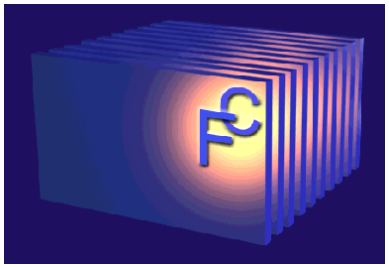
Country Highlights: United States

Nancy L. Garland, Ph.D.

Presentation at the ExCo 50th Meeting
Zürich, Switzerland, April 23-24, 2015



Key Messages from the U.S.

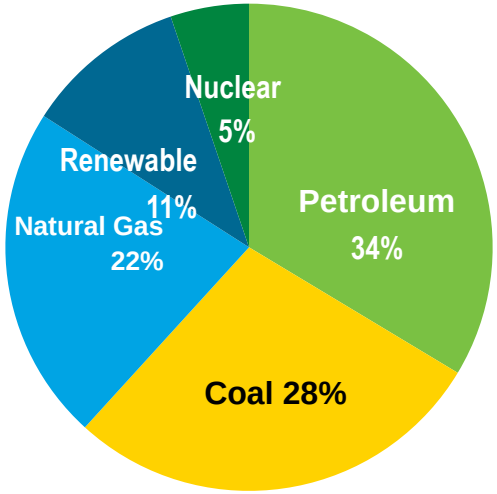
- President Obama signed an executive order in March to cut the federal government's greenhouse gas emissions 40% compared with levels in 2008

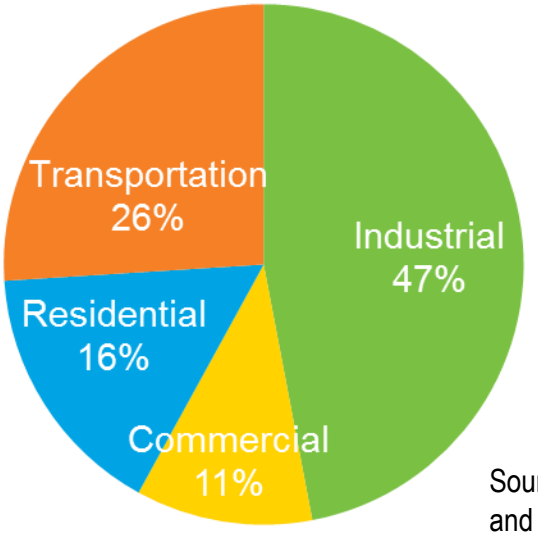
http://www.nytimes.com/2015/03/20/us/politics/obama-order-to-cut-federal-greenhouse-gas-emissions.html?_r=0

- DOE's Office of Fossil Energy is currently testing two 125 kW_e-class Solid oxide fuel cell modules
- Argonne National Laboratory has developed PtNi nanoframe electrocatalysts with 15x the specific activity of Pt/C and 20x the mass activity [Science, **343,** 1339 (2014)]; ANL is currently testing the catalyst in a membrane electrode assembly.
- Hyundai began leasing its first series production fuel cell electric vehicle at select dealerships in Southern California in 2014. Hyundai Tucson fuel cell drivers in Southern California accumulated sufficient mileage (>238,900 miles) to reach the Moon emissions-free [http://www.reuters.com/article/2015/02/25/hyundai-tucson-fuel-idUSnPn4TRY3R+9d+PRN20150225]

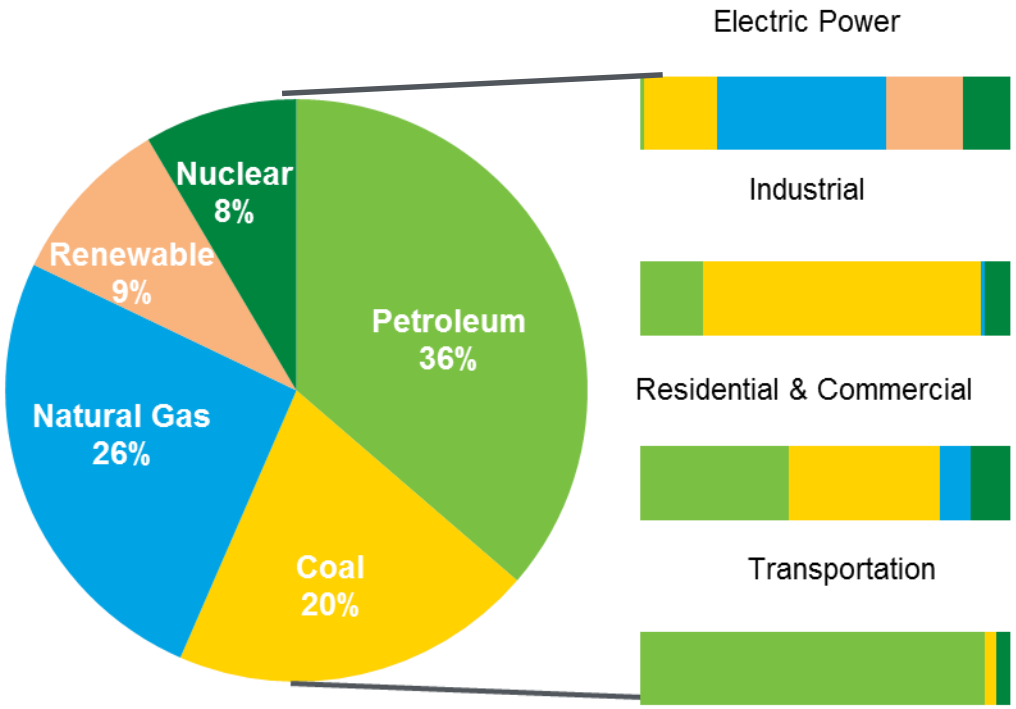
Energy Consumption

Global Primary Energy Consumption by Source and Sector





U.S. Primary Energy Consumption by Source and Sector



We are still using primarily fossil fuels.

Source: Energy Information Administration, International Energy Outlook 2013, Fig. 16 and Annual Energy Review 2011, Table 1.3

US National Energy Goals

National Energy Goals & Climate Action Plan

Net Oil Imports

50% by 2020

GHG Emissions

17% by 2020

>80% by 2050

President Obama signed an executive order in March to cut the federal government's greenhouse gas emissions 40% compared with levels in 2008.

http://www.nytimes.com/2015/03/20/us/politics/obama-order-to-cut-federal-greenhouse-gas-emissions.html?_r=0

US DOE's Office of Energy Efficiency and Renewable Energy

Sustainable
TRANSPORTATION

Renewable
ELECTRICITY GENERATION

Energy Saving
HOMES, BUILDINGS, & MANUFACTURING



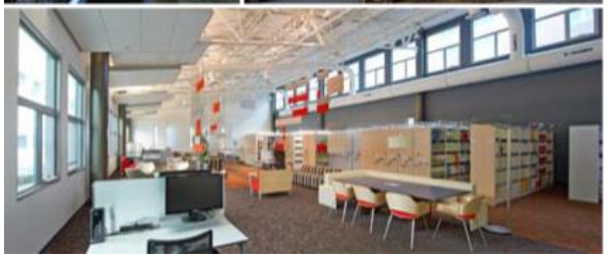










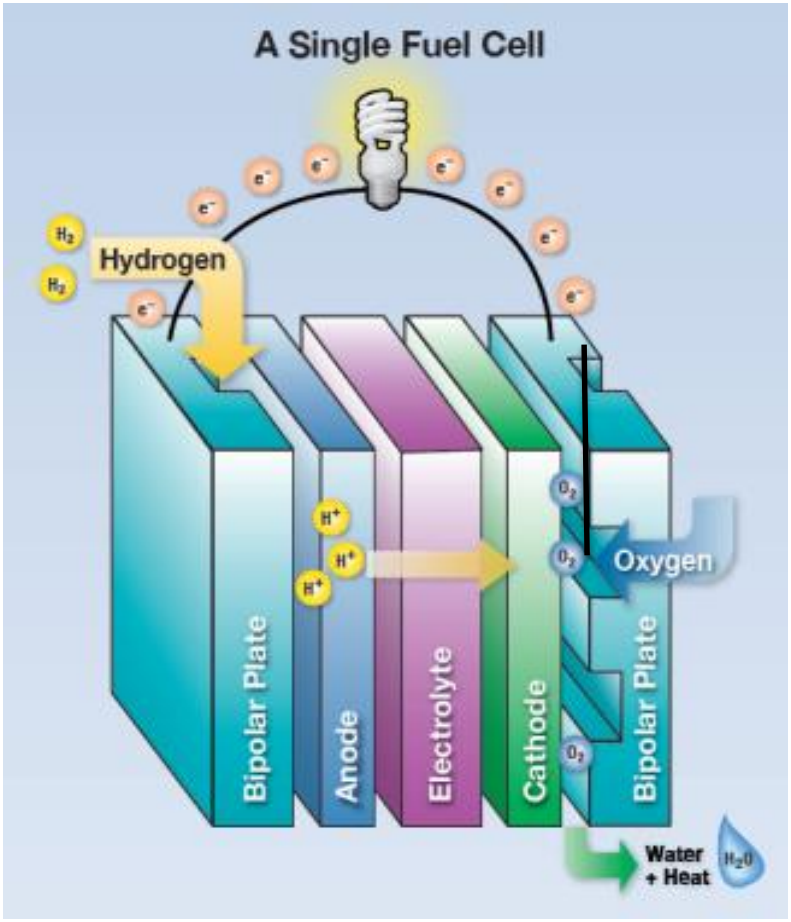
US DOE H_2 and Fuel Cells Strategy

BARRIERS	NEAR TO MID-TERM	LONG-TERM
R&D		
Fuel Cell Cost and Durability	Low-PGM catalysts, MEA performance, durability, components	Non-PGM Catalysts AEMs
Hydrogen Storage	700 bar tanks composites, cryo-compressed	Materials R&D for low pressure storage
Hydrogen Production and Delivery	H_2 from NG/electrolysis; Delivered H_2 compression	H_2 from renewables (PEC, biological, etc.), pipelines, low pressure option
NON-R&D		
Infrastructure Development	H2FIRST - Station validation, metering and sensors	Materials compatibility, sensors, station innovation- H-Prize
Manufacturing and Supply Chain	MEA and tank manufacturing; QC processes; supply chain	Manufacturing processes and scale-up; strong supply base
Safety Codes and Standards (SCS)	"Best Practices" Safety Dissemination	National and International harmonization of H_2 SCS
Public Acceptance and Awareness	H2Tools Education, Outreach; Early markets; H2USA	Widespread Outreach, Education & Social Acceptance

Level of Difficulty

- High
- Medium
- Low to Medium

US DOE H_2 and Fuel Cells Strategy



2.3x as efficient as today's gasoline engine

2020 Targets

Fuel Cell Cost	$40/kW	$1,000/kW $1,500/kW
Durability	5,000 h	80,000 h
H2 Storage Cost (On-Board)	$10/kWh	
H2 Cost at Pump	<$4/gge	

Impact

2-4 million barrels/day petroleum reduction by 2050

200- 450 million metric tons/year GHG emissions reduction by 2050

Government Expenditure: US DOE H_2 and Fuel Cell budget

Funding ($ in thousands)			
Key Activity	FY 2014 Appropriation	FY 2015 Appropriation	FY 2016 Request
Fuel Cell R&D	32,422	33,000	36,000
Hydrogen Fuel R&D[1]	34,467	35,200	41,200
Manufacturing R&D	2,879	3,000	4,000
Systems Analysis	3,000	3,000	3,000
Technology Validation	6,000	11,000	7,000
Safety, Codes and Standards	6,909	7,000	7,000
Market Transformation	2,841	3,000	3,000
NREL Site-wide Facilities Support	1,000	1,800	1,800
SBIR/STTR	3,410	TBD	----------
Total	$92,928	$97,000	103,000

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

US DOE SOFC Program

- **Focus of Office of Fossil Energy:**
  - Near Term: Natural gas distributed generation (DG)
  - Long Term: Coal and natural gas central station applications with CCS
- **Targets:**
  - System Performance Degradation: 0.2%/1,000 hours
    - ✓ **Present status: 1- 1.5%/1,000 hrs**
  - Stack Cost: $225/kWe*
  - Power Block Cost: $900/kWe*
- **Development Timeline**

  FY2015: 125 kWe-class Module Test
  - ✓ **Present status: Two tests under construction**

  FY2016: FOAK** 400 kWe Power System Field Test
  - ✓ **Present status: FOA closed, applications under review**

  FY2020: FOAK ** 1 MWe-class Power System at customer site

  Post-FY2020: Utility-scale IGFC/NGFC Central Station

Based on progressively larger natural gas-fueled validation tests, MWe-class DG SOFC Power Systems that are *cost-competitive* with existing DG technologies are envisioned circa 2020

* Nth –of-a-kind at specified volume, 2011$s

** FOAK – First-of-a-Kind

FY15 FE SOFC Program Update

- **FY15 Appropriation: $30M**
- **Two Funding Opportunity Announcements**
  - **Two 400 kW_e SOFC Field Tests**
    - **$12M, 30% Participant Cost Share**
  - **Innovative Systems and Core Technology**
    - **$9.5M, 20% Participant Cost Share**
  - ✓ **Present status: Both FOAs closed, applications under review**
- **Focus on system-level testing**
- **Emphasis on cost reduction and increased reliability**
- **Facilitate Industry Team - Core Technology collaboration**
- **Take advantage of revolutionary advances in materials and manufacturing processes**

Hydrogen and Fuel Cell Initiatives at the State Level

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 zero-emission vehicles on roads by 2025

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

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

California

FCEVs and Fuel Cell Buses

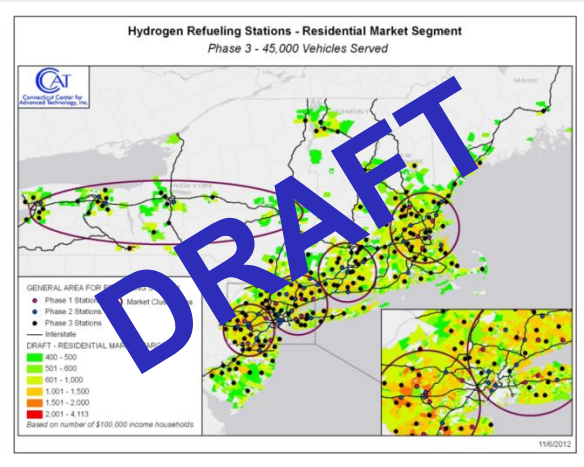
- **> 560 vehicles** in operation since 1999 — ~230 currently operating
- **> 6 million miles** driven
- **> 1 million passengers** on fuel cell buses

H_2 Station Investment

- **$51.5M invested** (CARB and CEC)
- **~$13M invested** by SCAQMD
- **~$29.9M available** (CEC PON 13-607)
- **$20M planned for 14/15** (CEC)
- **$20M annually** thru 2023 for at least 100 stations (AB8)

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

Preliminary Plan: 3 phase plan modelled by the Connecticut Center for Advanced Technology for development of hydrogen infrastructure and deployment of FCEVs in Northeastern coastal metro centers.



Hawai'i

Agreement signed by 12 stakeholders—including GM, utilities, hydrogen providers, DOD, DOE—to establish hydrogen as a major part of the solution to Hawaii's energy challenges.

- **15 GM FCEVs** currently in demonstrations with military
- **Renewable hydrogen** (from geothermal and wind energy) will be used for buses
- Projects include a public access refueling station on Oah'u by 2020 to support initial deployments of government and industry FCEV fleets

Hydrogen Stations in Planning / Development Stage - OAHU

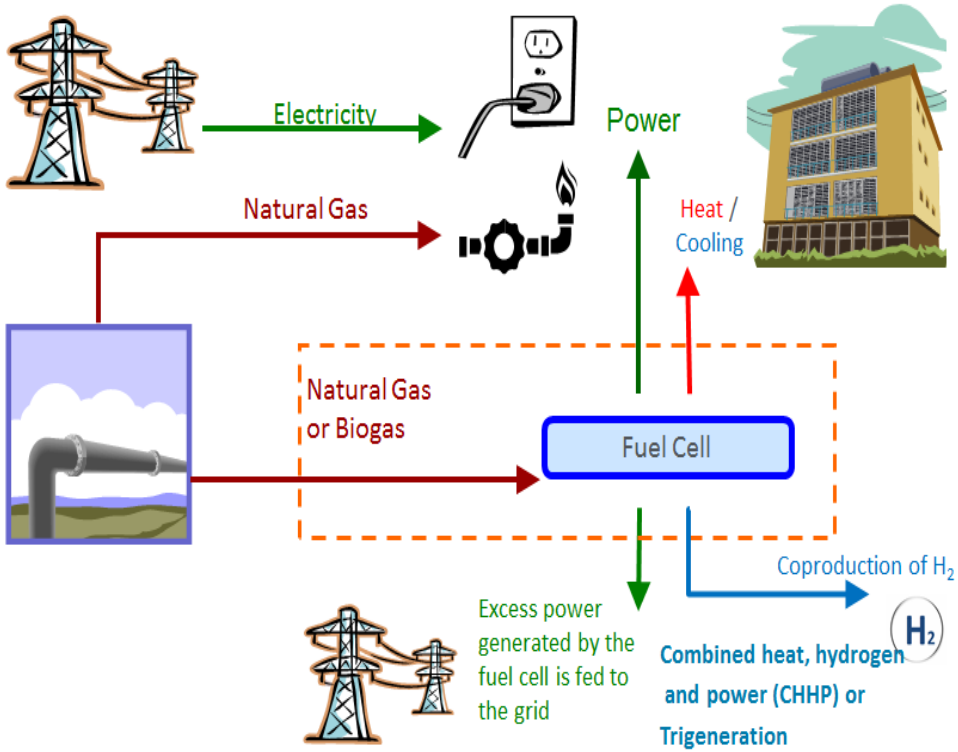
Research Highlights – Trigeneration in CA

Topic- Hydrogen from waste (industrial wastewater, landfill gas)

Organization: South Coast Air Management District, Orange County Sanitation District, DOE, FCE, NFCRC, Air Products

Aim: leverage the resources at industrial facilities, wastewater plants, and landfills in the U.S

Activity: use a high-temperature fuel cell and biogas produced from the anaerobic digestion of waste to efficiently produce hydrogen, electricity, and heat.



= Power + Heat + H_2

The electricity and heat produced are used to power and warm the facility.

The facility also produces up to 100 kg of hydrogen per day for a nearby hydrogen fueling station – enough to fuel 25-50 vehicles.

Research Highlights – Highly Active Electrocatalysts

Topic: Nanoframe catalysts
Organization: Argonne National Lab
Aim: increase activity of non-PGM catalysts

Activity: $PtNi_3$ crystalline polyhedra (with Pt-rich edges) are converted to Pt_3Ni nanoframes by interior erosion

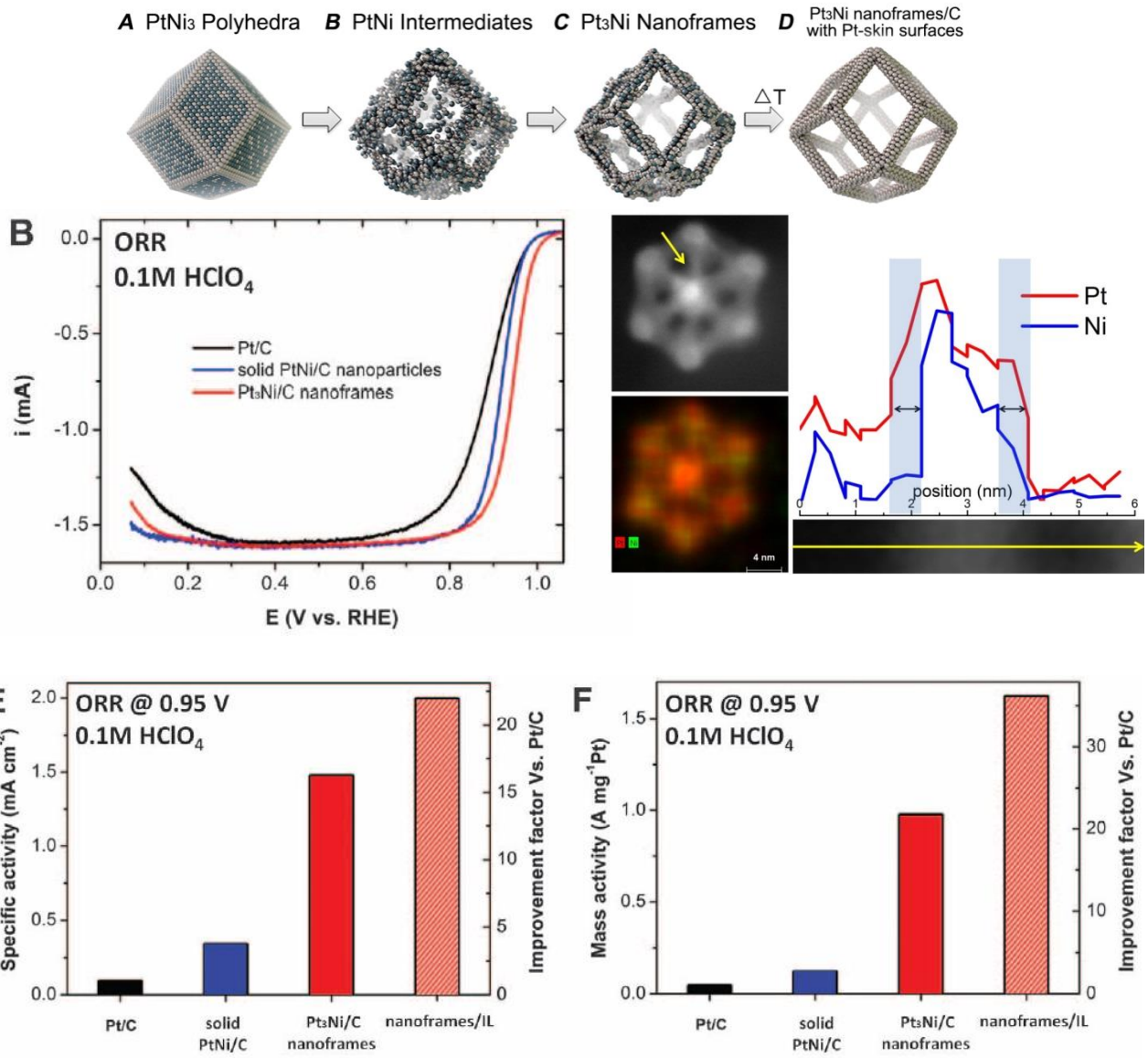
Final nanoframe particles have segregated Pt skin structure

Pt_3Ni nanoframe has 15x the specific activity of Pt/C and 20x the mass activity

Putting a protic ionic liquid inside the structure increases the specific activity and mass activity even further

Nanoframes are stable after wit no degradation after 10,000 RDE cycles

Outlook: test catalyst in MEA



Science, **343,** 1339 (2014)

Demonstration Highlights

Topic: Technology Validation

Organization: NREL

Aim: Assess technology status and progress

Activity: Validate fuel cell systems in transportation and stationary applications as well as hydrogen production, delivery and storage systems. Determine when technologies should be moved to the market transformation phase.

Outlook: New Awards and Deployments for light-duty fuel cell vehicle data collection projects

Funding: $5.5 million DOE

6 Auto partners: GM, BMW, Toyota, Honda, Hyundai, Nissan

Demonstration

Key scientific results

- Data collected from ≤90 vehicles
- Planned mileage:
  - Phase 1 = ~220,000 mi
  - Phase 2 (anticipated) = ~235,000 m

METRICS EVALUATED:

- Fuel cell stack durability and efficiency.
- FCV range, driving behavior, fuel
- economy, and maintenance.
- On-board hydrogen storage performance.
- Hydrogen refueling performance.
- FCV Safety

Deployment Activities: Early Market

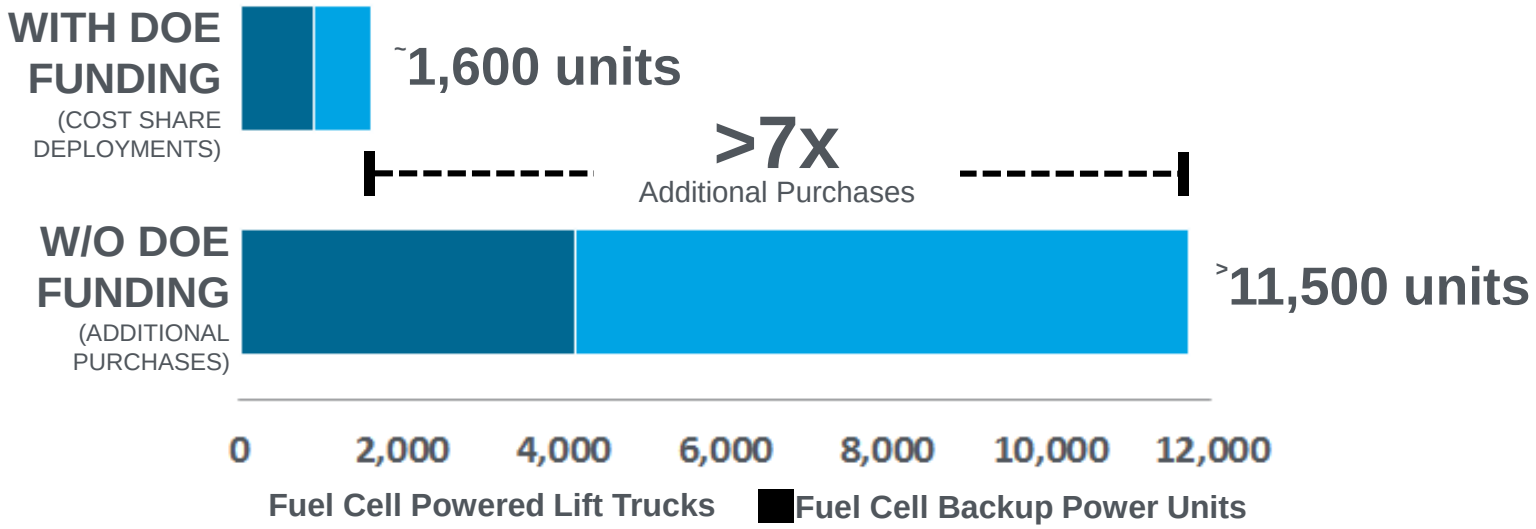
Early Market Applications Enable…

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

http://panasonic.co.jp/ap/FC/en_doc03_00.html

Integrated type

US DOE Impact



Products - Examples

Hydrogen Generation from Electrolysis

Proton's PEM Hogen S Series Electrolyzer System

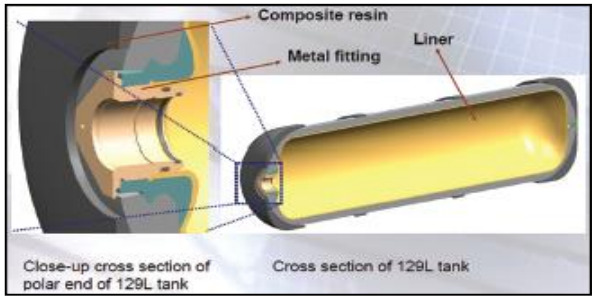
GenDrive™ Fuel Cell Power System

Class-1, -2, and -3 Forklifts Powered by Plug Power's GenDrive FCs

PEM Electrolyzer Incorporating a Low-Cost Membrane

Giner's PEM Electrolyzer System

Hydrogen Composite Tanks

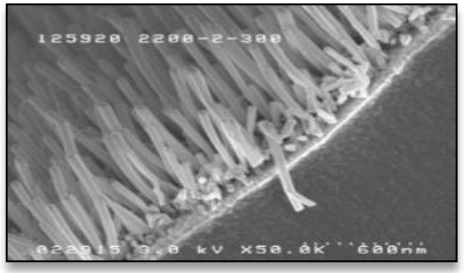


Quantum Technologies' Optimized 129L Tank

TITAN™: High-Pressure Hydrogen Storage Tank for Gaseous Truck Delivery

Hexagon Lincoln's 3,600 psi TITAN™ Tank and Frame System

3M Cathode Catalysts and Supports for PEMFCs



Scanning electron micrographs of 3M's nanostructured thin film catalysts

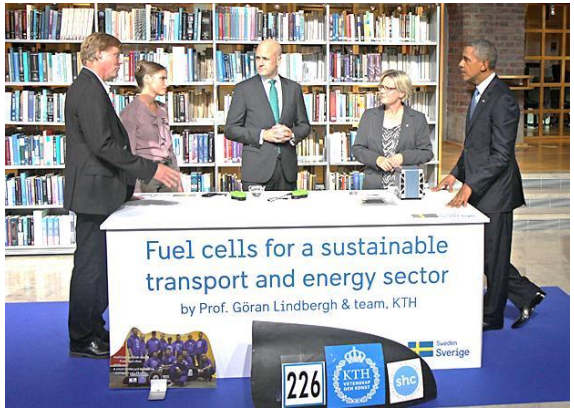
Dissemination Activities

- **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 & Drives**
  - Hyundai Fuel Cell Tucson Ride-and-Drive at DOE Headquarters on September 16, 2014
- **House & Senate Caucus Events**

Fuel Cell Technologies Program Newsletter Website Snapshot

Hydrogen fuel cell powers lights at entertainment industry events.

Developed education materials and educated more than 9,600 teachers on H_2 and fuel cells to date. Reached ~ 30,000 code officials & first responders



President Obama at Fuel Cell Exhibit in Sweden

Hydrogen fuel cell-powered light tower at Space Shuttle launch

Collaborations and Partnerships

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

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

- Pre-Competitive R&D
- USCAR, energy companies, EPRI and utilities

California Fuel Cell Partnership; SCHydrogen & Fuel Cell Alliance www.SCHydrogen.org; H2I Hawai'i Hydrogen Initiative; Connecticut Hydrogen-Fuel Cell Coalition

- State Partnership and Collaboration

IPHE

- International Government Coordination
- 17 countries and European Commission

iea Energy Technology Network

- Implementing Agreements
- 25 countries

H2FIRST — Hydrogen Fueling Infrastructure Research and Station Technology

- National Lab (SNL & NREL) activities with industry

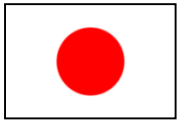
H2 USA

- Public-Private Partnership
- ~35 partners

DOE engages in collaborations focused on R&DD.

International Activities

Major public-private partnerships have been formed, and plans have been developed for the rollout of FCEVs and hydrogen infrastructure by 2015.



Hydrogen Supply/Utilization Technology (HySUT).
18 companies, including 3 auto companies, have announced plans to commercialize FCEVs and provide infrastructure by 2015.

By 2015: 100 H_2 stations and **FCEVs launched in 4 urban areas**

H_2Mobility. Public-private initiative for nationwide H_2 infrastructure—will develop into joint venture to install stations.

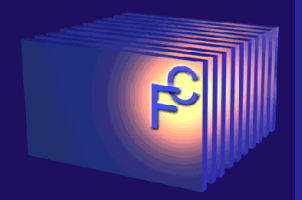
By 2015: 50 H_2 stations (public-private funds committed); and **5,000 FCEVs expected on the road**

UKH_2Mobility. Evaluating anticipated FCEV rollout in 2014-2015

- **Will develop action plan to make UK a leading market for FCEVs**

Scandinavian H_2 Highway Partnership (SHHP)
Partnership of ***Hydrogen Link*** (Denmark), ***HyNor*** (Norway) and ***Hydrogen Sweden.*** Goals is to establish a network of 45 H_2 stations (15 main stations, 30 satellite stations) and a large fleet of vehicles (500 cars, 100 buses, 500 specialty vehicles). Projects include ***H2Moves Scandinavia*** and ***Next Move***

H2USA. Public-private partnership to advance H_2 infrastructure to support transportation energy options for U.S. consumers, including FCEVs. Partnership brings together automakers, government, gas suppliers, and the H_2 and fuel cell industries to deploy infrastructure that can deliver affordable, clean H_2 fuel.



International Cooperation: H_2 Infrastructure and FCEVs

Region	2015 FCEVs	2015 Stations	Partnerships	Govt. Funding for Stations
Germany	**110**	**15**	**National Innovation Program-Clean Energy Partnership**	National Innovation Program, 2014: R&D: $18M Station Build-out: $64M **Total: $82M**
Japan	**65**	**25** (commercial)	**The Research Ass'n of H_2 Supply/Utilization Technology**	R&D: $32M Station Build-out: $63M **Total: $95M**
Korea		**13**	**Hydrogen Energy R&D Center Partnerships**	(R&D Hydrogen and Fuel Cells, 2014**:** **$31M)**
Scandinavian Countries	**45**	**11**	**Scandinavian Hydrogen Highway Partnership**	SHHP, 2006-2013: **$137M** Norway, 2014-2018: **$60M** (includes HRS, vehicles and O&M)
United States	**145**	**9** (public stations)	**H2USA** California Fuel Cell Partnership Hawaii H2 Initiative (H2I) Other State Associations	CEC, 2014: **$47M** CEC, 2015 - 2023: **$20M/yr** (DOE, FY2014: **$93M)**
UK		**9**	**H_2-Mobility**	Hydrogen Refuelling Stations (HRS) Infrastructure Grants Scheme: **$9.8M** (3 new stations, 9 upgrades)
EU	**40**	**2**	**Fuel Cells and Hydrogen Joint Undertaking (FCHJU)**	FCH-JU, 2014-2020: **$911M** FCH-JU, 2014 Call for Proposals on HRS R&D: €93M

Going forward

- **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**

Three Pillars of the FCTO Manufacturing Strategy

FCTO Manufacturing Strategy

Supply Chain

- New global competitive analysis
- New approaches to enhance supply chain

Improved Quality and Quality Control

- Develop defect diagnostics
- CEMI/EERE crosscuts (workshop, projects, consortia)

Processes Development and Optimization

- FY15 FOA topic (up to $2M)
- Reduce process steps in FC manufacturing

Enhanced global manufacturing competitiveness

Reduced manufacturing processes & cost

Global Manufacturing Competitiveness Analysis

Topic 2

Analysis of U.S. Hydrogen and Fuel Cell Manufacturing Global Competitiveness (with NREL)

FOA Requirements and Project Deliverables:

The outcome and deliverables from this topic area must address both of the following objectives:

(1) Global Competitiveness Analysis of hydrogen and fuel cell technologies manufacturing

(2) Analysis to assess the state of global hydrogen and fuel cell markets.

Teaming was encouraged to ensure the proposed team has the necessary complement of expertise to achieve both objectives.)

Recommended for Selection

Topic 2 **U.S. Clean Energy Hydrogen and Fuel Cell Technologies: A Competiveness Analysis**

GLWN – Westside Industrial Retention & Expansion Network

Project Summary

Period of performance: 48 months

Federal funds:	$695,000
Cost-share:	$0
Total budget:	$695,000

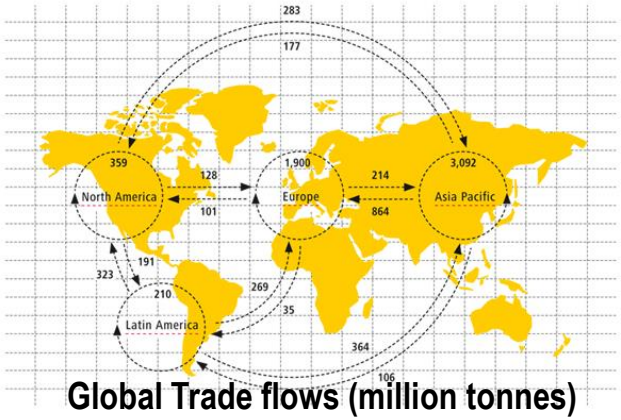
Objectives:

1) Determine the global cost leaders, the best current manufacturing processes, the key factors determining competitiveness, and potential means of cost reductions.

2) Assess global hydrogen and fuel cell markets.

Key Personnel

Patrick Fullenkamp PI – GLWN
Doug Wheeler - DJW Tech.
Brian James – SA, Inc.
Whitney Colella Ph.D.– SA, Inc.
David Hart Ph.D. - E4tech
Charles Stone Ph.D.- EON
Dee Holody – GLWN
Matt Bramson-GLWN



Global Trade flows (million tonnes)

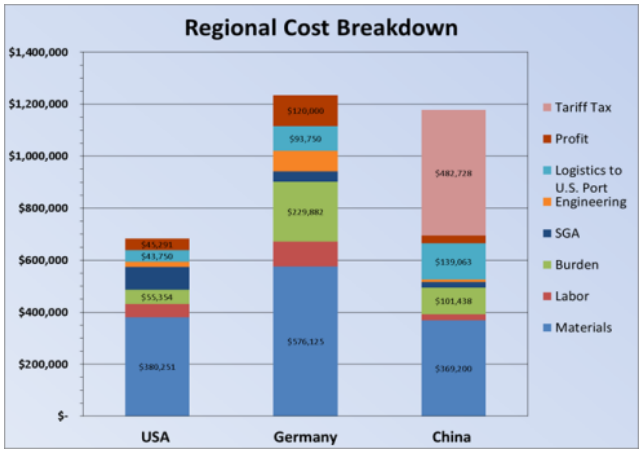
Source: https://www.dpdhl.com/reports/2010/annualreport/group-management-report/print-page-international-trade.html

U.S. Clean Energy Hydrogen and Fuel Cell Technologies: A Competiveness Analysis
GLWN – Westside Industrial Retention & Expansion Network

The Team proposes a comparative cost analysis to identify the cost breakdown of the high value components within the supply chain.

Cost Analysis Methodologies

- Global Cost Breakdown Analysis (top)
- Design for Manufacturing & Assembly (left)
- Value Stream Mapping (bottom)

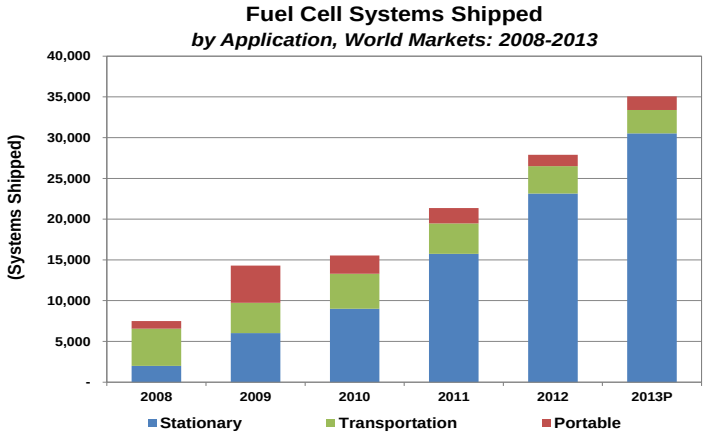


Sources: (left) DFMA detailed stack cost breakdown (SA)); (right top and bottom) offshore wind turbine Tower Cost Breakdown Analysis and Value Stream Mapping of 5 MW Tower (Ref. DOE Project DE-EE-0006102)

U.S. Clean Energy Hydrogen and Fuel Cell Technologies: A Competiveness Analysis
GLWN – Westside Industrial Retention & Expansion Network

Outcomes:

- o Identify areas where the U.S. might have viable manufacturing opportunities or vulnerabilities
- o Identify potential "tipping points" where the U.S. could lose or gain leadership within segments of the supply chain
- o Identify high value-added segments of the supply chain that dictate other upstream/downstream products
- o Show which segments are particularly well-suited to U.S. strengths (e.g., requiring a highly skilled, innovative workforce)



Example of Annual Fuel Cell Trend Data

	Key Milestones & Deliverables
Year 1	• Complete Map of Industry and Interviews of H&FC Industry • Cost Analysis – DFMA, CBA, VSM 50% complete • Annual Fuel Cell Trend Data -2014- **Units, MW, Country, Application**
Year 2	• Global Comparative Cost Analysis with recommendations • Annual Fuel Cell Trend Data - 2015
Year 3	• Annual Fuel Cell Trend Data - 2016
Year 4	• Annual Fuel Cell Trend Data - 2017

GLWN's project for the US DOE's Wind Program

Goal

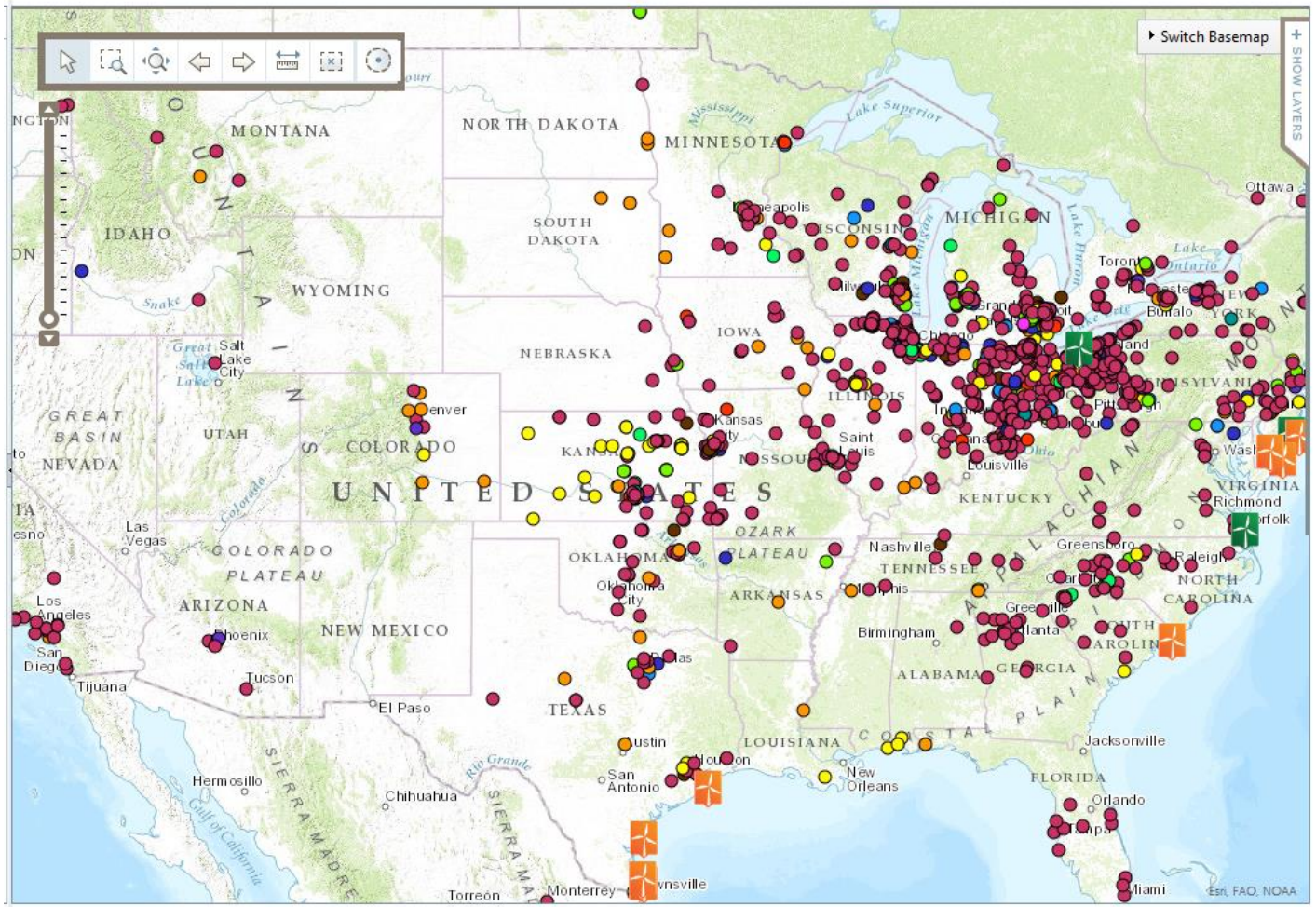
- The goal of the project was to develop a greater understanding of the key factors determining wind energy component manufacturing costs and pricing on a global basis to enhance the competitiveness of U.S. manufacturers, and to reduce installed systems cost.
- Multiple stakeholders including DOE, turbine OEMs, and large component manufacturers will all benefit by better understanding the factors determining domestic competitiveness in the emerging offshore and next generation land-based Wind industries.

Major objectives of this project were to:

- Carry out global cost and process comparisons for 5 MW jacket foundations, blades, towers, and permanent magnet generators
- Assess U.S. manufacturers' competitiveness and potential for cost reduction
- Facilitate informed decision-making on investments in U.S. manufacturing;
- Develop an industry scorecard representing the readiness of the U.S. manufacturers' to produce components for the next generations of wind turbines, nominally 3 MW land-based and 5 MW offshore
- Disseminate results through the GLWN Wind Supply Chain GIS Map, a free website that is the most comprehensive public database of U.S. wind energy suppliers; Identify areas and develop recommendations to DOE on potential R&D areas to target for increasing domestic manufacturing competitiveness, per DOE's Clean Energy Manufacturing Initiative.

http://energy.gov/sites/prod/files/2014/09/f18/U.S.%20Wind%20Energy%20Manufacturing%20and%20Supply%20Chain%20Competitiveness%20Analysis_0.pdf

GLWN Wind Industry Supply Chain



http://map.glwn.org/default.aspx

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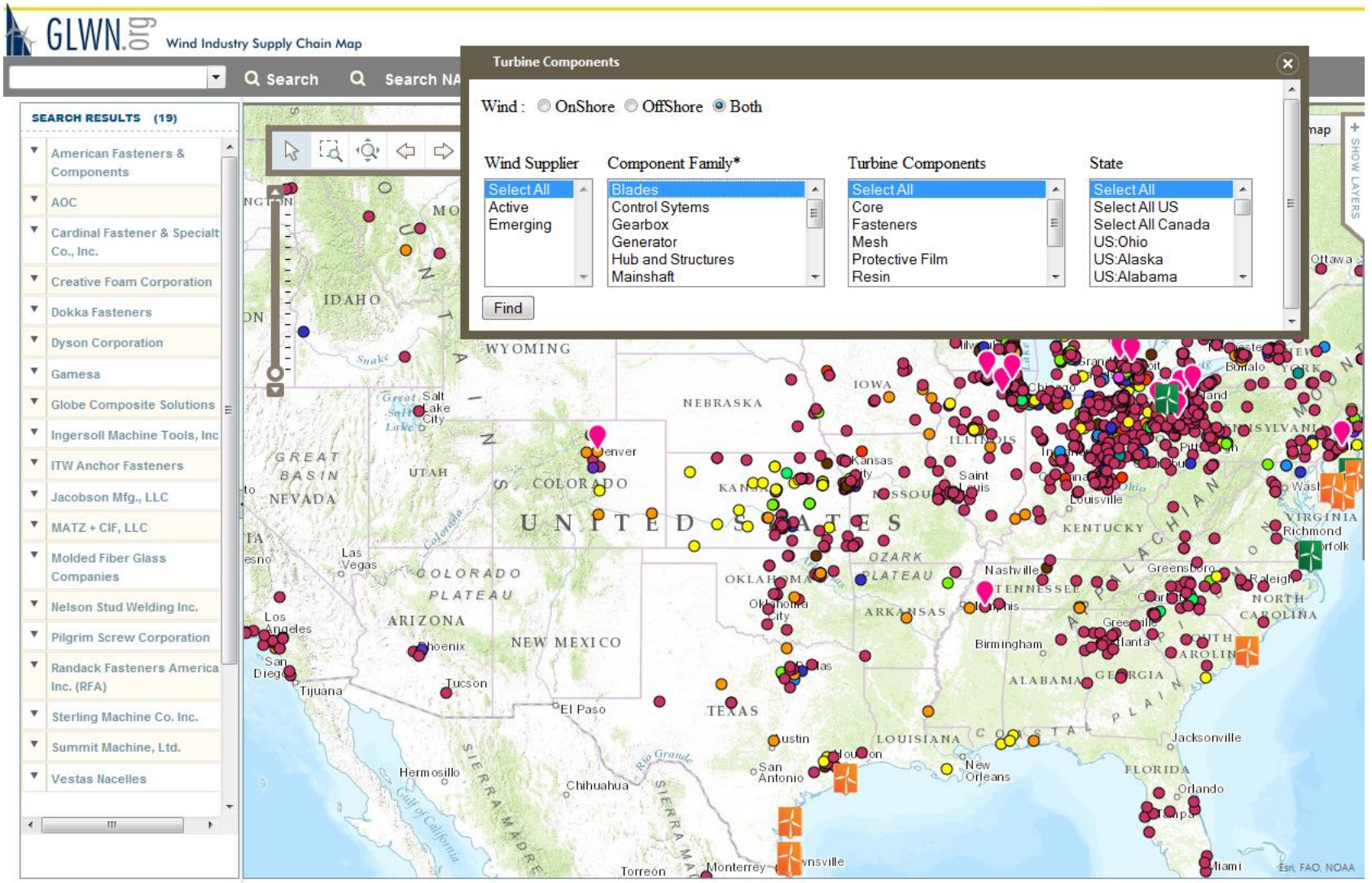

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IEA Advanced Fuel Cells IA
Executive Committee

An Integrated Strategy for Commercialization

Technology Validation; Safety, Codes & Standards; and Market Transformation are closely coordinated and essential for moving laboratory successes into commercial markets.

Technology Validation

- Demonstrates and validates pre-commercial technologies before deployment by collecting and analyzing performance data
- Validate vehicles and infrastructure (>180 vehicles; world's first Tri-Gen station)
- Future focus includes high pressure electrolyzers, ionic & electrochemical compressors, Reefers, and range extenders.

Safety, Codes and Standards

- Enables development of necessary codes & standards and provides critical safety information with hydrogen community.
- Enables smooth introduction of new technologies. Highlights include work on separation distances, refueling protocols, GTR, and MHE tank cycle-life testing.

Market Transformation

- Provides financial and technical assistance to enable deployments of ***proven technologies*** to spur early markets and build business cases
- Successes in material handling equipment and back up power deployments leading to additional purchases.

An integrated strategy enables expanding commercial markets…

… and successful deployments that catalyze early market growth