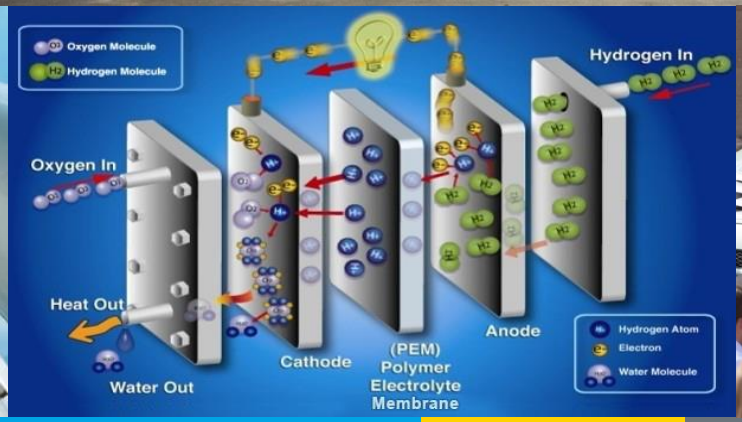
U.S. Department of Energy Hydrogen and Fuel Cells Program

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



DOE Activities and Progress in Fuel Cells and H_2

Washington, DC

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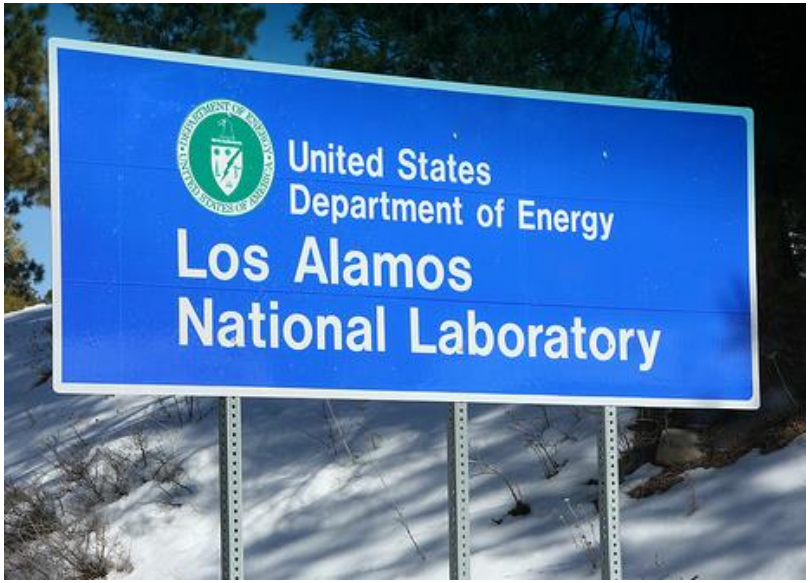
Dr. Sunita Satyapal

Director
Fuel Cell Technologies Office
U.S. Department of Energy

The beginning of the DOE Fuel Cell Program…

1970s



Labs, industry and gov't set the foundation for DOE fuel cell programs in the mid 1970s.

Lab researchers taught scientists around the world how to make fuel cells. GM relocated their fuel cell group to Los Alamos.

Recent Emphasis through EPACT 2005

Energy Policy Act of 2005 (Title VIII)

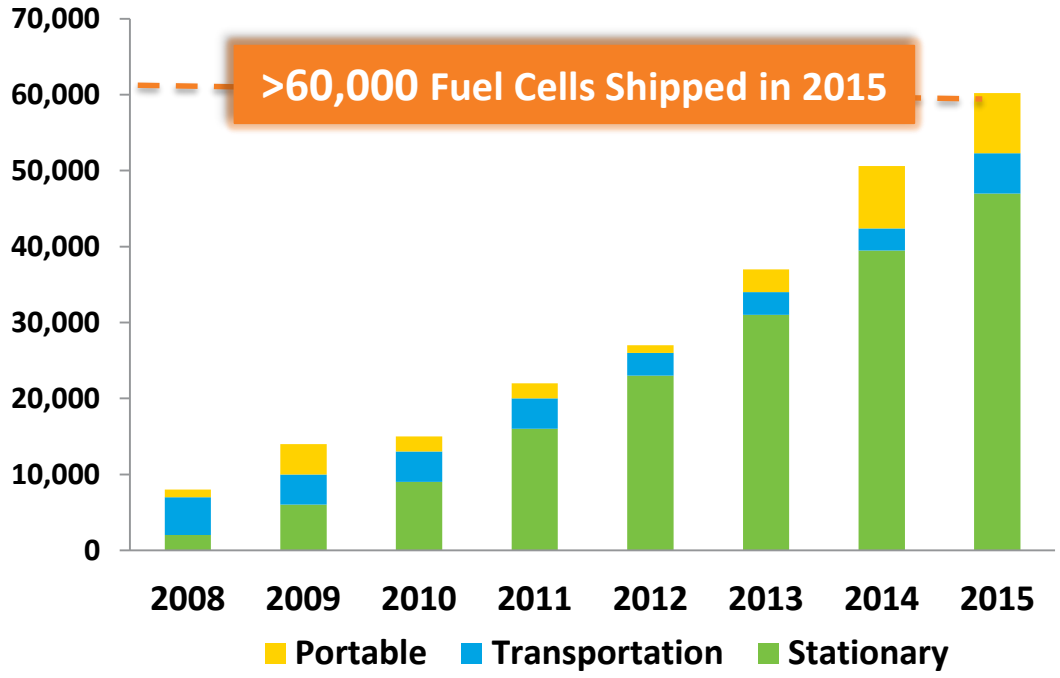
Program goals include:

"To enable a commitment by automakers *no later than year 2015* to offer safe, affordable, and technically viable hydrogen fuel cell vehicles in the mass consumer market"

Additional goals for infrastructure by 2020

Fuel Cells Market Overview

Fuel Cell Systems Shipped Worldwide by Application



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

- Consistent **~30% annual growth** since 2010
- Global Market Potential in 10- 20 years*

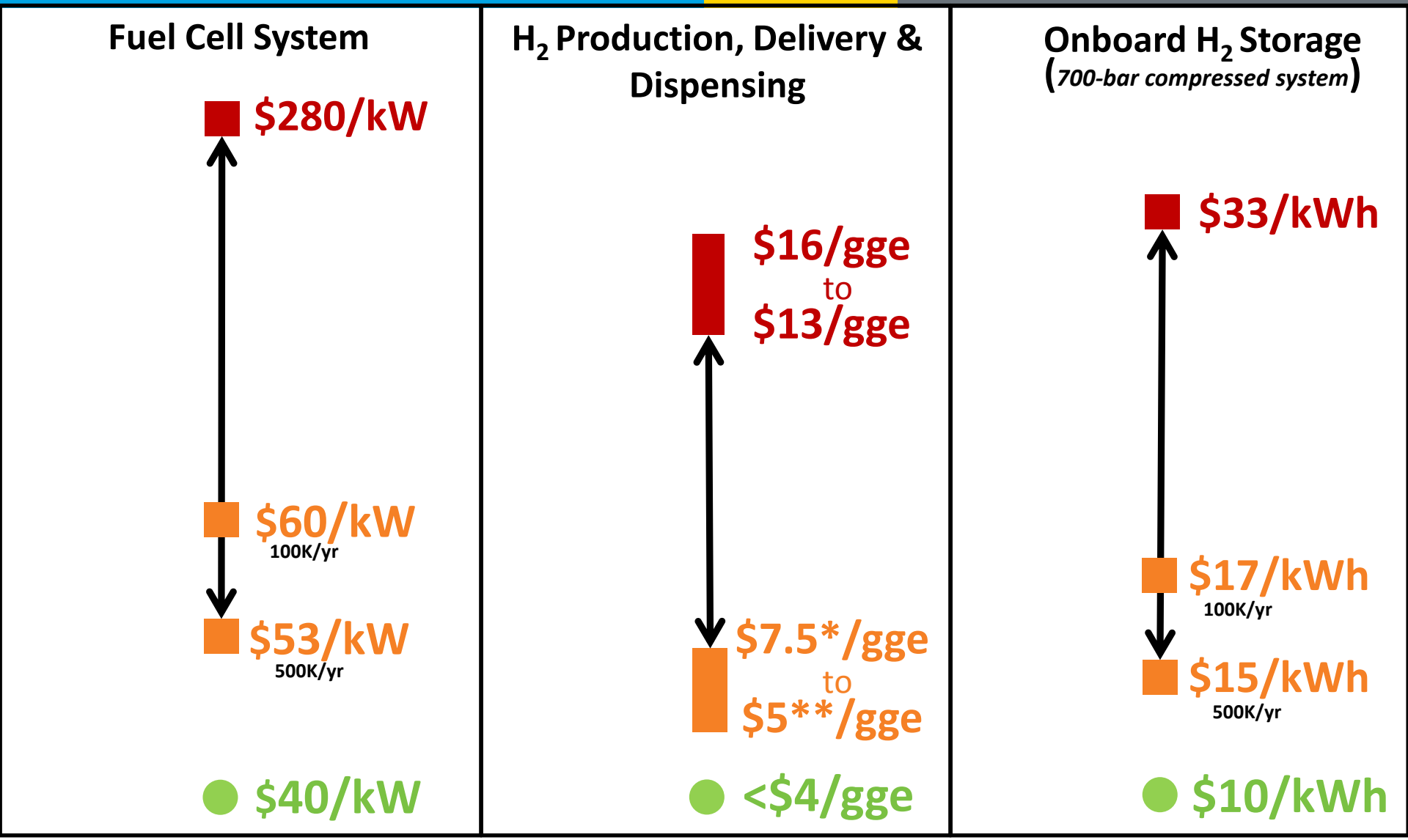
$14B – $31B/yr for stationary power
$11B /yr for portable power
$18B – $97B/yr for transportation

*Fuel Cell Economic Development Plan, Connecticut Center for Advanced Technology, Inc. January 2008

Fuel Cell Electric Vehicles (FCEVs) are here – more to come

Honda Clarity Fuel Cell Vehicle

Cost Status and Targets



*Based on Electrolysis **Based on NG SMR

*For illustration purposes only, not drawn to scale

Hydrogen & Fuel Cells Budget

Key Activity	FY 15	FY 16	FY17
	($ in thousands)		
	Approp.	Approp.	Request
Fuel Cell R&D	33,000	35,000	35,000
Hydrogen Fuel R&D[1]	35,200	41,050	44,500
Manufacturing R&D	3,000	3,000	3,000
Systems Analysis	3,000	3,000	3,000
Technology Validation	11,000	7,000	7,000
Safety, Codes and Standards	7,000	7,000	10,000
Market Transformation	3,000	3,000	3,000
Technology Acceleration	0	0	13,000[2]
NREL Site-wide Facilities Support	1,800	1,900	N/A
Total	97,000	100,950	105,500

Emphasis in FY17 Request

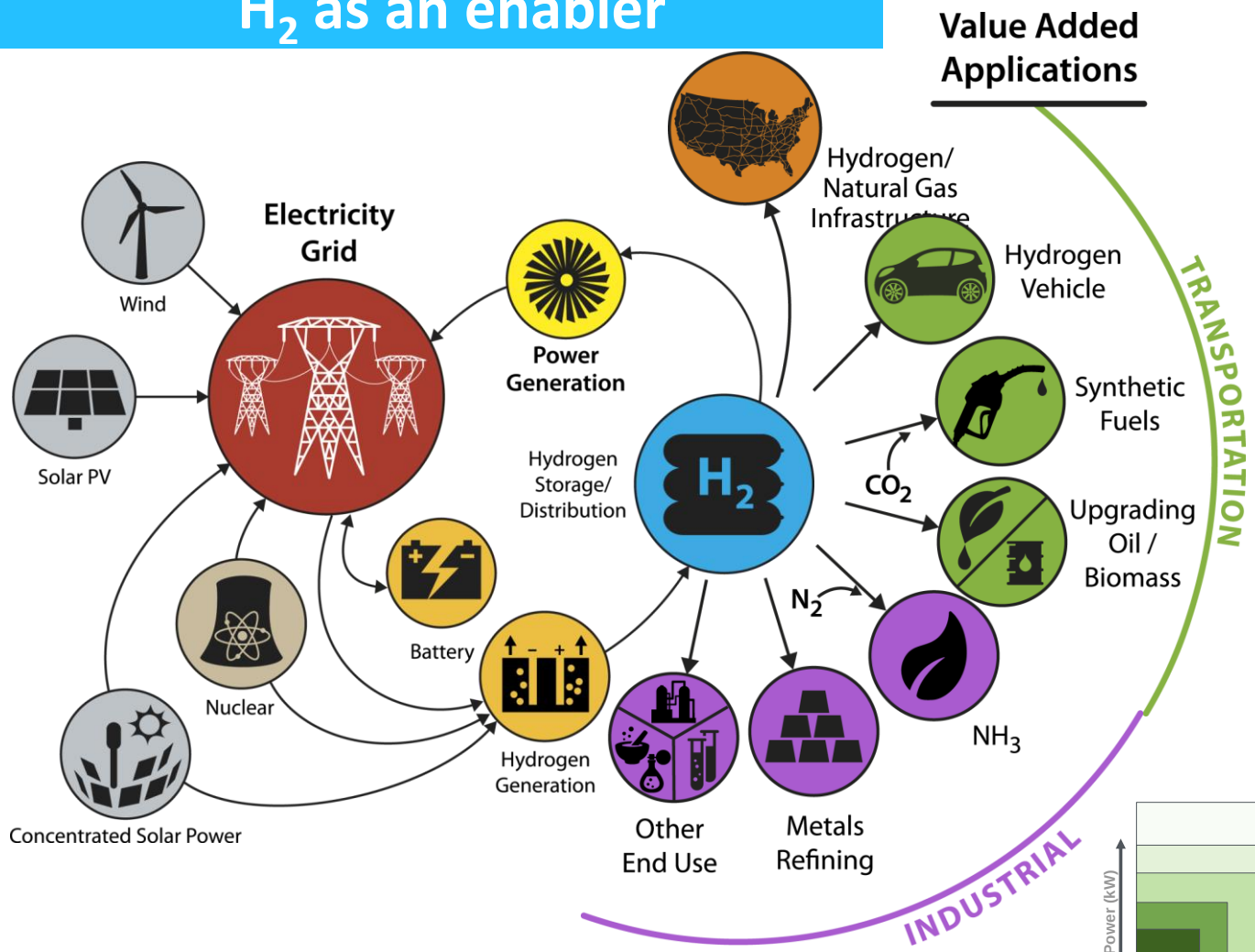
[1]Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D

[2]Combines Manufacturing R&D, Technology Validation, Market Transformation.

Sustained, stable funding requests and appropriations

H_2@Scale: A potential opportunity

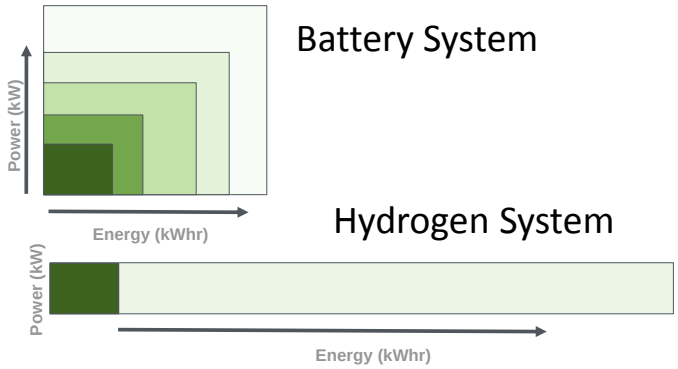
H_2 as an enabler



Today: 10M tons H_2 produced

>1600 mi pipeline

~ 50 stations (~20 public)



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

Complementing Retail Stations: H_2 Refuel H-Prize

H2refuel
U.S. Department of Energy

$1M Competition: On-site H_2 fueling

Finalist Team Announced!
More at hydrogenprize.org

simple.fuel.™

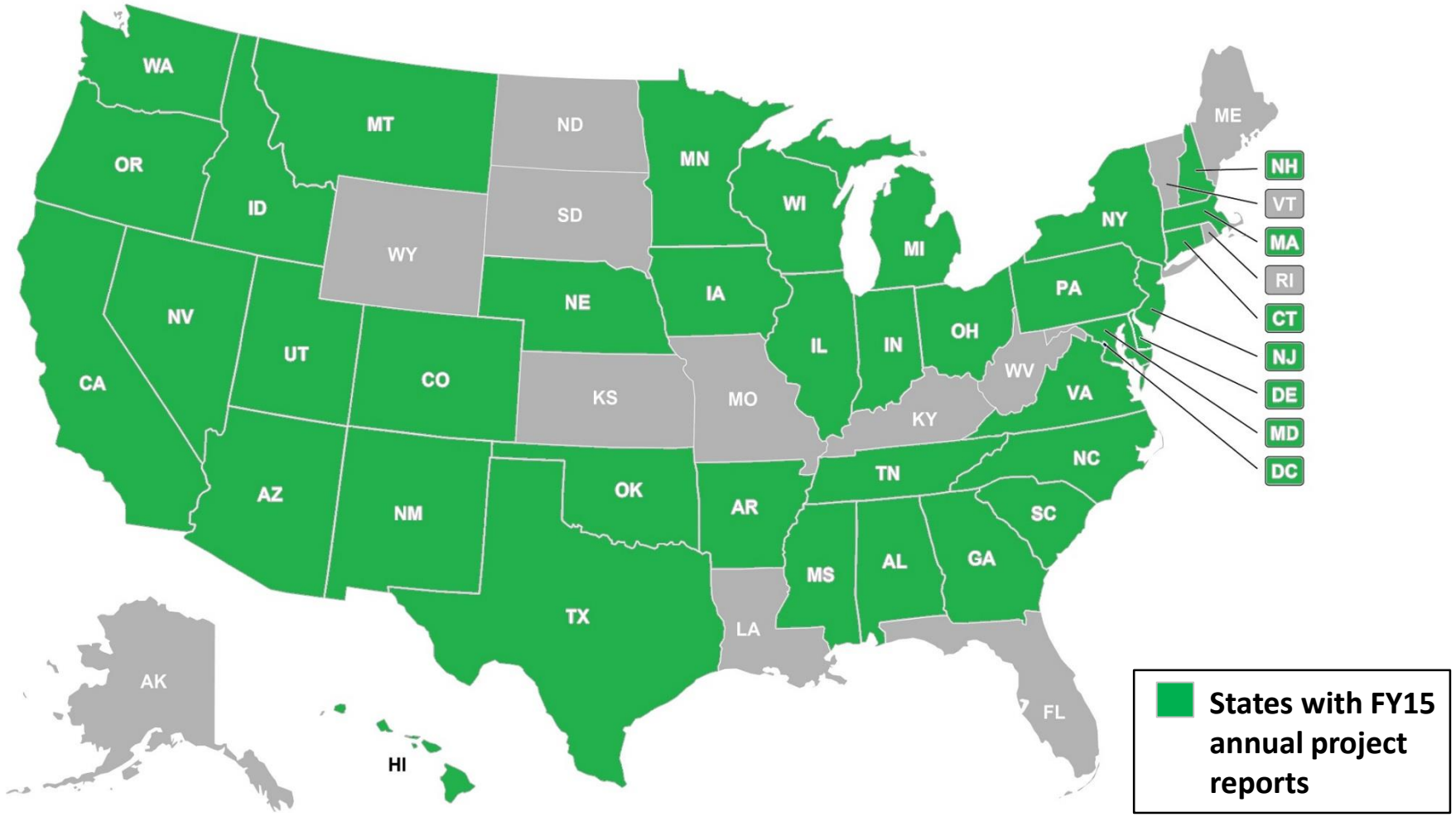
Innovative packaging concepts
Electrolysis 350 and 700 bar

www.hydrogenprize.org

States involved in DOE FCTO activities

Fuel Cell Technologies Office Activities By State

Prime and Subcontract Recipients



Source: [FY 2015 Annual Progress Report- Project Listings by State](https://www.hydrogen.energy.gov/pdfs/progress15/xv_project_listing_by_state_2015.pdf)
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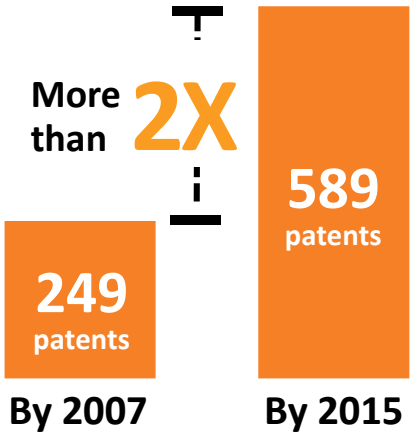
Impact: H_2 and Fuel Cells

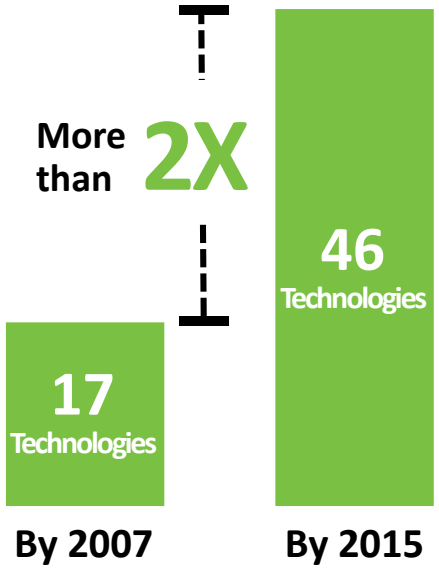
Innovation

Cumulative Number of Patents due to DOE funds



Commercialization

Cumulative Number of Commercial Technologies Entering the Market



Economy and Environment

U.S. Job Potential*

360K to 675K jobs in fuel cells and hydrogen

Job gains across **41 industries**

* 2008 DOE Employment Study currently being updated

GHG Emission Reduction

CO_2

More than **50% - 90%** per vehicle

GHG: Greenhouse Gases

Examples of Commercial Technologies

- Catalysts
- Fuel Cell System Components
- Tanks
- Electrolyzers

Impact of DOE Investment on Industry

Revenues	Additional Investment
More than 7X the DOE Investment	More than 5X the DOE Investment

*for selected companies

Thank You

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Back Up

FCEVs Reduce Greenhouse Gas Emissions

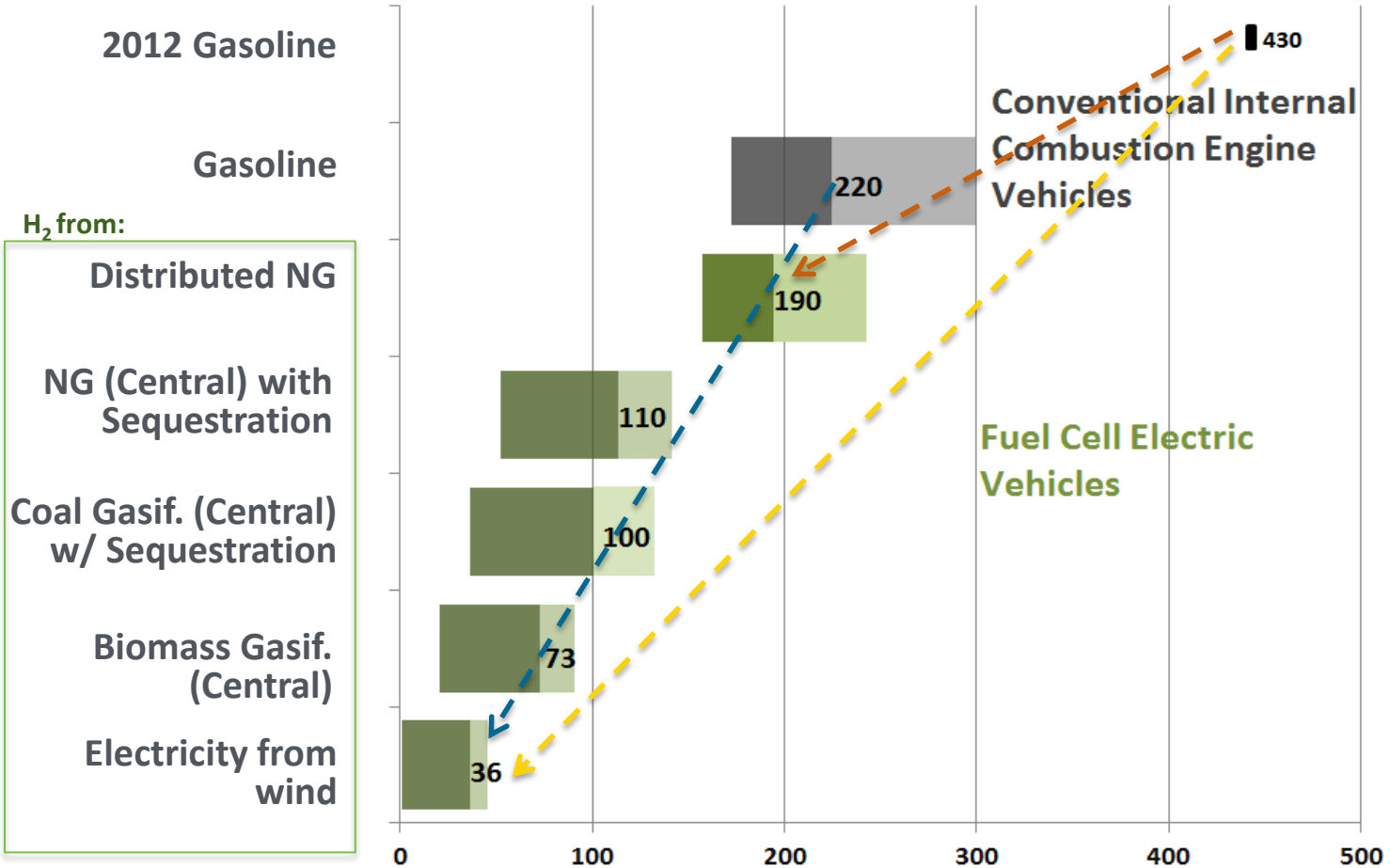
>50% with H_2 from Distributed Natural Gas*

>80% with H_2 from Renewables* (Wind)

>90% with H_2 from Renewables** (Wind)

*Compared to 2035 gasoline vehicle
**Compared to 2012 gasoline vehicle

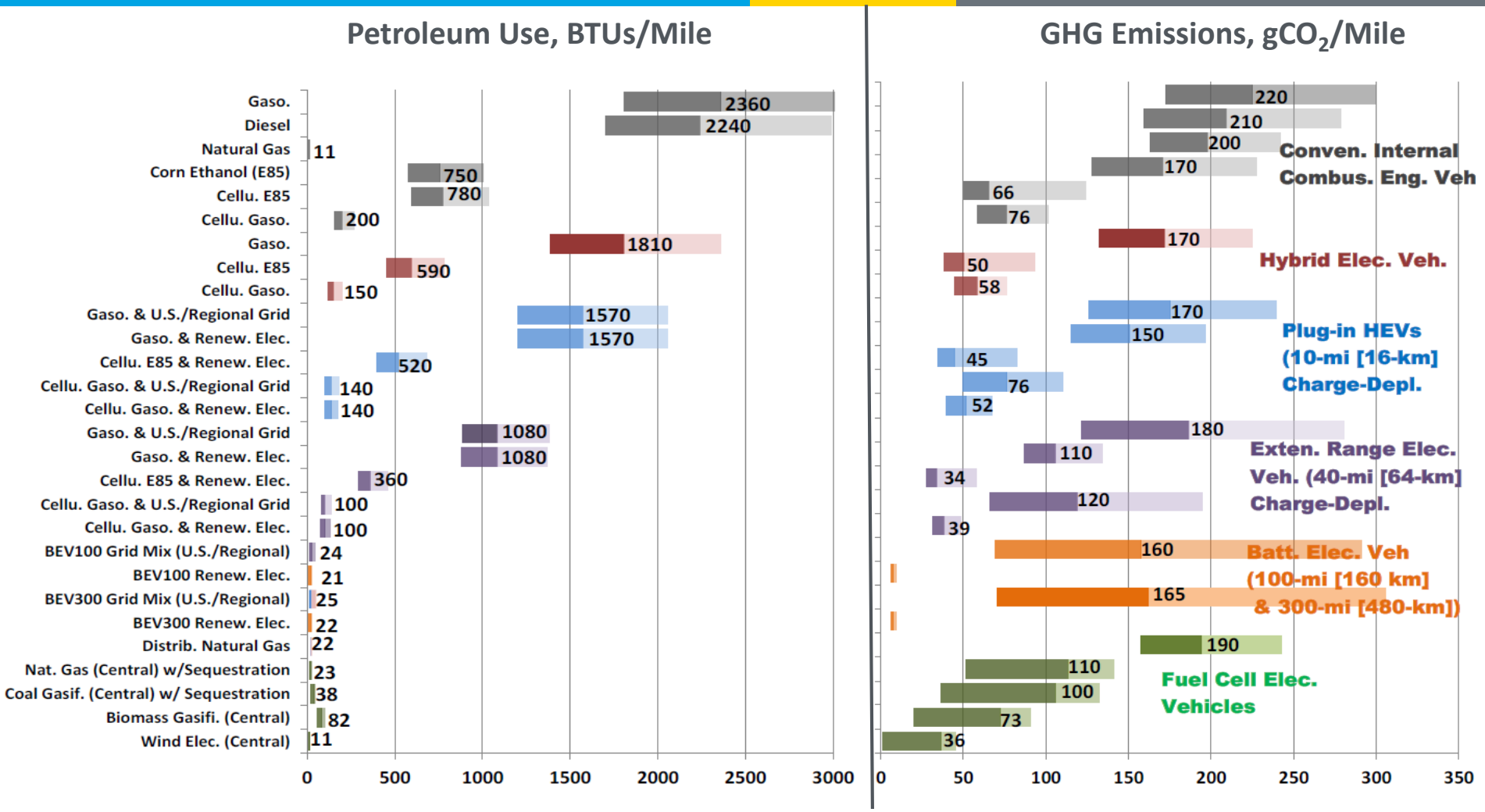
Well-to-Wheels CO_2 Emissions (in grams per mile) **for 2035 Vehicles Technologies,** *except were indicated*



Source: http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf
Advanced 2035 technologies

Substantial GHG reductions with H_2 produced from renewables

Well-to-Wheels Analysis: GHG Emissions and Petroleum Use



Program Record #13005: http://www.hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf

Electric Drive With Low Carbon Fuels - Pathway with lowest GHG emissions and petroleum use

REFUELING/RECHARGING TIME

Energy Source	Rate (miles/min)	Long-Trip % Charging Time
Gasoline	150	1-2%
Hydrogen	100	<2%
EV Supercharger	6	15%

Assumptions: Gasoline & Hydrogen Electric: 350 mile range, Battery Electric: 250 mile range

Source: General Motors, with permission April 2016

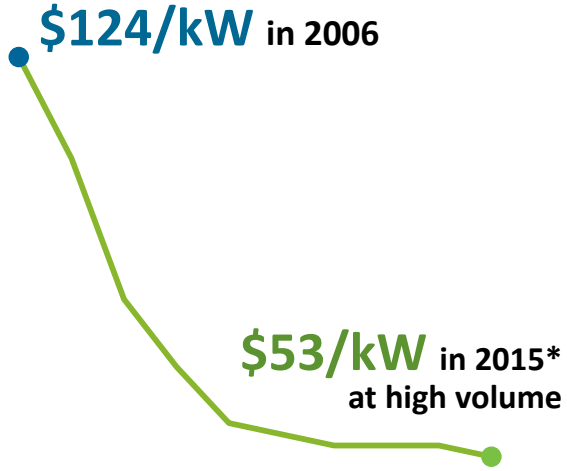
- Fuel cell vehicles have similar functionality to current Internal Combustion Engines
- Battery charging rates (mile/min) limited to about an order of magnitude less than H_2 refueling rates

DOE Activities Span from R&D to Deployment

1. Research & Development

Fuel Cells

- >50% decrease in cost since 2006
- 5X less platinum
- 4X increase in durability



*$280/kW low volume

2. Demonstration

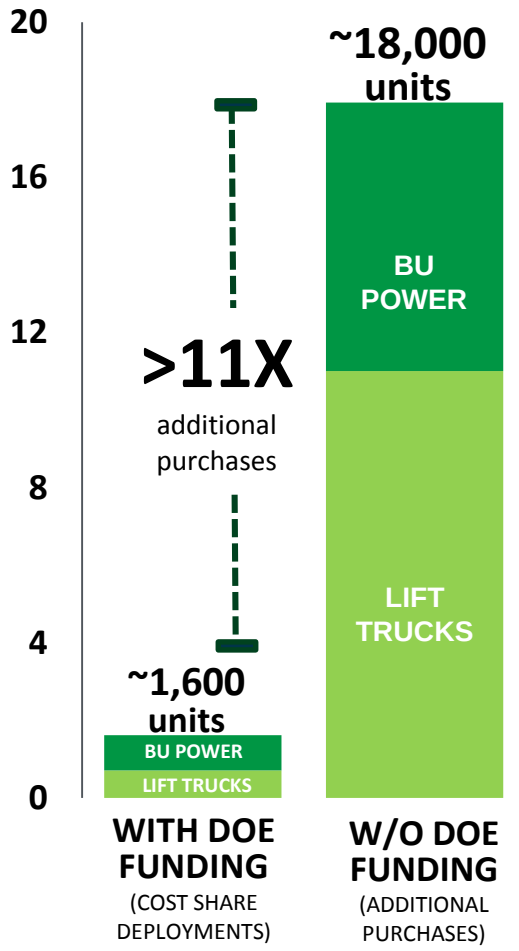
Forklifts, back-up power, airport cargo trucks, parcel delivery vans, marine APUs, buses, mobile lighting, refuse trucks

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

World's first tri-gen station

FCEV: Fuel Cell Electric Vehicle
APU: Auxiliary Power Units

3. Deployment

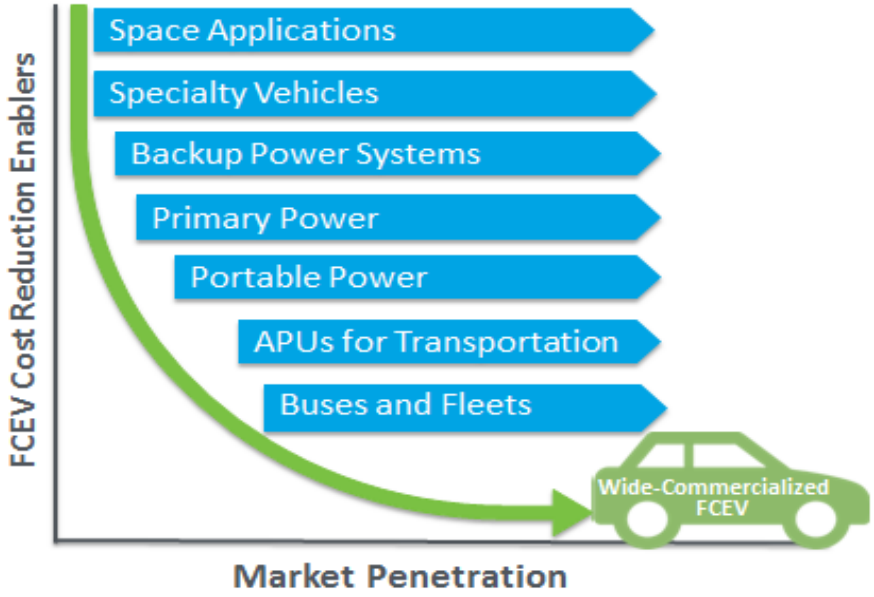


BU: Back Up Power

Early Market Strategies Increase Volume

Early Markets enable:

- Fuel cell cost reduction
- Robust supply base
- Emerging infrastructure
- Customer acceptance



Early Markets Applications Recently Deployed in the U.S.

Fuel Cell Tow Trucks

Fuel Cell Bus Fleets

Forklifts

Backup Power