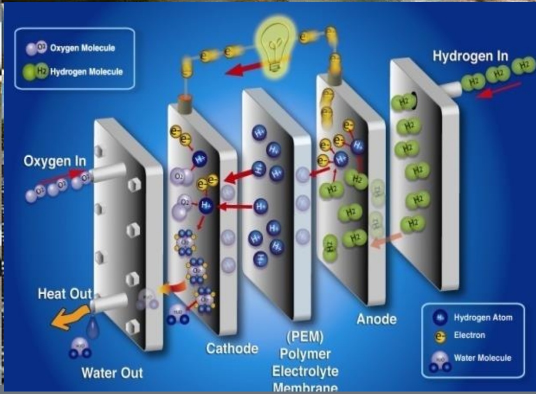
U.S. Department of Energy Hydrogen & Fuel Cells Program

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



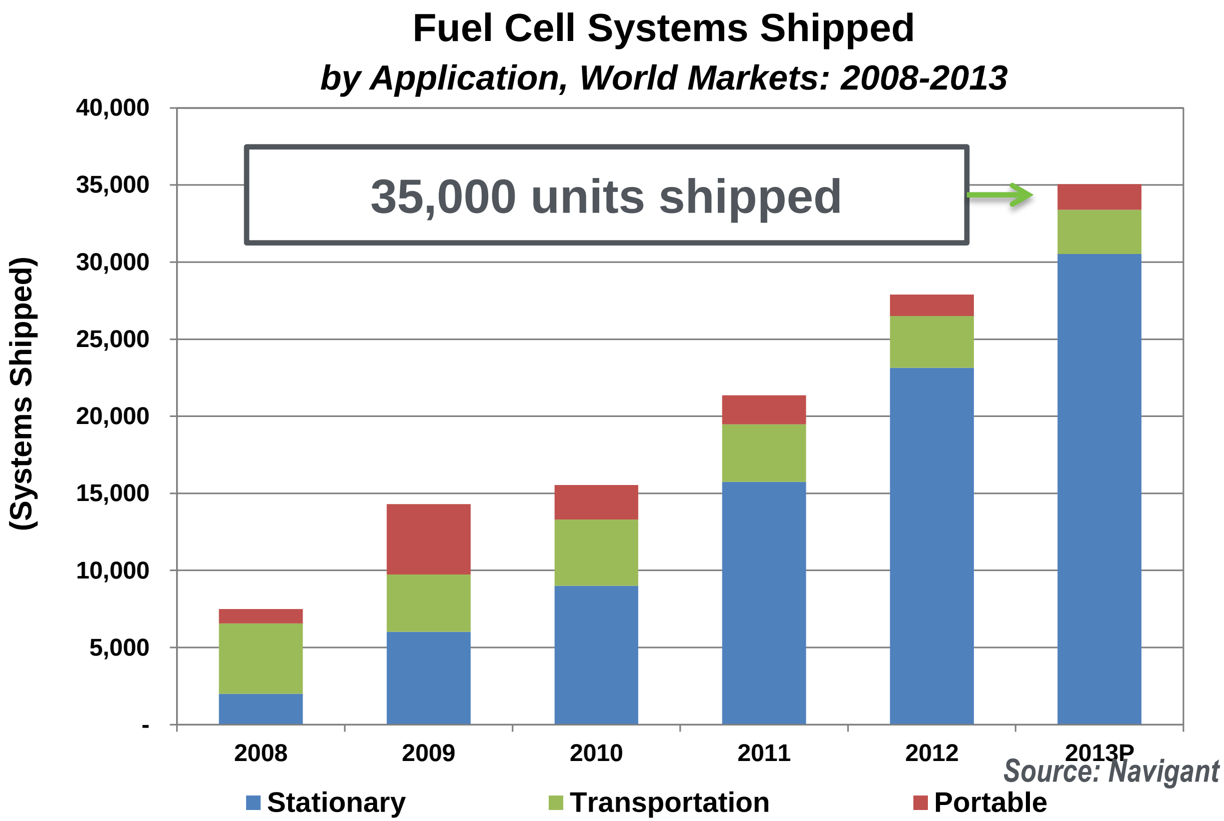
Annual Merit Review and Peer Evaluation Meeting

June 2014

Dr. Sunita Satyapal

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

Fuel Cell Market



Market Growth

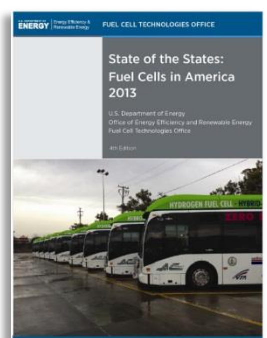
Fuel cell markets continue to grow

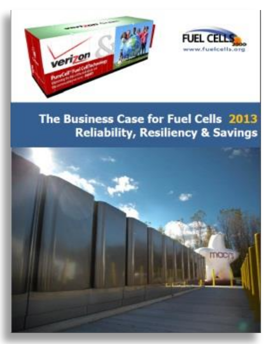
- >25% increase in global MWs shipped since 2012
- 35% increase in revenues from fuel cell systems shipped over last year
- Consistent ~30% annual growth in global systems shipped since 2010.

DOE Funded Reports

The Business Case for Fuel Cells 2013: Reliability, Resiliency & Savings
State of the States 2013: Fuel Cells in America
2012 Fuel Cell Technologies Office Market Report

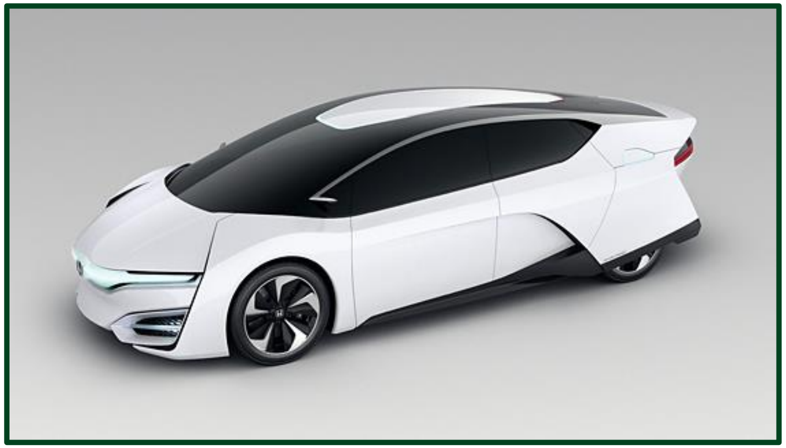
http://energy.gov/eere/fuelcells/market-analysis-reports





Fuel Cell Cars are Here!

FCEVs on display at North American auto shows.



Honda Fuel Cell Electric Vehicle

Toyota Fuel Cell Electric Vehicle

Hyundai's first mass-produced Tucson Fuel Cell SUVs arrive in Southern California
May 20, 2014

Lease includes **free H_2 and maintenance**.

DOE and Industry- Launched Public-Private Partnership

H2USA

Mission: To promote the commercial introduction and widespread adoption of FCEVs across America through creation of a public-private partnership to overcome the hurdle of establishing hydrogen infrastructure.

Current partners include (additional in process):

U.S. Department of Energy
Fuel Cell & Hydrogen Energy Association
Global Automakers
GM
Daimler
Hydrogenics – Advanced Hydrogen Solutions
Honda – The Power of Dreams
EDTA – Electric Drive Transportation Association
Nissan
Hyundai
Mercedes-Benz
Oak Ridge National Laboratory
AGA – American Gas Association
ITM Power – Energy Storage | Clean Fuel
California Fuel Cell Partnership – Driving for the Future
SCRA
Sandia National Laboratories
Proton – The Leader in On Site Gas Generation
Pacific Northwest National Laboratory
NREL – National Renewable Energy Laboratory
Air Liquide
arc:Hydrogen
Plug Power
Nuvera – Making hydrogen make sense.
Massachusetts Hydrogen Coalition
Toyota
Argonne National Laboratory

Established H_2FIRST Project–H_2 Fueling Infrastructure Research & Station Technology

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NREL and SNL Provide:

H2FIRST — Hydrogen Fueling Infrastructure Research and Station Technology — in support of H_2USA

- Technical expertise – Hydrogen specific materials and systems
- Facilities - for technical collaboration and validation
- Objectivity – Independent and objective assessment

Leverage DOE National Lab Network

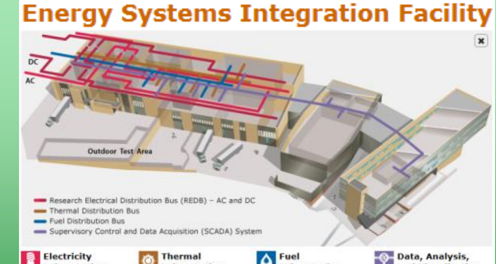
Project Teams:

- Station Qualification
- Dispenser Components Research
- Fuel Quality Sensor
- Station Component RD&D
- Reference Station Design

Sandia National Laboratories

NREL — NATIONAL RENEWABLE ENERGY LABORATORY

Energy Systems Integration Facility



Distributed Energy Resources Test Facility

Key Collaborations & Partnerships

R&D → **Demonstration & Deployment** → **Enabling Commercialization**

USDRIVE — Driving Research and Innovation for Vehicle Efficiency and Energy Sustainability

Precompetitive R&D

– USCAR, energy companies, EPRI, utilities

International Energy Agency (iea) (25 countries)

– Implementing Agreements
  – Advanced Fuel Cells
  – Hydrogen

California Fuel Cell Partnership

– Auto OEMs, energy companies, government, fuel cell companies

Other State Partnerships

Government, business, academia

– South Carolina (SCHFCA)
– CT, MA (e.g.,CCAT, H2-Fuel Cell Coalition)
– Hawaii (Hawaii Hydrogen Initiative, H2I)

H_2FIRST — Hydrogen Fueling Infrastructure Research and Station Technology

National lab led activities with industry
(SNL & NREL led project)

IPHE — *Government partnership*

Coordination on policy, lessons learned, accelerating commercialization

- 17 countries & the European Commission

H_2USA

Public-private partnership

~30 partners including global OEMs, H_2 providers, etc.

Hydrogen & Fuel Cells Budget

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

EERE Funding *($ in thousands)*		
Key Activity	**FY 2014 Enacted**	**FY 2015 Request**
Fuel Cell R&D	33,383	33,000
Hydrogen Fuel R&D[1]	36,545	36,283
Manufacturing R&D	3,000	3,000
Systems Analysis	3,000	3,000
Technology Validation	6,000	6,000
Safety, Codes and Standards	7,000	7,000
Market Transformation	3,000	3,000
NREL Site-wide Facilities Support	1,000	1,700
Total	**$92,928**	**$92,983**

	FY 2014
Basic Science[2]	~$25M
Fossil Energy, SECA	~$25M
ARPA-E (planned)	~$30M

FY14 DOE Total: >$170M

FCTO Incubator FOA, $4.6M
Concept papers due 7/7/14

Key Targets

Fuel Cells: *Automotive:* $40/kW, 5000 hours by 2020, ultimate $30/kW

Stationary: $1,000/kW (natural gas), $1,500/kW (biogas), 80,000 hrs

Hydrogen cost: <$4/gge by 2020

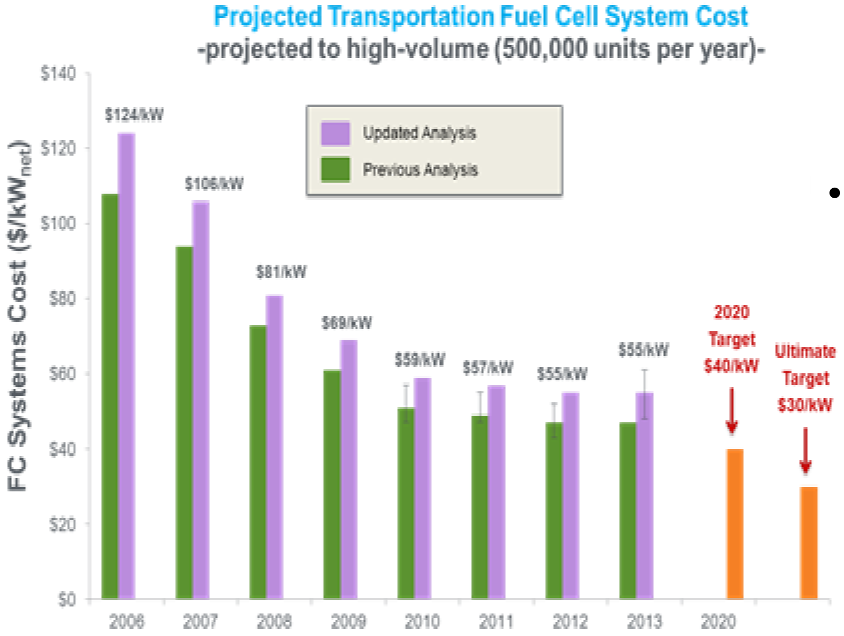
[1]Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D
[2]Hydrogen and Fuel Cell related funding finalized end of FY14

Major Technical Areas



Accomplishments

- Revised automotive fuel cell cost analysis with updated system and Pt price. **>30% cost reduction since 2008.**
- Achieved >2x increase in fuel cell catalyst specific power from 2.8 kW/g_{PGM} (2008) to 6.0 kW/g_{PGM}. (3M)
- Developed new nanoframe catalysts with mass activity >30X vs Pt/C in RDE testing. (ANL, LBNL)



Future Directions

- Reduce cost and enhance performance and durability of fuel cell stack components to meet 2020 targets
  - Catalysts, membranes, and MEAs
- Consortium approach to address non-PGM catalysts, interfaces, MEAs
  - Modeling & combinatorial approaches (aligned w/ Materials Genome Initiative)

Presolicitation Workshop 6/16 @ 6PM

Status

- Cost: ~$55/kW (500K/yr);
  ~$280/kW (20K/yr)
- Durability: 3,600 hours (lab data)
- Catalyst specific power: 6.0 kW/g_{PGM}

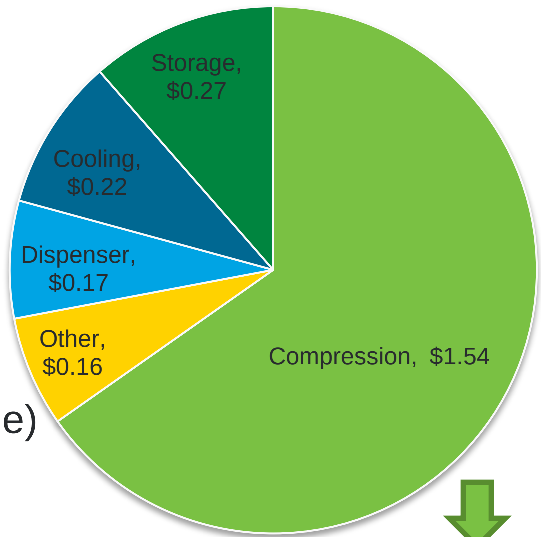
FY 2015 Goal

- Improve fuel cell catalyst specific power to 6.6 kW/g_{PGM}, on track to achieve: 8 kW/g PGM, $40/kW and 5,000 hr durability by 2020

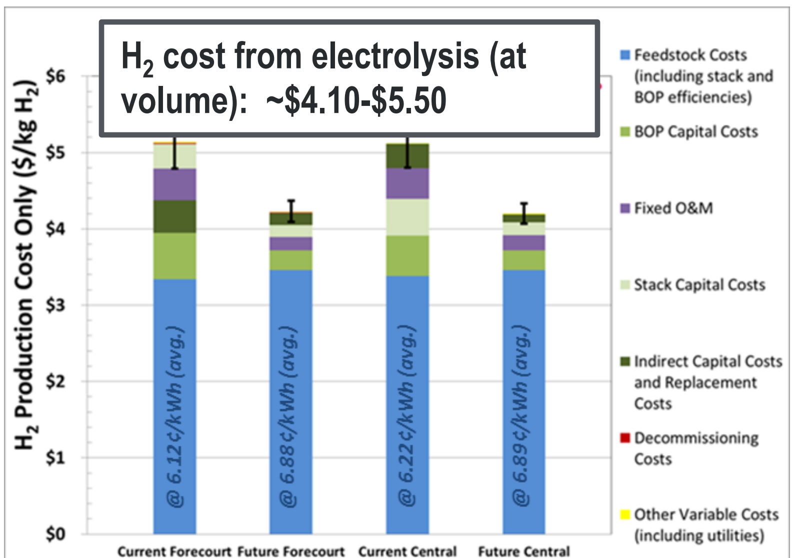
Accomplishments

- ≥10X reduction in electrolyzer PGM loading.
- Enhanced stability of III-V PEC devices (1.7X improvement in photocurrent density).
- Developed innovative refueling concept to reduce station cost 50% (compared to 2013 baseline)
- Four Workshops and a joint solicitation with NSF.

CSD can add up to $3 to H_2 cost



Compression is 65% of the cost of H_2



http://www.hydrogen.energy.gov/pdfs/h2a_pem_electrolysis_case_study_documentation.pdf

Future Directions

- RD&D on:
  - New components for 700 bar fueling
  - Low-carbon, near-term hydrogen production, and integrated solar water splitting systems
- Continued Analysis of Production & Delivery Pathways
  - Fermentative H_2 Production
  - High Temperature Electrolysis
  - Cost of Early Market P&D
  - Release new 2014 version of HDSAM
- 10 new awards in P&D! (see backup)

FY 2015 Goals

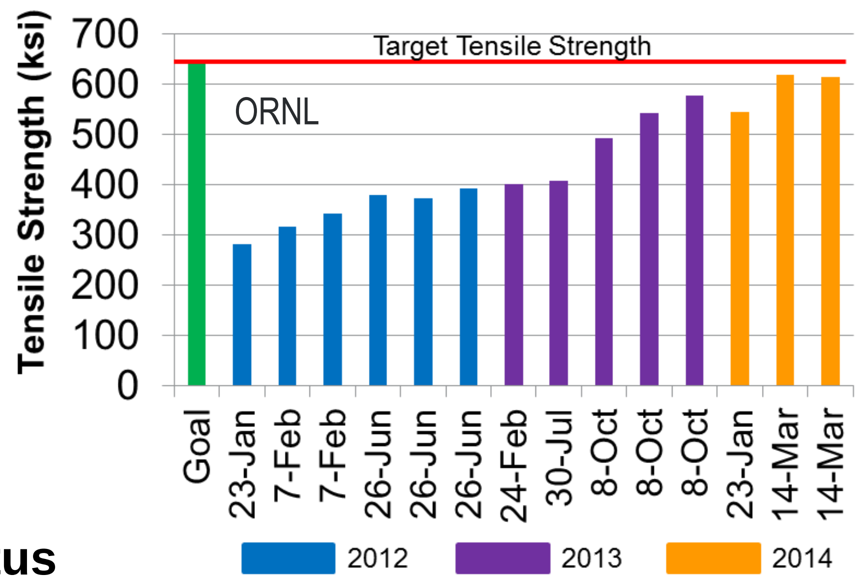
- Reduce the cost of H_2 from renewables to $6.80/gge from $8.00/gge (2011, dispensed, untaxed)
- Demonstrate PEC with >15% efficiency vs. 2011 baseline of 12%

Hydrogen Storage R&D

Accomplishments

- 6 new awards and $7M announced for advanced storage systems. Materia, PPG Industries, SNL, LLNL, Ardica, HRL
- Developed textile PAN fibers at ~25% lower cost than conventional PAN precursor. (ORNL)
- Two sorbent system prototypes in Phase 3 with the Engineering Center to demonstrate performance against targets (see below).

Yield Strength Progression



Future Directions

- Develop advanced hydrogen storage materials, guided by material property requirements established by Engineering Center.
- Develop storage technologies for early markets (e.g., forklifts).
- Validate low cost carbon fiber precursors.

Status

Projected H_2 Storage System Performance Current Status	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
Sorbent (MOF-5,100bar MATI, LN2)	1.1	0.7	16
Hexcell, flow-through cooling	1.2	0.6	13
2017 Target	**1.8**	**1.3**	**12**

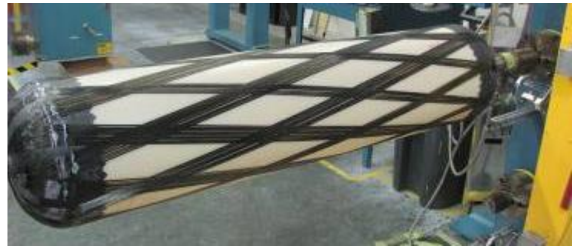
FY 2015 Goals

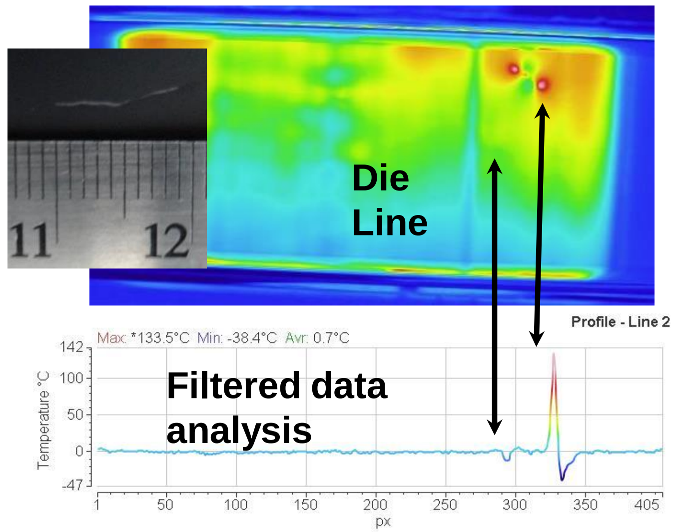
- Complete sorbent system prototypes and validate Engineering system models
- Reduce the cost of 700-bar H_2 storage systems by 15% from 2013 baseline projection of $17/kWh

Manufacturing R&D

Accomplishments

- Achieved 25% 3-layer MEA cost reduction (WL Gore)
- Achieved ~30% composite mass reduction & ~20% cost savings over 2013 baseline hydrogen storage tank (Quantum)
- Held EERE/CEMI Quality Control Workshop (Co-sponsored by FCTO, AMO, SETO, VTO, & BTO); identified gaps and opportunities (CEMI: Clean Energy Manufacturing Initiative)
  - Report Online: http://energy.gov/eere/fuelcells/eere-quality-control-workshop





Future Directions

- Funding Opportunity Announcement released on 5/20/14 (up to $2M DOE)
  - Topic 1: Supply chain outreach and development
  - Topic 2: Global manufacturing competitiveness analysis

Deadline: 6/30/2014

Status

- Inline membrane defect detection using IR/DC demonstrated (Ion Power/NREL), defects detected at 60 ft/min (NREL)
- GDL cost of $1.37/kW (projected for high volume manufacturing 500K/yr (Ballard)

FY 2015 Goals

- Demonstrate 3X increase of continuous in-line measurement processes to achieve 100 ft/min for MEA/component roll-to-roll processing
- Conduct supply chain analysis

Technology Validation & Market Transformation

Accomplishments

- Fuel cell bus fuel economies up to 2X better than 2008 baseline. Best durability near 2016 target (18,000 hrs).
- Awarded FCEV data collection projects to 6 OEMs (~90 vehicles; up to 235,000 mi anticipated).
- 2 new projects on fuel cell hybrid electric medium-duty trucks.
- Designed and built fuel cell system for airport ground support vehicle
- Developed prototype design for fuel cell power system for pier-side and auxiliary sea vessel power (w/ MARAD)
- Demonstrated landfill gas to H_2

GM

Hyundai

Mercedes-Benz

Toyota

Nissan

Honda

Future Directions

- Validate hydrogen refueling station/components and wind to H_2/energy storage systems
- Accelerate H_2FIRST project
- Test light duty battery electric fuel cell hybrid range extender and develop fleet strategies

RFI planned for fuel cell range extender

H2FIRST

Status

- FCEVs achieved 59% efficiency (target 60%); 3.5 million miles driven
- Commercial power systems demonstrated durability between 40,000-80,000 hours
- 1,600 DOE-supported MHE & BUP fuel cells resulted in >11,500 units with no DOE funding

FY 2015 Goals

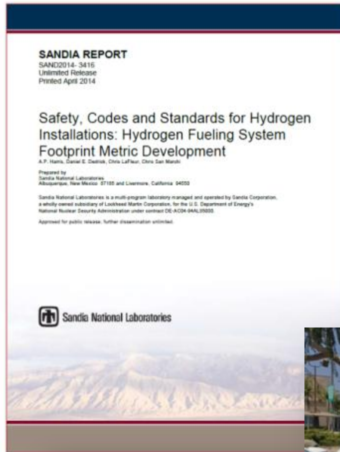
- Validate next generation FCEV and truck performance (e.g., parcel delivery vans with >100 mi range)
- Enable a 5X increase in the number of installed fuel cells vs. 2012 baseline
- Complete marine power and refrigerated truck APU demos

Safety, Codes and Standards

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

Accomplishments

- Global Technical Regulation adopted by UN Economic Commission for Europe Working Party 29 (US DOT NHTSA)
- Published report on SCS impact on station footprint (SNL)
- >900 downloads of Hydrogen Tools App covering 5 regions (PNNL)



SANDIA REPORT
SAND2014-3416
Unlimited Release
Printed April 2014

Safety, Codes and Standards for Hydrogen Installations: Hydrogen Fueling System Footprint Metric Development

Sandia National Laboratories

A "rescue" at Sunnyvale (CA) Department of Public Safety

Future Directions

- Quantify impact of liquid hydrogen release to reduce separation distances
- Develop hydrogen fueling station template (includes necessary safety codes & standards)
- Coordinate with State of California (e.g., CEC, CARB) to accelerate station deployment

Status

- Close to 30,000 code officials and first responders trained (NREL, PNNL)
- Assessed number of stations that can accept and deliver hydrogen (20% of 70 stations)
- H_2 Safety Panel reviewed 395 projects

FY 2015 Goals

- Initiate liquid hydrogen release studies
- Implement First Responder National Hydrogen Response Education Program
- Continued support of H_2USA and Market Support and Acceleration Working group

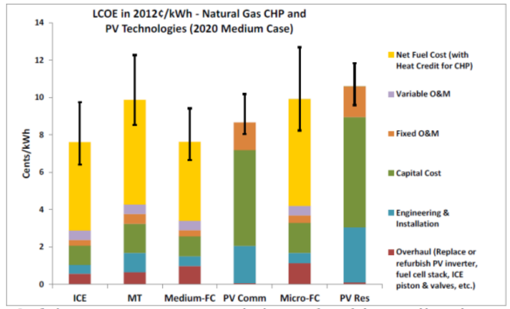
Systems Analysis

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

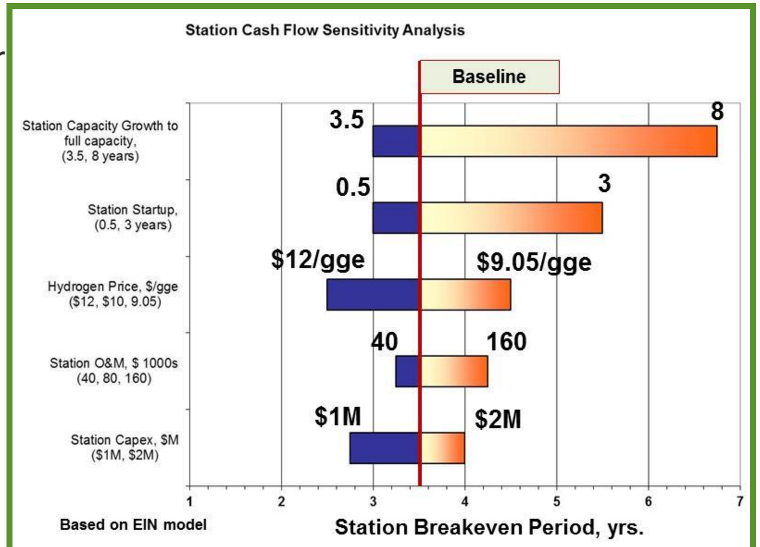
Accomplishments

- Analyzed future Pt requirements for ICEVs.
- Analyzed comparative LCOE for stationary PEM fuel cells.
  - 7 to 9¢/kWh competitive with solar PV and other CHP technologies.
- 8-13% potential cost improvement from improved fuel cell efficiency through R&D.
- Analyzed sensitivity of hydrogen infrastructure cost drivers.

LCOE in 2012 Cents/kWh (Technology in 2020, No Incentive Assumed)



Low/high: sensitivity to uncertainties associated with capacity factor, fuel prices, and heat utilization (heat recovery applies only to CHP systems)



Future Directions

- Develop interim hydrogen cost target.
- Continue life-cycle analysis of GHG, petroleum use and water for pathways.
- Assess gaps and drivers for early market infrastructure cost.
- Evaluate the use of hydrogen for energy storage.
- Issue RFI on hGallon. hGallon equates cost of hydrogen and gasoline.

Status

- Completed JOBS H_2 model; ~1300 jobs ('job-years') created/retained (ARRA)
- Completed fact sheets for analysis models

FY 2015 Goals

- Continue analyses to guide R&D
- Infrastructure cost and financing scenario analysis.

Highlights

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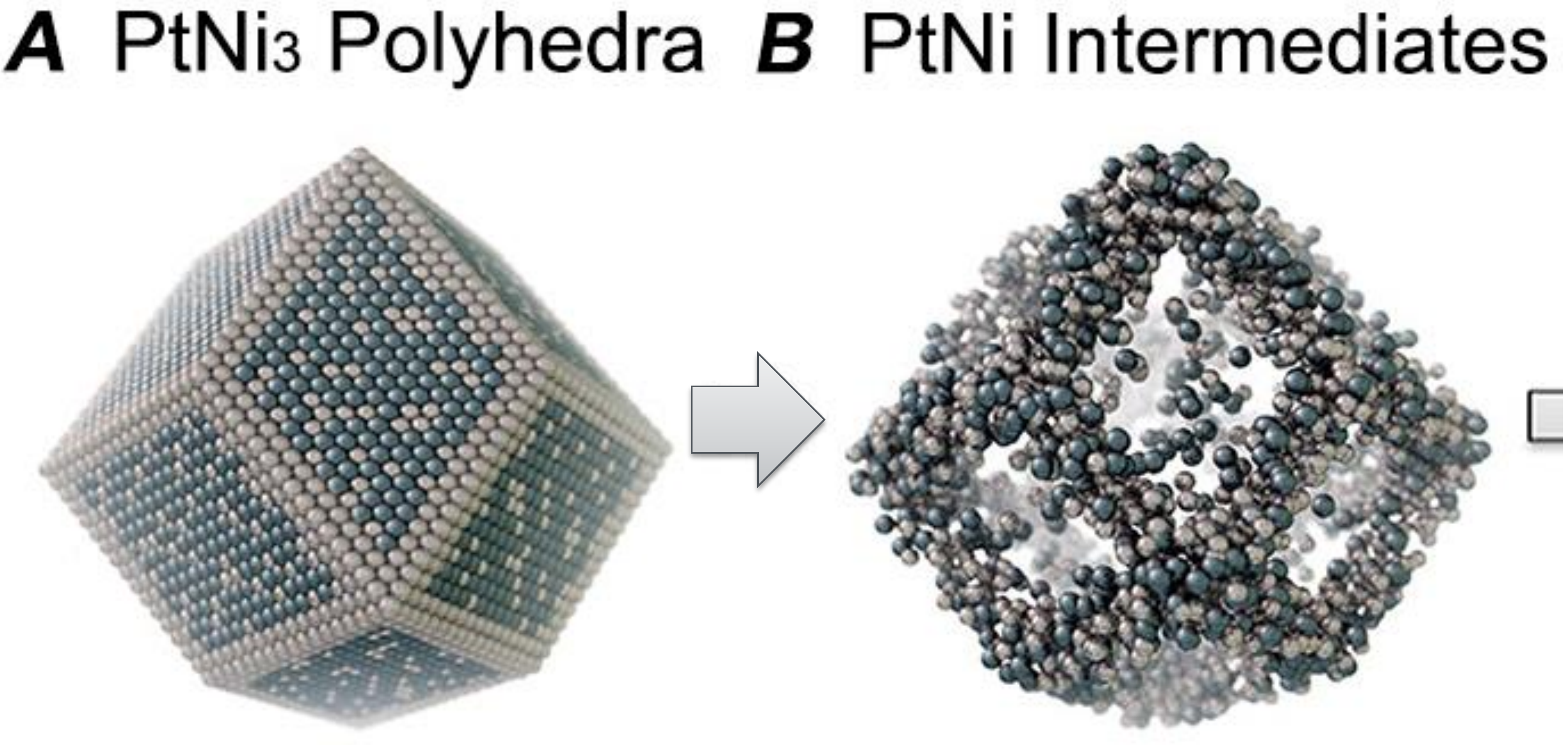
New nanoframe catalysts developed with mass activity >30X higher than Pt/C catalysts in RDE testing (BES-EERE collaboration)



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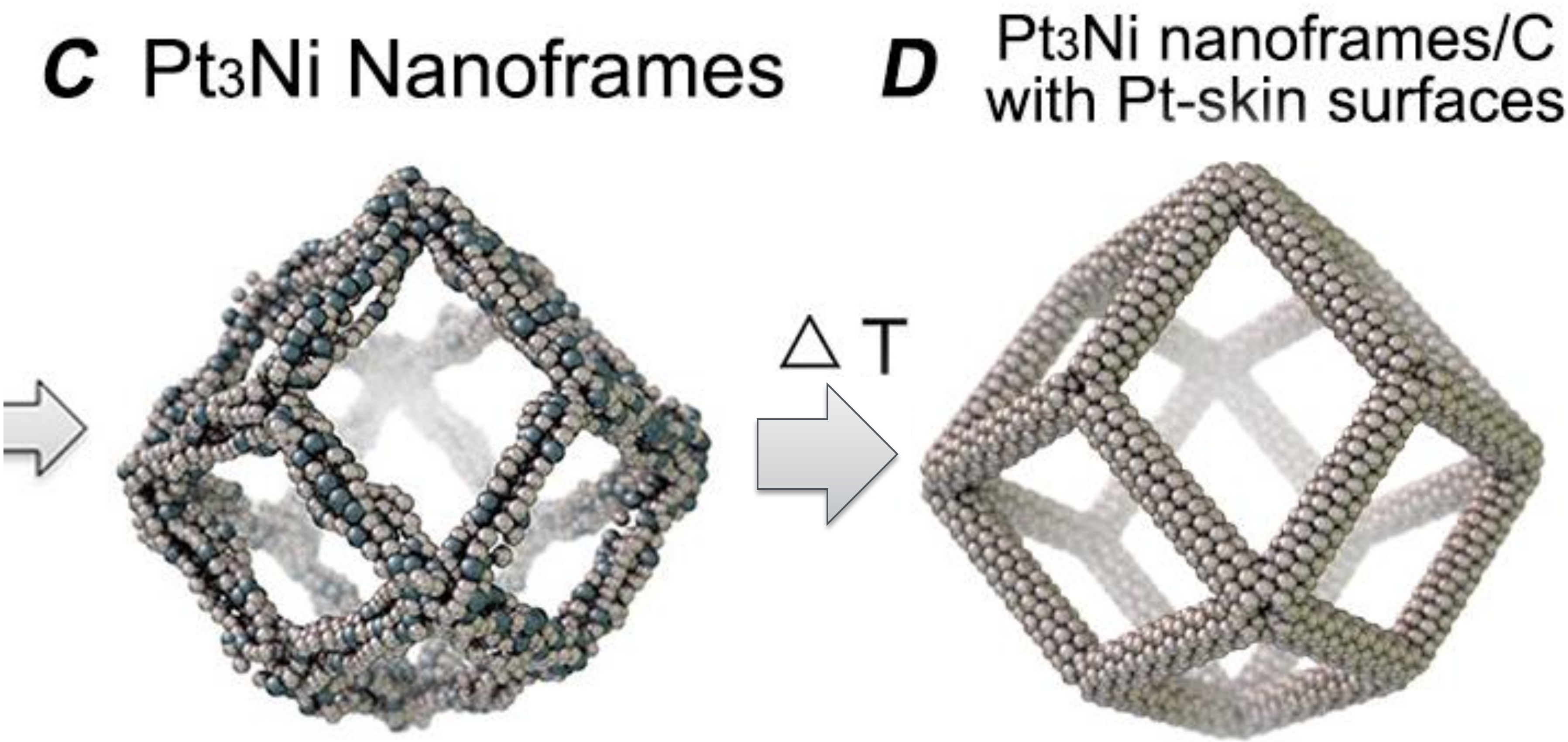

Dispersible cathode catalyst with extended thin film catalyst properties

Synthesis & Evaluation of Nanoframes

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

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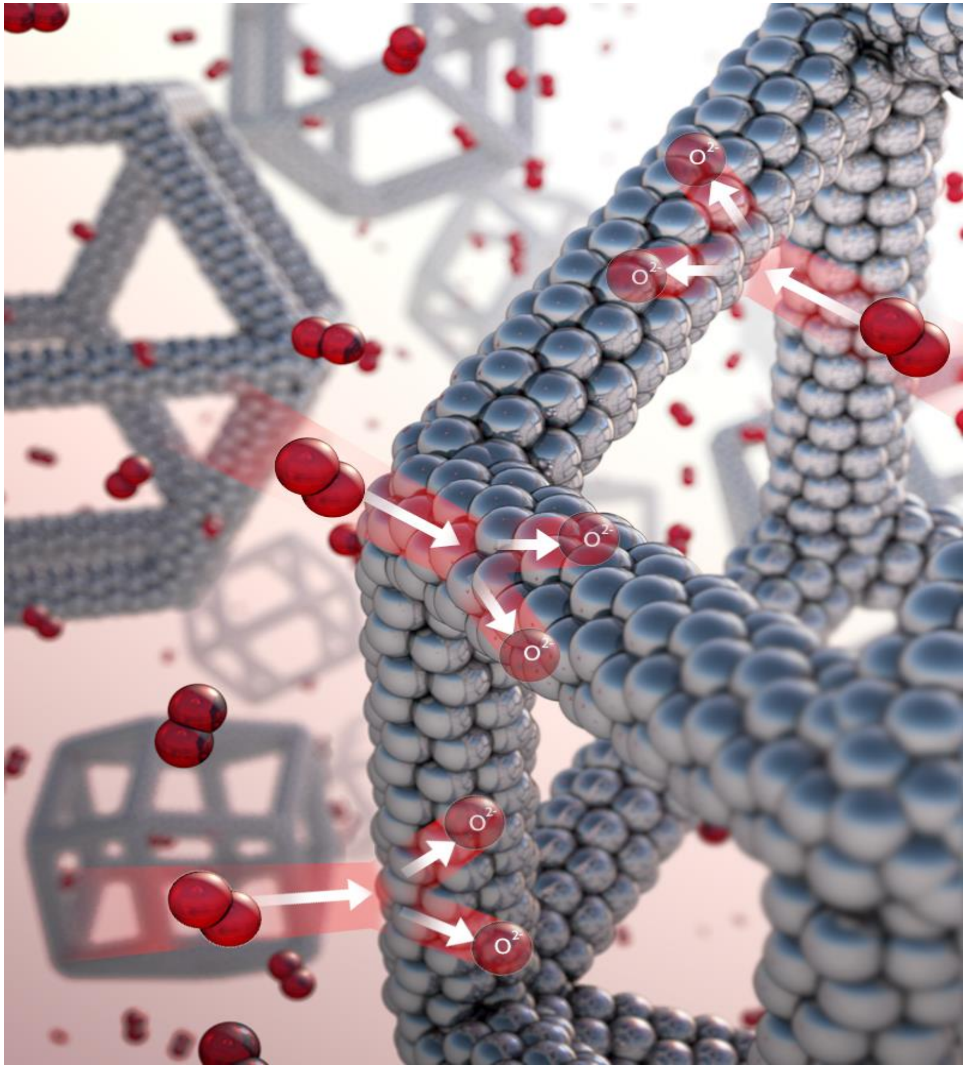

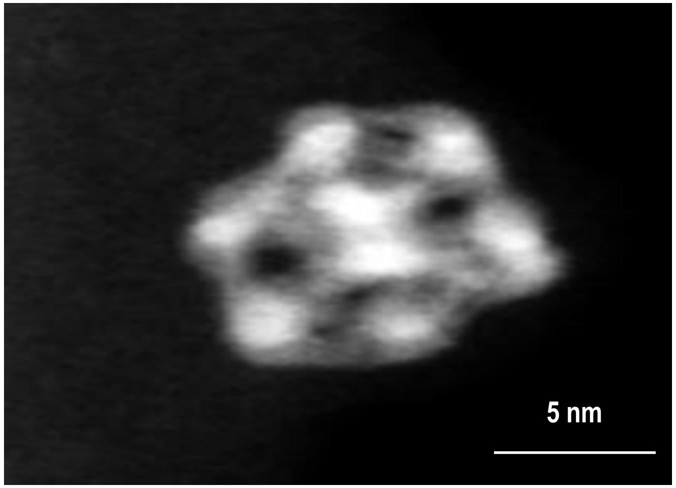

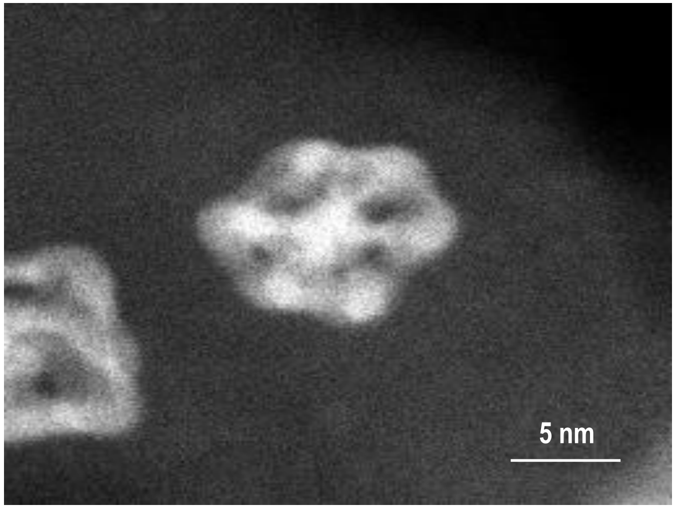

TEM- Karen Morre, ORNL

Synthesis & Evaluation of Nanoframes

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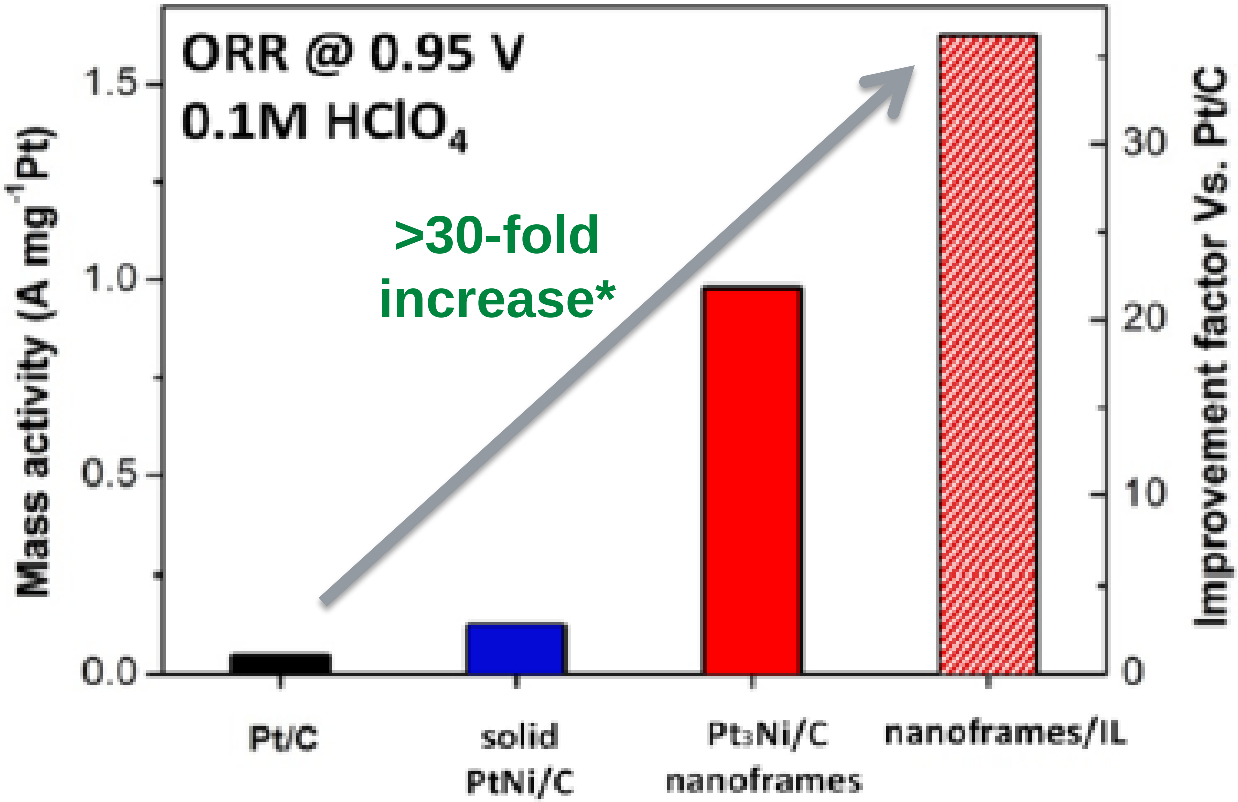


*Catalyst only, Future plans: Demonstrate MEAs

"Highly Crystalline Multimetallic Nanoframes with Three-Dimensional Electrocatalytic Surfaces"

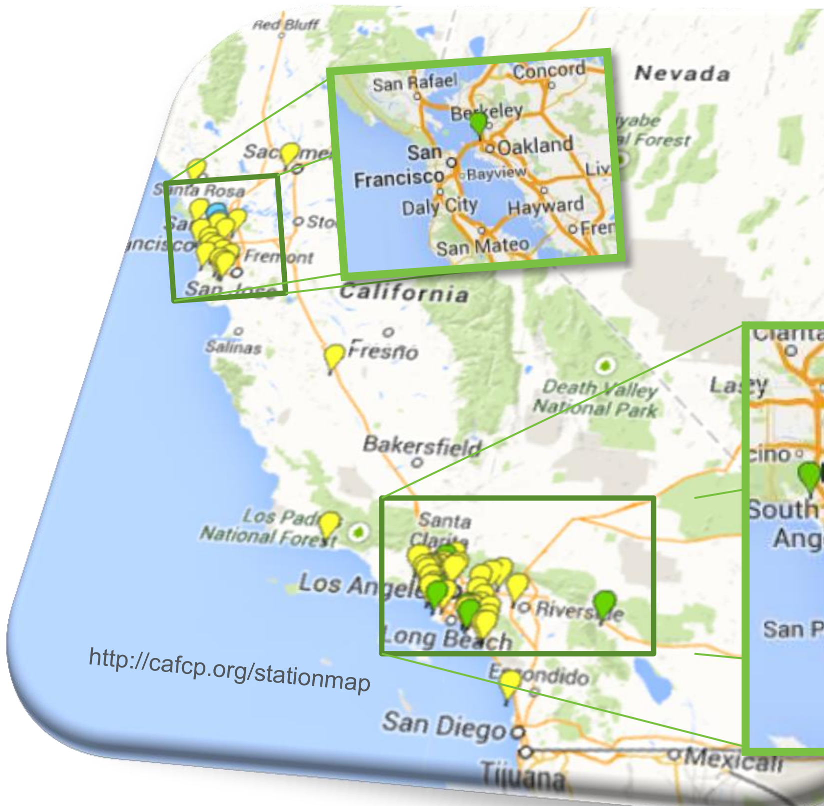
Vojislav Stamenkovic (ANL) & Peidong Yang (LBNL/UCB)

Science, 343 (2014) 1339

Infrastructure Status – California

- 10 public stations operating in CA
- 46 stations in development
  - $46.6 million announced for 28 new H_2 refueling stations
  - 13 in Northern CA
  - 15 in Southern CA

Station	Type	Source	Capacity
Burbank	Gaseous	SMR	108 kg/day
Emmeryville/ AC transit	Gaseous & Liquid	Electrolyzer & Liquid truck	60 kg/day
Fountain Valley	Gaseous	SOFC – biogas conversion	100 kg/day
Harbor City	Gaseous	Tube trailer	100 kg/day
UC Irvine	Liquid	Liquid truck	25 kg/day
New Port Beach	Gaseous	SMR	108 kg/day
Thousand Palms	Gaseous	SMR	~200 kg/day
Torrance	Gaseous	Pipeline	50 kg/day
West LA	Gaseous	Electrolyzer	32 kg/day
CSU-LA	Gaseous	Electrolyzer	60 kg/day



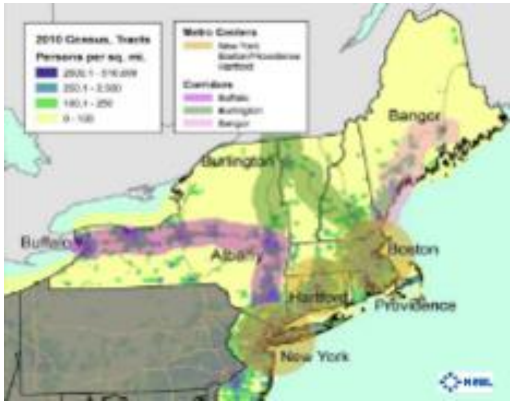
Infrastructure Scenarios - Northeast

Developed infrastructure model for station rollout strategies.

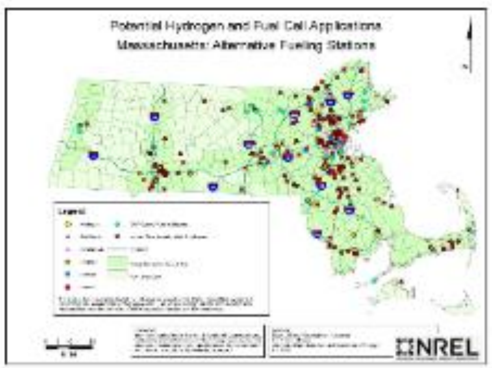
Factors considered include:

- Resource availability
- Cost
- Financial analysis
- Policy and incentive analysis.

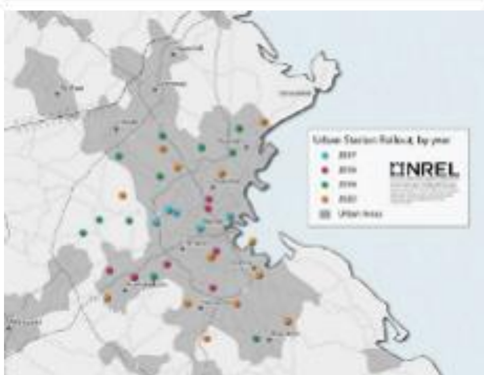
Northeast Region

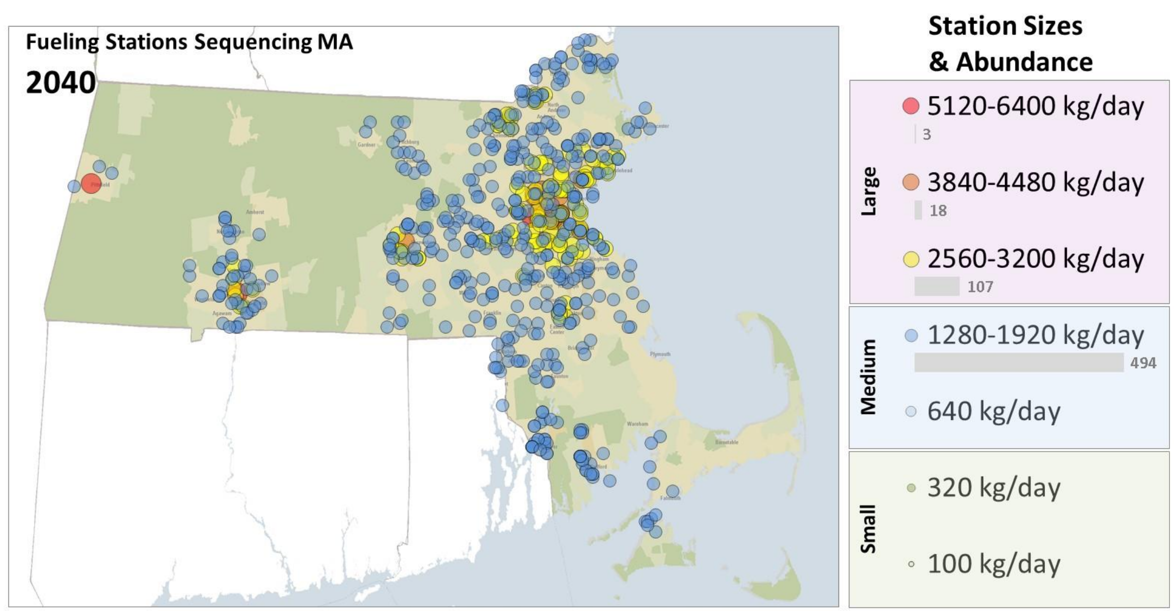


State



Greater Boston





Source: M. Penev, NREL

Maps shown are draft and intended for discussion locating fleets and siting hydrogen locations.

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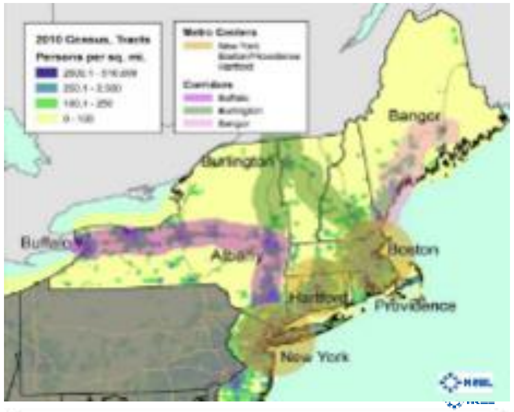
Northeast Region



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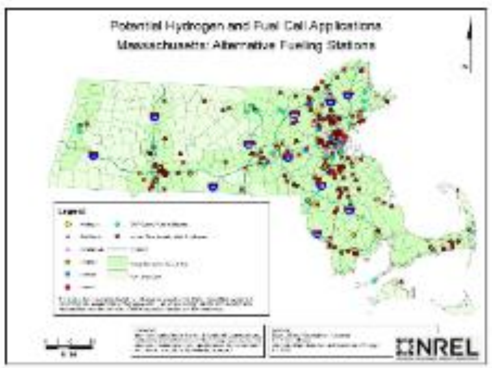
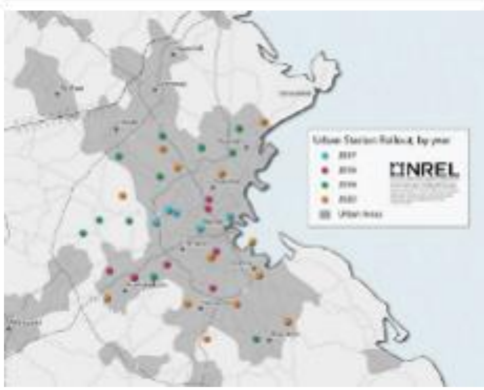
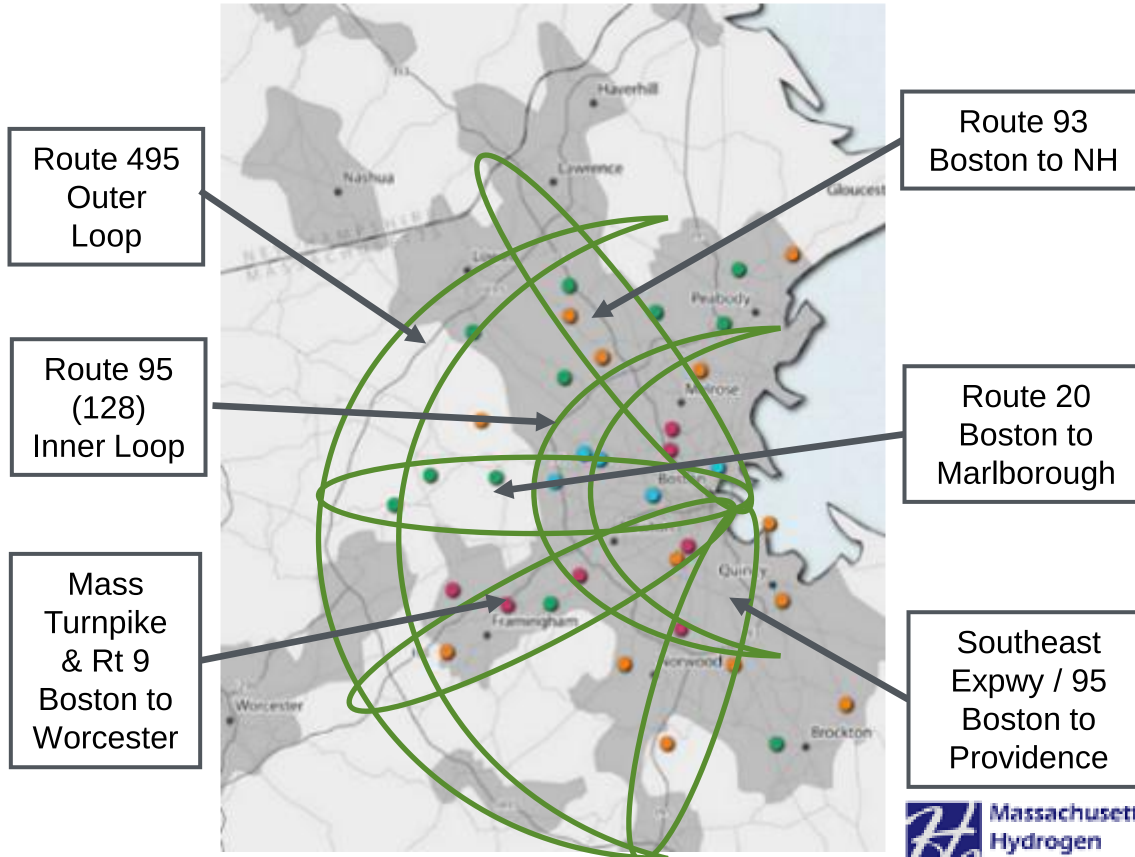


Greater Boston



Greater Boston Corridors



Massachusetts Hydrogen Coalition

Source: Charlie Meyers

Maps shown are draft and intended for discussion locating fleets and siting hydrogen locations.

Hydrogen Tools

CENTRALIZED LOCATION organizes current H_2 resources in one robust location—including **more than 20** existing tools, with plans for adding future content

FOCUSED CONTENT tailored to the specialized needs of H_2 user groups

CUSTOMIZABLE INTERFACE allows content to display based on the H_2 user's role or interests

RESPONSIVE DESIGN enables H_2 safety work across both desktop and mobile devices

TRUSTED COMMUNITIES fostered through social networking around H_2 subject matter expertise

EXPANDABLE FORMAT built with frequently requested future feature sets in mind

PNNL

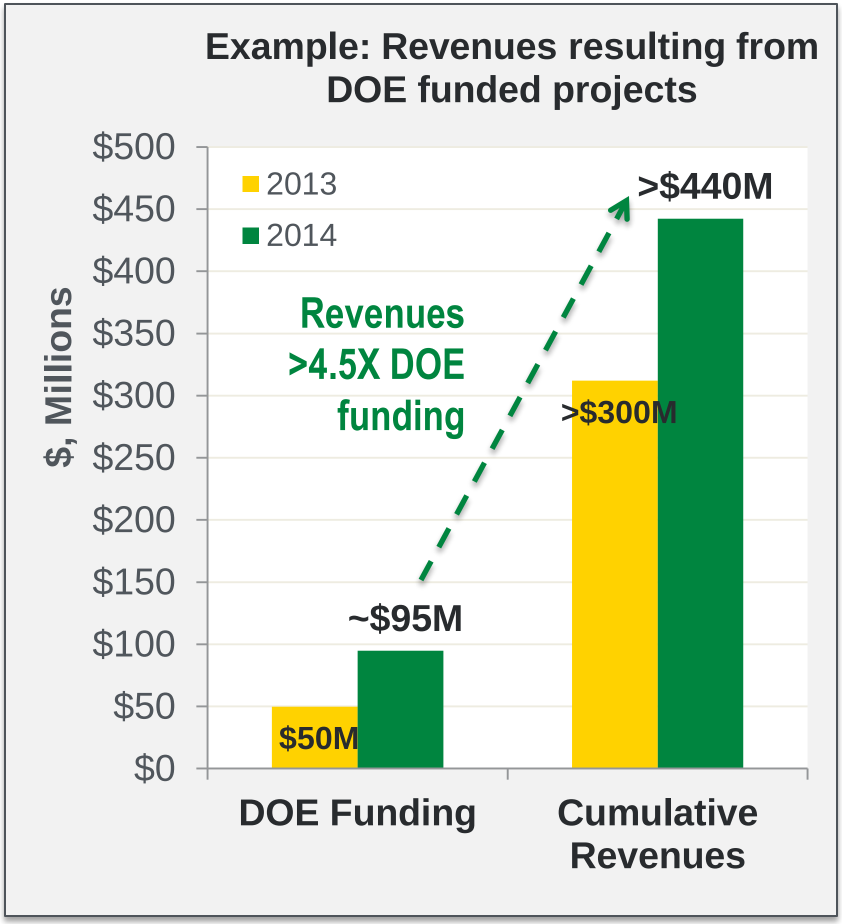
› **Credible** and **reliable** safety information from a **trustworthy** source

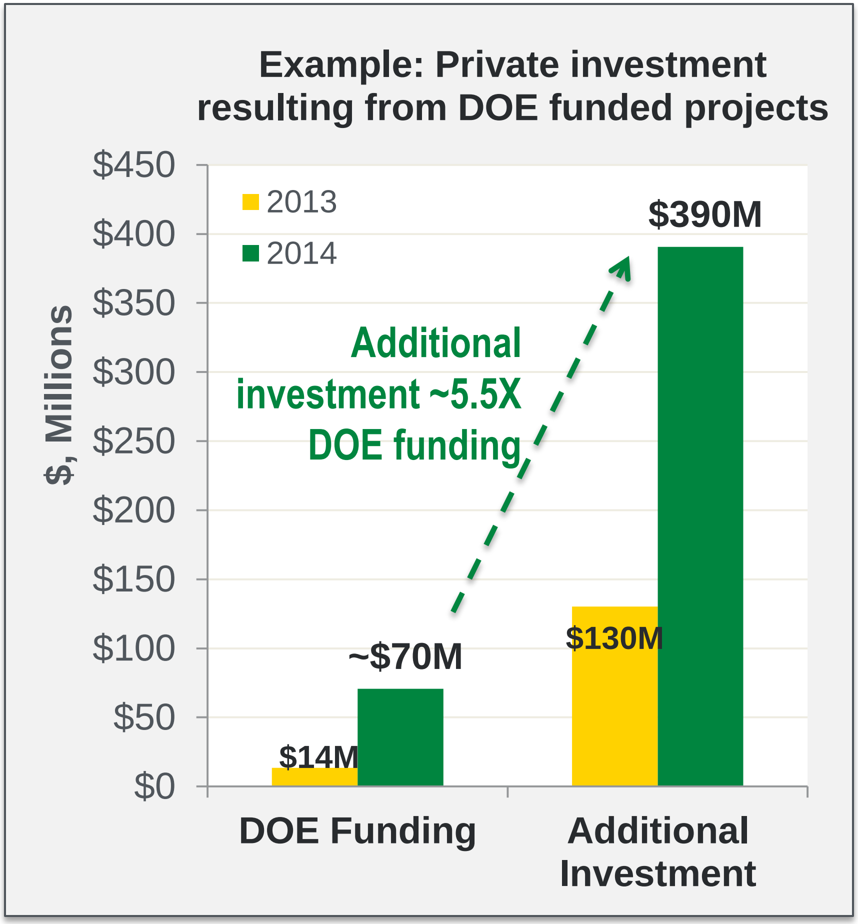
"Tech to Market"
Assessing the Impact of DOE FCTO Funding

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

For selected projects tracked, DOE EERE funding has led to:

- **Revenues valued at >4.5 times the DOE investment**
- **Additional private investment valued at ~5.5 times the DOE investment**



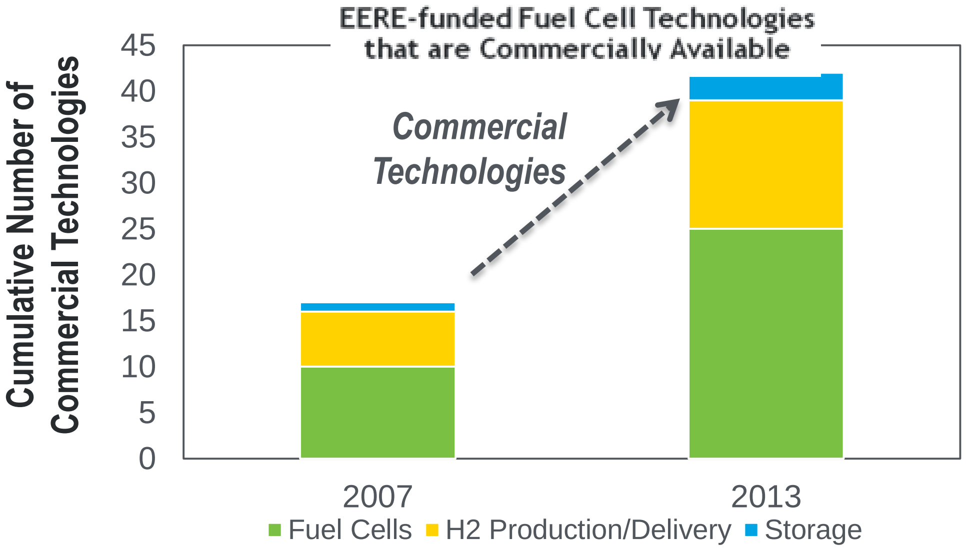


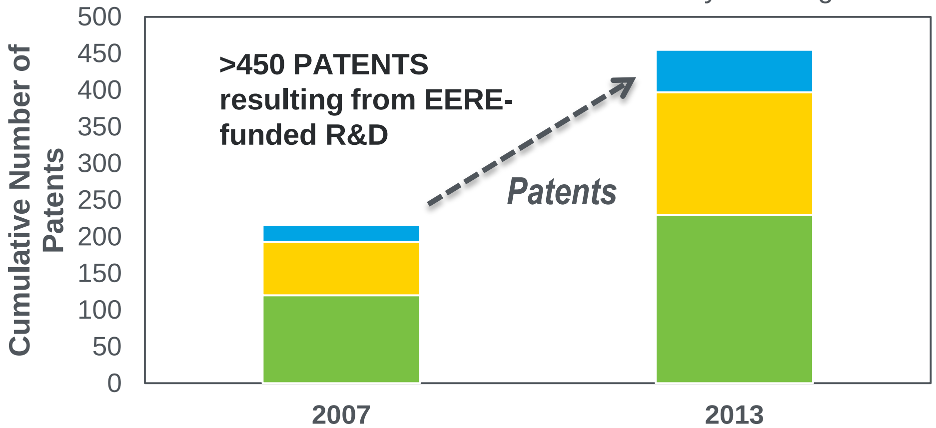
Assessing the Impact of DOE Funding

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

DOE FCTO funding has led to >450 patents, 42 commercial hydrogen and fuel cell technologies and 65 emerging technologies.

Accelerating Commercialization

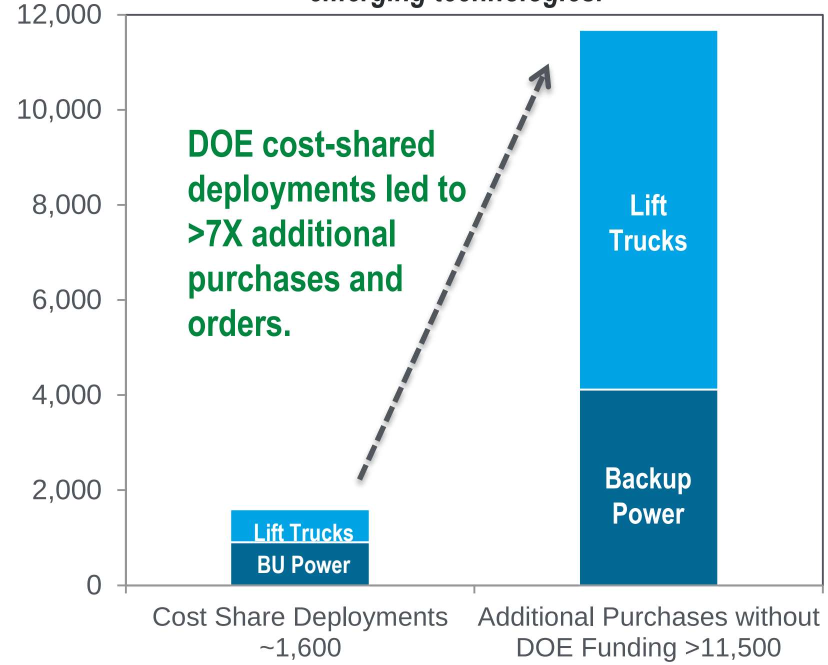




Source: Pacific Northwest National Laboratory
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2013.pdf

Leveraging DOE Funds:

Government as "catalyst" for market success of emerging technologies.



Over $37M saved in the last 5 years through active project management

Future Plans- New early markets to enable volumes

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

Exciting new opportunities for fuel cells in early market applications – airport ground support equipment and medium-duty trucks

Hybrid Medium-Duty Trucks

Delivery & refrigerated trucks and waste transport vehicles

4 new DOE projects and
2 SBIRs
Projects in CA, TN, GA

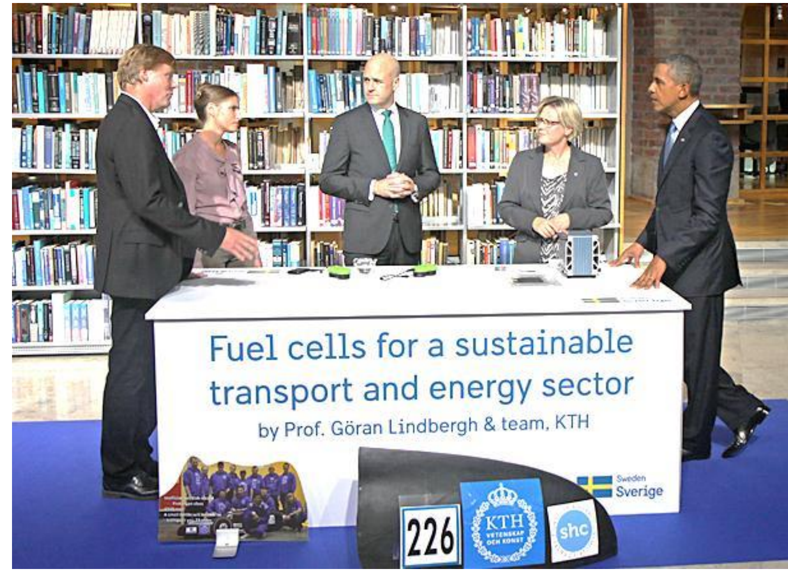
Ground Support Equipment

Seaports & Airports

Events & Outreach

"Investor Day" events- East & West Coasts

November, 2013 at NY Times Building in NYC
April, 2014 at Stanford University



President Obama at Fuel Cell Exhibit in Sweden

Secretary Moniz at DC Autoshow

>80 news articles (blogs, etc) published in the last year

Webinars, google+hangout & workshops disseminate information

In Memorium

Peter Hoffman

Editor, Hydrogen and Fuel Cell Letters & Journalist

- Author of **The Forever Fuel—The Story of Hydrogen** and **Tomorrow's Energy: Hydrogen, Fuel Cells, and the Prospects for a Cleaner Planet**
- Longtime supporter and hydrogen and fuel cell advocate

Dale Gardner, National Renewable Energy Laboratory

Associate Lab Director of the Renewable Fuels and Vehicle Systems Directorate

- Astronaut on space shuttle
- Longtime contributor and leader in hydrogen, biofuels and vehicle technologies

Jim McGrath, Virginia Tech University

University Distinguished and Ethyl Corporation Professor of Chemistry

- Synthesis and characterization of new directly copolymerized sulfonated aromatic copolymers for proton exchange membranes

Sheldon Shore, Ohio State University

Emeritus Professor

- Long time (~60 years) researcher of boron compounds
- First researcher to synthesize ammonia borane.

Adam Weber (LBNL) received a 2013 Presidential Early Career Award for Scientists & Engineers (PECASE). PECASE is the most prestigious U.S. award for young scientists and engineers.

The only EERE PECASE awardees ever were from FCTO!

Maria Ghirardi (NREL)

- NREL's Research Fellows Council

James Miller and Riccardo Scarcelli (ANL)

- SAE McFarland Award

Sanjeev Mukerjee (Northeastern University) and Piotr Zelenay (LANL)

- Electrochemical Society Fellows

Kathy Ayers (Proton OnSite)

- American Chemical Society Women Chemist Committee's Rising Star Award

Jeff Long (LBNL, Univ. of CA – Berkeley)

- American Chemical Society Inorganic Chemistry Lectureship Award

Thank You

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Director

Fuel Cell Technologies Office

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hydrogenandfuelcells.energy.gov

Novel approaches to hybrid reforming, bio-derived liquids and solar water splitting

6 selections, $13.3 M in federal funds

FuelCell Energy Inc.

($900k), Danbury, CT

- Novel reformer-electrolyzer-purifier (REP) system

Pacific Northwest National Laboratory

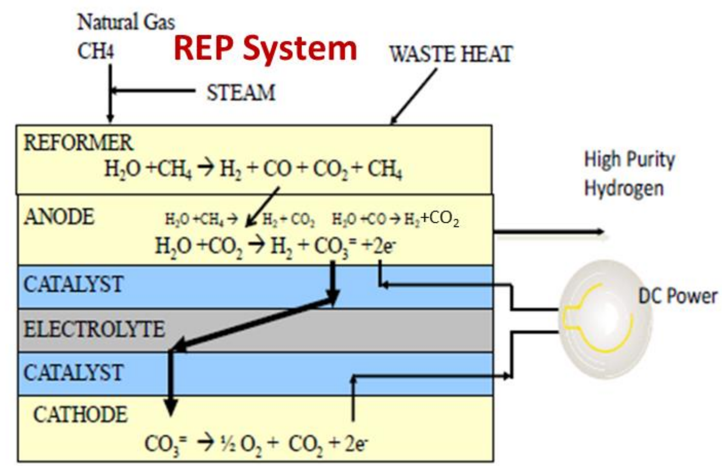
($2.2M), Richland, WA

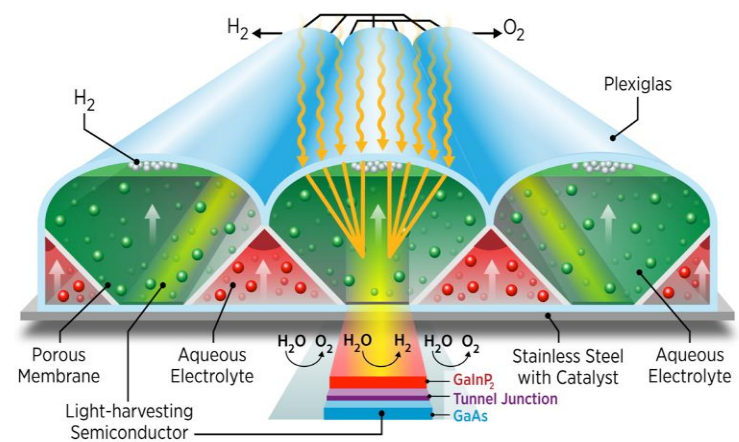
- Scalable, compact piston-type reactor for H_2 production from bio-derived liquids.

National Renewable Energy Laboratory

($3M), Golden, CO

- High-efficiency tandem absorbers based on novel semiconductor materials
- Economical solar hydrogen production from water.





New Selections for Hydrogen Production RD&D

Novel approaches to hybrid reforming, bio-derived liquids and solar water splitting

6 selections, $13.3 M in federal funds

University of Hawaii ($3M), Honolulu, HI

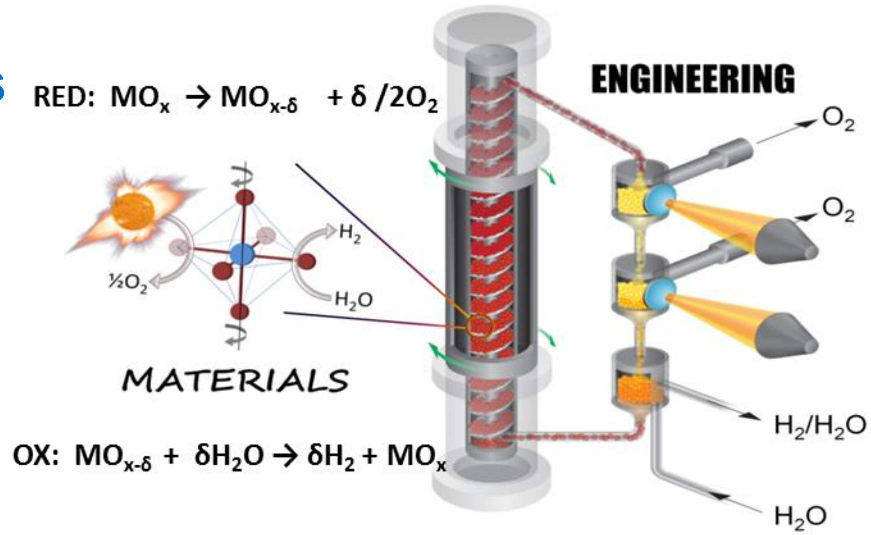
- Photoelectrodes based on novel wide-bandgap thin-films for direct solar water splitting.

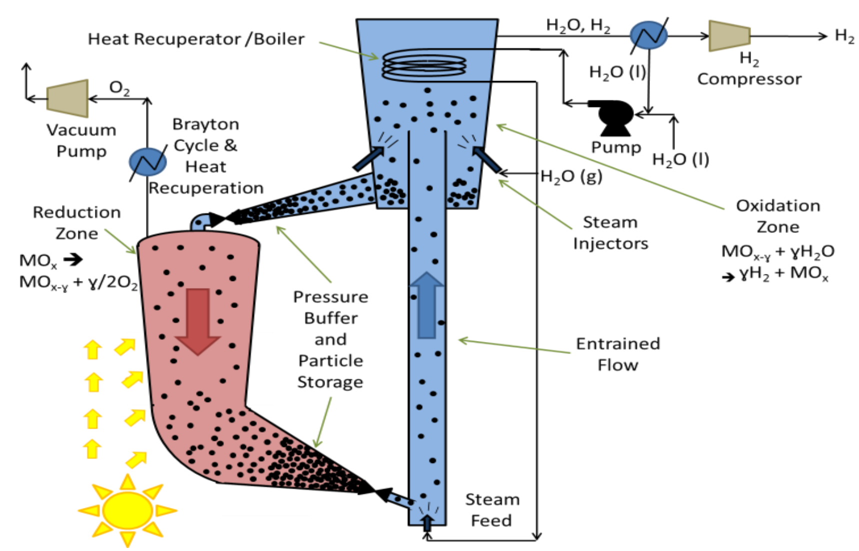
Sandia National Laboratories ($2.2M) Livermore, CA

- Innovative high-efficiency solar thermochemical reactor for H_2 production.

University of Colorado, Boulder ($2M), Boulder, CO

- Novel flowing particle bed solar-thermal reactor to split water with concentrated sunlight.





New Selections for Hydrogen Delivery RD&D

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Innovative technologies for forecourt compression, storage and dispensing

4 selections, $7.3 M in federal funds

Southwest Research Institute ($1.8M), San Antonio, TX

- Linear motor reciprocating compressor for forecourt H_2 compression

Oak Ridge National Laboratory ($2.0M), Oak Ridge, TN

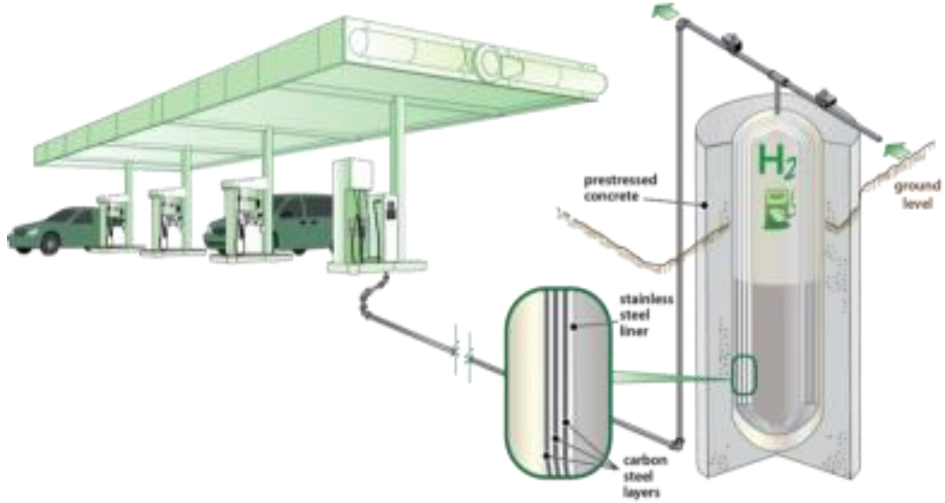
- Low cost steel concrete composite vessel for high pressure forecourt H_2 storage.

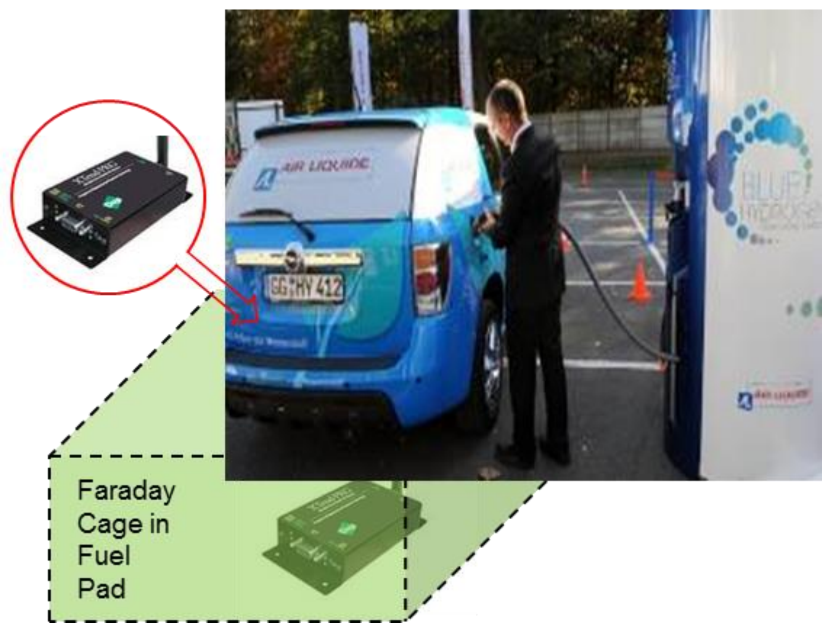
Wiretough Cylinders LLC ($2.0M), of Bristol, VA

- Low cost 875 bar H_2 storage vessel using a steel wire overwrap.

Nuvera Fuel Cells Inc. ($1.5M), Billerica, MA

- Integrated, intelligent 700 bar H_2 dispenser for fuel cell electric vehicle fueling





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

Concept:

Hydrogen Cost → Hydrogen gasoline gallon equivalent cost → hGallon Cost
$8/kg → $8/gge[1] → $3.8/gallon

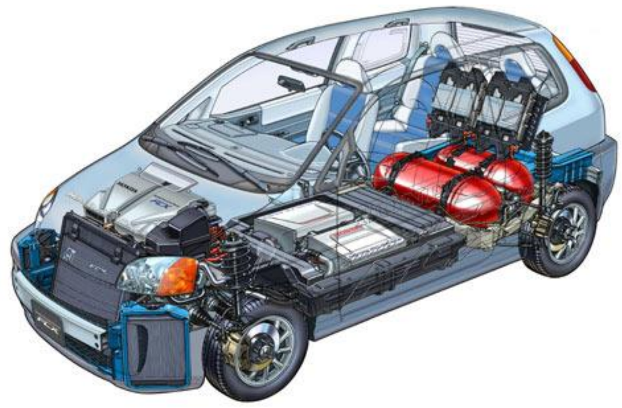
Filling up your tank costs the same if H_2 is $8/kg or gasoline is $3.8/gal.

An example, for a constant driving distance of 300 miles:

Gasoline Vehicle
Fuel Cost = $3.8/gallon

Gasoline fillup = ~10.7 gallons
Fill up cost = ~$41 (3.8 X 10.7)

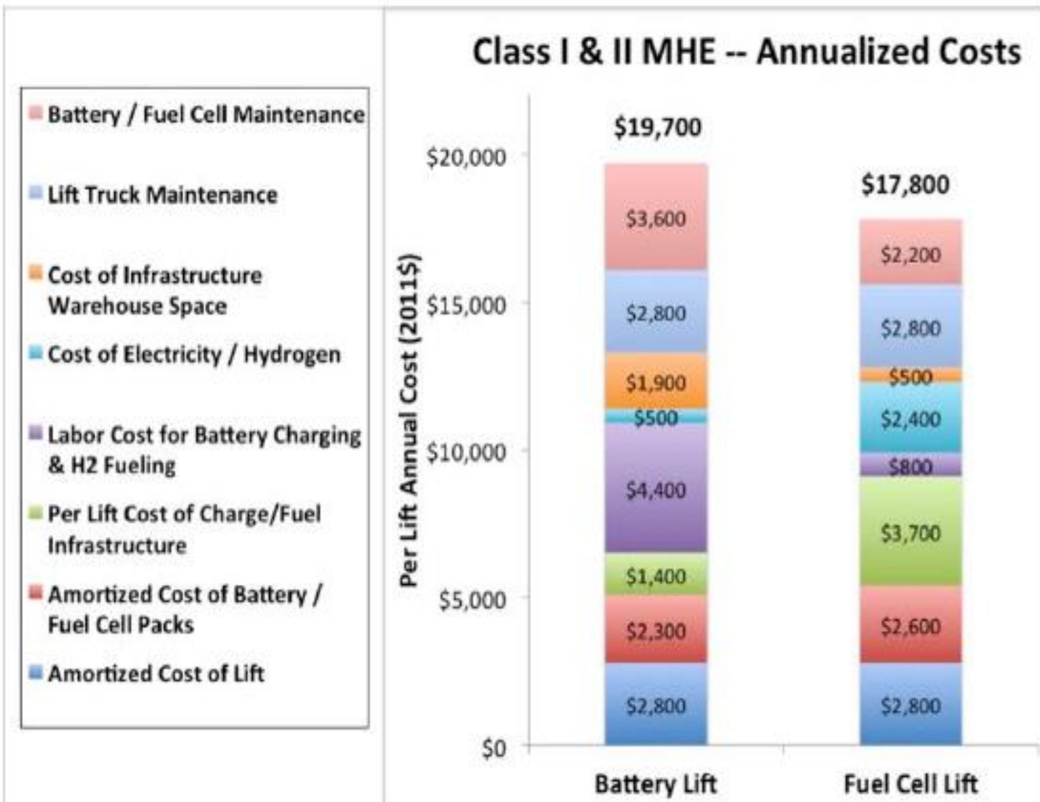
Hydrogen Fuel Cell Electric Vehicle
Fuel Cost = $8/kg → $3.8/gallon



Hydrogen fillup = ~5.1 kg = 5.1 gge
Fill up cost = ~$41 (8 X 5.1)

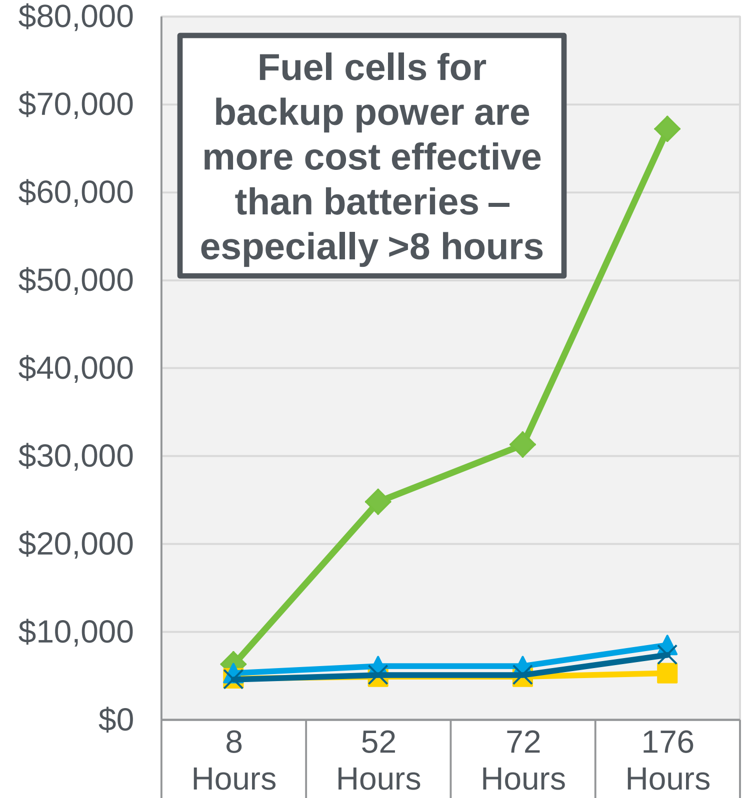
[1] gge = gasoline gallon equivalent
Assumptions: ICE fuel economy = 28 mpg, FCEV fuel economy = 59 mpgge

Fuel cells are becoming competitive in early markets!



An Evaluation of the Total Cost of Ownership of Fuel Cell-Powered Material handling Equipment http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/fuel_cell_mhe_cost.pdf

Annualized Cost of Ownership Backup Power



	8 Hours	52 Hours	72 Hours	176 Hours
Battery	$6,300	$24,800	$31,300	$67,200
Diesel	$4,700	$4,900	$4,900	$5,300
FC	$5,300	$6,100	$6,100	$8,500
FC*	$4,600	$5,100	$5,100	$7,400

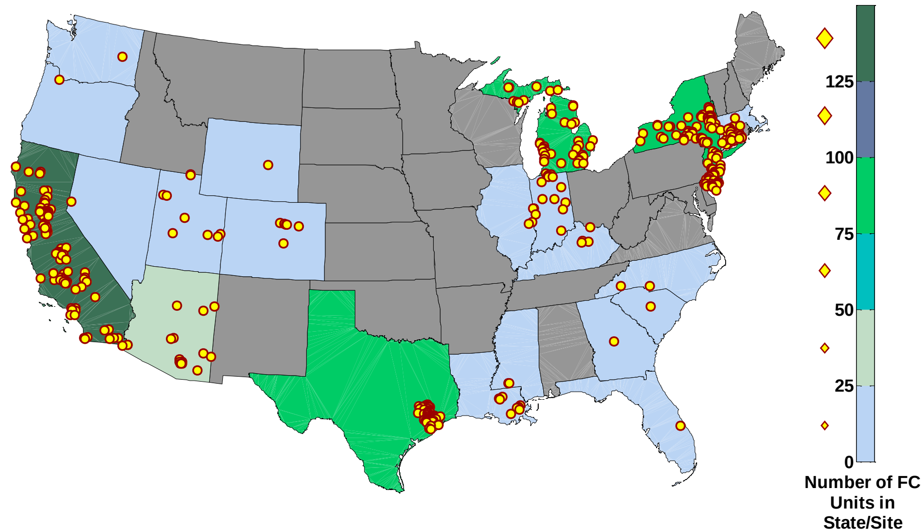
NREL report Backup Power Cost of Ownership Analysis and Incumbent Technology Comparison FC* = fuel cell with incentives

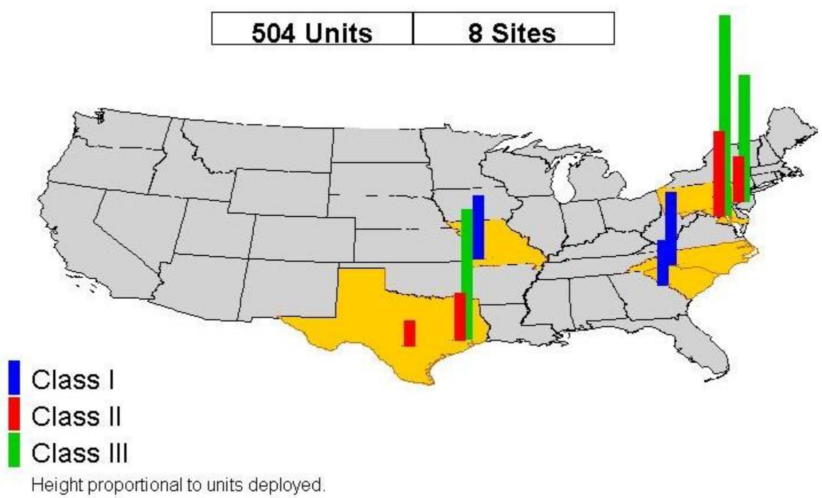
Data Collection & Analysis: Backup Power and Material Handling Equipment

Validated over 800 backup power units with seven industry partners

- FedEx Freight East, GENCO, Nuvera Fuel Cells, Plug Power, ReliOn Inc., Sprint Communications, Sysco of Houston –

- **842 units in operation[1]**
- **1.94 MW installed capacity**, average site capacity of 4-6 kW
- **99.7% successful starts** (2,579 start attempts)
- **65 continuous hours demonstrated**
- **>1,600 operation hours**





Validated over 450 material handling equipment units with seven industry partners

- **490 units in operation[2]**
- **>1,800,000 operation hours**, 4.4 average operation hours between fills
- **~230,000 kg of hydrogen dispensed** during more than **290,000 hydrogen fills** with an average of **0.6 kg per fill**

[1]Not all systems have detailed data reporting to NREL. [2]One project has completed.

Data from 2009 Q1 to 2013 Q2.

Energy Department Launches National Fuel Cell Technology Evaluation Center

a national resource for hydrogen and fuel cell stakeholders

supported through Energy Efficiency and Renewable Energy's Fuel Cell Technologies Office

ESIF Dedication, September 2013

http://apps1.eere.energy.gov/news/news_detail.cfm/news_id=19607

Photos by Dennis Schroeder, NREL