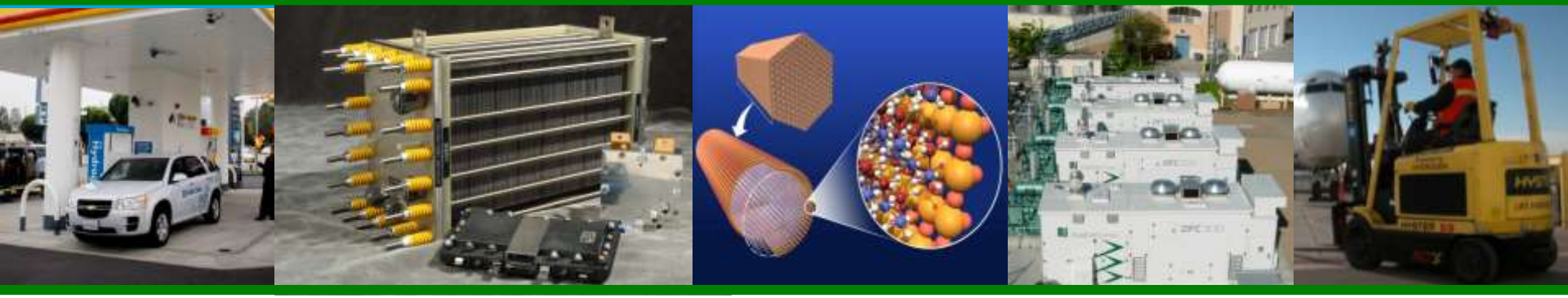
U.S. DEPARTMENT OF ENERGY



2016 NELHA Energy Storage Conference

Fuel Cell Transportation and Energy Storage

Pete Devlin

DOE Fuel Cell Technologies Office

September 13, 2016

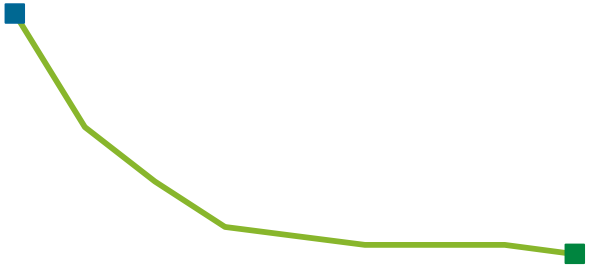
DOE Activities Span from R&D to Deployment

1. Research & Development

Fuel Cells

- Cut cost in half since 2007
- 5X less platinum
- 4X increase in durability

$106/kW in 2007



$53/kW in 2015 at high volume*

*$280/kW low volume

2. Demonstration

Forklifts, back-up power, airport cargo trucks, parcel delivery vans, marine APUs, buses, mobile lighting, refuse trucks

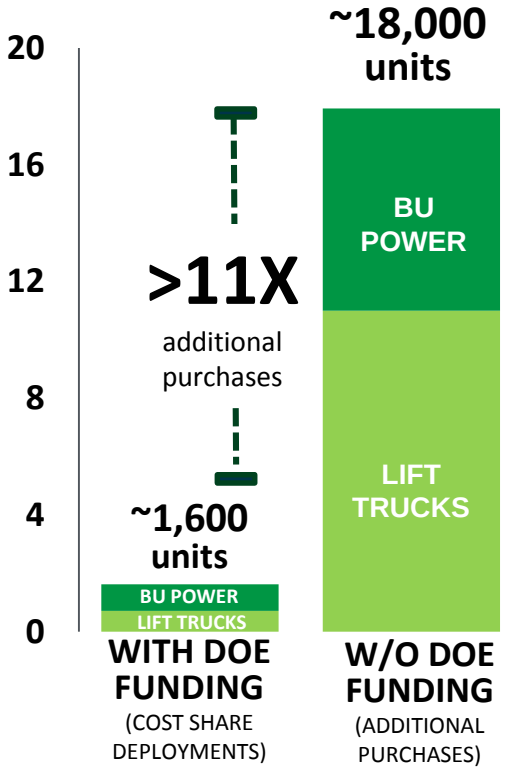
>220 FCEVs, >30 stations, >6M miles traveled

World's first tri-gen station

H_2 technology station in Washington D.C.

FCEV: Fuel Cell Electric Vehicle

3. Deployment



BU: Back Up Power

Examples of consortia supporting R&D

- Fuel Cell Performance & Durability
- Advanced H_2 Storage Materials
- PGM-Free Catalysts for Fuel Cells
- Renewable H_2 Production

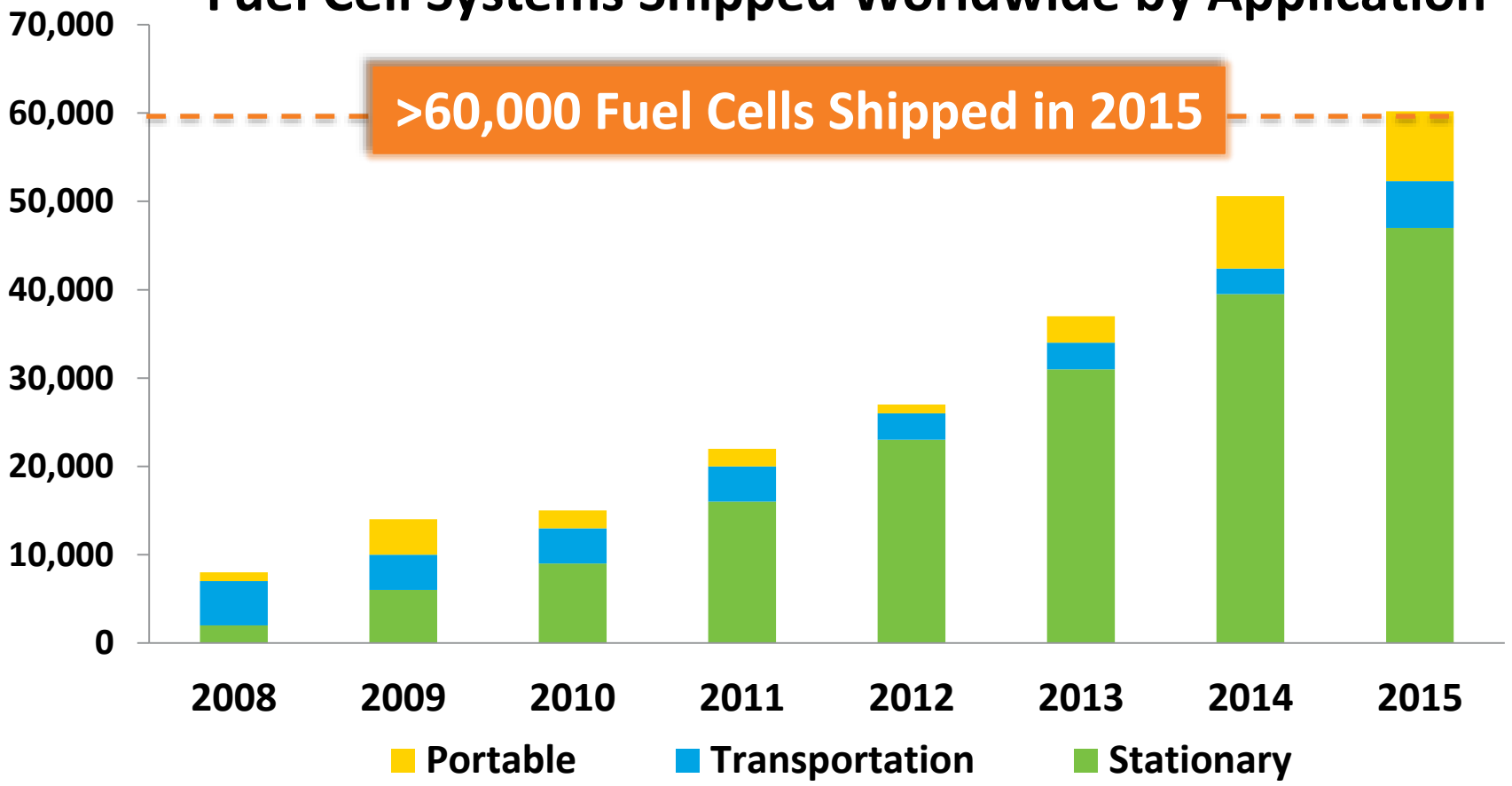
Supporting Deployment

H_2 USA

Collaboration to address H_2 Infrastructure Barriers

Market Growth in Fuel Cell Sales

Fuel Cell Systems Shipped Worldwide by Application



Capacity shipped **in 2015** → Approximately **300 MW** & **~2X** → the capacity **in 2014**

Source: Navigant Research (2008-2013) & E4tech (2014-2015)

Consistent ~30% annual growth since 2010

Fuel Cells: Big Leaps in the Last Year


Hyundai Tucson Fuel Cell SUV


Toyota Mirai


Honda FCV

Commercial FCEVs are here **today!**

FCEV: Fuel Cell Electric Vehicle

H_2USA: Public-Private Partnership

H_2USA

Partners

~ 45 Partners

Mission

To address hurdles to **establishing hydrogen fueling infrastructure**, enabling the **large scale adoption of fuel cell electric vehicles**

Structure

4 Working Groups coordinated by the **Operations** Steering Committee

H_2FIRST Coordination panel

H_2FIRST

H_2USA's Working Groups

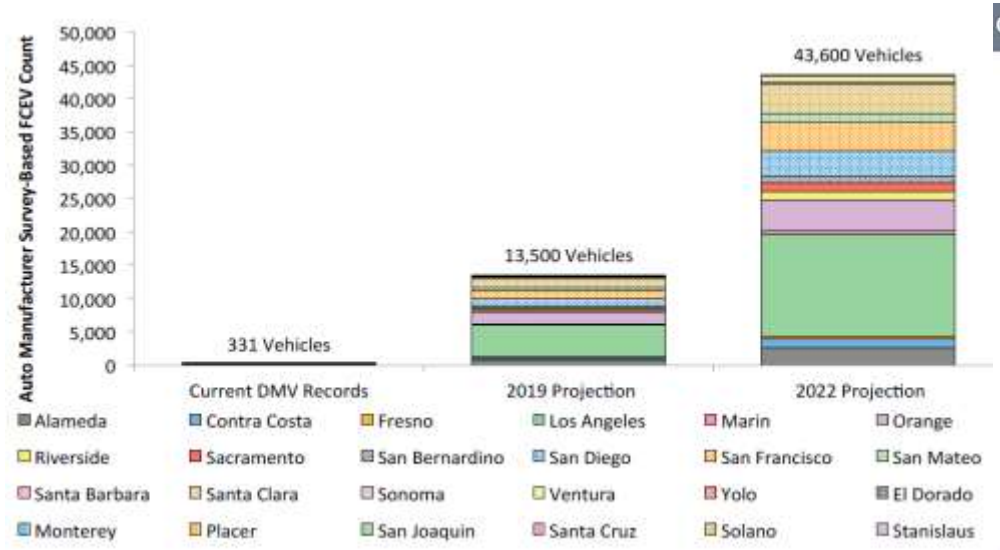
- **Hydrogen Fueling Station**
- **Locations Roadmap**
- **Financing Infrastructure**
- **Market Support & Acceleration**

More than 45 partners working towards adoption of FCEVs and H_2

LD FCEV Sales Projections

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

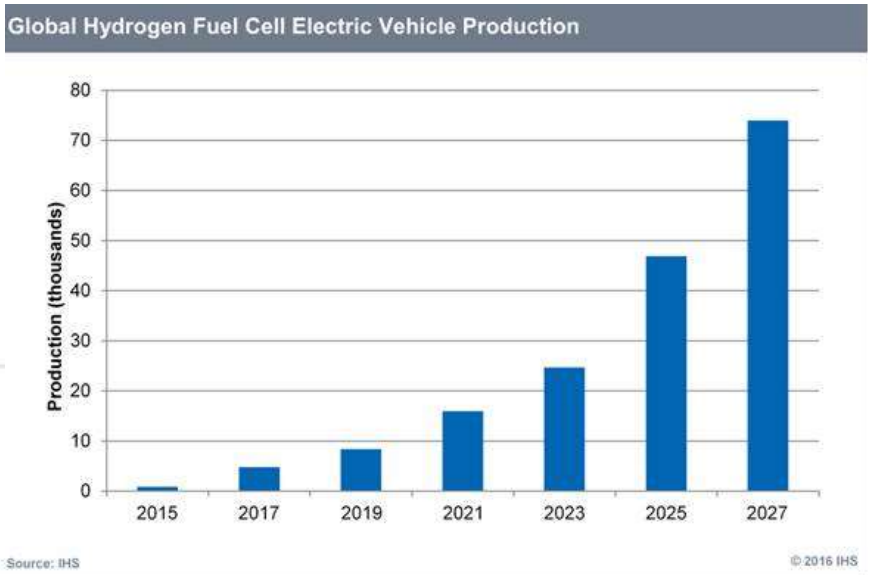
California Cumulative Sales: 2016-2022 *



*** Source: CARB AB8 Report (July 2016)**
https://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2016.pdf

- ✓ Auto OEM survey of estimates of cumulative California FCEV registrations
- ✓ FCEV fleet projected to grow from 331 registered vehicles April 2016 to 13,500 vehicles on the road in 2019 and 43,600 vehicles on the road in 2022
- ✓ FCEV projections based on growth of H2 stations to 90 stations by 2022

World-Wide Annual Sales: 2015-2027 **



**** Source: IHS Automotive (May 2016)** http://press.ihs.com/press-release/automotive/global-hydrogen-fuel-cell-electric-vehicle-market-buoyed-oems-will-launch-1

- ✓ Global FCEV production to grow to more than 70,000 units annually by 2027
- ✓ Commercially available FCEV models to grow from 3 today to 17 by 2027
- ✓ Japan and Korea production leaders through 2020
- ✓ Europe manufacturers to lead production by 2021-2027
- ✓

Fuel Cell Powered Airport Ground Support Equipment Deployment

- ✓ Completed fleet build and commissioning of 15 additional cargo tractors at Memphis Airport (April 2015)
- ✓ Submitted first fleet data set to NREL NFCTEC (October 2015)

NEXT STEPS & MILESTONES

- ❑ Customer acceptance of stack re-design (August 2016: completed)
- ❑ Deliver units with new stacks to Memphis (October 2016)
- ❑ Resume data collection and analysis at NREL NFCTEC (November 2016)
- ❑ Go/No-Go Decision to proceed with 2nd year of operation (December 2016)

Medium-Duty Parcel Delivery Van

Project Team: FedEx (Prime), Plug Power, Workhorse

Project Scope: Demonstrate that fuel cell hybrid drivetrain significantly extends zero-emission driving range vs. battery only

- Phase 1: development phase to build & test prototype
- Phase 2: demo of multi-unit fleets under “real world” operating environments.

Status:

Kick-off meeting May; Vehicle spec and component sizing complete

Next Steps:

- ❑ Complete vehicle design/optimized packaging analysis
- ❑ Complete FAT for fuel cell system at Plug Power
- ❑ Complete build and testing of first prototype vehicle (Dec 2016)

DOE Light-Duty Commercial Van Demo

Northeast Demonstration and Deployment of FC-e-NV200

Project Concept and Teams

- Fuel cell hybrid drivetrain significantly extends zero-emission driving range vs. battery only
- Project Team: US Hybrid (prime), Nissan, ANL, and National Grid (fleet operator)

Project Scope

- Phase 1: development phase to build & test prototype range-extended delivery van
- Phase 2: two-year demo of multi-unit fleets at host site under “real world” operating environments.

Status

- Selection Oct. 8; project kick-off by year-end 2015

Proposed Technical Specifications:

- Nissan e-NV200 base vehicle platform
- 5 kW US Hybrid PC5 fuel cell stack
- 2-3 kg H2 storage @ 700 bar
- 250 miles extended usable range (vs. BEV @ 100 miles)
- 24 kWh lithium-ion battery

Global Landscape: Infrastructure Activities

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Japan

Hydrogen Supply/Utilization Technology (HySUT)

- 18 companies (3 car companies)
- **2016 Status: ~80 stations & >570 FCEVs**
- **Goals: FCEVs 40K by 2020, 200K by 2025, 800K by 2030**
  Stations: 160 by 2020, 320 by 2025, 900 by 2030

Germany

H2Mobility

- Public-private initiative for nationwide H_2 infrastructure
- **2016 Status: >40 stations** (in process) **& >100 FCEVs**
- **Goals: Stations- 100 by 2018-2019 and 400 by 2023**

UK

UKH2Mobility

- **2016 Status: 16 stations and 12 fuel cell buses (FCEBs)**
- **Goals: 65 H_2 Stations by 2020**

Denmark
Norway
Sweden

Scandinavian H2 Highway Partnership (SHHP)

- 2012 MOU with industry and NGOs
- **2016 Status: ~20 stations, >70 FCEVs**
- **45 H_2 stations** and a fleet of **~1K vehicles.**

Korea

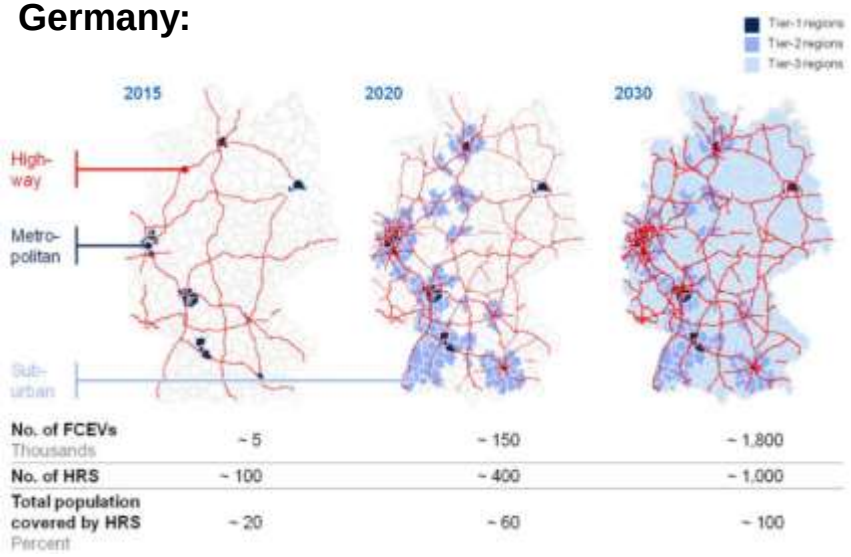
Deployment Activities

- **2016 Status: 10 stations and >47 FCEVs**
- **Goals: 100 stations and 10K FCEVs by 2020**
- **Public transportation** (bus, taxi, etc.) focused initial market deployment

***France also has plans to accelerate hydrogen and FCEV market**

Examples of Plans

Germany:

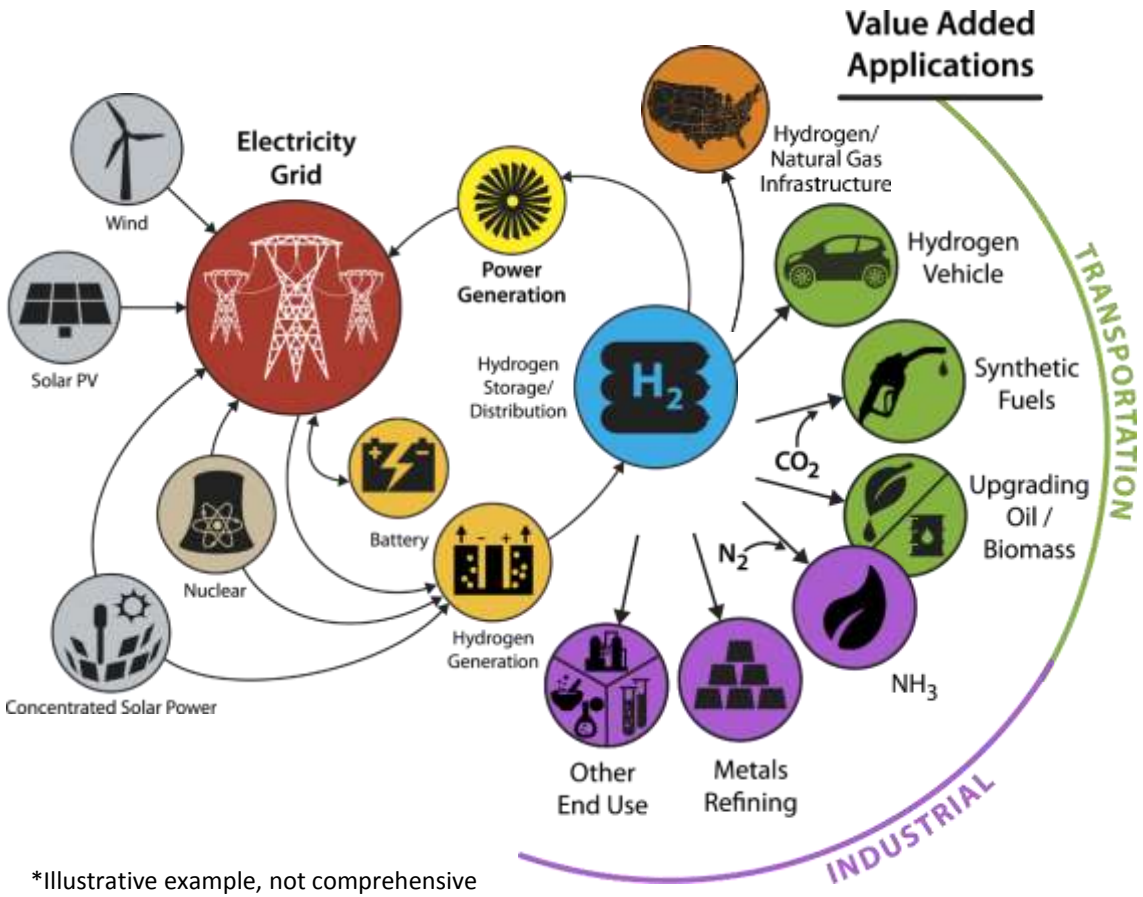


United States

- **California**
  - **~50 H2 stations (~20 public) and >300 FCEVs registered**
  - **Goal: 100 H2 stations, ~$100M** through 2023
- **8-ZEV state MOU**
  - **3.3M ZEVs by 2025 (including FCEVs)**
  - **California, Connecticut, Massachusetts, Maryland, New York, Oregon, Rhode Island, Vermont**

International partnerships established to accelerate hydrogen infrastructure

H_2 as an enabler

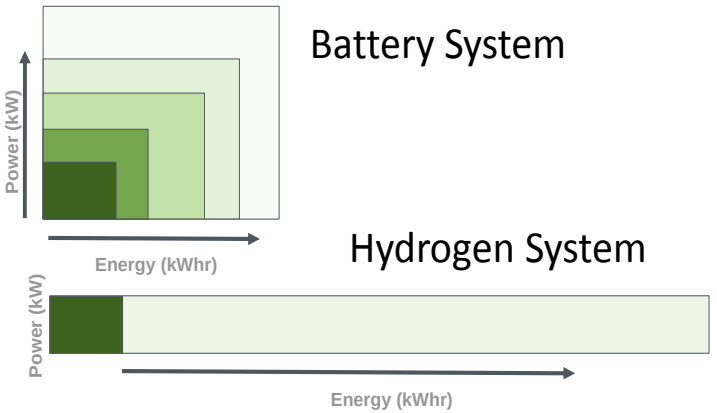


*Illustrative example, not comprehensive
Source: NREL; Lab Big Idea Summit

Potential for:

Approx. **50%** **less GHG emissions** by 2050*

***Preliminary analysis**

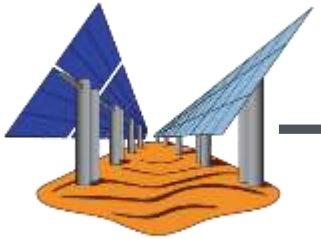


3 H_2 Focus Areas

- Advanced **Generation**
- **Storage and Distribution**
- **End use** and **systems integration**

H_2 for Energy Storage- New DOE Efforts Underway

Wind



Solar

Geothermal

Electricity Grid

Generator

Fuel Cell,
Internal Combustion,
Steam Turbine

Electrolyzer

Ramp–up &
Ramp-down
capability for
Grid stabilization

Natural Gas Infrastructure

Oxygen Storage

Hydrogen Storage

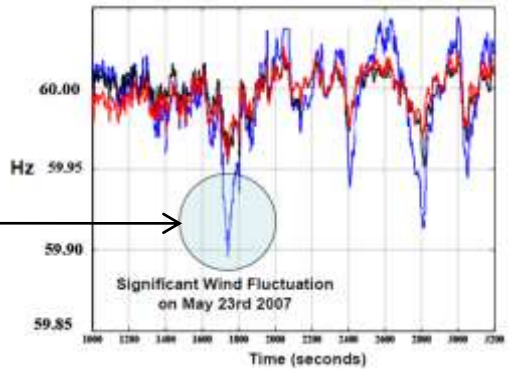
Value Added Applications

- Vehicle Fuel
- Fertilizer NH_3
- Emergency Backup FC

BLK 1 MW /1 minute of H_2 storage

BLUE No H_2 storage

RED 1 MW/∞



Models indicate modest energy storage mitigates negative effects of wind penetration

Adapted from: www.hydrogen.energy.gov/pdfs/review12/mt008_ewan_2012_o.pdf
Hawaii Natural Energy Institute Mitch Ewan, GE Transient PSLF™

Hydrogen may be produced from a variety of renewable resources, and hydrogen-based energy storage could provide value to many applications and markets.

FCEVs and H2 Stations Providing Grid Support

FCEVs providing backup power to grid and renewable hydrogen stations providing grid support.

- Investigate capabilities for FCEVs to provide backup power to buildings
  - Requirements and costs
  - Extent these capabilities may be utilized
  - Benefits (e.g. reduced non-spinning reserves)
  - Sensitivity to increasing adoption of FCEVs
- Investigate capability for renewable hydrogen stations to provide grid support
  - Determine quantity of hydrogen to meet vehicle needs while providing grid services
  - Investigate available capacity throughout day for offering grid services (driving/fueling behavior)
  - Sensitivity to increasing adoption of FCEVs (increasing utilization of capacity for vehicle fuel, growing number of stations providing services)

Toyota Mirai FCEV—connection to grid

CSULA: PV-electrolysis-based hydrogen station

Vision of the Future

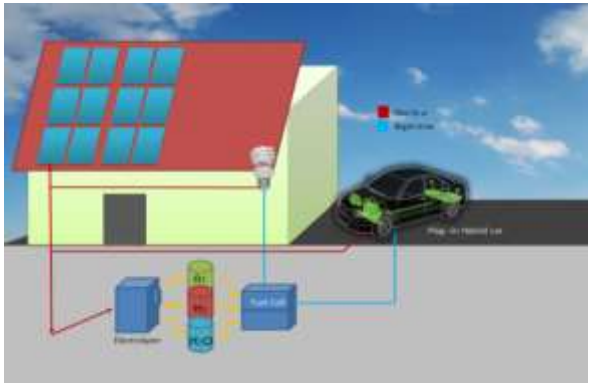
Roads…

…with FCEVs, BEVs and plug-in hybrids

On Water…

…APUs and port-based energy hubs

Homes…



… with recharging hubs at night and powered by clean energy during the day

On Air…

H_2 & biofuels…aircraft APUs & at airports

Thank You

Pete Devlin

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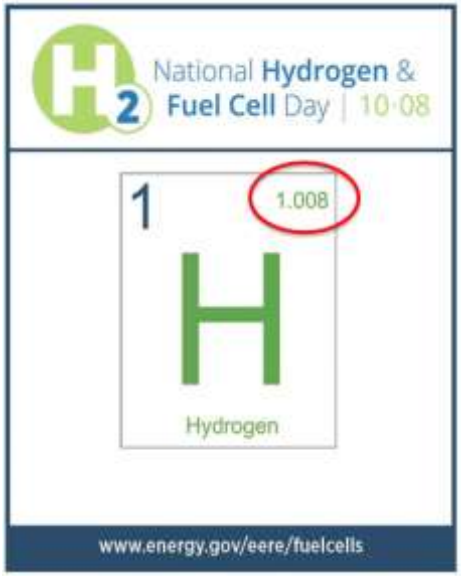

Save the Date: June 5- 9 2017 Washington DC

Annual Merit Review and Peer Evaluation Meeting