U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Technology Acceleration and H_2 Infrastructure R&D Overview

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2018 Annual Merit Review and Peer Evaluation Meeting

June 13, 2018 – Washington, DC

New Structure

Transformation of Technology Acceleration Associated R&D to H_2 Infrastructure R&D from FY17 to FY19

FY17
- Market Transformation R&D
- Techology Validation R&D
- Manufacturing R&D
- Safety, Codes & Standards R&D
- Systems Analysis

INTERIM FY18
- TECHNOLOGY ACCELERATION R&D
- Manufacturing R&D
- Safety, Codes & Standards R&D
- Systems Analysis

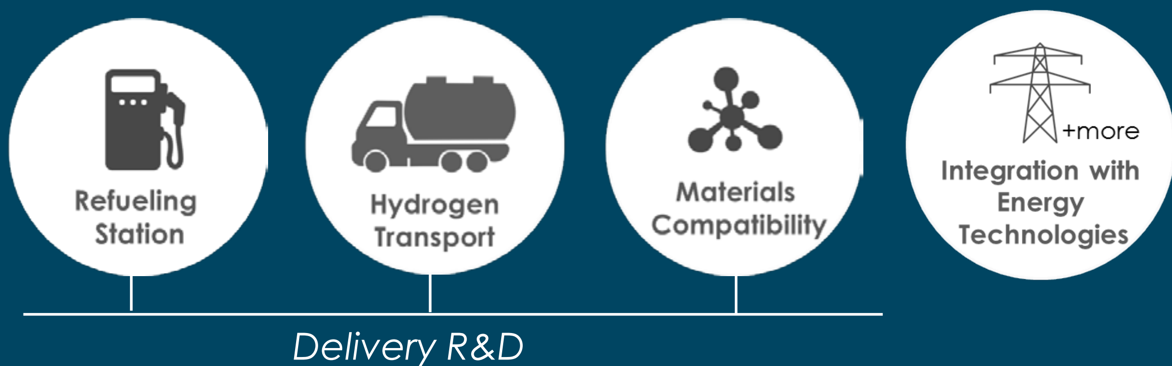
FY19
- H_2 INFRASTRUCTURE R&D
  - Includes Delivery R&D
- Systems Analysis

H_2 Infrastructure R&D Goals and Objective

Focus

The H_2 Infrastructure R&D Sub-program aims to enable hydrogen technologies that connect **diverse domestic resources** across sectors & support **infrastructure development** through **innovative R&D**.

Focus R&D Areas



Enabling

Infrastructure

Goal

Enable reliable, low cost and safe H_2 infrastructure technologies for multiple applications.

Objectives & Strategy

Delivery R&D

Focus Areas	Refueling Station	Hydrogen Transport	Materials Compatibility	+more Integration with Energy Technologies
Strategy	○ Innovative materials for emerging technologies in CS&D ○ Study H_2 diffusion characteristics and detection technologies to enable reductions in station footprint	○ Develop advanced concepts to enable a 2x increase in liquefaction efficiency to enable cost competitive, scalable delivery of H_2 . ○ Exploratory R&D in chemical carriers	○ H-Mat Consoritum • Metallic & non-metallic materials for use in H_2 • Understand physics of H_2 degradation and microstructural properties	○ Innovative technologies to enable integration of H_2 technologies with nuclear generation and the grid
Objective	**Enable a levelized cost of $7/gge for hydrogen production, delivery, and dispensing into fuel cell vehicles by 2025.**	**Reduce the cost long-distance hydrogen delivery through innovations in liquefaction, chemical carriers, and gaseous pathways.**	**Conduct early-stage R&D to increase materials service life 2x.**	**Enable technologies that integrate hydrogen production technologies with the grid and diverse power generators**

FY17-19 Budget

(Dollars in Thousands)				
Subprogram Distribution	FY 2017 Enacted	FY 2018 Request	FY 2018 Omnibus	FY19 Request
Total Appropriation/Requested Funding	**101,000**	**45,000**	**115,000**	**58,000**
Fuel Cell R&D	32,000	15,000	32,000	19,000
Hydrogen Fuel R&D	41,000	29,000	54,000	19,000
Systems Analysis	3,000	1,000	**3,000**	**1,000**
Safety, Codes and Standards	7,000	0	**7,000**	**0**
Technology Acceleration R&D	18,000	0	**19,000**	**0**
H_2 Infrastructure	0	0	**0**	**19,000** *

* includes Delivery R&D

$19M

FY19 Request

Infrastructure Key Focus Areas

Examples:

Refueling Station R&D

Innovative Energy Carriers R&D

Materials Compatibility R&D

Integration with Energy Technologies R&D

FY17 & FY18 Technology Acceleration
and
Systems Analysis
Accomplishments

Hydrogen Safety is a Priority

Analysis & Validation

Completed near-field cryogenic hydrogen dispersion analysis and modeling validation

Risk Assessment

Initiated expansion of HyRAM to include flexibility for broader application to new and emerging hydrogen applications

Fuel Quality Assurance

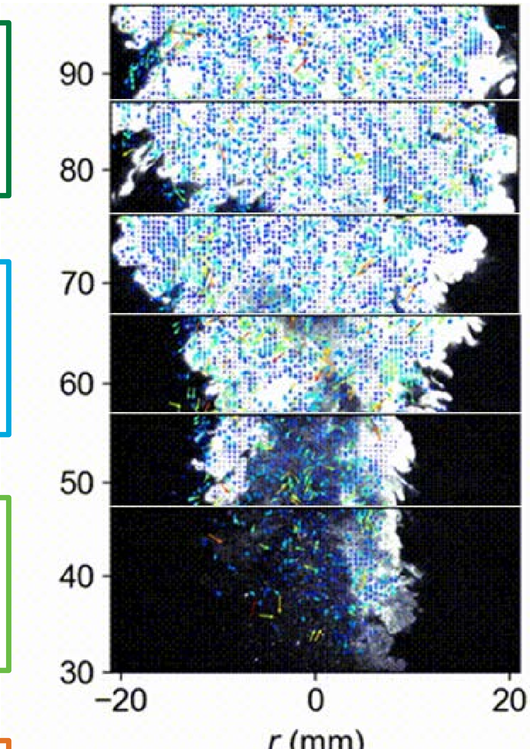
Initiated fuel testing of in-line hydrogen contaminate detector with improved baseline stability

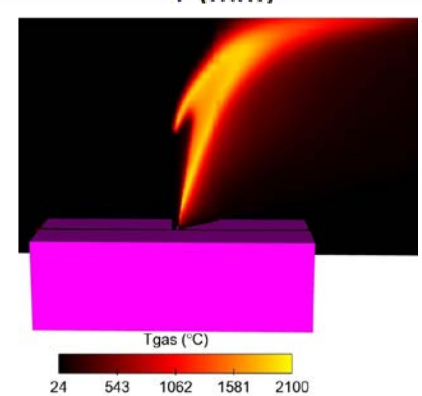
Enabling Infrastructure

Published report on tunnel safety analysis including risk analysis and CFD modeling to support access decisions for FCEVs

Partnership

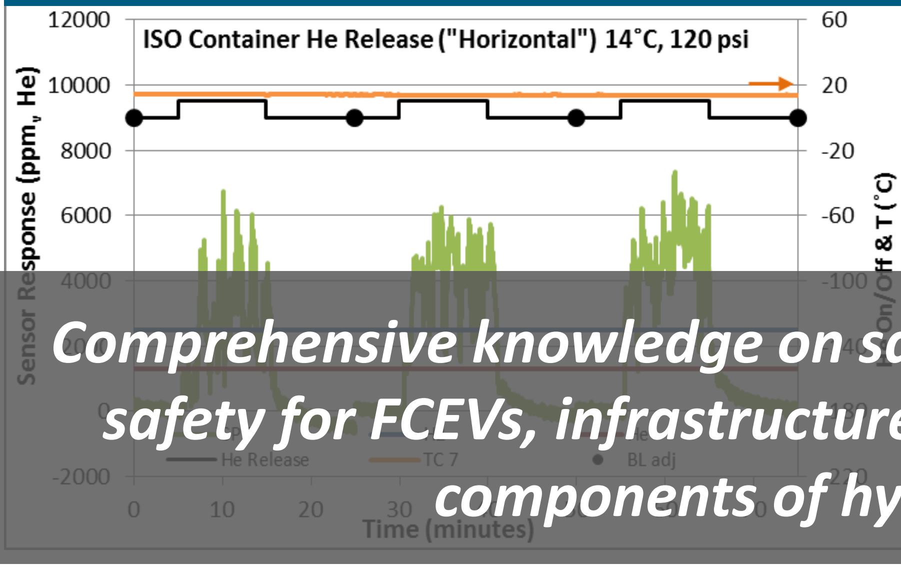
Initiated partnership with AiCHE to enable broader access to Hydrogen Safety Panel and training resources





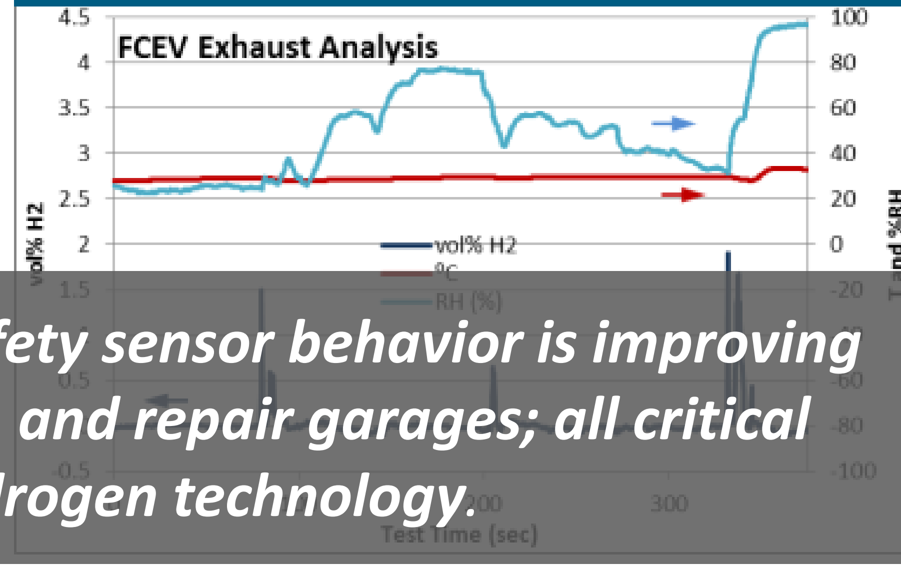
Low cost, low power, durable, and reliable H_2 safety sensor for vehicle and infrastructure applications.

Indoor Placement Study



- CFD modelling and empirical verification of indoor hydrogen releases
- Empirical verification using the NREL HyWAM
- Good agreement between model and measurement Independent CFD verification ongoing

Vehicle Tailpipe H_2 Emissions



- Collaboration with DOT NHTSA in support of Global Technical Regulation (GTR)
- Developed FCEV Exhaust Analyzer for verification of GTR-13 requirements
- Performance verified in the laboratory and vehicle; Field tested on FCEV; detected hydrogen successfully

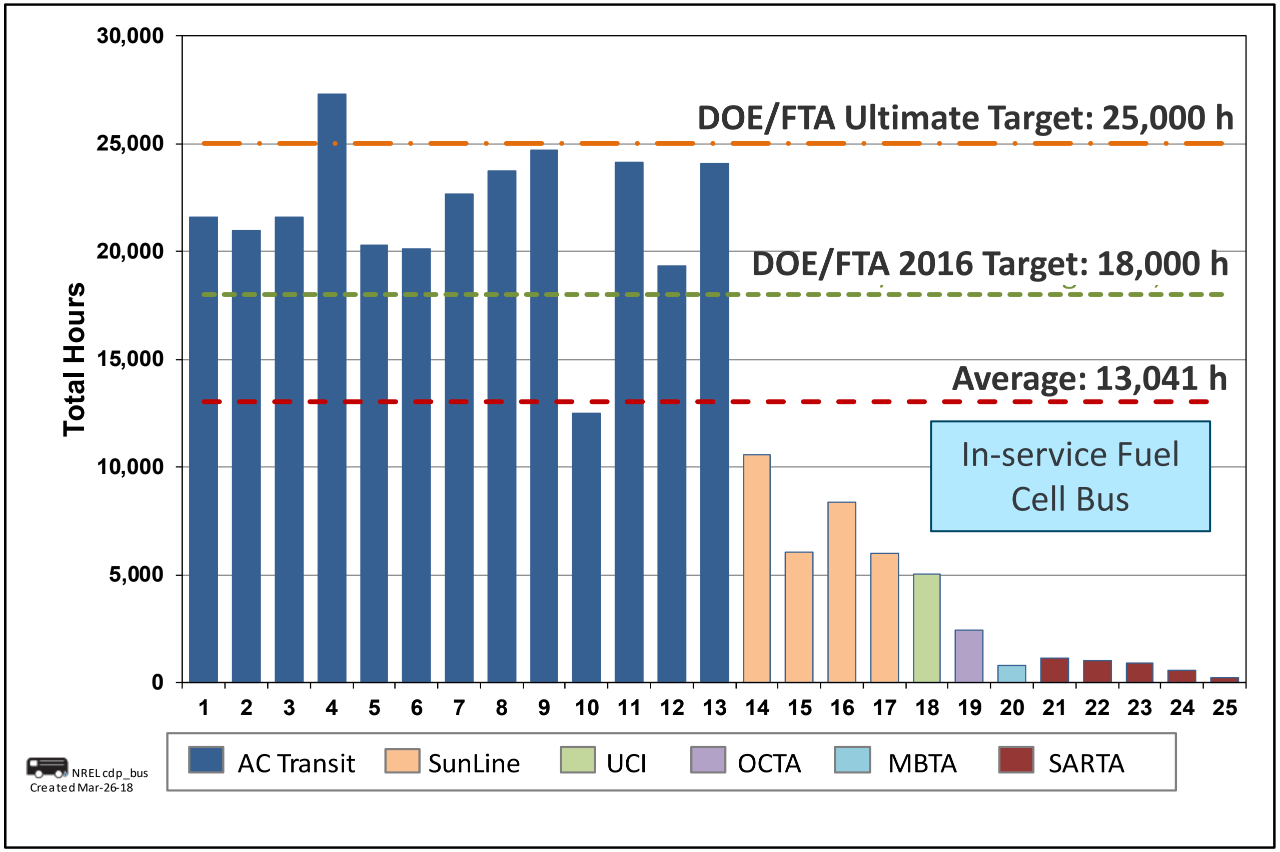
Comprehensive knowledge on safety sensor behavior is improving safety for FCEVs, infrastructure, and repair garages; all critical components of hydrogen technology.

Exceeded DOE-DOT Fuel Cell Bus Durability Target

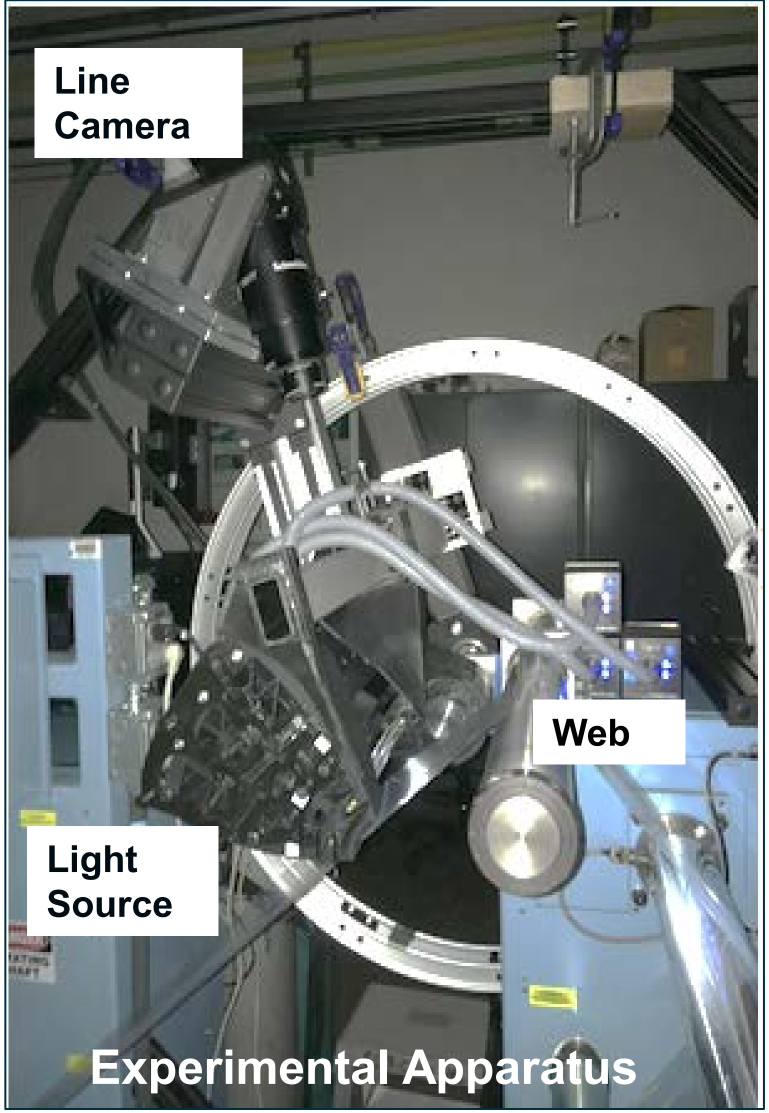
Top fuel cell bus runs **>27,330 hours**, surpassing DOE/DOT ultimate target

12 fuel cell buses have more than **19,000 hours**

Total Hours Accumulated On Each Fuel Cell Bus as of 2/28/18



Advances in QC Technique R&D for MEA Manufacturing of Rolled Goods



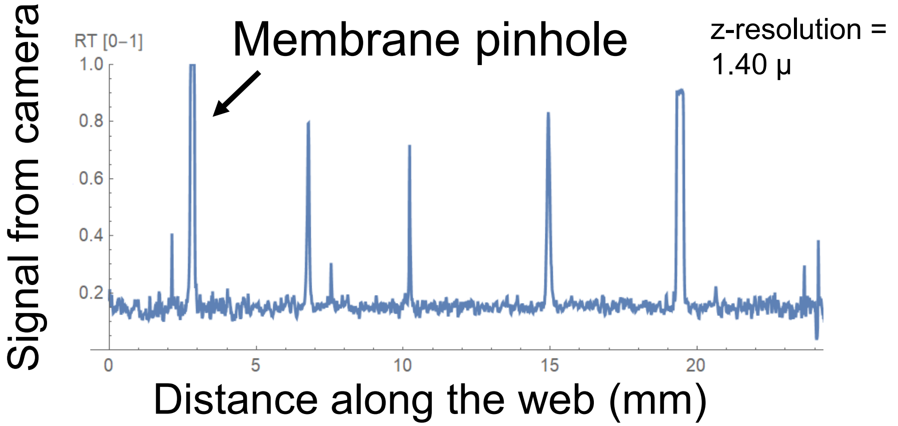
Objective:
- High resolution characterization of Gore-Select membrane roll quality

Accomplishment:
- Developed optical inspection (transmission/reflection) apparatus and classification algorithms for automated defect detection
- Optically scanned full-width, full-length production rolls at high resolution and provided full-roll metrics

Plans:
- Scan additional production rolls

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

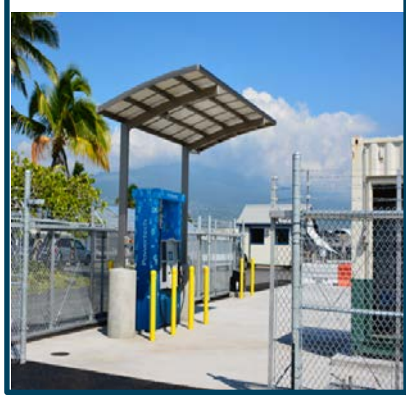
Experimental Data from Optical Scan



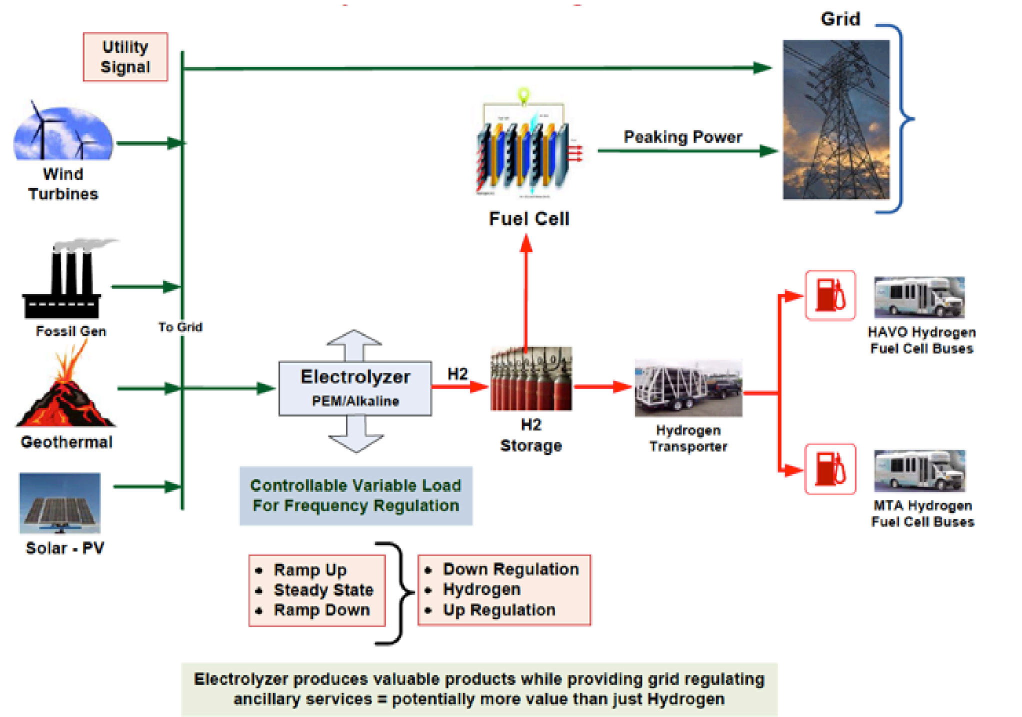
Hydrogen Energy Systems as a Grid Management Tool Project

Objective

Assess use of electrolyzer as a variable controllable load that can be reduced/ increased to maintain the total load balance and frequency stability



System Diagram



NELHA

US Hybrid

U.S. NAVAL RESEARCH LABORATORY

hcatt

Project Partners

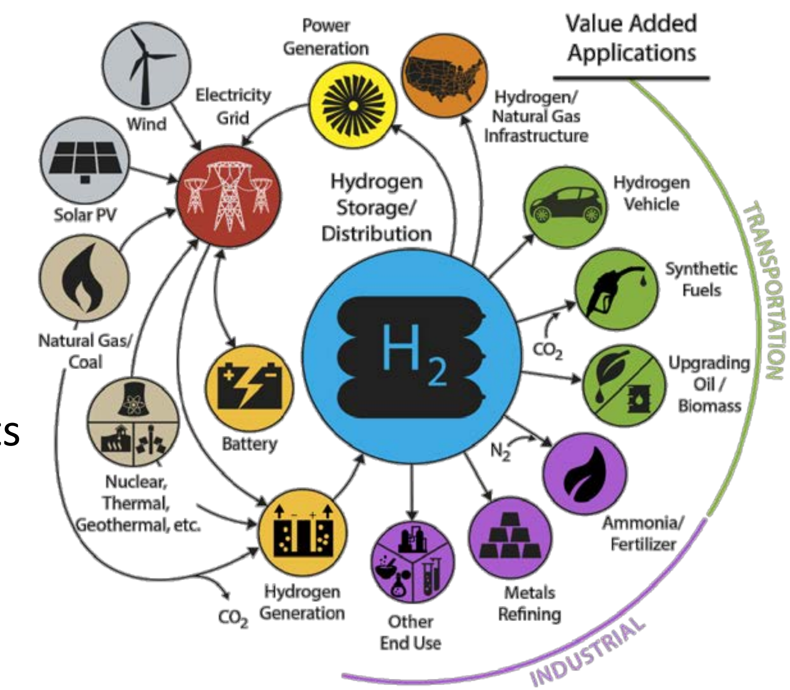
Accomplishment

- ✓ Completed NELHA site infrastructure installation
- ✓ Reduced H_2 transport cost from centralized production to dispensing by ~50%
- ✓ Utilized electrolysis in grid management applications

H2@Scale Analysis

Initial Step ✓ (Complete)

- Identify potential demand
- Examine supply resources
- Identify impact potential
- Identify infrastructure issues



*Illustrative example, not comprehensive
Source: NREL

In-Depth Analysis (FY17)

- Evaluated H_2 price requirements
- Identified supply options and costs
- Examined 3 scenarios
- Performed stage-gate review

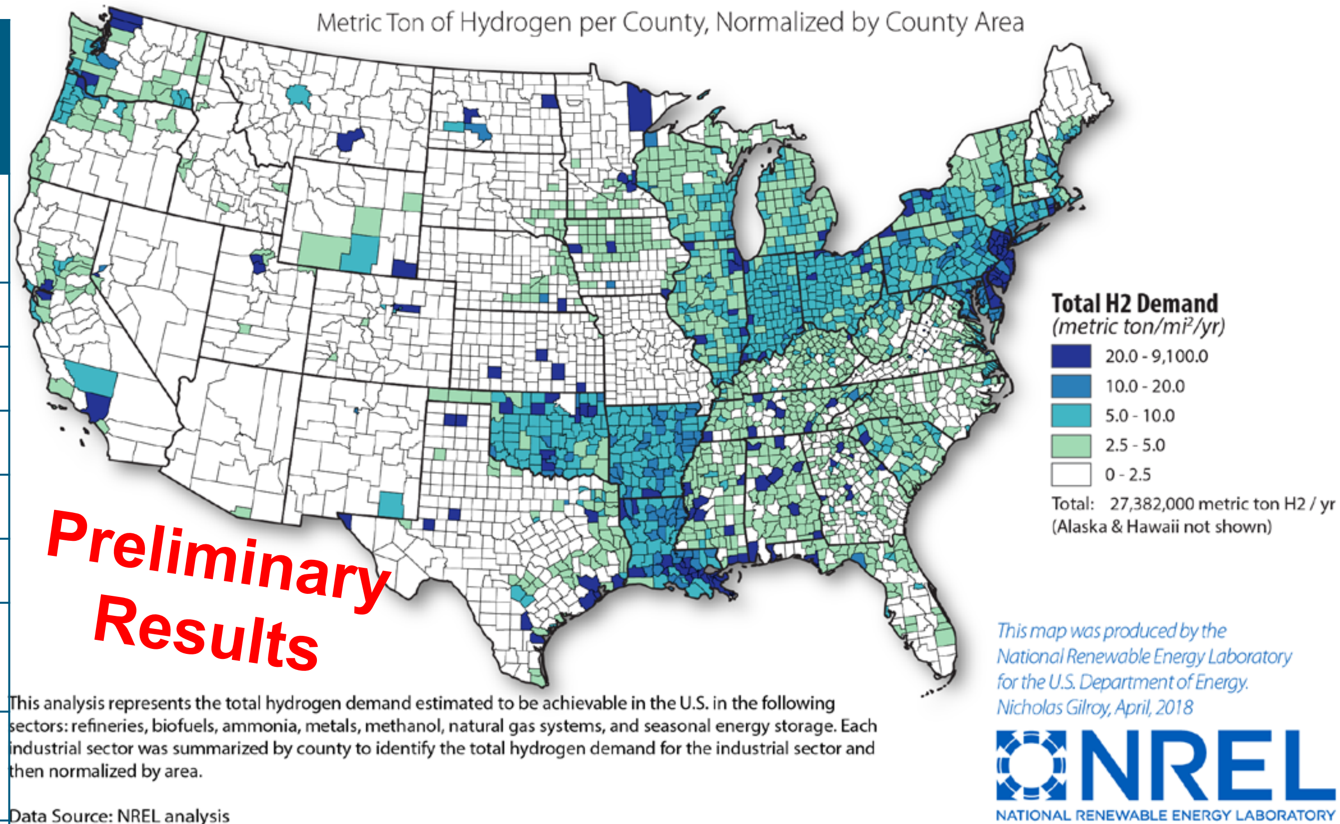
Additional Analysis (FY18)

- Evaluated regional scenarios
- Examined economic inertia and externalities
- Performed spatial analysis

NREL National Renewable Energy Laboratory | Argonne National Laboratory | INL Idaho National Laboratory | Berkeley Lab | Lawrence Livermore National Laboratory | Pacific Northwest National Laboratory

H2@Scale Analysis: Estimated Technical Potential Hydrogen Demand

Demand	Technical potential (MMT* / year)
Refineries & CPI§	8
Metals	6
Ammonia	5
Methanol	1
Biofuels	1
Natural Gas	7
Light Duty Vehicles	28
Other Transport	3
Electricity Storage	28
Total	87



Technical Potential Demand: 87 MMT/yr

Current U.S. market: ≈ 13 MMT/yr
Including captive generation for ammonia and refining

* MMT: Million metric tonnes

§ CPI: Chemical Processing Industry not including metals, ammonia, methanol, or biofuels

Light duty vehicle calculation basis: 190,000,000 light-duty FCEVs from http://www.nap.edu/catalog/18264/transitions-to-alternative-vehicles-and-fuels

Technology Acceleration Team

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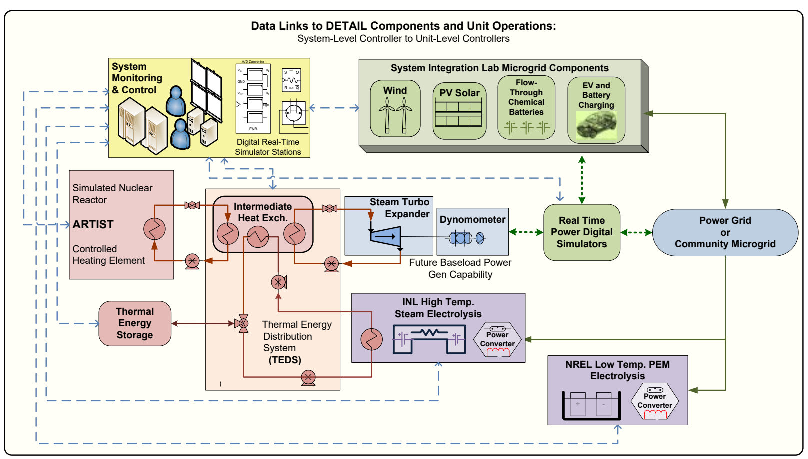
Panel Discussion

Can you expand on the activities you have in collaboration with nuclear energy?

Thermal & Electrical Energy from Nuclear Plants for H_2 Production

- Balance renewable energy on the grid
- Better utilize clean baseload generation assets
  - Low electricity rates
  - Increased renewable energy
  - Historically low natural gas prices
- Increase utilization of renewable energy

Nuclear can go beyond the grid
  - Hydrogen is essential feedstock to many industries



INL Integrated Energy System Lab

- 100 kW (thermal) nuclear reactor emulator
- 250 kW high-temp electrolyzer test bed
- Real time grid simulator
- Prove reactor thermal stability to license operation
  - Normal (open/close valves, weather, varying loads
  - Abnormal (weather storms/ events, failures)
- Fuel synthesis skid
- 25 kW high temp. electrolysis stack module test station

How is FCTO R&D addressing the role hydrogen can play in grid resiliency?

FUEL CELLS
as primary or backup power

- NREL's Data Center
- Backup cell phone towers
- Energy Dispatch Controller optimizes DG fuel cells with building loads and grid

ELECTROLYZERS
as a controllable load

- Sub-second response time (NREL)
- Sufficient demand analysis (LNBL)
- Real-time grid simulator (INL)
- Electrolysis test bed (NREL)
- Real-world scenarios tested through intra-lab connection between INL/NREL

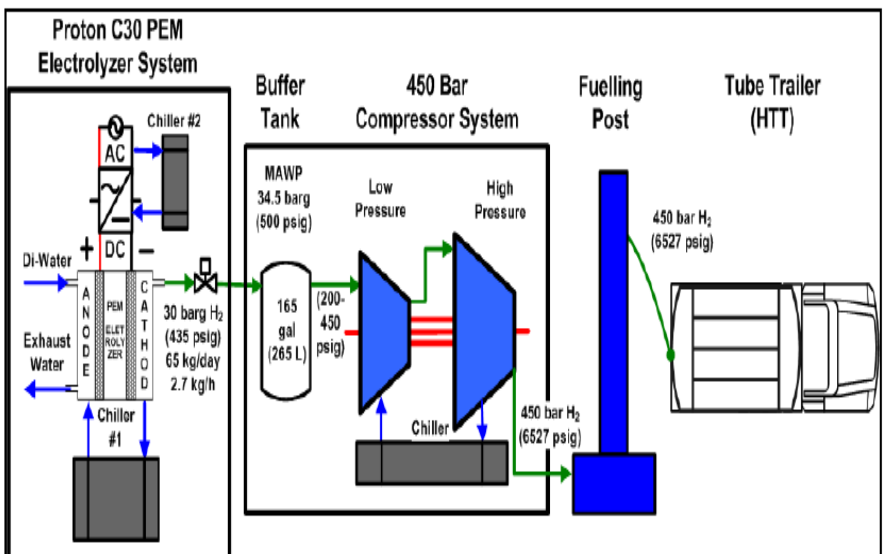
HYDROGEN
as a generation feedstock

- Power to gas concept
- Hydrogen pipelines & large scale energy storage

What activities have you funded to guide the R&D of hydrogen fueling stations?

Fuel Cell Delivery Truck R&D

- ✓ **Collaboration -** Industry, FedEx and Plug Power providing a H_2 solution for sector
- ✓ **System Integration R&D** - 2x 10kW FC stacks, tanks (11.9 kg), fuel lines, refueling procedures complying with NFPA 52 Standards, refueling procedures



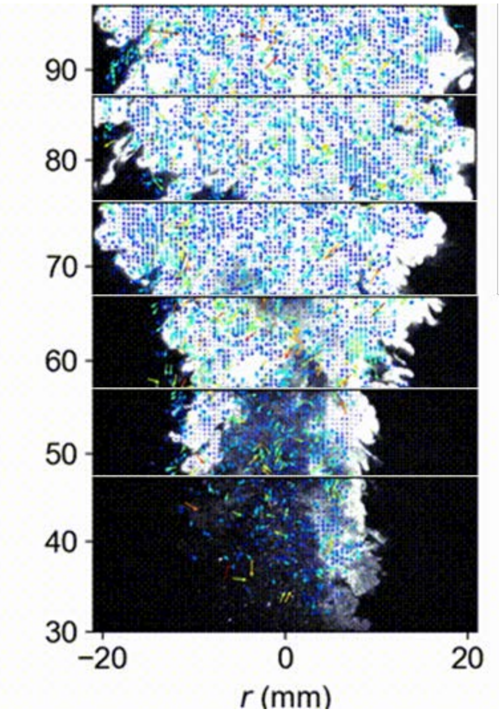
NELHA H_2 Fueling Station

- ✓ **Performance** - Improve cascade fill utilization from 50% to 90% by developing a new boost compressor fueling post.

What work has FCTO funded to enable stations to be sited in urban locations, where land is a constraint?

Science-based analysis of the risk of hydrogen releases to enable reductions in station footprint

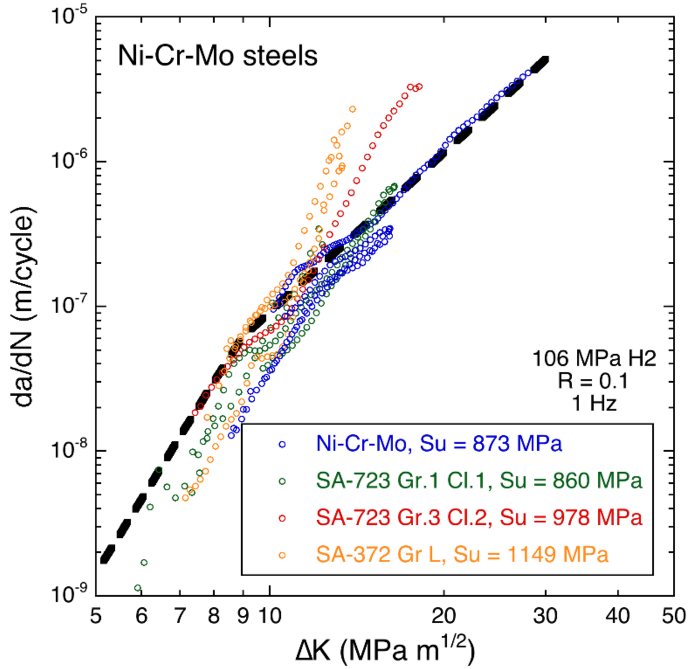
- Developed unique capabilities to experimentally characterize cryogenic hydrogen releases at temperatures never before achieved at the lab scale.
- Completed the first ever nearfield measurement and validation of plume concentration and extent, ignitability and heat flux values, and velocity of cryogenic plumes at 50K
- Will enable code committees to modify the separation distances on the basis of risk that has been scientifically characterized



Can you describe how early-stage R&D has been used to improve the reliability of fueling station components?

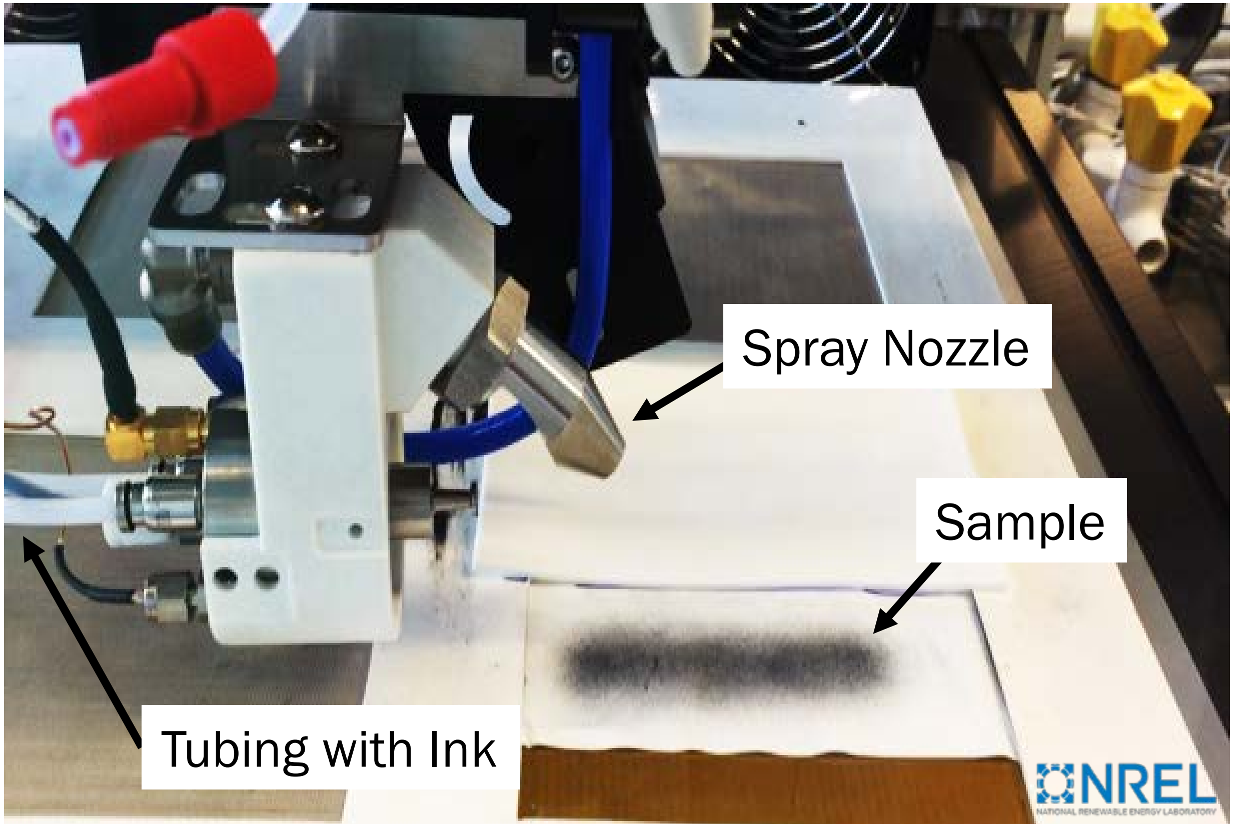
Developed a universal fatigue crack growth curve was developed to capture the general behavior of pressure vessel steels

- Represents a family of curves that depend on the load ratio of minimum to maximum pressure in the vessel
- Proposed to the ASME pressure vessel committee, which is incorporating it into a code case
- Will allow pressure vessels to be designed to conform to these curves in lieu of performing actual tests, which will reduce the cost and time required significantly



$$\frac{da}{dN} = C\left[\frac{1 + C_H R}{1 - R}\right] \Delta K^m \left(\frac{f}{f_{ref}}\right)^{1/2}$$

Can you give an example of a DOE accomplishment this year in reducing the costs of fuel cell and electrolyzer technologies?



Sprayer To Coat Catalyst Ink On Membranes for Fuel Cells and Electrolyzer

- A fuel cell OEM, has an automated fuel cell assembly line but a limited capacity to manufacture membrane electrode assemblies.
- NREL and OEM set up a CRADA to reduce cost and improve performance of fuel cell products
- NREL reduced the time to spray a catalyst-coated membrane by 100x without loss in performance.

Can you explain the approach for the techno-economic analysis of H2@Scale?

Developed hydrogen supply and demand scenarios with national labs and stakeholders

- Hydrogen supply growth developed using the ReEDS grid interaction model with natural gas prices and curtailed resources of wind, solar and nuclear energy. (NREL)
- Hydrogen demand growth assessed (ANL)
  - Growth in FCEVs
  - Future gasoline and diesel demand
  - Ammonia production
  - Synthetic fuel growth
- Assessed the hydrogen supply from nuclear generation assets in conjunction with the Office of Nuclear Energy. (INL)