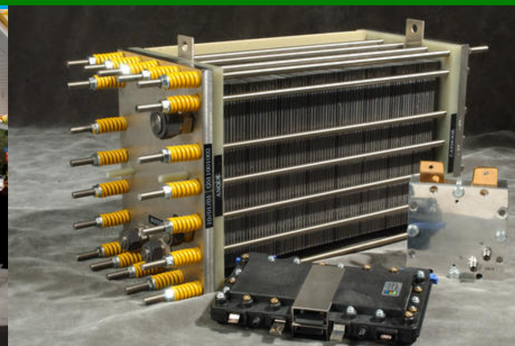
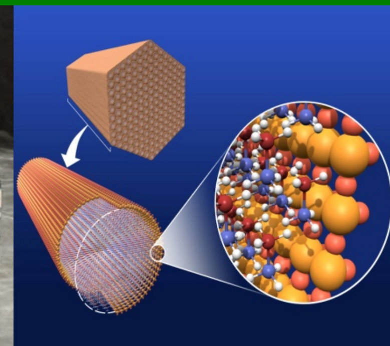
U.S. DEPARTMENT OF
ENERGY


Technology Validation Program Area
-Plenary Presentation-

Jim Alkire

Fuel Cell Technologies Office

2017 Annual Merit Review and Peer Evaluation Meeting

June 5 - 9, 2017

Goals and Objectives

OBJECTIVES

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 5kg H_2/ 3 min; 700 bar)

By 2020:

- ❑ Validate large-scale systems for grid energy storage that integrate renewable hydrogen generation and storage with fuel cell power generation by operating for more than 10,000 hours with a round-trip efficiency of 40%

GOAL: ***Develop processes and systems to move technology from labs into the field, through independent data collection/analysis and real-world demonstrations.***

Strategy and Barriers

TECHNOLOGY VALIDATION develops processes and systems to move technology from labs into the field, through independent data collection/analysis and real-world demos.

STRATEGY

- ❑ **VERIFY** components in lab
- ❑ **INTEGRATE** components into systems
- ❑ **VALIDATE** performance against targets under real-world conditions
- ❑ **DEVELOP** siting, construction, installation, and operations processes
- ❑ **SUPPORT** business practices, facilities, or services
- ❑ **PROVIDE** feedback to R&D and target setting

IMPACT

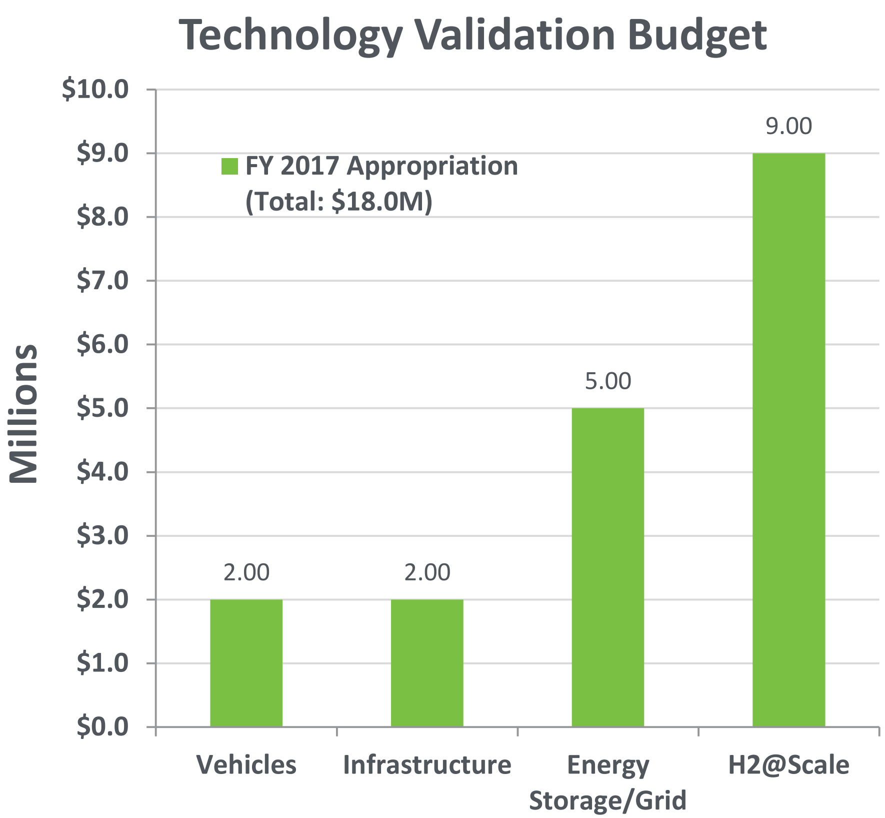
- ❑ **PROVIDE** unbiased and independent information to investors and decision-makers
- ❑ **EVALUATE** technology market readiness
- ❑ **MITIGATE** technical risks for market introduction

BARRIERS

- ❑ Lack of FCEV and FCEB performance and durability data
- ❑ Lack of hydrogen refueling infrastructure performance and availability data
- ❑ Hydrogen from renewable resources

Budget

FY 2017 Appropriation = $18M



EMPHASIS ON R&D FEEDBACK

VEHICLES

- Light-duty cars, buses, delivery trucks

INFRASTRUCTURE / H2FIRST

- Fueling station and component performance and reliability
- Delivery and dispensing
- Meter benchmarking
- Fuel contaminant detection
- Mobile refueler

GRID INTEGRATION / ENERGY STORAGE

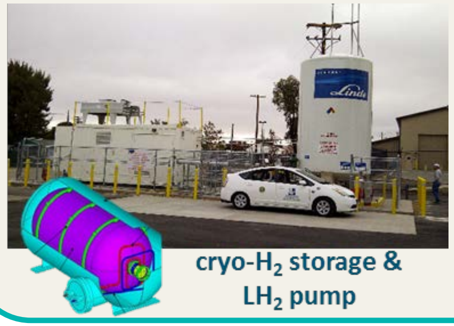
- Electrolyzers in real-time grid simulation
- Energy Dispatch Controller
- Hydrogen-vehicle-grid systems
- high current density SOEC system

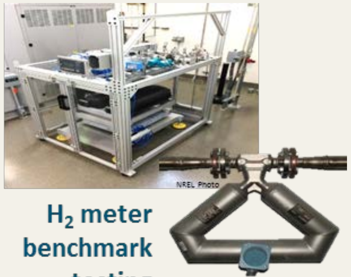
H2@Scale

- Analysis and data collection
- Electrolyzer MEA
- Dynamic Compressor Operation
- High-temp electrolysis testing
- Planned CRADA call

Project Portfolio

LAB TESTING


cryo-H_2 storage & LH_2 pump


H_2 meter benchmark testing

grid simulation & resiliency (RTDS)

DEVELOPMENT

HyStEP device (station perf.)

H_2 high-P tube trailer

mobile H_2 refueling

hybrid electric FC parcel truck

H_2 station


component performance evaluation


hydrogen contamination evaluation

DEMO & VALIDATION

AC Transit, Oakland, CA

Hyundai

Mercedes Benz

GM

MBTA, Boston, MA

Nissan

Toyota

Honda

SunLine, Thousand Palms, CA

UCI Irvine, CA

OCTA, Orange County, CA

ACCOMPLISHMENTS: Hydrogen Stations & Fuel Cell-based Transportation Data Collection and Analysis

Real-world performance of technologies are validated in field through data collection and analysis.

KEY ACCOMPLISHMENTS

Stations:

- ✓ >3x number of stations providing data
- ✓ >10x H_2 dispensed vs. last year
- ✓ Dispensers leading cause of downtime; overtaking compressors as #1; **failure rates improving as more hydrogen dispensed**

Cars:

- ✓ 2 fuel cell stacks now over 5,000 hours
- ✓ 227 cars traveled >7 million miles--to date (42 vehicles and 2.4 million miles--latest evaluation period)

Buses:

- ✓ One FCEB >23,000 hours now; 6 buses >18,000 hours (2016 DOE/DOT target)
- ✓ Fleet max values exceeding ultimate targets

WHY?

Validate car, bus, hydrogen station performance through analysis of real-world performance data for current status, benchmarking, and technology readiness.

BUSES

Fuel cell buses exceeding targets…

	Fleet Avg.	Fleet Max	2016 Target	Ult. Target
Availability	----	93%	85%	90%
Durability	----	23,423 hrs	18,000 hrs	25,000 hrs
Fuel Econ.	----	7.22 mpdge	8 mpdge	8 mpdge
Miles betw. Road Calls *(bus/FC system)*	*4,710/ 20,705*	----	*3,500/ 15,000*	*4,000/ 20,000*

CARS

Range	200 - 300 mi	
Durability	4,100 hrs *(max fleet avg.)*	5,648 hrs *(max oper. hrs.)*
Fuel Econ. *(avg. on-road)*	51 mpgge *(median)*	57.5 mpgge *(max)*
Fuel Econ. *(commercial vehicles)*	up to 68 mpgge	
Fuel Cell Eff. *(avg. at ¼ power)*	57%	

H_2 STATIONS

Validating emerging H_2 infrastructure

H_2 Dispensed*	202,364 kg	
Avg. Fill Time	4.6 min	
# of Stations	61 *(current)*	36 *(planned)*

***Cumulative through Q4, 2016**

Lead: NREL | **TV001, 008, 017**

ACCOMPLISHMENTS: H_2 Meter Benchmarking Testing

Testing accuracy of flow meters for commercial sale of hydrogen is providing feedback to flow meter manufacturers, helping develop improved flow meter technologies.

WHY?

- H_2 meters currently meeting 5% tolerance level in the field
- All relaxed accuracy classes will sunset in 2020

KEY ACCOMPLISHMENTS

- ✓ Designed/built lab-grade gravimetric hydrogen standard
- ✓ Conducted high-pressure testing of commercially available flow meters (2 Coriolis; 1 Turbine) over range of simulated SAE J2601 fueling protocols

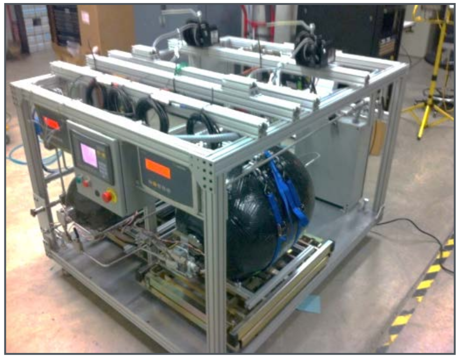
Table T.2.
Accuracy Classes and Tolerances for Hydrogen Gas-Measuring Devices

Accuracy Class	Application or Commodity Being Measured	Acceptance Tolerance*	Maintenance Tolerance**
2.0	Hydrogen gas as a vehicle fuel	1.5 %	2.0 %
3.0 [1]		2.0 %	3.0 %
5.0 [1]		4.0 %	5.0 %
10.0 [2]		5.0 %	10.0 %

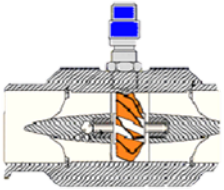
*Acceptance tolerance = first test in lab
**Maintenance tolerance = test in field

	2%	5%	10%
All Cases	82.2%	99.9%	100%
High Flow	64.6%	98.8%	100%
Typical Ramp	88.1%	100%	100%

BEST METER PROBABILITY THAT SINGLE FILL WILL BE WITHIN % TOLERANCE LEVELS



H_2 Test Stand



Turbine

Coriolis

Lead: NREL
Partnering with NIST

TV037

ACCOMPLISHMENTS:
Hydrogen Station and Components Evaluation

Tube cutting and cleaning processes shown to have substantial contamination effects.

WHY?
Determining contaminants and methods to remove contaminants helps identify opportunities to improve station reliability.

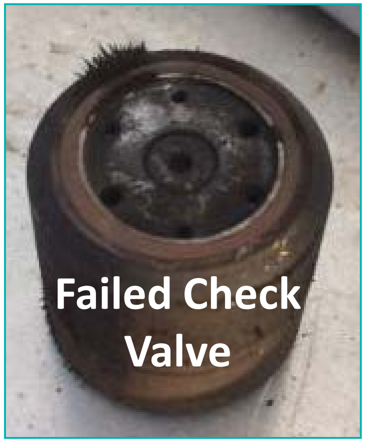
KEY ACCOMPLISHMENTS

Contaminant Detection

- ✓ Determined ***greases*** containing siloxanes harmful to fuel cells
- ✓ Determined effect of ***tube-cutting*** and ***cleaning techniques*** on particulate contamination (metal particles)
- ✓ Quantified effect of tube cleaning techniques on reducing metal particulates--plugging with tube brush doesn't require significant additional effort, yet it can reduce metal particulates

Reliability & Maintenance

- ✓ Showed 1/3 of maintenance hours at stations are for compressors
- ✓ Communicating results with equipment manufacturers



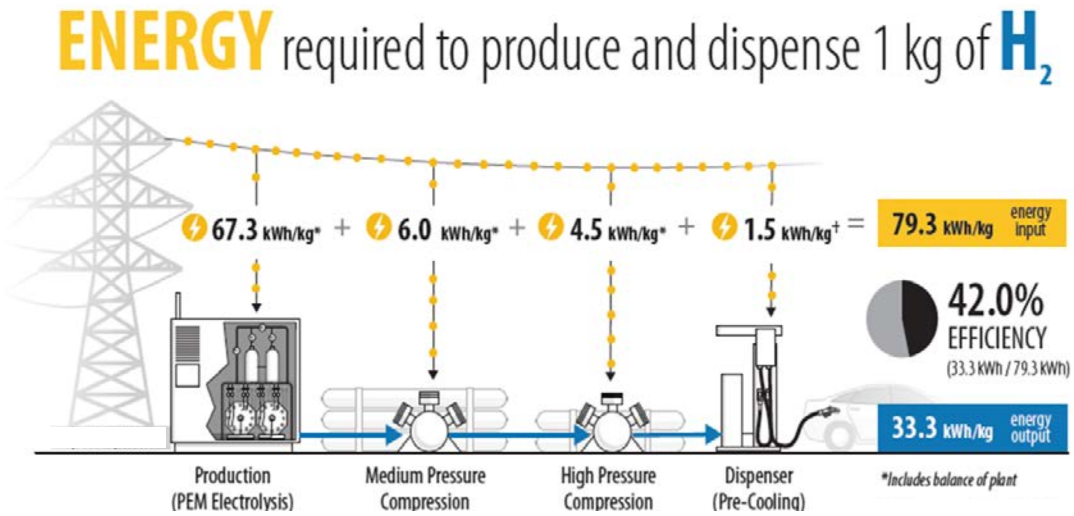
Lead: NREL **TV019**

Partners: PDC; PPI/Sundyne; Shell Hydrogen; CSULA; SCAQMD; Sunline; H2Frontiers; Proton OnSite; FirstElement

Hydrogen Station and Components Evaluation

Energy use of various station components quantified; areas for further improvement identified.

WHY?
Benchmarking station component energy use helps identify components to focus on to achieve better efficiencies and reduce costs.



KEY ACCOMPLISHMENTS

Power & Energy Demand

- ✓ Quantified energy consumption of major station components and impact on station operation costs
- ✓ Chiller performance shown to be highly dependent on ambient temperature and station throughput, ranging from <1 kWh/kg to 7 kWh/kg
- ✓ Compressor performance found to be constant around 4-6 kWh/kg

Lead: NREL **TV019**

Partners: PDC; PPI/Sundyne; Shell Hydrogen; CSULA; SCAQMD; Sunline; H2Frontiers; Proton OnSite; FirstElement

ACCOMPLISHMENTS: Developing & Demonstrating Cryo-H_2 Storage & Liquid-H_2 Pump

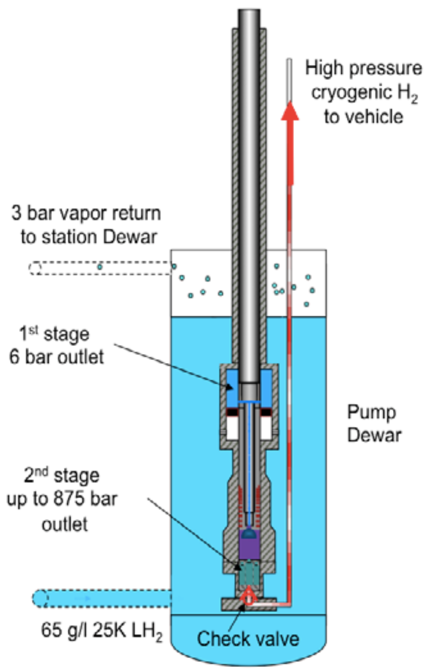
Demonstrated performance characteristics and benefits of liquid hydrogen pump through testing over multiple cycles.

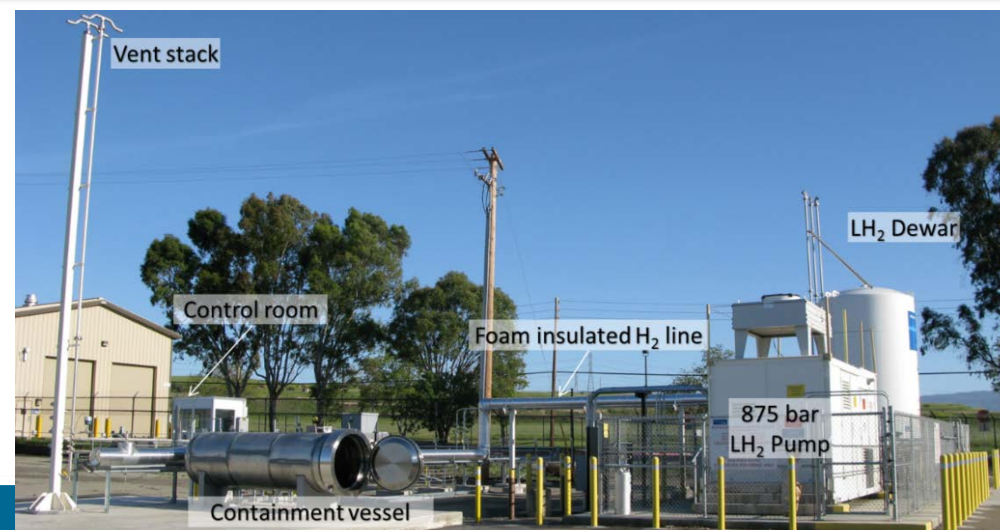
WHY?

Potential to increase hydrogen storage density (and vehicle driving range) by 30% while enabling 5 minute refuels and minimizing delivery cost.

KEY ACCOMPLISHMENTS

- ✓ Collected LH_2 pump performance and durability data over **456 cycles** and **1,650 kg H_2**
- ✓ Demonstrated **1.55 kgH_2/min** (93 kgH_2/h) average pumping rate
- ✓ Demonstrated **low consumption of electricity** (1.1 kWh/kgH_2 active; .5 kVAh/kgH_2 apparent)
- ✓ Estimated **3.6% venting losses** in a **future** LH_2 pump station with improved design





Lead: LLNL

Partners: Linde N. America; BMW; Spencer Composites

TV029

ACCOMPLISHMENTS: Developing & Demonstrating Advanced Hydrogen Mobile Refueler

Design completed for fully functional hydrogen fueling station on wheels; ready to begin construction.

WHY?
- ❖ Self-contained, 700-bar capable, J2601-compliant
- ❖ Short-term coverage while stations built
- ❖ Temporary backup while stations down

KEY ACCOMPLISHMENTS
- ✓ Completed specifications
- ✓ Completed detailed design
- ✓ Completed hazard analysis
- ✓ Ordered long lead-time equipment

SPECIFICATION	DESCRIPTION
Pressure Class	H70 (70 MPa) after compressing high bank storage
Pre-cooling	T30 (-30° C) or T40 (-40° C)
Performance	Up to 15 kg per hour, 100-120 kg in 8-10 hours
Fueling Protocol	SAE J2601-2014 table based for 2-7 kg tanks. SAE J2799-2014
Setup	One hour for limited performance, 8 hours for full performance
Storage	Up to 170 kg H_2 at 45 MPa with ability to connect to external storage
Power	On-board 480VAC, low noise, low emissions diesel generator with option of using external power
Usage	Dispenser human machine interface allows fueling by minimally trained users.

Lead: Electricore
Partners: Air Liquide; HTEC; Quang Assoc.; Manta Consulting

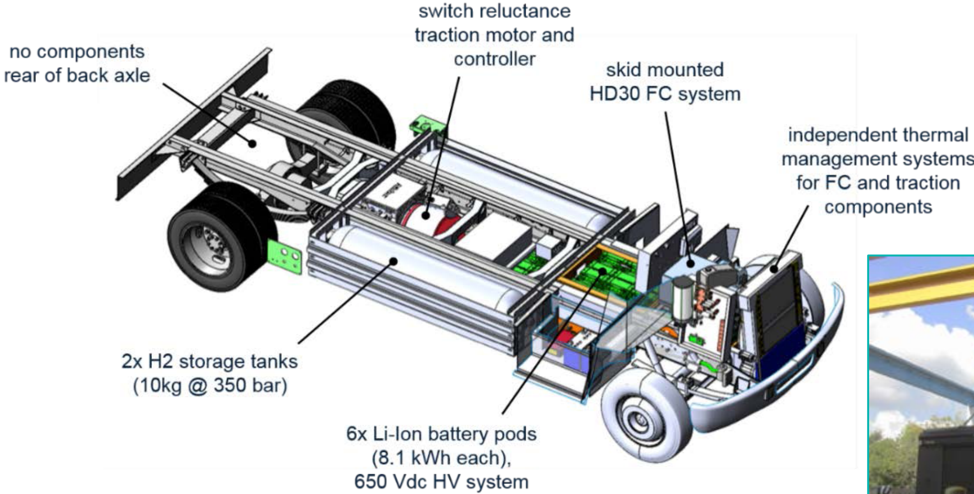
TV039

ACCOMPLISHMENTS: Developing & Demonstrating Hybrid Electric Fuel Cell Parcel Truck

Hybrid electric fuel cell parcel truck designed, built, and on track for 2017 demonstration.

WHY?

- Extend range from 75 to 125 miles
- Validate in real-world operation (up to 16 vans)
- Potential to replace ~46,000 diesel walk-in vans in UPS' fleet



KEY ACCOMPLISHMENTS

- ✓ Completed detailed design
- ✓ Completed hazard analysis
- ✓ Integrated powertrain components and hydrogen fuel system onto chassis

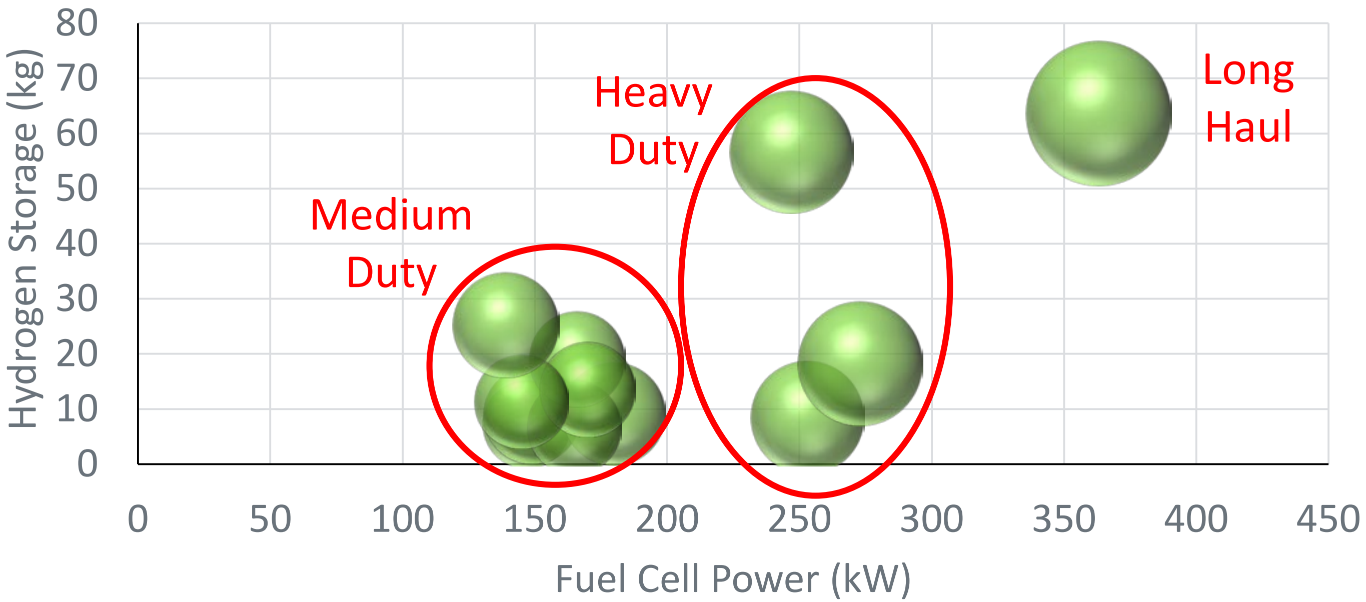
Lead: Center for Transportation & the Environment (CTE) TV034
Partners: University of Texas; Unique Electric Solutions; Hydrogenics USA; Valence Technology; UPS

ACCOMPLISHMENTS:
Fuel Cell Electric Trucks (FCET) Target Development

Demonstrated feasibility of FCETs for many applications; establishing techno-economic targets.

- ✓ Analysis and Publications
- ✓ Draft Targets
- ✓ Stakeholder Feedback

Representative Trucks
Market Data Sets
→
H_2 Storage Volumes
Body Builder Guides and Specs
→
H_2 Storage System Mass
Developed Physical Model
→
Component Sizing and Simulation
Autonomie Software



Representative Vehicle Class and Vocation
Class 2 Van
Class 3 Enclosed Van
Class 3 School Bus
Class 3 Service
Class 4 Delivery Van
Class 5 Utility
Class 6 Construction
Class 7 School Bus
Class 8 Construction
Class 8 Linehaul
Class 8 Refuse
Class 8 Tractor Trailer

Lead: Argonne National Lab
Partners: DOE Fuel Cell Technologies Office; NREL

ACCOMPLISHMENTS:
Integrating H_2 & Fuel Cells with the Grid

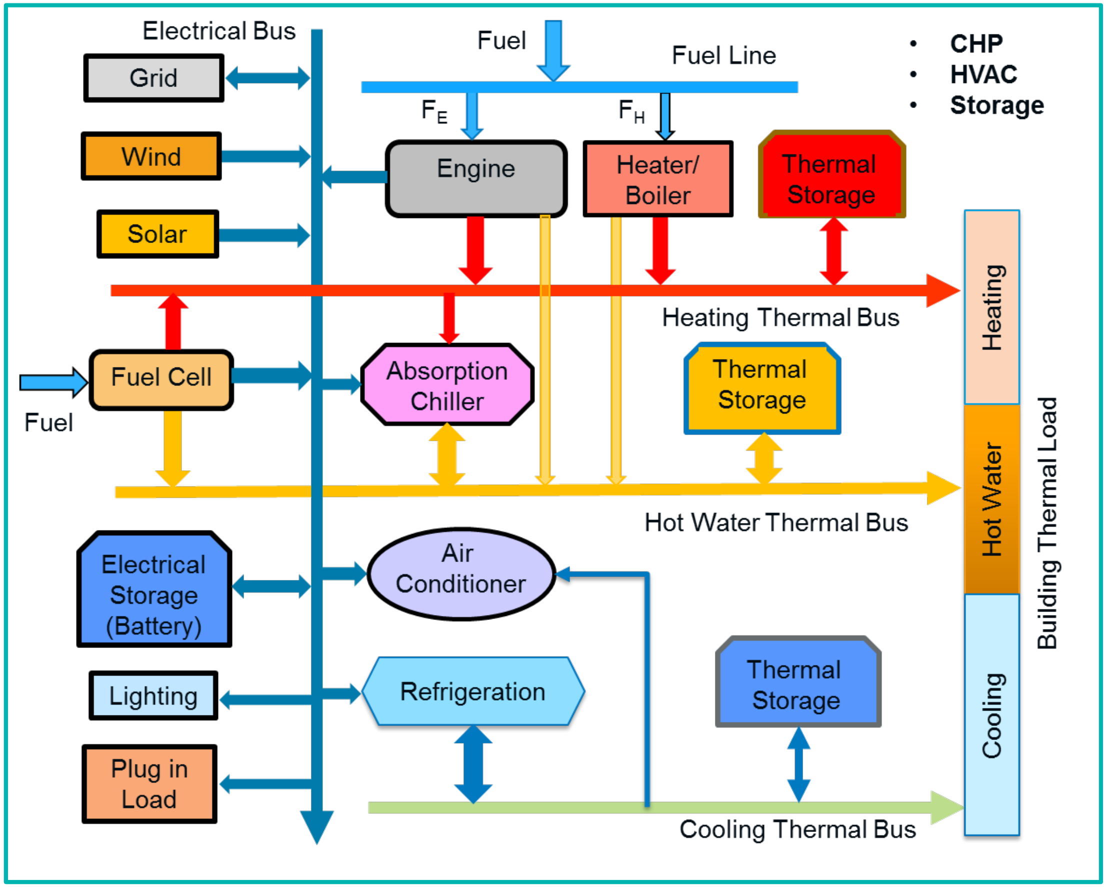
Created open-source tool (Energy Dispatch Controller) to foster growth in fuel cell-integrated buildings with emphasis on optimal dispatch control.

WHY?

- Optimized dispatch for buildings with integrated components – fuel cell, HVAC, boiler, thermal and electrical storage systems
- Participation of buildings and components in ancillary grid services
- Enabling better planning—optimum component selection and sizing (onsite generation/storage, etc.)

KEY ACCOMPLISHMENTS:

- ✓ Energy Dispatch Controller--initial formulation of algorithms and forecasting
- ✓ Functional GUI interface
- ✓ Building design module
- ✓ Co-simulation environment



Lead: NREL **TV042**

Partners: PNNL; NREL; Washington State Univ.; Humboldt Univ.; Doosan; Plug Power; Ballard

ACCOMPLISHMENTS: Integrated Systems Modeling of H_2-Vehicle-Grid Interactions

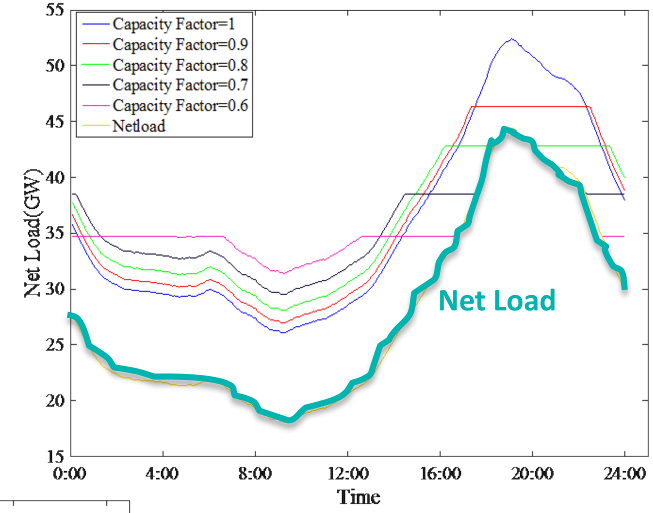
Technical potential for centralized electrolysis to provide grid peak shaving and valley filling support for California in 2025 has been modeled for first time.

WHY?

Optimize operation and capacity of electrolyzer and hydrogen storage at renewable hydrogen stations for:

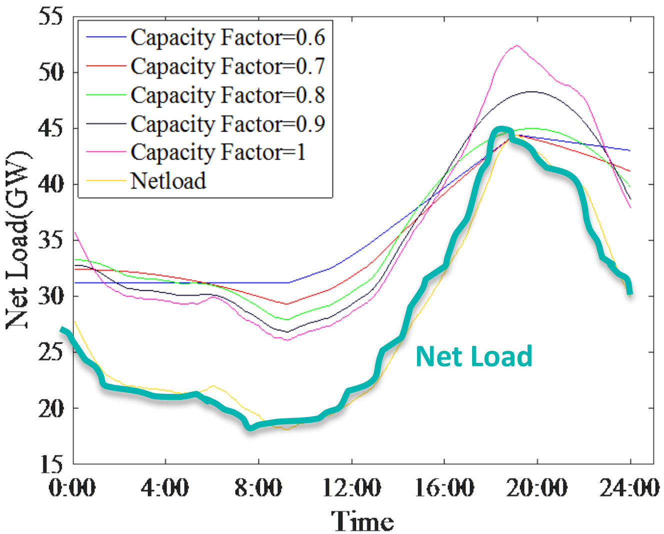
- Demand response
- Vehicle fuel
- Absorbing lower-cost curtailed renewable power

- Valley Filling
- Peak Shaving



KEY ACCOMPLISHMENTS

- ✓ Developed sub-models (individual vehicle; dynamic station; FCEV adoption and H_2 station deployment)
- ✓ Integrated sub-models with hydrogen station models developed by NREL
- ✓ Performed preliminary case studies



Ramping Mitigation

Lead: LBNL
Partners: NREL, INL

TV043

ACCOMPLISHMENTS: Electrolyzers in Real Time Grid Simulation

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

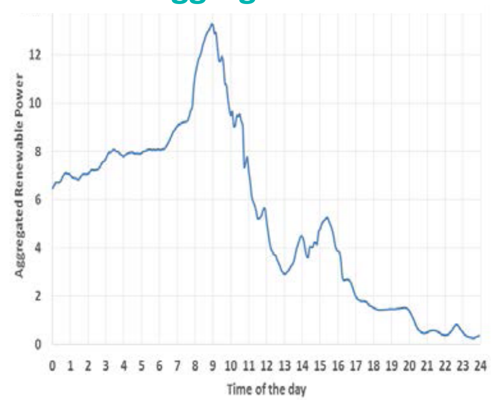
WHY?

Demonstrate fast-reacting performance of electrolyzers; characterize potential and highest economic value of their installation to enable their participation in energy markets and demand response programs

KEY ACCOMPLISHMENTS

- ✓ Completed first of a kind, distributed real-time simulation with PHIL (electrolyzer) between INL and NREL ; 200 hours (FY 2016) and 300 hours (FY 2017) of testing
- ✓ Ensured that electrolyzer stack efficiency and hydrogen quality is acceptable

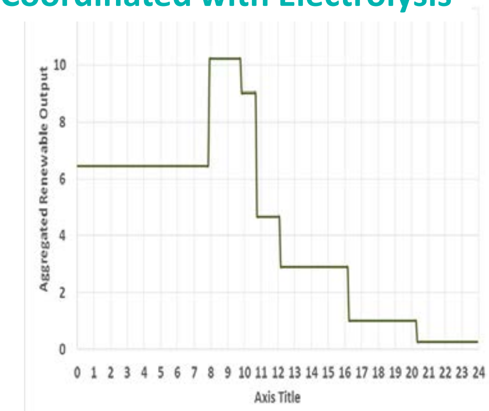
Solar & Wind Power Aggregated



From variable renewables…

to

Renewable Energy Coordinated with Electrolysis



smoother signal to grid…

Improving fidelity of H2@Scale value proposition through detailed analyses of market potential, resources, emissions, economic factors, and regional opportunities and challenges.

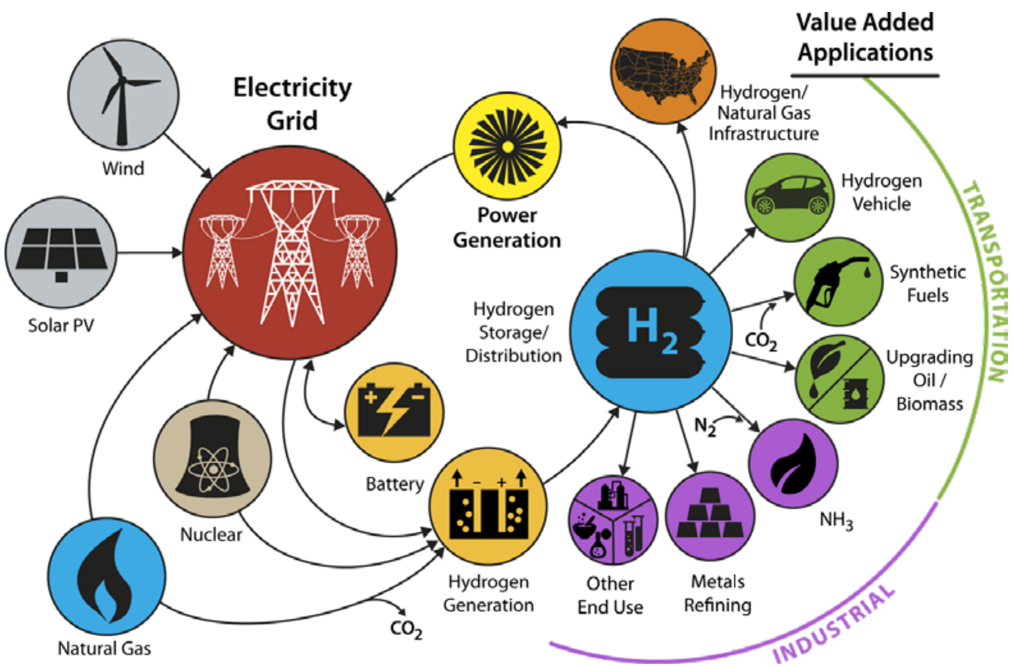
WHY?

Potential for wide-scale hydrogen production and utilization in U.S. that will improve stability of electric grid and economics of baseload power generation, while economically producing hydrogen that can be distributed and used in industrial and transportation applications.

KEY ACCOMPLISHMENTS:

Through initial analysis, determined that:*

- ✓ Hydrogen demand of 60 MMT/yr possible when transportation and industry are considered
- ✓ Resources available to meet that demand
- ✓ Using renewable resources would reduce emissions and fossil use by >15%



* For the U.S., by the year 2040.

Lead: NREL

Partners: ANL, LBNL, PNNL, INL, LLNL, DOE Nuclear Energy Office

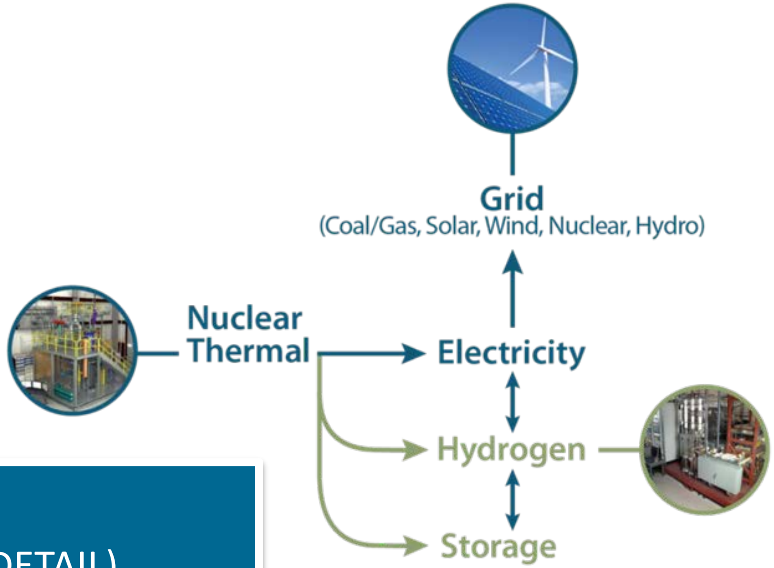
TV045

ACCOMPLISHMENTS:
High-temperature Electrolysis (HTE) Test Stand

Established technical and functional requirements for integrated nuclear-renewable-HTE test bed and developed dynamic nuclear-HTE process model.

WHY?

- Exploits thermal energy sources with higher thermodynamic efficiency
- Provides flexible operation of nuclear power plants as load-following plants that switch to hydrogen production based on market signals
- Provides large-scale energy storage based on diurnal and seasonal electricity demand



KEY ACCOMPLISHMENTS

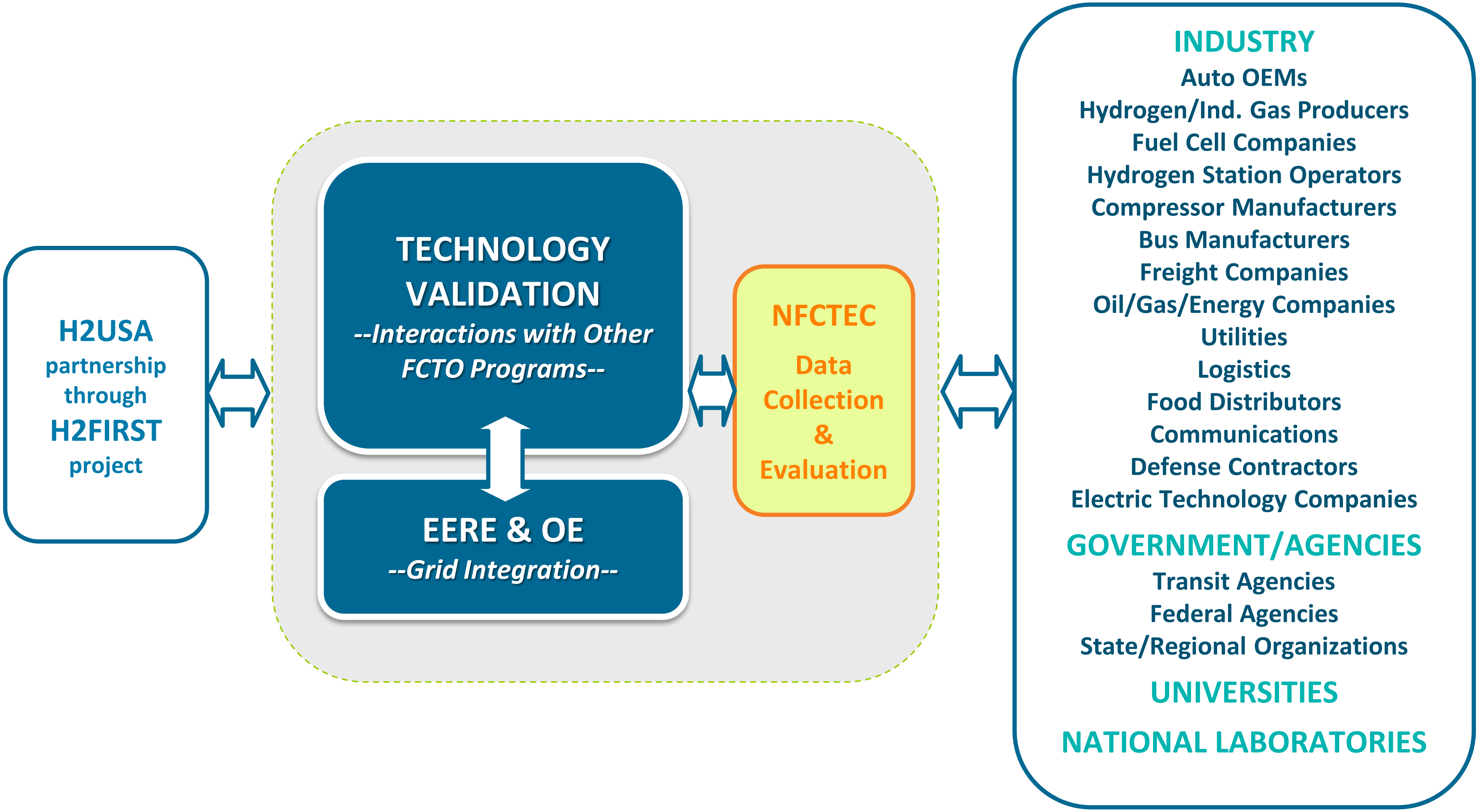
Establishing an integrated nuclear-renewable-HTE test bed (DETAIL)

- ✓ Engineering design ongoing
- ✓ Renewable micro-grid in place
- ✓ Nuclear reactor emulator and thermal loop under construction
- ✓ HTE test skid work plan completed

Dynamic process model for renewable-nuclear-HTE coupling developed and will be validated

Lead: INL **TV040**
Partners: DOE Nuclear Energy Office, EPRI, utilities, SOEC manufacturers, H_2 suppliers, syngas consumers

Collaborations



Activities are coordinated among various partners.

Summary

VEHICLES

- Fuel cell delivery truck designed, built, and on track for 2017 demonstration
- MD/HD truck targets--demonstrated feasibility for many applications; establishing techno-economic targets
- Fuel cell bus durability is >23,000 hrs; several LDV fuel cell stacks now over 5,600 hours

GRID INTEGRATION/ENERGY STORAGE

- Modeled technical potential for centralized electrolysis to provide grid peak shaving and valley filling support
- Created open-source tool to foster growth in fuel cell-integrated buildings with emphasis on optimal dispatch control
- Connected real-time grid simulator at INL with electrolyzer testbed at NREL to test capabilities to absorb curtailed renewable energy

INFRASTRUCTURE & H2@Scale

- Testing accuracy and providing feedback to H_2 flow meter manufacturers
- Tube cutting and cleaning processes shown to have substantial contamination effects at H_2 stations
- Demonstrated performance characteristics and benefits of liquid hydrogen pump
- Design completed for fully functional hydrogen fueling station on wheels; ready to begin construction
- Improving fidelity of H2@Scale value proposition through detailed analyses

Contacts

Jason Marcinkoski – Team Lead
202-586-7466
Jason.Marcinkoski@ee.doe.gov

Jim Alkire *Golden Office* 720-356-1426 James.Alkire@ee.doe.gov	**Shaun Onorato** *Contractor Support* 720-356-1309 Shaun.Onorato@ee.doe.gov
Elvin Yuzugullu *Contractor Support* 202-586-9583 Elvin.Yuzugullu@ee.doe.gov	**James Kast** *Fellow* 202-586-8477 James.Kast@ee.doe.gov

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