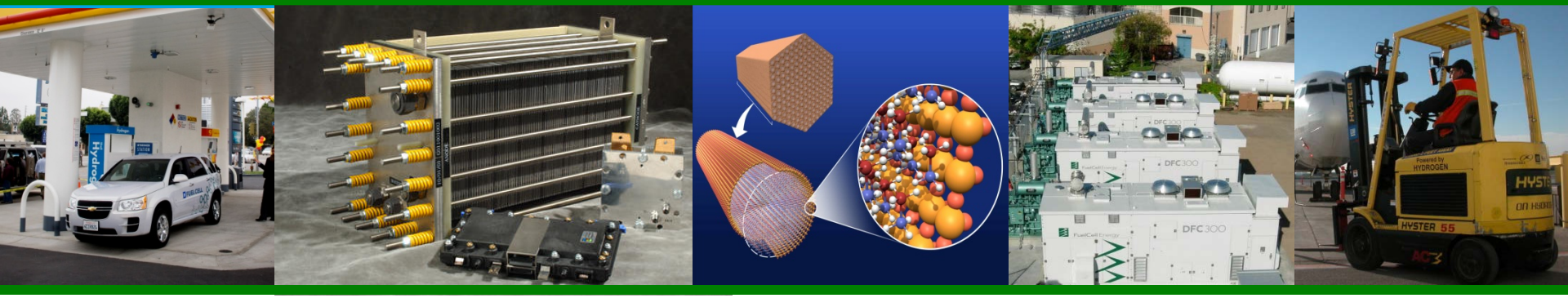
U.S. DEPARTMENT OF ENERGY



Technology Validation Program Area
-Plenary Presentation -

Jason Marcinkoski

Fuel Cell Technologies Office

2014 Annual Merit Review and Peer Evaluation Meeting

June 16 - 20, 2014

Goals and Objectives

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***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.*

OBJECTIVES

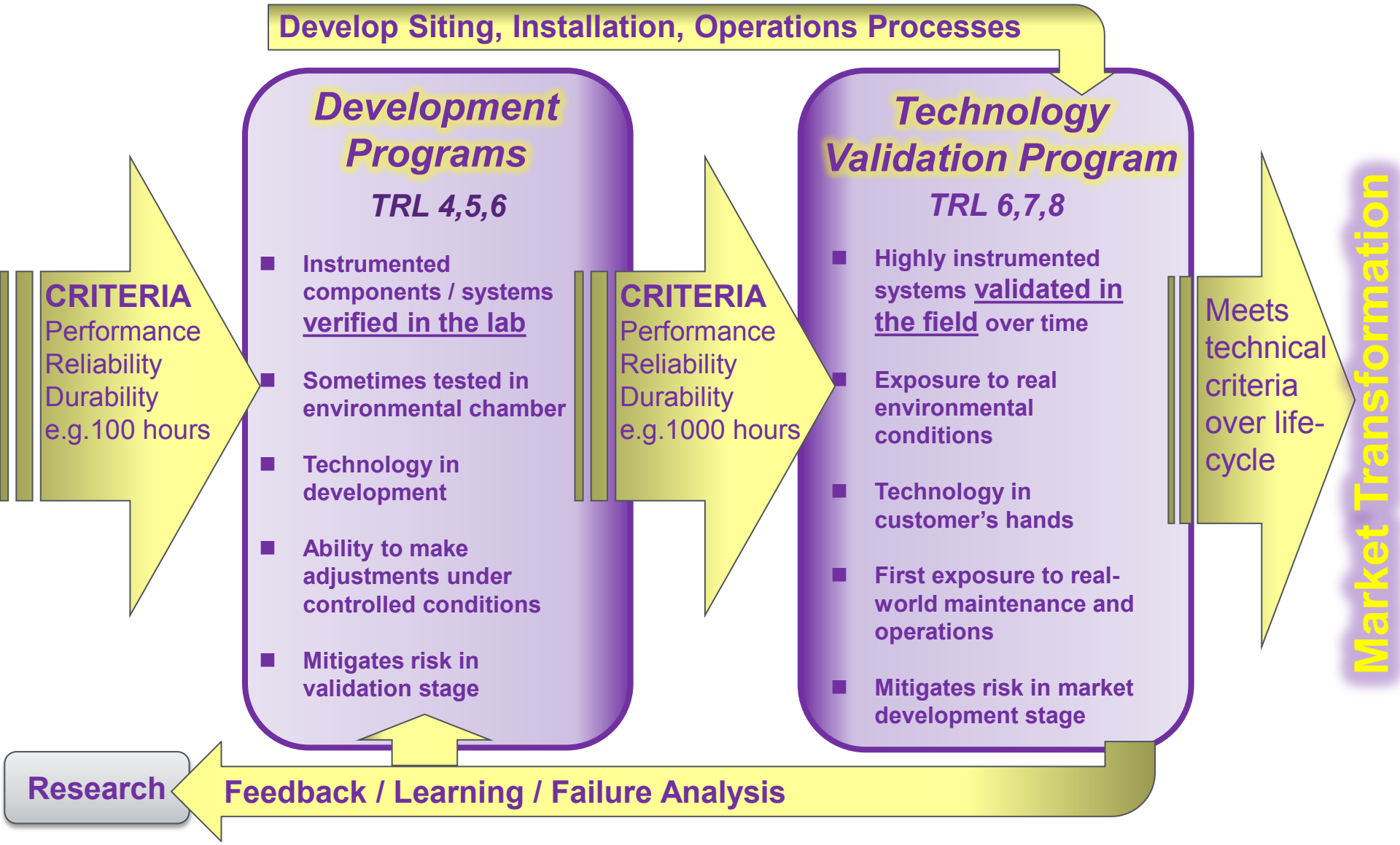
By 2017:

- Validate commercial stationary fuel cells (100 kW to 3 MW) against 2015 system targets (50,000 hours, 45% electrical efficiency).
- Validate durability of auxiliary power units (APUs) against 2015 fuel cell system target (15,000 hours, 35% electrical efficiency).

By 2019:

- Validate hydrogen fuel cell electric vehicles with greater than 300-mile range and 5,000 hours fuel cell durability.
- Validate a hydrogen fueling station capable of producing and dispensing 200 kg H_2/day (at 5kgH_2/3 min; 700 bar) to cars and/or buses.

Strategy


Develop Siting, Installation, Operations Processes
CRITERIA
Performance
Reliability
Durability
e.g.100 hours
Development Programs
TRL 4,5,6
Instrumented components / systems verified in the lab
Sometimes tested in environmental chamber
Technology in development
Ability to make adjustments under controlled conditions
Mitigates risk in validation stage
CRITERIA
Performance
Reliability
Durability
e.g.1000 hours
Technology Validation Program
TRL 6,7,8
Highly instrumented systems validated in the field over time
Exposure to real environmental conditions
Technology in customer's hands
First exposure to real-world maintenance and operations
Mitigates risk in market development stage
Meets technical criteria over life-cycle
Market Transformation
Research
Feedback / Learning / Failure Analysis

Addressing Challenges of Technology Validation

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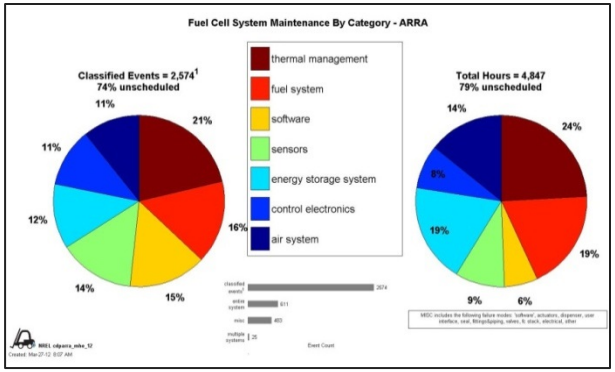

National Renewable Energy Lab

National Fuel Cell Technology Evaluation Center

a national resource for hydrogen and fuel cell stakeholders

- ✓ **Independent, secure analysis**
- ✓ **Industry collaboration**

http://www.nrel.gov/hydrogen/facilities_nfctec.html

- ✓ **Confirmation of component and system technical targets**
- ✓ **Technology validation**
- ✓ **Evaluation, optimization, and demonstration in integrated energy systems and real-world operation**

Current Targets and Status

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FUEL CELL DURABILITY

Element	Current 2013 Status	2015 Goal	2020 Goal
Light Duty Passenger Durability (hrs)	2,521	3,600	5,000
Residential Power Durability (hrs)	12,000	25,000	50,000
Commercial Power Durability (hrs)	40,000-80,000	45,000	65,000
APU Durability (hrs)	3,000	10,000	15,000

FUEL CELL SYSTEM AVAILABILITY

Element	Current 2013 Status	2015 Goal	2020 Goal
Residential Power Availability	97%	97%	98%
Commercial Power Availability	95%	97%	98%
APU Availability	97%	97.5%	98%

ELECTRICAL EFFICIENCY

Element	Current 2013 Status	2015 Goal	2020 Goal
Light Duty Passenger Vehicles - FC System Efficiency @ 25% Power	59%	60%	60%
1-10 kW Residential Power System Efficiency	34-40%	40%	42%
100 kW-3MW Commercial Power System Efficiency	42-47%	43%	48%
APU System Efficiency	25%	33%	38%

Source: Fuel Cell Technologies Office Multi-year Research, Development and Demonstration Plan, available at:

http://energy.gov/eere/fuelcells/fuel-cell-technologies-office-multi-year-research-development-and-demonstration-plan

Budget

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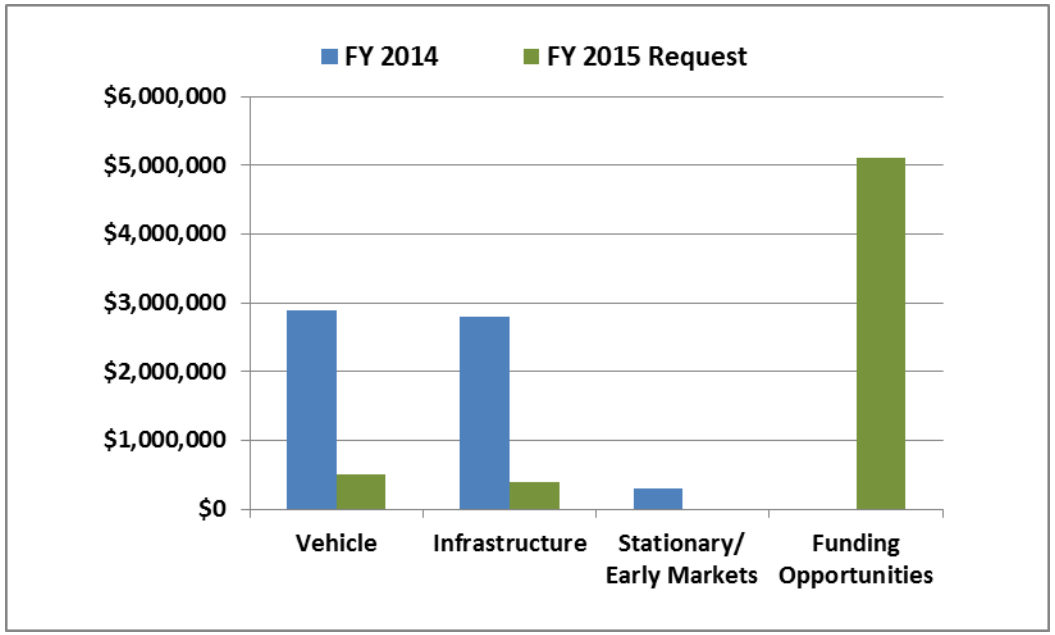
FY 2015 Request = $6M

FY 2014 Appropriation = $6M



EMPHASIS

➢ VEHICLES

- ❑ Light-duty Vehicles
- ❑ Medium-duty Trucks* (collaboration with Market Transformation)
- ❑ Buses (collaboration with DOT)

➢ INFRASTRUCTURE

- ❑ Fueling Station Data:
  - ❖ Advanced High-pressure Electrolyzer*
  - ❖ High-pressure Tube Trailer*
  - ❖ Compressor Reliability Testing
  - ❖ Cryo-compressor testing*
- ❑ H2FIRST*, **
- ❑ Grid Integration*

➢ STATIONARY/EARLY MARKETS

- ❖ Material Handling Equipment
- ❖ Back-up Power
- ❖ Stationary Fuel Cells

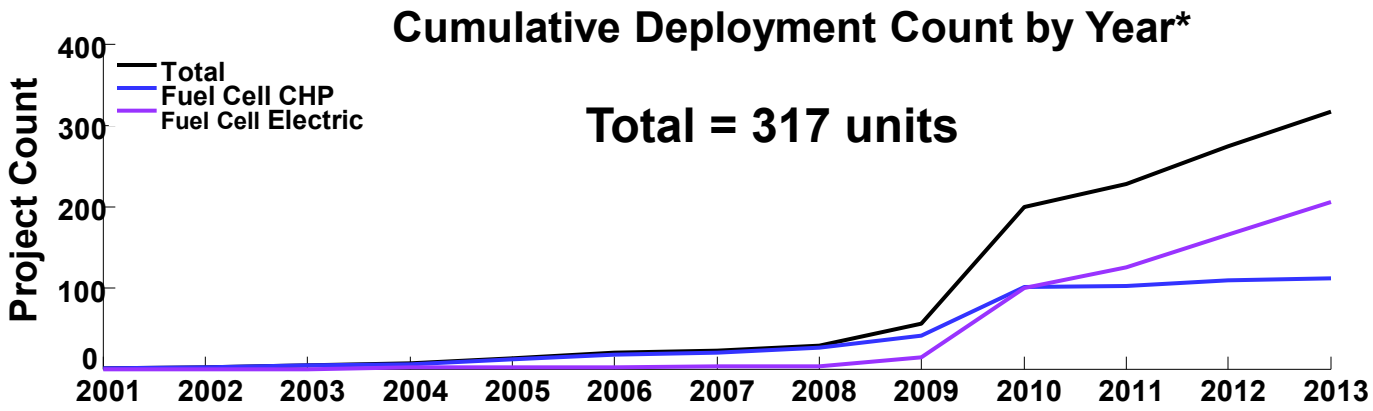
* Projects that include Technology Validation funding for equipment or development.
Many Technology Validation projects validate equipment/ technologies funded by industry, states, U.S. agencies, or other DOE programs.

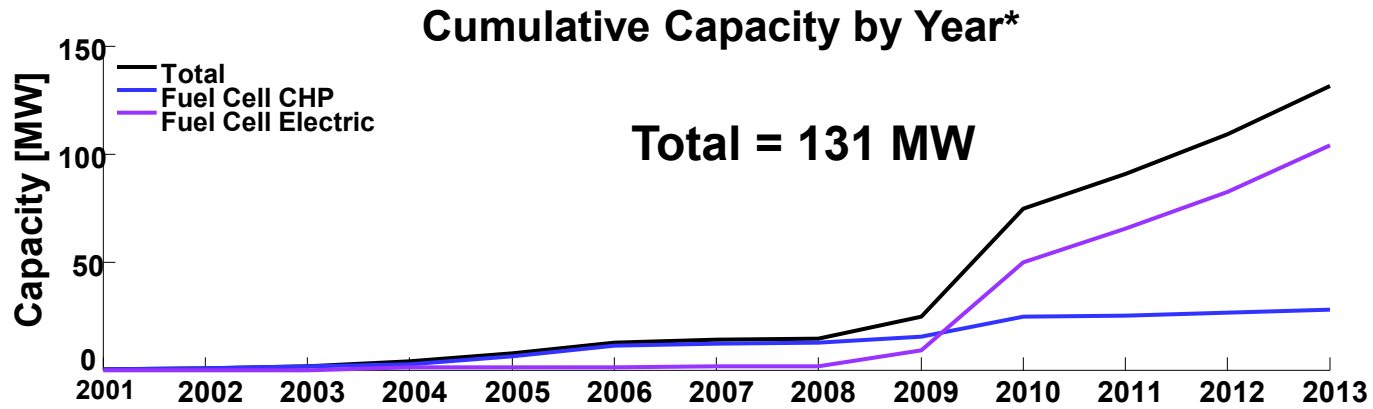
** Hydrogen Fueling Infrastructure Research and Station Technology

Accomplishments: Stationary Fuel Cells

U.S. DEPARTMENT OF ENERGY

Stationary fuel cell deployment is increasing steadily, incentive expenditure (in California SGIP*) is decreasing, but project prices are still generally higher for fuel cells.





Mean FC system availability:
93%

Mean FC electrical efficiency:
27% (HHV)

Natural gas is leading fuel source, but many larger installations also use biogas.

*SGIP: Self Generation Incentive Program—a distributed generation incentive program.

Accomplishments: Fuel Cell Buses

U.S. DEPARTMENT OF ENERGY

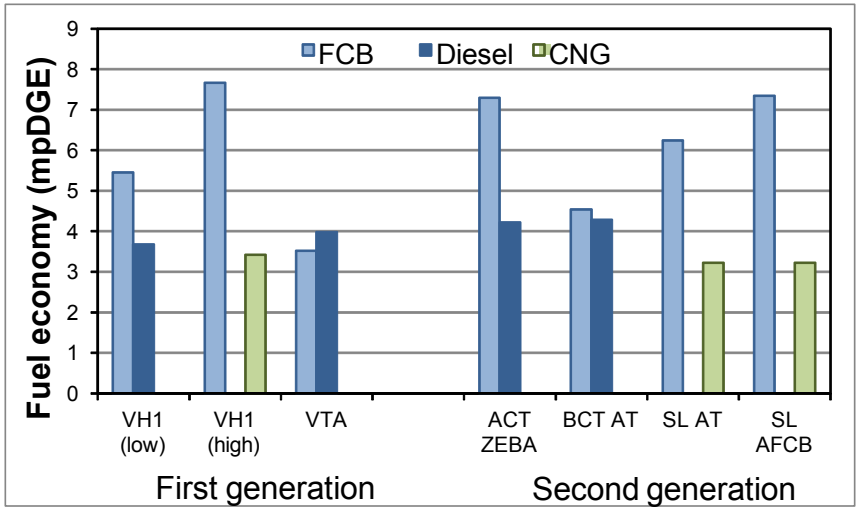
Fuel cell bus fuel economies are up to 2x better than baseline.

	Units	Current Status	2016 Target	Ultimate Target
Bus lifetime	Years / miles	**5/ 100,000**	12/ 500,000	12/ 500,000
Powerplant lifetime[1]	Hours	**1,000 – 16,000**	18,000	25,000
Bus availability	%	**55 – 72**	85	90
Roadcall frequency[2] (Bus/fuel cell system)	Miles between road call	**1,500 – 4,000 / 6,000 – 19,000**	3,500/ 15,000	4,000/ 20,000
Operation time	Hours per day/ days per week	**19/7**	20/7	20/7
Maintenance cost	$/mile	**0.39 – 1.60**	0.75	0.40
Fuel economy	Miles per diesel gallon equivalent	**4.5 – 7.3**	8	8
Range	miles	**220 – 310**	300	300

[1] Fuel cell hours accumulated to date from newest FCPP to oldest FCPP. Does not indicate end of life. [2] MBRC: range from lowest to highest for current designs.

60% of FCPPs over 7,000 hours*

Top 3 fuel cell power plant hours:*
- ✓ **16,419**
- ✓ **11,908**
- ✓ **9,903**



Accomplishments:
Fuel Cell Hybrid Electric Medium-duty Trucks

U.S. DEPARTMENT OF ENERGY

Selected two projects* to demonstrate fuel cell hybrid electric medium-duty trucks.

FedEx Express –Memphis, TN airport with:

- **Smith Electric Vehicles:** 80 kWh eTruck, extending range from 56 to 150 miles
- **Plug Power:** 10 kW fuel cell

IMPACT:

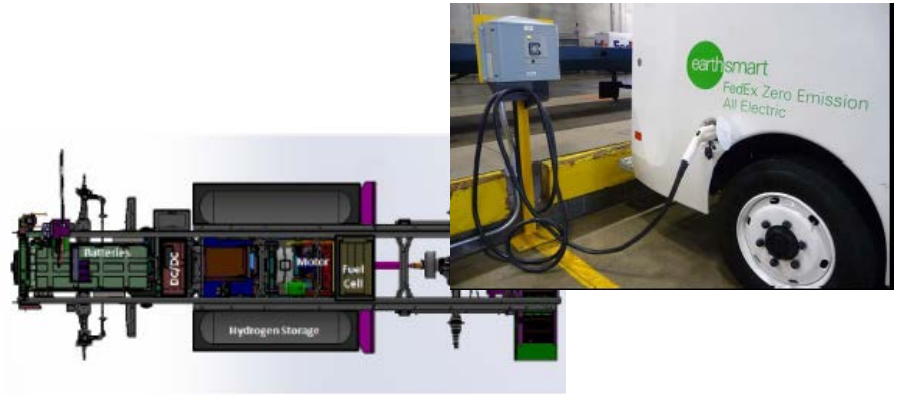
FedEx Express uses approximately 40,000 vehicles in its fleet, which could potentially be replaced with fuel cell hybrid vehicles. With fuel cells, the vehicles could save 196 million gallons diesel fuel and associated emissions per year.

Center for Transportation-Environment (UT Austin, TX) with:

- **UPS (United Parcel Service):** Sacramento, CA demo
- **Electric Vehicles International:** 99 kWh eVan, extending range from 75 to 125 miles
- **Hydrogenics USA:** 16 KW fuel cell

IMPACT:

Fuel cell hybrid vehicles could potentially take the place of ~46,000 diesel walk-in vans in UPS' fleet alone. With fuel cells the vehicles could save 120 million gallons of diesel fuel and associated emissions per year.



** Projects selected/pending negotiation.*

Accomplishments:
New Auto Awards and Deployments

U.S. DEPARTMENT OF ENERGY

DOE awards light-duty fuel cell vehicle data collection projects

- ❑ **$5.5 million DOE funding**
- ❑ **6 auto partners**
- ❑ **Data collected from up to 90 vehicles**
- ❑ **Planned mileage:**
  - ✓ Phase 1 = ~220,000 mi
  - ✓ Phase 2 (anticipated) = ~235,000 mi

METRICS EVALUATED:

- ❑ Fuel cell stack durability and efficiency.
- ❑ FCV range, driving behavior, fuel economy, and maintenance.
- ❑ On-board hydrogen storage performance.
- ❑ Hydrogen refueling performance.
- ❑ FCV Safety.

First Composite Data Products to be released October 2014.

GM

MERCEDES-BENZ

HYUNDAI

ELECTRICORE
POWERING THE FUTUR

TOYOTA

HONDA

NISSAN GROUP OF NORTH AMERICA

NISSAN

Accomplishments:
Hydrogen Station Developments

U.S. DEPARTMENT OF ENERGY

$2.4M awarded for 9 Hydrogen Station Evaluations and Advanced Refueling Components

350 bar and 700 bar fast-fill capability at all stations.

California State University—Los Angeles (CSULA)

- **Station Location:** Los Angeles, CA (on CSULA campus).
- **Station Characteristics:** Electrolyzer; 30-60 kg H_2/day.
- ✓ **Accomplishments:** Station commissioned on May 7, 2014.Data collection is commencing. Installed buffer tank to minimize pressure fluctuations.

California Air Resources Board (CARB)

- **Station Location:** Newport Beach, CA.
- **Station Characteristics:** 100 kg H_2/day; natural gas reforming.
- ✓ **Status & Plans:** Station operational and additional data collection hardware installed and calibrated. Full data set available soon.

Proton Energy (Proton OnSite)

- **Station Location 1:** Wallingford, CT ***(SunHydro #1)***.
- **Station Characteristics:** 65 kg H_2/day, advanced 57 bar PEM electrolyzer.
- ✓ **Milestone:** New advanced electrolyzer has been built. Data monitoring underway.

Proton Energy (Proton OnSite)

- **Station Location 2:** Braintree, MA ***(SunHydro #2)***
- ✓ **Status & Plans:** Design and fabrication has begun.

CALIFORNIA

NORTHEAST U.S.

Gas Technology Institute (GTI)

- **Station Locations:** Northern California (Foster City, Cupertino, Mountain View, West Sacramento) & Southern California (San Juan Capistrano).
- **Station Characteristics:** New 900 bar ionic compression (Linde); gaseous or liquid delivered hydrogen.
- ✓ **Status & Plans:** Permitting initiated for 2 sites. West Sacramento station expected to be installed by end of 2014.

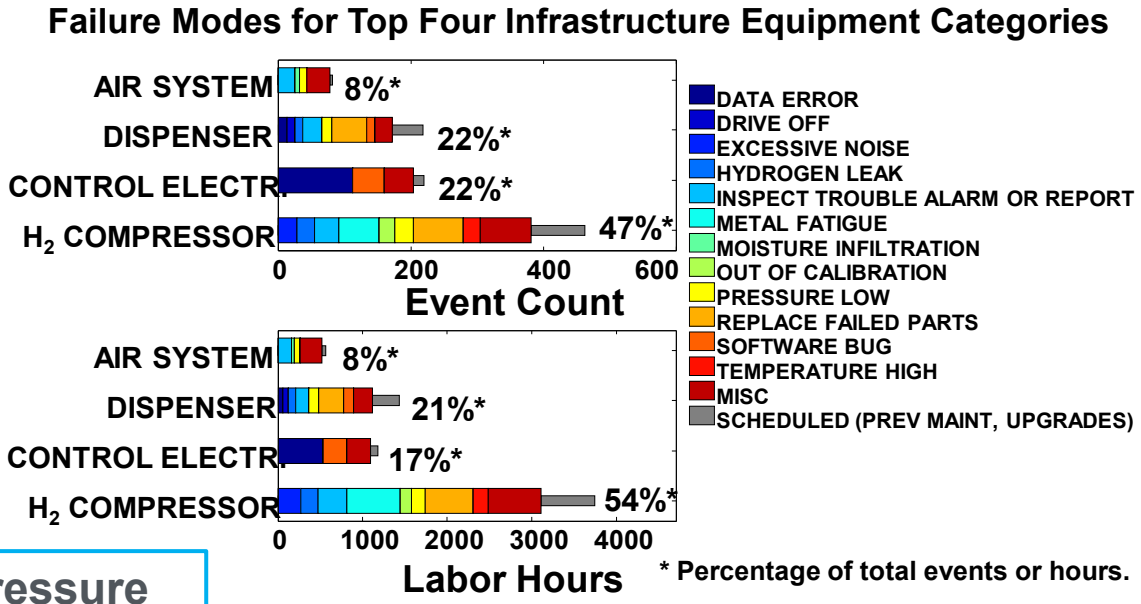
Accomplishments:
NREL Testing to Address Hydrogen Compressor Reliability

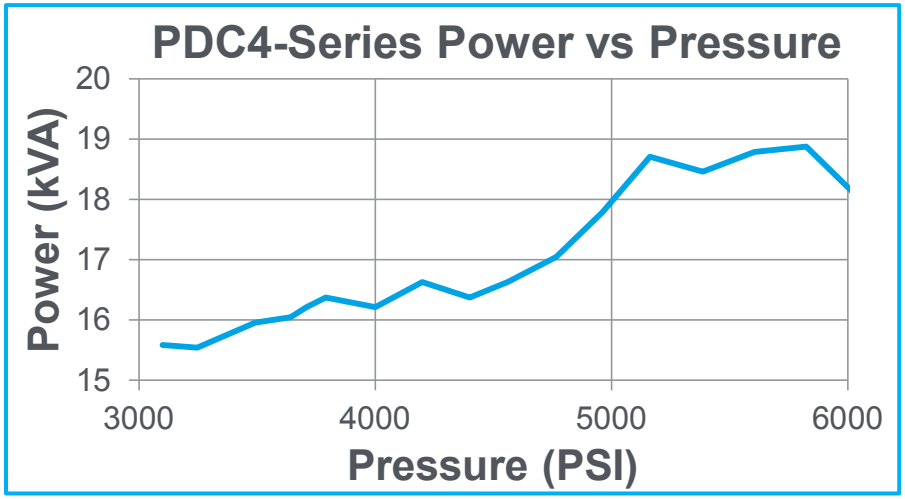
U.S. DEPARTMENT OF ENERGY

Highly accelerated life testing (HALT) reproduces component failures and correlates them to real-world usage.

APPROACH

- Diaphragm compressor testing: Long-duration operation (>1,000 hrs). Identify failures and work with manufacturer to improve reliability of future designs.
- Work with PNNL to improve diaphragm compressor modeling.
- Develop CRADAs with additional compressor technology manufacturers in 2015.





STATUS

- ✓ Instrumented and operated a PDC compressor.
- ✓ Analyzed and mapped compressor performance (power and pressure data).

Accomplishments:
Cryogenic Pressurized Hydrogen Storage and Delivery

U.S. DEPARTMENT OF ENERGY

High-pressure liquid hydrogen pump installed and operating.

Validation testing underway.

LAWRENCE LIVERMORE NATIONAL LABORATORY

PI: Salvador Aceves

OBJECTIVE:

Measure fill density, electricity consumption, and refuel time during long-term testing of a high pressure liquid hydrogen pump

IMPACT:

Liquid hydrogen pump has potential to increase H_2 storage density (and vehicle driving range) by up to 30% while enabling 5 minute refuels and minimizing delivery cost

PARTNERS:

- **Linde North America:** Liquid hydrogen pump manufacturer.
- **BMW:** Technology assessment and commercialization.
- **Spencer Composites:** Manufacturer of new generation high performance vessels.

DOE Funding: $1,200,000

Non-Federal Funding: $400,000

TOTAL FUNDING: $1,600,000

TECHNOLOGY & KEY SPECS:

- 100 kg/hr 875 bar liquid hydrogen pump.
- 50 g/L, 9% H_2 weight fraction cryogenic vessel storage target.
- $1.50/kg station, $0.60/kg truck, $1.60/kg liquefaction.
- $4.90/kg$H_2$ total dispensing cost (Argonne).
- Liquid hydrogen delivery from Linde:
  - ❑ Ontario, California.
  - ❑ $8.00/ kg LH_2 (estimated).

PROJECT PHASES:

(Cross-cutting project that also includes cryogenic on-vehicle storage technology development.)

- **Phase 1 (1 year):** Manufacture of new generation pressure vessel.
  - ❑ ***Go/No-go: burst test at minimum pressure (1,600 bar).***
- **Phases 2-3 (2 years):** Long-term LH_2 pump and vessel testing over 24 tonnes of LH_2 dispensing (5,000 refuels).

Accomplishments: High-pressure Hydrogen Bulk Delivery

U.S. DEPARTMENT OF ENERGY

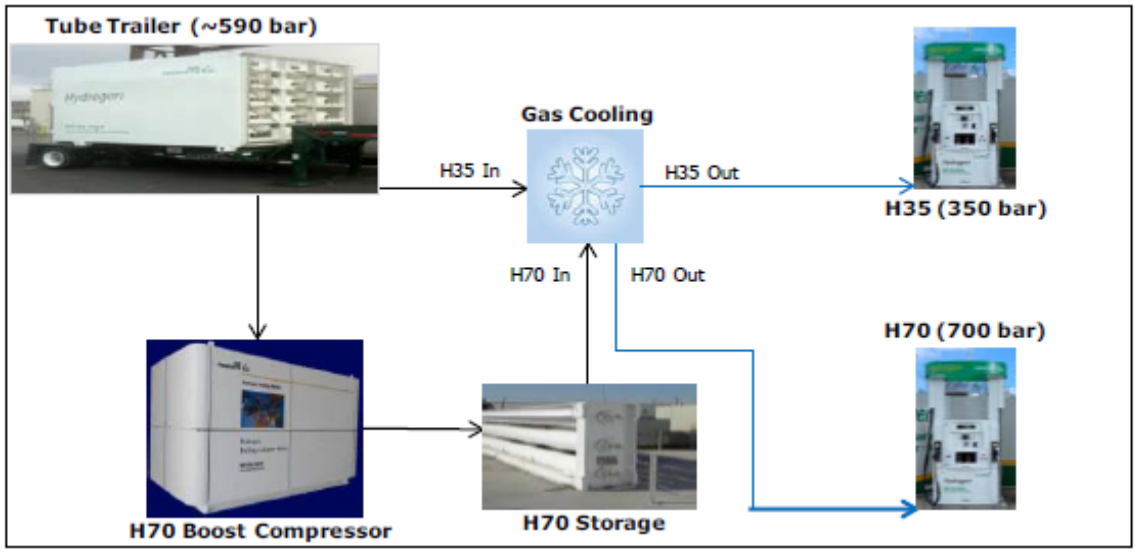
Air Products and Chemicals, Inc. has partnered with Structural Composite Industries to develop advanced tube trailers for hydrogen delivery.*

OBJECTIVE:

Develop advanced tube trailer based on high-pressure (8,500 psi or 590 bar) composite storage technology--***composite over-wrapped pressure vessel (COPV)***. Test performance (for 6 months) under real-world conditions.

IMPACT:

High-pressure composite hydrogen storage can lower existing hydrogen fueling costs by 30-60%. Ultimately can eliminate need for some of the on-site compression.



TECHNOLOGY & KEY SPECS:

Higher-pressure COPV tube trailer (Type III, carbon fiber):

- Up to 920 kg hydrogen on a single trailer (providing ***3x capacity increase***).
- Eliminates need for compressor at station site (lowers capital cost; decreases station space needs).
- Tube trailer platform can provide 700 bar or both 350 and 700 bar dispensing pressures.
- Advances current 7,500 psi approval from DOT.

****Project selected/pending negotiation.***

Accomplishments: H2FIRST Project

U.S. DEPARTMENT OF ENERGY

MISSION: Ensure fuel cell vehicle customers have a positive fueling experience relative to conventional gasoline/diesel stations as vehicle are rolled out in the near term and transition to advanced fueling technology beyond 2017.

Approach

- Focus on station components/system.
- Led by SNL and NREL, using core laboratory capabilities.
- Leveraging resources to maximize impact.
- H2FIRST organization with industry, academic, and government partners.
- H2USA coordination.

Accomplishments

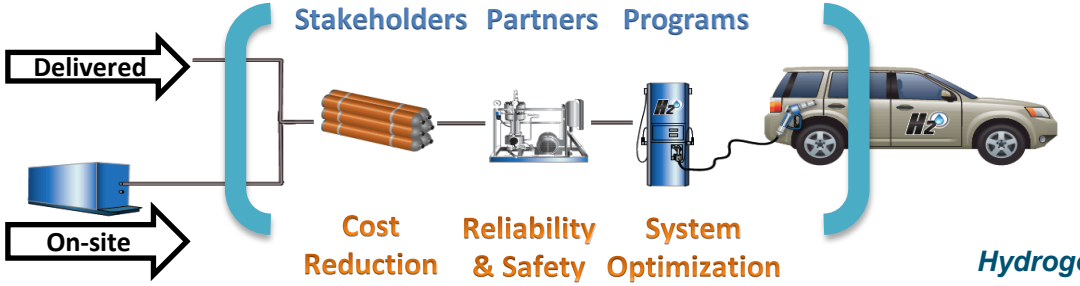
- ✓ Organized 5 project teams.
- ✓ Developing reference station matrix for targets and metrics.

Project Teams

1. Station Performance Testing
2. Dispenser/Components
3. Reference Station Design
4. Hydrogen Contamination Detector
5. Technical Assistance

Project Participants
(as of May 2014)

- ❑ Air Liquide
- ❑ California Air Resources Board
- ❑ California Fuel Cell Partnership
- ❑ California Governor's Office of Business & Economic Development
- ❑ California State University Los Angeles
- ❑ CSA Group
- ❑ Honda
- ❑ Nissan
- ❑ South Coast Air Quality Management District
- ❑ Toyota
- ❑ Shell
- ❑ Daimler
- ❑ Linde
- ❑ Boyd Hydrogen



H2FIRST

Hydrogen Fueling Infrastructure Research and Station Technology

Accomplishments:
Grid Integration/Hydrogen for Energy Storage

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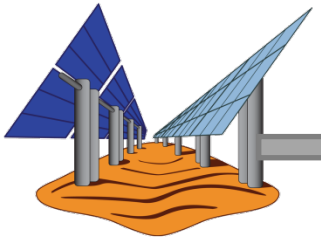
Initiated grid integration project. Enables higher penetration of variable renewable energy resources. Large-form electrolyzer will provide demand response to compensate for grid variability.

Wind



Solar

Geothermal

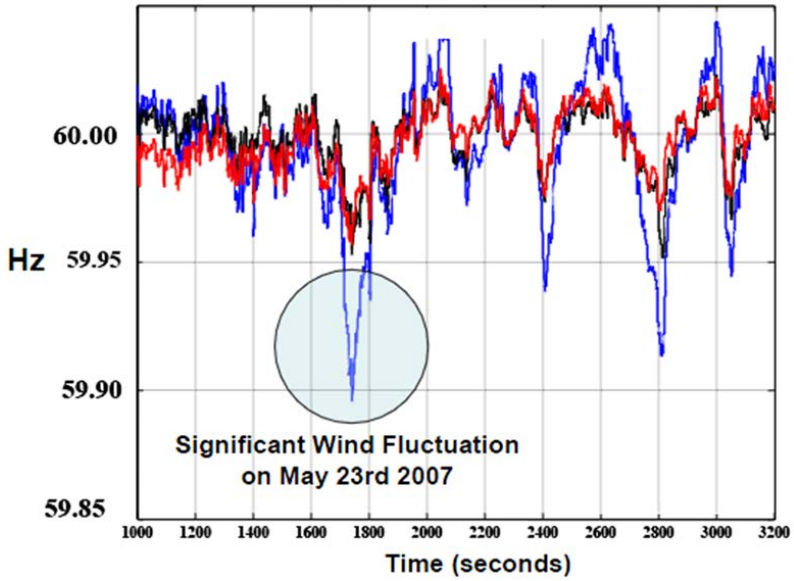
Electricity Grid

Electrolyzer

Ramp–up & ramp-down capability for grid stabilization

Hydrogen Storage

Vehicle Fuel Dispenser



Models indicate modest energy storage mitigates negative effects of wind penetration

H_2 storage
BLK 1 MW /1 min.
BLUE No storage
RED 1 MW/

Collaborations

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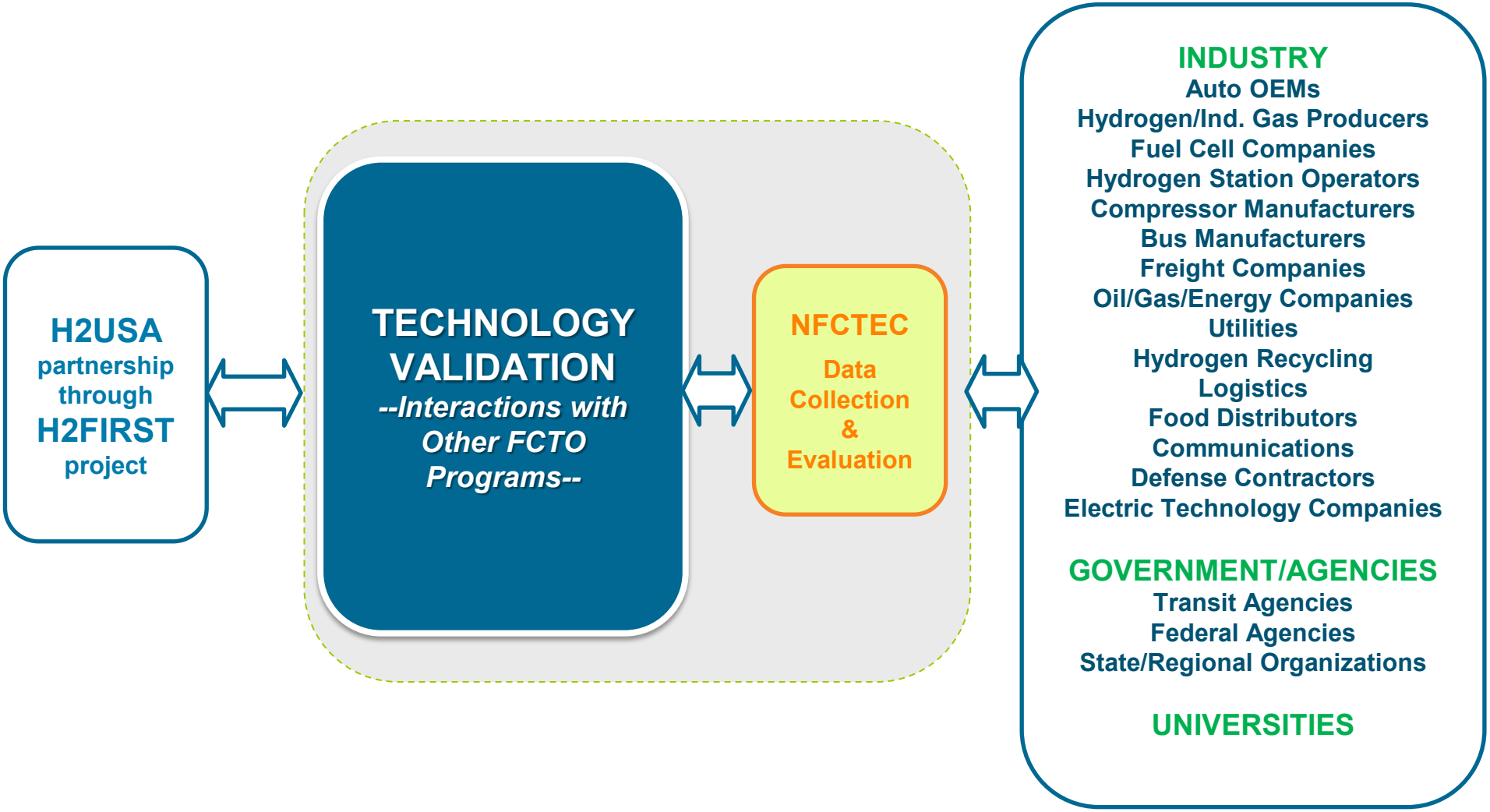
Activities are coordinated among various partners.



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Potential Future FOAs (~Fall 2014)*

- May emphasize hydrogen refueling station and components validation.
- May also include validation of stationary and early market fuel cells.

Hydrogen Contamination Detector—RFI and Workshop

- **GOAL:** To identify low-cost hydrogen contamination detection strategies that can be deployed at hydrogen stations to protect fuel cell vehicles from degradation, by stopping hydrogen flow before contaminated hydrogen reaches the vehicle.

- **RFI:** Released on April 14, 2014, seeking feedback from interested stakeholders on existing and potential hydrogen contamination detectors and related factors such as performance characteristics, system integration requirements, costs, deployment guidance, and R&D needs. Closed on May 19, 2014.

- **Workshop:** Held June 12, 2014 in Troy, MI. Results anticipated to be posted later this year. Insights gained from the workshop will help determine path forward for research related to hydrogen contamination detectors.

* ***Subject to appropriations.***

Recent and Upcoming Activities

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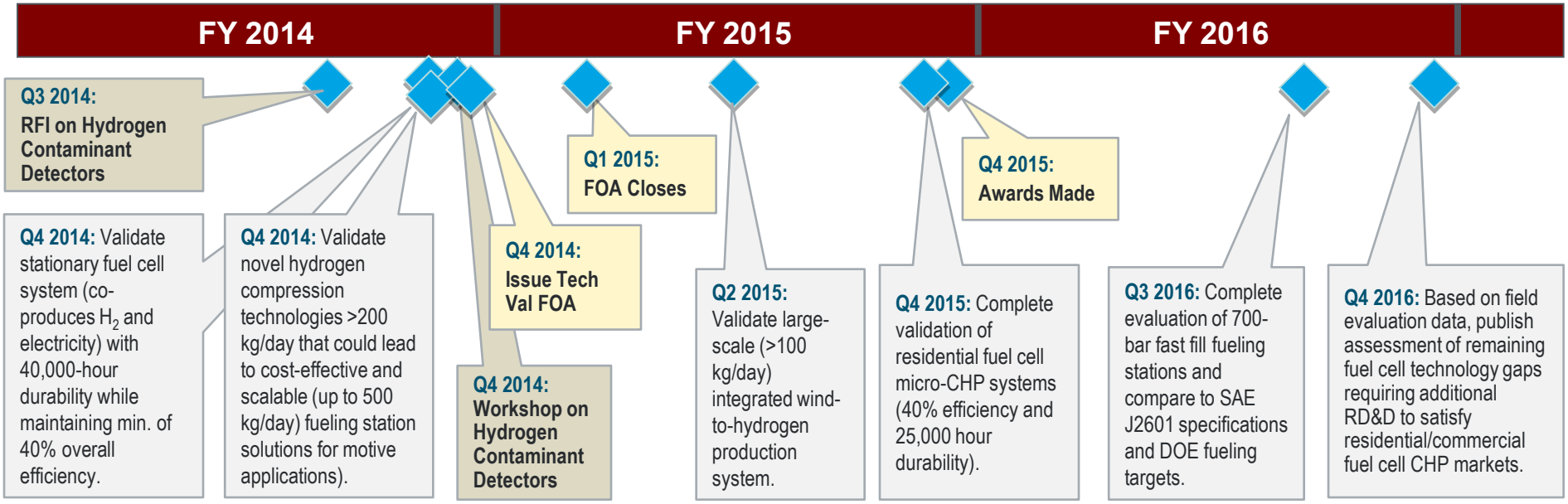
New investments in critical areas of infrastructure support upcoming FCEV commercialization.

ONGOING PROGRESS

- **Fuel cell-based forklifts and back-up power systems** continue to demonstrate successful and reliable operations under real-world conditions.
- **Stationary fuel cells** demonstrate high availability; deployments are increasing steadily, with most running on natural gas. However, prices for these systems remain high.
- **Fuel cell buses** continue to demonstrate fuel economies up to twice as high as the baseline.

NEW INVESTMENTS

- 6 auto manufacturers to provide **light-duty fuel cell vehicle** data.
- 2 new projects will develop and demonstrate fleets of **fuel cell hybrid electric medium-duty trucks**.
- 9 **hydrogen station** evaluations.
- **Compressor** reliability.
- **Cryogenic hydrogen pump** testing.
- **High pressure tube trailer.**
- Grid-integrated hydrogen stations.
- **H2FIRST** project:
  - Station Performance Testing
  - Dispenser/Components
  - Reference Station Design
  - Hydrogen Contamination Detector
  - Technical Assistance



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

THANK YOU…

Additional Information

Accomplishments: Hydrogen Refueling at CSULA

U.S. DEPARTMENT OF ENERGY

Hydrogen refueling station commissioned in May 2014.

Location: Los Angeles, CA (on CSULA campus).

Characteristics: Electrolyzer; 30-60 kg H_2/day.

STATUS

- ✓ Designed and implement enhanced data acquisition for station performance evaluation.
- ✓ Installed power meter, flow meters, and buffer tanks.
- ✓ Created Microsoft SQL database, ability to generate quarterly reports, and perform individual equipment performance assessment.

PLANS

- Regular data collection and reporting.
- Hydrogen purity testing.
- Outreach and training for student, public, and government.

Accomplishments: Advanced High-pressure Electrolyzer

U.S. DEPARTMENT OF ENERGY

Proton Onsite validating hydrogen fueling infrastructure performance gains: 57bar PEM electrolyzer, 87MPa composite storage tanks, and skid-mounted compact refueling.

STATUS

- ✓ 57 bar electrolyzer stack built; passed manufacturing ATP.
- ✓ Design confirmed for 57 bar input compressor.
- ✓ Local authorities engaged for permitting.
- ✓ SunHydro#1 Station: Data acquisition software installed and operating.
- ✓ SunHydro#2 Station: Design complete (2X 20ft containers; generation and compression/storage). Construction underway.

Locations: Wallingford, CT (SunHydro #1) and Braintree, MA (SunHydro #2).

Characteristics: 65 kg H_2/day, advanced 57 bar PEM electrolyzer (at SunHydro #1 station).

PLANS

- Data reporting for SunHydro#1 station.

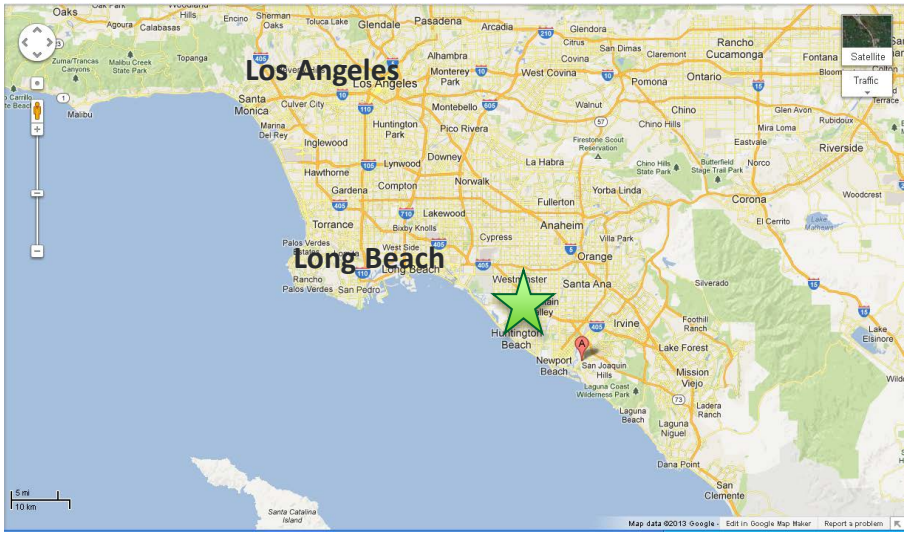
Accomplishments: Newport Beach Hydrogen Station

U.S. DEPARTMENT OF ENERGY

California Air Resources Board, in partnership with Shell and Hydrogenics, is demonstrating and validating natural gas-based hydrogen production and dispensing at Newport Beach, CA.

Location: Newport Beach, CA.

Characteristics: 100 kg H_2/day; natural gas reforming.



STATUS

✓ Installed, tested, and calibrated equipment (low- and high-pressure mass flow meters; power meters).

PLANS

- Data collection and reporting to NREL to begin **~July 2014**.

Accomplishments: Delivered Hydrogen Fueling Stations

U.S. DEPARTMENT OF ENERGY

900 bar ionic compression technology to be tested and validated. Initial fueling sites being prepared.

Locations: Northern California (Foster City, Cupertino, Mountain View, West Sacramento) & Southern California (San Juan Capistrano).

Characteristics: New 900 bar ionic compression (Linde); gaseous or liquid delivered hydrogen.

STATUS

- ✓ Site locations identified and funding was secured for stations in California:
  - ❑ San Juan Capistrano—***permitting initiated; permit drawings submitted***
  - ❑ West Sacramento—***permitting initiated; construction bid phase initiated***
- ✓ Data acquisition system design completed.
- ✓ Instrumentation and data logger components received.

PLANS

- Fabrication, testing, and installation of systems on initial sites (San Juan Capistrano & W. Sacramento).
- Initiate remaining sites: Foster City, Cupertino, Mountain View.
- First set of data produced for West Sacramento station is expected **by end of 2014**.