Hydrogen Fueling Infrastructure Research and Station Technology

2014 DOE Annual Merit Review

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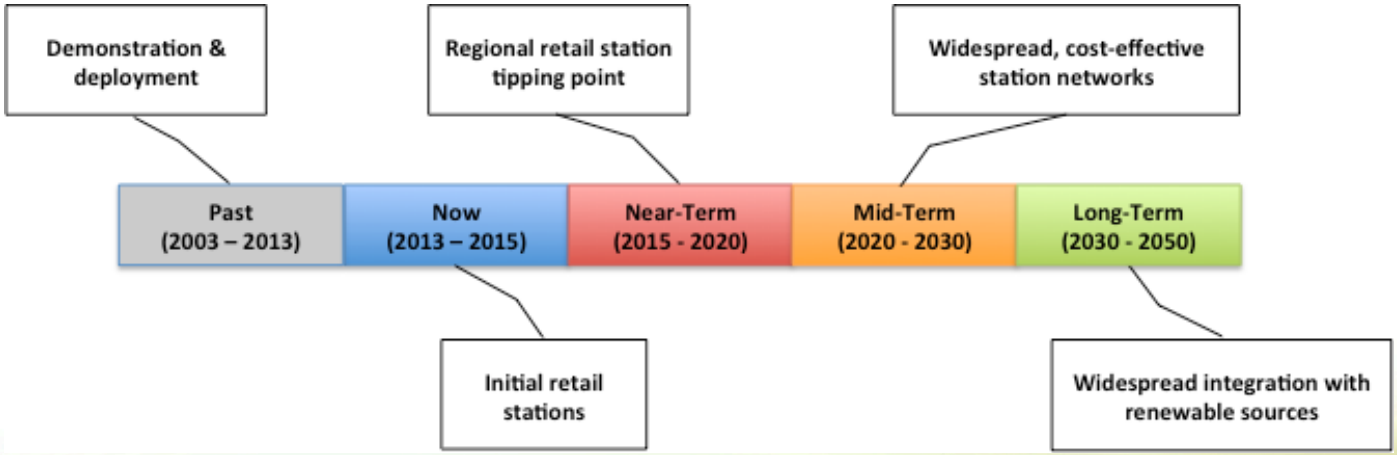
Overview

Timeline	Barriers
Project start date: March 2014 Project end date: September 2014* Percent complete: On-going	C. Hydrogen Storage D. Lack of Hydrogen Refueling Infrastructure Performance and Availability Data E. Codes and Standards
Budget	**Partners**
Total project funding FY13 DOE Funding: $0k Planned FY14 DOE Funding: $400k Total DOE Project Value: $400k	See partner slide

*Project continuation and direction determined annually by DOE

H2FIRST Long-term Objectives

- Reduce the installation cost of a hydrogen fueling station to be competitive with conventional liquid fuel stations.
- Improve the availability, reliability, and cost while ensuring the safety of high-pressure components.
- Focus a flexible and responsive set of technical experts and facilities to help solve today's urgent challenges and the unpredicted needs.
- Enable distributed generation of renewable hydrogen in a broader energy ecosystem.



Relevance

- **Mission: Ensure fuel cell vehicle customers have a positive fueling experience relative to conventional gasoline/diesel stations as vehicles are rolled out in the near term and transition to advanced fueling technology beyond 2017.**
- The success of FCEVs relies largely upon a positive user experience (their first experience), which depends on fueling infrastructure performance, availability, and reliability issues.

Commercial FCEVs Launch ~2015

CA.GOV The California ENERGY COMMISSION — News Release

For Immediate Release: May 1, 2014
Media Contact: Teresa Schilling - 916-654-4989

California Investing Nearly $50 Million in Hydrogen Refueling Stations

Accelerates construction of 28 new stations and one mobile refueler to boost statewide public network

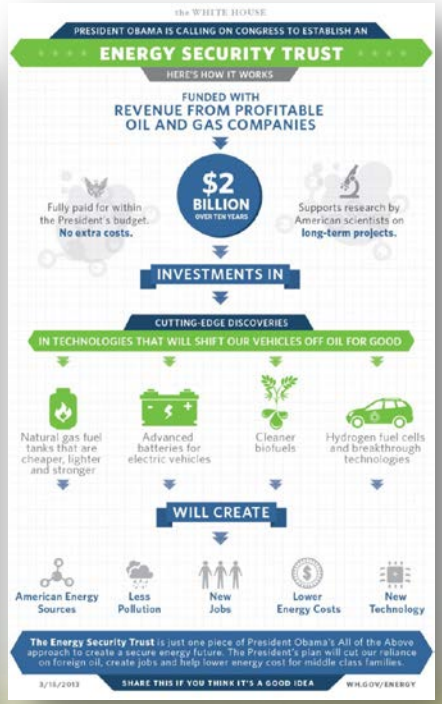
SACRAMENTO - The California Energy Commission today announced it will invest $46.6 million to accelerate the development of publicly accessible hydrogen refueling stations in California in order to promote a consumer market for zero-emission fuel cell vehicles.

The recommended funding awards to eight different applicants were made through the Energy Commission's Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP). The recommended awards include six 100 percent renewable hydrogen refueling stations and will add 13 new locations in Northern California and 15 in Southern California, strategically located to create a refueling network along major corridors and in regional centers. The mobile refueler will provide added reliability to the early hydrogen refueling network to provide refueling capability when stations are off-line.

"Transitioning to low- and zero-emission vehicles is critical to meeting air quality goals and to reducing the emissions that lead to climate change," said Energy Commissioner Janea A. Scott. "With this funding, California will accelerate the construction of a reliable and affordable refueling infrastructure to support the commercial market launch of hydrogen fuel cell vehicles."

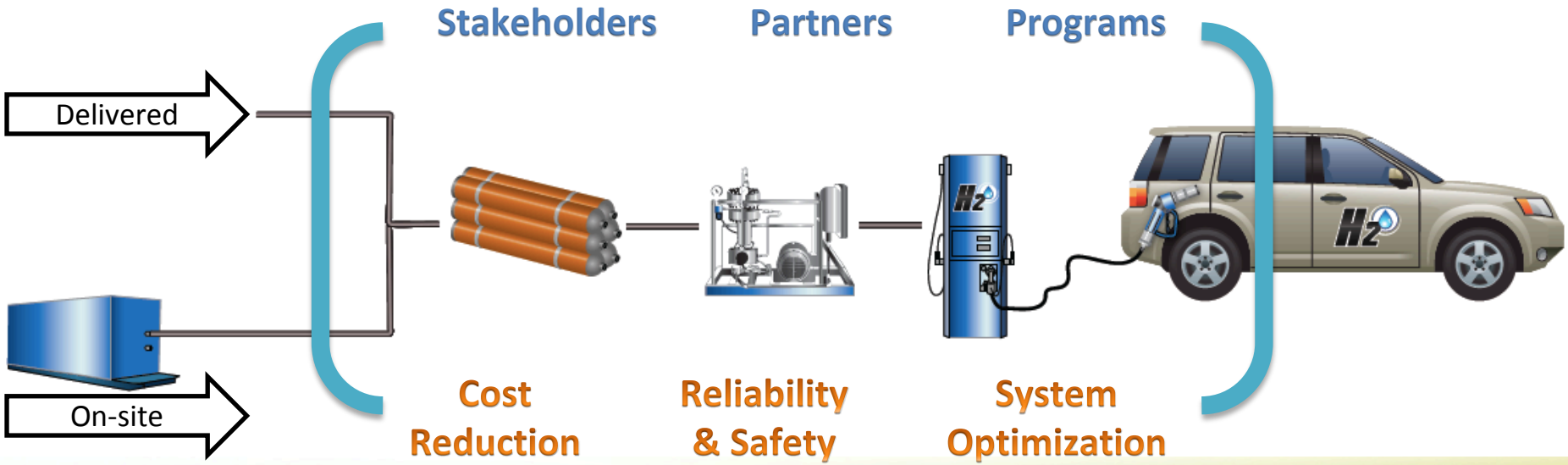
The recommended awards will advance Gov. Brown's executive order directing state government to support and facilitate the rapid commercialization of zero-emission vehicles (ZEVs) in California, with a benchmark that by 2020 "the State's zero-emission vehicle infrastructure will be able to support up to one million vehicles."

Today's recommended awards will add 28 new stations to 9 existing and the 17 stations currently under development. These 54 hydrogen refueling stations represent significant progress towards meeting California's goal of establishing a 100-station network to support the full commercialization of fuel cell vehicles in California.



Approach

- Identify "high probability for success opportunities" for timely advancement of near-term fueling stations.
- Identify and develop common laboratory capabilities that can serve many purposes for advancing hydrogen fueling technologies.
- Ensure relevance of activities through appropriate industry engagement.



Approach: Maximize Impact by Leveraging National Resources

Broad role of the DOE labs:

- Perform high-impact R&D to make H_2 fueling technologies affordable and convenient
- Assist in breaking down barriers to H_2 fueling technology deployment

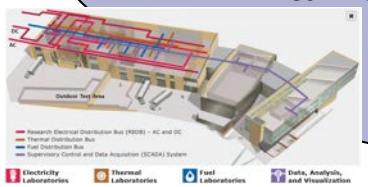
DOE and State Agency Support

Broad role of the private sector :

- Develop and commercialize affordable and convenient H_2 technologies
- Implement successful business models for $H_2$and FC systems

National Labs

- Provide objective, scientifically sound assessments and coordination
- Develop R&D plans
- Provide capabilities and perform research that cannot be accessed elsewhere



H2FIRST

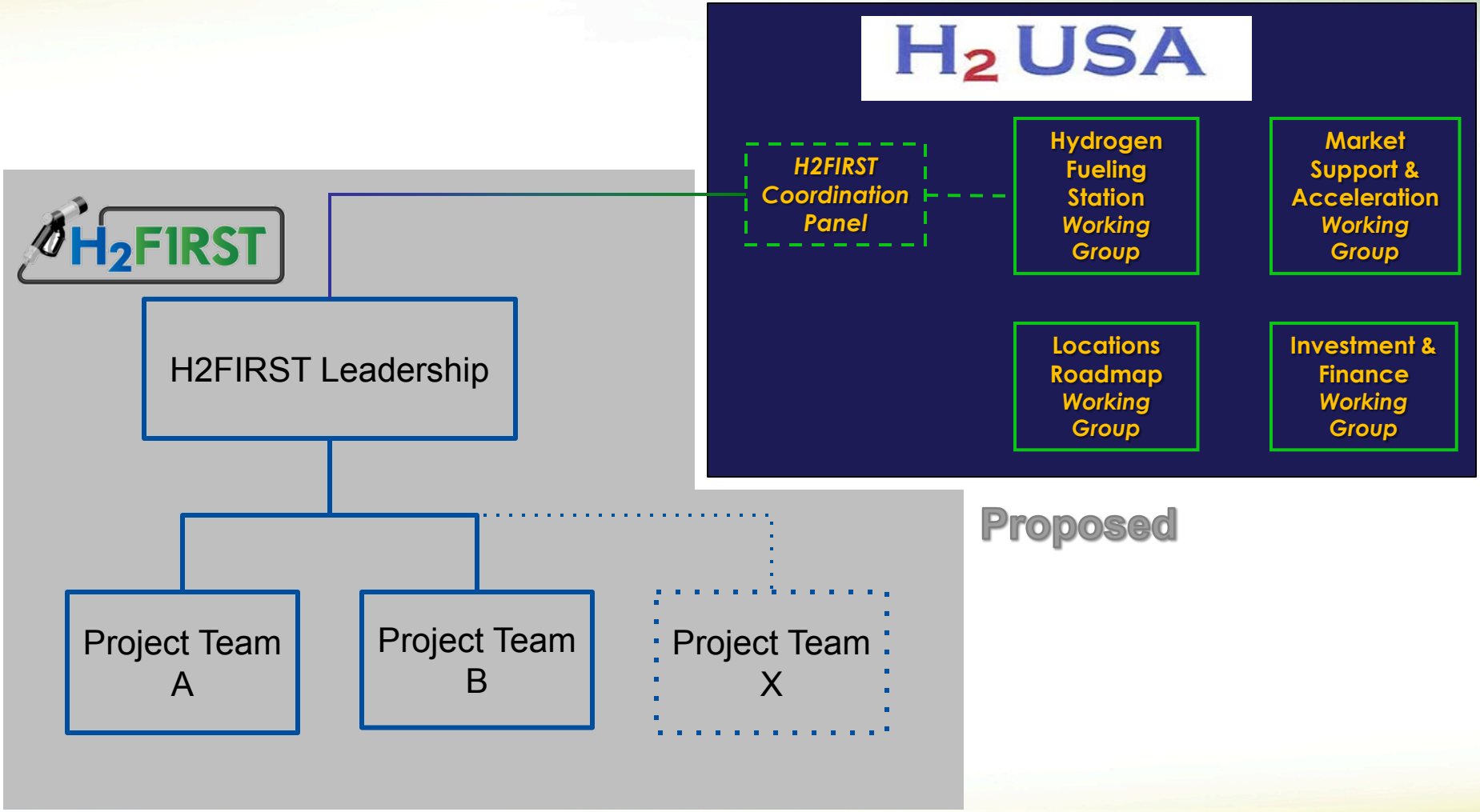
Advanced station technology
Enhanced customer experience

Private Sector

- Inform H2FIRST activities from a market perspective
- Contribute people, equipment, time, money to achieve H2FIRST objectives
- Implement results from H2FIRST into technology development

Market Growth

Approach: H2FIRST is a DOE project that supports the goals and objectives of H2USA



Approach: H2FIRST Coordination Panel

- Provide a voice for industry to help set technical priorities and provide guidance for shared resources, ensuring alignment with the H2FIRST mission and national goals
- Review H2FIRST progress and plans quarterly (2 face-to-face and 2 interim Web meetings/teleconferences) and provide feedback to H2FIRST leadership team
- Provide annual feedback to H2FIRST leadership in written form, including how the member organization is benefitting from the project
- Catalyze, propose, and assemble project teams around topics of interest
- Propose strategic new members to the H2FIRST leadership team
- Participation in H2FIRST coordination panel is available to any active H2USA Fueling Station Working Group members

Resource commitments from the private sector are critical for success.

Accomplishment: SNL & NREL MOU

Sandia MOU number 13-S-649
NREL MOU number: MOU-14-328

MEMORANDUM OF UNDERSTANDING
between
Sandia Corporation
and
Alliance for Sustainable Energy, LLC

SUBJECT: Sandia and the Alliance for Sustainable Energy, LLC will coordinate activities to lead a multi-year, national Hydrogen Infrastructure Partnership that provides coordination of independently funded research, development, and deployment (RD&D) activities to reduce deployment risks and increase technology commercialization.

INTRODUCTION.
Sandia Corporation (Sandia) is a Delaware Corporation that operates Sandia National Laboratories (SNL) pursuant to Contract No. DE-AC04-94AL85000 with the United States Department of Energy (DOE). Among other programs, SNL conducts transportation energy research focused on critical technology solutions to ensure secure and sustainable transportation fuel supplies, a resilient delivery infrastructure, and the clean and efficient use of fuels in vehicle systems. SNL's Center for Infrastructure Research and Innovation (CIRI) is a key element in pursuit of these goals, performing RD&D to reduce barriers to the deployment and widespread adoption of refueling infrastructure for fuel cell electric vehicles (FCEVs).

Alliance for Sustainable Energy, LLC is a Delaware Limited Liability Company that operates the National Renewable Energy Laboratory (NREL) pursuant to Contract No. DE-AC36-08GO28308 with the United States Department of Energy. NREL is a national laboratory with principal facilities in Golden, CO. Among other programs, NREL conducts transportation energy research focused on vehicle systems, fuels performance, and operational testing and analysis simulate and evaluate real-world scenarios to assess the benefits and challenges of deploying alternative transportation technologies at large scales. Findings make it possible to develop solutions compatible with vehicle technology and fueling infrastructure, while addressing regulatory and commercial barriers.

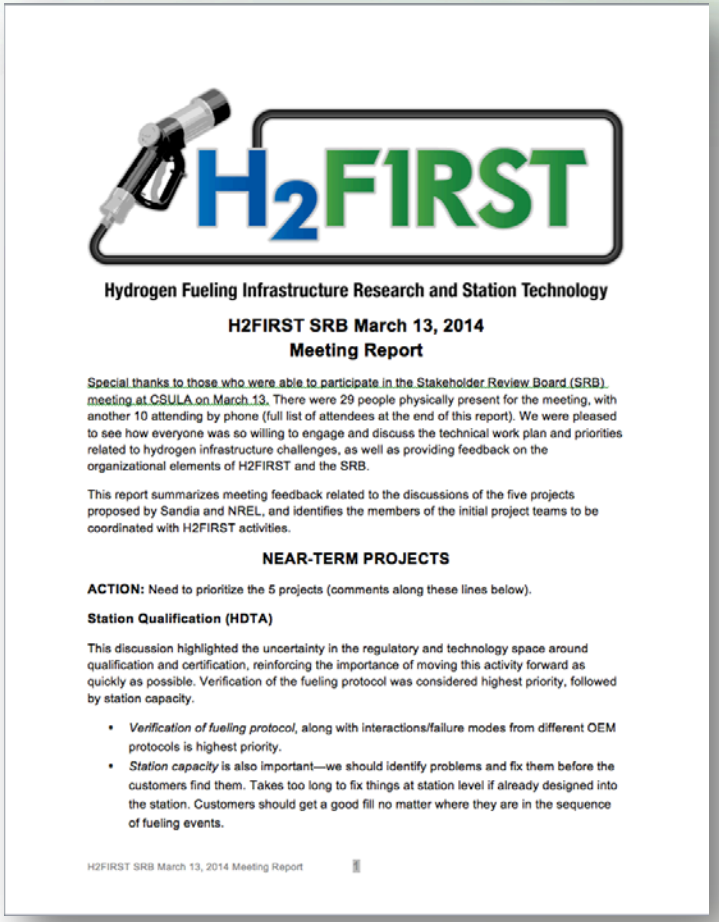
Collectively, Sandia and the Alliance for Sustainable Energy, LLC are the Parties; individually, each is the Party.

The Parties propose to coordinate and synergize their independently funded RD&D in the area of hydrogen fuel infrastructure to reduce deployment risks and increase technology commercialization. SNL and NREL will coordinate to lead a national research and development Hydrogen Infrastructure Partnership (HIP) intended to remove technical barriers associated with

Coordination of capabilities to address technical challenges

- Technical expertise – Hydrogen specific materials and systems engineering expertise to develop technical solutions
- Facilities - Physical venues for technical collaboration among diverse stakeholders
- Objectivity – Trustworthy and objective assessment of options to achieve broader goals
- Partnerships – Industry, government, laboratories, universities

Accomplishment: Inaugural Meeting Held March 2014



H2FIRST

Hydrogen Fueling Infrastructure Research and Station Technology

H2FIRST SRB March 13, 2014
Meeting Report

Special thanks to those who were able to participate in the Stakeholder Review Board (SRB) meeting at CSULA on March 13. There were 29 people physically present for the meeting, with another 10 attending by phone (full list of attendees at the end of this report). We were pleased to see how everyone was so willing to engage and discuss the technical work plan and priorities related to hydrogen infrastructure challenges, as well as providing feedback on the organizational elements of H2FIRST and the SRB.

This report summarizes meeting feedback related to the discussions of the five projects proposed by Sandia and NREL, and identifies the members of the initial project teams to be coordinated with H2FIRST activities.

NEAR-TERM PROJECTS

ACTION: Need to prioritize the 5 projects (comments along these lines below).

Station Qualification (HDTA)

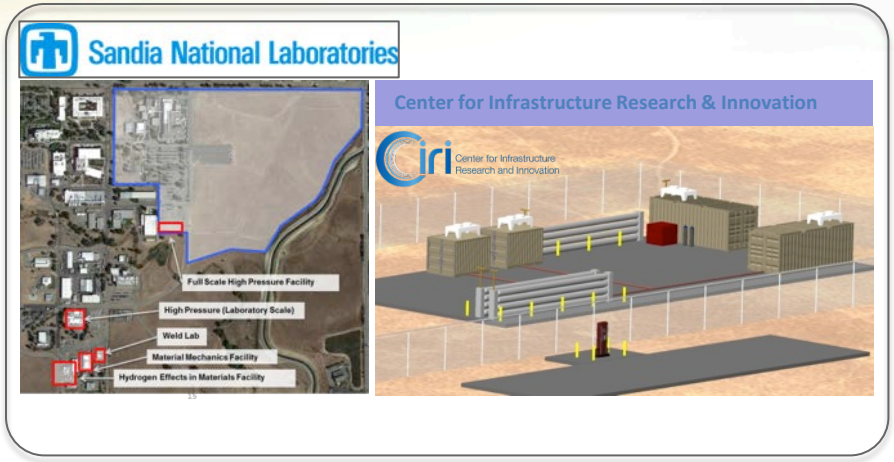
This discussion highlighted the uncertainty in the regulatory and technology space around qualification and certification, reinforcing the importance of moving this activity forward as quickly as possible. Verification of the fueling protocol was considered highest priority, followed by station capacity.

- *Verification of fueling protocol*, along with interactions/failure modes from different OEM protocols is highest priority.
- *Station capacity* is also important—we should identify problems and fix them before the customers find them. Takes too long to fix things at station level if already designed into the station. Customers should get a good fill no matter where they are in the sequence of fueling events.

H2FIRST SRB March 13, 2014 Meeting Report 1

- 29 in-person attendees & 12 telephone attendees
- Discussed responsibilities, near-term projects, and project teams

Accomplishment: Supporting Capabilities – CIRI Materials Science & Engineering Science Focus



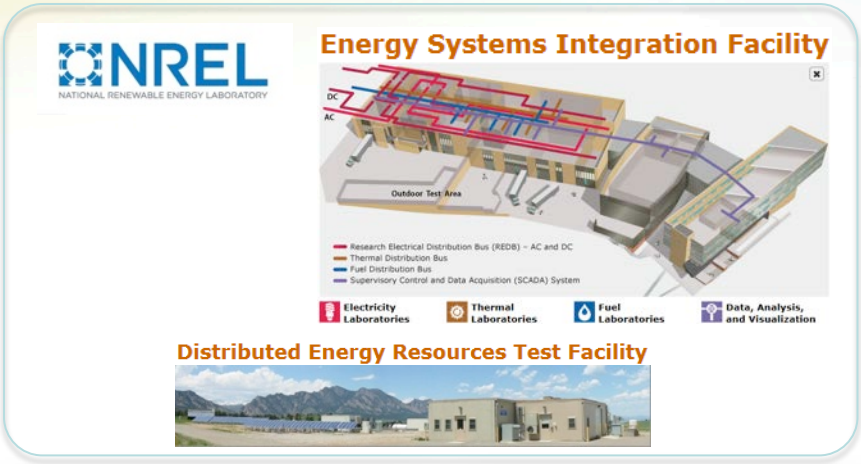
CIRI Capabilities

- Materials and Components
  - Materials testing in high-pressure H_2 at variable temperature
  - Customized testing on metals and non-metals
  - Weld research and development
  - Full-scale component testing in H_2
- Systems Engineering
  - Full-scale H_2 station breadboard for system optimization
  - Real world equipment evaluation and innovation platform

Status

- Assessing HyReF (full-scale component testing and H_2 station breadboard) planned for 2015

Accomplishment: Supporting Capabilities – ESIF & DERTF Testing & Analysis Focus



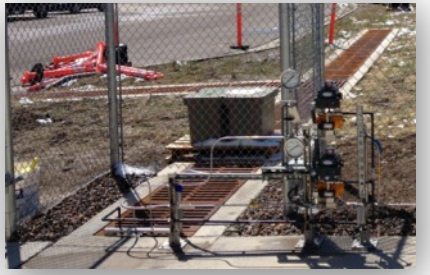


Photo credit: NREL (April 2014)

Capabilities

- On-site hydrogen generation (electrolyzers)
- High pressure component testing
- Flexible, renewable-ready hydrogen energy storage platform
- Advanced hydrogen sensor testing
- 700-bar and 350-bar (nom) dispensing
- Research Electrical Distribution Bus (REDB) capability for grid integration
- Physical and photo-electrochemical material characterization
- Systems integration & device under test platforms

Research Station Status

- 700-bar research station construction for basic system architecture started and expected completion in July 2014

Accomplishment: 5 Project Teams Established – *Station Acceptance/Qualification*

Goal – *Accelerate station acceptance by developing, validating, and implementing test methods and hardware for capacity and performance testing of commercial hydrogen stations*

- Draft Work Plan (Near-term)
  - Develop consensus on requirements for station acceptance.
  - Assist in developing, validating and implementing alpha hardware unit to support initial station acceptance needs.
  - Transition testing responsibilities to responsible organizations or agencies to support hydrogen station market growth.
- Initial Feedback
  - Highest priority is fueling protocol verification & station capacity is next
  - Coordination required between stations, OEMs, and regulatory agencies
- Current Activity
  - Convening process to develop requirements with input from the private sector and government agencies.

Accomplishment: 5 Project Teams Established – *Dispenser/Components*

Goal – *Cost reduction and reliability improvements through component and fueling technique enhancements*

- Draft Work Plan (Near-term)
  - Test innovative components and fueling techniques to inform reliability and cost reduction
  - Design, construct and commission a test-bed dispenser system and related components
  - Leverage existing materials expertise for longer-term reliability improvement and component cost reduction
- Initial Feedback
  - Reliability, durability, and lower cost components are a higher priority than optimized fill methods for consumer acceptance of initial stations
  - Station costs and reliability must be addressed first but protocols influence cost issues when they significantly affect station design.
- Current Activity (oral update)

Accomplishment: 5 Project Teams Established – *Reference Stations*

Goal – *Improve station components and design by identifying gaps and generating example designs through industry feedback and modeling*

- Work Plan (Near-term)
  - Develop reference station designs based on state-of-the-art components
  - Characterize cost, throughput, reliability and footprint using DOE models
  - Report results and influence component evaluation and development of testing facilities
- Initial Feedback
  - Coordinate with H2USA
  - Standardize station sizes and metrics for comparison

Current Activity: Initial station matrix (03/2014 Milestone) integrated HDSAM modeling

Description	Units of Measure or Station Characteristics	Low Utilization/Low	Low Utilization/Med	Low Utilization/High	Med Utilization/Low	Med Utilization/Med	Med Utilization/High	High Utilization/Low	High Utilization/Med	High Utilization/High	High Utilization/High
Intended Purpose	Cluster, Connector, Destination	Destination	Destination	Connector	Destination	Connector	Cluster	Connector	Cluster	Cluster	Cluster
Utilization-Daily	%	15	20	30	30	40	50	50	60	70	80
Utilization-Annually	%	15	20	30	30	50	70	70	80	90	100
Peak Use	# of 70MPa 7kg fills per hour	2	5	10	2	5	10	2	5	7	10
Daily Capacity	kg/day dispensed	48.3	126.0	273.0	54.6	147.0	315.0	63.0	168.0	249.9	378.0
Number of Cars filled per day	#	7	18	41	8	22	49	10	27	40	62
Fueling Protocol Used	J2601, MC Method	J2601 C	J2601 B	J2601 A	J2601 C	J2601 B	J2601 A	J2601 C	J2601 B	J2601 A	J2601 A
Bulk Storage Type	liquid, gas (a)	gas	gas	gas	gas	gas	gas	gas	gas	gas	liquid
H2 Source	On-site, Delivery, Pipeline	On-Site	On-Site	On-Site	On-Site	Gas Delivery	Gas Delivery	On-Site	Gas Delivery	Gas Delivery	Pipeline
Bulk Storage Quantity	kg	322.0	630.0	910.0	182.0	367.5	630.0	126.0	280.0	357.0	472.5
Pre-cooling type	coolant, cryogenic (b)	coolant	coolant	coolant	coolant	coolant	coolant	coolant	coolant	coolant	cryogenic
Compression Type	piston, diaphram, cryogenic (c)	diaphram	diaphram	diaphram	diaphragm	piston	piston	diaphram	piston	piston	cryogenic
Equipment Footprint	sqft	2612	4359	5897	1867	2520	4400	1571	2053	2944	4040
Number of Dispensers	#	1	2	2	1	2	3	1	2	3	4
Number of compressors	#	2	2	2	2	1	2	2	1	2	3
Fueling time	min	25	15	3	25	15	3	25	15	3	3

Accomplishment: 5 Project Teams Established – *Hydrogen Station Research*

Goal – *Provide a flexible, responsive set of technical experts and facilities to solve urgent/unexpected challenges for hydrogen stations*

- Draft Work Plan (Near-term)
  - Create the team of experts and facilities
  - Establish and maintain public lessons-learned database
  - Deployment of the rapid response team as-needed
- Initial Feedback
  - Incident/issue response is different than a deployment acceleration team
  - Confidentiality and intellectual property may be important
- Current Activity
  - Clarifying scope
  - Creation of expert team
  - Strong coordination with California Governor's Office of Business and Economic Development (GO-Biz)

Accomplishment: 5 Project Teams Established – *Fuel Contamination Detector*

Goal – *Develop a cost effective, deployable, inline fuel quality system that can be installed at stations to prevent damage to fuel cell vehicles*

- Draft Work Plan
  - Identify technology requirements and key contaminants
  - Develop inline quality measurement device and perform field trials
  - Use results to drive next generation technology development and market for hydrogen fuel quality
- Initial Feedback
  - High priority project
  - First iteration should be simple and improved upon in the future
- Current Activities
  - Identify and reach out to partners with significant interest
  - Participate in RFI and workshop coordinated by DOE

Accomplishment: Response to Previous Year Reviewers' Comments

- This project was not reviewed in FY13.

Partners

- Project Team Members (as of April 2014)
  - Air Liquide (Station Qualification, Dispenser/Components, Fuel Contamination Detector, Reference Station)
  - Canadian Standards Association (Station Qualification)
  - California Air Resources Board (H_2 Rapid Research, Station Qualification, Fuel Contamination Detector, Reference Station)
  - California Fuel Cell Partnership (H_2 Rapid Research)
  - California Governor's Office of Business & Economic Development (H_2 Rapid Research)
  - California State University Los Angeles (Fuel Contamination Detector, Station Qualification)
  - Honda (Dispenser/Components)
  - Nissan (Reference Station)
  - South Coast Air Quality Management District (Fuel Contamination Detector)
  - Toyota (Station Qualification, Dispenser/Components, Fuel Contamination Detector)

Future Work

- FY14
  - Coordination Panel and Project Team meeting June 2014
  - Initiation of at least one research project
  - Active collaboration with H2FIRST and other DOE programs (e.g. Safety, codes, and standards)
  - Host a public information webinar to review station requirements and proposed priorities
  - Establish reference station designs for 3 – 5 types that are peer reviewed
- FY15
  - Continue refinement of reference station design set
  - Establish high priority research projects in the 5 near-term project teams

Summary

- Relevance
  - Solving real-world station technical problems in the lab and in the field
- Approach
  - Meaningful partnerships to leverage resources and maximize impact
  - H2USA coordination panel
  - H2FIRST project team organization with industry, academic, and government partners
- Accomplishments
  - Inaugural meeting and active stakeholder engagement
  - Reference station matrix for targets and metrics in development
  - 5 project teams formed
- Collaborations
  - SNL/NREL MOU
  - Industry (auto OEMs and gas suppliers), academic, and state agencies
- Future Work
  - Continue partner recruitment
  - Identification of "high probability for success opportunities" for timely advancement of near-term fueling stations

BACKUP

H2FIRST Partnership Kickoff Meeting Summary

Reliable & Consistent (Accessible & low downtime)	Components (high pressure fittings, compressors, dispenser, nozzle, etc.)
Positive customer experience	Station qualification & performance
Cost Reduction	Permitting acceleration
Acceleration (lab-to-industry and issues)	Open dispensing protocol (fuel protocol)
Minimize ambient temperature impact on performance	Fuel quality (station & vehicle requirements)
Footprint reduction	Improve existing stations
Stakeholder engagement (e.g. developers, operators, consumers, standards, suppliers, etc.)	Multiple types of stations (metro and connector)

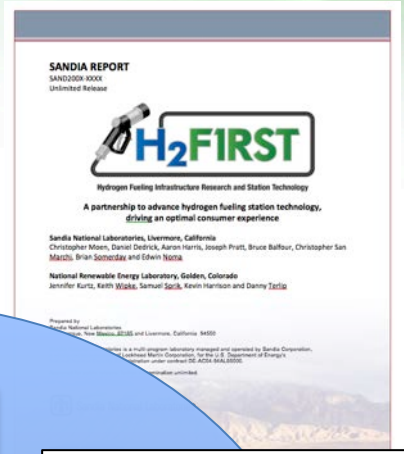
Attendees covered industry, government, and labs (> 30 attendees)

University Engagement

- Future goal of H2FIRST to engage universities

- University contributions to H2FIRST could include:
  - Use of facilities (including hydrogen fueling stations)
  - Technical experts & student researchers
  - Workforce development tied to H2FIRST activities
  - Education and Outreach
  - TBD

Potential Hydrogen Infrastructure R&D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H2FIRST
Hydrogen Fueling Infrastructure Research and Station Technology
A partnership to advance hydrogen fueling station technology, driving an optimal consumer experience
Sandia National Laboratories, Livermore, California
National Renewable Energy Laboratory, Golden, Colorado

System Performance
Station benchmarks and targets
Test methods and devices for metering, quality and capacity
Siting and footprint

Component Reliability
Low-utilization effects (e.g. start/stop, idle, etc.)
High-utilization effects (e.g. failure modes, maint. planning)

System Integration
Fueling protocols and CSD engineering cost trade-offs
Dynamic effects of fueling (e.g. back-to-back cycles, pre-cooling) Parts-reduction and component configuration strategies

Component Innovation
Reliability, accuracy, and durability improvements
Novel concepts in compression, storage and dispensing

Materials
Temperature and pressure effects on material performance
System and component reliability and cost reduction
Material performance under aging conditions