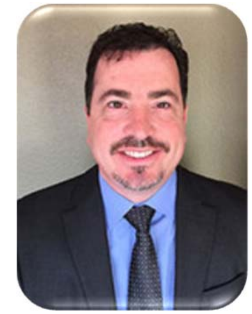
Photo courtesy of the California Fuel Cell Partnership

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

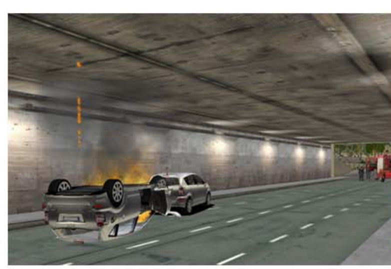
First Responder Training Resources



Nick Barilo

- **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)

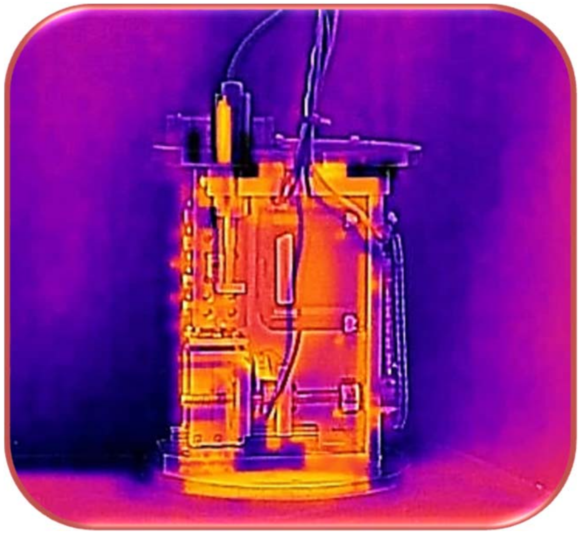
A properly trained first responder community is critical to the successful introduction of hydrogen fuel cell applications and their transformation in how we use energy.



H_2 – Polymer Compatibility Capabilities

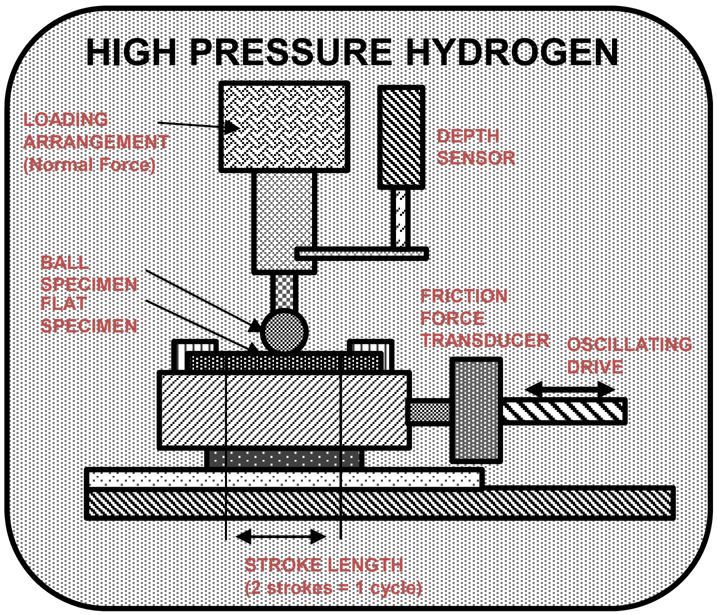
Kevin Simmons

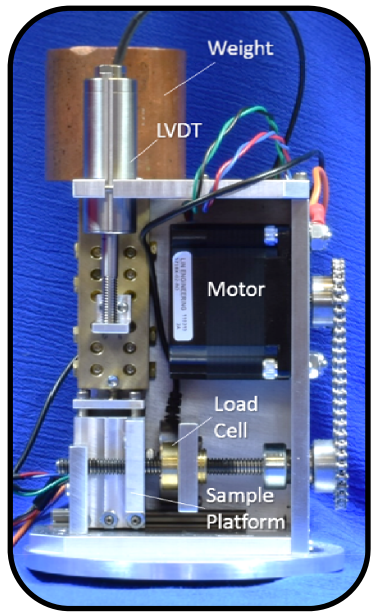
- In situ tribometry
  - Friction and wear testing in H_2 atmosphere (38 MPa)
- X-Ray micro CT for internal damage
- H_2 impact on materials before and after hydrogen exposure to look for correlations with other tests
  - Hardness changes – directly after exposure and 1 week after
  - Swelling – directly 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

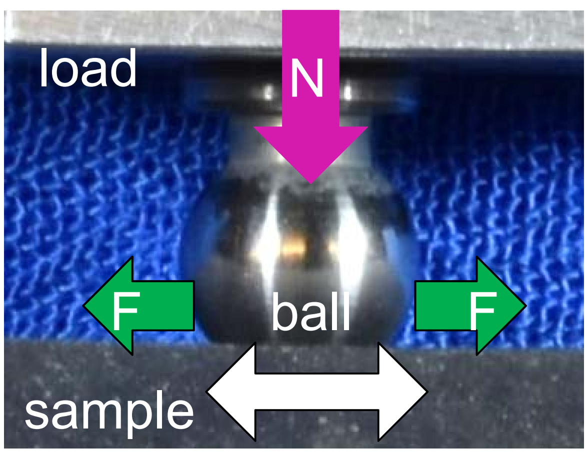


Overview of PNNL's Unique In Situ Tribometer

Kevin Simmons







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

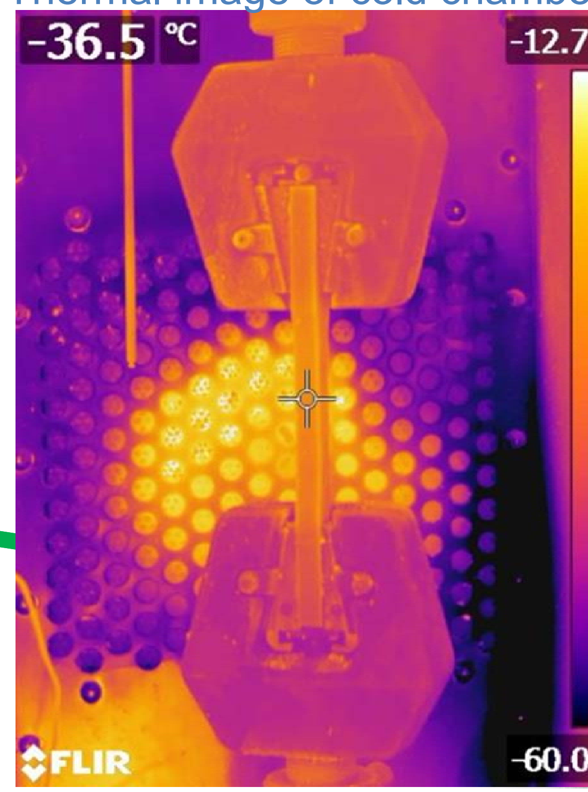
Kevin Simmons

- 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

Enhanced environmental chamber on test frame

Thermal image of cold chamber

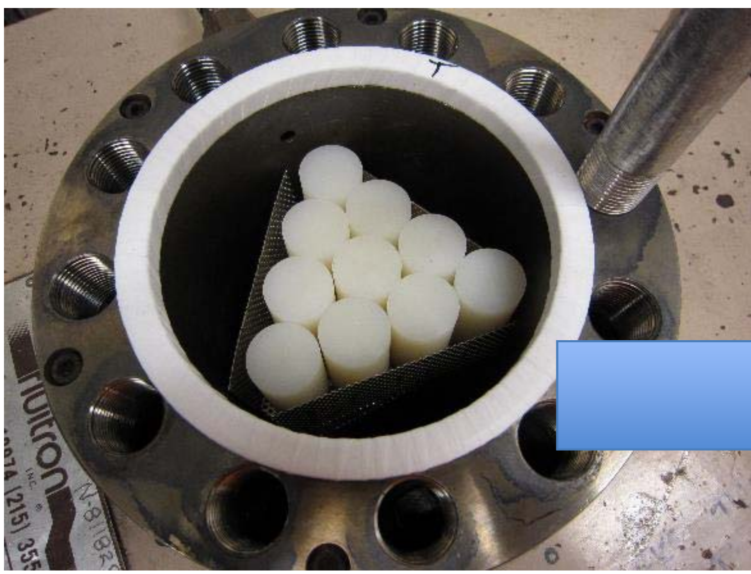


Ex Situ Polymer Testing: Hydrogen saturated cryogenic tests

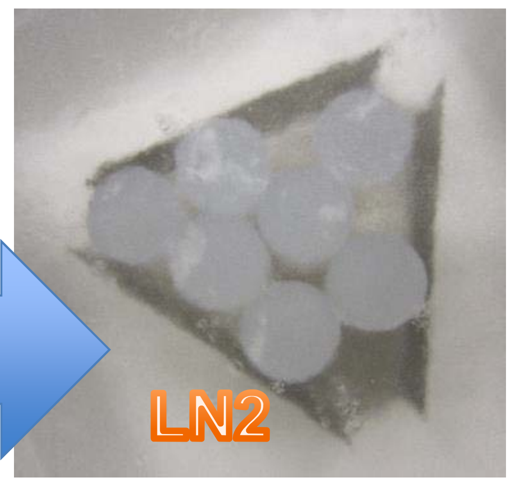
Kevin Simmons

- 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

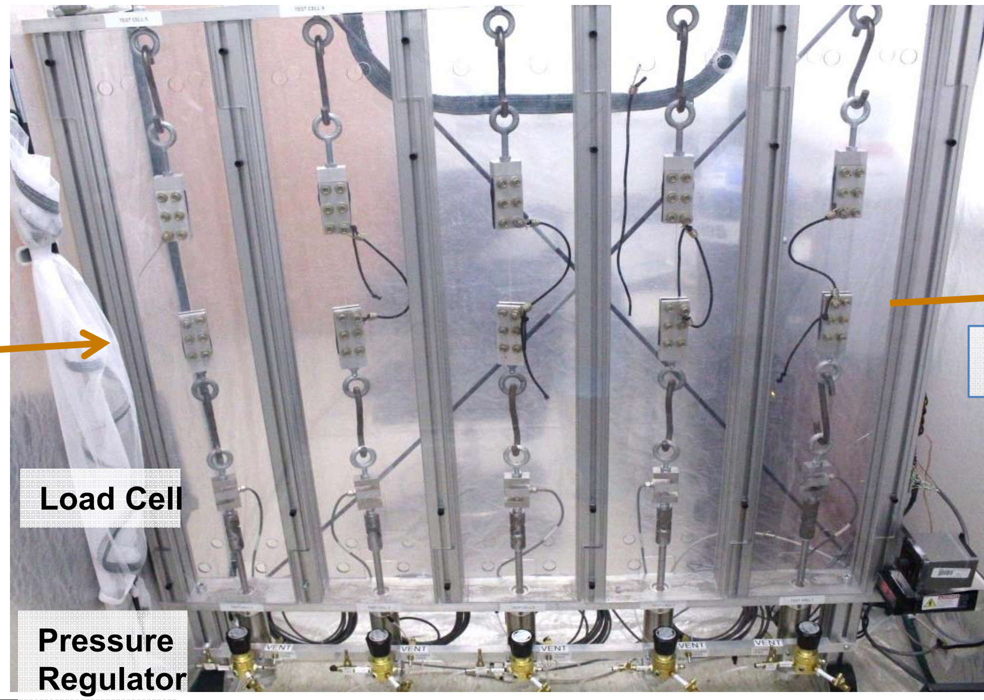


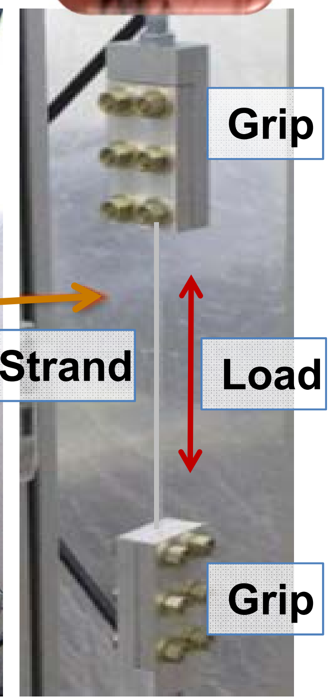
Poly samples in LN2



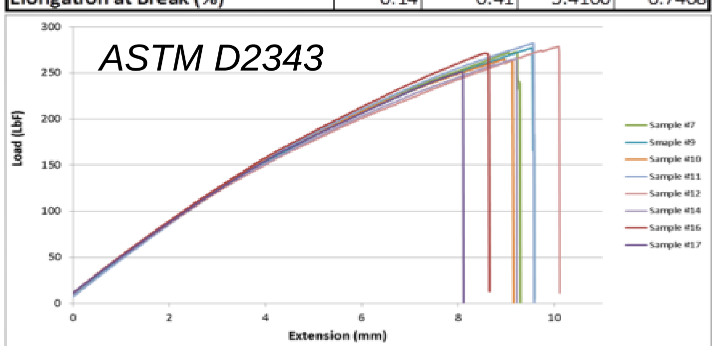
High pressure hydrogen autoclave

Stress Rupture Testing Capabilities



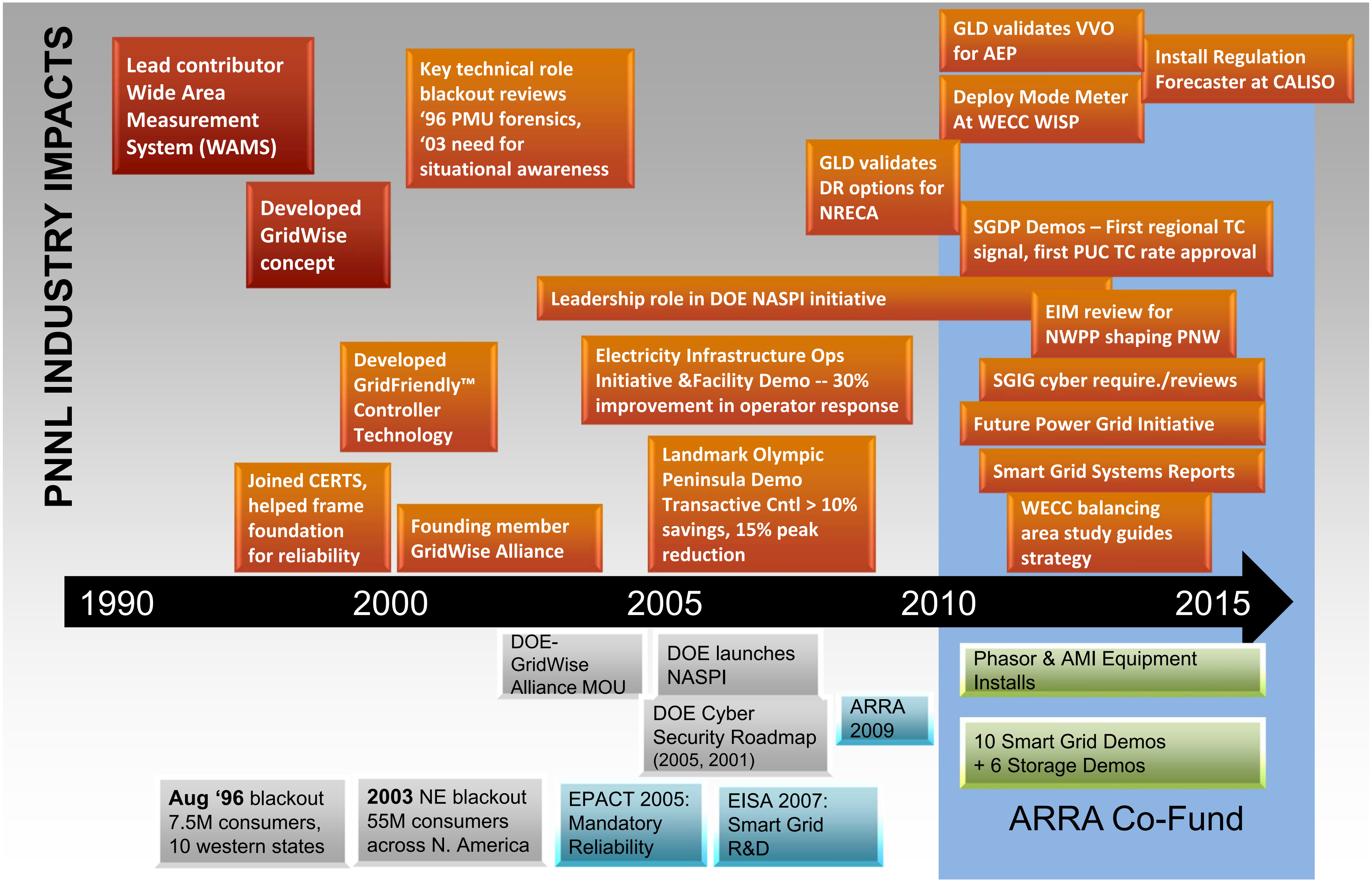


BareFiber PNNL Custom Grip	Average	Stdev	Min	Max
Peak Load (LbF)	270.64	9.87	251.0476	282.2207
Extension (mm)	8.30	2.80	8.1159	10.1112
Elongation at Break (%)	6.14	0.41	5.4106	6.7408



- **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



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 ft^2
- 3 Control Centers
- 70+ staff
- Live / historical Grid feed
- Simulate Grid
- State of the Art industry software

Distribution Systems & Demand Response

National Challenge

Extract the full value of emerging "smart grid" concepts, tools and functionality

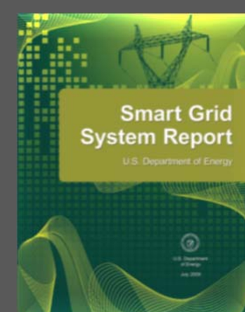
Our Approach: Enabling demand response to be an active tool for increasing grid efficiency and reliability. Key elements include:

- **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

Transmission Reliability

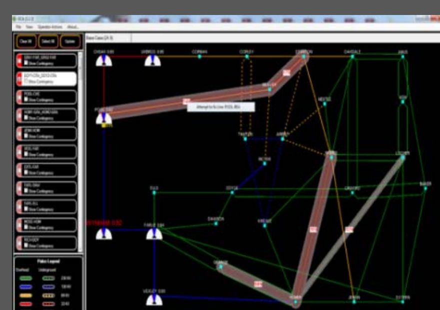
National Challenge

Ensure a reliable U.S. power system by leveraging new data streams that provide wide-area visualization, monitoring and control

Our approach: Improve power system performance and transmission reliability by extracting greater value from grid measurements and data. Key elements include:

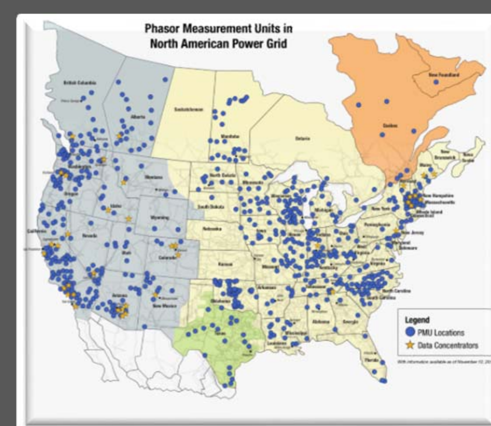
- DOE's lead for the North American Synchrophasor Initiative (NASPI) – joint effort with the North American Electric Reliability Council (NERC) and industry
- **Planning models validation using measurement-based analysis**
- **Decision support tools for operators**
- **EIOC – providing utilities, vendors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

Graphical Contingency Analysis



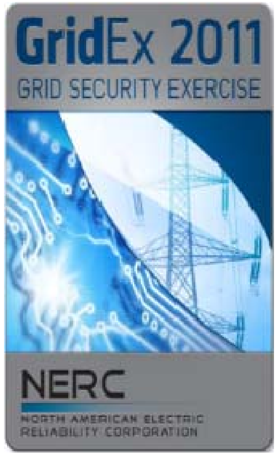
Real-time power flow visualization identifies/prioritizes issues, recommends corrective actions

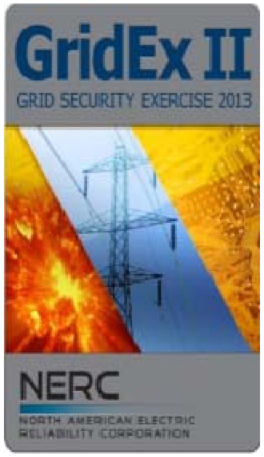
NASPI

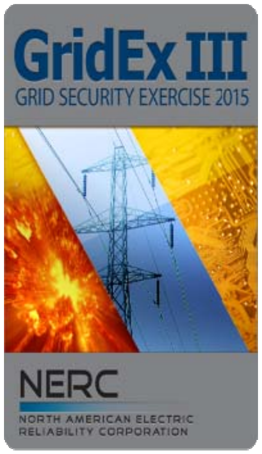


PNNL Cyber Activities (partial list)

- 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.

DISCOVERY in Action

Hydrogen Tools

A Transformative Step Towards Hydrogen Adoption

CENTRALIZED LOCATION organizes current H_2 resources in one robust location—including many proven tools, with plans for adding future content

FOCUSED CONTENT tailored to the specialized needs of H_2 user groups

RESPONSIVE DESIGN enables H_2 safety work across both desktop and mobile devices

TRUSTED COMMUNITIES fostered through social networking around H_2 subject matter expertise

EXPANDABLE FORMAT built with frequently requested future feature sets in mind

http://**h2tools**.org

› **Credible** and **reliable** safety information from a **trustworthy** source

PNNL

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

EMSL

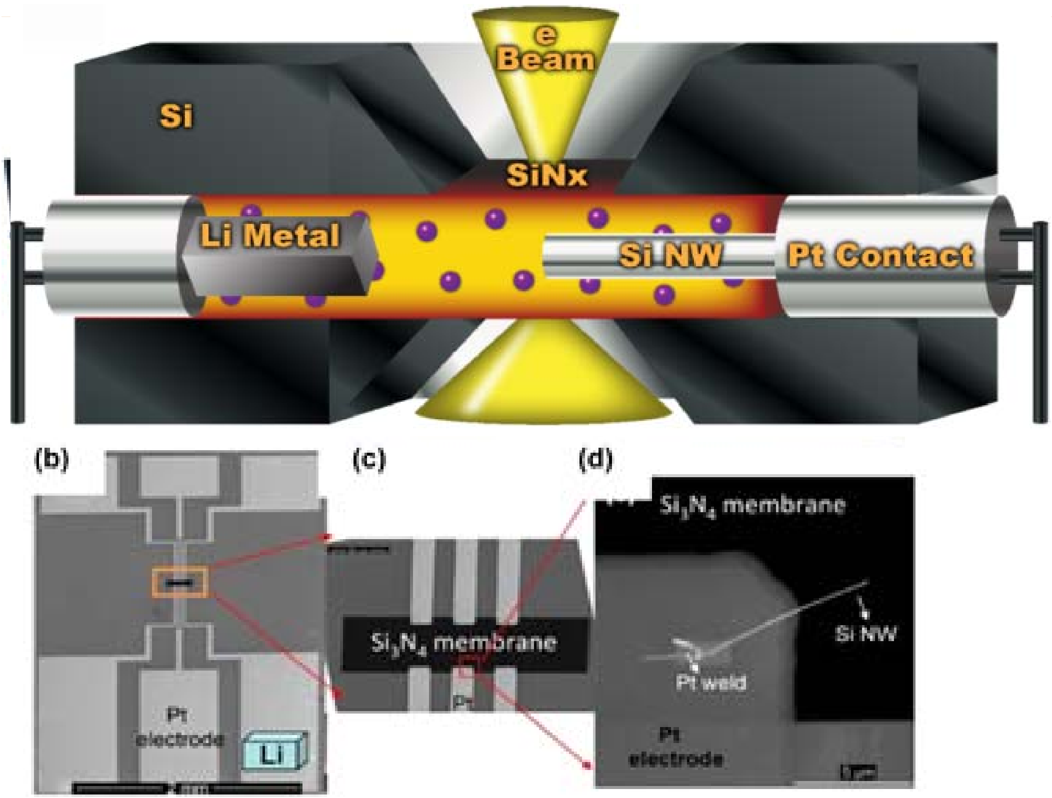
http://www.emsl.pnl.gov/emslweb/

PNNL-SA-94292

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

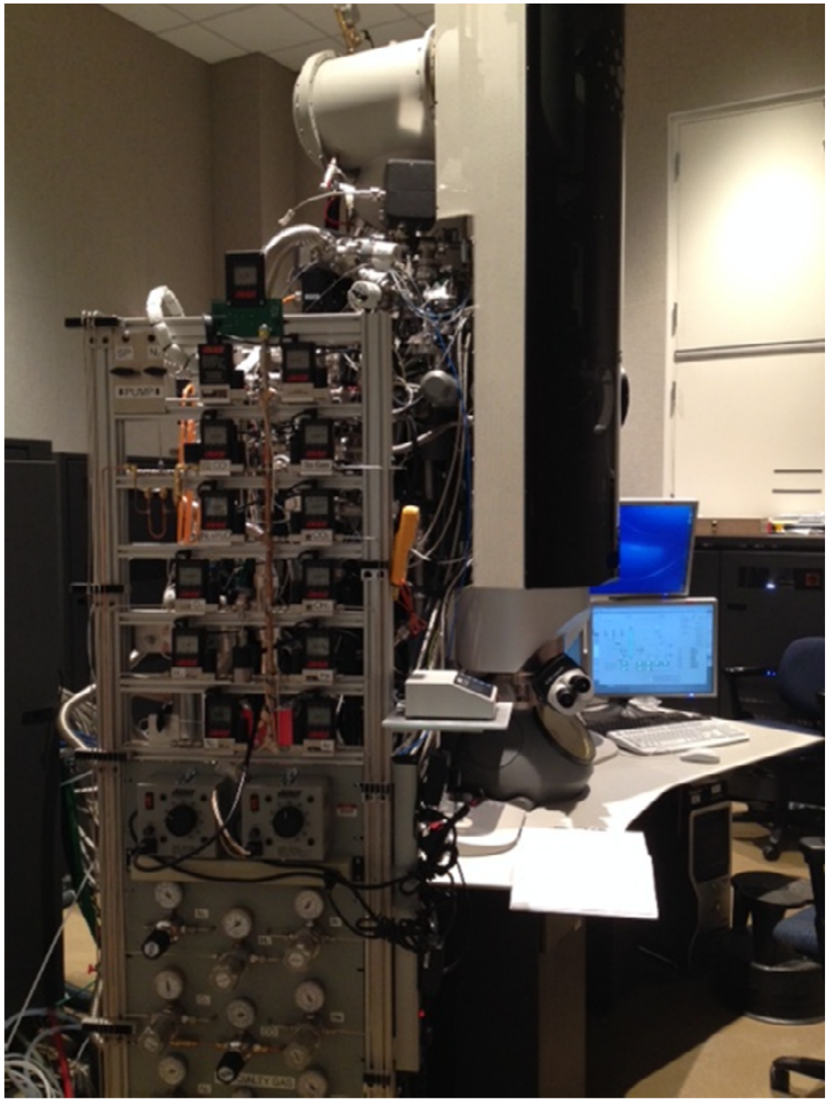
EMSL Equipment Example: In-situ TEM an Environmental TEM

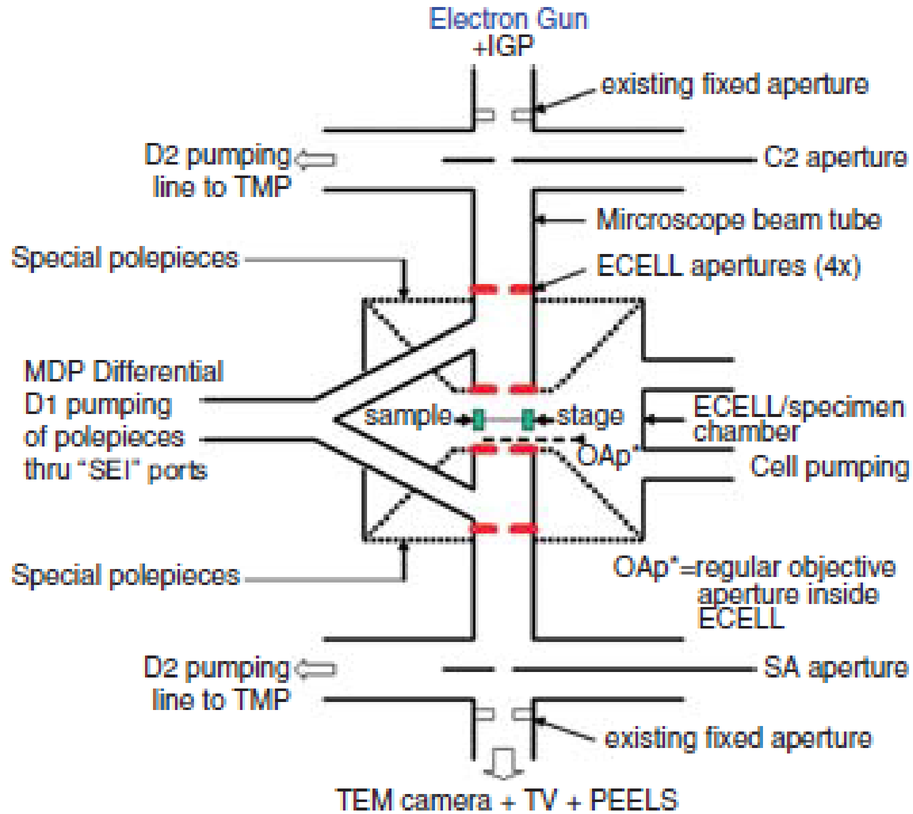


In-situ liquid cell for battery study; a new cell can be designed for electrocatalysts study.

Environmental TEM

EMSL Equipment Example: Aberration corrected Environmental TEM



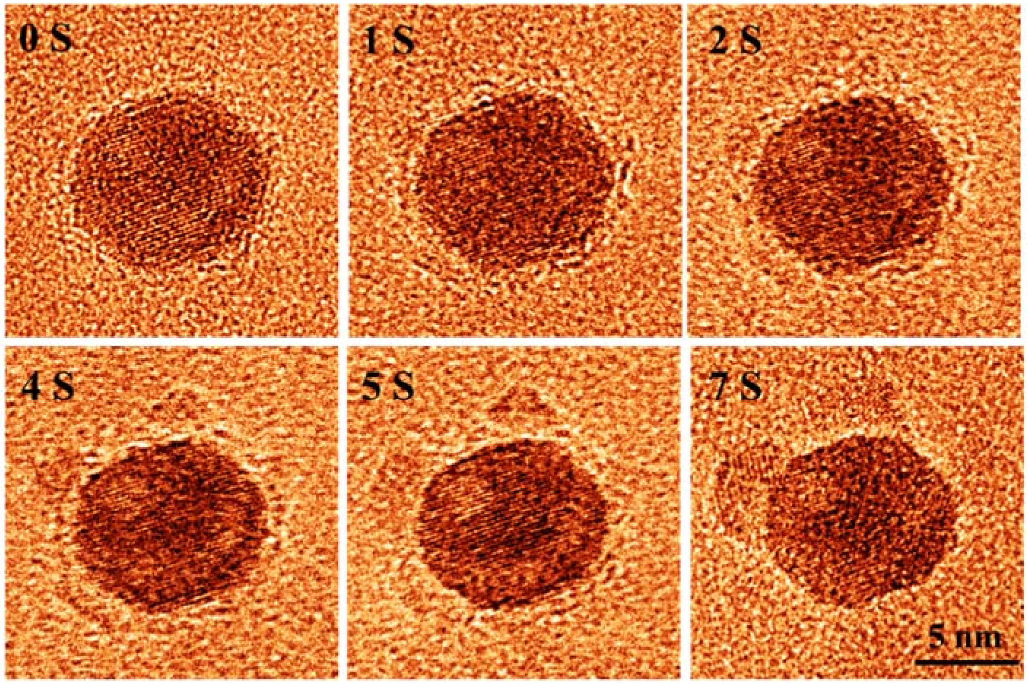


Environmental: H_2, O_2, CO, CO_2, CH_4, etc.

Image corrected ETEM

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

EMSL Equipment Example: Aberration Corrected E- TEM: Atomic Restructuring of Pt−Co Nanoparticles



Atomic-scale reaction dynamics of a single $Pt_{0.5}Co_{0.5}$ nanoparticle in an oxidizing environment (0.1 mbar O_2, 250 °C)

TEM of a Co-Pt nanoparticle during oxidation in 100 mTorr O_2 environment at 250 °C. Co segregates from the Co-Pt alloy nanoparticle and forms CoO islands around the nanoparticle.

H. L. Xin et al, Nano Lett., 2014, 14, 3203−3207