Department of Energy
Fuel Cell Technologies Office

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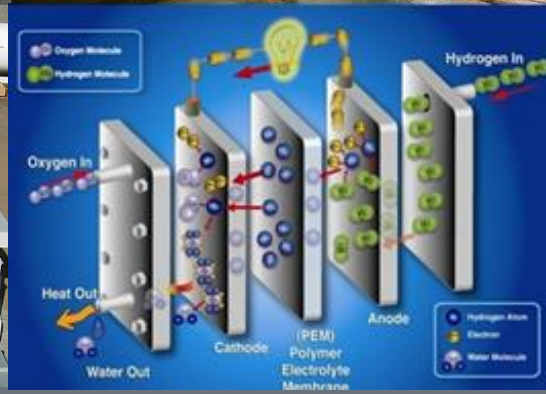

DOE Hydrogen Storage Program
Vision 2016 and Beyond
Lab H_2 PI Meeting

November, 2015

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Fuel Cell Technologies Office
U.S. Department of Energy

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http://energy.gov/eere/fuelcells/fuel-cell-technologies-office

Outline

- Background on the DOE H_2 Storage Program
- Organization of the DOE H_2 Storage Program
- The Lab Consortium Approach
  - HyMARC
  - Hydrogen Characterization Research Team Effort
- Why are we here today
  - Core/Enabling Lab Capabilites
  - Existing lab capabilities to complement current team efforts

Mission and Focus

To enable and accelerate the **successful commercialization of hydrogen fuel cell technologies through development of advanced hydrogen storage technologies** able to cost-effectively meet application performance requirements.

Light-duty fuel cell electric vehicles

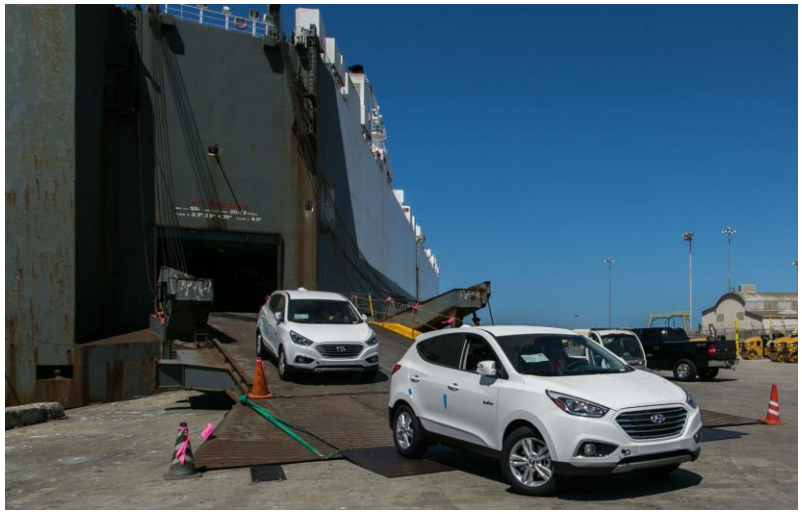
- Primary focus
- Driving range of at least 300 miles without compromising passenger and cargo space or vehicle performance
- Cost & performance targets established in consultation with automotive OEMs

High-value, non-automotive applications

- Secondary Focus
- Support advancement of FCEVs:
  - Infrastructure / supply chain development (e.g., material handling equipment)
  - Leverage prior DOE-supported R&D
- Targets for MHE and portable power established with stakeholder input

Advanced Hydrogen Storage technologies are critical for successful commercialization of hydrogen fuel cell technologies

Current State of H_2 Storage Technologies

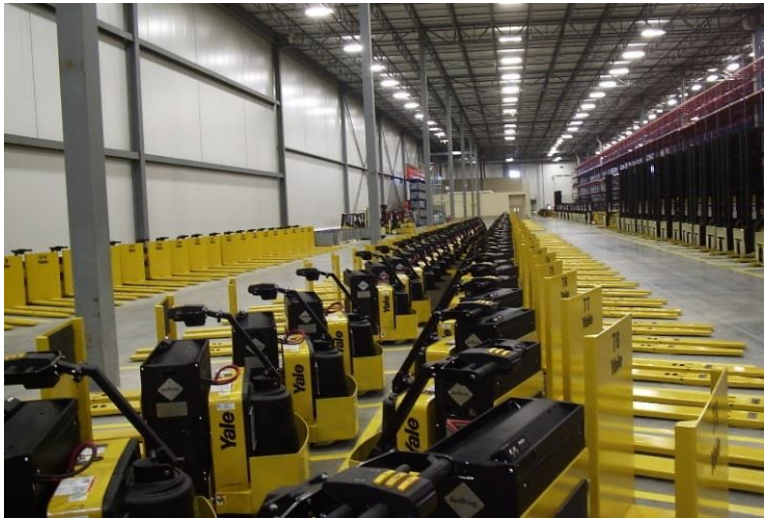


H_2 fuel cell electric vehicles have arrived!

- 70 MPa onboard storage
- Type IV composite overwrapped tanks
- Driving range: 265-312 miles*
- 70 MPa refueling infrastructure being deployed in certain geographic areas

H_2 fuel cell forklifts/pallet jacks successfully commercialized

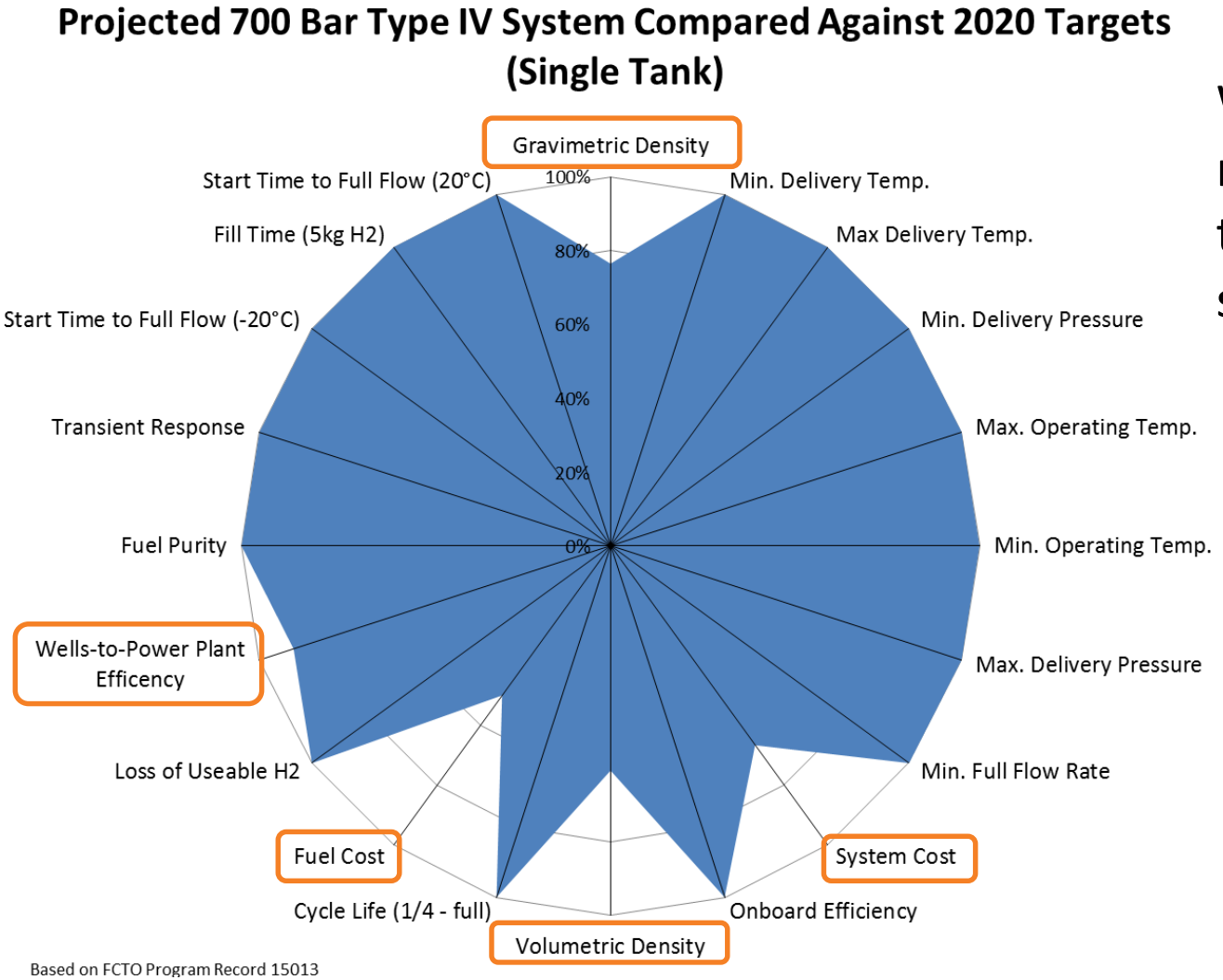
- 35 MPa onboard storage
- Type I/III/IV pressure vessels
- Performance benefits over battery forklifts
- 35 MPa refueling infrastructure deployed, but at a premium over battery charging



* Ranges based on EPA estimates for 2016 model year vehicles: https://www.fueleconomy.gov/feg/fcv_sbs.shtml

Initial commercialization occurring with compressed H_2 storage

70 MPa System Performance



While performance meets many 2020 targets, certain targets still remain a challenge:

- System cost
- Volumetric Density
- Gravimetric Density
- Fuel Cost
- WtPP Efficiency

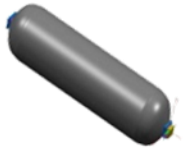
70 MPa compressed hydrogen storage has theoretical limitations that prevent it from meeting all onboard targets

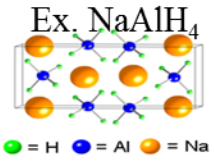
Dual strategy to address near and long-term needs

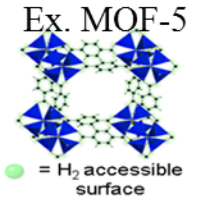
Dual approach

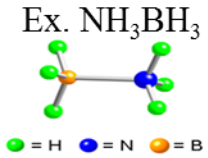
- Hydrogen Storage
  - Near-Term Approach
    - 700 bar Compressed
    - Cold / Cryo-Compressed
  - Longer-Term Approach
    - Metal Hydrides
    - Sorbents
    - Chemical H_2 Storage

Technology Focus









Barriers and R&D Focus

- Lower Cost Carbon Fiber
- Improved Composites
- Conformable designs
- Lower Cost BOP

- System Engineering
- Advanced Insulation
- Improved Dormancy
- Composite Development

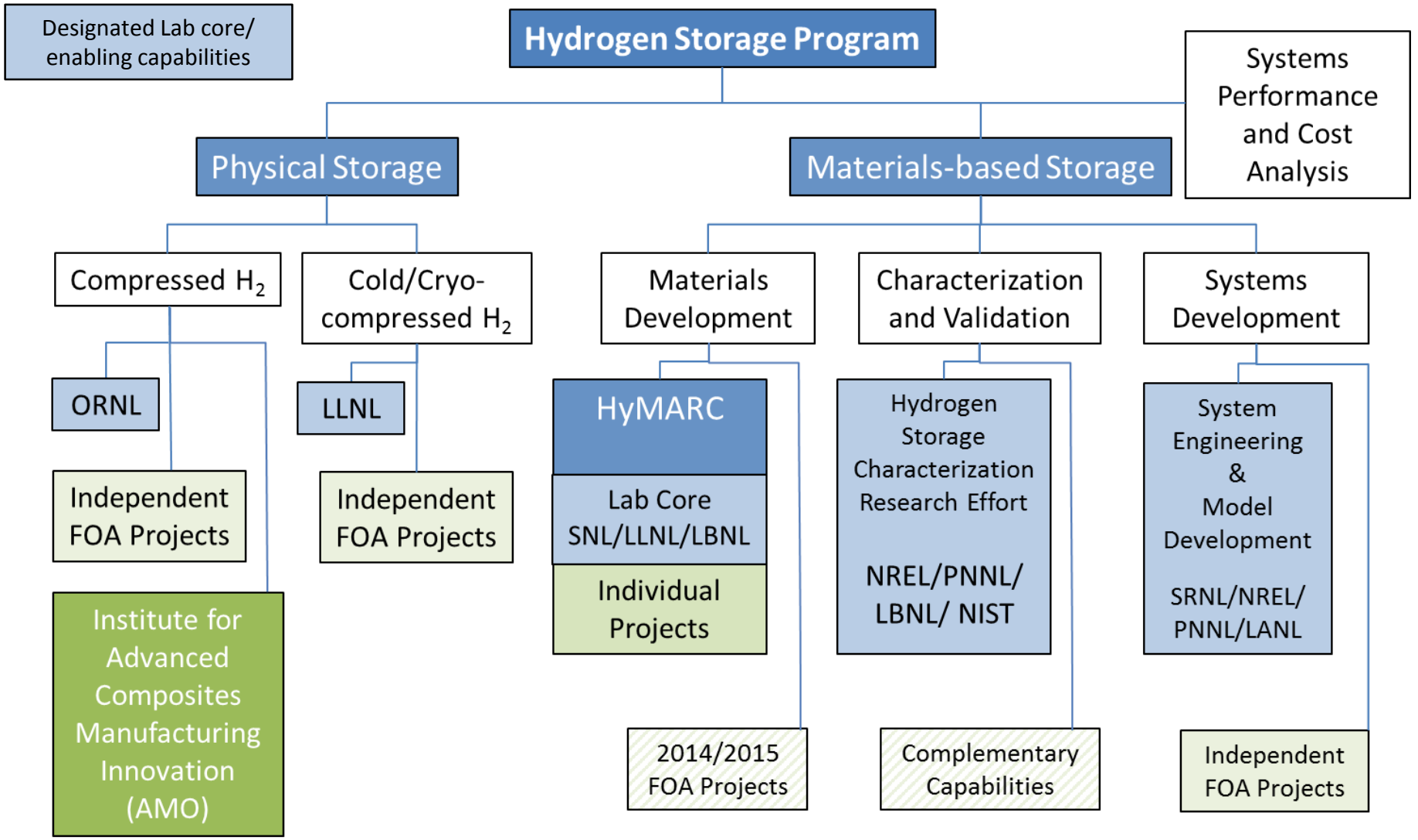
- Higher Material Capacity
- System Cost
- Fill Time
- Onboard Efficiency

- Higher Material Capacity
- System Cost
- Dormancy
- WTP Efficiency

- Lower Cost Off-board Regen
- System Cost
- Gravimetric Density

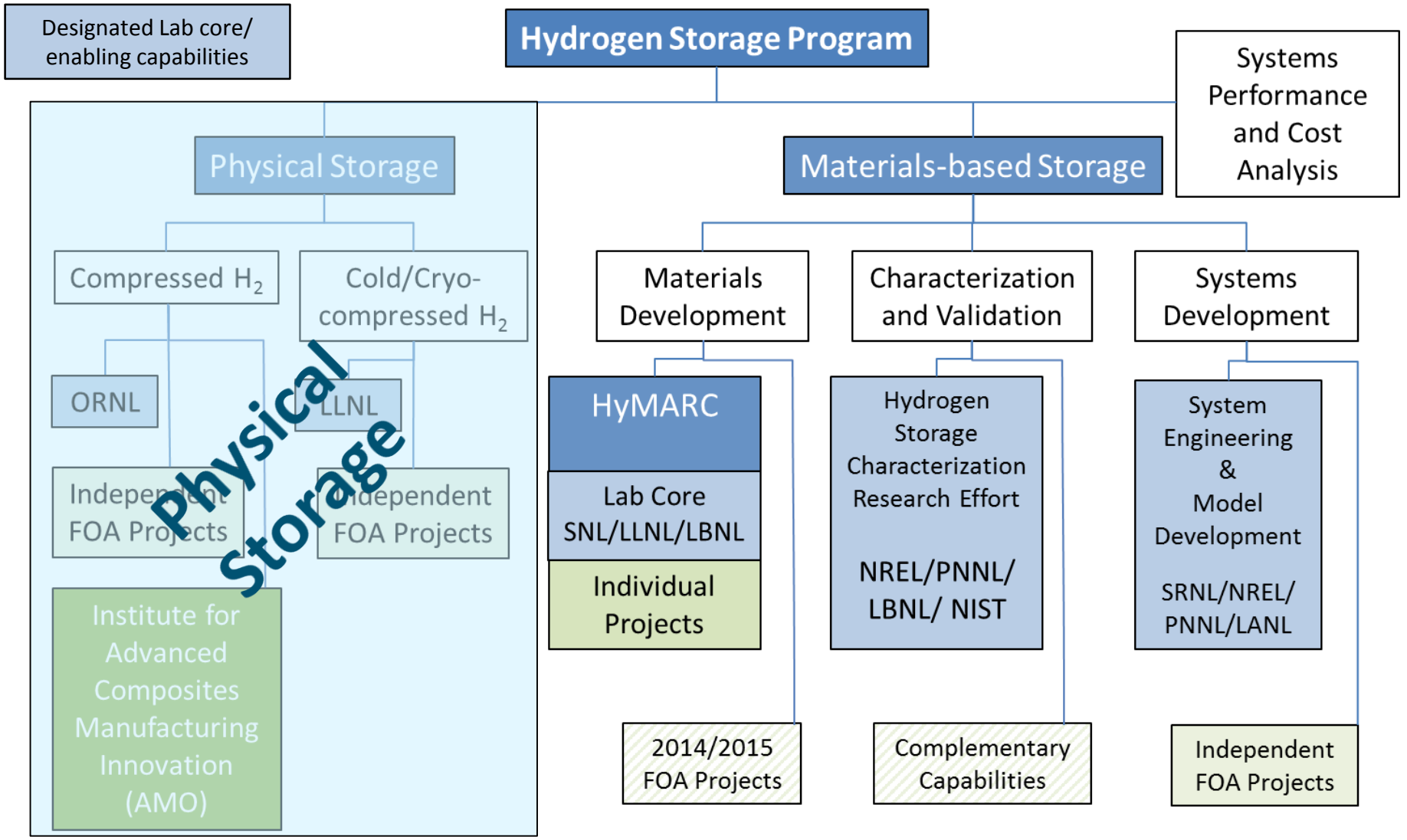
Near-term – address cost and performance of 70 MPa H_2 storage;
Long-term – develop advanced technologies with potential to meet all targets

Hydrogen Program Organization



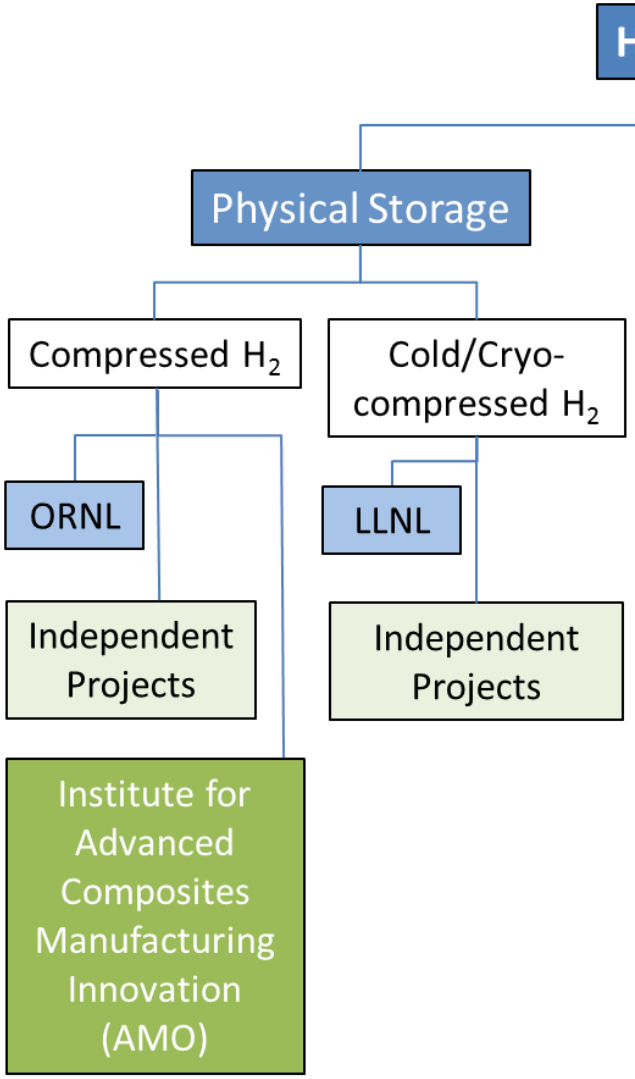
Program organized to address near and long-term technology development

Hydrogen Program Organization



Program organized to address near and long-term technology development

Physical Storage



Current Activities (FY2016):

Compressed Gas Storage:

- ORNL – low-cost precursors
- Materia – alternative resin and manufacturing
- PPG – alternative glass fibers
- CTE – conformable pressure vessels
- CTD – graded construction (SBIR Phase II)
- SNL – alternative materials for BOP

Cold/Cryo-compressed

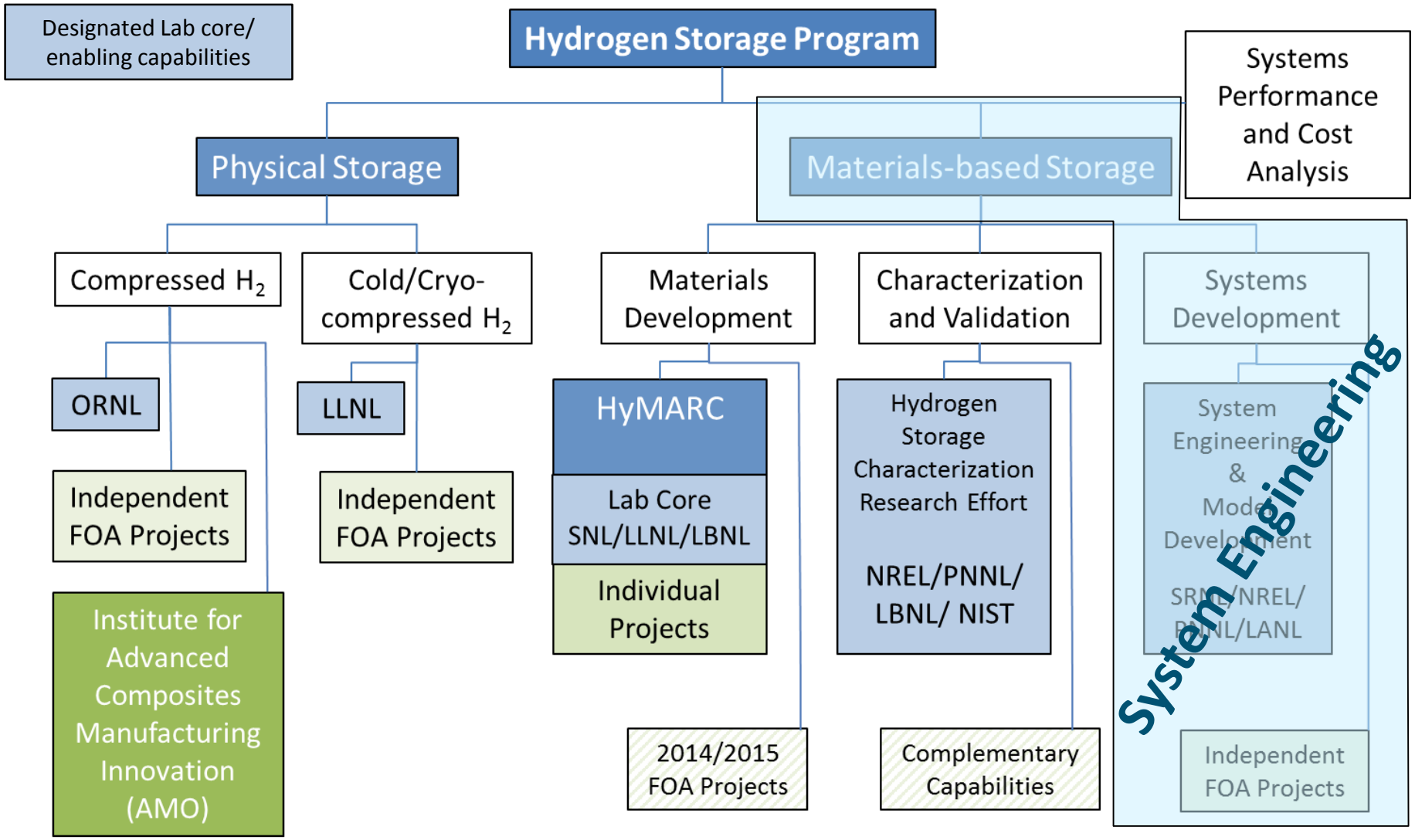
- PNNL – Synergistic system design – 200 K operation
- LLNL – Cryo-compressed (pump and system eval.)

Going forward:

- **Leverage IACMI for system design and manufacturing**
- **Focus on unique features for H_2 storage:**
  - Low-cost precursors/alternative fibers
  - Conformable designs
  - Sub-ambient storage

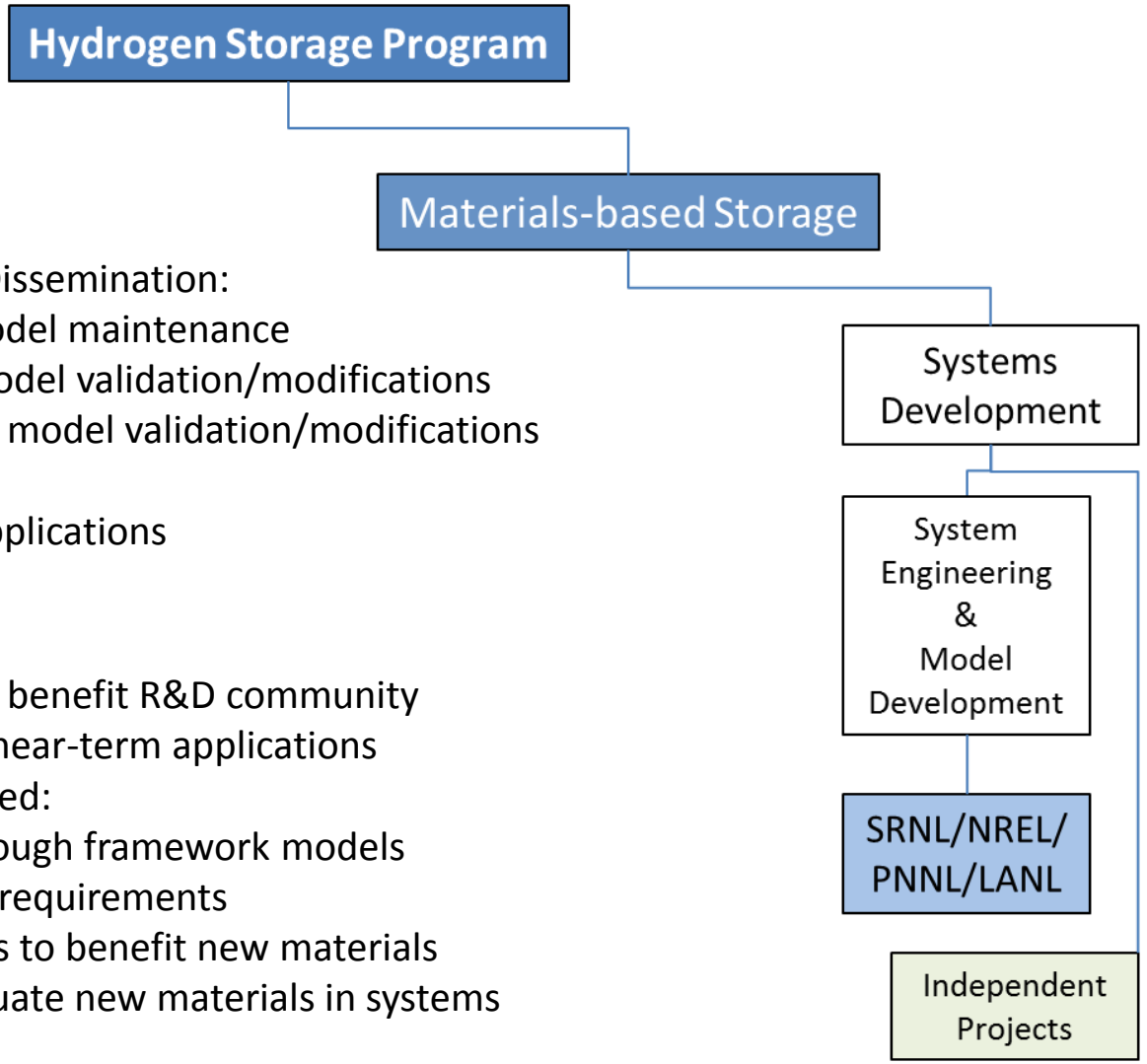
Going forward: leverage other CGS activities; focus on aspects unique for onboard H_2 storage

Hydrogen Program Organization



Program organized to address near and long-term technology development

Materials System Engineering



Current Activities (FY2016):

System Model Validation and Dissemination:

- NREL – lead on HSECoE model maintenance
- SRNL – sorbent and MH model validation/modifications
- PNNL – chemical hydrogen model validation/modifications

System Engineering

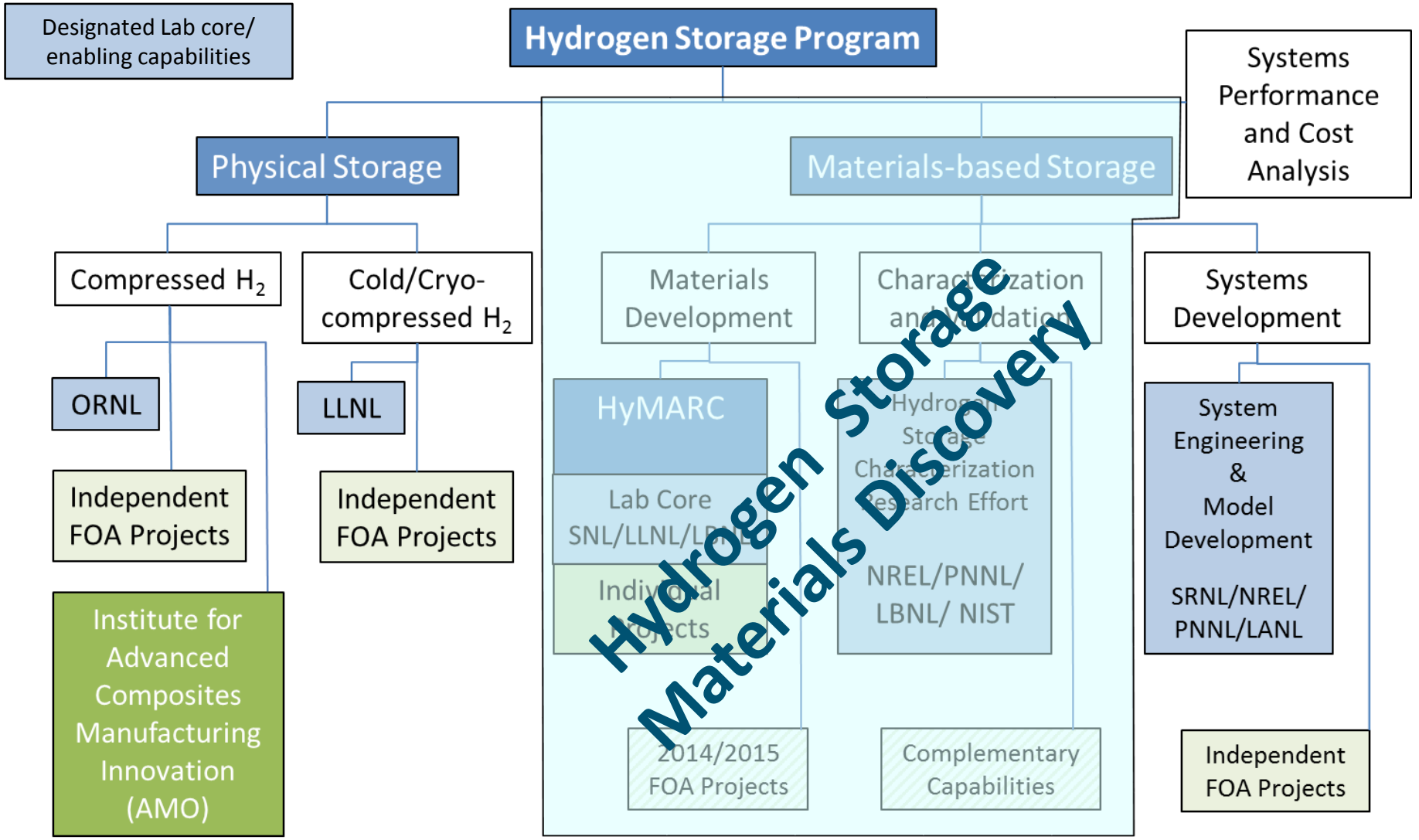
- SRNL – systems for UUV applications

Going forward:

- Continue to evolve models to benefit R&D community
- Apply system engineering to near-term applications
- As new materials are developed:
  - Evaluate performance through framework models
  - Refine materials property requirements
  - Develop optimized designs to benefit new materials
  - Build prototypes and evaluate new materials in systems

Guide future material development efforts through leverage of system models and "reverse engineering" to material properties

Hydrogen Program Organization



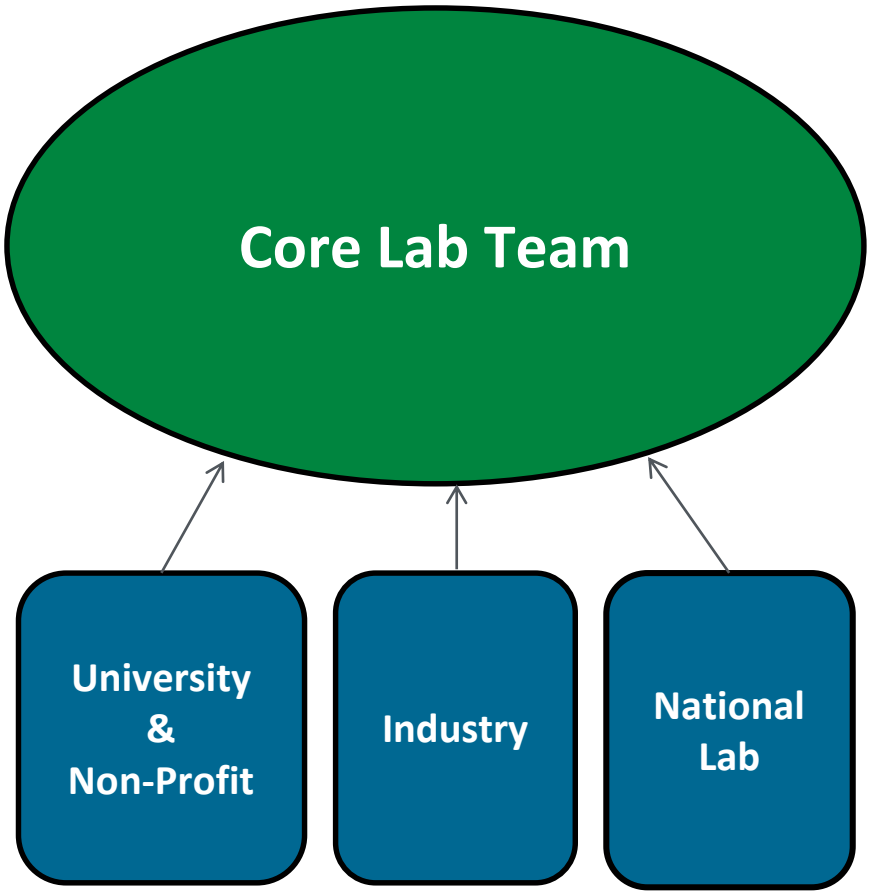
Program organized to address near and long-term technology development

What's needed for hydrogen storage materials development, is an approach that is:

- **Smarter**
- **Better**
- **Faster**

A more intelligent approach for hydrogen storage materials development to meet system performance requirements

The Consortia Approach



Core lab team:

- Foundational science for hydrogen storage materials development
- Develop resource tools for the R&D community:
  - Computational methodologies
  - On-line databases
  - Synthetic protocols
- ***Knowledge disseminated through core lab team to the R&D community***

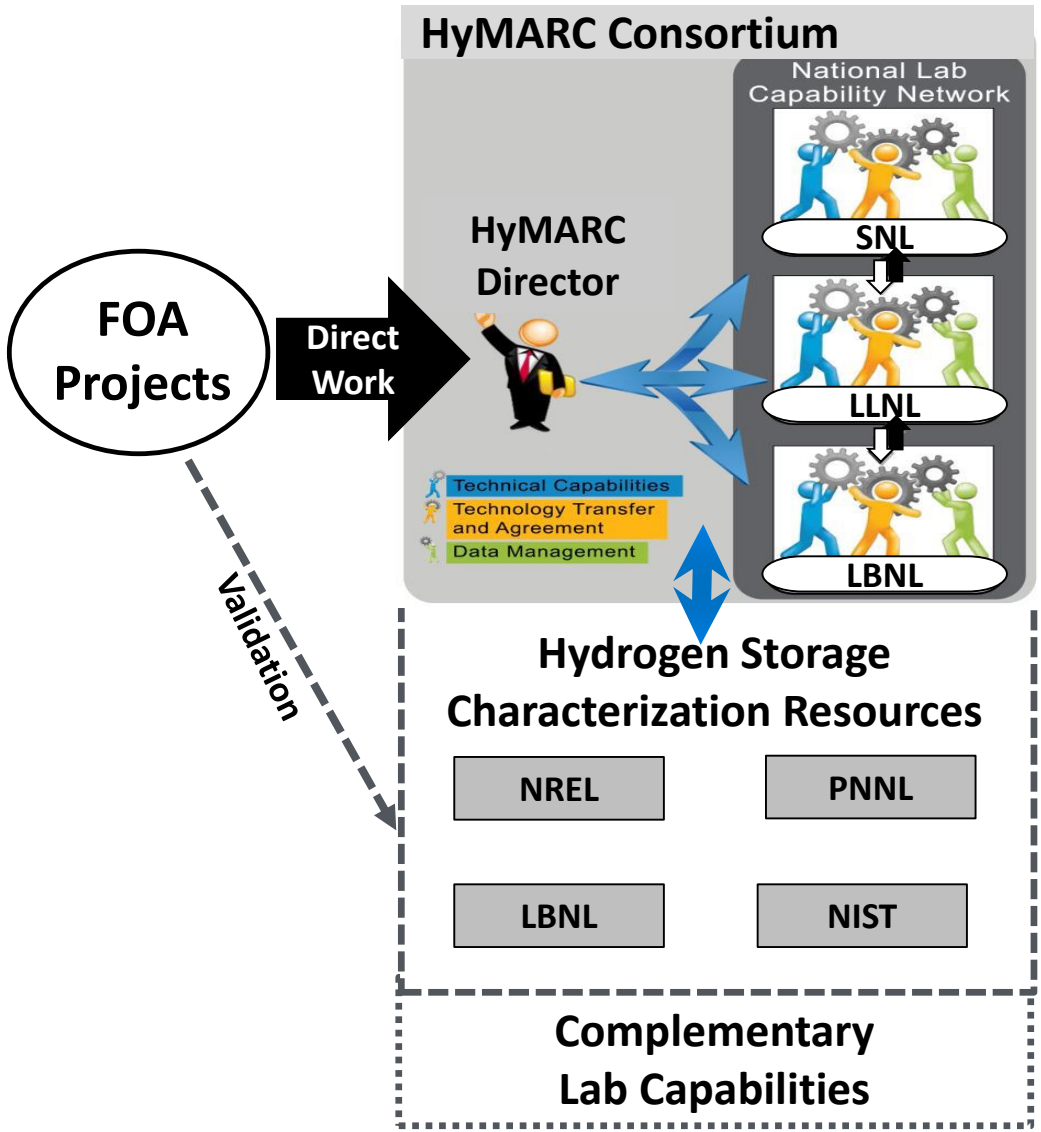
Individual Projects:

- Selected through FOAs/Lab Calls
- Investigations focused on specific innovative materials
- DOE provides support to demonstrate feasibility, a prerequisite for obtaining longer-term support
- Innovation through competition

Annual funding competitions to generate fresh innovative ideas

The Hydrogen Storage Consortium Model

Consortium Framework



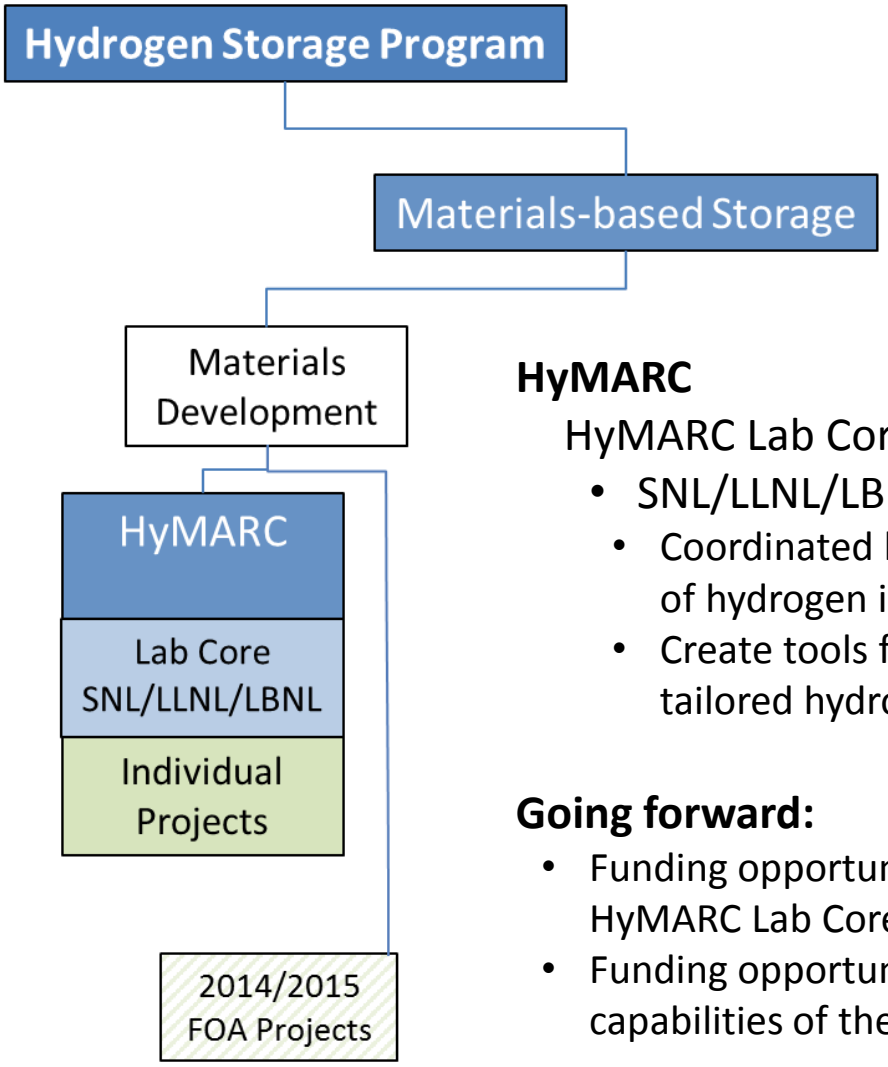
Roles

- **Material development tools**
  - Foundational R&D
  - Computational modeling development
  - Synthetic/characterization protocol development
- **Guidance to FOA projects**
- **Database development**

- **Characterization Resources**
  - Validation of Performance
  - Validation of "Theories"
- **Characterization Method Development**
- **"User-facility" for HyMARC/FOA projects**

- **Synthetic, Computational and Characterization Methodologies**

Hydrogen Materials – Advanced Research Consortium (HyMARC)



2014/2015 FOA Projects:

- HRL – boron-based materials
- Ardica/SRNL – alane production
- Caltech – C-sorbents from graphene
- UMich – best-of-class MOFs
- TAMU – new MOFs
- Ames Lab – Si-based borohydrides
- LLNL/SNL – $Mg(BH_4)_2$

HyMARC

HyMARC Lab Core Team:

- SNL/LLNL/LBNL
  - Coordinated basic and applied R&D to understand the phenomena of hydrogen interactions with materials related to hydrogen storage
  - Create tools for use by the materials R&D community to develop tailored hydrogen storage materials

Going forward:

- Funding opportunities to select individual projects to work with the HyMARC Lab Core to develop specific materials
- Funding opportunities to select individual projects to supplement the capabilities of the Lab Core Team

All future Hydrogen Storage Materials Development efforts will be coordinated with HyMARC

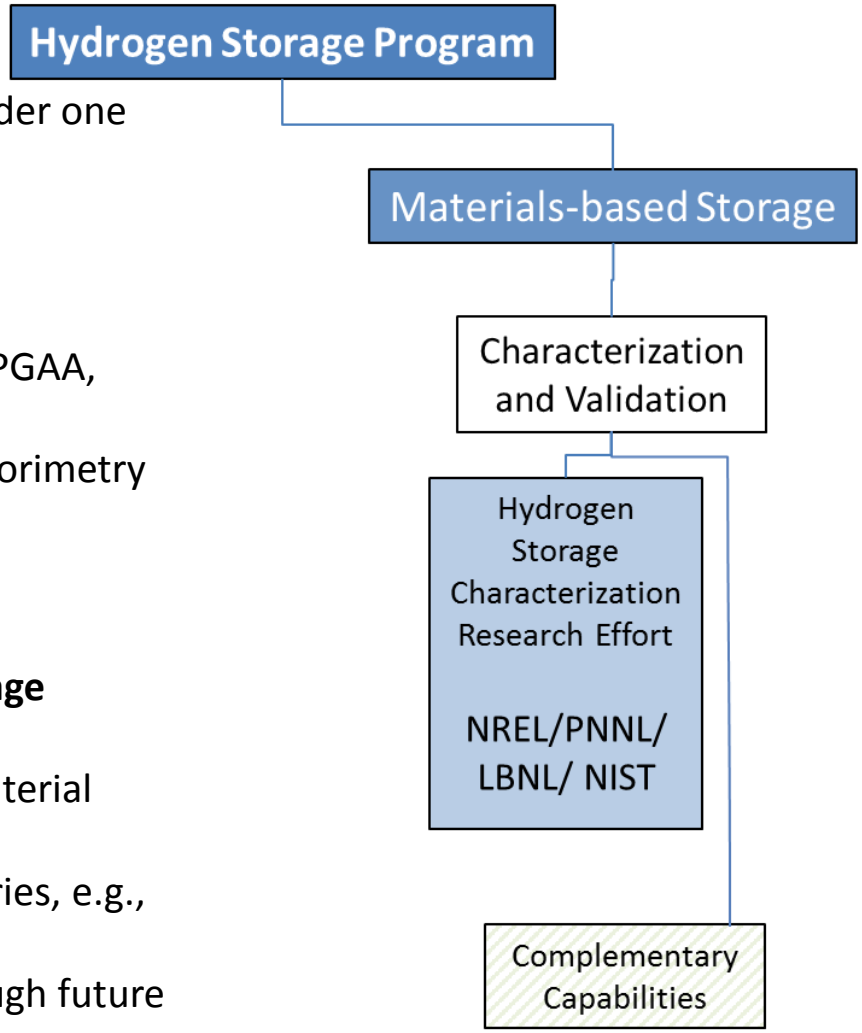
Materials Characterization Resources

Current Activities (FY2016):

Materials characterization resources consolidated under one umbrella – NREL to be the overall lead

Material Characterization Core/Enabling Capabilities:

- NREL – sorption characterization, measurement methodologies/protocols, variable temp. TC
- NIST – neutron methods (diffraction, scattering, PGAA, imaging and interpretations of data)
- PNNL – advanced NMR & microscopy (EMSL), calorimetry
- LBNL – DRIFTS, surface area measurements



Going forward:

- **Characterization team to be a resource for H_2 Storage Program projects**
- Characterization team to be resource to validate material property claims for the DOE
- Characterization team to help validate various theories, e.g., spillover, binding of multiple H_2 per metal center
- Inclusion of other capabilities may be possible through future funding opportunities

Consolidating world-class materials characterization capabilities as a ready resource for DOE H_2 Storage R&D projects

The Role of the HyMARC Core Lab Team

- Development of tools for materials discovery
  - Computational methods based on foundational R&D
  - Synthetic methods development for morphology/defect control
  - Characterization method development to understand hydrogen interactions
- Guidance to the individual projects
  - Computational materials design
  - Compositional modifications
  - Morphology control
- Database development
  - Computational methods
  - Material properties

HyMARC Core Lab Team accelerates hydrogen storage materials development through foundational science and rapid transfer of information

HyMARC – Individual Projects

- Selected through FOAs and Lab Calls on periodic basis

- Materials discovery projects
  - Focused on specific materials/materials classes
  - Work with the Core Lab Team
  - Access to the Characterization team resources
  - Demonstrate concept feasibility for funding support beyond Phase I

- Complementary capability projects
  - Provides access to unique capabilities to supplement core lab team
  - Characterization, synthetic and computational capabilities
  - Resources to complement, not duplicate those of core lab team

FOAs/Lab Calls to provide stream of innovative ideas to the consortium

H_2 Storage Program Lab Capabilities Matrix

● Core Capability ◑ Enabling Capability

May 05, 2015

Capability	State	Cross-Walk to DOE Core Capabilities Related Facility	Ames	ANL	BNL	INL	LANL	LBNL	LLNL	NETL	NREL	ORNL	PNNL	SLAC	SNL	SRNL	Comments
H2 Storage																	
Solid state storage and regeneration/Engineering Center of Excellence	Transitioning	19, 22								◑		◑			◑		The Center of Excellence (competitively selected) is nearing end of the planned project life
Carbon fiber development, production and testing	Existing	17									●						Unique capability leveraging other Offices (AMO, NNMI, etc.)
Polymer composite testing and evaluation	Existing	22									◑	◑		◑	◑		Will investigate status and plans in FY15-16
H2 Storage Sorbent Material characterization capability	Existing	18								●							Core capability to measure gravimetric capacity at a range of temperatures; established ~2008 with Center of Excellence
Prototype solid state hydrogen storage system testing, engineering and modeling	Existing	19												◑	◑		Capabilities to test and evaluate complete prototype materials-based hydrogen storage system against model predictions

Identifying and establishing key lab core and enabling capabilities for the H_2 Storage Program

Complementary Capabilities

- Accelerate the rate of hydrogen storage materials development
- To be able to rapidly identify concepts that have potential from those that do not have potential
- Establish a suite of capabilities as resources to benefit program supported R&D efforts
- Avoid difficulties for non-lab partners to access lab resources

- Target is to complement the current team efforts, NOT duplicate the capabilities

The program cannot afford to continue to make long-term commitments to material development efforts that will not meet the needs

•Smarter
•Better
•Faster

- Coordinated basic and applied R&D
  - Foundational research for better understanding phenomena
- Computational methods to guide materials development
  - Less Edisonian approach to materials development
- National lab capabilities as a resource for R&D projects
  - Eases access and takes the guess work out of it
- No long-term commitment without demonstrated feasibility
  - Better use of funding and resources, stimulates innovation

A more intelligent approach to develop hydrogen storage materials to meet system performance requirements

Thank you

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