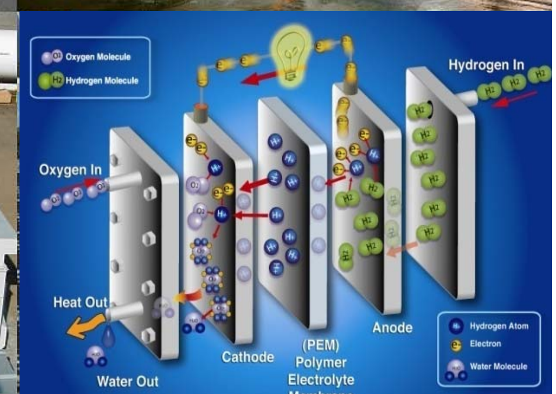
# US Department of Energy Hydrogen and Fuel Cell Perspectives for Backup Power Applications

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








## Fuel Cell Backup Power for Telecommunication Base Stations

Wuhan, P.R. China

5/29/2015

**Dr. Dimitrios Papageorgopoulos**

Fuel Cells Program Manager
Fuel Cell Technologies Office
Energy Efficiency and Renewable Energy
U.S. Department of Energy

# All-of-the-Above Energy Strategy

*"We've got to invest in a serious, sustained, **all-of-the-above energy strategy** that develops every resource available for the 21st century."*

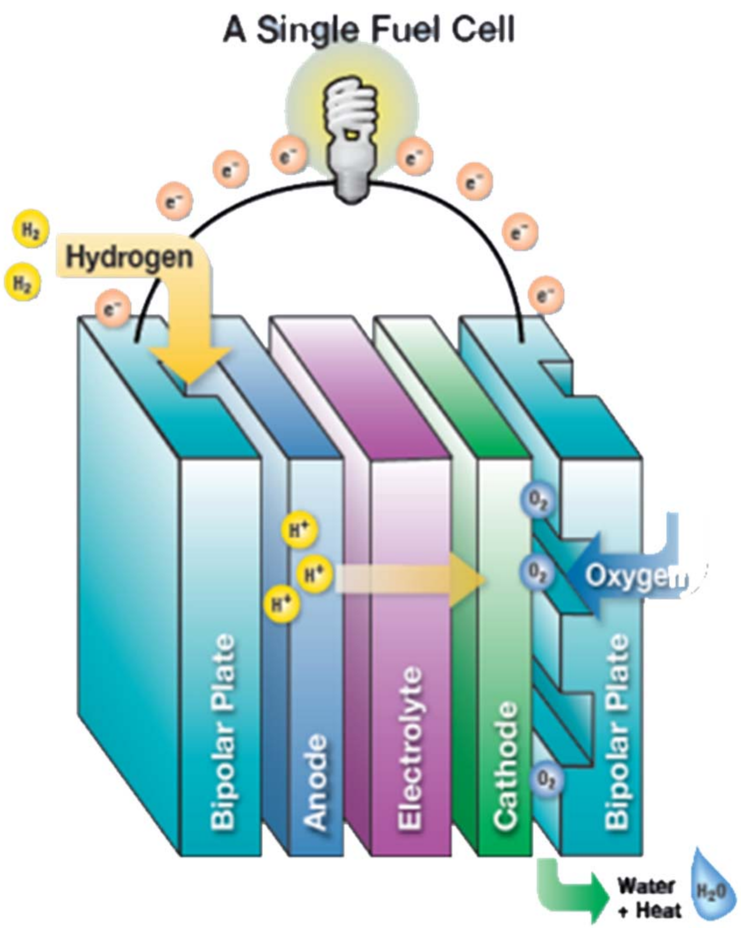
*- President Barack Obama*

***"As part of an all-of-the-above energy approach, fuel cell technologies are paving the way to competitiveness in the global clean energy market and to new jobs and business creation across the country."***

*- Secretary Moniz,*
*U.S. Department of Energy*

Secretary Moniz at DC Auto Show

# Why Fuel Cells and Hydrogen?




**>2x** as efficient as today's gasoline engine

**Natural Gas** | **Renewable Sources** | **Coal** *(With carbon sequestration)* | **Nuclear**

***Produces…***

**Hydrogen**
***Clean Energy Carrier***

***Used for…***

### Fuel

- Fuel Cells
- Engines
- Turbines
- Biofuels

### Industry

- Petroleum Recovery & refining
- Methanol, Ammonia & Metal Production
- Electronics/Cosmetics
- Food Processing

**Energy storage for renewables**

***Key component to a diversified and clean energy strategy***

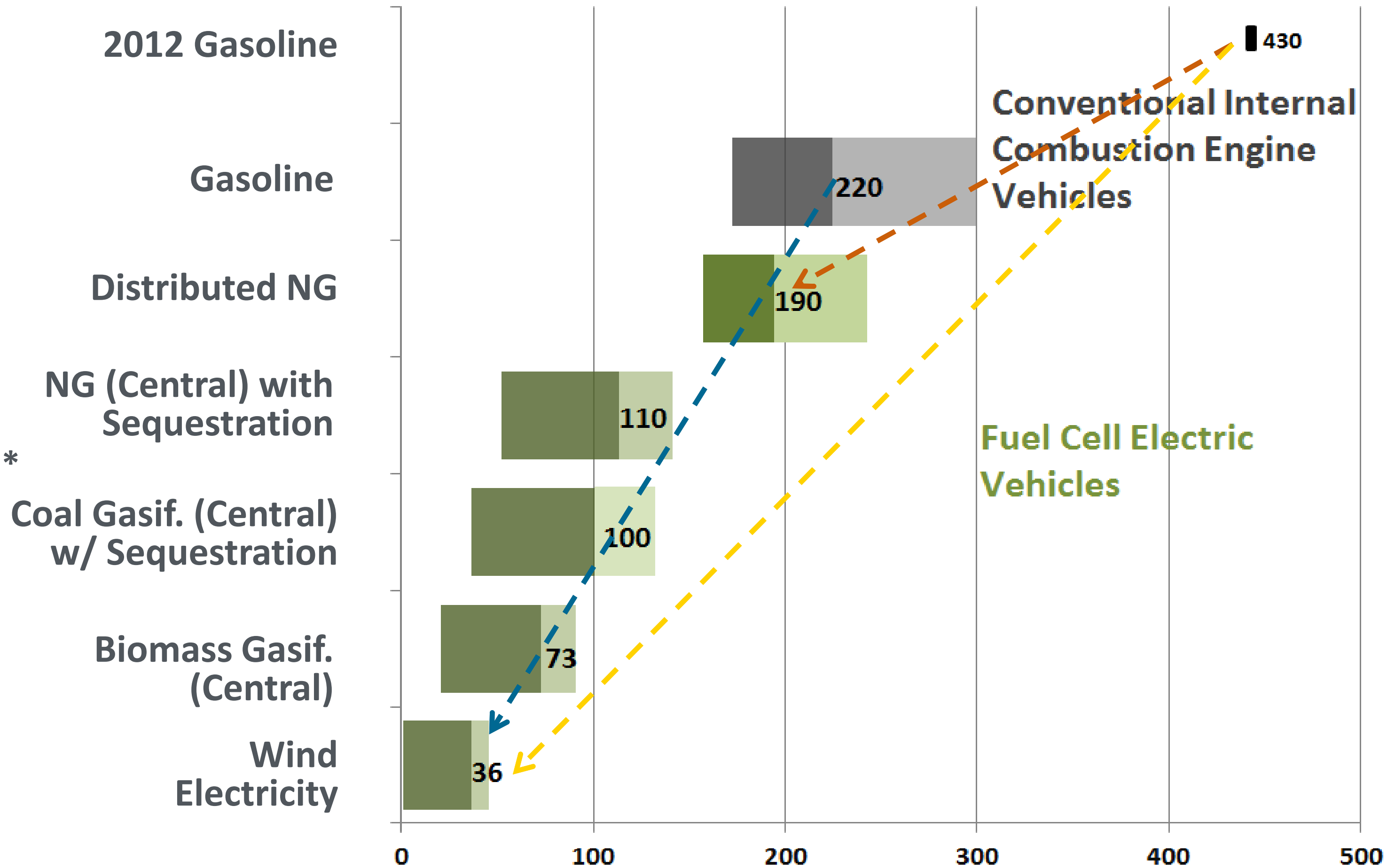
# FCEVs Reduce Greenhouse Gas Emissions

**>50%** from Distributed Natural Gas*

**>80%** from Renewables** (Wind)

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

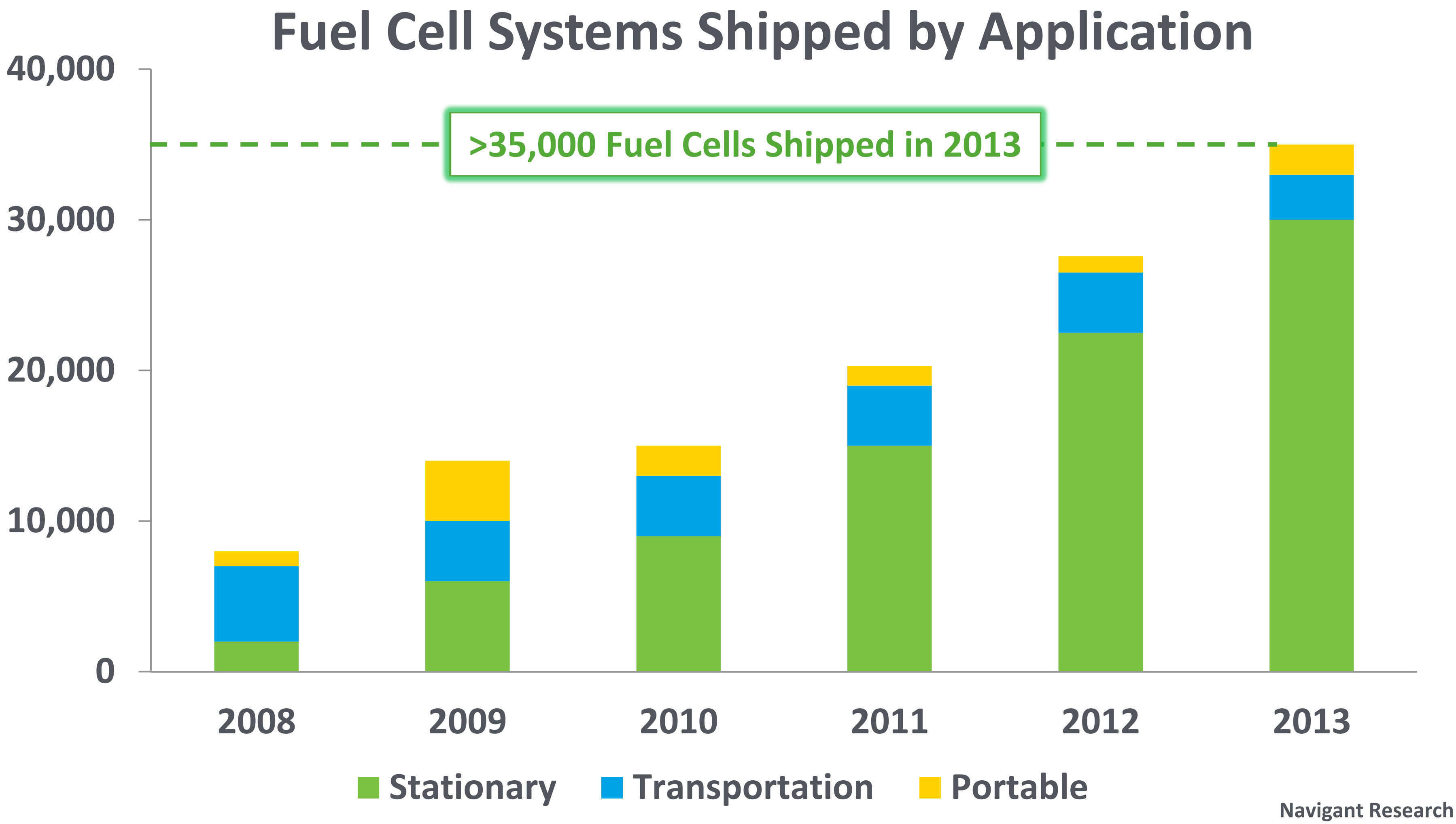
**Well-to-Wheels $CO_2$ Emissions** (in grams per mile) **for 2035 Vehicles Technologies,** *except were indicated*




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

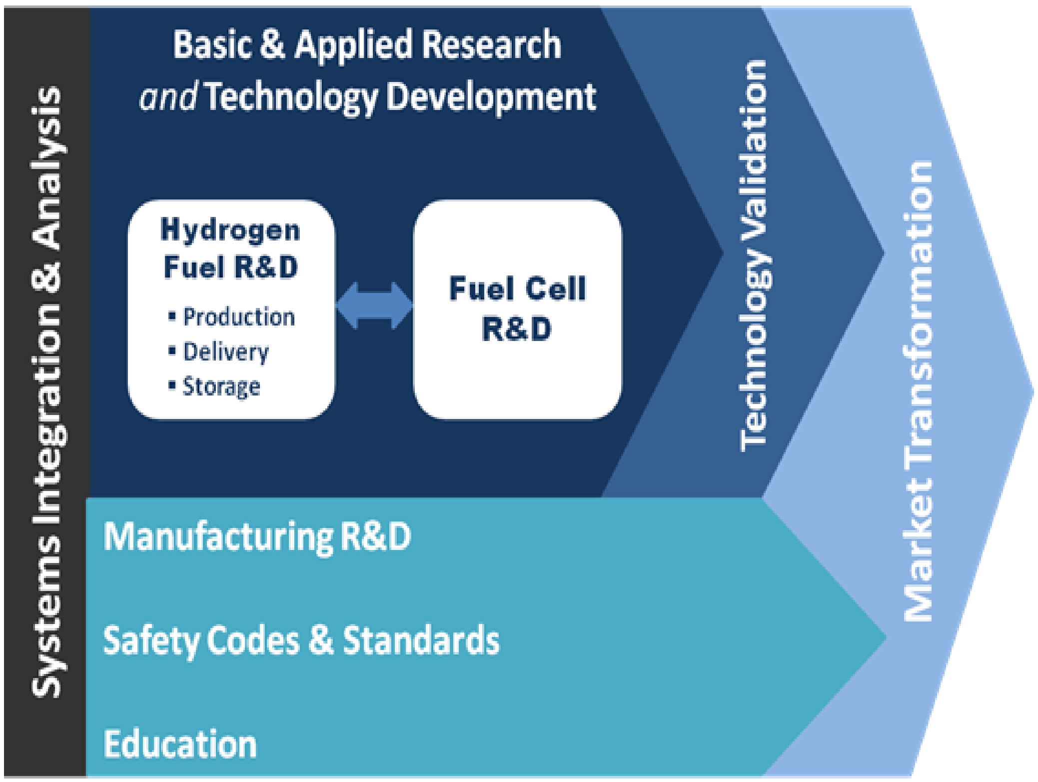
***Substantial GHG reductions with $H_2$ produced from renewables***

# Market Growth in Fuel Cell Sales




***Consistent 30% annual growth since 2010***

## Integrated Work Areas




## 2020 Targets by Application

| | Vehicle | Stationary |
|---|---|---|
| Fuel Cell Cost | $40/kW | $1,000/kW*<br>$1,500/kW** |
| Durability | 5,000 hrs | 80,000 hrs |
| $H_2$ Storage Cost (On-Board) | $10/kWh<br>1.8 kWh/L, 1.3 kWh/kg | |
| $H_2$ Cost at Pump | <$4/gge | |

*For Natural Gas
**For Biogas

***Integrated approach to widespread commercialization of $H_2$ and fuel cells***

# U.S. Department of Energy Role and Activities

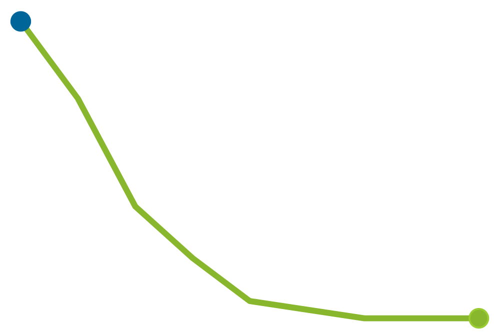


## 1. Research & Development

**Cost Reductions**

- **50%** for fuel cell systems

**$124/kW** in 2006



**$55/kW** in 2014*
at high volume
*$280/kW low volume

- **80%** for electrolyzers (since 2002)

## 2. Demonstration

**FCEV Demo**

- **>180** FCEVs
- **25** stations
- **3.6M** miles

World's first tri-gen station

GSE, back-up power app.

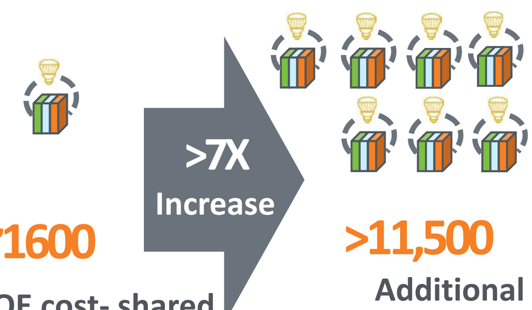

## 3. Deployment

**Lift Trucks**

- **700** DOE cost-shared deployments led to **>7,500** additional purchases

**Emergency Back-Up Power**

- **900** DOE cost-shared deployments led to **4,000** additional purchases




**~1600**
DOE cost- shared deployments
2014

**>11,500**
Additional purchases without DOE funding

# U.S. Hydrogen and Fuel Cells Progress



## In R&D…

**50%** Cost Reduction in fuel cell systems

**$124/kW** in 2006

**$55/kW** today* at high volume

*$280/kW low volume

**2X** Increase in fuel cell durability

**5X** Platinum content reduction in fuel cells

## In the Market…

### FCEVs in the US:

Recently announced

Now Leasing

In Auto Shows

### Public-private partnership addressing infrastructure:

$H_2$USA

**4X** Increase in partners and growing since 2013

### State Activities:

- 8 states committed to 3.3 million ZEVs by 2025
- CA has committed to 100 $H_2$ stations

## Key Challenges

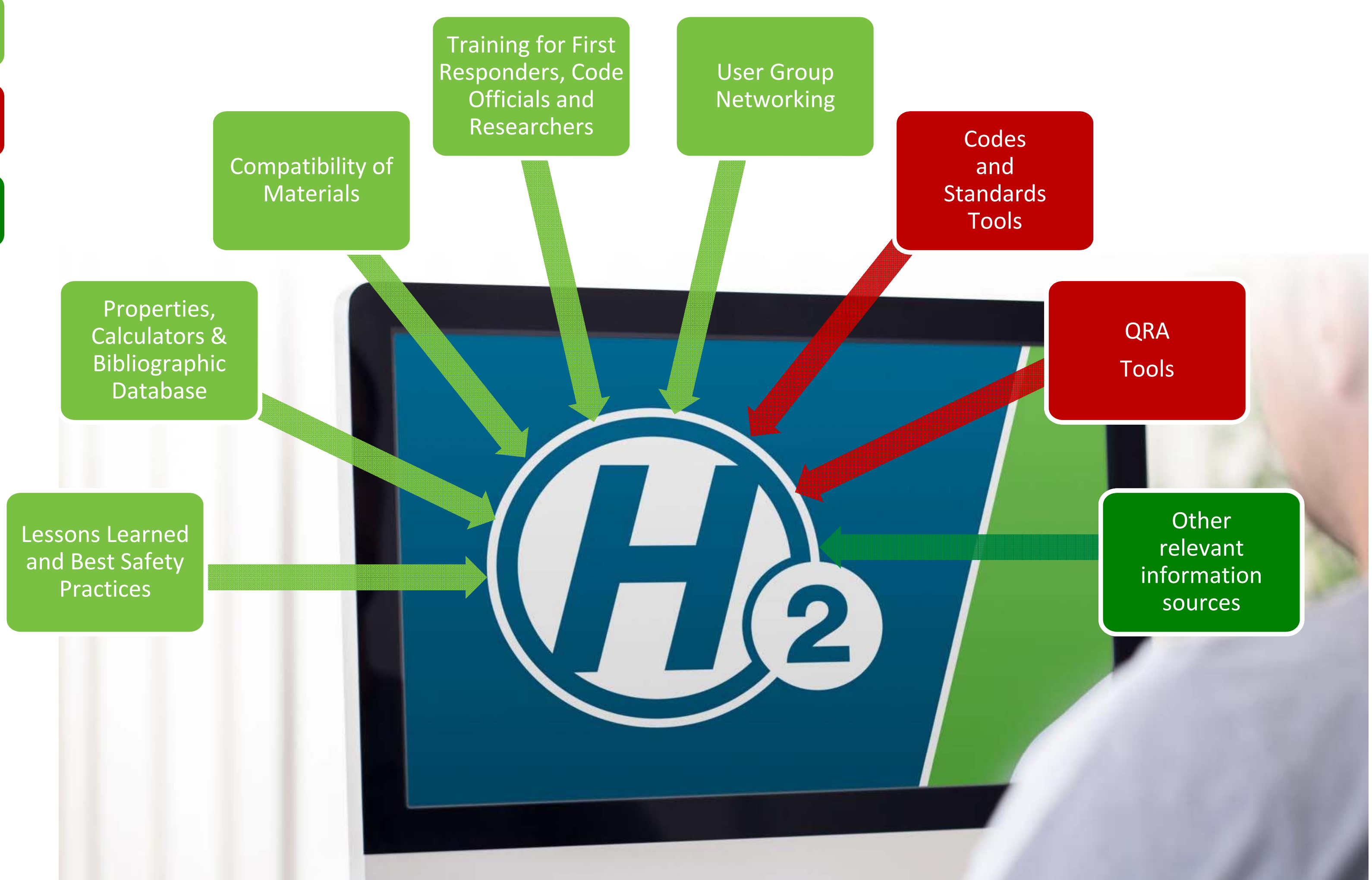
- Fuel Cell Cost and Durability
- Hydrogen Production
- Hydrogen Delivery
- Hydrogen Storage
- Infrastructure
- Manufacturing and supply chain
- Safety codes and standards
- Widespread public acceptance

# Hydrogen Safety Resources

**Phase 1 Spring 2015**

**Potential Future Tools**

**Share your ideas!**




***The Hydrogen Tools Portal provides a Centralized Location, Focused Content, a Customizable Interface and Responsive Design, Trusted Communities, and an Expandable Format***

# Fuel Cells for Backup Power: Technical Targets

| Technical Targets*: Fuel Cell Backup Power Systems Operating on Direct $H_2$ | | | |
|---|---|---|---|
| **Characteristic** | **Units** | **2015 Status** | **2020 Targets** |
| Lifetime | Years | 10 | 15 |
| Durability[a] | hours | 2,500 | 10,000 |
| Energy efficiency[b] | % | 50 | 60 |
| Mean time between failures | years | 5 | 5 |
| Ambient temperature range | °C | -20 to 40 | -50 to 50 |
| Noise | dB at 1 m | 65 | 60 |
| Start-up time[c] | seconds | 60 | 15 |
| Availability | % | 99.7 | 96.3 |
| Equipment cost[d] | $ kW$^{-1}$ | 3,000 | 1,000 |
| Maintenance cost[d] | $ kW$^{-1}$ year$^{-1}$ | 30 | 20 |

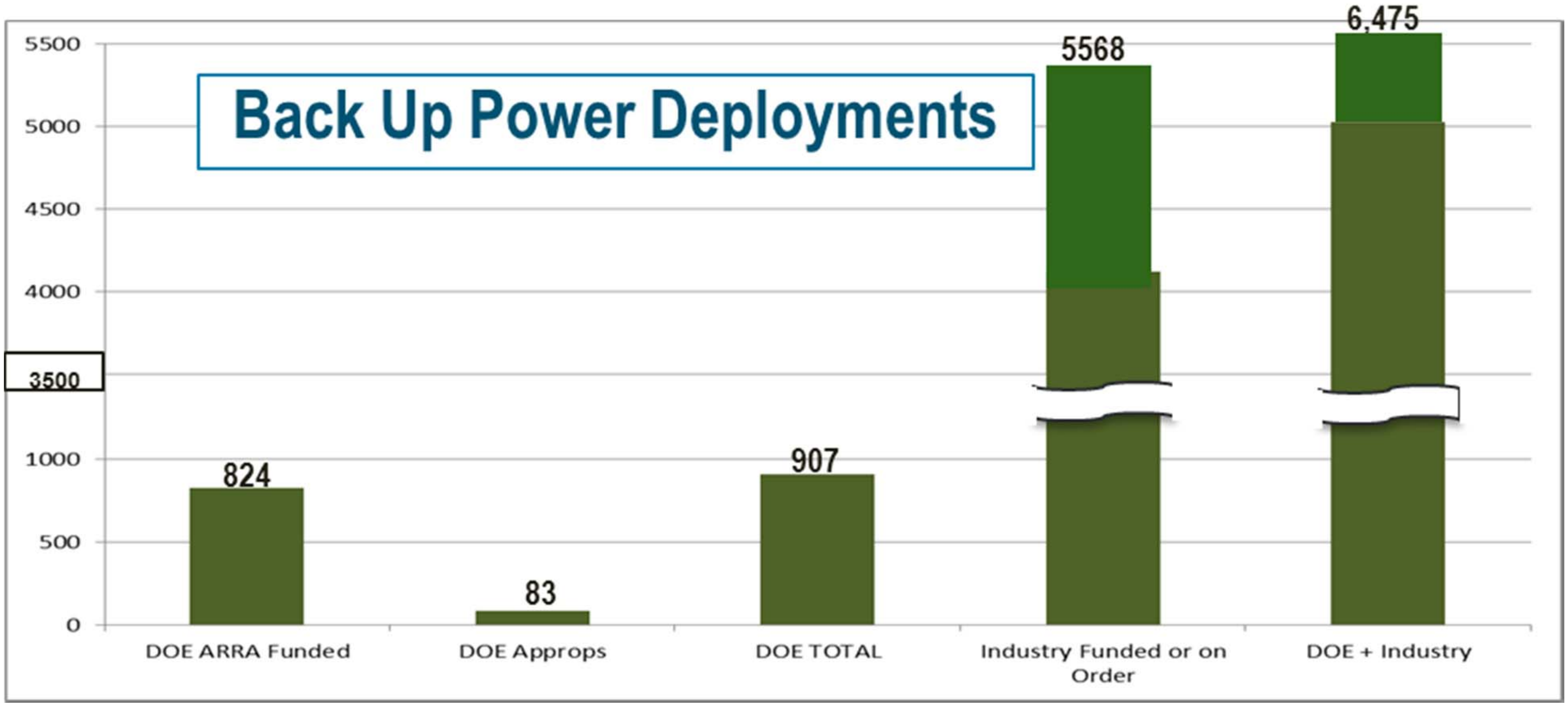
a. Time until 10% voltage degradation when operated on a backup power duty cycle.
b. Ratio of DC output energy from the powerplant to the lower heating value of the input fuel (hydrogen), averaged over duty cycle.
c. Time indicated is start-up time for the fuel cell. The backup power system, including hybridized batteries, is expected to provide uninterruptible power.
d. Excludes tax credits and subsidies.

**Preliminary; developed with stakeholder input*

**http://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22**

# Market Transformation Deployments

***The funding of over 900 DOE fuel cell backup power systems has led to over 5,500 industry installations and on-order backup power units with no DOE funding***

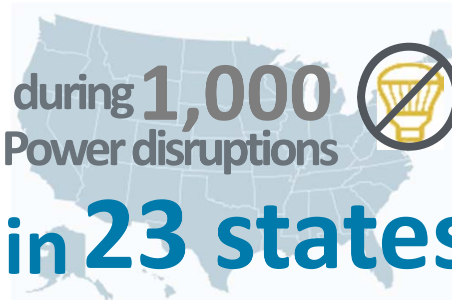



***The 6,475 backup power fuel cell shipments and units on-order equate to >32,000 kW of fuel cell systems***

# Fuel Cells Provide Resiliency to the Grid

**800** Fuel Cells for back up power **deployed**

at cell phone **towers** providing **electricity**



during **1,000** Power disruptions **in 23 states**

AZ CA CO CT FL GA IL IN KY LA MA MI MS NV NJ NY NC OR SC TX UT WA WY

During **Hurricane Sandy**

the largest Atlantic hurricane on record

**5 sites** operated providing power **for over 100 hours**

as validated by NREL

***Source:*** *"Hydrogen Fuel Cell Performance as Telecommunications Backup Power in the United States" NREL/TP-5400-60730*

***1,034 out of 1,047 successful fuel cell starts for back-up power***

## NREL compiled backup power operation summary 2009 Q1 – 2013 Q4

**1.99**
Installed capacity in MW

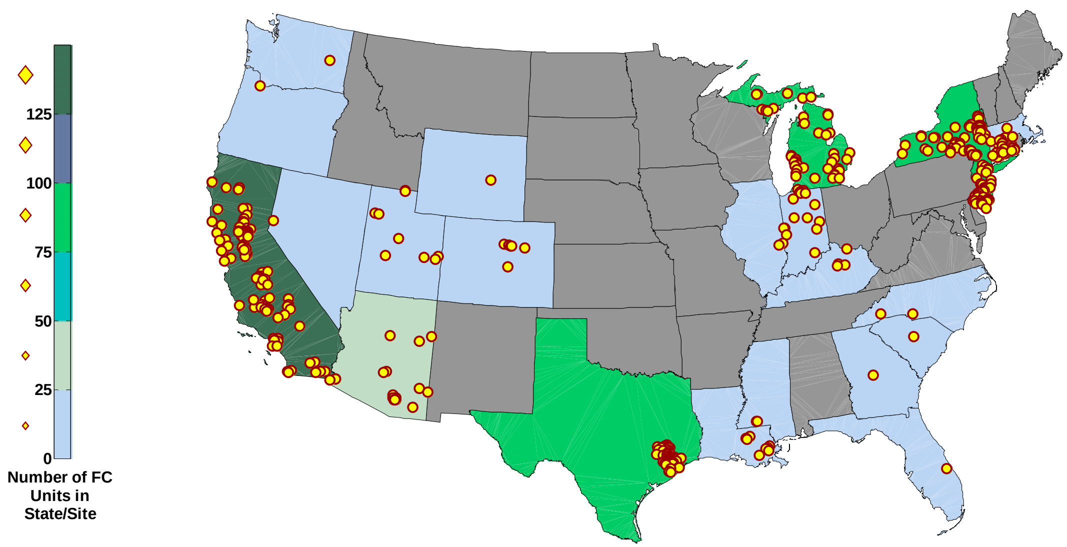
Systems are operating reliably in 23 states. Reasons for unsuccessful starts include an e-stop signal, no fuel, and other system failures.

**99.5%**
Successful starts

**852**
Systems in operation*

**4–6**
Average site capacity in kW

**2,578**
Start attempts




**65**
Continuous run hours demonstrated

**1,749**
Operation hours

*Not all systems have detailed data reporting to NREL

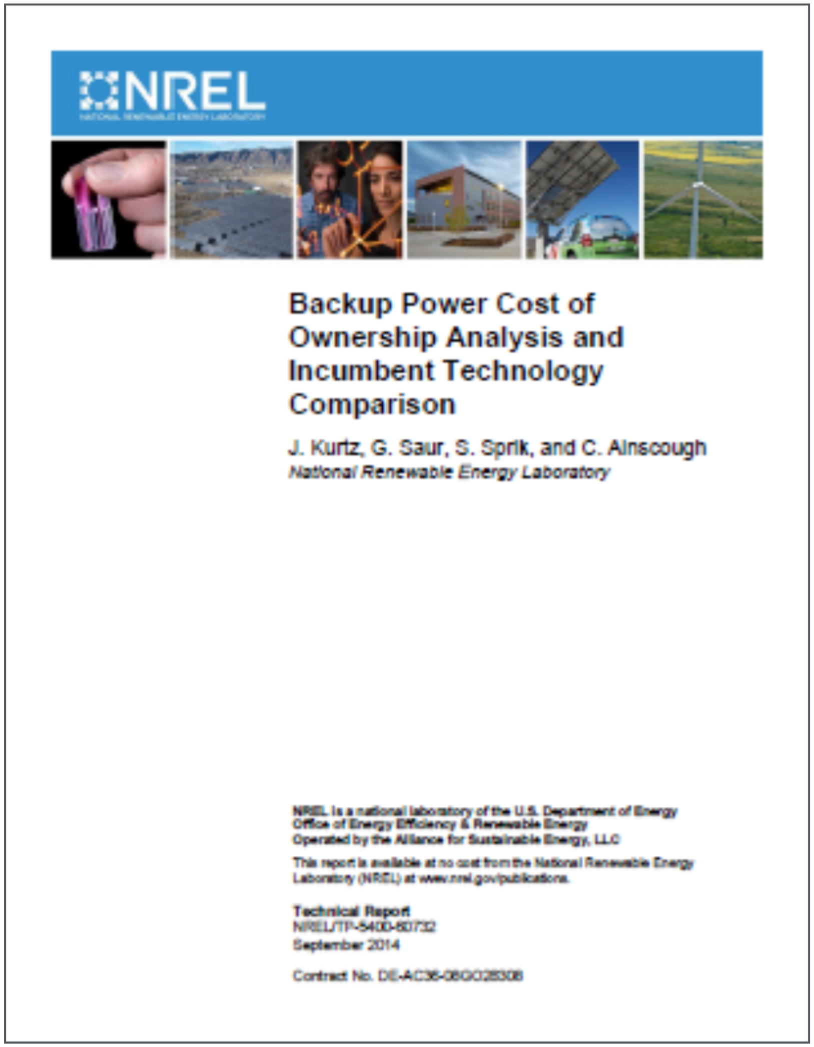
## Objective

Analysis of the annualized cost of ownership for backup power technologies in different annual runtime scenarios to evaluate the economic value proposition of fuel cell backup power systems.

The ownership costs are based on operation lifetime, efficiency, maintenance, installation, fuel, and incentives.

A detailed report on the assumptions, method, and results is available at:

*http://www.nrel.gov/hydrogen/cfm/pdfs/60732.pdf*


NREL

Backup Power Cost of Ownership Analysis and Incumbent Technology Comparison

J. Kurtz, G. Saur, S. Sprik, and C. Ainscough
*National Renewable Energy Laboratory*

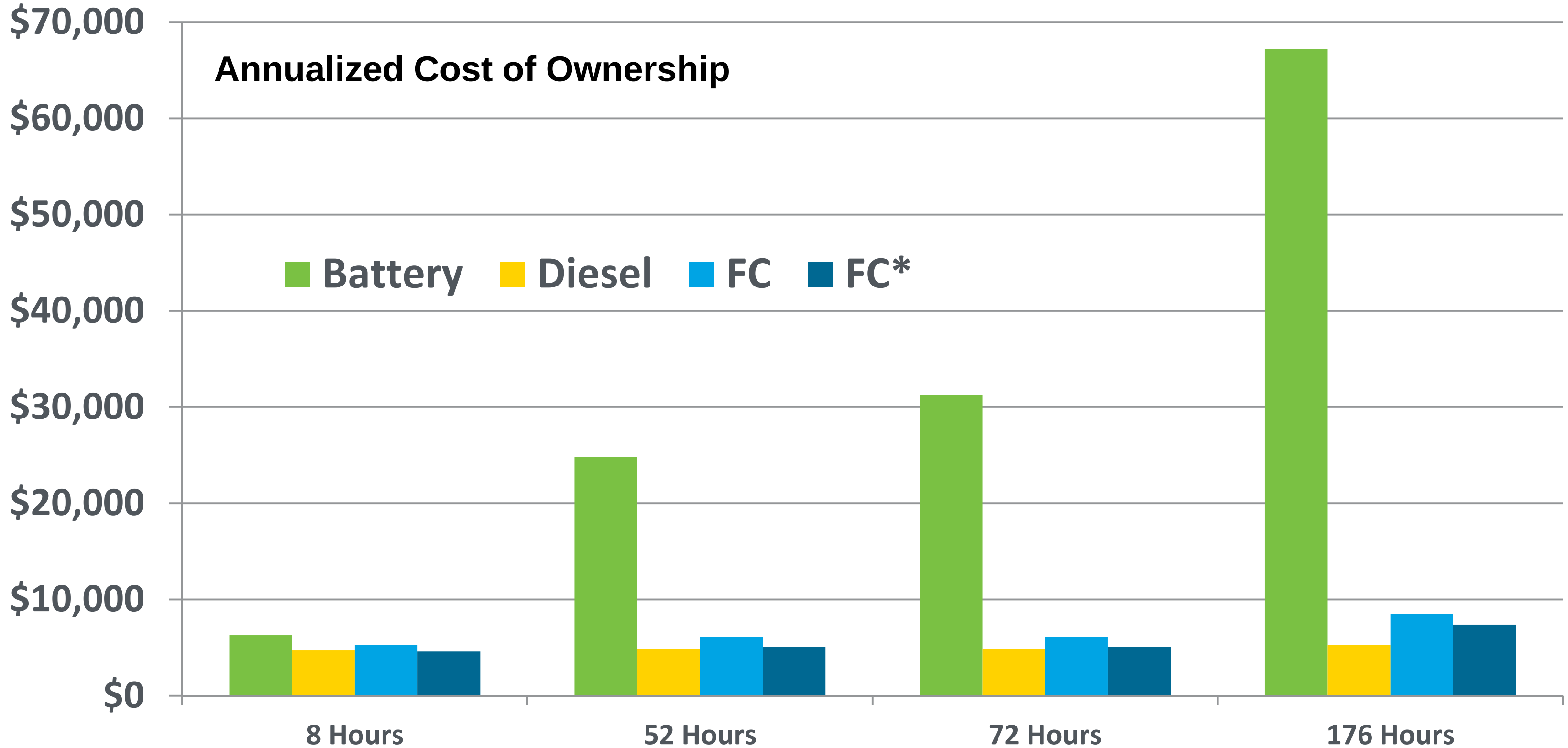
NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

**Technical Report**
NREL/TP-5400-60732
September 2014

Contract No. DE-AC36-08GO28308

# Backup Power Cost of Ownership: Technology Comparison



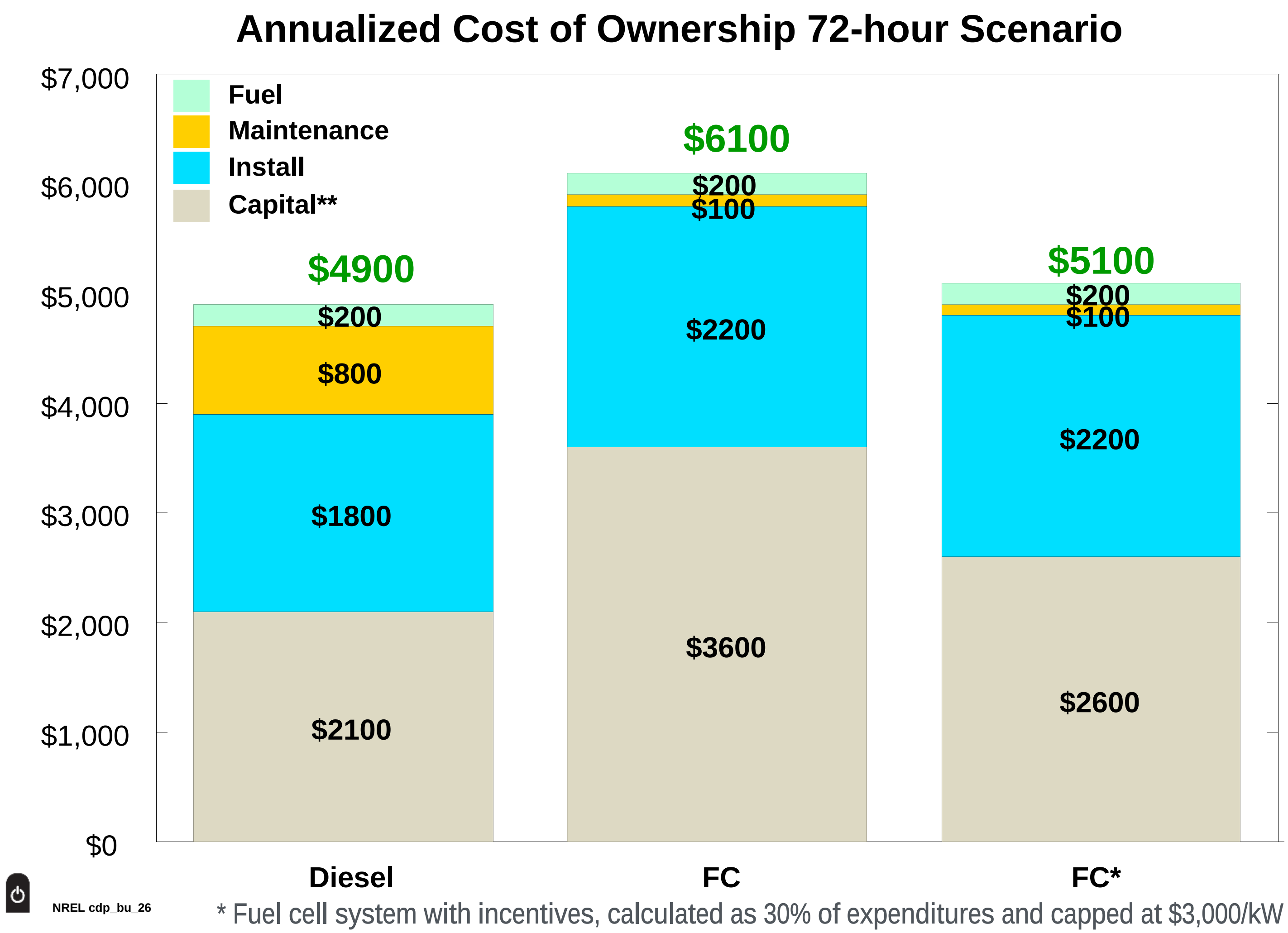

| | 8 Hours | 52 Hours | 72 Hours | 176 Hours |
|---|---|---|---|---|
| **Battery** | $6300 | $24800 | $31300 | $67200 |
| **Diesel** | $4700 | $4900 | $4900 | $5300 |
| **FC** | $5300 | $6100 | $6100 | $8500 |
| **FC*** | $4600 | $5100 | $5100 | $7400 |

NREL cdp_bu_23

* Fuel cell system with incentives, calculated as 30% of expenditures and capped at $3,000/kW of system capacity

***Technologies are comparable at continuous 8-hour runtime and battery cost increases significantly for the higher operation scenarios***

# 72-Hour Runtime Scenario




* Fuel cell system with incentives, calculated as 30% of expenditures and capped at $3,000/kW of system capacity

***Includes capital costs for fuel storage*

***Fuel cell system with incentives can be cost competitive with diesel generators***

# Backup Power Cost of Ownership Analysis: Summary & Outlook

- **Diesel generator is one of the lower-cost options, but with additional challenges including: cost of annual maintenance, noise, emissions, low efficiency, and/or poor reliability**

- **Battery system is likely selection for telecom sites requiring < 8 hours of run time**

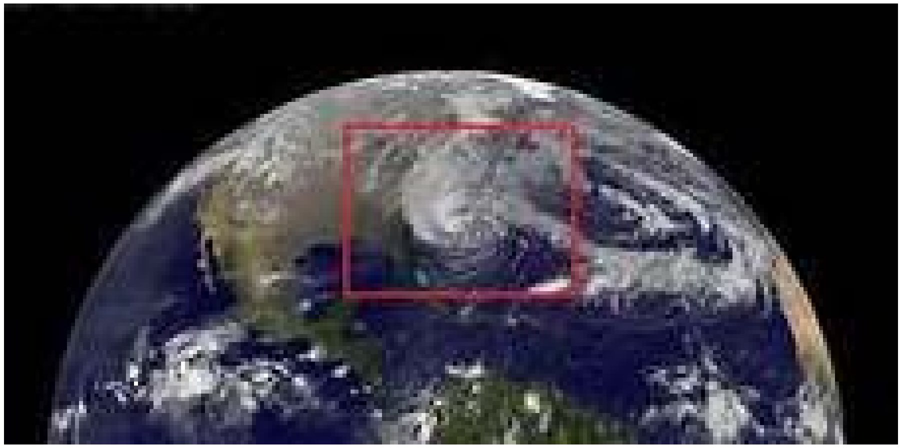
- **Fuel cell capital and installation cost reduction will result in stronger value proposition**

- **Permitting of hydrogen systems, specifically the inconsistency of how requirements are implemented from site to site and how long the process takes needs development**

***For decision makers initial cost is a key driver, but other aspects to consider are permitting, emissions, run time capability, ease of refueling, noise, footprint, and user comfort with the technology***

## Hurricane Sandy (October 2012) was the largest Atlantic hurricane on record.

## Winds spanning more than 1,100 miles



**More than $63 billion in damages**

# Impact of Super Storm Sandy on Telecom

Major cell phone service disruption and power outages

## Wireless Telecommunications

- 25% of cell towers in 10-state area stopped operating
- Cellphone outages reported in more than 150 counties from Virginia to Massachusetts
- Many post-Storm cellphone disruptions caused by battery or diesel backup generators running out of fuel before grid power restored

# Fuel Cell Performance During Super Storm Sandy and Hurricane Irene



## Electricity Grid

- In the US, 22 of the 23 400 kW UTC Power (Doosan Fuel Cells) stationary fuel cells in the area provided continuous power to buildings.
  - The only fuel cell to shut down was quickly restarted after a brief repair.

## Wireless Telecommunications

- In the Bahamas, all of Ballard's 17 ElectraGen™-ME systems operated continuously, producing more than 1,200 kWh of electricity.
- In the US, all of the 60+ Altergy's backup power systems operated flawlessly.
  - The only wireless cell tower sites that remained operational after Hurricane Sandy were those with backup power fuel cell systems.
- During Hurricane Irene, all 56 ReliOn (Plug Power) systems installed at Sprint Sites operated throughout entire outage duration

*UTC Fuel Cells at Verizon Garden City*

*Altergy Fuel Cell*

*ReliOn Fuel Cells at Sprint*

# Thank you

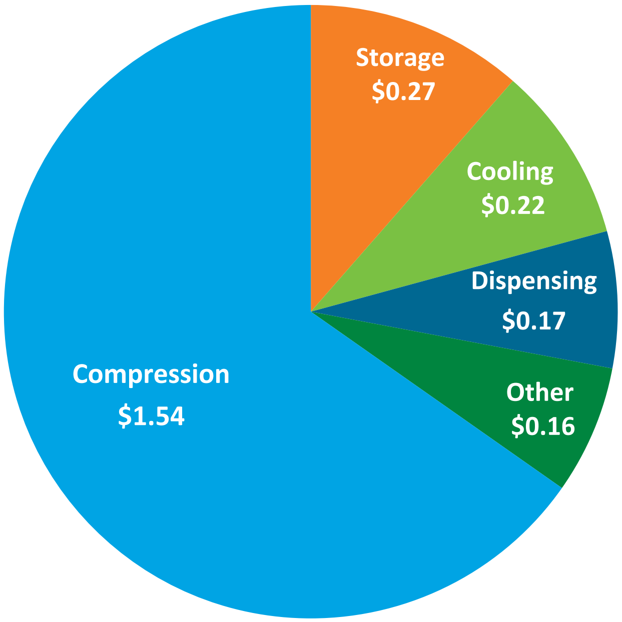
Dimitrios.Papageorgopoulos@ee.doe.gov

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

# Backup

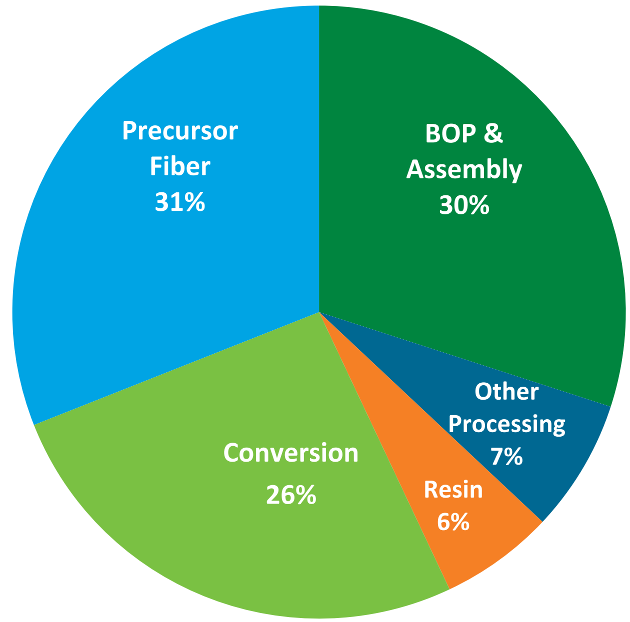
# Hydrogen Delivery and Onboard Storage Costs

## Delivery Costs: Compression, Storage and Dispensing (CSD) Cost Breakdown for the Pipeline Scenario ($2.40/kg total)** Storage




- Compression and Storage comprise approximately **75%** of CSD costs when delivered via pipeline

## On-board Storage Costs: 700 bar system cost breakdown at 500,000 systems/year




- Composite materials account for **>60%** of total storage tank system cost
- Carbon fiber precursor is the largest single cost contributor.

***Delivery costs: ~$2.40 to $5/gge vs. Target of $2/gge by 2020***
***Onboard 700 bar storage costs: ~$17/kWh vs. Target of $10/kWh by 2020*** *(high volume)*

# Hydrogen Production: Cost Status

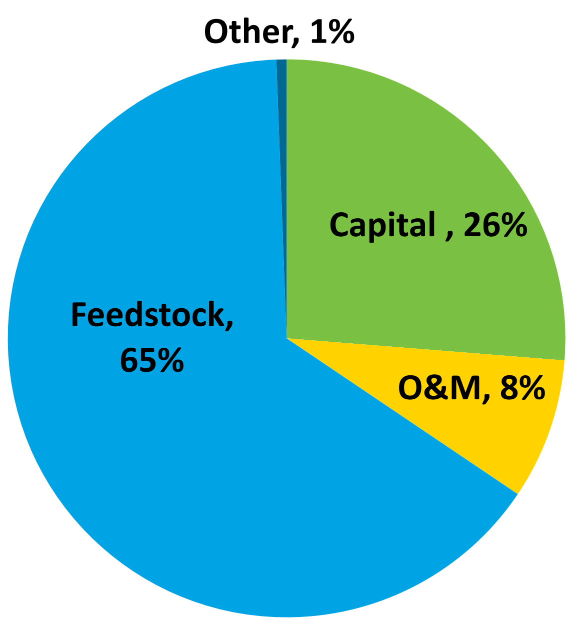


*Costs analyses provide information that allows for informed, prioritization of funding. Some results indicate major cost drivers are outside the scope of FCTO portfolio.*

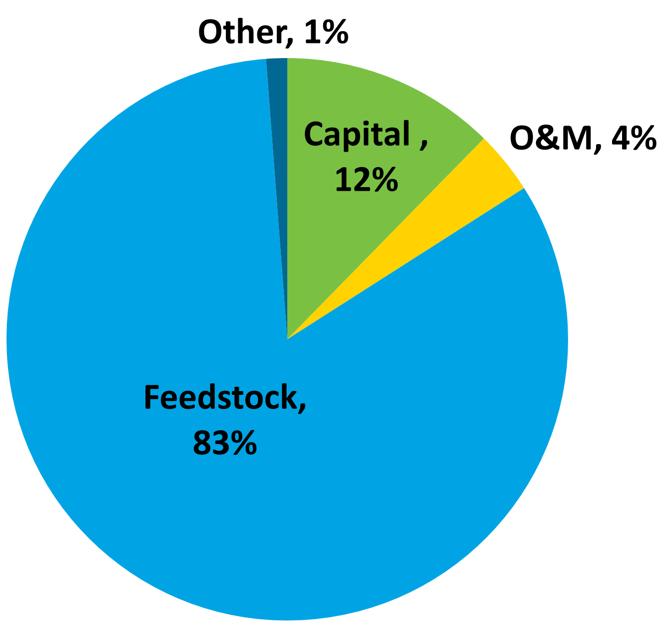
**Table 1. Current Status of Projected Pathway-Dependent Hydrogen Production Cost Ranges**

| Current $H_2$ Production Cost [6] | LOW $/kg | BASELINE $/kg | HIGH $/kg |
|---|---|---|---|
| **Distributed Pathways** | | | |
| Distributed PEM Electrolysis | 3.40 | 5.10 | 6.60 |
| Distributed Bio-Derived Liquids | 3.20 | 6.60 | 7.90 |
| **Central Pathways** | | | |
| Central PEM Electrolysis | 3.40 | 5.10 | 6.50 |
| Central Biomass | 2.10 | 2.50 | 4.20 |

## Distributed PEM Electrolysis




## BDL Reforming



# Current Status of $H_2$ Storage Technologies



| Storage Targets | Gravimetric kWh/kg (kg $H_2$/kg system) | Volumetric kWh/L (kg $H_2$/L system) | Costs $/kWh ($/kg $H_2$) |
|---|---|---|---|
| 2020 | 1.8 (0.055) | 1.3 (0.040) | $10 ($333) |
| Ultimate | 2.5 (0.075) | 2.3 (0.070) | $8 ($266) |

Full comprehensive sets of hydrogen storage targets can be found in the Program's Multi-year Research, Development and Demonstration Plan: http://energy.gov/sites/prod/files/2014/03/f12/storage.pdf

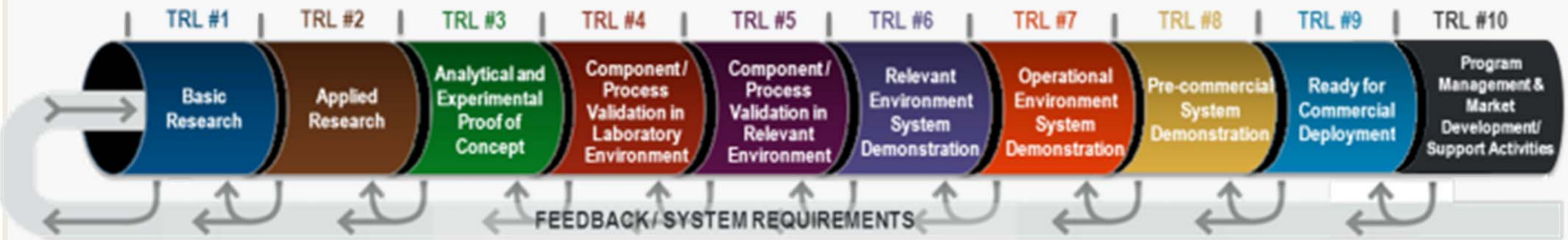
| Projected $H_2$ Storage System Performance (5.6 kg $H_2$ usable) | Gravimetric kWh/kg | Volumetric kWh/L | Costs* $/kWh |
|---|---|---|---|
| 700 bar compressed (Type IV) | 1.5 | 0.8 | 17 |
| 350 bar compressed (Type IV) | 1.8 | 0.6 | 13 |
| Metal Hydride ($NaAlH_4$/Ti) | 0.4 | 0.4 | 43 |
| Sorbent (MOF-5, 100 bar) MATI, LN2 cooling [HexCell, flow-through cooling] | 1.2 [1.2] | 0.7 [0.6] | 16 [15] |
| Chemical Hydrogen Storage (AB-50 wt.%) [$AlH_3$ – 60 wt.%] | 1.5 [1.1] | 1.4 [1.2] | 17 [22] |

- 700 bar and 350 bar compressed $H_2$ system projections based on 2013 Program Record #13010
- Materials-based system projections from Hydrogen Storage Engineering Center of Excellence (5/2015)

* Projected to 500,000 units / year

# Market Transformation Challenges

- To test emerging applications at the Technology Readiness Level (TRLs) 6-9 level to expand user and servicing expertise




- To test new technology applications in user operating conditions to establish baseline energy efficiency and reliability performance and determine commercial viability

**Examples:**

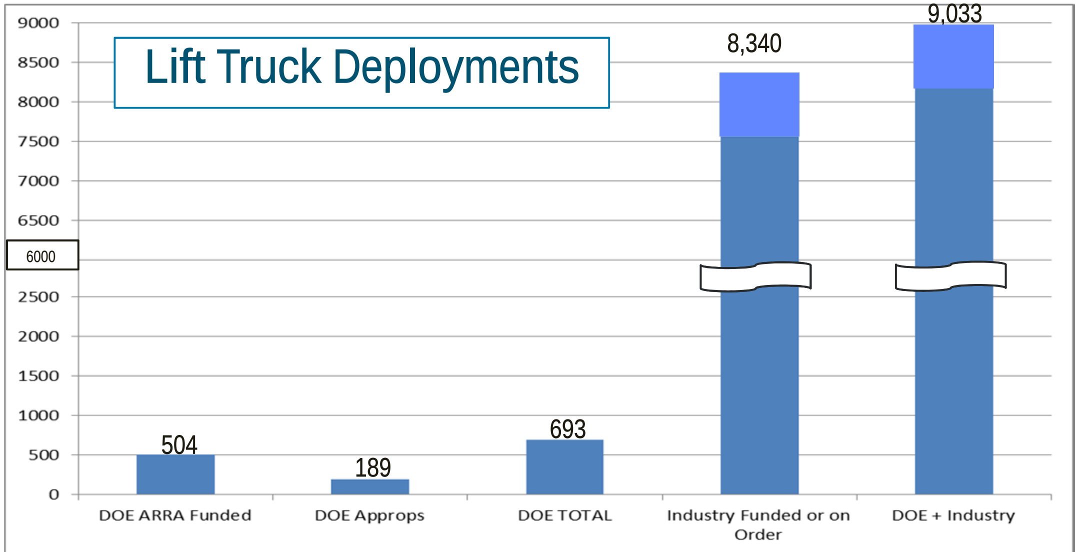
***A 1-kW fuel cell system providing power for this FAA radio tower near Chicago***

(Photo courtesy of ReliOn/Plug Power)

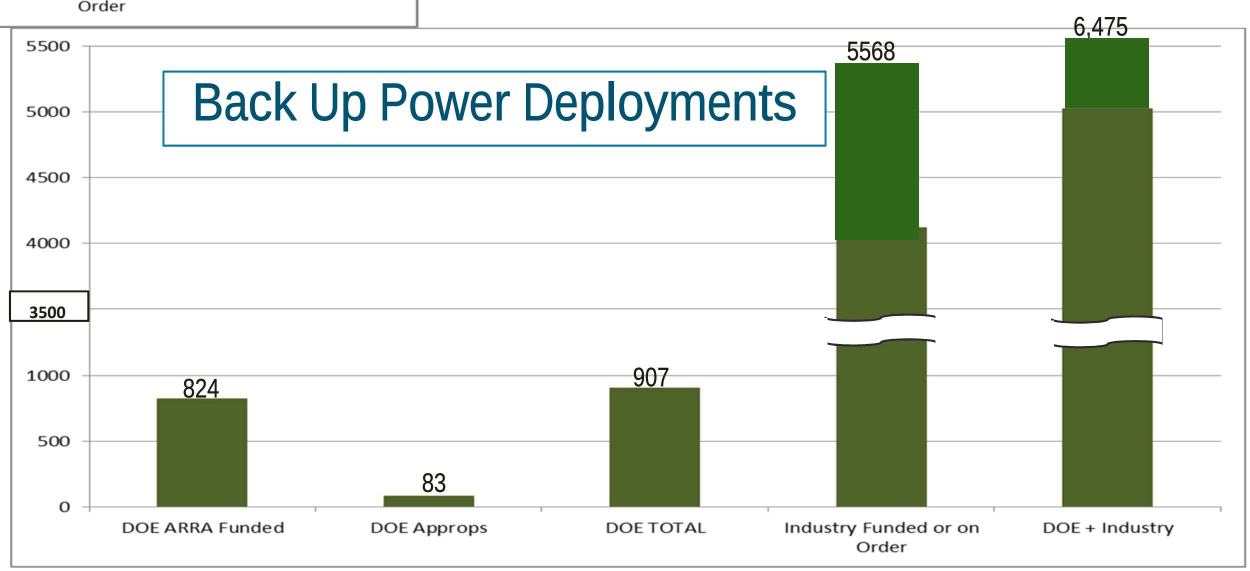
***Material Handling Equipment at work in U.S. airports***
(Photo courtesy of Hydrogenics)

# Market Transformation Deployments

***DOE investment in lift trucks and back up power has lead to thousands of industry installations.***



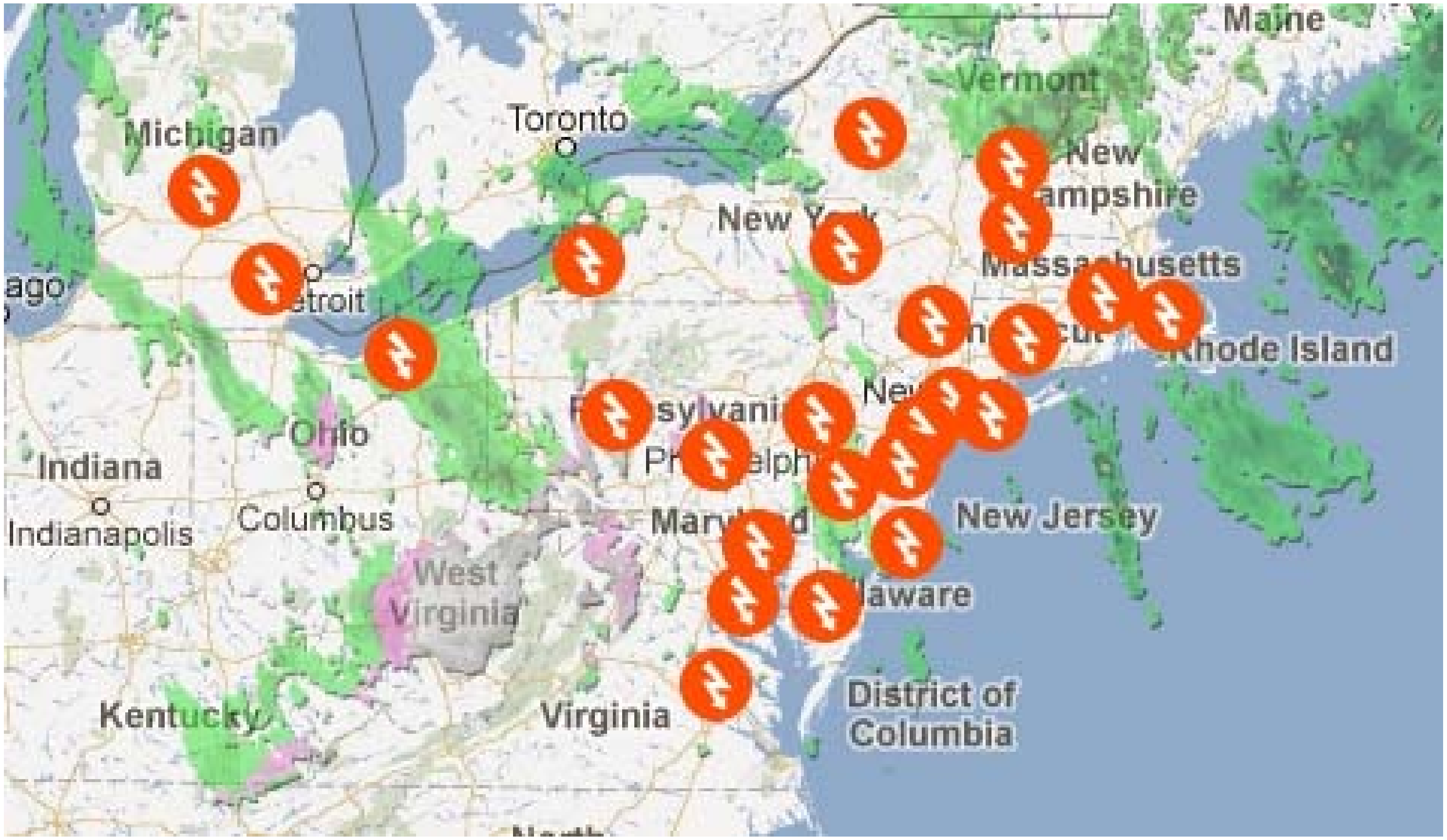

The successful deployment of nearly 700 DOE fuel cell material handling units has led to over 13,500 industry installation and on order units with no DOE funding.




The funding of 907 DOE fuel cell backup power systems has led to over 5,500 industry installations and on-order backup power units with no DOE funding.

# Electricity Grid Outages

- 8.5 million power outages reported across 21 states
- 65% of New Jersey utility customers lost power – 2.6 million homes and businesses
- 25% of West Virginia utility customers lost power



# Accomplishments: MHE Operation Summary 2009 Q4 – 2014 Q3

Validation of MHE is based on real-world operation data from high-use facilities.

**2,683,567**
Operation hours

**352,527**
Hydrogen fills

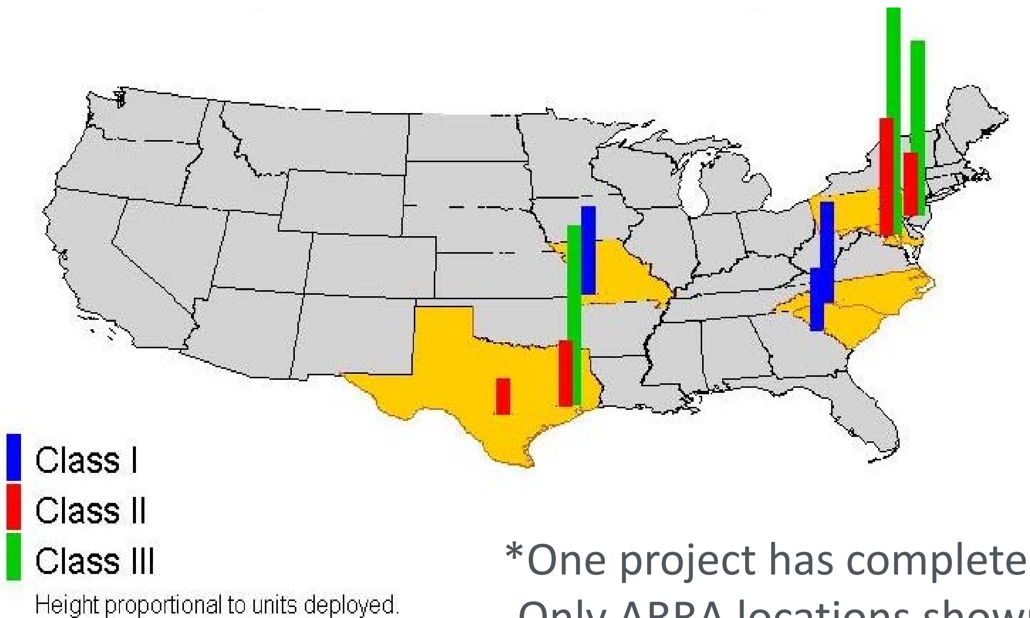
**720**
Units in operation*

**3.7**
Average operation hours between fills

**287,967**
Hydrogen dispensed in kg

**0.7**
Average fill amount in kg

**2.5**
Average fill time in minutes




*One project has completed. Only ARRA locations shown