DOE's Hydrogen Fuel Cell Activities: Developing Technology and Validating it through Real-World Evaluation

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Alternative Fuels & Vehicles Conference
Las Vegas, NV
May 12, 2008

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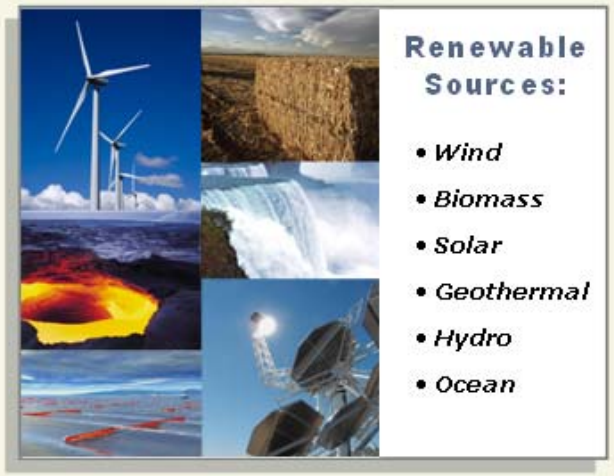
This presentation does not contain any proprietary or confidential information

Why Hydrogen?

- *Diverse Domestic Resources*
- *High Efficiency & Reliability*
- *Zero / Near-zero Emissions*



Renewable Sources:

- *Wind*
- *Biomass*
- *Solar*
- *Geothermal*
- *Hydro*
- *Ocean*

Non-Renewable Sources:

- *Nuclear*
- *Coal* (*with carbon sequestration*)
- *Natural Gas* (*for transition period only*)

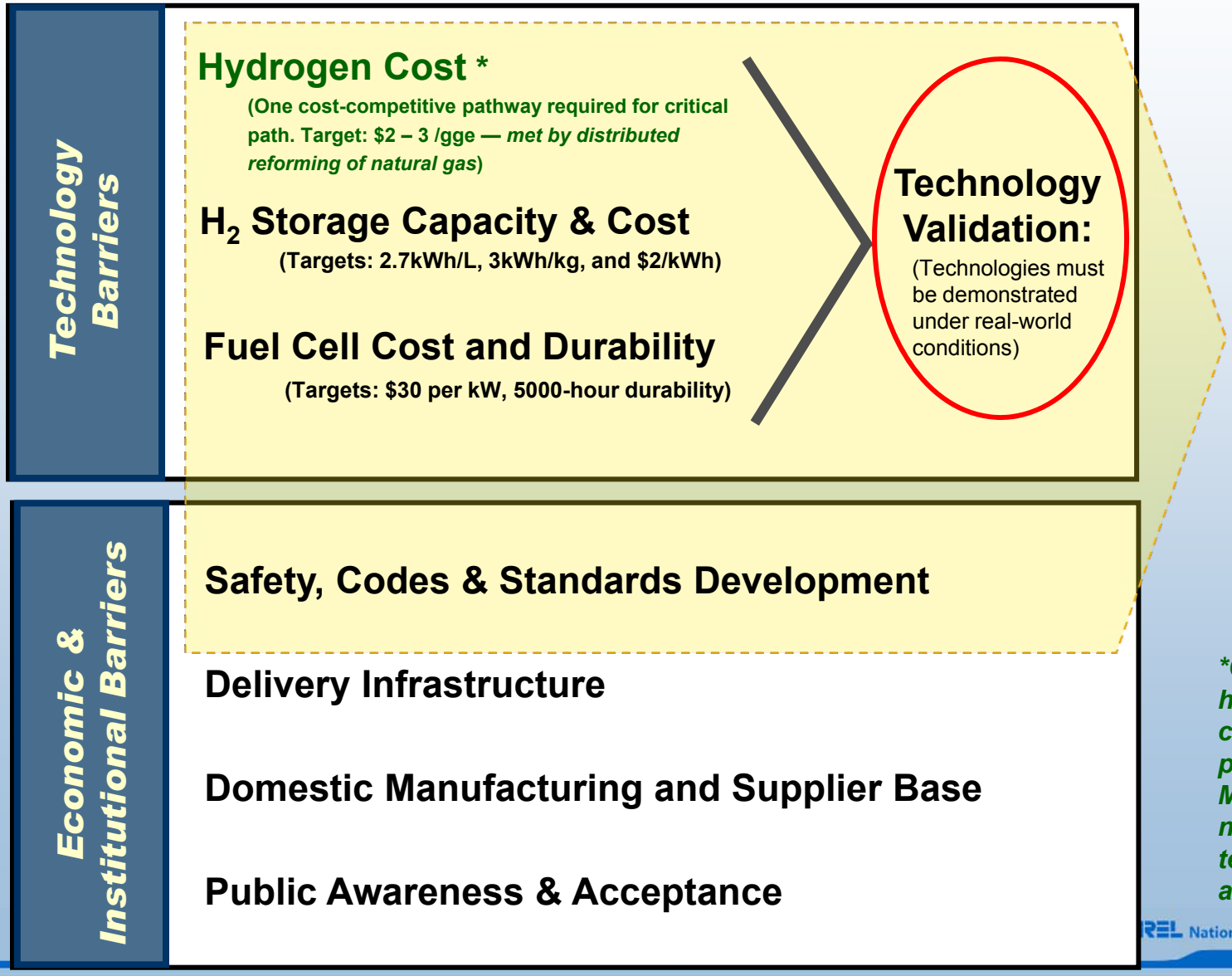
H_2

Stationary/ Backup Power

Transportation

Specialty Markets

Vehicular Hydrogen Challenges and Barriers



Critical Path Barriers for Fuel Cell Vehicle Technology Readiness in 2015

Critical Path for hydrogen cost is one cost-competitive production pathway. Multiple pathways are needed for longer-term energy security and sustainability.

Fuel Cell Vehicle Learning Demonstration Seeks to Validate Real-World Progress

- Objectives
  - Validate H_2 FC Vehicles and Infrastructure in Parallel
  - Identify Current Status and Evolution of the Technology
    - Assess Progress Toward Technology Readiness
    - Provide Feedback to H_2 Research and Development

Key Targets

Performance Measure	2009	2015
Fuel Cell Stack Durability	2000 hours	5000 hours
Vehicle Range	250+ miles	300+ miles
Hydrogen Cost at Station	$3/gge	$2-3/gge

Photo: NREL

Industry Partners: 4 Automaker/Energy-Supplier Teams; Rollout: 2nd Generation FC Introduction in 2008 Has Begun

CHRYSLER

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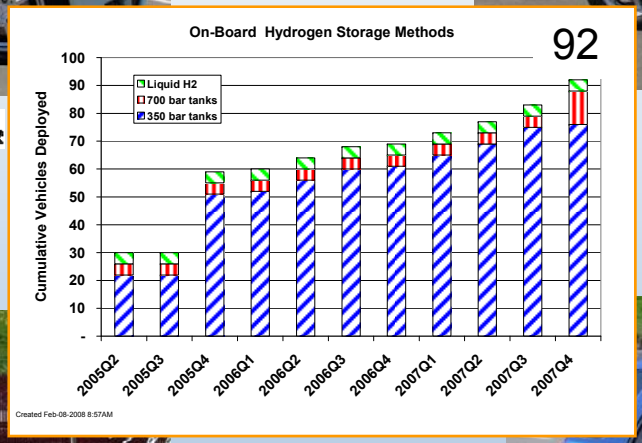

Ford

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GM

>1.1 Million Miles and 50,000 Vehicle Hours

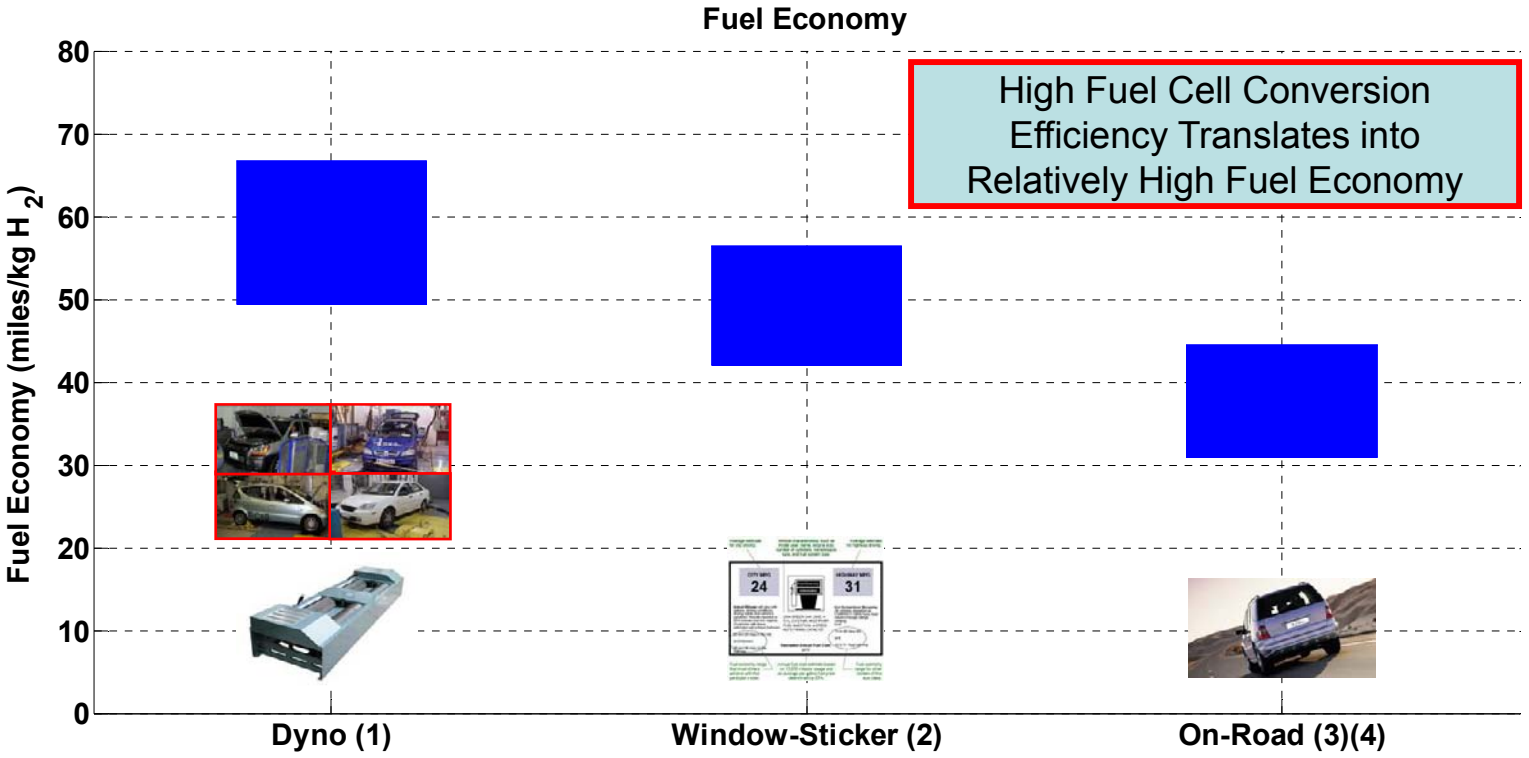
Chevron

HYUNDAI

KIA

UTC Power
A United Technologies Company

Dynamometer and On-Road Fuel Economy from Gen 1 Learning Demonstration Vehicles



(1) One data point for each make/model. Combined City/Hwy fuel economy per DRAFT SAE J2572.

(2) Adjusted combined City/Hwy fuel economy (0.78 x Hwy, 0.9 x City).

(3) Excludes trips < 1 mile. One data point for on-road fleet average of each make/model.

(4) Calculated from on-road fuel cell stack current or mass flow readings.

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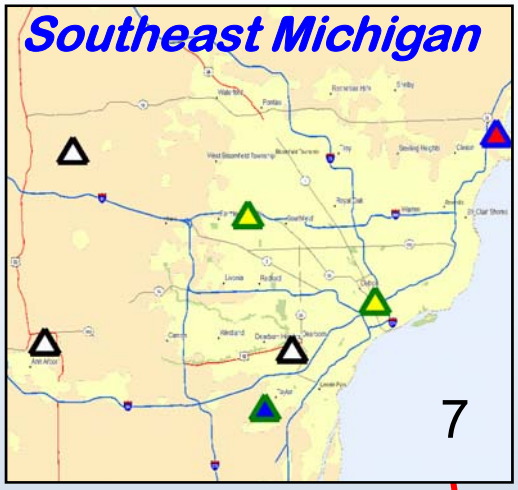
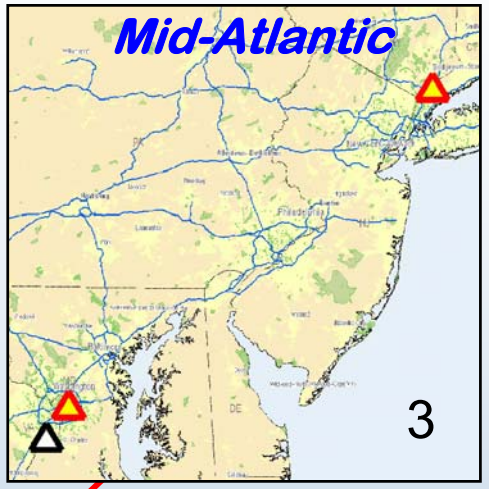
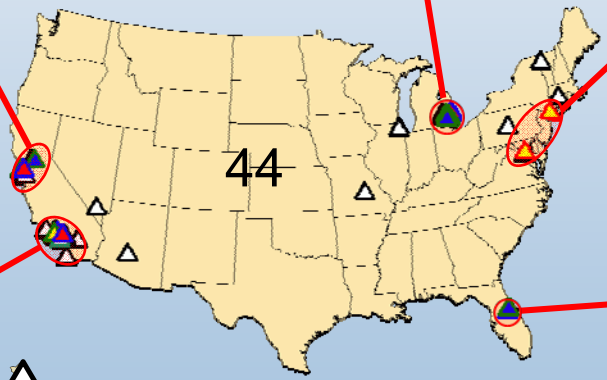
Refueling Stations Test Performance in Various Climates; Learning Demo Comprises ~1/3 of all US Stations





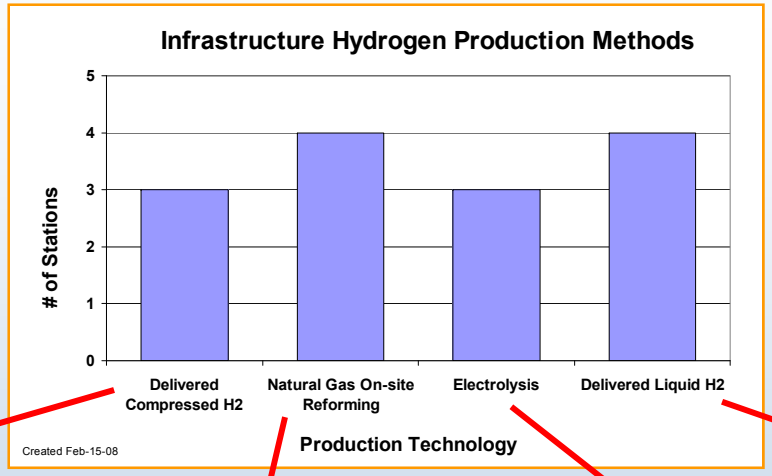


Legend

- Chevron & Hyundai/Kia
- DaimlerChrysler & BP
- Ford & BP
- General Motors & Shell
- Air Products
- Other Companies

Majority of Project's Fixed Infrastructure to Refuel Vehicles Has Been Installed – Examples of 4 Types

Mobile Refueler
Sacramento, CA



Delivered Liquid, 700 bar
Irvine, CA

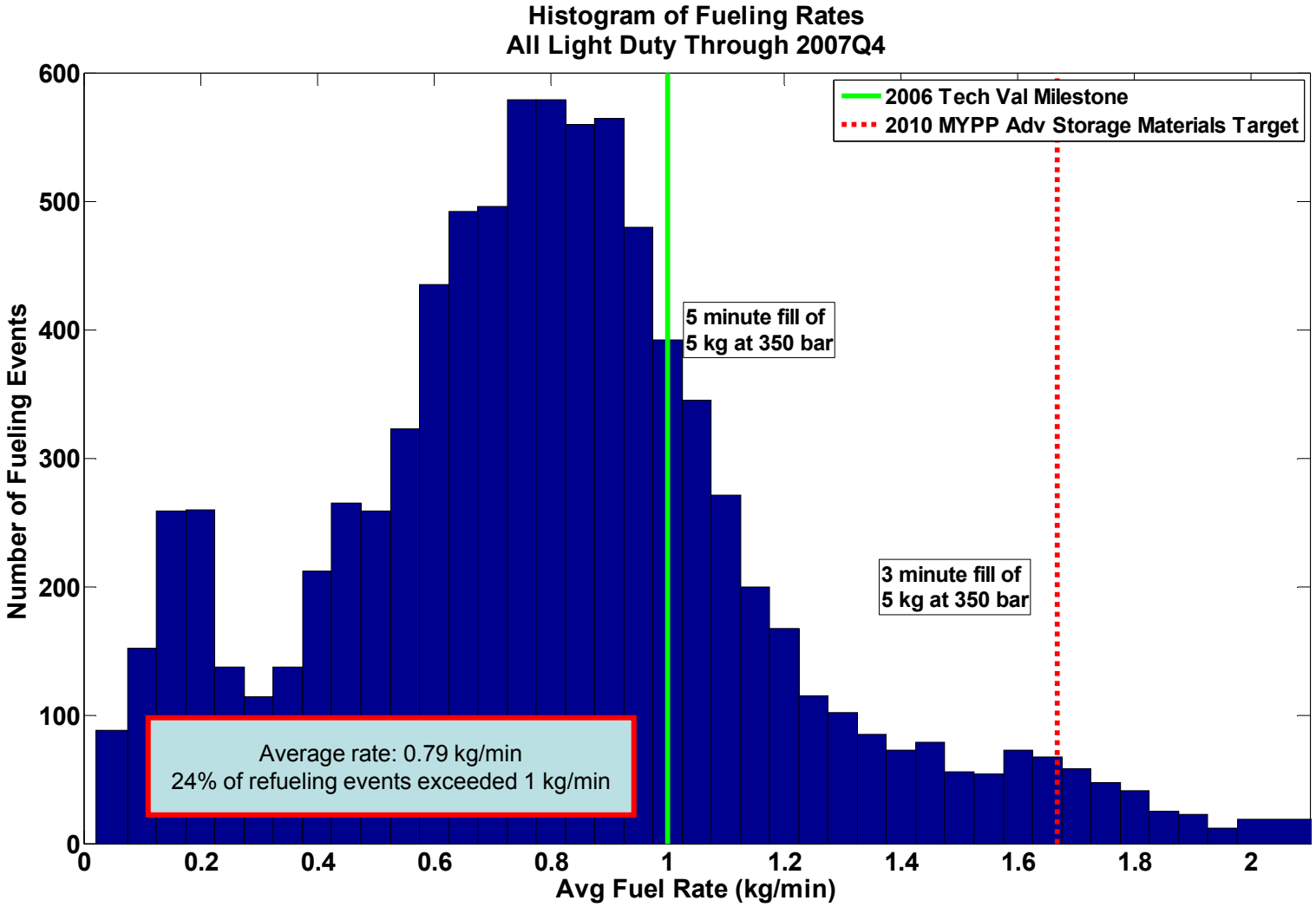
Steam Methane Reforming
Oakland, CA

Water Electrolysis
Rosemead, CA

Total of >40,000 kg H2 produced or dispensed

Recent station additions include:
SMUD (BP) and White Plains, NY (Shell).
15 stations now deployed

Actual Vehicle Refueling Rates from >8,700 Events: Measured by Stations or by Vehicles



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Hydrogen Production Progress

GOAL: *Diverse cost-competitive domestic pathways to hydrogen production*

PROGRESS: *Significant cost reductions have been achieved*

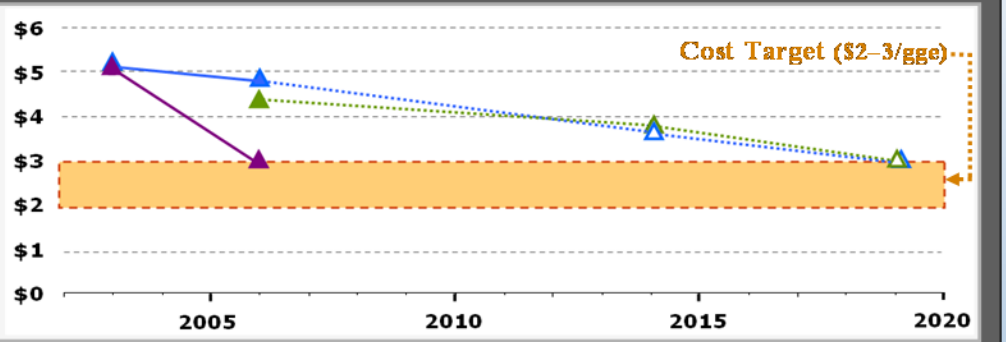
Cost of Hydrogen (Delivered) — Status & Targets

(in $/gallon gasoline equivalent (gge), untaxed)

NEAR TERM: **Distributed Production**

→ *Hydrogen is produced at station to enable low-cost delivery*

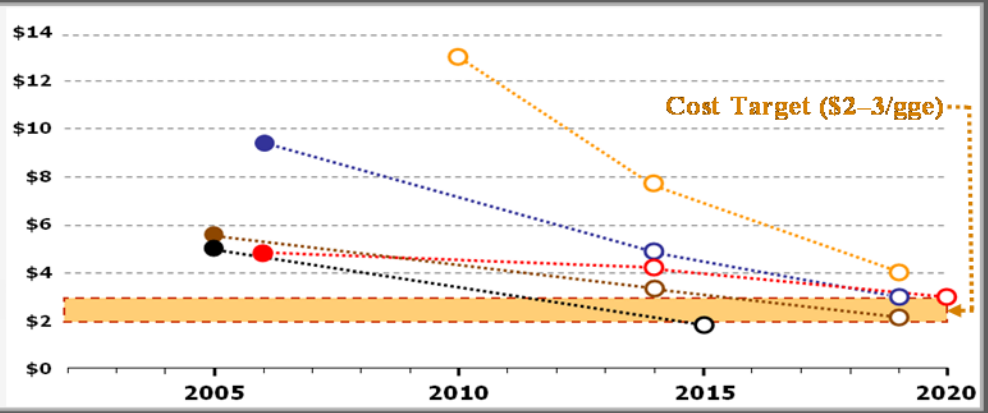
- Distributed Natural Gas
- Distributed Electrolysis
- Distributed Bio-Derived Renewable Liquids



LONGER TERM: **Centralized Production**

→ *Large investment in delivery infrastructure needed*

- Biomass Gasification
- Coal Gasification with Sequestration
- Solar High-Temperature Thermochemical Cycle
- Central Wind Electrolysis
- Nuclear



Examples of Renewable Pathways for Electricity and Vehicular Fuel Demonstrated

Four Renewable Fuel/Power Demonstration Projects

Hydrogen for Vehicles from On-Site Solar and Water Electrolysis *(ongoing)*

DTE: Southfield, Michigan

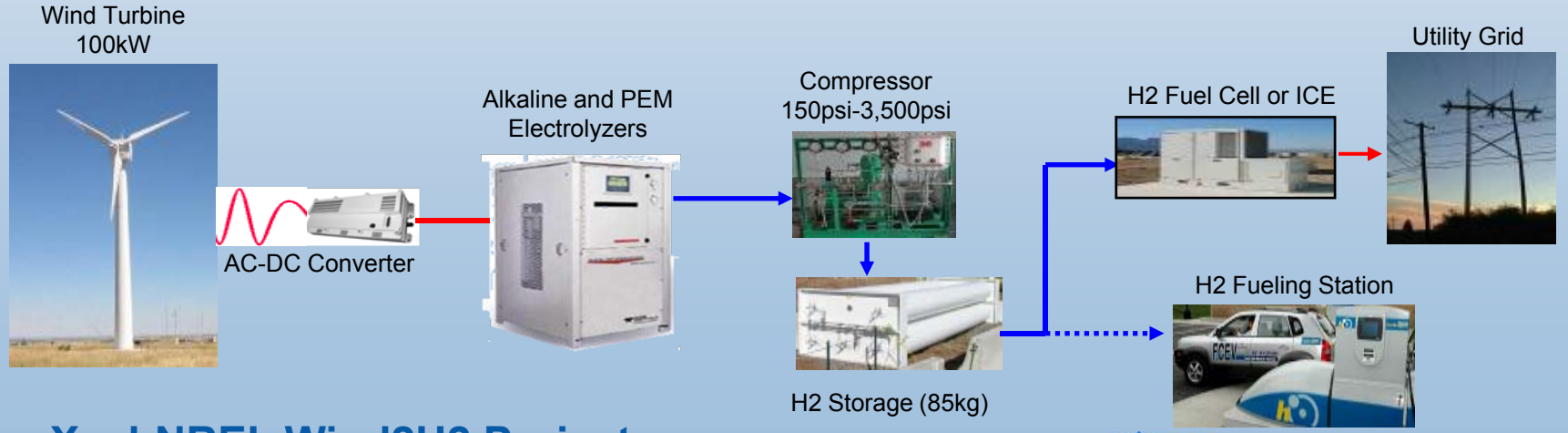
SMUD: Sacramento, CA

Xcel/NREL Wind/Hydrogen Project *(ongoing, shown below)*

Integrates electrolyzers and wind turbines to understand the benefits and impacts of adding hydrogen production facilities to the electric power grid (NREL wind site at Golden, Colorado)

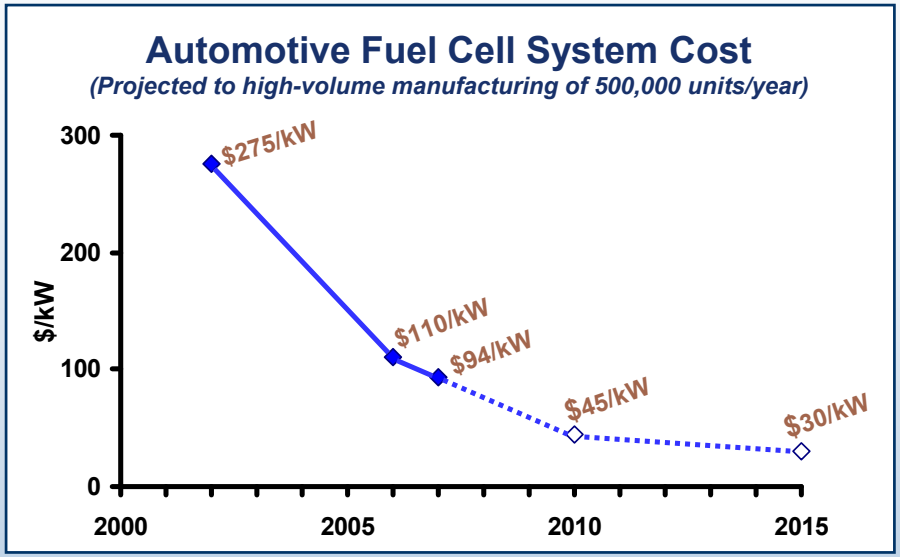
Hawaii *(planned)*

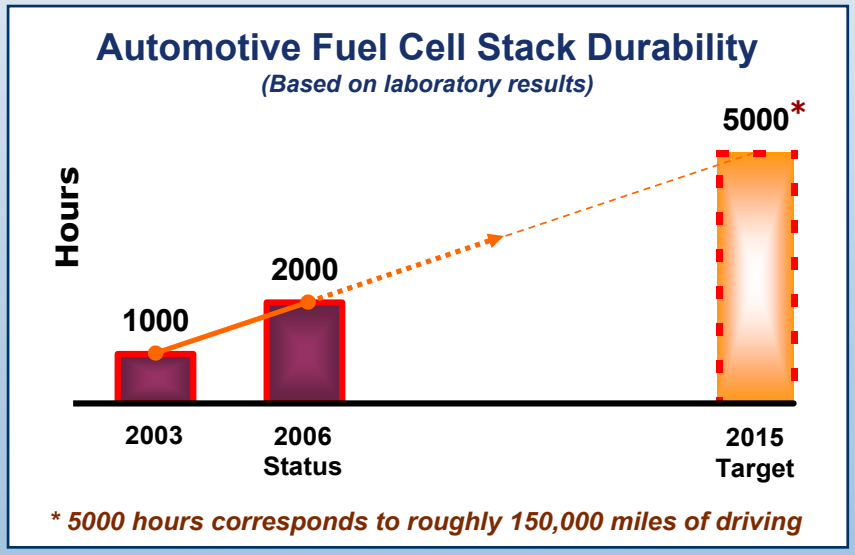
Hydrogen production using curtailed wind and geothermal energy to generate electricity and to fuel hydrogen buses at national parks



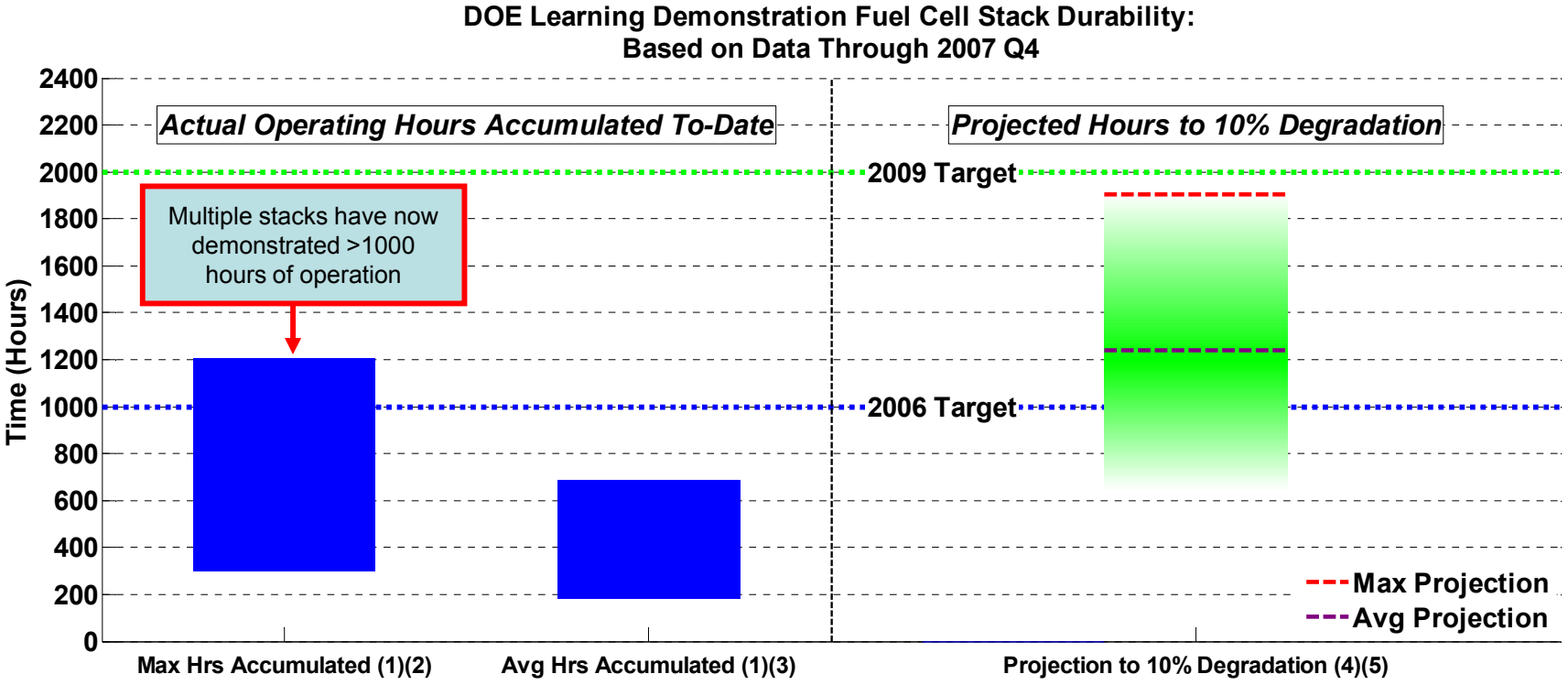
Xcel-NREL Wind2H2 Project

Automotive Fuel Cells Progress:
Projected Cost (at Volume) and Laboratory Durability





In Real-World Operation, Some First Generation Vehicles Have Met 2006 Target of 1,000 Hours



(1) Range bars created using one data point for each OEM.
(2) Range (highest and lowest) of the maximum operating hours accumulated to-date of any OEM's individual stack in "real-world" operation.
(3) Range (highest and lowest) of the average operating hours accumulated to-date of all stacks in each OEM's fleet.
(4) Projection using on-road data -- degradation calculated at high stack current. This criterion is used for assessing progress against DOE targets, may differ from OEM's end-of-life criterion, and does not address "catastrophic" failure modes, such as membrane failure.
(5) Using one nominal projection per OEM: "Max Projection" = highest nominal projection, "Avg Projection" = average nominal projection. The shaded green bar represents an engineering judgment of the uncertainty due to data and methodology limitations. Projections will change as additional data are accumulated.

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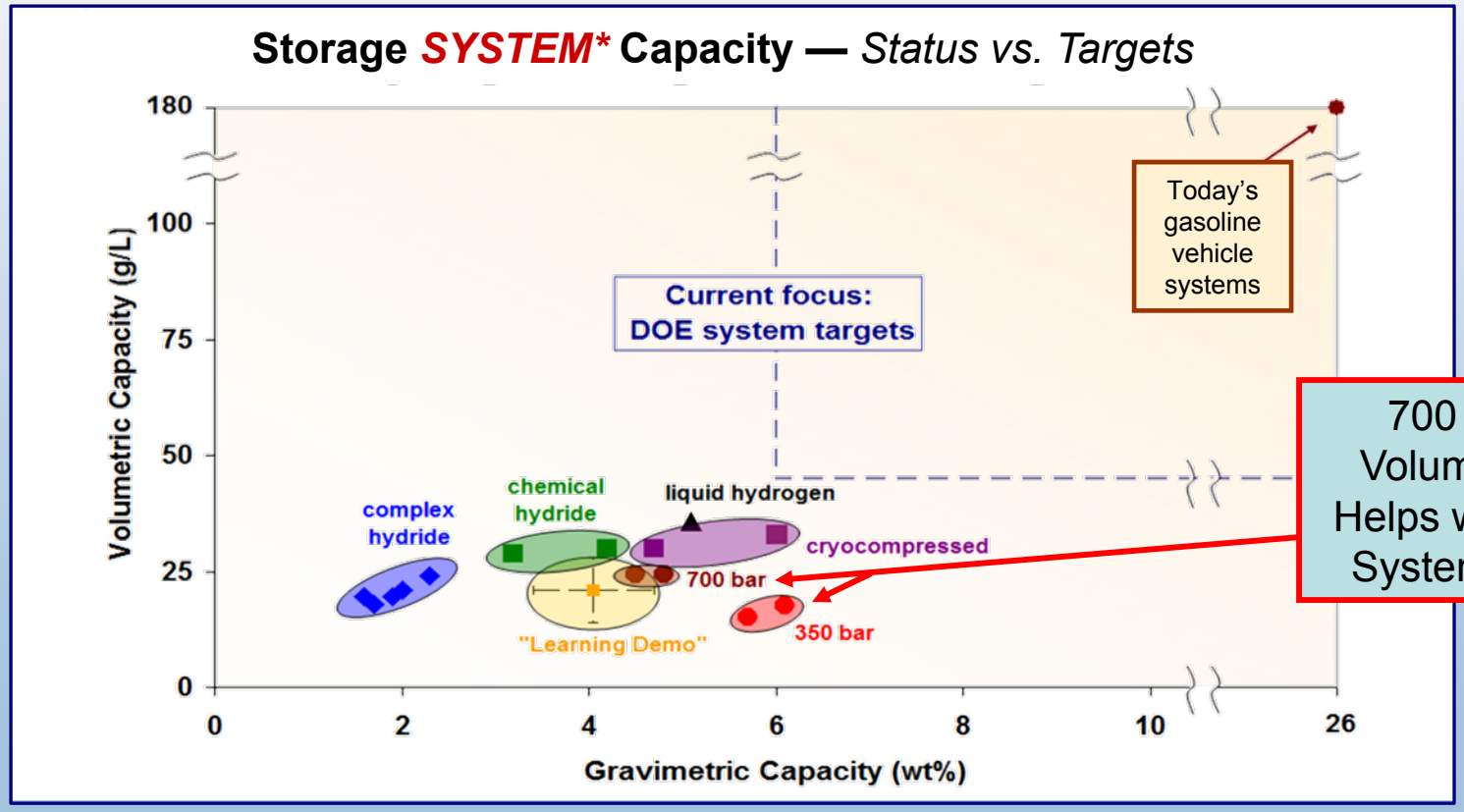
Hydrogen Storage Progress: Current Products and Advanced Technology

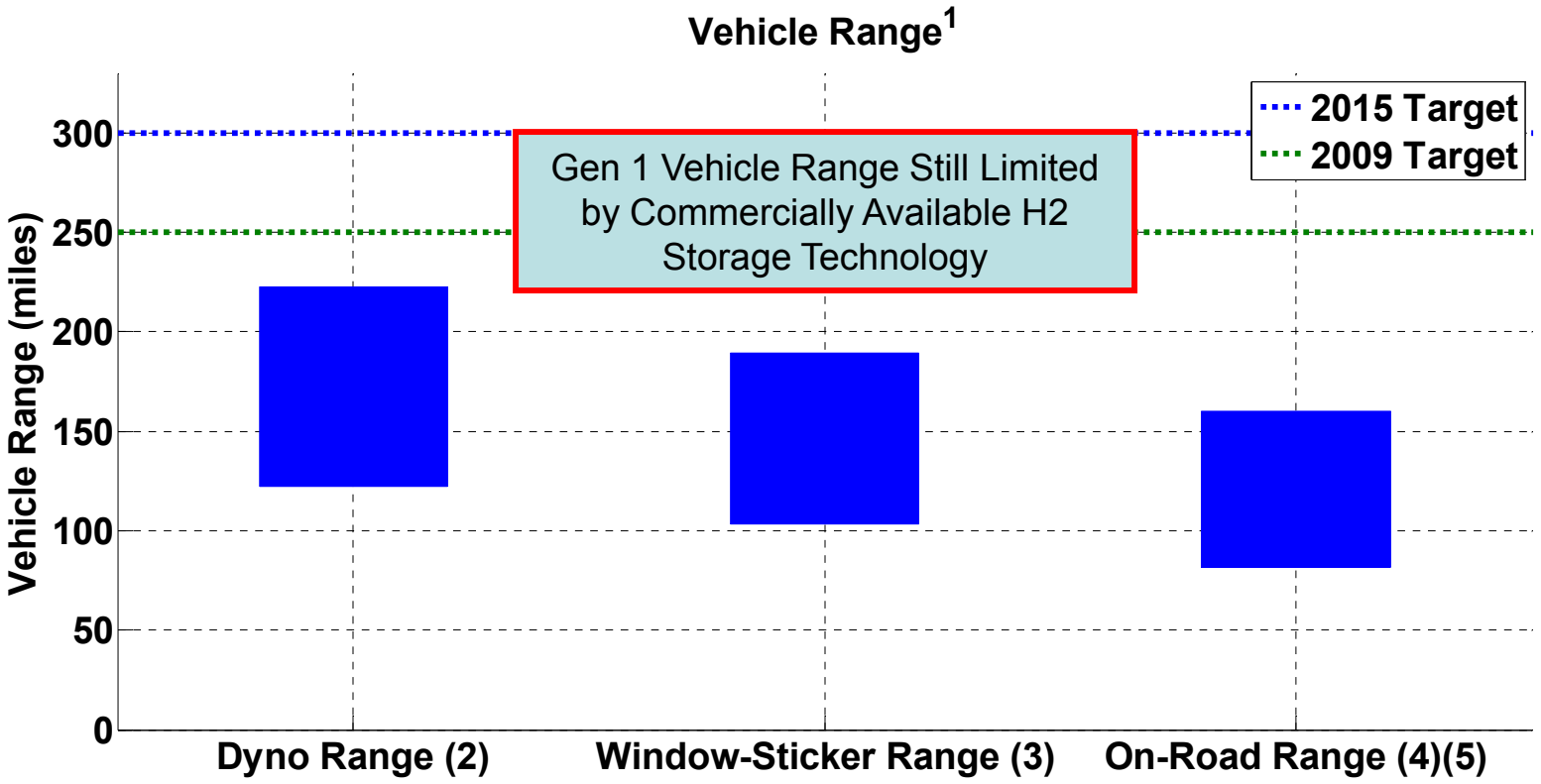
GOAL: *On board storage with > 300-mile driving range (meeting req. for safety, cost, performance)*

PROGRESS: *The Program has identified materials with > 50% improvement in capacity since 2004*



** System capacity estimates include materials, tanks, and balance of plant*

Current Status of Range from Gen 1 FCVs



(1) Range is based on fuel economy and usable hydrogen on-board the vehicle. One data point for each make/model.
(2) Fuel economy from unadjusted combined City/Hwy per DRAFT SAE J2572.
(3) Fuel economy from EPA Adjusted combined City/Hwy (0.78 x Hwy, 0.9 x City).
(4) Excludes trips < 1 mile. One data point for on-road fleet average of each make/model.
(5) Fuel economy calculated from on-road fuel cell stack current or mass flow readings.

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Evaluation of Hydrogen and Fuel Cell Buses in Five Fleets

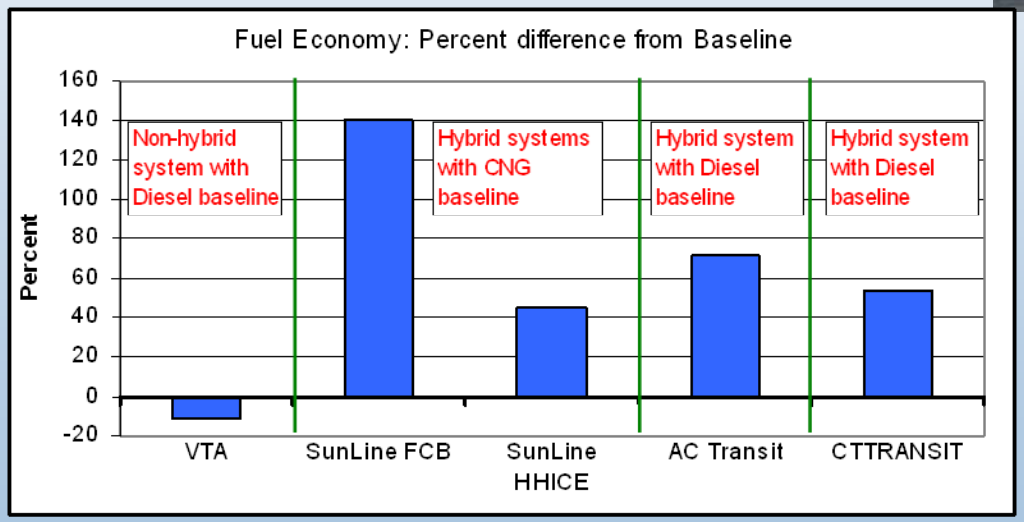
Santa Clara VTA, San Jose, CA

SunLine, Thousand Palms, CA

AC Transit, Oakland, CA

CTTRANSIT, Hartford, CT

Hickam AFB, Honolulu, HI

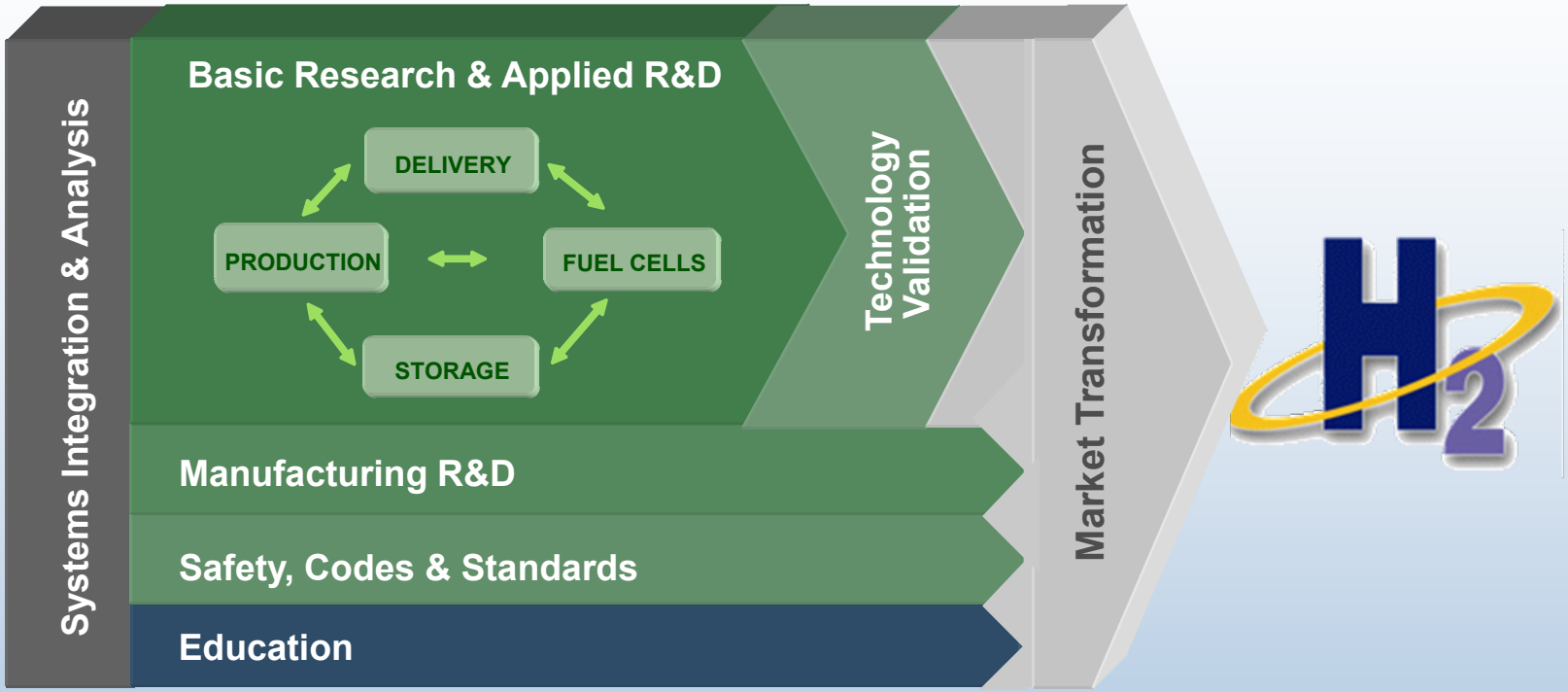


Fuel economy is highly dependent on duty-cycle and hybridization, but shows improvement approaching 2X

Summary

- Program continues to advance the state-of-the-art in fuel cell and hydrogen production technology through an R&D portfolio in collaboration with industry
  - Projected FC system costs at volume production are coming down; currently at ~3X target
  - Hydrogen production pathway from distributed natural gas reforming economically viable for near-term
  - Multiple H2 production pathways including renewables are needed for longer-term energy security and sustainability.
- Program is simultaneously validating real-world performance to ensure robust progress
  - 92 FCVs and 15 stations deployed
  - 1.1 million miles traveled, 40,000 kg H_2 produced or dispensed
  - Project to continue through 2010
  - Total of 47 composite data products published to date
  - FC buses and forklifts also being evaluated
  - Roll-out of 2nd generation FCVs has begun

Questions and Discussion



Project Contact: Keith Wipke, National Renewable Energy Lab
303.275.4451 keith_wipke@nrel.gov

All public Learning Demo CDPs, papers, and presentations are available online at http://www.nrel.gov/hydrogen/proj_tech_validation.html