U.S. Department of Energy
Overview of Hydrogen and Fuel Cell Activities

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

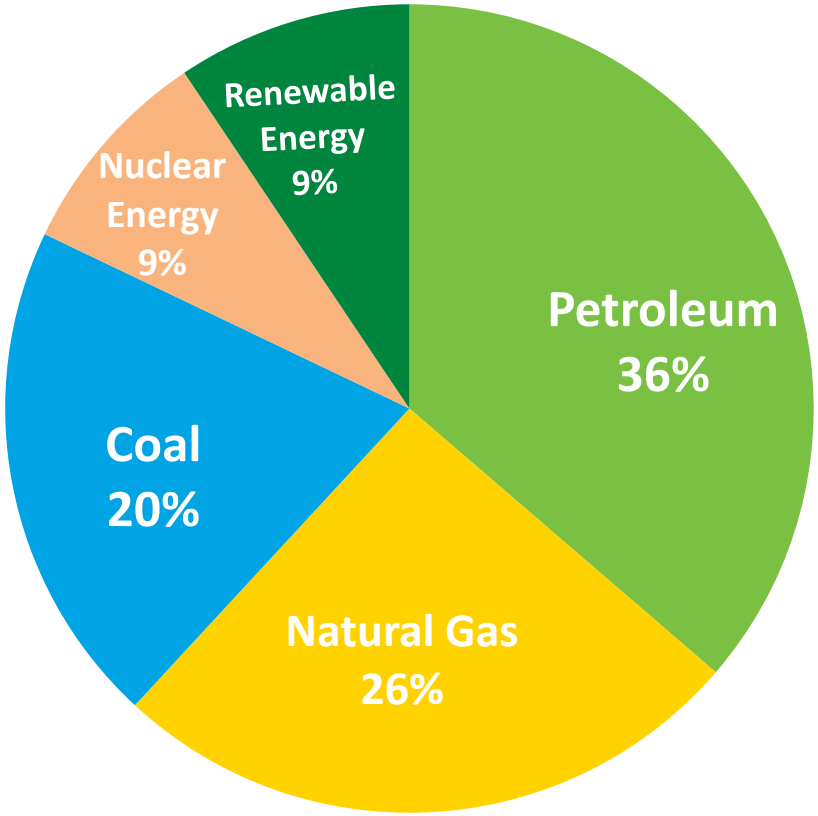
Eco-Mobility 2014

October 20th, 2014

Vienna, Austria

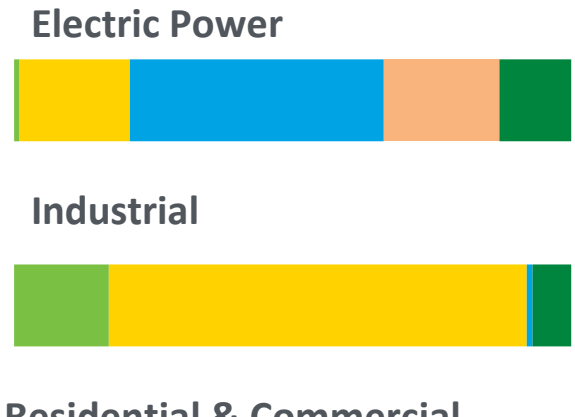
Dr. Sunita Satyapal
Director
Fuel Cell Technologies Office
Energy Efficiency and Renewable Energy
U.S. Department of Energy

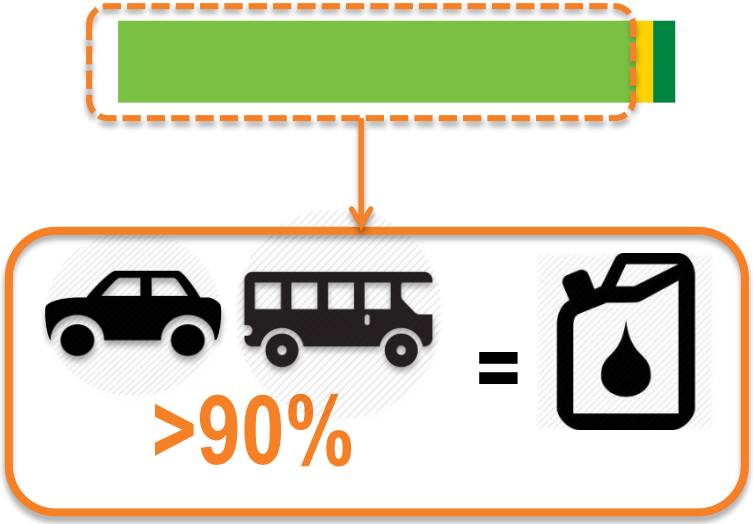
U.S. Energy Consumption



Total U.S. Energy

97 Quadrillion Btu/year





Source: Energy Information Administration, *Annual Energy Review 2011,* Table 1.3

U.S. 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

Growth in Electric Drive Vehicle Sales

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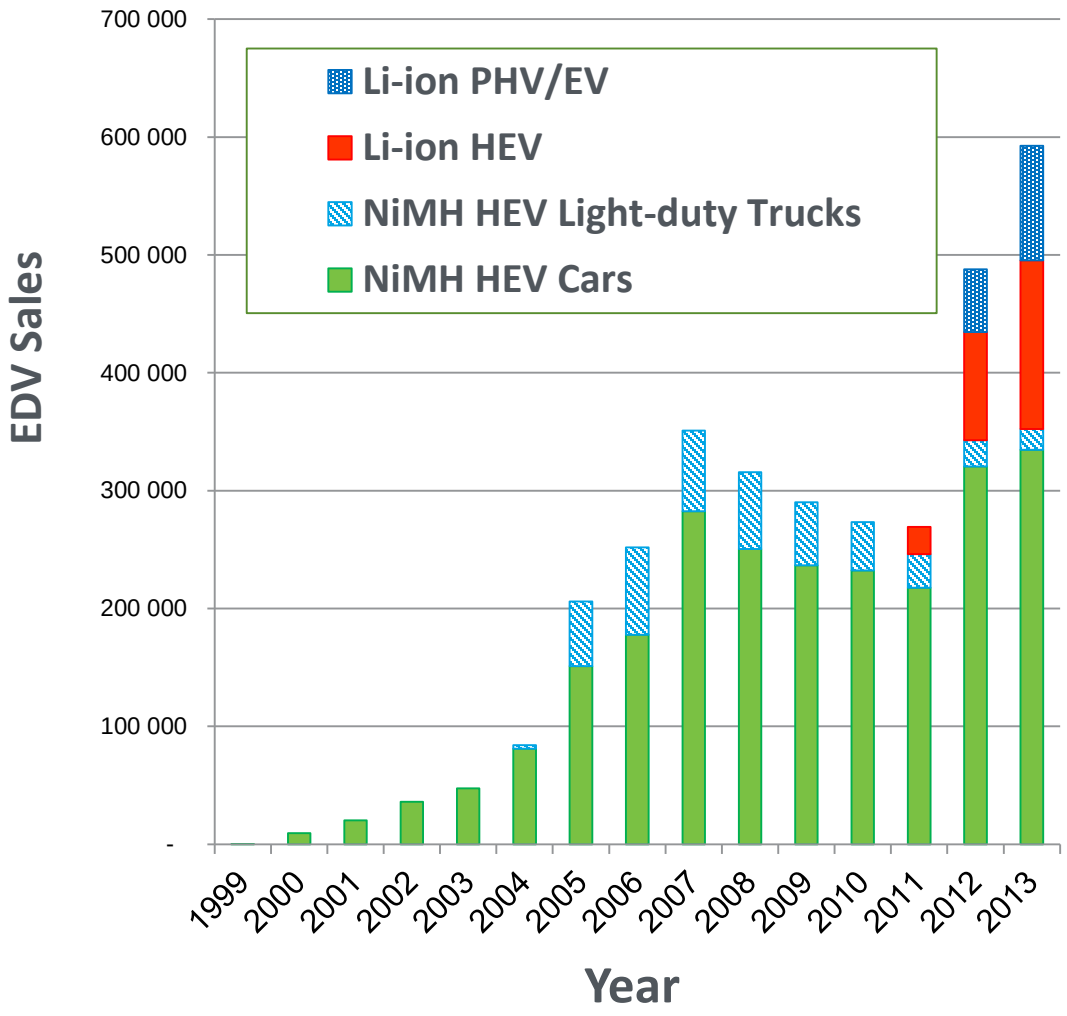
U.S. Electric Drive Vehicle Sales, by Technology (1999-2013)

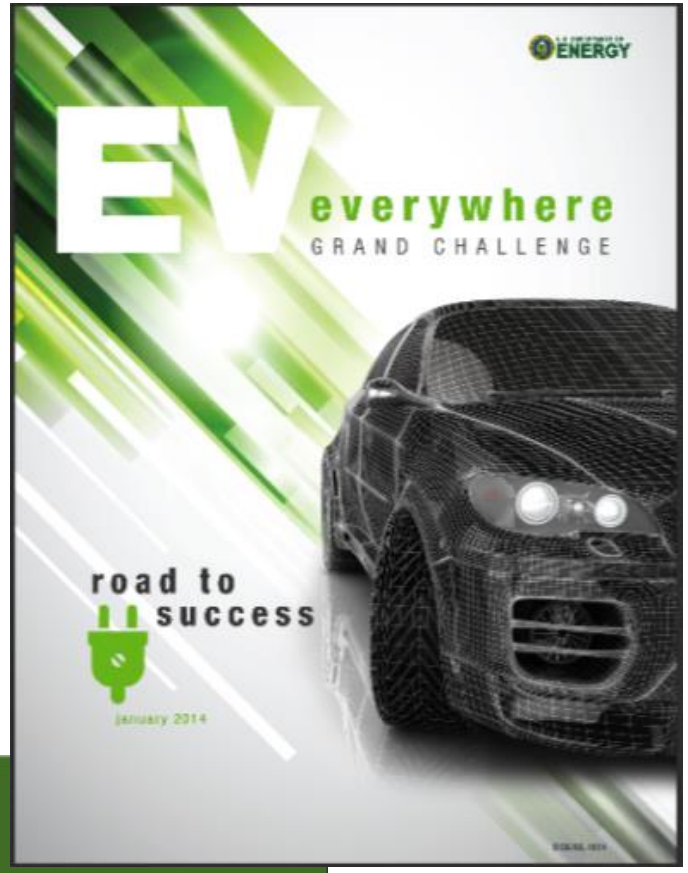


2013 Sales Set Record

- **46 EDV models were available for sale**
  - 575,000 Sales
- **~97,000 PEVs Sold. The top 6 models represent 95% of the sales :**
  - Volt (23,094)
  - Leaf (22,610)
  - Model S (19,400)
  - Prius PHEV (12,088)
  - Cmax Energi (7,154)
  - Fusion Energi (6,089)
- **Over 3.1 million EDVs on the road Jan.1, 2014**

EV Everywhere Grand Challenge

President Obama announced EV Everywhere during a visit to Daimler Trucks in North Carolina, March 2012



EV EVERYWHERE – EARLY SUCCESSES

The top four things you need to know

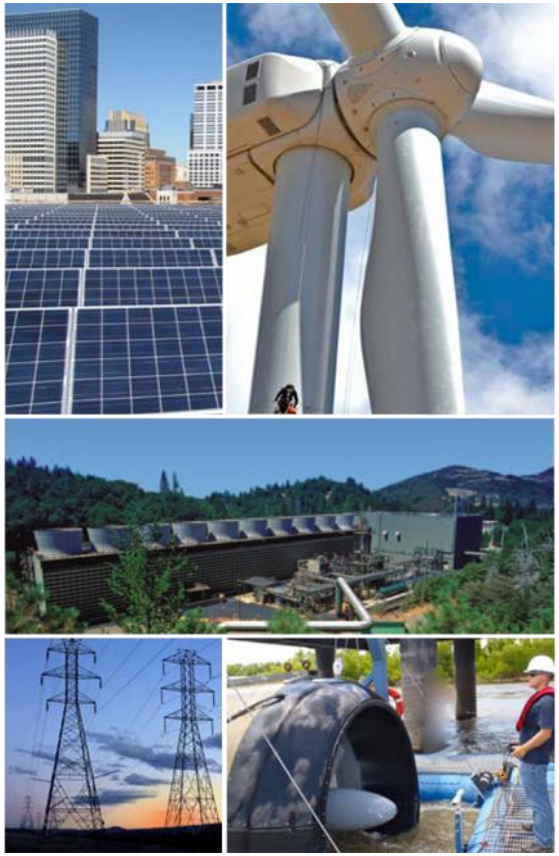
- DOE research and development has reduced the cost of electric drive vehicle batteries to $325/kWhr, 50% lower than just four years ago.
- In the first year of the Workplace Charging Challenge, more than 50 U.S. employers joined the Challenge and pledged to provide charging access at more than 150 sites.
- DOE investments in *EV Everywhere* technology topped $225 million in the last 12 months, addressing key barriers to achieving the Grand Challenge.
- Consumer acceptance is rapidly growing – 97,000 plug-in electric vehicles were sold in 2013, nearly doubling 2012 sales.

Office of Energy Efficiency and Renewable Energy (EERE)

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

Three offices support EERE's mission to create and sustain American leadership in the transition to a global clean energy.

Renewable
ELECTRICITY GENERATION



Sustainable
TRANSPORTATION

Energy Saving
HOMES, BUILDINGS, & MANUFACTURING

Sustainable Transportation- Areas of Focus

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

Efforts in three areas -H_2 and Fuel Cells, Vehicle Technologies and Bioenergy- are helping to meet national Energy goals and Climate Action Plan

Sustainable TRANSPORTATION

- Efficiency Improvement
- Fuel Diversification
- Domestic & Renewable Sources
- Reduced GHG

Hydrogen and Fuel Cells

Vehicles

Bioenergy

National Energy Goals & Climate Action Plan

50% in oil imports

17% in GHG Emissions

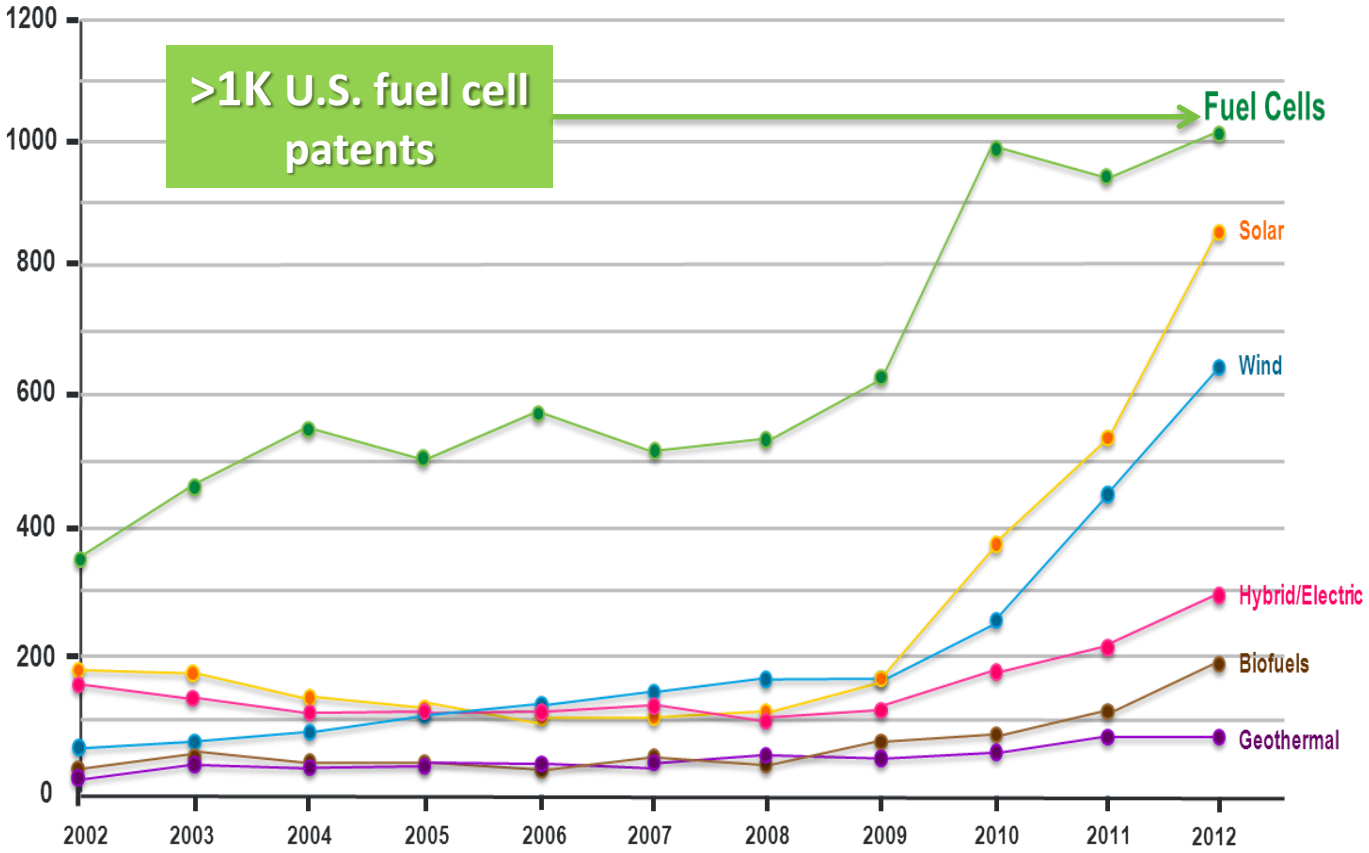
by 2020

Growth in Clean Energy Patents

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

Number of patents in clean energy technologies continues to grow and roughly 1,000 U.S. patents have been issued for fuel cell technologies for 3 consecutive years.

US Clean Energy Patents[1]



Examples of companies with most fuel cell patents:

- GM
- Honda
- Toyota
- Samsung
- Nissan
- Ballard
- Panasonic
- Plug Power
- Delphi

[1] Clean Energy Patent Growth Index http://cepgi.typepad.com/heslin_rothenberg_farley_/2013/03/clean-energy-patent-growth-index-2011-year-in-review.html

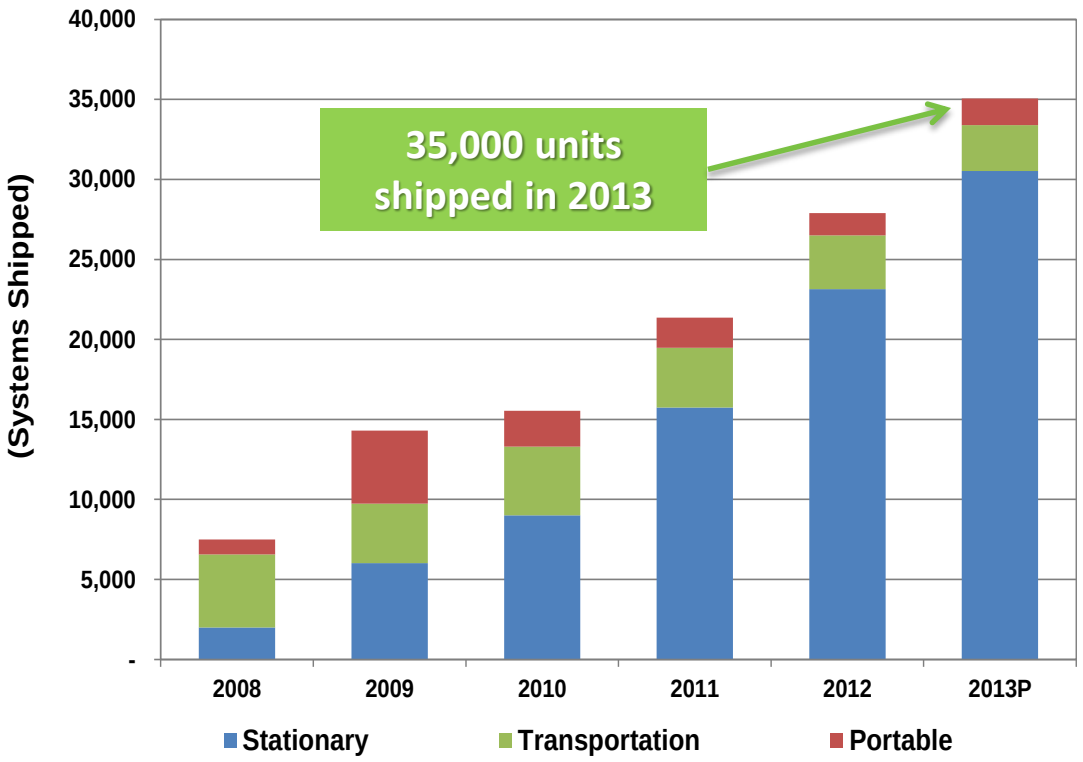
Fuel Cell Market is Growing

Fuel cell market is growing with a consistent ~30% annual market growth rate since 2010

Market Growth

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

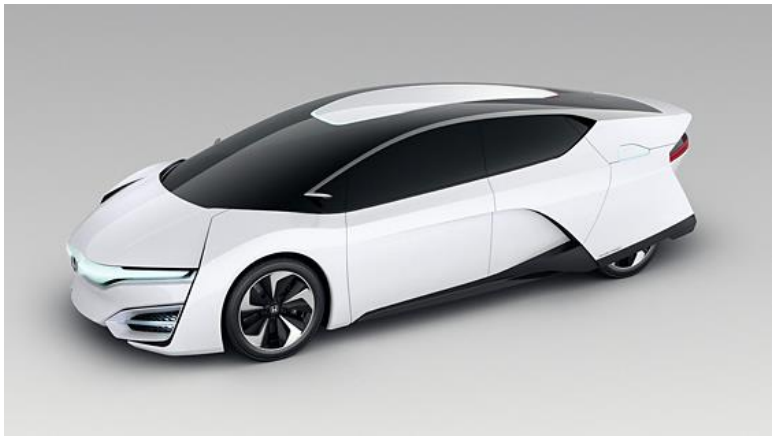
Fuel Cell Systems Shipped by Application



Source: Navigant Research

Fuel Cell Cars are Here!

FCEVs on display at North American auto shows in 2013



Honda Fuel Cell Electric Vehicle

Toyota Fuel Cell Electric Vehicle

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

Lease includes **H_2** and **maintenance**.

Well-to-Wheels Greenhouse Gases Emissions Projections

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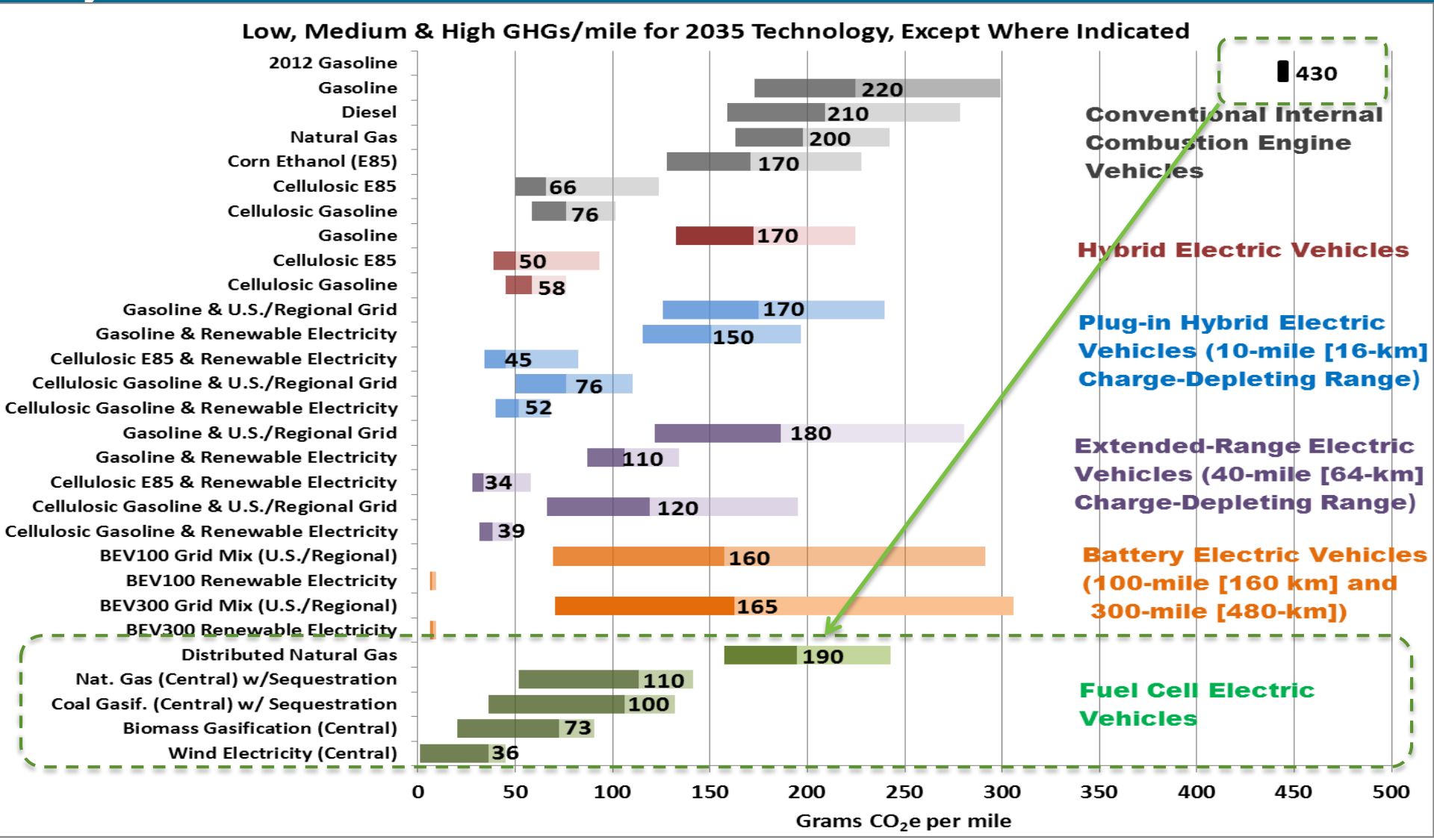

Low/medium/high: sensitivity to uncertainties associated with projected fuel economy of vehicles and selected attributes of fuels pathways, e.g., electricity credit for biofuels, electric generation mix, etc.

H_2 from Distributed NG can reduce CO_2 emissions by 50%

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

DOE Hydrogen and Fuel Cells Program

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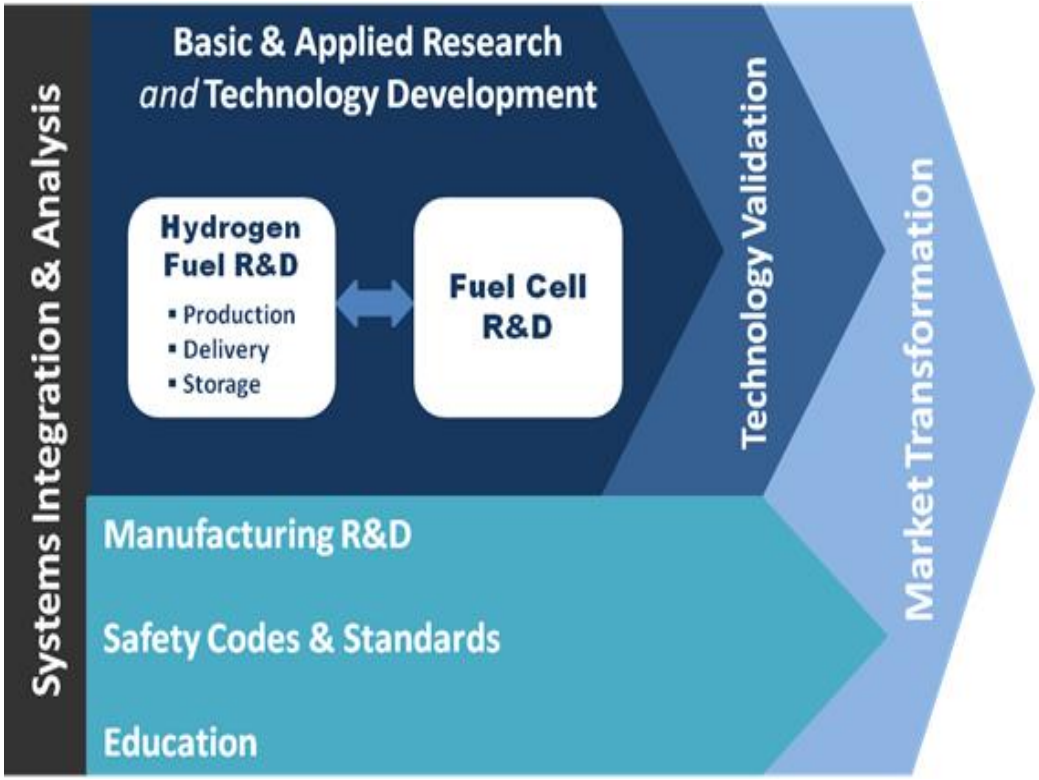
Integrated and structured effort to address all the key challenges and obstacles facing widespread commercialization of hydrogen and fuel cells in a wide range of applications.



2020 Targets by Application

Fuel Cell Cost	$40/kW	$1,000/kW* $1,500/kW**
and Durability	5,000 hrs	80,000 hrs
H_2 Cost (delivered and dispensed at pump)	<$4/gge	
H_2 Storage Cost (700-bar tank)	$12/kWh	

DOE Fuel Cell Technologies Office covers Research, Development, Demonstration & Deployment

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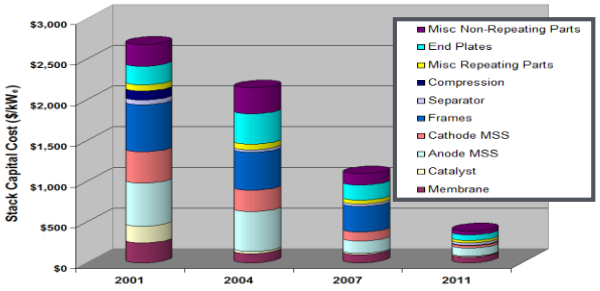
DOE R&D

Fuel Cell System Cost

Transportation projected to (500,000 units per year)

50% reduction vs. 2006 ($55/kW)

Electrolyzer Stack Costs



80% reduction since 2002

DOE Demonstrations

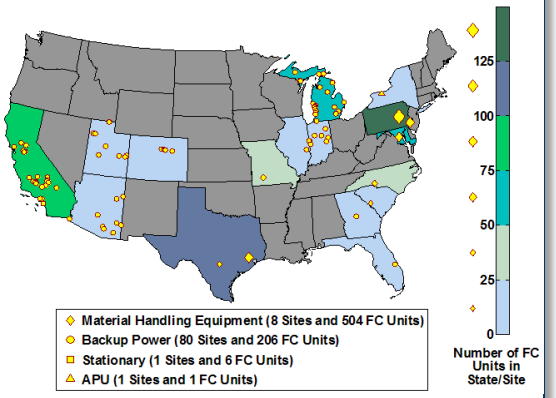
Demonstrated

- ***>180 FCEVs***
- ***25 stations***
- ***3.6 million miles traveled***
- ***World's first tri-gen station*** *(250 kW on biogas, 100 kg/d H2 produced)*

Deployments

- ***DOE Recovery Act***
- ***Market Transformation Projects***
- ***Government Early Adoption (DoD, FAA, California, etc.)***
- ***Tax Credits: 1603, 48C***

Recovery Act & Market Transformation Deployments



~1,600 fuel cells deployed
>11,000 follow on orders

Hydrogen & Fuel Cells Budget

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DOE FCTO funding has led to >450 patents, 42 commercial hydrogen and fuel cell technologies and 65 emerging technologies. DOE cost-share deployments led to 7X additional back up power and lift trucks.

Key Activity	FY 2014 ($ in thousands)		FY 2015 ($ in thousands)
	Request	Approp.	Request
Fuel Cell R&D	37,500	32,422	33,000
Hydrogen Fuel R&D[1]	38,500	34,467	36,283
Manufacturing R&D	4,000	2,879	3,000
Systems Analysis	3,000	3,000	3,000
Technology Validation	6,000	6,000	6,000
Safety, Codes and Standards	7,000	6,909	7,000
Market Transformation	3,000	2,841	3,000
NREL Site-wide Facilities Support	1,000	1,000	1,700
SBIR/STTR	TBD	3,410	TBD
Total	$100,000	$92,928	$92,983

Office	FY 2014
Basic Science[2]	~$25M
Fossil Energy, SECA	~$25M
ARPA-E[3]	~$33M

FY14 DOE Total: ~$175M

[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
[3] Fuel cell related new projects from ARPA-E

Fuel Cell Cost Reductions Enabled by R&D

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R&D has enabled significant fuel cell cost reductions but catalyst cost is still a key challenge.

Fuel Cell Cost Reductions

50% ↓ 30% **Fuel Cell** from 2006 to from 2008

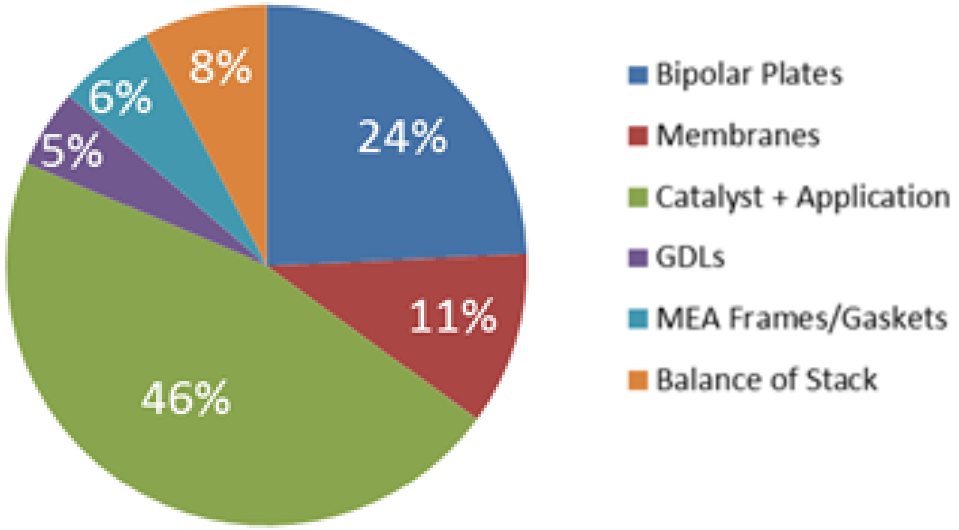
5X ↓ **Platinum Catalyst**

Fuel Cell Cost Status and Goal

- **$55/kW*** for high volume
- **~$280/kW†** for low volume
- **$40/kW** by **2020** is the goal

*SA, bottom-up analysis of model system manufacturing cost, 500,000 sys/year with next-gen lab technology.
†ORNL, top-down analysis based on OEM input, 20,000 sys/yr. with current technology.

Fuel Cell System Cost* Cost Breakdown

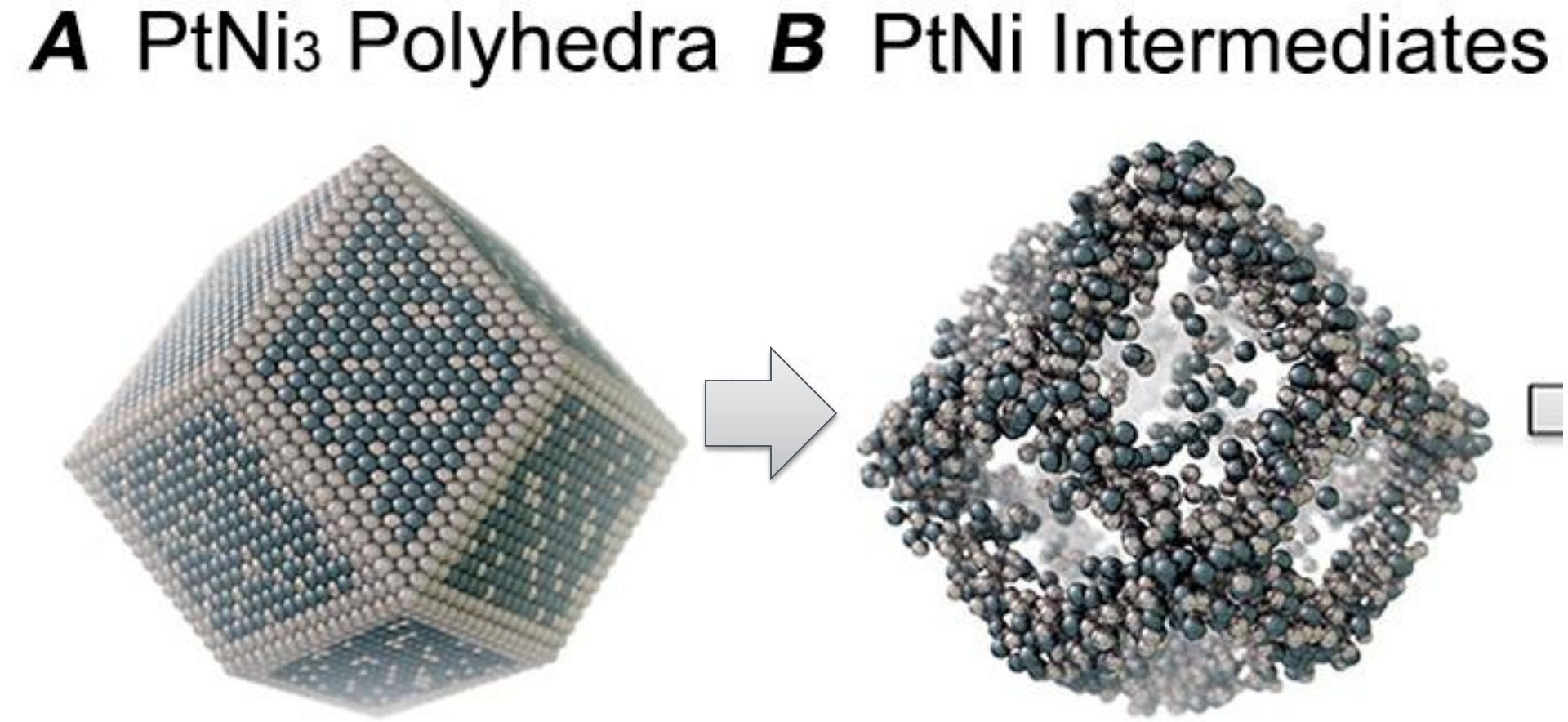


Catalyst accounts for **>45%** of total system cost

*For PEMFC Stack cost, 500,000 units per yr.
Cost is shows as $/kW-net.

Synthesis & Evaluation of Nanoframes

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



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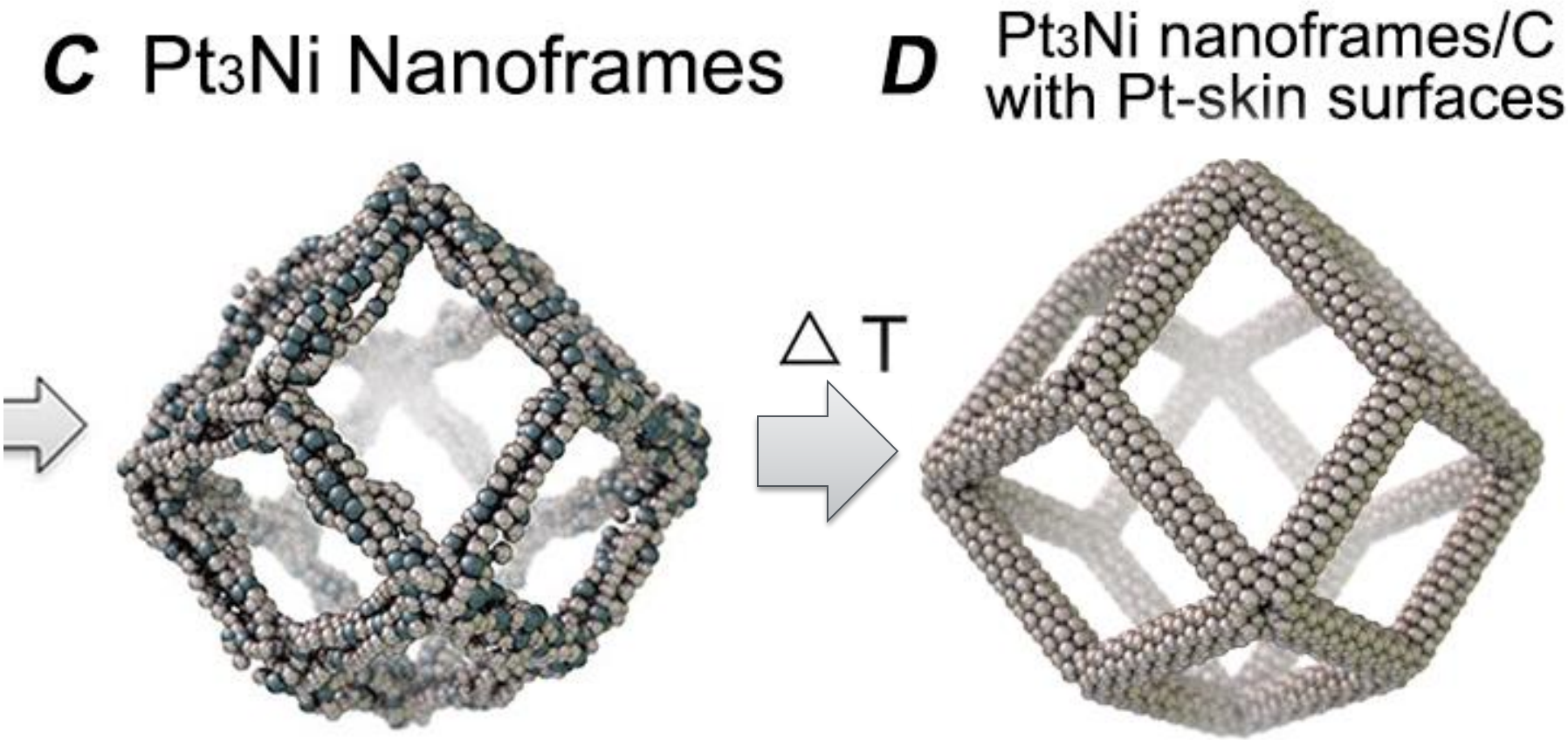

Dispersible cathode catalyst with extended thin film catalyst properties

Synthesis & Evaluation of Nanoframes

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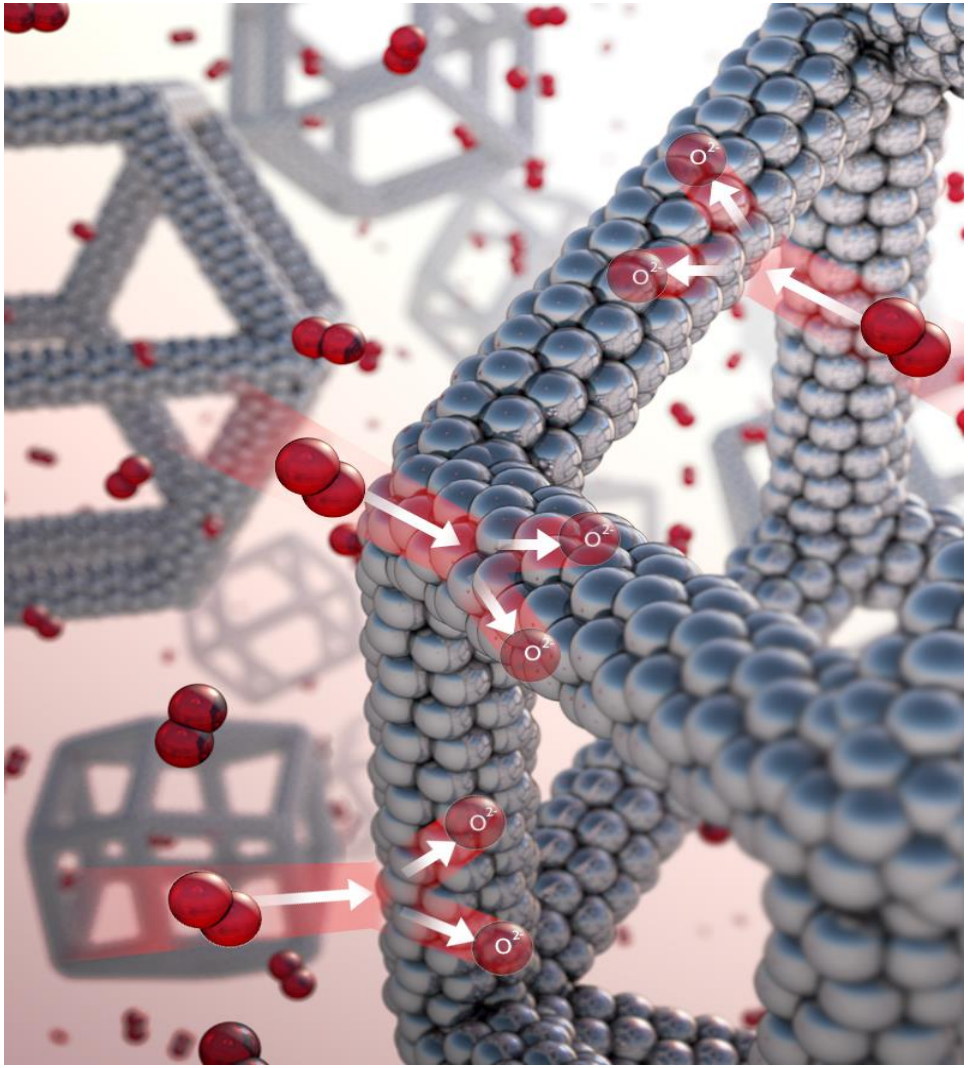

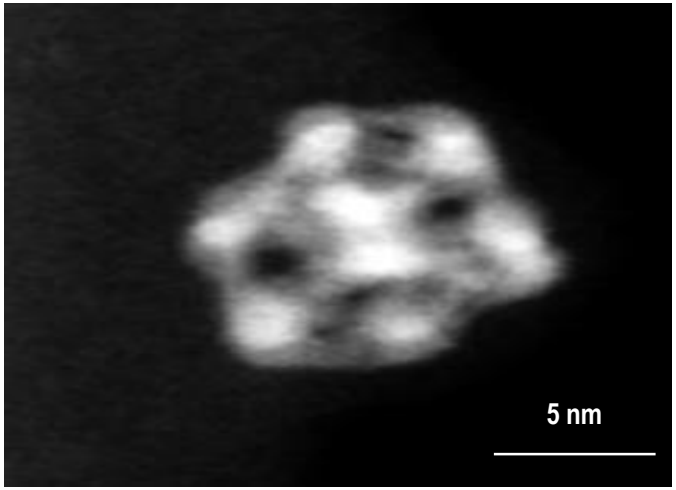

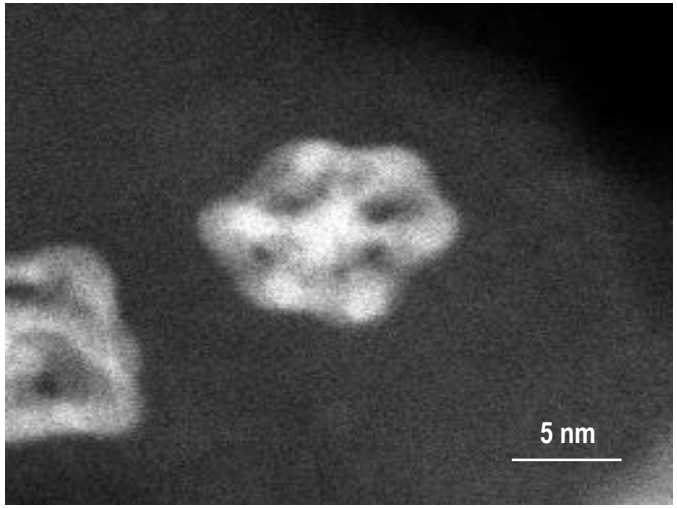

TEM- Karen Morre, ORNL

Synthesis & Evaluation of Nanoframes

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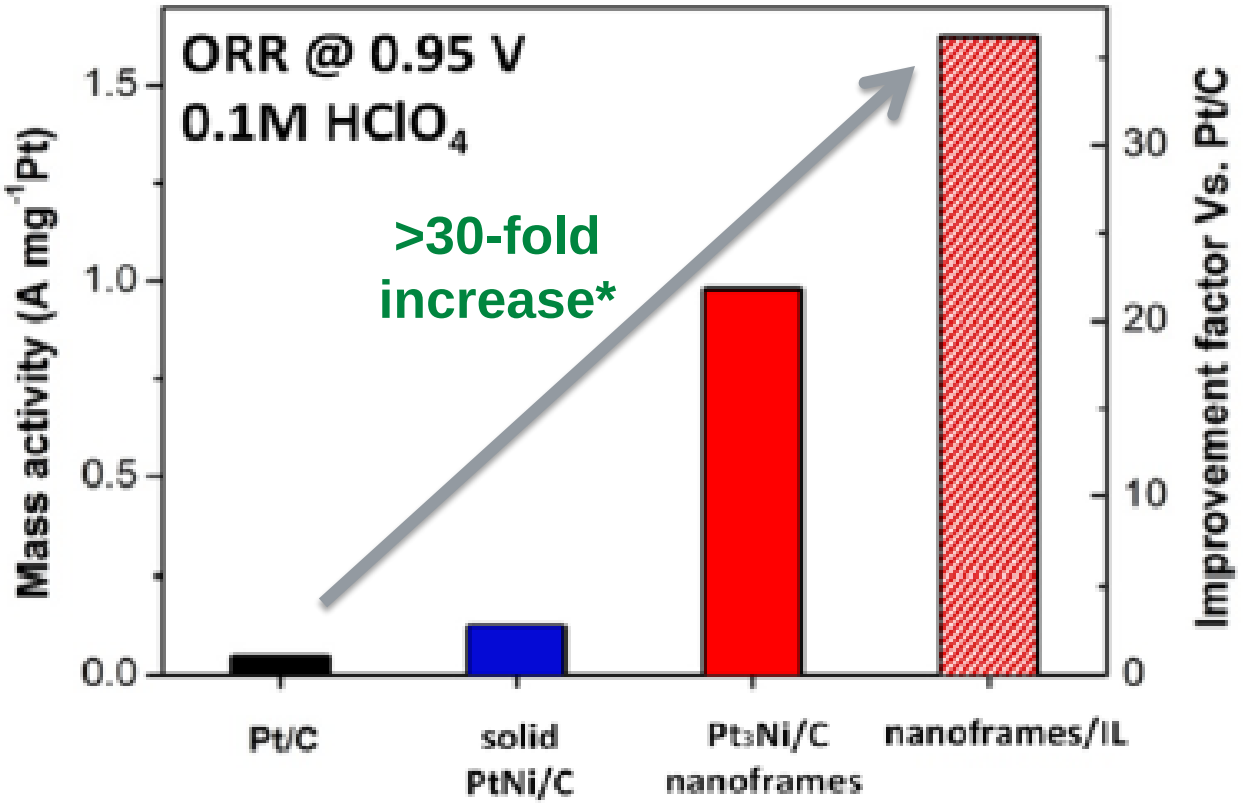


*Catalyst only, Future plans: Demonstrate MEAs

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

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

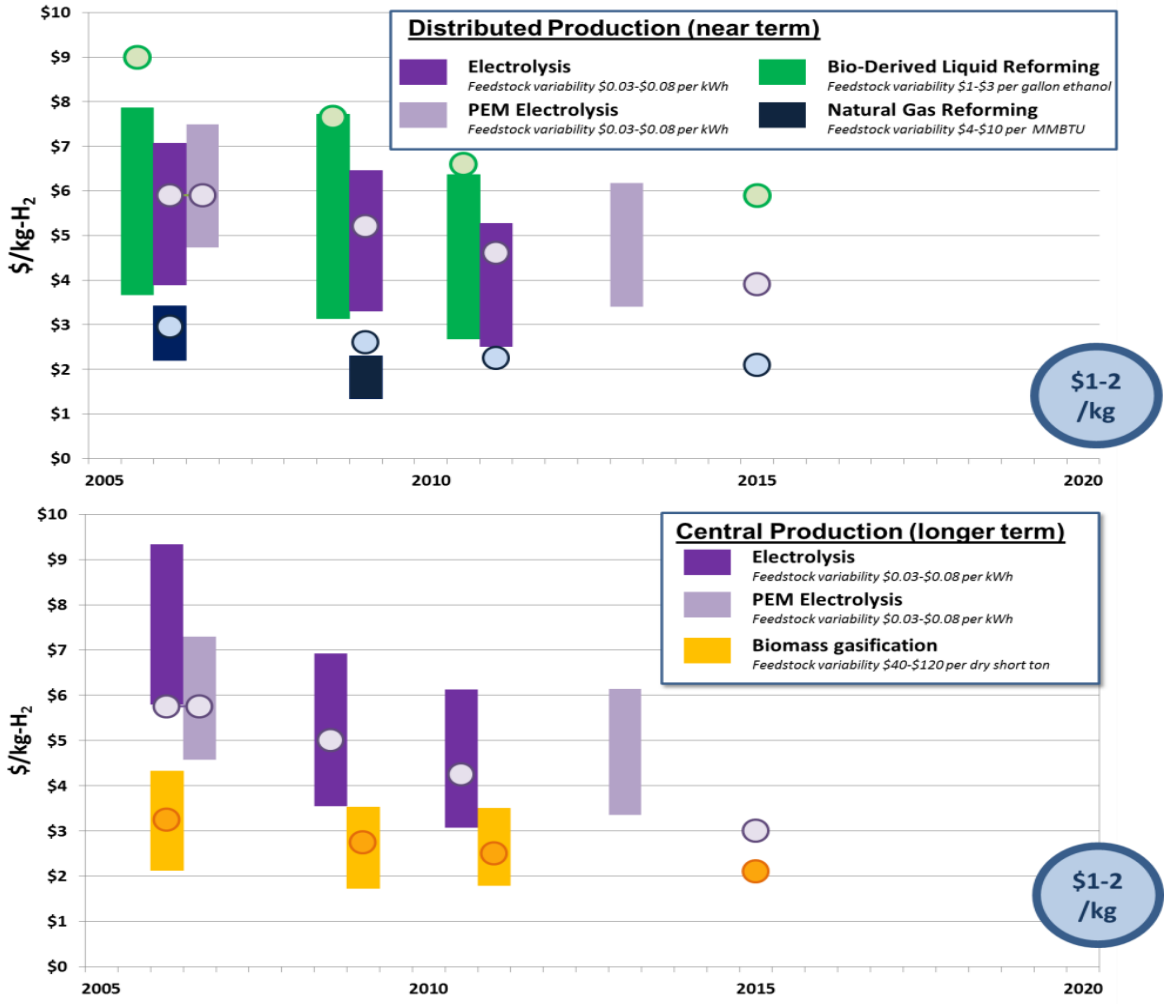
Science, 343 (2014) 1339

Hydrogen Production Strategies

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

Distributed production is a feasible option for the near term while central production will be more relevant in the longer term.

- **Short Term:**
  - Natural Gas
- **Long Term:**
  - Renewables
  - Biological
  - Electrolysis (Wind & Solar)
  - High Temperature Thermochemical (e.g. solar, nuclear heat, etc.)



Hydrogen Delivery

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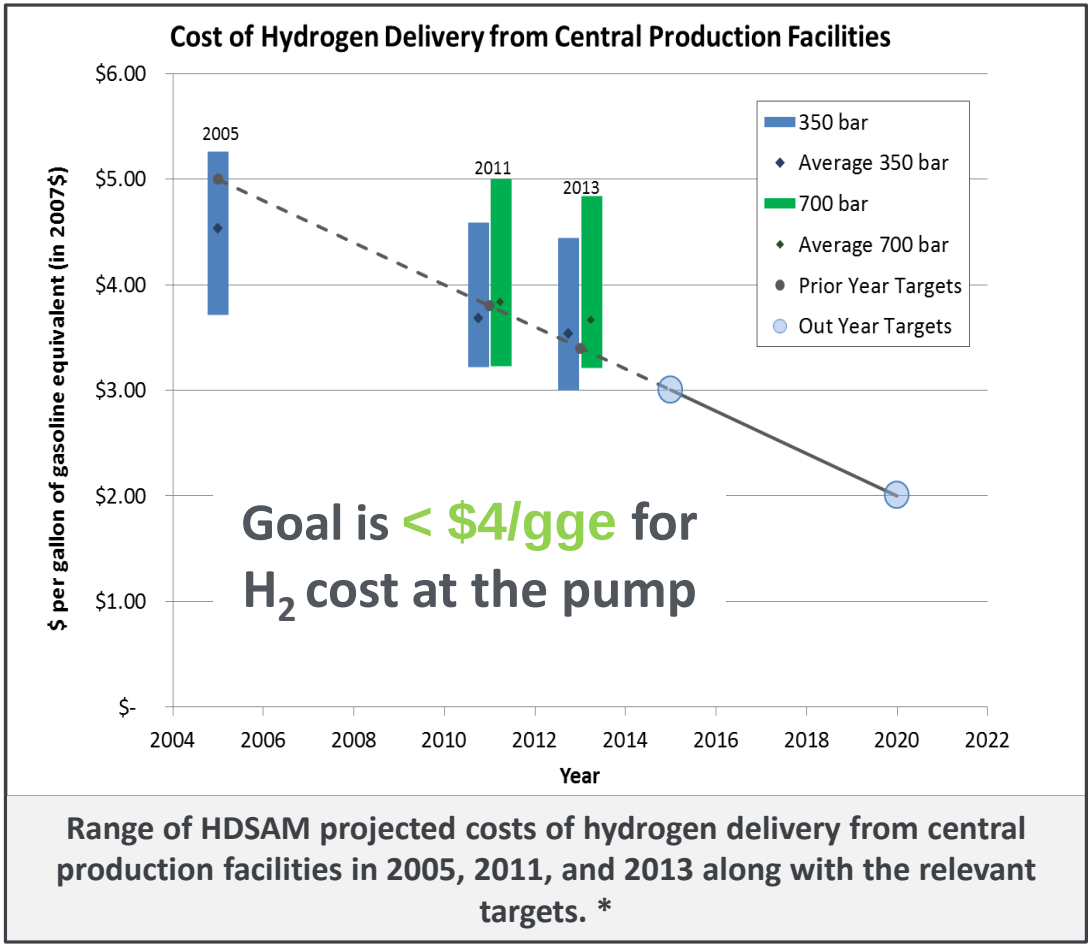
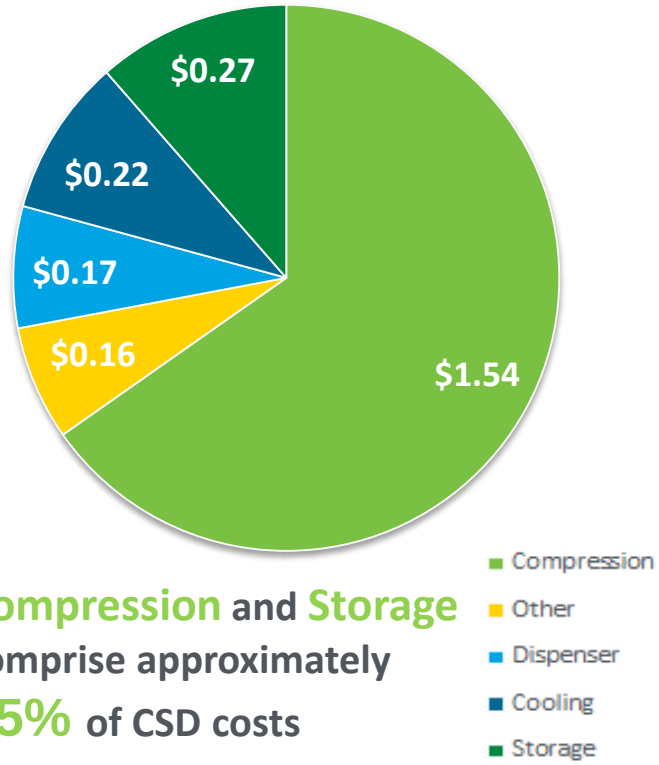
R&D has enabled H_2 delivery reduction costs but compression is still a key challenge.



Range of HDSAM projected costs of hydrogen delivery from central production facilities in 2005, 2011, and 2013 along with the relevant targets. *

CSD Cost Breakdown for the Pipeline Scenario ($2.40/kg total)**



Compression and **Storage** comprise approximately **75%** of CSD costs

* Details for the high volume cost projection assumptions can be found in Record 13013

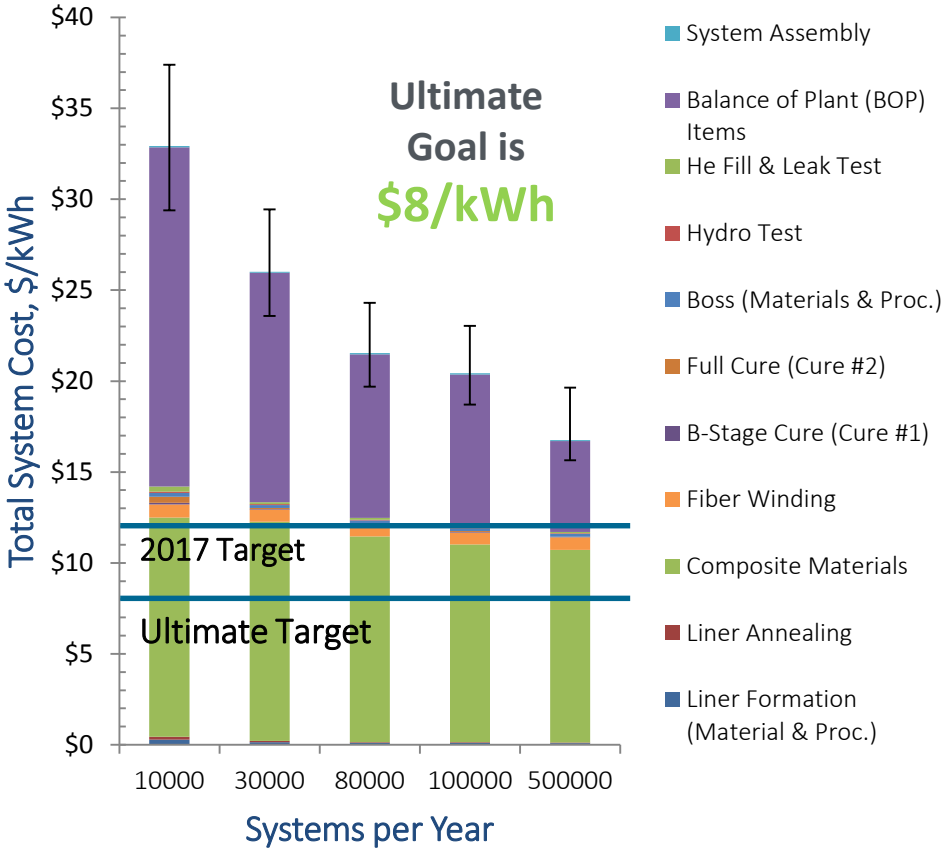
**Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs, May 2014, ttp://www.hydrogen.energy.gov/pdfs/58564.pdf

Understanding H_2 Storage System Costs

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

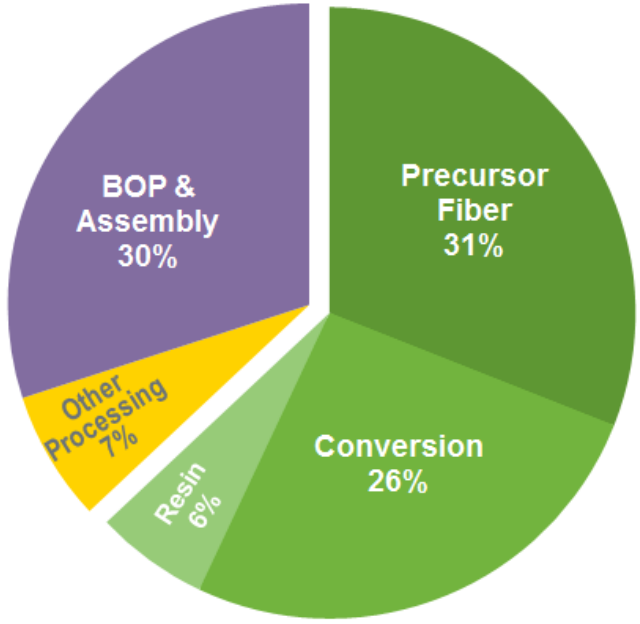
700 bar compressed hydrogen is the onboard storage technology for initial FCEV rollout, however cost reductions are needed – Carbon Fiber is the key

700 bar Compressed Gas Storage System Cost* and Targets



*Single tank holding 5.6kg H2 total, cost in 2007$

700 bar system cost breakdown at 500,000 systems/year



Composite materials (including precursor fiber) account for **>60%** of total storage tank system cost

Addressing Data Validation Challenges

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DOE awards light-duty fuel cell vehicle data collection projects.

QUICK STATS:

$5.5M in DOE funding

6 auto partners

Data from **~ 90**

Planned mileage: **~500K** mi.

- Phase 1 = ~220,000 mi
- Phase 2 (anticipated) = ~235,000 mi

METRICS:

- Fuel cell stack durability and efficiency.
- FCV range, driving behavior, fuel economy, and maintenance.
- On-board H_2 storage performance.
- H_2 infrastructure and refueling performance.
- H_2 fuel constituents measured at stations.
- Safety

First Composite Data Products to be released October 2014

ELECTRICORE
POWERING THE FUTURE

Honda

Nissan

Toyota

Hyundai

H_2 Infrastructure

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

H_2 Production and Delivery efforts are focusing on achieving a cost of H_2 dispensed at the pump of < $4/gge to be competitive with conventional fuels.

Current U.S. H_2 Infrastructure

- **1,500 miles** of H_2 pipelines (CA, TX, LA, IL, and IN)
- **> 9 million metric tons** of H_2 produced/yr.
- **~ 50** fueling stations in the U.S. (~ 10 public)

Options for Low-Cost Early Infrastructure

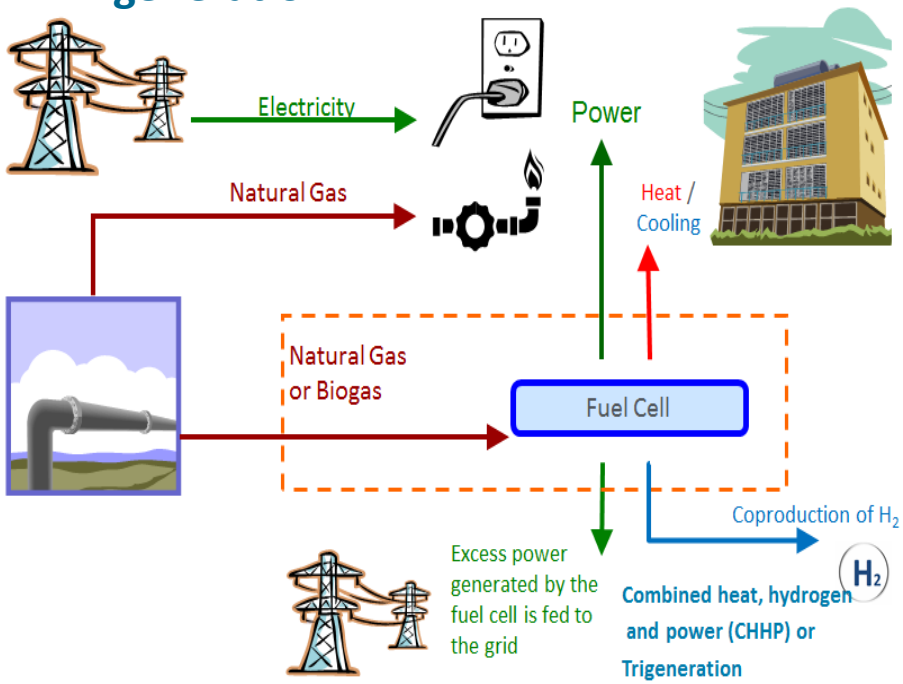
- **H_2 delivered from central site:**

  Low-volume stations (~200-300 kg/day) would cost <$1M and provide hydrogen for $7/gge

- **Distributed production (e.g. natural gas, electrolysis)**

Other Options

- **H_2 from waste** (industrial, wastewater, landfills)
- **Trigeneration**



Power + Heat + H_2

are coproduced through trigeneration

Examples of Hydrogen and Fuel Cell Initiatives at the State Level

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Several states—including California, Connecticut, Hawaii, Ohio, New York, and South Carolina—have major hydrogen and fuel cell programs underway.

8 states sign MoU to put 3.3M ZEVs on roads by 2025

California, Connecticut, Massachusetts, Maryland, New York, Oregon, Rhode Island, & Vermont

- **Represents a new vehicle market penetration of ~15%**

California

FCEVs and Fuel Cell Buses

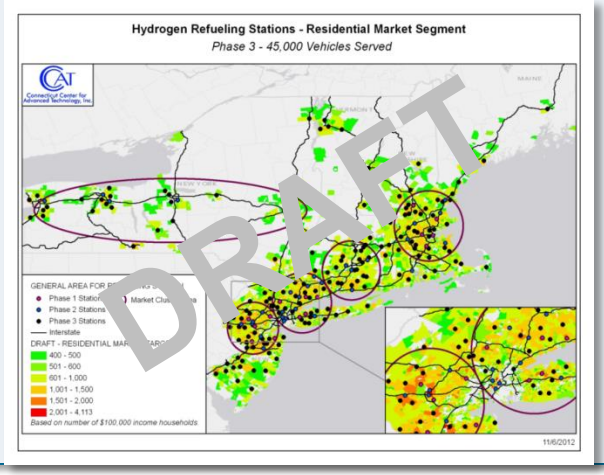
- **> 560 vehicles** in operation since 1999
- **> 6 million miles** driven
- **> 1 million passengers** on fuel cell buses

H_2 Station Investment

- **>$50M invested** *(CARB and CEC)*
- **~$47M for 28 stations and 1 mobile refueler** (CEC PON 13-607)
- **$20M planned annually** thru 2023 for at least 100 stations (AB8)

Northeast (e.g. MA, NY, CT)

3 phase plan modelled by CCAT for the development of hydrogen infrastructure and deployment of FCEVs in the north eastern coastal metro centers.



Hawaii

Agreement signed by 12 stakeholders that includes several provisions:

- **15 GM FCEVs** currently in demonstrations with military
- **Renewable hydrogen** (geothermal and wind) to power buses
- **Public access** nascent refueling **infrastructure** on Oahu by 2020

Hydrogen Stations in Planning / Development Stage - OAHU

H2USA: 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.

Established H_2FIRST Project–H_2 Fueling Infrastructure Research & Station Technology

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

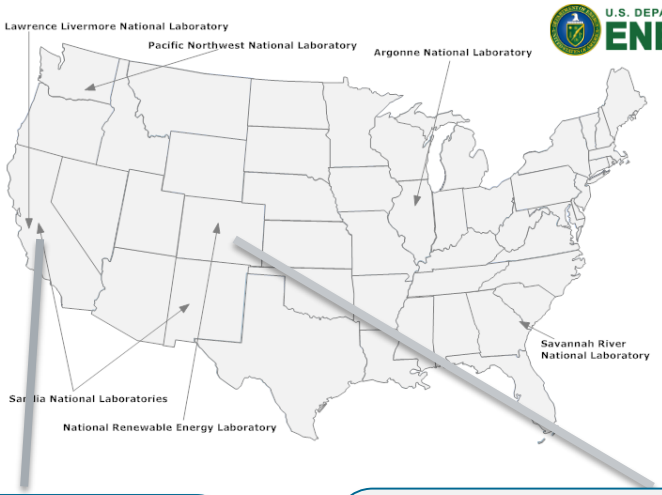
NREL and SNL Provide:

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

H2FIRST — Hydrogen Fueling Infrastructure Research and Station Technology

in support of H_2USA

Leverage DOE National Lab Network



Project Teams

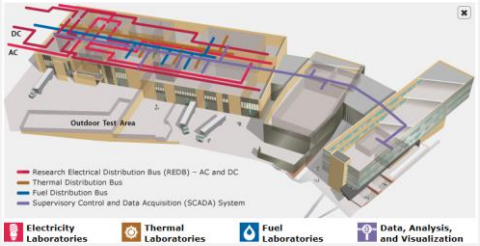
- Station Qualification
- Dispenser Components Research
- Fuel Quality Sensor
- Station Component RD&D
- Reference Station Design

Sandia National Laboratories

Center for Infrastructure Research & Innovation

NREL — NATIONAL RENEWABLE ENERGY LABORATORY

Energy Systems Integration Facility



Distributed Energy Resources Test Facility

Key Early Market Challenges Addressed by H_2USA

Photo Credits Top: NREL, Middle: NREL, Bottom: Hexagon Lincoln

➢ Station Cost Reduction

- Fueling resources & delivery
- State and local regulations

➢ Station Locations

- Identify and prioritize markets
- Regulatory barriers (zoning)
- Station rollout timing

➢ Investment and Finance

- Private sector financing
- Government support

➢ Market Support and Acceleration

- Product launch and timeline
- Codes and standards (non-vehicle related)
- Public education

The Importance of Early Market Applications

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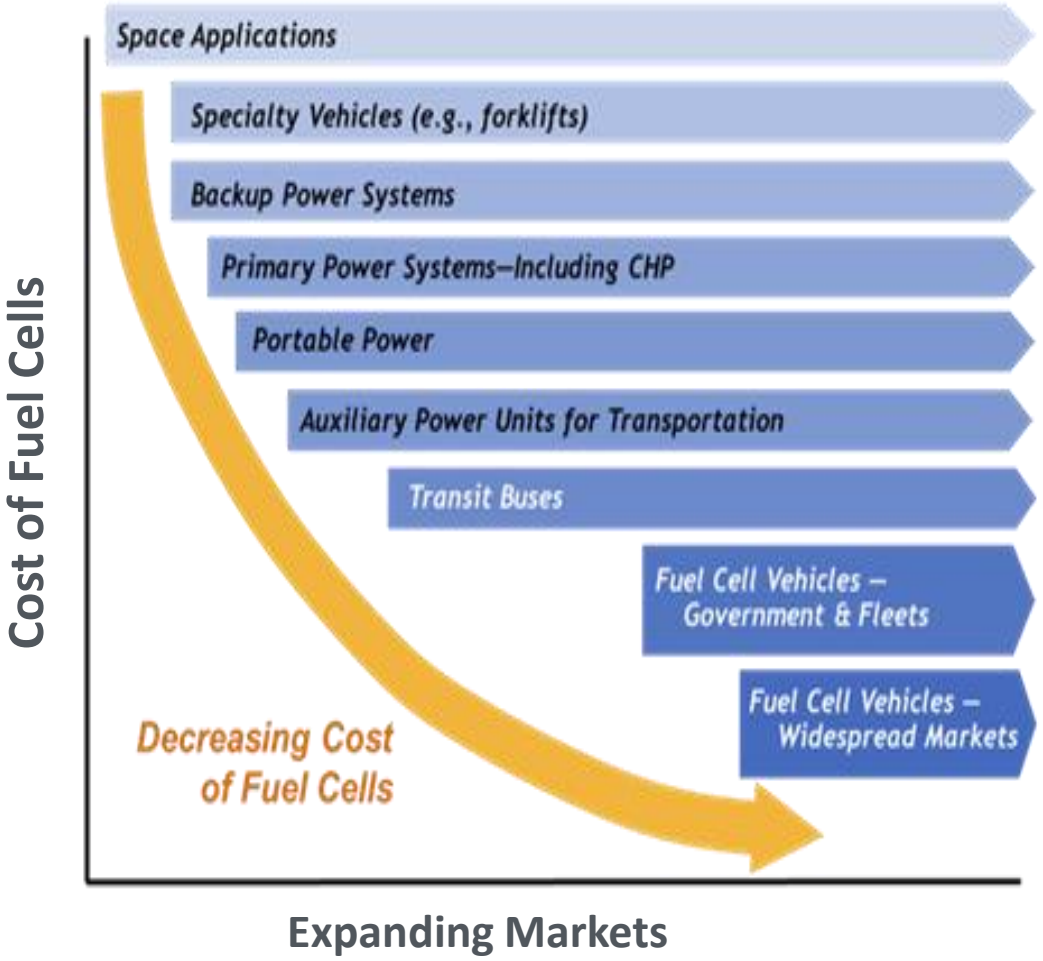
Early market applications enable fuel cell cost reduction, a domestic supply base, an emerging infrastructure and customer acceptance, en route to light duty vehicles.

Widespread Market Entry Pathway for Fuel Cells




Forklifts


Waste Hauling Trucks


Baggage Tow Tractors


Drayage Trucks

Delivery Vehicles


Delivery Vehicles

Full Size Buses


Shuttle Buses

Outreach and Communications

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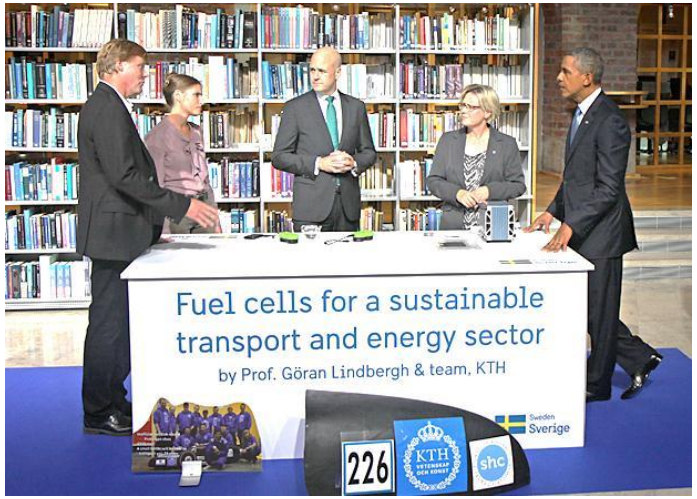
- **Publications - ~80/yr.**
  - Monthly Newsletter
  - Success Stories
  - News Alerts
  - Blogs
- **Annual Merit Review & Peer Evaluation**
  - June 2014- 1,800 attendees
- **Investor Days**
  - NYC and CA- showcased H_2 and fuel cell companies to investment community & peer reviewed projects
- **Ride-n-Drives**
  - Hyundai Fuel Tucson Ride-n-Drive at DOE Headquarters on September 16, 2014
- **House Senate Caucus Events**

Fuel Cell Technologies Program Newsletter Website Snapshot

Deputy Secretary of Energy, Daniel B. Poneman test driving Hyundai Fuel Tucson



President Obama at Fuel Cell Exhibit in Sweden

International Partnerships

International Partnership for Hydrogen and Fuel Cells in the Economy

- **Representatives from 16 member countries & the European Commission**
- **Facilitates international collaboration and a forum for advancing policies education**
- **Recent Activities:**
  - Launched international round robin testing of Type IV tanks

International Energy Agency

- **Implementing Agreements**
  - Advanced Fuel Cells Implementing Agreement: 13 member countries currently implementing seven annexes
  - Hydrogen Implementing Agreement: 18 member countries, plus the European Commission currently implementing nine tasks

Other Collaboration examples

Joint Technology Initiative (JTI); **MOUs** (NEDO-AIST-LANL, Hiroshima U-LANL);
Bi-lateral agreements, strong international collaboration on safety

What's Next

- ✓ **Continue to promote and strengthen R&D activities**
  - H_2, fuel cells, safety, manufacturing, etc.
  - Cost, performance, durability need to be addressed
- ✓ **Conduct strategic, selective demonstrations of innovative technologies**
  - Industry cost share and potential to accelerate market transformation
- ✓ **Continue to conduct key analyses to guide RD&D and path forward**
  - Life cycle cost; infrastructure, economic & environmental analyses, etc.
- ✓ **Leverage activities to maximize impact**
  - U.S. and global partnerships
  - H2USA: Public-Private partnership to enable widespread commercialization of H_2 vehicles in the United States

"It is literally true that you can succeed best and quickest by helping others to succeed"

- Napoleon Hill

Thank You

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