

# U.S. DOE Fuel Cell Technologies Office Overview of Fuel Cell Power Systems and Hydrogen Infrastructure

U.S. DEPARTMENT OF  
**ENERGY**

Energy Efficiency &  
SAND2013-4698C



The U.S. Department of Energy Fuel Cell  
Technologies Office  
June 13, 2013

**Joe Pratt**  
Sandia National Laboratories

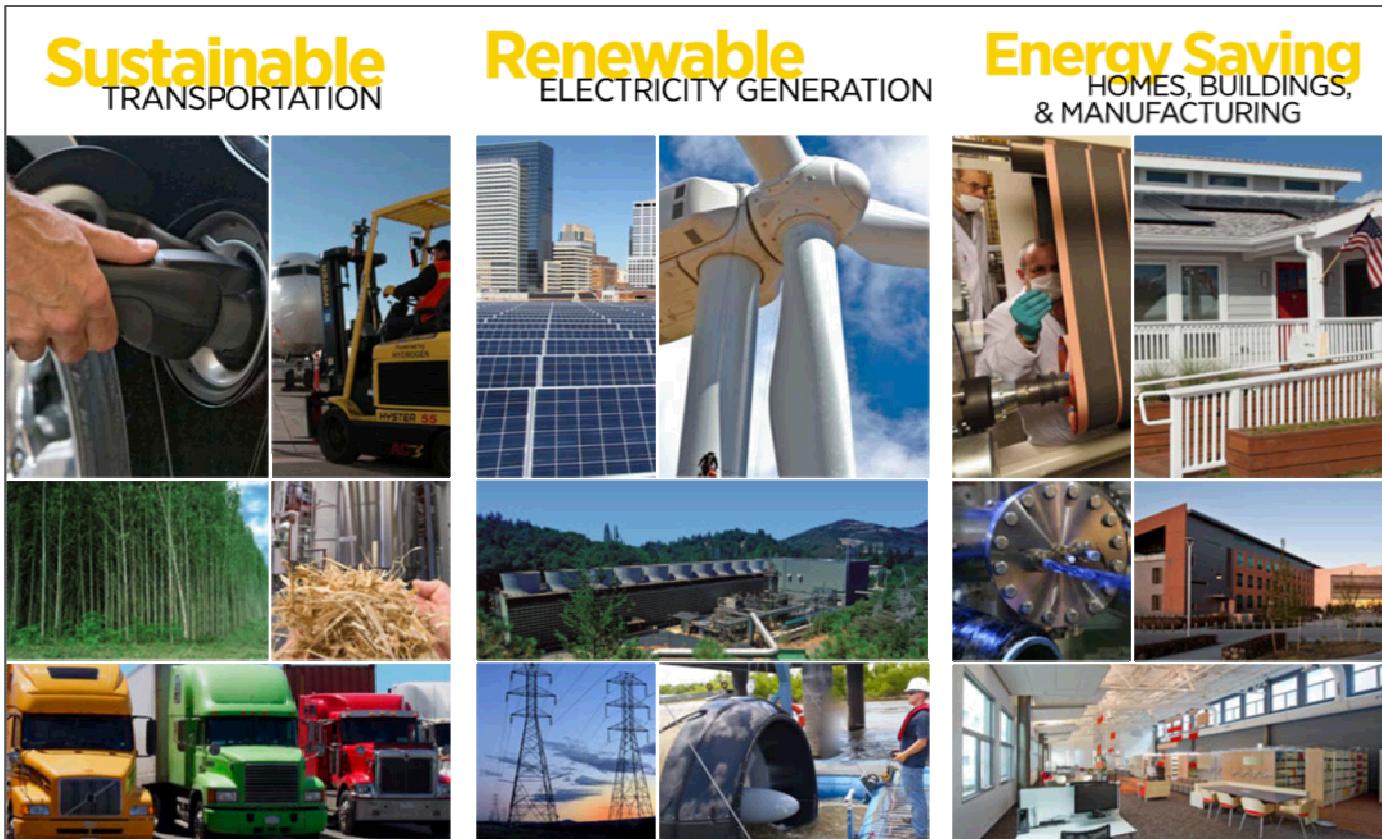
## Overview – DOE Fuel Cell Technologies Office and Commercial Fuel Cell Technologies

### Fuel Cells for Airport and Airplane Applications

- Fuel Cell Mobile Light Stand
- Fuel Cell Powered Generators
- Fuel Cell Motive Power
  - Airport GSE
  - Heavy Duty Trucks
  - Medium Duty Trucks
  - Truck Refrigeration Units
- FAA Incentive Programs
- Fuel Cells On-Board Airplanes

### Conclusion

# OVERVIEW



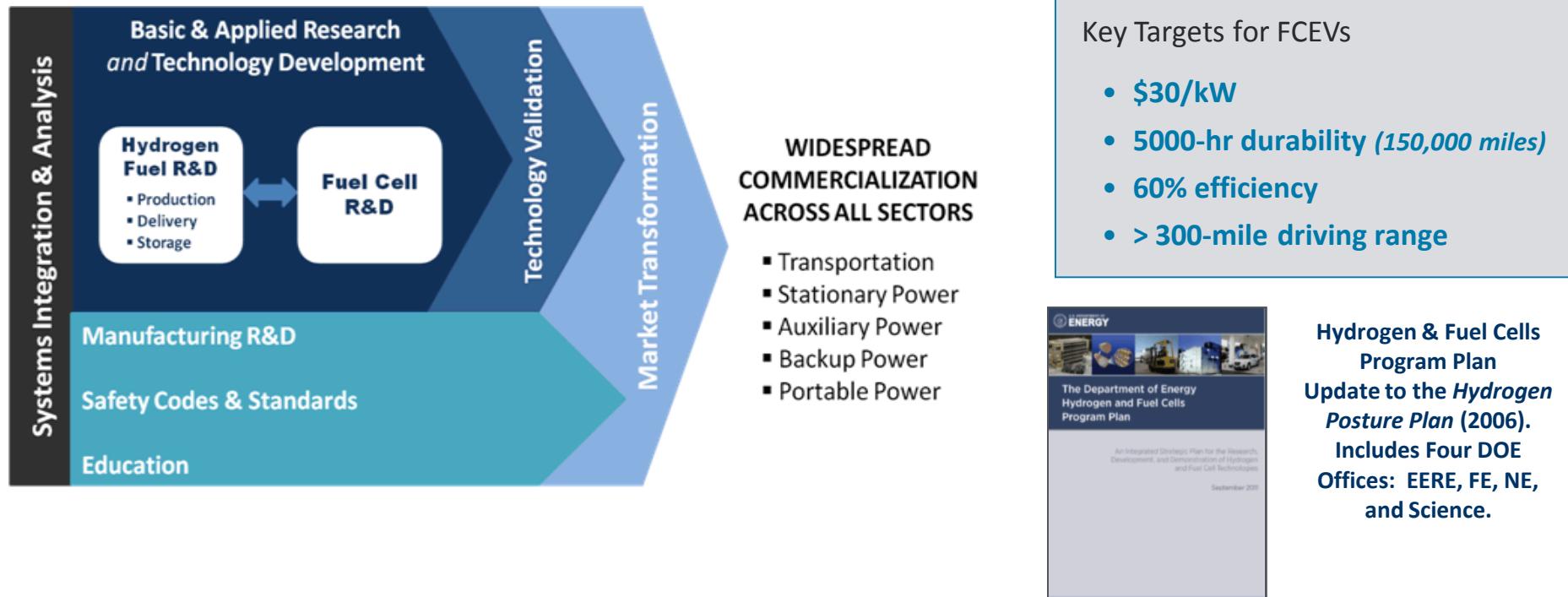
## EERE's National Mission

To create American leadership in the global transition to a clean energy economy through:

- 1) High-impact research, development, and demonstration to make clean energy as affordable and convenient as traditional forms of energy
- 2) Breaking down barriers to market entry

**Mission:** Enable widespread commercialization of a portfolio of hydrogen and fuel cell technologies through applied research, technology development and demonstration, and diverse efforts to overcome institutional and market challenges.

**Key Goals:** Develop hydrogen and fuel cell technologies for early markets (stationary power, lift trucks, portable power), mid-term markets (CHP, APUs, fleets and buses), and long-term markets (light duty vehicles, aircraft APU).



**DOE has a long-standing and substantial commitment to hydrogen and fuel cells:**

- **Nearly 300 projects currently funded by DOE at companies, national labs, and universities/institutes**
- **More than \$1.3 billion invested from FY 2007 to FY 2012 across four DOE offices**

# Summary: Program Impact

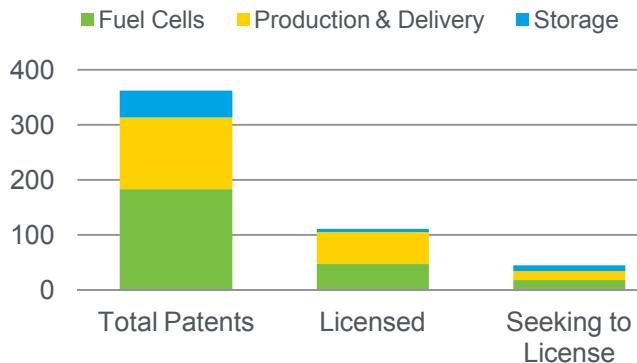
**DOE FCT funding has led to 363 patents, 35 commercial technologies and 65 emerging technologies.**

**Example of Impact:** ~\$70M in funding for specific projects was tracked – and found to have led to nearly \$200M in industry investment and revenues.

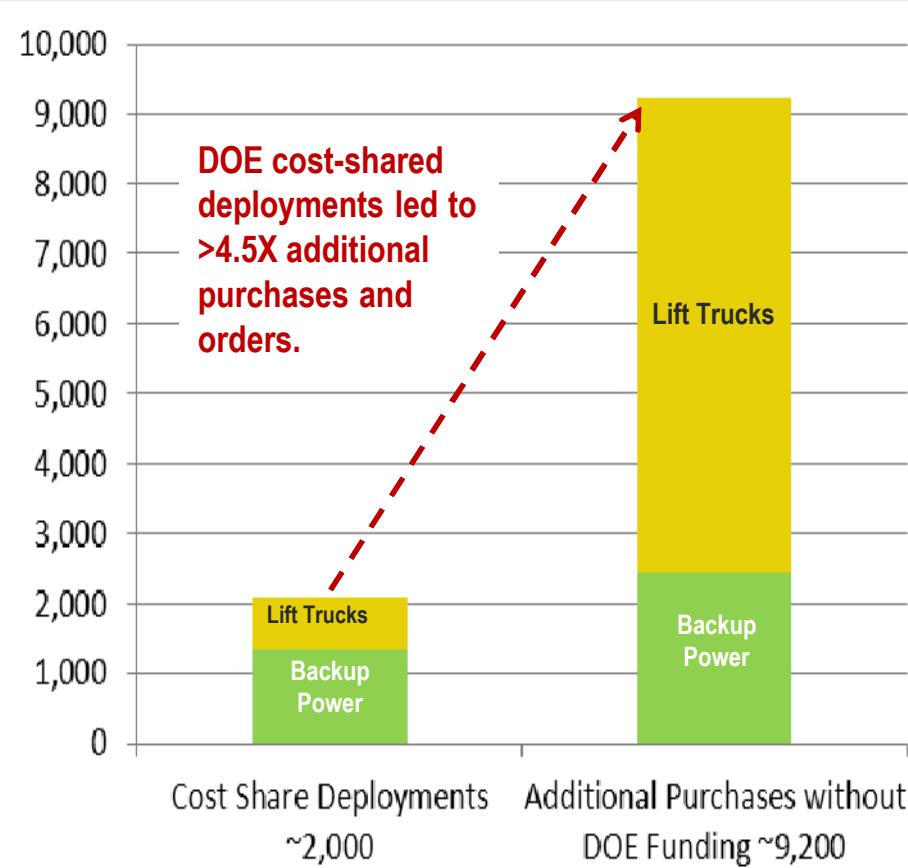
## DOE FCT funding has enabled:

- > 80% cost reduction in PEM fuel cells since 2002, > 35% since 2008
- Reduction in Pt by a factor of 5 since 2005
- > Double the durability since 2006
- > 80% cost reduction in electrolyzer stacks in the last decade

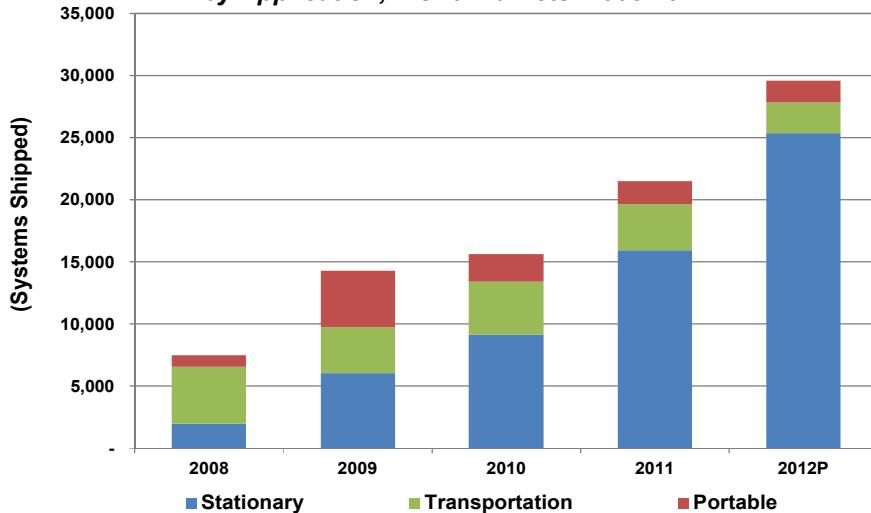
### Patents Developed with FCT Funding



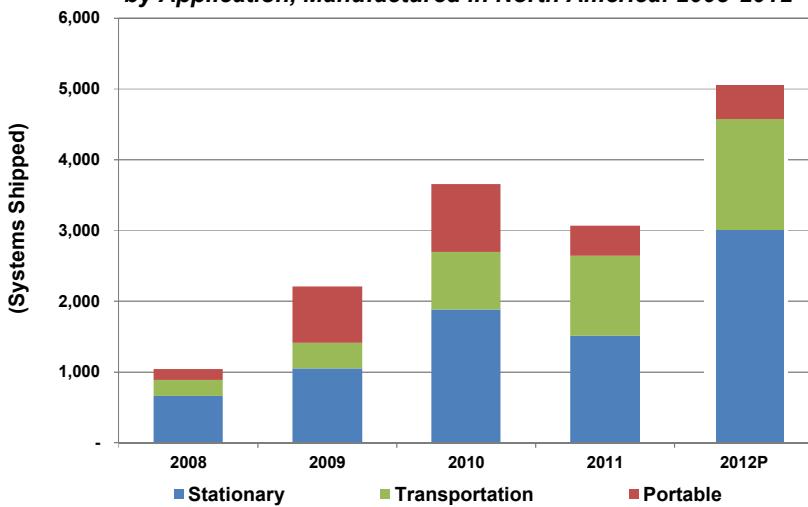
### Leveraging DOE Funds: Government as “catalyst” for market success of emerging technologies.



**Fuel Cell Systems Shipped**  
by Application, World Markets: 2008-2012



**Fuel Cell Systems Shipped**  
by Application, Manufactured in North America: 2008-2012



Source: Navigant Research

## Market Growth

Fuel cell markets continue to grow  
48% increase in global MWs shipped  
62% increase in North American  
systems shipped in the last year

## The Market Potential

Independent analyses show global markets  
could mature over the next 10–20 years,  
producing revenues of:

- \$14 – \$31 billion/year for stationary power
- \$11 billion/year for portable power
- \$18 – \$97 billion/year for transportation

Several automakers have  
announced commercial FCEVs in  
the 2015-2017 timeframe.

For further details and sources see: *DOE Hydrogen and Fuel Cells Program Plan*, [http://www.hydrogen.energy.gov/pdfs/program\\_plan2011.pdf](http://www.hydrogen.energy.gov/pdfs/program_plan2011.pdf);  
FuelCells 2000, Fuel Cell Today, Navigant Research

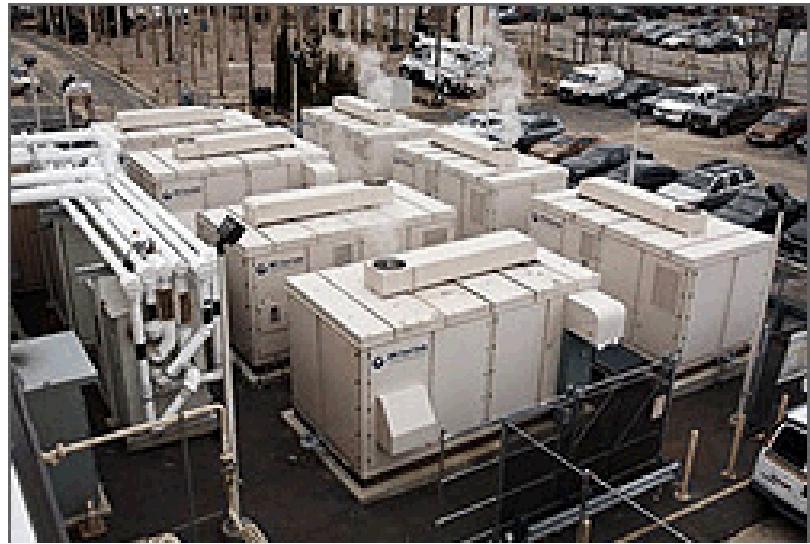
## Electricity Grid

- In the US, 22 of the 23 400 kW UTC Power (ClearEdge) 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 Systems installed at Sprint Sites operated throughout entire outage duration

### *ClearEdge Power Fuel Cells at Verizon*



### *Altery Fuel Cell*



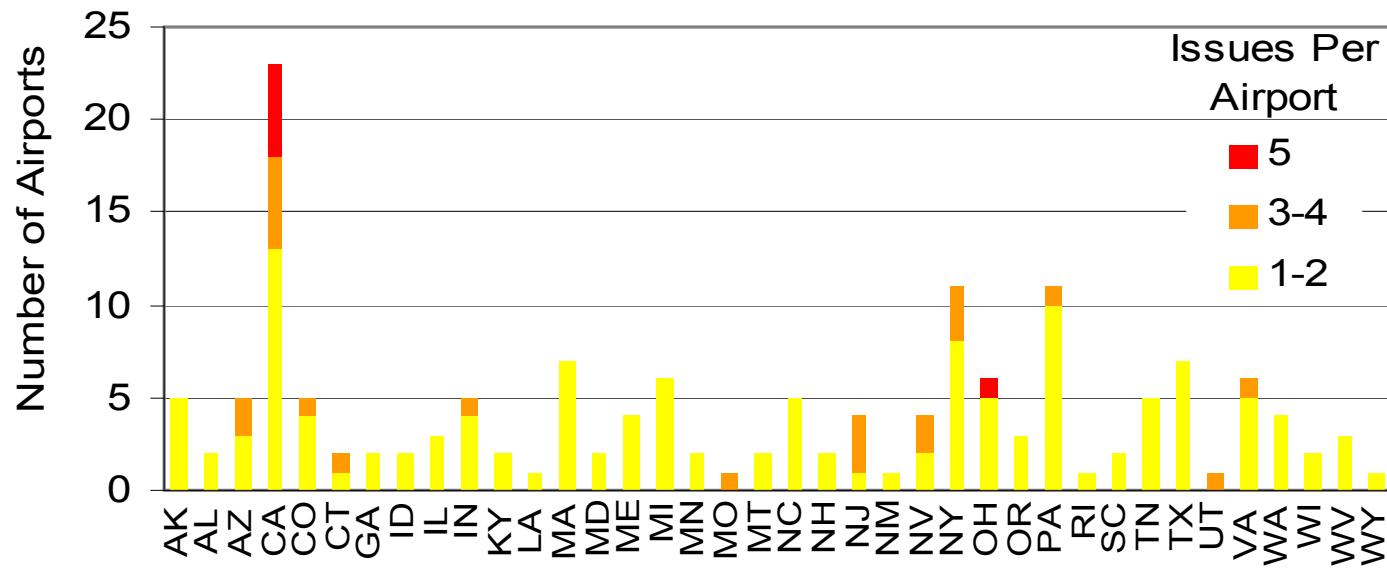
### *ReliOn Fuel Cells at Sprint*



# FUEL CELLS FOR AEROSPACE AND AIRPORT APPLICATIONS

*Many U.S. airports are in emissions non-compliance or maintenance zones*

## Non-Attainment / Maintenance Emission Issues

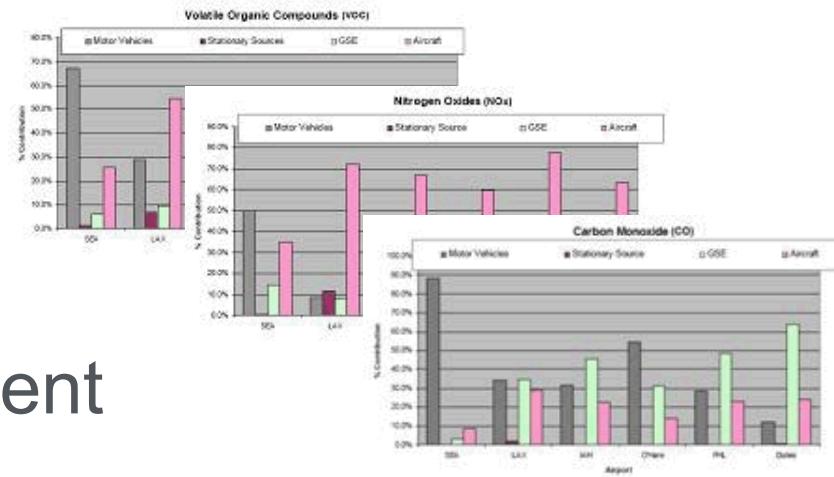


- Local & national regulations are applicable
- Airport revisions require emissions management

Source: Joe Breit, Associate Technical Fellow, Boeing Commercial Airplanes, "Fuel Cell GSE and its Fabric in the Airport Environment," SAE 2012 Aerospace & Defense Ground Support Equipment Conference

## Multiple sources contribute to airport emissions inventories

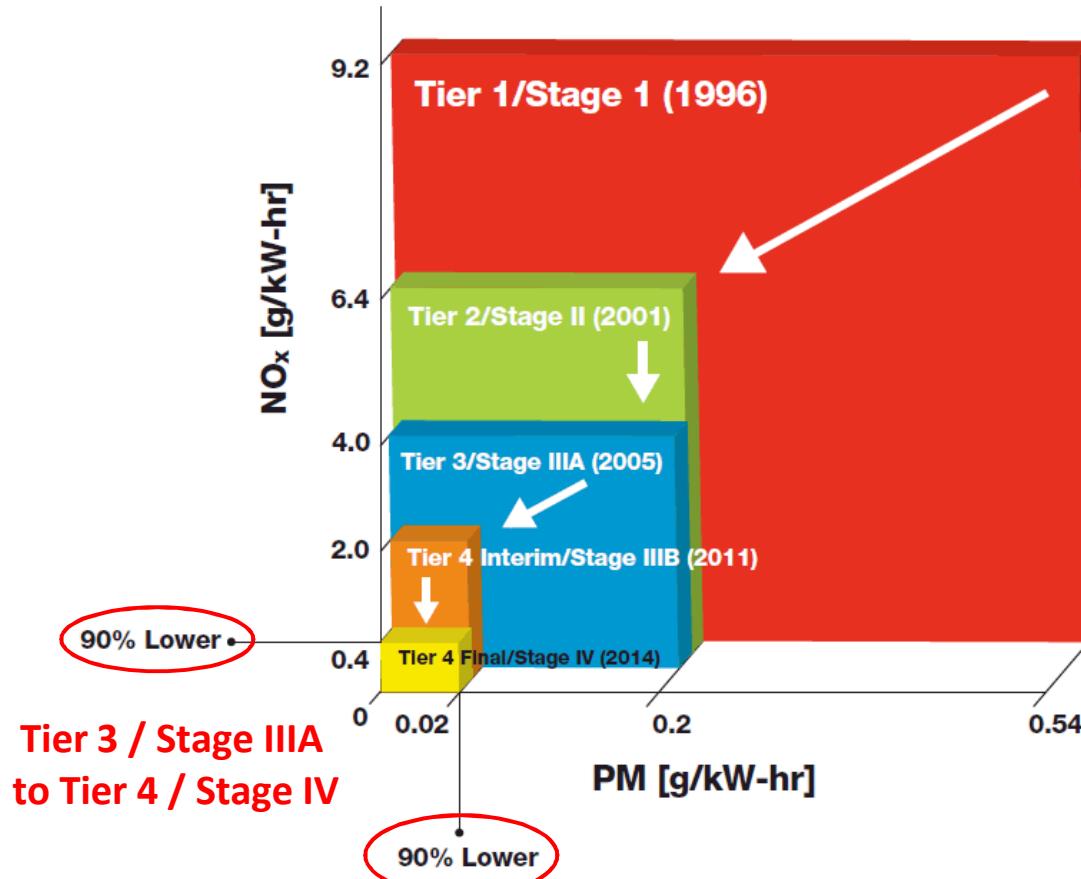
- Local transportation
- Facility
- Fuel tanks
- Airplanes
- Ground support equipment
- ...



- LAX Master Plan requires zero or reduced emission GSE
- Similar strategies are in place or evolving at other airports

Source: Joe Breit, Associate Technical Fellow, Boeing Commercial Airplanes, "Fuel Cell GSE and its Fabric in the Airport Environment," SAE 2012 Aerospace & Defense Ground Support Equipment Conference

*Ever-tightening off-road diesel emission regulations increase engine costs.  
Fuel cells inherently meet EU and EPA regulations.*



Graphic by  
**Cummins**  
**Emissions**  
**Solutions**

Notes:

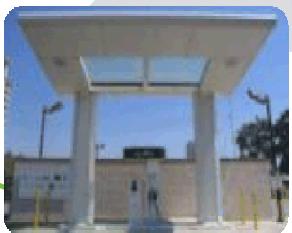
- EU Stage IV standard for PM is  $0.025 \text{ g/kW}\cdot\text{hr}$  (vs.  $0.020 \text{ g/kW}\cdot\text{hr}$  for US EPA)
- Tier IV / Stage IV graphic represents the 56-560 kW engine range. Prior to Tier IV / Stage IV, emissions regulations are shown for the 130-560 kW range – for lower powers the regulations were slightly more relaxed.
- Chart is a simplification and does not completely represent various compliance options available to manufacturers.

## Shipboard APUs



Air Cargo Loader

## FC MHE



## Fuel Cell Bus



Perimeter H2  
Fueling Station  
(Public Access)



eMDV

## FCEV LDV

## Aircraft APUs



Class 8  
eTruck



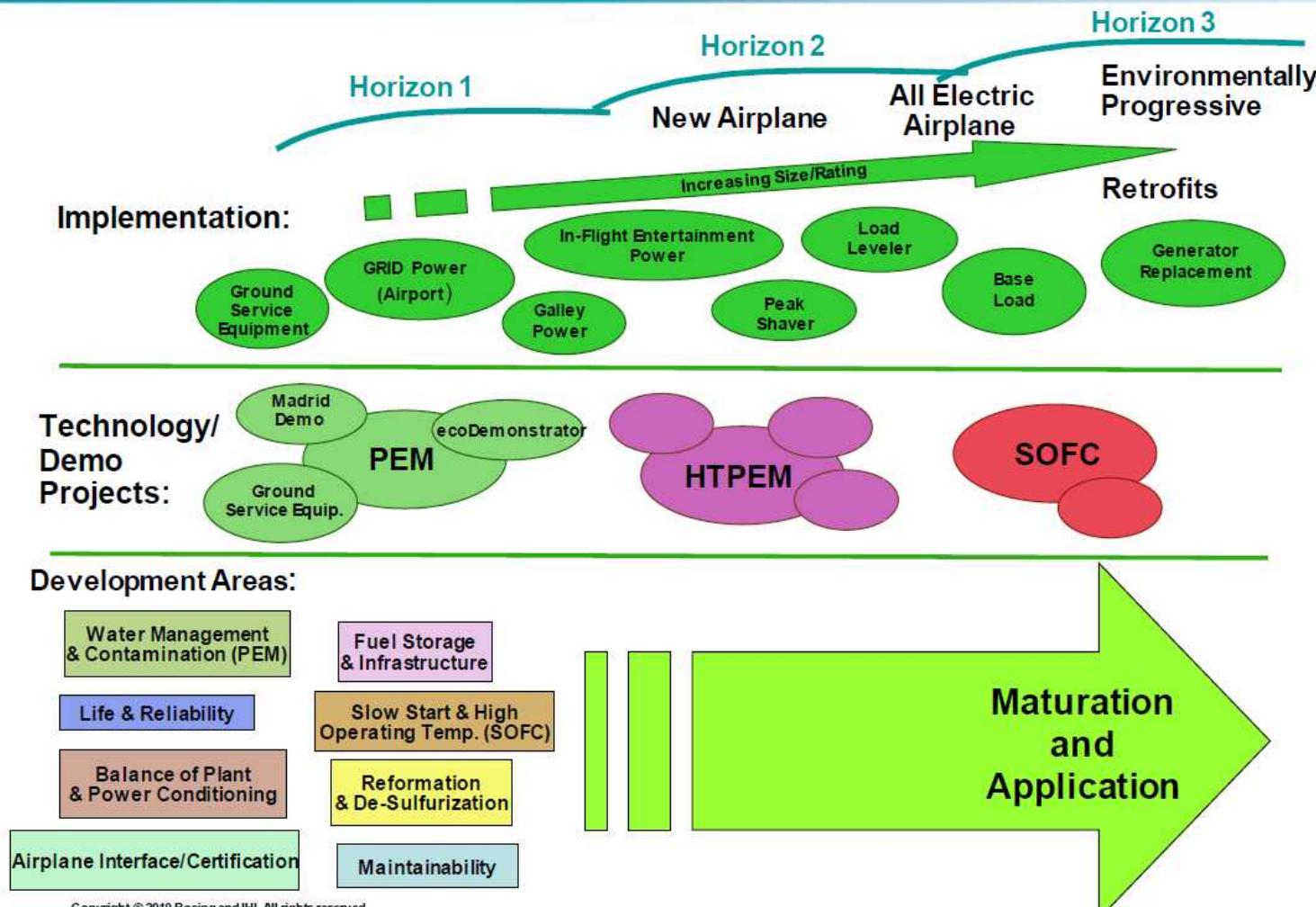
Refr.  
Truck  
FC APU



Terminal  
Tractor

**Today's Prices (So Cal)**  
Gasoline \$4.04/gal  
Diesel \$4.26/gal  
Hydrogen ~\$5-9/gge

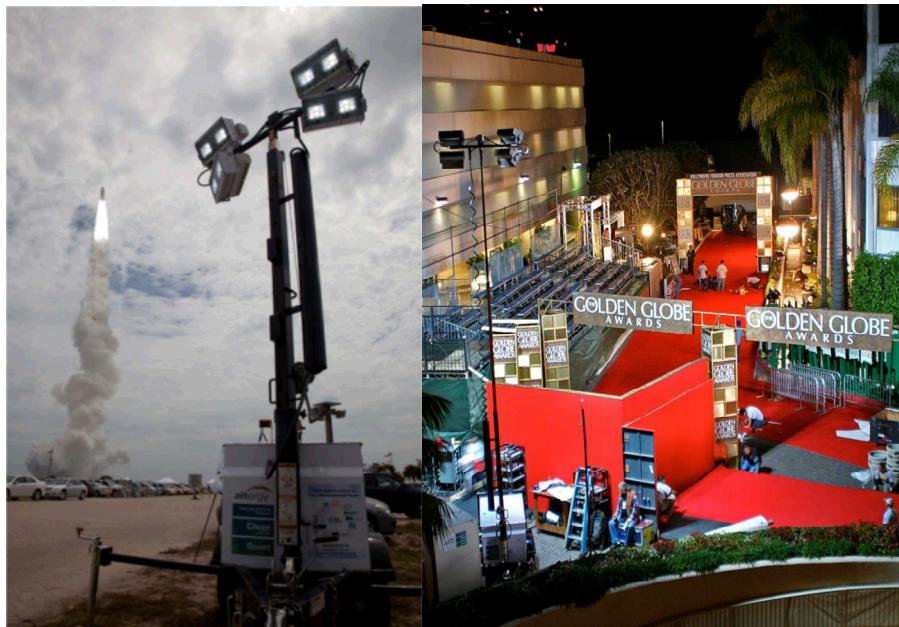
## Today's roadmap



Copyright © 2010 Boeing and IHI. All rights reserved.

Source: Joe Breit, Associate Technical Fellow, Boeing Commercial Airplanes, "Fuel Cell GSE and its Fabric in the Airport Environment," SAE 2012 Aerospace & Defense Ground Support Equipment Conference

Combining modern PEM fuel cells and high efficiency LED lighting, fuel cell mobile lighting provides superior performance.



Fuel Cell Mobile Light at Shuttle Launch and Golden Globes

## Mobile Lighting Capabilities & Benefits

- *~66 hour duration (lighting)*
- *Indoor or outdoor use*
- *50 yds X 75 yds area of illumination*
- *Option for ~3kW AC power*
- *Quiet: 43 dB noise level at 23 ft*
- *>70% reduction in GHG emissions*
- *Target Markets (est. ~ \$250 million sales/year): Construction (highways, buildings, etc.); Seaports/Airports (industrial campuses, tarmacs); Entertainment Industry (remote or temporary locations)*

## Next Steps

- Real World deployments at SFO, NASA, State DOT (CA, CT), and the entertainment industry
- Continue to improve technology
- Multiquip to commercialize in 2013

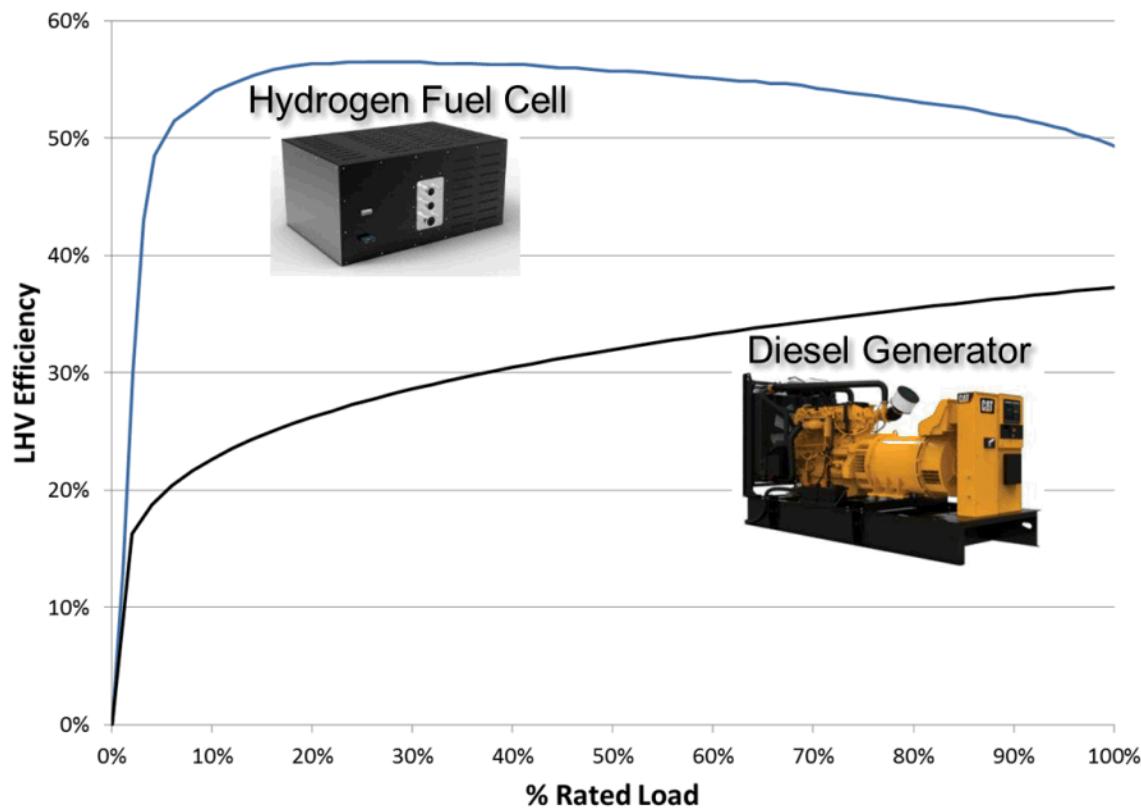
# Fuel Cell Mobile Generators

U.S. DEPARTMENT OF  
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Energy Efficiency &  
Renewable Energy

Zero emission fuel cell generators can replace diesel gen sets used in airports and other markets. Fuel cells have higher efficiency and perform better at part loads vs. diesel gen sets.

***Higher efficiency = Less fuel burned***



**Multiquip H2G Fuel Cell Generator  
5 kW, Altery Fuel Cell (zero-emission)**



**Multiquip SG1400 Studio Generator  
160 kW, Cummins QSB7-G5 (Tier 3)**



**Hobart 72 kW Aviation  
GPU, Cummins QSB (Tier 3)**

# Fuel Cell Airport GSE Demonstrations

U.S. DEPARTMENT OF  
**ENERGY**

Energy Efficiency &  
Renewable Energy

## Background/Status:

- Awarded January 31, 2013
- Fuel Cell Powered Airport Ground Support Equipment (GSE) Deployment
- 3 years, \$2.5M DOE share, 50% cost share, two phases:
  - Product development and testing
  - Demonstrations under “real world” operating environments
- 15 Baggage Tow Tractors with ~20kW fuel cell systems
- 10 units at FedEx in Memphis, TN
- 5 units at FedEx in Oakland, CA

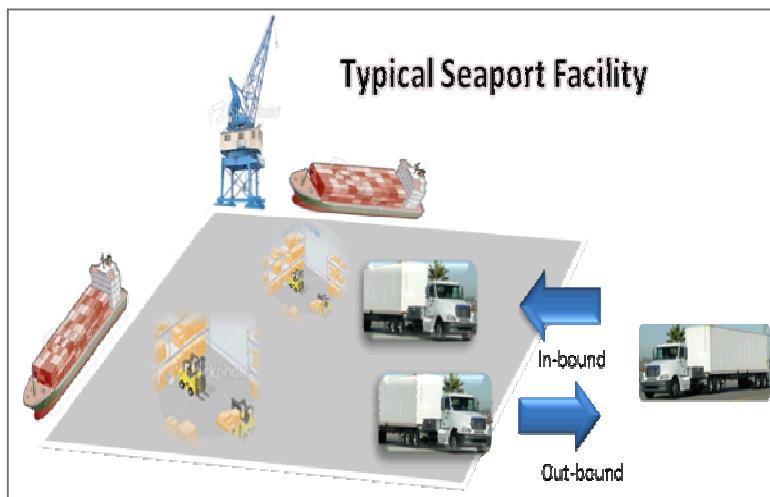


	Near Term	50 % Total Market
<b>USA Market Potentials</b>	1,400	31,000
<b>Diesel reduction (gal/yr)</b>	8,000,000	~ 177,000,000
<b>NOx, PM, HC, CO, (MTs/yr)</b>	2,875	~ 63,250
<b>CO2 (MTS/yr)</b>	80,000	~ 1,760,000

# C8 and C6 Electric Trucks

## Background/Status:

- **Three Projects Awarded August 8, 2012:**
  - Zero emission cargo transport in areas of severe non-attainment and severe traffic congestion
  - One year development and two-year demonstration phases
- **South Coast Air Quality Management District (CA):**
  - \$9.3M (\$4.1M DOE share) for 13 zero-emission electric C8 drayage trucks
  - Includes 9 battery electric and 4 fuel cell hybrid-electric trucks
  - Manufacturers: Balqon (3), TransPower (4), US Hybrid (2), and Vision Industries (4)
- **Houston Area Council (TX):**
  - \$7.7M (\$3.4M DOE share) for 20 fuel cell hybrid-electric C8 drayage trucks
  - Manufacturer: Vision Industries
- **Houston Area Council (TX):**
  - \$5.2M (\$2.4M DOE share) for 30 battery-powered C6 delivery trucks
  - Manufacturer: Smith EV



**Vision Industries C8 Fuel Cell Hybrid-Electric Drayage Truck**

## Background/Status:

### DOE Notice of Intent (DE-FOA-0000922):

#### Topic 1: Demonstration and Deployment of Fuel Cell Hybrid-Electric Medium-Duty Trucks

- On-board, fuel cell hybrid- electric powered Class 3-6 medium-duty trucks (MD eTrucks) to substantially increase the zero emission driving range.
- Targets of interest are commercial vehicles that deliver cargo, parcels, or packaged freight on daily routes and return to their distribution centers at the end of their daily operations.
- DOE envisions up to two financial assistance awards in the form of cooperative agreements, with a period of performance of up to five years for each award.
- If a FOA is released, DOE funding up to \$3M per award, 50% minimum cost share required.

<https://eere-exchange.energy.gov/Default.aspx#Foald25726dad-5980-4925-b74d-79a7782c59f2>



**Smith Newton Battery-Electric Van**



**Mercedes-Benz FCV Sprinter Van**

# Truck Refrigeration APUs

## Background/Status:

- Awarded January 31, 2013
- \$1.3M (\$0.7M DOE share)
- Objective to enable the market penetration of fuel cell-powered transport refrigeration units (TRUs) by:
  - Establishing the business case for the product;
  - Developing a working prototype, based on a Class 8 trailer application
  - Demonstration performance in real-world operating conditions
- Stakeholders include Pacific Northwest National Laboratory, Nuvera Fuel Cells, H-E-B, Sysco, Ingersoll Rand (Thermo King)

U.S. fleet total ~ 300,000 units + 300,000 Tractor Trailers  
Customer surveys show ~ 1:1 ratio of Truck Ref. Unit (TRU) to Material Handling Equipment (MHE) equipment  
Potential near-term FC TRU APU market of 2,700 units, based on ARRA fuel cell MHE deployments in food industry

- 10-year average life required (prior to stack replacement)



**Sysco C8 Refrigeration Truck**



**H-E-B C8 Trailer with Refrigeration Unit**

- **Voluntary Airport Low Emission Program (VALE)**
  - Created by 2003 *Vision 100* legislation
  - Implemented in cooperation with EPA
  - Applies to several airport emission sources
- **Zero Emission Airport Vehicle and Infrastructure Program (ZEV)**
  - Authorized in the *2012 FAA Reform and Modernization Act*
  - Section 511 of H.R. 658 provides specifics

# VALE Project Categories

## Renewable Energy

- Geothermal (4%)
- Solar (9.4%)

13.4%

14.3%

15.9%

56.4%

## Other Stationary

- HVAC and pollution control devices (10.4%)
- Underground fuel hydrant and vehicle elimination (3.9%)

- Gate Electrification**
- Ground Power
  - Pre-Conditioned Air (PCA)

## Low Emission Vehicles

- GSE (8.5%)
- HD on-road (7.1%)
- LD on-road (0.3%)

Eligibility Requirements: Commercial service airports in EPA-designated non-attainment or maintenance areas. Grants provide funds for 75%-100% incremental cost of vehicle. Retrofits are allowed. Equipment must be airport-owned to be eligible.

- New for 2013
- Preference given to air quality problem areas but all public-use airports may apply
- Grant funds 50% of vehicle and infrastructure costs
- Traditional grant-in-aid funding rules apply
- Vehicle eligibility
  - Zero-emission only (all electric or hydrogen)
  - On-road vehicles
  - New vehicles (no retrofits allowed)
  - Airport-owned and airport-dedicated

## Analysing the Use of Fuel Cells on Commercial Aircraft



Funded by DOE-EERE In Collaboration with Boeing



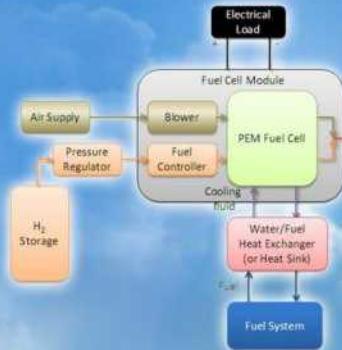
### Applications



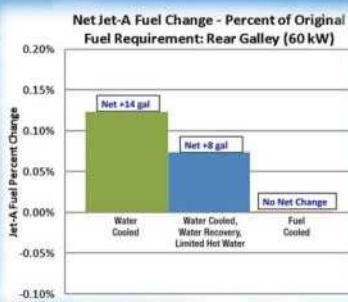
### Focus on 787 Dreamliner

Dual-Class Configuration Short to Medium Range  
291 Passengers, 24 First Class Seats, 267 Economy Class Seats

### What We Learned



The aircraft fuel should be used to dissipate fuel cell waste heat to minimize needed fuel.



### Approach



Compare



Find



For further information contact Joe Pratt, Sandia National Laboratories, (925) 294-2133, [jwpratt@sandia.gov](mailto:jwpratt@sandia.gov)  
Lennie Klebanoff, Sandia National Laboratories, (925) 294-3471, [lekleba@sandia.gov](mailto:lekleba@sandia.gov)

Pratt et al., *Applied Energy* 101, 776-796

# CONCLUSION

## Summary

- Many fuel cell product applications exist today – and more can be commercialized in the near term. Successful launch of these products will provide both air quality and GHG improvements at airport locations, provide a value proposition to the customers, and supplement the pathway toward the long-term goals, such as APUs on-board aircraft;
- Focusing fuel cell deployments at airports using multiple, early market vehicle applications will help reduce the cost of hydrogen fuel;
- Deploying fuel cells in fleet applications minimizes the refueling infrastructure conundrum;
- Government fuel cell deployment efforts and incentive programs will help catalyze industry and contribute manufacturing economies of scale and the resulting lower cost capital equipment.





## Pathways to Commercial Success: Technologies and Products Supported by the Fuel Cell Technologies Program

By PNNL, <http://www.pnl.gov/>

See report: [http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways\\_2011.pdf](http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2011.pdf)

## The Business Case for Fuel Cells 2011: Energizing America's Top Companies

By FuelCells2000, <http://www.fuelcells.org>

See report:

[http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/business\\_case\\_fuel\\_cells\\_2011.pdf](http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/business_case_fuel_cells_2011.pdf)

## State of the States 2011: Fuel Cells in America

By FuelCells2000, <http://www.fuelcells.org>

See report:

<http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/stateofthestates2011.pdf>

## Annual Merit Review & Peer Evaluation Proceedings

*Includes downloadable versions of all presentations at the Annual Merit Review*

[http://www.hydrogen.energy.gov/annual\\_review11\\_proceedings.html](http://www.hydrogen.energy.gov/annual_review11_proceedings.html)

## Annual Merit Review & Peer Evaluation Report

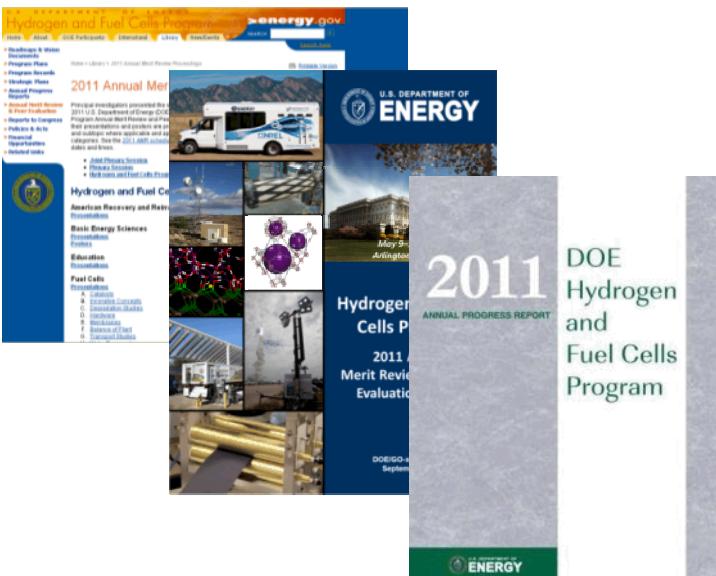
*Summarizes the comments of the Peer Review Panel at the Annual Merit Review and Peer Evaluation Meeting*

[http://hydrogen.energy.gov/annual\\_review11\\_report.html](http://hydrogen.energy.gov/annual_review11_report.html)

## Annual Progress Report

*Summarizes activities and accomplishments within the Program over the preceding year, with reports on individual projects*

[www.hydrogen.energy.gov/annual\\_progress.html](http://www.hydrogen.energy.gov/annual_progress.html)



# Thank You

[Peter.Devlin@ee.doe.gov](mailto:Peter.Devlin@ee.doe.gov)

[Greg\\_moreland@sra.com](mailto:Greg_moreland@sra.com)

New energy data initiative to share the latest energy information and data. Please visit:

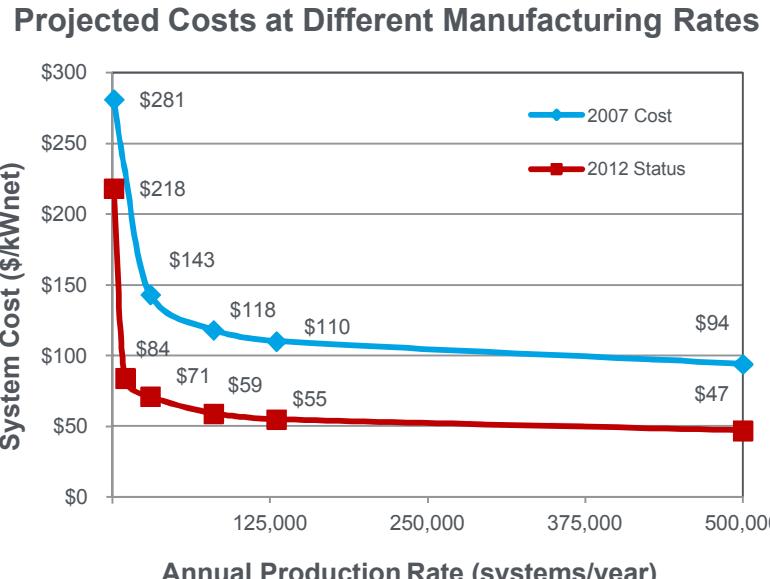
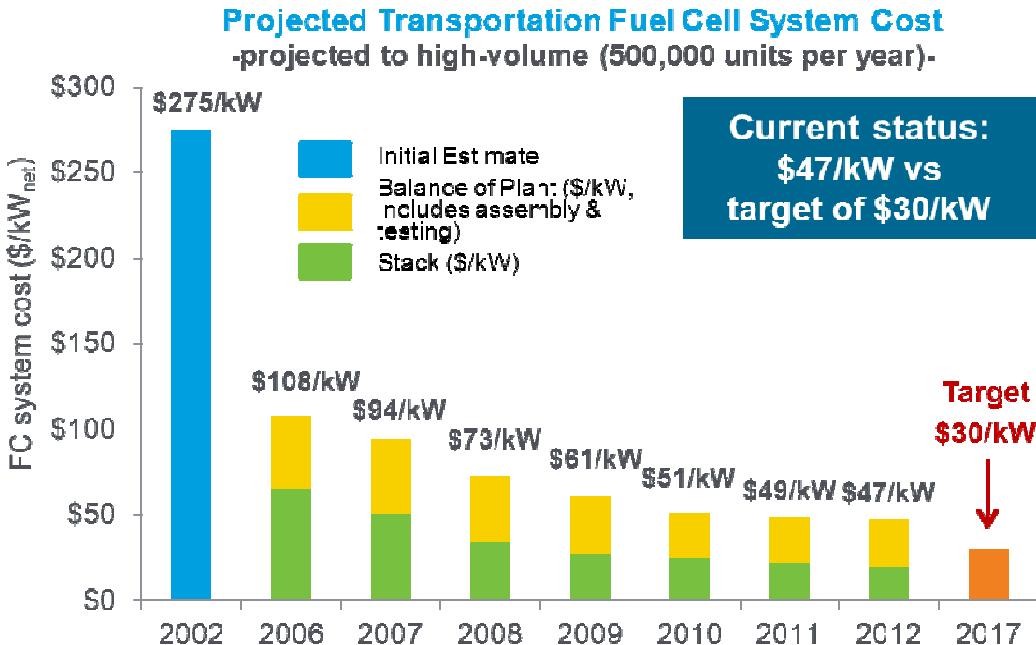
<http://en.openei.org/wiki/Gateway:Hydrogen>

**hydrogenandfuelcells.energy.gov**

# BACKUP

## Reduced high-volume cost of automotive fuel cells to \$47/kW (2012)\*

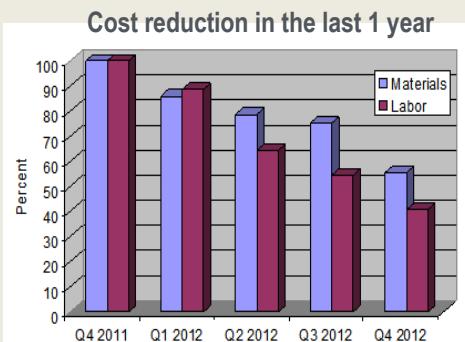
**More than 35% reduction since 2008, more than 80% reduction since 2002**



\*Based on state-of-the-art lab scale technology projection to high-volume manufacturing (500,000 units/year).- Strategic Analysis

**Solid oxide fuel cell (kW-scale)**  
R&D led to 75% weight reduction and >80% volume reduction since 2004.

Reduced cost of SOFCs 5X since 2004.

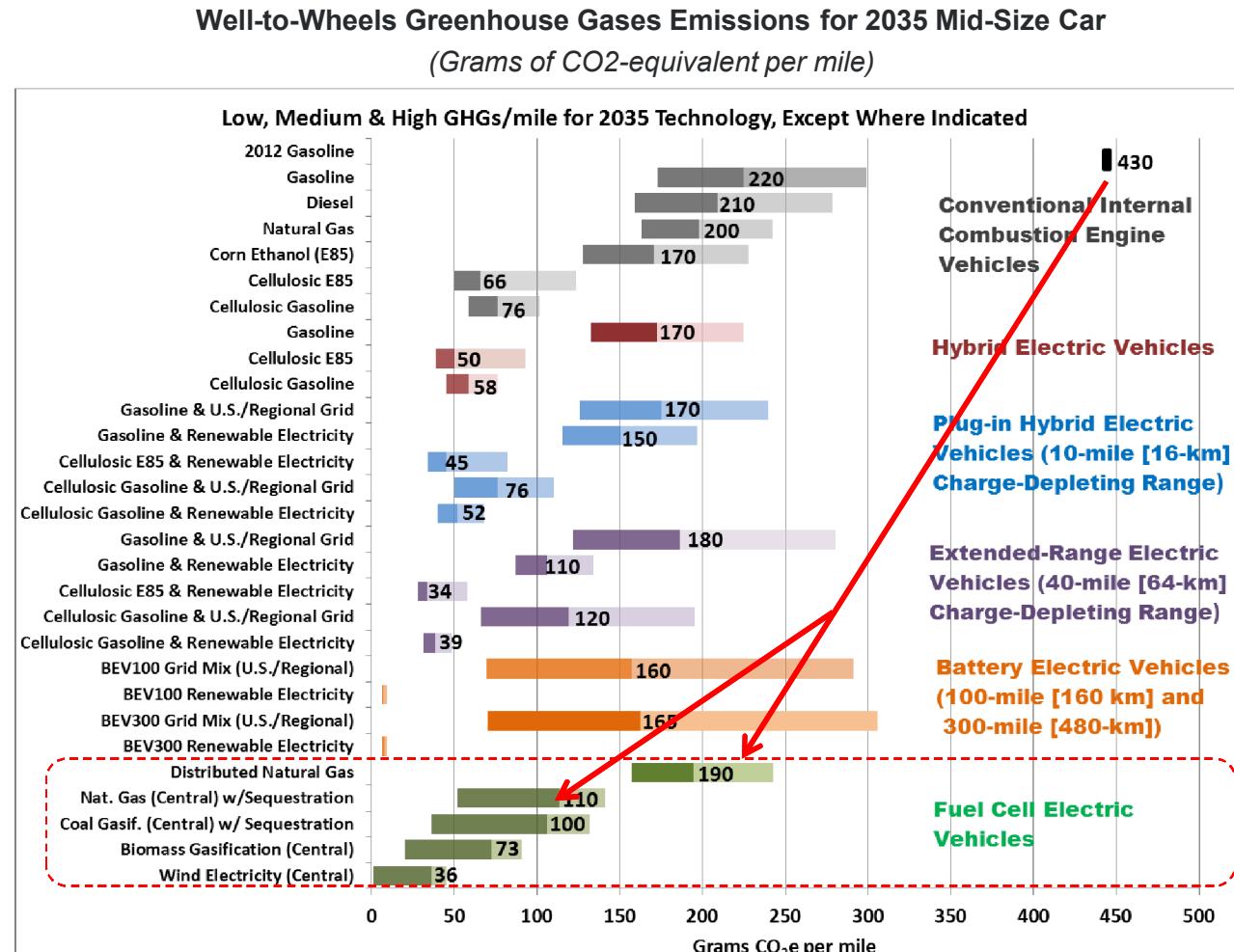


**Systems have demonstrated over 300,000 hours**

Acumentrics

**Analysis by Argonne National Lab, National Renewable Energy Lab, DOE Vehicle Technologies Office, DOE Bioenergy Technologies Office and DOE Fuel Cell Technologies Office shows benefits from a portfolio of options**

- Updated, peer-reviewed analysis (EERE multi-Office coordination)
- Hydrogen from natural gas can reduce GHG emissions by >50% (significantly less if centrally produced and with carbon capture)

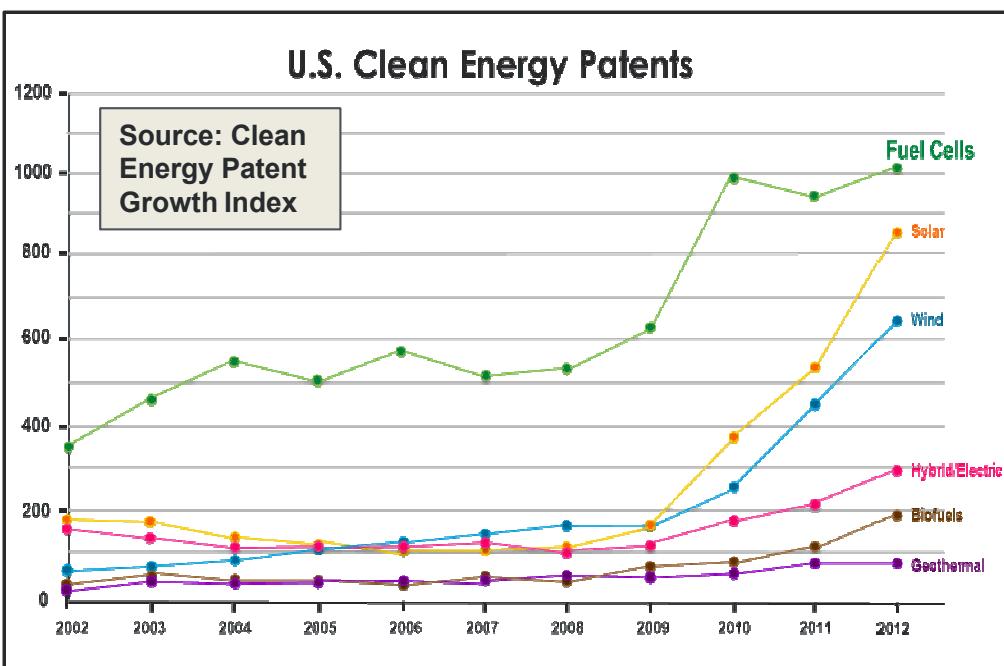


See reference for details:

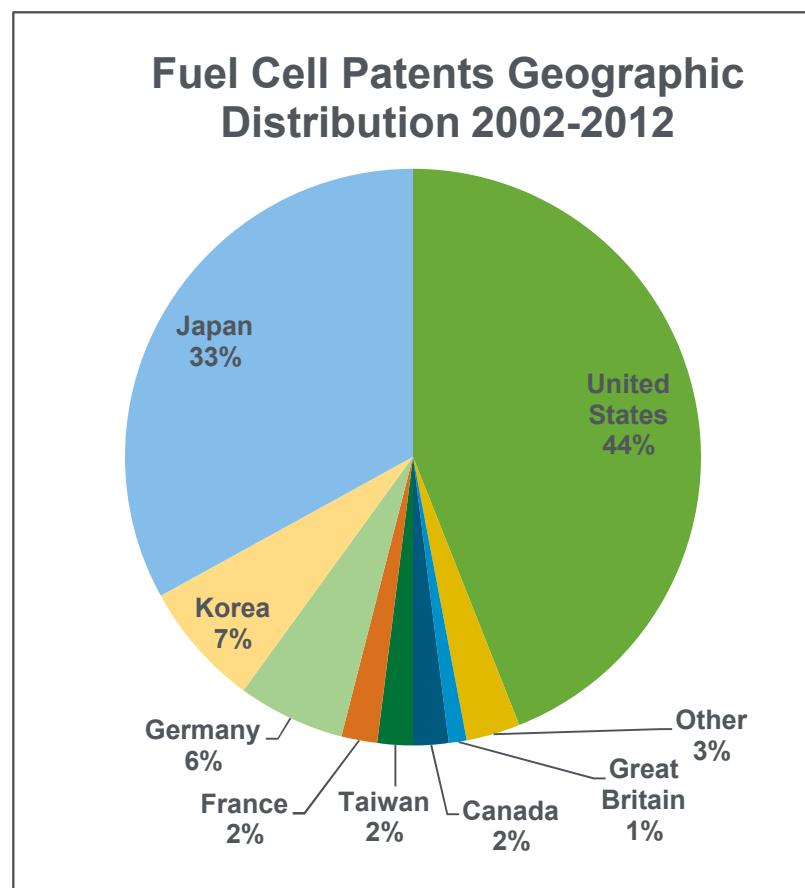
[http://hydrogen.energy.gov/pdfs/130\\_05\\_well\\_to\\_wheels\\_ghg\\_oil\\_idvs.pdf](http://hydrogen.energy.gov/pdfs/130_05_well_to_wheels_ghg_oil_idvs.pdf)

Low/medium/high: sensitivity to uncertainties associated with projected fuel economy of vehicles and selected attributes of fuels pathways, e.g., electricity credit for biofuels, electric generation mix, etc.

# Fuel Cell Market Overview: Patents



Top 10 companies for fuel cell patents: GM, Honda, Toyota, Samsung, UTC Power, Nissan, Ballard, Panasonic, Plug Power, Delphi Technologies



- Clean Energy Patent Growth Index<sup>[1]</sup> shows growth in all clean energy technology patents
- More than 1,000 fuel cell patents issued in 2012

[1] [http://cepgi.typepad.com/heslin\\_rothenberg\\_farley\\_/2013/03/clean-energy-patent-growth-index-2011-year-in-review.html](http://cepgi.typepad.com/heslin_rothenberg_farley_/2013/03/clean-energy-patent-growth-index-2011-year-in-review.html)

**Hurricane Sandy was the largest Atlantic hurricane on record.  
Winds spanning more than 1,100 miles**



**More than \$60 billion in damages**



- Cellphone outages reported in more than 150 counties from VA to MA
- 25% of cell towers in 10-state area stopped operating
- 8.5 million power outages reported across 21 states