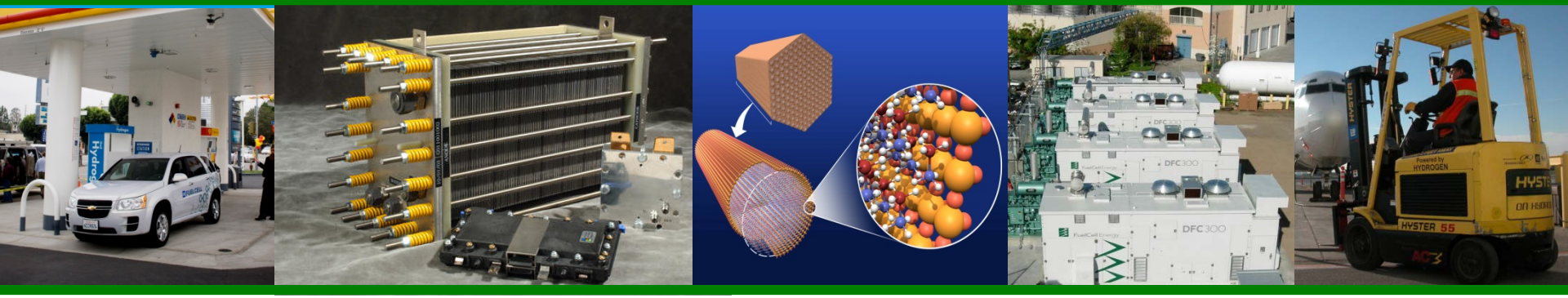
U.S. DEPARTMENT OF ENERGY



Technology Validation Program Area

-Plenary Presentation-

Jason Marcinkoski

Fuel Cell Technologies Office

2016 Annual Merit Review and Peer Evaluation Meeting

June 6 - 10, 2016

Goals and Objectives

OBJECTIVES

By 2019:

- ❑ Validate a hydrogen fueling station capable of producing and dispensing 200 kg H_2/day (at 5 kg H_2/3 min; 700 bar)

By 2021:

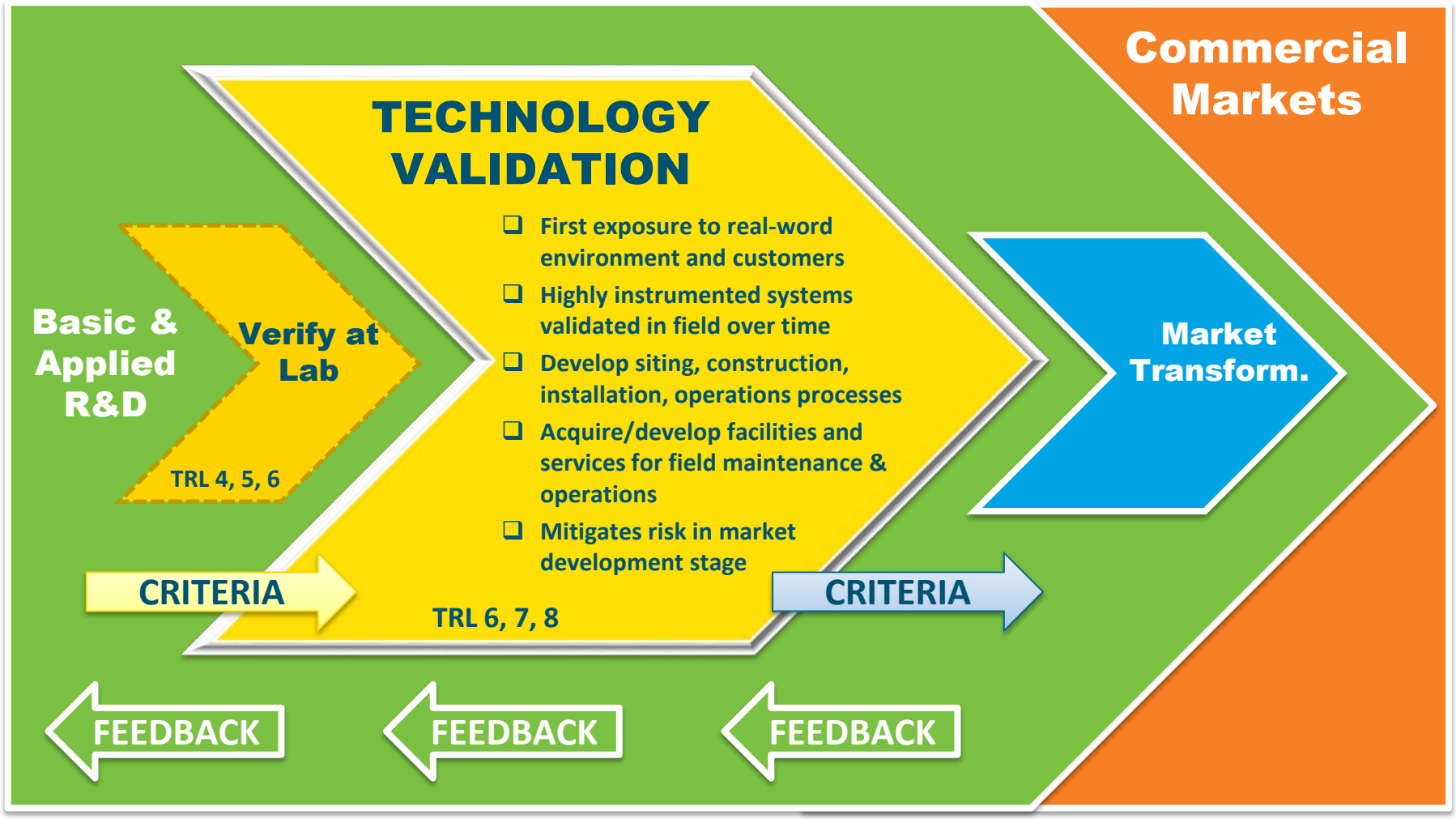
- ❑ Validate large-scale systems for grid energy storage that integrate renewable hydrogen generation and storage by operating for more than 10,000 hours with an electrolysis system efficiency of 60% LHV

By 2023:

- ❑ Validate hydrogen fuel cell electric vehicles with 65% LHV FC System efficiency, 300-mile range and 5,000 hours fuel cell durability

GOAL: ***Validate fuel cell systems in transportation and stationary applications as well as hydrogen production, delivery and storage systems. Assess technology status and progress to determine when technologies should be moved to the market transformation phase.***

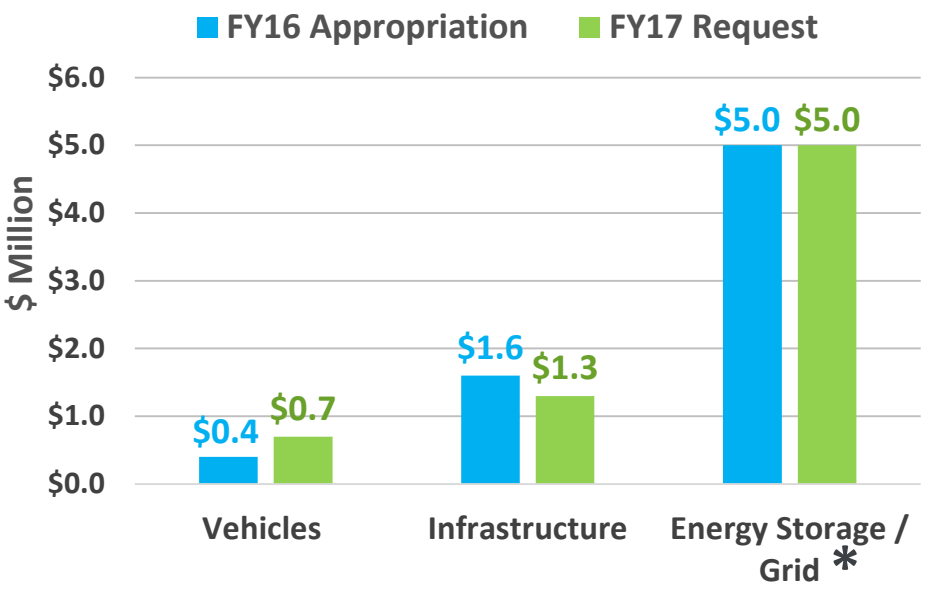
Strategy


Commercial Markets
TECHNOLOGY VALIDATION
Basic & Applied R&D
Verify at Lab
TRL 4, 5, 6
First exposure to real-word environment and customers
Highly instrumented systems validated in field over time
Develop siting, construction, installation, operations processes
Acquire/develop facilities and services for field maintenance & operations
Mitigates risk in market development stage
TRL 6, 7, 8
Market Transform.
CRITERIA
CRITERIA
FEEDBACK
FEEDBACK
FEEDBACK

Budget

FY 2017 Request = $7M

FY 2016 Appropriation = $7M



*FY16 Congressional Direction: $5M for fuel cell technologies as industrial-scale energy storage devices. Energy storage/grid activities include synergistic work on hydrogen infrastructure (renewable electrolysis) and stationary fuel cell systems.

EMPHASIS

VEHICLES

- Light-duty cars, delivery trucks, buses, and truck targets

INFRASTRUCTURE / H2FIRST

- Fueling station and component performance and reliability
- Hydrogen Station Equipment Performance Device (HyStEP)
- Delivery and dispensing
- Station Operational Status System (SOSS)

GRID INTEGRATION / ENERGY STORAGE

- Real-time grid simulation
- High- and low-temperature dynamic electrolysis
- FC / HVAC / energy storage dispatch controller with DERMS and building communication

NFCTEC: NREL Data Collection and Analysis

NFCTEC Analysis & Reporting of Real-World Operation Data

Bundled data (operation and maintenance/safety) delivered to NREL quarterly





Internal analysis completed quarterly in NFCTEC

National Fuel Cell Technology Evaluation Center

Results

DDPs

Confidential

Public

CDPs

Detailed Data Products (DDPs)

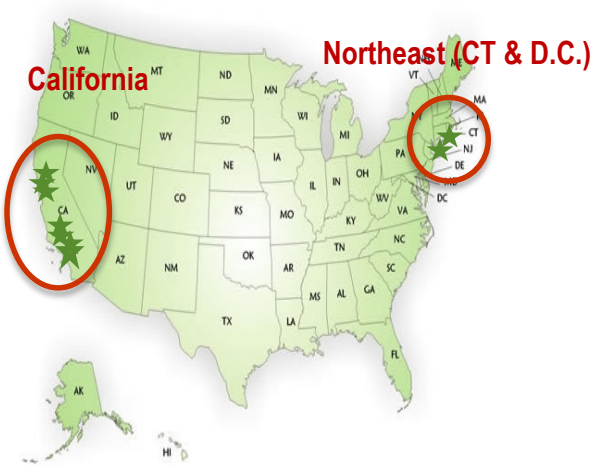
- Individual data analyses
- Identify individual contribution to CDPs
- Shared every six months only with the partner who supplied the data

Composite Data Products (CDPs)

- Aggregated data across multiple systems, sites, and teams
- Publish analysis results every six months without revealing proprietary data

ACCOMPLISHMENTS: Infrastructure

H_2 Stations Data Collection & Analysis (NREL)



Data Collection Results

- **92,287 kg cumulative H_2 dispensed**
  40% increase over previous year
- **5.6 min avg. fill time**
  24% of fills less than 3.3 min
  13% of fills less than 2.5 min
- **0.58 kg/min avg. fueling rate**
  [2020 target 1.5 kg/min]
- Failure rates decreasing as more hydrogen is dispensed
- Large variation in utilization across stations indicates room for more cars
- Avg. H_2 station costs $2.2 million

Partners Providing Station Data

California State University—Los Angeles (CSULA)

- Electrolysis-based station

Proton Energy (Proton OnSite)

- SunHydro#1 (Wallingford, CT)
  - High pressure electrolysis (57 bar) and expanded tank capacity
- SunHydro#2 (Washington, D.C.)
  - Electrolysis-based station
  - Commissioning to be complete in June 2016

Gas Technology Institute (GTI)

- 5 Linde liquid-delivered ionic compressor-based stations in California
  - 2 in operation
  - 3 in progress

ACCOMPLISHMENTS: Fuel Cell Electric Vehicles (FCEVs)

FCEV Data Collection & Analysis (NREL)

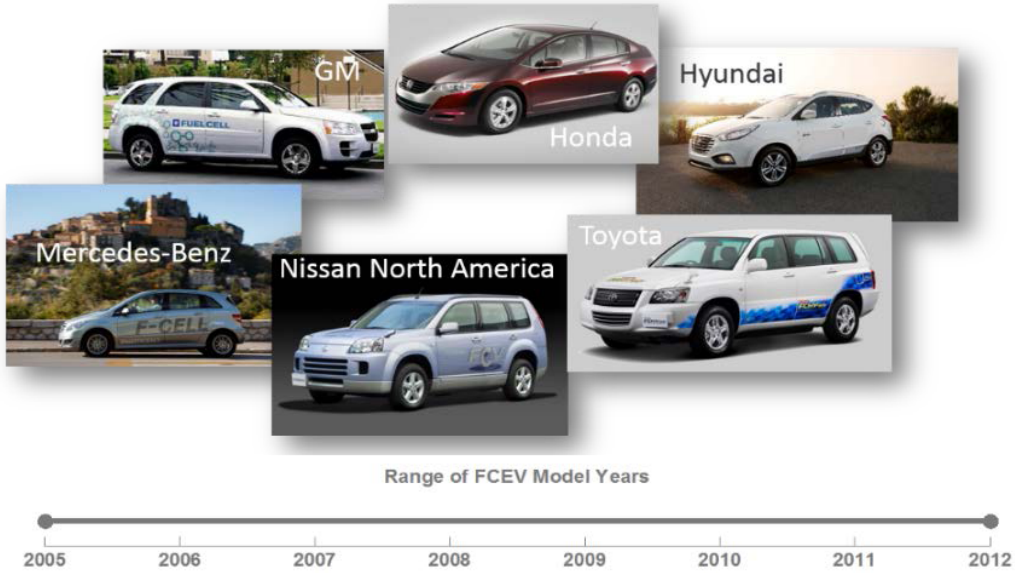
- **RANGE: 200 – 320 mi**

- **DURABILITY INCREASED:**
  - **4,100 hrs (from 3,900 hrs in 2015)** (max fleet average) **[2020 target 5,000 hrs]**
  - **5,605 hrs** (max. operation hours)

- **FUEL ECONOMY:** (avg. on-road)
  - **51 mpgge (median)** **~30% increase from 2006**
  - **57.5 mpgge (max)**

- **FUEL CELL EFFICIENCY: 57%** (avg. at ¼ power) **[2023 target 65% peak efficiency]**

***NOTE:* Not all metrics are necessarily met simultaneously.**



Completed Electricore project (for FCEVs) with Toyota/Honda/Nissan

Hyundai, GM, and MBRDNA projects are continuing

55 FCEVs traveled >3 million miles since 2012, and 600,000 miles since last year.

ACCOMPLISHMENTS: Fuel Cell Electric Buses (FCEBs)

FCEB Data Collection & Analysis (NREL)

	2015 Fleet Avg.	2016 Fleet Avg.	2016 Target	Ultimate Target
Fuel economy (mpDGE)	7.26	6.85	8	8
Range (miles)	265	271	300	300
Powerplant lifetime*(hours)	8,528	11,462	18,000	25,000
Bus availability (%)	70	73	85	90
Bus lifetime (years)	5	3.9	12	12
Bus lifetime (miles)	100,000	91,381	500,000	500,000
Roadcall frequency (FC system; mi betw. road call)	18,896	22,532	15,000	20,000
Roadcall frequency (bus; mi betw. road call)	4,256	4,492	3,500	4,000
Maintenance cost ($/mi)	0.67	1.61	0.75	0.40

* *Average durability value includes fuel cells that have not yet reached end of life.*

AC Transit
(Zero Emission Bay Area)
13 buses

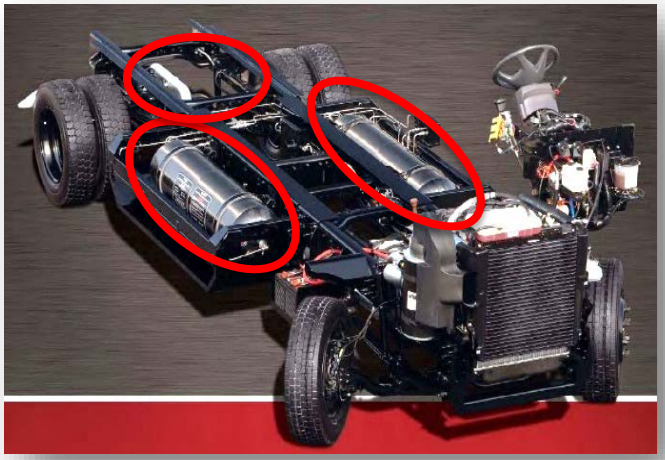
SunLine Transit
(American Fuel Cell Bus)
4 buses

Top FC powerplant ran >22,000 hrs [exceeds 2016 target of 18,000 hrs].

ACCOMPLISHMENTS: Fuel Cell Electric Trucks (FCETs)

Truck Component Sizing (ANL)

- Supports development of truck targets – ***RFI to be issued June 2016***
- Performed component sizing for 12 fuel cell-based trucks comparable to conventional diesel powered trucks
- NREL provided commercial fleet vehicle operating data (FleetDNA) to simulate real world requirements



Example Component Sizing - Preliminary Design

Vehicle	Motor Continuous Power (kW)	Fuel Cell Power (kW)	H_2 Stored (kg)	Vehicle Range (miles)
Class 2 Van	135	155	7	150
Class 4 Delivery Van	165	170	19	200
Class 6 Construction	155	170	14	200
Class 8 Line haul	355	375	80	400
Class 8 Tractor Trailer	260	265	62	400

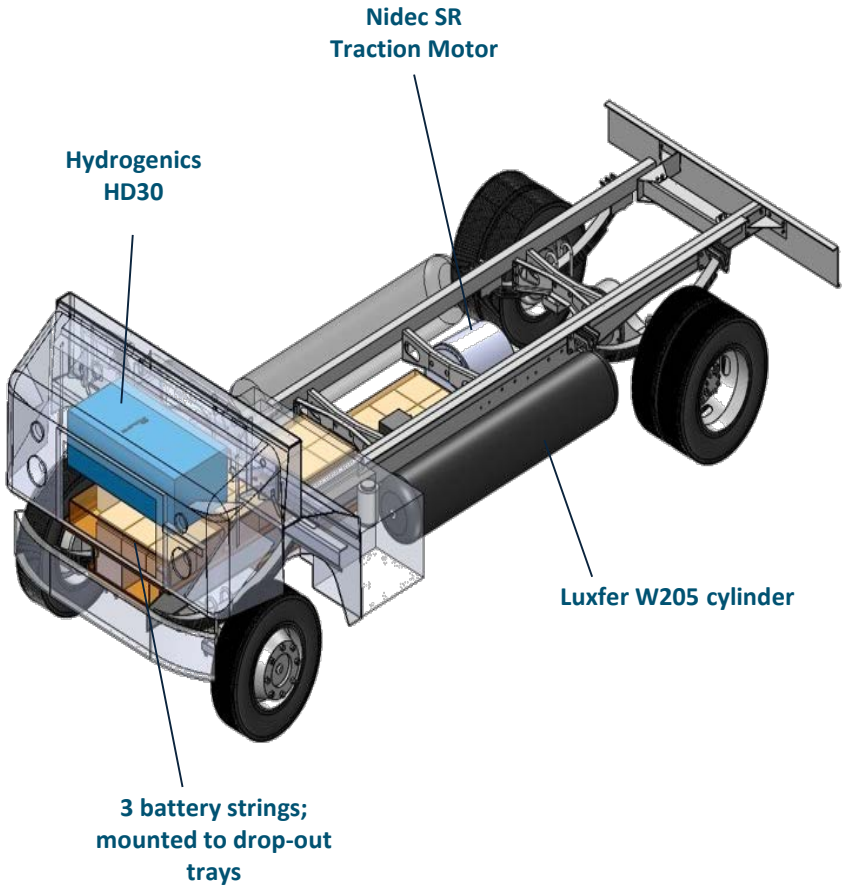
Preliminary design indicates sufficient hydrogen can be stored on trucks to meet range.

ACCOMPLISHMENTS: Fuel Cell Electric Trucks (FCETs)

Development of Fuel Cell Hybrid Electric Delivery Vans (CTE)

- Fuel cell system will extend range from 90 to 125 miles
- Up to 17 vehicles will be validated in real-world operation (1 prototype in phase I; 16 in phase II)

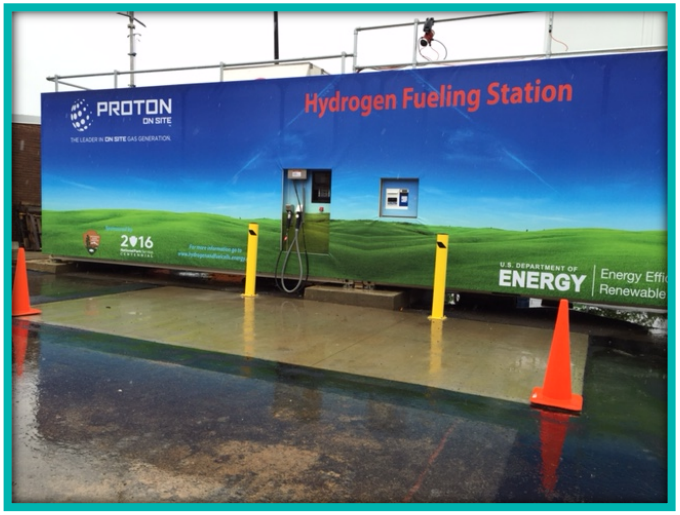
Key Specifications	Fuel Cell Hybrid Van
Vehicle Chassis	Navistar International 1652SC 4X2
Maximum Speed	65 mph
Maximum Range	125 miles
Acceleration (0-60 mph)	26 seconds at 19,500 lbs
Gross Vehicle Weight	Class 6 (23,000 lbs)
Battery System	Valence Technology P40-24
Chemistry	$LiFeMgPO_4$
Energy	45 kWh
Fuel Cell	Hydrogenics HD30
Rated Power	32 kW continuous
Peak Efficiency	55%
Hydrogen Storage	Luxfer W205 (x2)
Capacity	9.78 kg
Pressure	350 bar



CTE selects strong team with established truck maintenance operations in N. CA and extensive expertise in hybrid systems power electronics and controls.

Washington, D.C. H_2 Station

- Document lessons learned to reduce time and costs associated with deploying hydrogen fueling technology
  - ✓ Completed site access agreement, A&E, permitting, construction, and install
  - ✓ M&O contract
- Commissioning June 2016



COLLABORATIONS:

- National Park Service
- Proton Onsite
- Werken
- Anderson-Burton

Station installed and ready for commissioning at a National Park Service site in Washington, D.C. (Brentwood Maintenance Facility).

ACCOMPLISHMENTS: Infrastructure Support

HyStEP (Hydrogen Station Equipment Performance) (SNL/NREL)

- Completed pre-deployment testing at three H_2 stations
- Validated to test against CSA HGV 4.3
- Planned further deployment in CA
- Enables more rapid H_2 station commissioning
- Provides data for analysis to NREL data center (NFCTEC)

Lead: SNL

Partners:
- NREL
- Air Liquide
- Boyd Hydrogen
- CA Air Resources Board
- Toyota

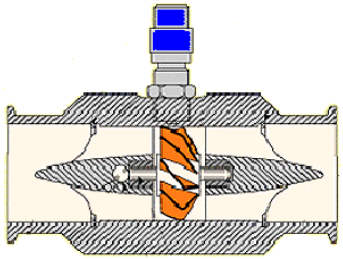
HyStEP device validated and deployed in California to measure hydrogen dispenser performance.

ACCOMPLISHMENTS: Infrastructure Support

H_2 Flowmeter Benchmark Testing (NREL)

Objective: Test meter performance of commercially available flow meters in relevant conditions specified in SAE J2601 fueling protocol: flow intervals, ramp rates, and pressure

- ❑ Flow meters selected--two Coriolis and one turbine meter
- ❑ System design--flow meter location, process, safety, hardware, assembly in progress; parameters defined for pre-test of system

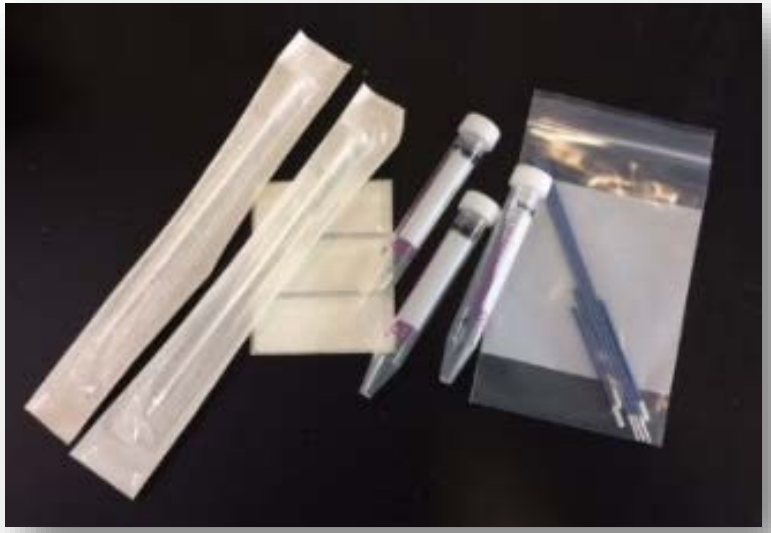


NREL develops equipment to test accuracy of hydrogen flow meters for commercial sale of hydrogen (1.5% accuracy requirement).

ACCOMPLISHMENTS: Infrastructure Components

Performance Validation and Contaminant Detection (NREL)

- NREL's HITRF provides a configurable 700-bar H_2 station:
  - ✓ ***Contaminant Library***
  - ✓ ***Power and Energy Demand***
  - ✓ ***Maintenance and Reliability***
- Communicating with compressor manufacturers on insights gained
- HITRF enables fueling protocol development
- Will publish data through **H2Tools.org**



NREL commissions configurable hydrogen station for R&D and validates HyStEP.

ACCOMPLISHMENTS: Infrastructure Components

Cryogenic Vessels & High-Pressure Liquid H_2 Pump (LLNL)

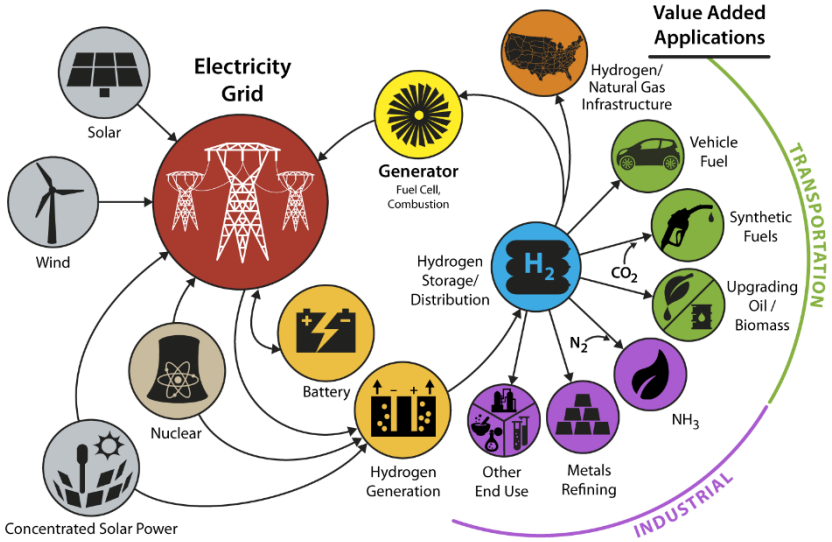
- Built a Hydrogen Test Facility:
  - For durability, cyclic, thermomechanical, permeation, leak, and burst testing
  - In collaboration with Linde, conducted extensive HAZOP review
- Built and cycle tested five cryogenic vessels with continuously improving cycle life
- ***Next:*** Test pump durability by dispensing 24 tons of liquid hydrogen

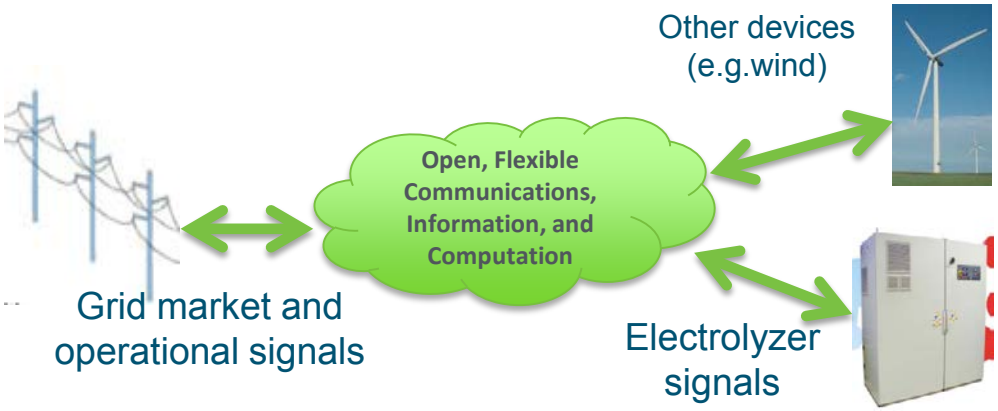
LLNL develops capabilities for testing performance limits of cryo-compressed storage and delivery technology.

ACCOMPLISHMENTS: Grid/Energy Storage

Electrolyzers in Real-Time Grid Simulation (INL/NREL)

- 120 kW electrolyzer stack at NREL commanded by INL remotely for 200 hours
- Demonstrating response to dynamic conditions derived from PG&E network information
- Work confirms acceptable electrolyzer performance for dynamic operation and response to control signals from standard utility programs





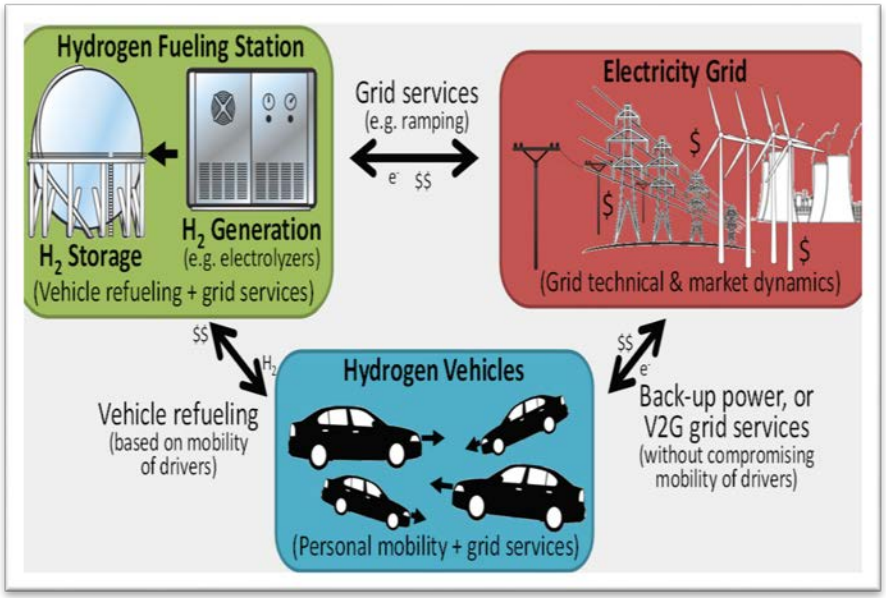
Project connects real-time grid simulator at INL with electrolyzer testbed at NREL to test capabilities to absorb curtailed renewable energy.

NEW PROJECTS: Grid/Energy Storage

Grid Modernization Lab Call

Integrated Systems Modeling of H2-Vehicle-Grid Interactions (LBNL)

- Optimize electrolyzer and hydrogen storage size at renewable hydrogen stations for
  - Demand response
  - Vehicle fuel
  - Absorbing lower-cost curtailed renewable power
- Quantify value of FCEV backup power
  - Consumer
  - Grid



Optimal stationary Fuel Cell Integration & Control (NREL)

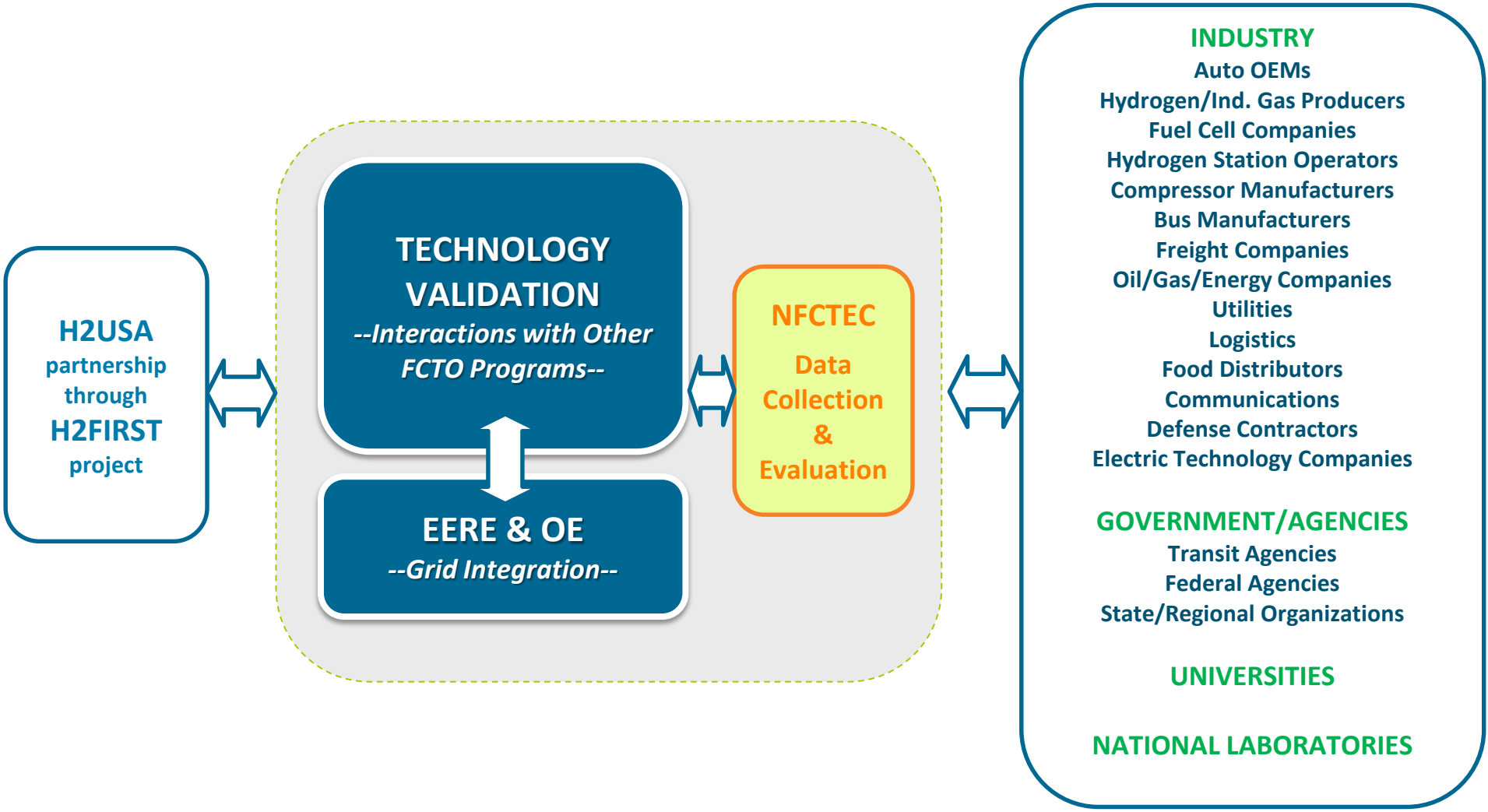
- Develop dispatch controller to optimize the control
  - Fuel cells
  - Thermal and electrical storage
  - HVAC
  - Grid transactions
  - Building automation

Regional Partnership Topics

- **Distributed Energy Resources Siting & Optimization Tool (LBNL)**
- **Smart Reconfiguration of Idaho Falls Power Grid (INL)**

Awarded $6 million FCTO funds for Grid Modernization Lab Call projects.

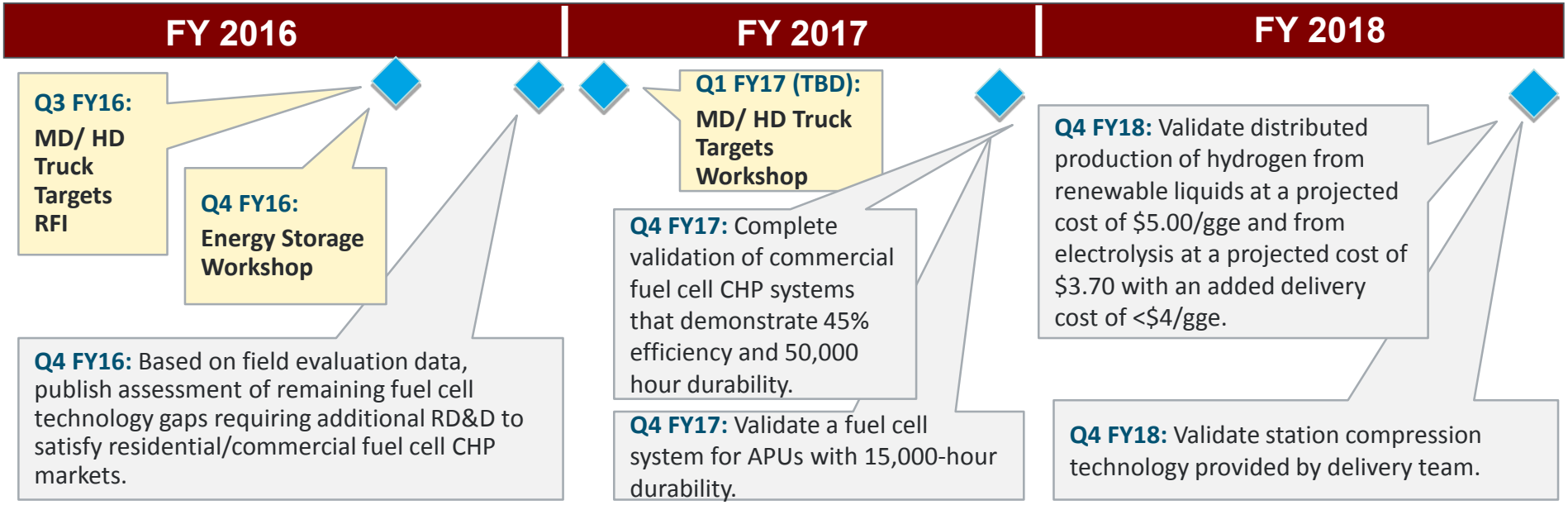
Collaborations



Activities are coordinated among various partners.

Recent and Upcoming Activities

- ✓ **INFRASTRUCTURE- H2FIRST** projects are making significant progress in supporting critical infrastructure needs (hydrogen station case study; HyStEP; SOSS; meter benchmarking; contamination detection)
  - ❖ Facilities/equipment developed for testing station components, hydrogen meters, liquid hydrogen tanks, and electrolyzers
- ✓ **VEHICLES –** Fuel cell delivery truck project is on track. Background analysis for MD/HD truck targets completed. RFI on fuel cell truck targets is to be issued in June 2016
  - ❖ Bus durability reaches 22,000 hrs.; light duty vehicle durability reaches 4,100 hrs
- ✓ **NEW hydrogen energy storage and grid integration** activities support renewable electrolysis and fuel cells as distributed energy resources



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

This Week…

TV Oral Sessions

- ❑ Tuesday, 11:00 am to 3:45 pm
- ❑ Thursday, 8:30 am to 5:15 pm (INFRASTRUCTURE Session)

TV Poster Sessions

- ❑ Tuesday, 6:30 pm – 8:30 pm