Fuel Cell Technologies Office Webinar

FCTO Lab Consortia Overview: ElectroCat and HyMARC

Presenter(s)
Debbie Myers – ANL (ElectroCat)
Piotr Zelenay – LANL (ElectroCat)
Mark Allendorf – SNL (HyMARC)

Tuesday, November 8th, 2016
Question and Answer

Please type your questions into the question box
Webinar Topics

- Summary of the organization of two Fuel Cell Technologies Office consortia within DOE-EERE’s Energy Materials Network
  - Electrocatalysis Consortium (ElectroCat)
  - Hydrogen Materials—Advanced Research Consortium (HyMARC)
- Current/planned scientific activities and capabilities
- Role of individual projects selected to work with these consortia
- Utilizing existing consortia capabilities
- Upcoming FY17 Funding Opportunity Announcement (FOA)
FCTO Lab Consortia Overview: ElectroCat

Purpose, scope, and capabilities of ElectroCat
Steering Committee

Dimitrios Papageorgopoulos and Adria Wilson, DOE-EERE-FCTO
ElectroCat Materials Domain: Electrocatalysts

Project Focus: PGM-free catalysts for automotive fuel cells
Problem Statement

Fuel cell system targets set to be competitive with ICEVs.

Durability and cost are the primary challenges to fuel cell commercialization and must be met concurrently.

PGM-free catalysts lag behind platinum in efficiency, durability, cost, and ease of integration into membrane electrode assemblies.
### Technical Targets: Electrocatalysts for Transportation Applications

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Units</th>
<th>2015 Status</th>
<th>2020 Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platinum group metal total content (both electrodes)</td>
<td>g/kW (rated, gross) @ 150 kPa (abs)</td>
<td>0.16</td>
<td>0.125</td>
</tr>
<tr>
<td>Platinum group metal (PGM) total loading (both electrodes)</td>
<td>mg&lt;sub&gt;PGM&lt;/sub&gt;/cm&lt;sup&gt;2&lt;/sup&gt; (electrode area)</td>
<td>0.13</td>
<td>0.125</td>
</tr>
<tr>
<td>Mass activity</td>
<td>A/mg&lt;sub&gt;PGM&lt;/sub&gt; @ 0.9 V&lt;sub&gt;IR-free&lt;/sub&gt;</td>
<td>&gt; 0.5</td>
<td>0.44</td>
</tr>
<tr>
<td>Loss in initial catalytic activity</td>
<td>% mass activity loss</td>
<td>66</td>
<td>&lt; 40</td>
</tr>
<tr>
<td>Loss in performance at 0.8 A/cm&lt;sup&gt;2&lt;/sup&gt;*</td>
<td>mV</td>
<td>13</td>
<td>&lt; 30</td>
</tr>
<tr>
<td>Electro catalyst support stability</td>
<td>% mass activity loss</td>
<td>41</td>
<td>&lt; 40</td>
</tr>
<tr>
<td>Loss in performance at 1.5 A/cm&lt;sup&gt;2&lt;/sup&gt;</td>
<td>mV</td>
<td>65</td>
<td>&lt; 30</td>
</tr>
</tbody>
</table>

| PGM-free catalyst activity                               | A/cm<sup>2</sup> @ 0.9 V<sub>IR-free</sub> | 0.024 A/cm<sup>2</sup> | > 0.044*     |

*Equivalent to PGM catalyst mass activity target of 0.44 A/mg<sub>PGM</sub> at 0.1 mg<sub>PGM</sub>/cm<sup>2</sup>*

PGM-free containing MEAs need to meet DOE performance and durability targets.
## Strategy: Research Priorities

### Materials Discovery & Development

- **Catalysts** for oxygen reduction in low-temperature PEMFCs and PAFCs
- **Catalysts** for oxygen reduction and hydrogen oxidation in AMFCs
- Development of **electrodes and MEAs** that are compatible with PGM-free catalysts

### Tool Development

- Optimization of **atomic-scale** and **meso-scale models** of catalyst activity to predict macro-scale behavior
- **High-throughput techniques for catalyst synthesis**
- **High-throughput techniques for characterization** of catalysts, electrodes, and MEAs
- **Aggregation of data in an easily searchable, public database** to facilitate the development of catalyst materials and MEAs
Introduction to FOA

• High-performing and durable PGM-free catalysts and electrodes to significantly reduce fuel cell cost primarily for automotive applications

• Goal is durable PGM-free oxygen reduction reaction catalysts that achieve activity of 0.044A/cm² at 0.9 V in a PEMFC MEA by 2020

• Proposed projects are expected to leverage specified collaboration with one or more ElectroCat national lab-based capabilities, which include:
  – catalyst synthesis, characterization, processing, and manufacturing
  – high-throughput, combinatorial techniques
  – advanced computational tools

• Projects for this topic will be up to 3 years with interim go/no-go decision points

• Interested applicants are encouraged to interface with the ElectroCat Steering Committee to determine potential for collaboration before the FOA is released
ElectroCat Capabilities Overview

**Synthesis, Processing and Manufacturing**
Synthesis and post-synthesis processing of PGM-free catalysts in high-surface-area form or as planar model systems, and fabrication of electrode layers and MEAs
- High surface area catalysts
- Model systems synthesis
- Fabrication of electrodes and membrane-electrode assemblies

**Characterization and Testing**
Composition, structure, and performance of high-surface-area PGM-free catalyst powders, catalyst-ionomer inks, electrode layers, membrane electrode assemblies, and thin film model catalysts.
- Materials Characterization
- Electrode/Cell Characterization & Diagnostics
- Model Systems Characterization

**Computation, Modeling and Data Management**
Guiding and complementing experimental efforts with computational and modeling capabilities at the catalyst, electrode, and membrane electrode assembly levels, as well as by data management expertise.
- Modeling structure-function relationships
- Methods and models to characterize behavior
- Systems for handling and correlating data
Synthesis, Processing and Manufacturing Capabilities

**High Surface Area Catalysts**
- PGM-free Catalyst Synthesis, Analytical Characterization, and Electrochemical and Fuel Cell Testing (LANL)
- Sputter Deposition of Thin Films and High Surface Area Catalysts (ORNL)
- Powder Sputter and Implant System (NREL)
- High-throughput Synthesis of PGM-free Catalysts and Electrodes (ANL)

**Model Systems Synthesis**
- Controlled Functionalization of Model Catalysts (LANL)
- Sputter Deposition of Thin Films and High Surface Area Catalysts (ORNL)
- High-throughput (HT) Thin Film Fabrication and Characterization (NREL)

**Fuel Cell Fabrication**
- Membrane-Electrode Assembly Fabrication (LANL)
- High-throughput Synthesis of PGM-free Catalysts and Electrodes (ANL)
- High-throughput Approaches to Scaling PGM-free Electrodes (NREL)
- Manufacturing Porous Electrodes (ORNL)
Characterization and Testing Capabilities

Materials Characterization
- PGM-free Catalyst Synthesis, Analytical Characterization, and Electrochemical and Fuel Cell Testing (LANL)
- X-Ray Characterization Techniques (LANL)
- X-Ray Photoelectron Spectroscopy (ORNL)
- Electron Tomography (ORNL)
- Analytical Electron Microscopy (ORNL)
- In situ Electron Microscopy (ORNL)
- Structure/Composition-Function Relationships and Active Sites (ANL)
- In situ and Operando Atomic, Nano-, and Micro-structure Characterization (ANL)
- Combinatorial Hydrodynamic Screening of PGM-free Catalyst Activity and Stability (ANL)
- High-throughput Characterization of PGM-free Catalysts and Electrodes (ANL)

Electrode and Cell Characterization
- Operando Differential Cell Measurements of Electrochemical Kinetics and Transport (NREL)
- PGM-free Catalyst Synthesis, Analytical Characterization, and Electrochemical and Fuel Cell Testing (LANL)
- Electrode Microstructure Characterization and Simulation (ANL)
- Electron Tomography (ORNL)
- Analytical Electron Microscopy (ORNL)
- In situ and Operando Atomic, Nano-, and Micro-structure Characterization (ANL)
- Segmented Cell System Optimized for R&D Combinatorial Studies (NREL)
- In situ Fluoride and Carbon Dioxide Emission Measurements (LANL)
- Segmented Cell and Neutron Imaging (LANL)
- High-throughput Characterization of PGM-free Catalysts and Electrodes (ANL)

Model Systems Characterization
- Controlled Functionalization of Model Catalysts (LANL)
- X-Ray Photoelectron Spectroscopy (ORNL)
- High-throughput (HT) Thin Film Fabrication and Characterization (NREL)
Catalyst Modeling
• Multi-scale Modeling
• Rational Design of PGM-free Catalysts (LANL)

Electrode/Fuel Cell Performance Modeling
• Electrode Microstructure Characterization and Simulation (ANL)
• Modeling Kinetic and Transport Processes in PGM-free Electrodes (ANL)

Data Management
• Experimental and Computational Materials Data Infrastructure (NREL)
• Materials Data Facility and Globus (ANL)

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
Materials Characterization

PGM-free Catalyst Synthesis, Analytical Characterization, and Electrochemical and Fuel Cell Testing

The expertise in PGM-free catalyst synthesis, characterization, and fuel cell testing at LANL is built on decades-long experience and proven results, and is the most important capability within LANL’s PGM-free program by far.

Laboratory: LANL, ANL, ORNL, or NREL

Capability Expert: Person to contact with specific questions about capability

Capability Details:

- Title
- Class
- Description
- Capability Bounds
- Unique Aspects
- Availability
- References
- Benefit
- Illustrative Graphic

Reference:


Benefit: ORNL’s unique STEM instruments provide capabilities for the complete analytical and structural characterization of PGM-free catalysts and MEAs at multiple length scales to correlate structure and chemistry with material performance.
• Questions about capabilities:
  Contact@ElectroCat.org
  (to Steering Committee members)

• Questions about FOA:

• Note: If you intend to interact with ElectroCat through a FOA-awarded project, please do not contact either Steering Committee members or capability experts after the FOA has been released
Thank you

Dimitrios Papageorgopoulos
dimitrios.papageorgopoulos@ee.doe.gov

Debbie Myers
dmyers@anl.gov

Piotr Zelenay
zelenay@lanl.gov

hydrogenandfuelcells.energy.gov
Introduction to FOA - HyMARC

• High-risk, high-reward seedling projects to develop innovative and novel onboard rechargeable hydrogen storage material concepts for use in automotive applications enabling higher capacity and lower cost storage systems
• Projects will work collaboratively with the HyMARC core team
• Multi-phase, stage-gated projects, up to 3 years total length, and $250k-1M in DOE funding
• Projects must demonstrate the development of materials that meet agreed upon quantitative metrics to continue past the initial seedling phase (12-18 months)
HyMARC: A Consortium for Advancing Solid-State Hydrogen Storage Materials

Mark D. Allendorf, P.I., Sandia National Laboratories

November 8, 2016

This presentation does not contain any proprietary, confidential, or otherwise restricted information
Sorbents: Eng. COE target: 15 – 20 kJ/mol
- Volumetric capacity at operating temp.
- Increased usable hydrogen capacity needed
- Distribution of H₂ binding sites and ΔH at ambient temperature not optimized

Metal hydrides: Eng. COE target: ≤27 kJ/mol H₂
- Poor understanding of limited reversibility and kinetics
- Role of interfaces and interfacial reactions
  - Solid-solid
  - Surfaces
- Importance and potential of nanostructures
Need for multiscale modeling approaches to address both thermodynamic and kinetic issues.
Objective: accelerate discovery of breakthrough storage materials by providing **capabilities** and **foundational understanding**

**Foundational understanding** of phenomena governing thermodynamics and kinetics limiting the development of solid-state hydrogen storage materials

HyMARC will deliver **community tools and capabilities**:  
- **Computational models and databases** for high-throughput materials screening  
- **New characterization tools and methods** (surface, bulk, soft X-ray, synchrotron)  
- **Tailorable synthetic platforms** for probing nanoscale phenomena
A simple conceptual framework for energetics of H₂ storage focuses activities on two overarching aspects of storage materials:

1. Thermodynamics of uptake and release
   - Tasks 1
     - Sorbents
     - Hydrides

2. Kinetics of uptake and release
   - Tasks 2, 3, 4, and 5
     - Surface reactions
     - Mass transport
     - Solid-solid interfaces
     - Additives

“Effective thermal energy for H₂ release”

\[ \Delta E(T) = \Delta H^\circ (T) + E_a \]
Technical approach: Organizational structure of Core Lab Team

Mark Allendorf
Director
SNL Lead
Vitalie Stavila
Deputy

Jeff Urban
LBL Lead
David Prendergast
Deputy

Brandon Wood
LLNL Lead

Lab program POC
Jeff Roberts

Task 2
Transport
Tae Wook Heo

Task 6
Databases
Brandon Wood

Lab program POC
Chris San Marchi

Task 1
Thermodynamics
Vitalie Stavila

Task 3
Surface Chem.
Robert Kolasinski

Task 5
Additives
Lennie Klebanoff

Task 4
Sol.-Sol. Interfaces
Jeff Urban

Molecular Foundry
POC: David Prendergast

ALS
POC: Jinghua Guo
Technical approach/Modeling capabilities: high-performance National Lab computing allows simulations at all relevant length scales.
Accurate physisorption energetics

H₂ physisorption energetics with high-accuracy quantum chemistry and electronic structure methods

Chemical substitution/functionalization

Open metal sites

Morphology & strain

Crystal structure/coordination

H₂ binding energy on MOF-505 (eV)

QMC

TPSS

BLYP

PBE

TS

PBE+D3

PBE+D2
Sorbent characterization & $\text{H}_2$ uptake

- Surface area and porosity characterization
- Isotherm prediction

![CuBTC/ HKUST-1 at 77 K](chart.png)
Ab initio thermodynamics

- Reaction free energy
- Effects of mechanical stress and nanosizing
- Phase diagram prediction
- Phase fractions at intermediate (de)hydrogenation

[Graphs and diagrams illustrating mole fraction versus pressure for different sizes.]
Multiscale mass transport simulations

- Molecular dynamics (\textit{ab initio} \& classical)
- Defect formation and migration barriers
- Non-equilibrium diffusion
- Polycrystalline effective diffusion

AlH$_3$ structural diffusion

Ni catalyst clustering in Mg

Polycrystalline models for effective diffusion

Non-equilibrium surface H diffusion on metals
Interface simulations

- Simulations of interfaces with gas ($\text{H}_2$), liquids, or solids
- Electronic and chemical properties

**Gas-surface interactions**

$\text{H}_2$ dissociation on MgB$_2$

**Heterogeneous solid interfaces**

$\text{Dr} = 0.125\text{e per C}$

**Graphene-MgO-Mg interfaces**

**Solid-liquid interfaces**

**Surface oxide-solvent interface**
HyMARC capabilities summary: Modeling and simulation

- Accurate physisorption energies (beyond-DFT, QMC, hybrid/vdW DFT)
- Sorbent characterization and hydrogen uptake (porosity, GCMC)
- Quantum chemistry and electronic structure (DFT)
- *Ab initio* thermodynamics (DFT, GCLP, CALPHAD)
- Multiscale mass transport (AIMD, KMC, phase field)
- Computational spectroscopy (DFT)
- Interface simulations with gas/liquid/solid (DFT, AIMD, MD, continuum)
- Solid-state phase transformation kinetics (phase field)
- Kinetic modeling and fitting (continuum)
Synthesis capabilities: bulk materials, dopants, sorbants, and nanoscale platforms

- Bulk metal hydrides and additives
- Macroscale (multiple phases and/or microstructures)
- Controlled-atmosphere ball mills
- Ultra-high pressure reactor

- Meso-macroscale microstructure (2 – 100 nm)
- Grains (up to ~ 10 μm)
- Sorbents
- Porous carbon templates
- Graphene
- Nanobelts
- Molecular and microscales (0.5 – 2 nm)
- Molecular scale

Time (s) vs. Length (m) graph:
- $10^{-12}$, $10^{-9}$, $10^{-3}$, $10^0$, $10^{-6}$, $10^{-8}$, $10^{-10}$
Technical approach/storage materials: build and validate capabilities using simple “model” systems, then progress to higher complexity

Effective thermal energy for H₂ release:

\[ \Delta E(T) = \Delta H^\circ(T) + E_a \]

<table>
<thead>
<tr>
<th>Sorbents</th>
<th>Metal hydrides</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Thermodynamics of H₂ release</td>
<td>• Thermodynamics</td>
</tr>
<tr>
<td>Library of sorbents with representative structural motifs:</td>
<td>- Bulk vs. nano</td>
</tr>
<tr>
<td>• MOFs with open metal sites</td>
<td>• Kinetics of uptake and release</td>
</tr>
<tr>
<td>• Porous carbons</td>
<td>• Surface reactions</td>
</tr>
<tr>
<td>• Doped materials</td>
<td>• Mass transport</td>
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<tr>
<td></td>
<td>• Solid-solid interfaces</td>
</tr>
<tr>
<td></td>
<td>• Additives</td>
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</tbody>
</table>

A progression of model systems will enable development of new capabilities:
Increasing complexity

Binary hydrides ➔ “Simple” Complex hydrides ➔ Complex systems, e.g. Mg(BH₄)₂
Phase segregation ➔ “Molecular” species (e.g. B₁₂H₁₂)
Bulk ➔ Nano
Graphene nanobelts, templates, colloidal synthesis
Bulk and nanoscale metal hydrides

What synthesis-structure-property relationships govern hydrogen uptake and release?

Phase minimization strategies: overcome transport problems due to phase segregation

Doping and defect creation: solid solutions to minimize the number of solid phases

Entropy tuning: crystalline-to-amorphous transitions to improve $\Delta G^\circ$

Ultra-high $H_2$ pressures (up to 700 bar) as a new strategy to regenerate metal hydrides

Consortium capabilities for bulk hydride synthesis include:
- High-pressure reactors (up to 2000 bar/500 °C)
- PCT equipment (200 bar/400 °C)
- Extensive ball-milling equipment
New capability: high-pressure station

Redesigned and upgraded the Sandia high-pressure hydrogen station (pressures up to 1000 bar $H_2$)

Pressure: 0 – 100 MPa
Temperature: up to 400 °C
Fill-time: 1-15 sec
Sample size: 1-10,000 mg
Synthesis of Metal Hydride Composites

- Scalable bottom-up synthetic route
- Atomically defined, tunable graphene-based materials as stabilizing support for metal hydride and complex hydride nanoparticles
- Demonstrated using Mg and MgH₂ nanocrystals
  - Graphene oxide (GO) sheets as encapsulation layer
  - Selectively permeable to hydrogen
- Extension to complex metal hydrides underway

Modified graphene nanoribbons: functional catalysis

Modified graphene nanoribbons for controlled catalysis

GNR: fix the location and chemical identity of catalytic active sites in well-defined materials. Can be integrated with other storage materials

Quite adaptive: catalytic metals, or chelating and ED/EWD groups

Schematic representation illustrating the integration of molecular-defined transition metal catalyst centers via:

a) bipyridine or
b) bidentate phosphine ligands along the edges of atomically defined GNRs.

M = Pt, Pd, Rh, Re, Ir, Cr, Mn, Fe, Co, Ni, Cu
Characterization: state-of-the-art tools probing bulk and surface chemistry, microstructure, phase composition

- **Atomic/Molecular scale** (0.5 – 2 nm)
- **Molecular and microscales** (2 – 100 nm)
- **Meso-macroscale microstructure** (up to ~ 10 μm)
- **Grains**
- **Macroscale (multiple phases and/or microstructures)**

**Time (s)**
- 10^0
- 10^-3
- 10^-6
- 10^-9
- 10^-12

**Length (m)**
- 10^-10
- 10^-8
- 10^-6
- 10^-4
- 10^-2

Image credit: Lawrence Livermore National Laboratory, Sandia National Laboratories, Advanced Light Source.
Surface: key to hydrogen storage

$H_2$ environment

Surface chemistry
(Adsorption/desorption)
(Dissociation/association)

Bulk incorporation

Surface/interface/diffusion

Schematic by Brandon Wood (LLNL)
Detecting hydrogen is challenging with most surface analysis techniques.

Detecting H poses unique challenges:
- Direct detection impossible with most surface techniques (AES, XPS)
- Detectable signal overwhelmed by substrate (LEED, STM, HREELS)
- Ambiguous/difficult to interpret. (TDS)
Surface sensitivity of the HyMARC analysis probes: information depth depends on particle range

HyMARC surface analysis techniques provide access to a range of length scales that complement the modeling tools we are developing.
Direct mapping of hydrogen on surfaces by Low Energy Ion Scattering (LEIS) spectroscopy

- Optimized for direct sensitivity to H on surfaces (< 0.05 ML)
- High surface specificity
- Distinguishes H and D (exchange experiments)
- Adsorption kinetics on compressed particle beds/thin films (res. ~ 1 – 10 s)
- Atomic doser available to characterize uptake of H₂ vs. H
- Surface diffusion measurement: laser-induced pump probe

X-ray photoelectron spectroscopy provides unique insight into surface chemistry of storage materials, including oxidation states

- Quantitative surface composition
- Detailed adsorbate binding information
- Reactor chamber available for sample exposure (up to 40 Torr H\textsubscript{2}.)
- Near Ambient Pressure XPS allows surface/gas interactions (up to 10 Torr \textit{in situ})

- NAP-XPS is at the ALS (LBNL) and under development at SNL, CA:

In previous NAP-XPS studies, we described the mechanism of hydrogen utilization in operating Pt-based SOFCs

Summary: HyMARC surface tools

- **Sandia, CA:**
  - Low Energy Ion Scattering*
  - Auger Spectroscopy*
  - XPS* + reactor chamber

- **Advanced Light Source (LBNL):**
  - Near-Ambient-Pressure XPS* beamlines *(requires approved ALS user proposal)*

- In development at Sandia, CA:
  - *Lab-based Near-Ambien-Pressure XPS*

*Clean transfer from glove box available for all techniques

Please ask us about your specific needs!
X-ray spectroscopies enable element-specific characterization of the electronic density of states (DOS)

- Measurement of the occupied DOS
- Resolve structure of filled electronic density of states states

- Angular momentum resolved probe of the unoccupied electronic DOS
- Provides structure and bonding information
- Suitable for amorphous and crystalline materials – incl. short range order.
Computational spectroscopy

- X-ray spectroscopic simulations for interpreting XAS, XES, and XPS data
- Infrared and Raman spectroscopic simulations
- Calculation of NMR chemical shifts
X-ray spectromicroscopy – spatially resolved XAS

Simple and reliable approach for in situ STXM

Material sealed between two Si$_3$N$_4$ membranes

- Scan sample - transmitted intensity provides image
- Zone plate: ~25 nm resolution
Clean transfer systems ensure materials can be examined without adventitious oxide formation or contamination from air exposure.

- Designed and fabricated at Sandia
- Transfers samples under inert atmosphere
- Available for XPS systems at Sandia & ALS
- Available for LEIS/AES
Synchrotron techniques implemented under HyMARC

X-ray Emission and Absorption Spectroscopy (XES/XAS)
Beamline 6.3.1.2 (ISAAC), ALS – Approved Program
Beamline 8.0.1.1, ALS – General User Proposal
REIXS beamline, CLS – General User Proposal

X-ray Spectromicroscopy – Scanning Transmission X-ray Microscopy (STXM)
Beamline 5.3.2.2, ALS – Approved Program

Ambient Pressure X-ray Photoelectron Spectroscopy (AP-XPS)
Beamline 11.0.2, ALS – Director’s Discretion Access
## Community tools

<table>
<thead>
<tr>
<th>Open-source software</th>
<th>Distributed/federated database development</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase fraction prediction</strong> code (thermodynamics)</td>
<td>What properties belong in the materials database?</td>
</tr>
<tr>
<td><strong>Phase field modeling</strong> for hydrogen storage in hydrides (kinetics)</td>
<td></td>
</tr>
<tr>
<td><strong>Kinetic Monte Carlo</strong> (transport)</td>
<td>Computational:</td>
</tr>
<tr>
<td></td>
<td>• Crystallographic/structural quantities</td>
</tr>
<tr>
<td></td>
<td>• Enthalpy, entropy, surface energy, elastic moduli</td>
</tr>
<tr>
<td></td>
<td>• Defect formation energies &amp; mobilities</td>
</tr>
<tr>
<td></td>
<td>• Computational spectroscopy (e.g., XAS/XES, XPS)</td>
</tr>
<tr>
<td></td>
<td><strong>Experimental:</strong></td>
</tr>
<tr>
<td></td>
<td>• Absorption isotherms (P, T, size) &amp; time-dependent uptake</td>
</tr>
<tr>
<td></td>
<td>• Transport (surface, bulk)</td>
</tr>
<tr>
<td></td>
<td>• Characterization data from all tasks</td>
</tr>
</tbody>
</table>
HyMARC web site is on line

https://hymarc.org/

- Capabilities descriptions
- Contact information
- Recent news
We gratefully acknowledge the EERE Fuel Cell Technologies Office for funding HyMARC.
Thank you

Ned Stetson
Ned.Stetson@ee.doe.gov

Mark Allendorf
mdallen@sandia.gov

hydrogenandfuelcells.energy.gov
Question and Answer

Please type your questions into the question box