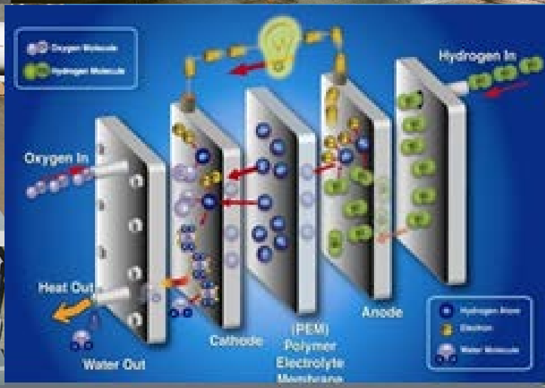
U.S. Department of Energy
Fuel Cell Technologies Office Program Overview

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



Hydrogen and Fuel Cell Technical Advisory Committee

Washington, DC

November 18, 2014

Dr. Sunita Satyapal

U.S. Department of Energy

Fuel Cell Technologies Office

Program Director

Agenda

- HTAC Charter & Membership
- Program Overview
  - Budget & Organization
- HTAC Recommendations
  - Key Accomplishments & Program Responses
- National Lab Impact Initiative and Next Steps

HTAC Members

Academia

- Anthony Eggert, UC-Davis
- Dr. Timothy Lipman, UC-Berkeley
- Dr. Joan Ogden, UC-Davis
- Dr. Levi Thompson, U. of Michigan

Associations/Non-Profits

- **Catherine Dunwoody, California Fuel Cell Partnership → CARB**
- **Dr. Kathryn Clay, American Gas Association**
- Robert Rose, Fuel Cell and Hydrogen Energy Association → BTI

Environmental

- **Margo Oge, Environmental Protection Agency (ret'd)**

Fuels Production

- John Hofmeister, Shell Oil Company (ret'd)

Government

- Dr. Peter Bond, Brookhaven National Laboratory
- Dr. Richard Carlin, Office of Naval Research
- Maurice Kaya, State of Hawaii (ret'd)
- **Commisioner Janea Scott, California Energy Commission**

Stationary Power

- Harol Koyama, H2 PowerTech

Transportation

- Charles Freese, GM
- Dr. Alan Lloyd, ICCT (ret'd)

Utilities (Electricity & Natural Gas)

- Frank Novachek, Xcel Energy

Venture Capital

- **Paul Leggett, Morgan Stanley → Mithril Capital**
- Robert Shaw, Aretê Corporation

New Members

Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) Scope

To advise the Secretary of Energy on:

1. The implementation of programs and activities under Title VIII of EPACT

2. The safety, economical, and environmental consequences of technologies to produce, distribute, deliver, store or use hydrogen energy and fuel cells

3. The DOE Hydrogen & Fuel Cells Program Plan

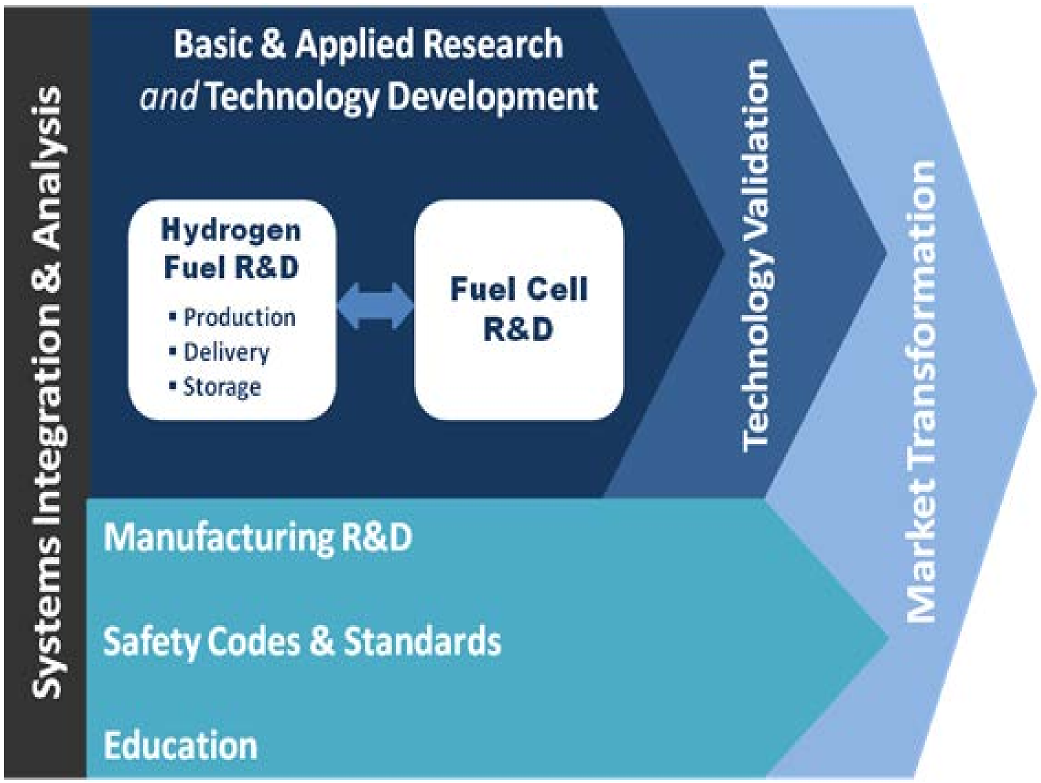
Title VIII Sec. 802

“The purposes of this title are—

1) to enable and promote comprehensive development, demonstration, and commercialization of hydrogen and fuel cell technology in partnership with industry;
2) to make critical public investments in building strong links to private industry, institutions of higher education, National Laboratories, and research institutions to expand innovation and industrial growth;
3) to build a mature hydrogen economy that creates fuel diversity in the massive transportation sector of the United States;
4) to sharply decrease the dependency of the United States on imported oil, eliminate most emissions from the transportation sector, and greatly enhance our energy security; and
5) to create, strengthen, and protect a sustainable national energy economy. ”

DOE Hydrogen and Fuel Cells Program Areas and Targets

Mission: Enable widespread commercialization of a portfolio of H_2 and fuel cell technologies through basic and applied research, technology development and demonstration.

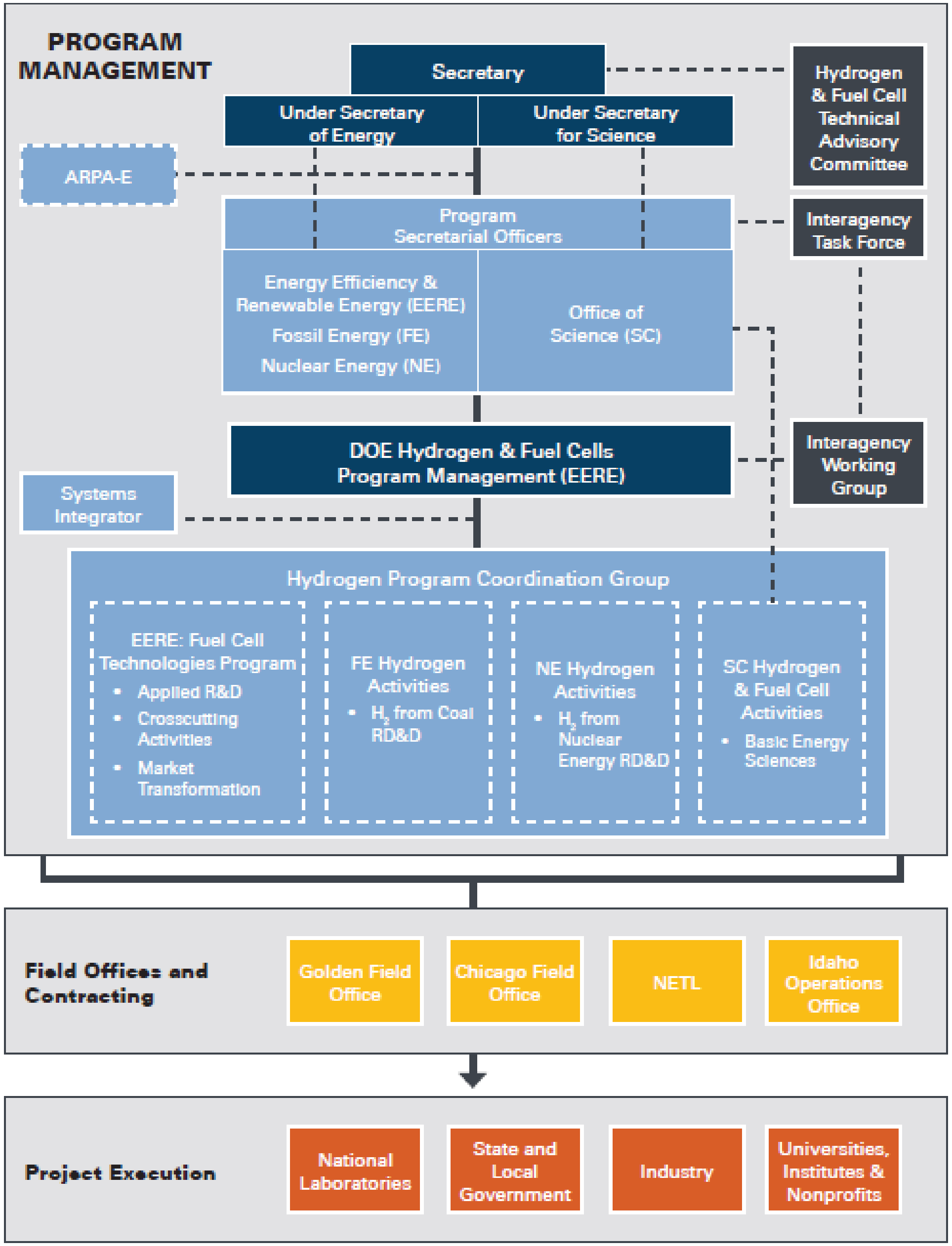


		
Fuel Cell Cost	$40/kW	$1,000/kW* $1,500/kW**
Durability	5,000 hrs	80,000 hrs
H_2 Storage Cost (On-Board)	$10/kWh	
H_2 Cost at pump	<$4/gge	

*For Natural Gas
**For Biogas

The Program includes a comprehensive portfolio of activities to address the purposes in EPACT 2005 Title VIII.

Overall Hydrogen and Fuel Cells Program Organization

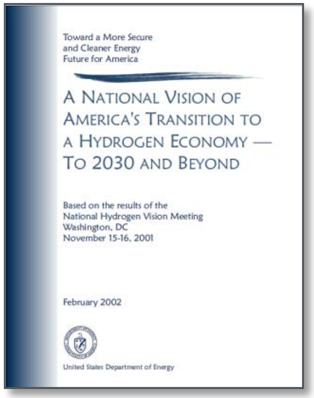


History:

- Hydrogen Program (renamed Hydrogen and Fuel Cells Program in FY10) includes EERE, FE, NE and SC
- EERE is lead for overall Program (since 2004)
- Program conducts monthly coordination working group meetings across EERE, FE, NE, and SC, and has an integrated strategic plan (Program Plan)
- Each office has its own multiyear RD&D plan

Guiding Documents

Stakeholder input

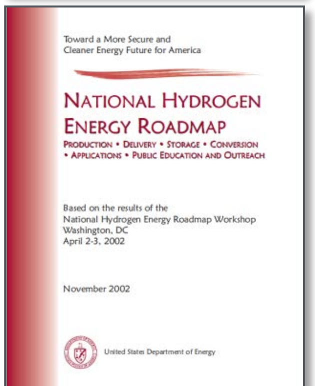

Toward a More Secure and Cleaner Energy Future for America

A NATIONAL VISION OF AMERICA'S TRANSITION TO A HYDROGEN ECONOMY — TO 2030 AND BEYOND

Based on the results of the National Hydrogen Vision Meeting
Washington, DC
November 15-16, 2001

February 2002

United States Department of Energy


Toward a More Secure and Cleaner Energy Future for America

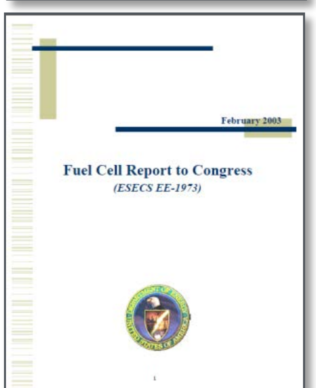
NATIONAL HYDROGEN ENERGY ROADMAP

PRODUCTION • DELIVERY • STORAGE • CONVERSION • APPLICATIONS • PUBLIC EDUCATION AND OUTREACH

Based on the results of the National Hydrogen Energy Roadmap Workshop
Washington, DC
April 2-3, 2002

November 2002

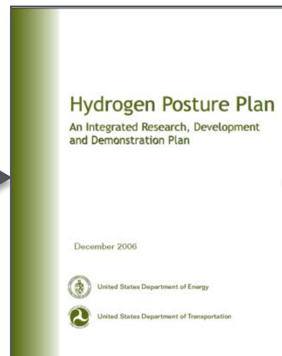
United States Department of Energy


February 2003

Fuel Cell Report to Congress
(ESECS EE-1973)

Strategy

Hydrogen Posture Plan


Hydrogen Posture Plan

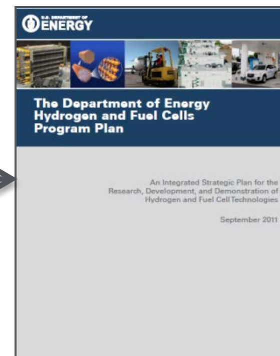
An Integrated Research, Development and Demonstration Plan

December 2006

United States Department of Energy

United States Department of Transportation

The Department of Energy Hydrogen and Fuel Cells Program Plan


U.S. DEPARTMENT OF ENERGY

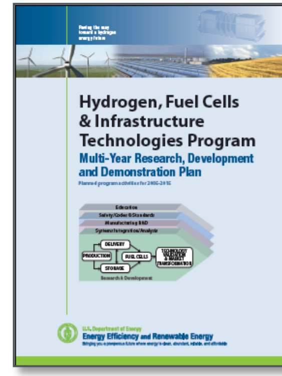
The Department of Energy Hydrogen and Fuel Cells Program Plan

An Integrated Strategic Plan for the Research, Development, and Demonstration of Hydrogen and Fuel Cell Technologies

September 2011

Planning

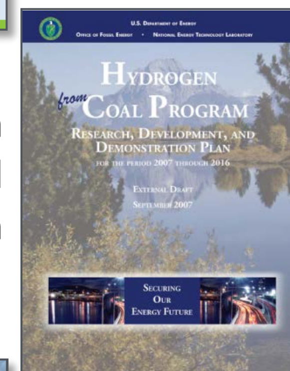
Multi-Year RD&D Plan


Hydrogen, Fuel Cells & Infrastructure Technologies Program

Multi-Year Research, Development and Demonstration Plan

U.S. Department of Energy
Energy Efficiency and Renewable Energy

Hydrogen from Coal RD&D Plan


U.S. Department of Energy

Office of Fossil Energy • National Energy Technology Laboratory

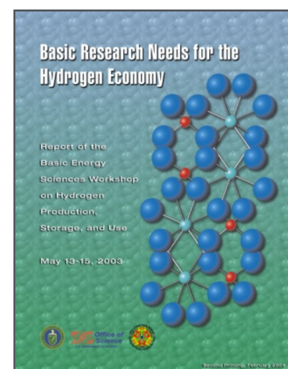
HYDROGEN from COAL PROGRAM

RESEARCH, DEVELOPMENT, AND DEMONSTRATION PLAN
FOR THE PERIOD 2007 THROUGH 2016

EXTERNAL DRAFT
SEPTEMBER 2007

SECURING OUR ENERGY FUTURE

Basic Research Needs for the Hydrogen Economy

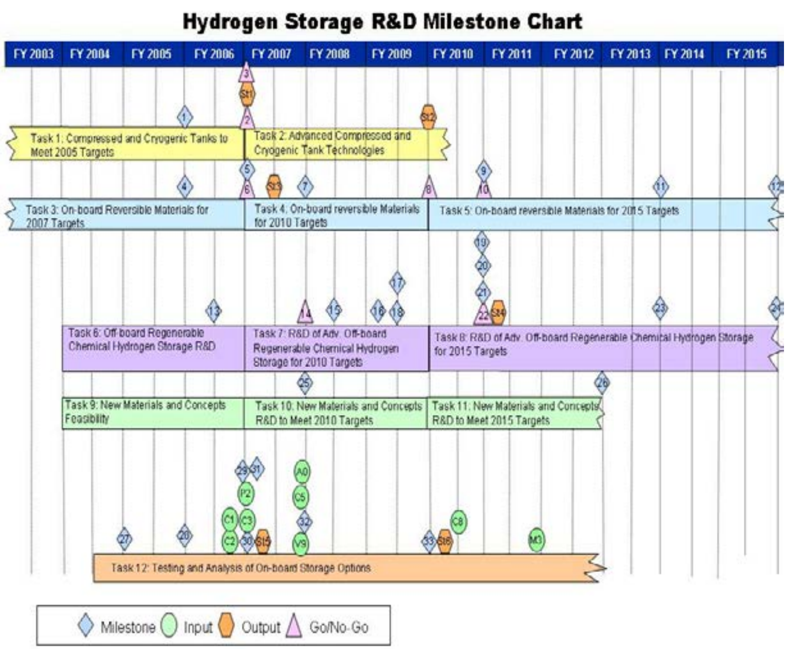

Basic Research Needs for the Hydrogen Economy

Report of the Basic Energy Sciences Workshop on Hydrogen Production, Storage, and Use

May 13-15, 2003

Subprogram Milestones and Targets - Examples

Each subprogram has detailed milestones, inputs, outputs, go-no go decision points and technical targets



Update of Multiyear RD&D Plan in process

Example- Target Table for Electrocatalysts

Electrocatalysts for Transportation Applications	Status[a]	Targets[b]
	2011	**2017**
Platinum group metal (PGM) total content (both electrodes)	**0.19 g/kW**	**0.125 g/kW**
PGM Total Loading	**0.15 mg/cm²**	**0.125 mg/cm²**
Loss in catalytic (mass) activity[c]	**<40%**	**<40% loss of initial**
Catalyst support loss[d]	**<10% mass loss**	**< 10% mass loss**
Mass activity[e]	**0.24 A/mg Pt in MEA >0.44 A/mg Pt new alloy in RDE**	**0.44 A/mg PGM**
Activity per volume of supported catalyst (non-PGM)[f]	**60 A/cm³ (measured) 160 A/cm³ (extrapolated)**	**>300 A/cm³**

[a] single cell status – will require scale-up
[b] preliminary targets – approval pending
[c] after 30,000 cycles from 0.6 – 1.0 V; after 400 hours at 1.2 V
[d] after 400 hours at 1.2 V
[e] baseline @ 900mV$_{IR\text{-}free}$
[f] baseline @ 800mV$_{IR\text{-}free}$

H	= High (significant challenge)	M	= Medium
M/H	= Medium/High	L	= Low (minimal challenge)

Collaborations and Partnerships

R&D → Demonstration & Deployment → Accelerated Commercialization

R&D

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

Demonstration & Deployment

- State Partnership and Collaboration

Accelerated Commercialization

- International Government Coordination
- 17 countries and European Commission

International Energy Agency

- Implementing Agreements
- 25 countries

H_2FIRST

Hydrogen Fueling Infrastructure Research and Station Technology

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

H_2USA

- Public-Private Partnership
- ~30 partners

In addition to above partnerships, advice & peer review provided by Federal Advisory Committee (HTAC), NAS, GAO, IG, AMR

Key HTAC Recommendations

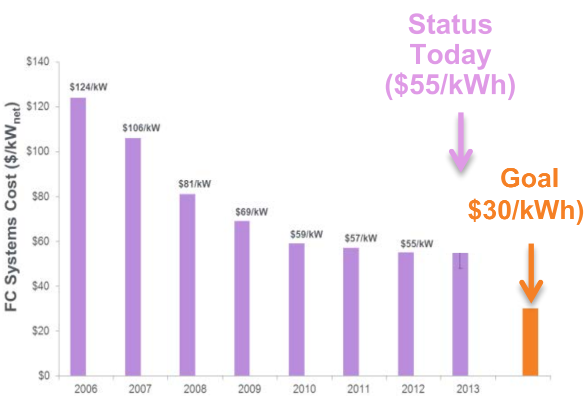
- Stronger commitment to R&D to ensure U.S. technology leadership.
- Direct investment in hydrogen infrastructure as part of a integrated strategy or comprehensive National Energy Policy to accelerate deployment and attract private investment.
- Collaboration with infrastructure initiatives in Germany, Japan, Korea, and the UK on technical and regulatory issues to reduce cost and accelerate deployment.
- Emphatic public support for FCEV deployment to inspire confidence and increase public awareness.

DOE Activities Span from R&D to Deployment

Research & Development

- *50% reduction since 2006*
- *80% electrolyzer cost reduction since 2002*

Fuel Cell System Cost*



*At 500,000-unit production

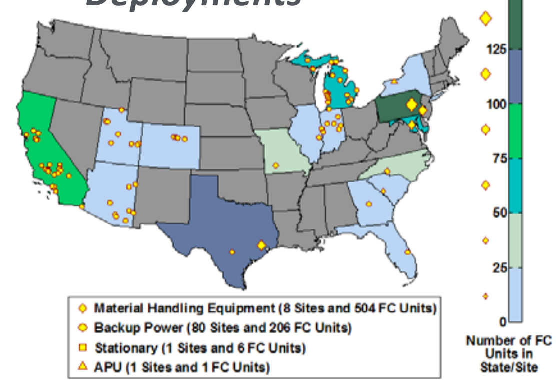
Demonstration

- *>180 FCEVs*
- *25 stations*
- *3.6 million miles traveled*
- *World's first tri-gen station*

  (250 kW on biogas,
  100 kg/d H2 produced)

Deployment

- *Government Early Adoption* (DoD, FAA, California, etc.)
- *Tax Credits: 1603, 48C*
- *~1,600 fuel cells deployed*
- *DOE Recovery Act & Market Transformation Deployments*



DOE's RDD&D activities are enabling commercialization of fuel cells

Hydrogen & Fuel Cell Budget

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	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	-------	3,410	TBD
Total	$100,000	$92,928	$92,983

Office	FY 2014
EERE	$93M
Basic Science[2]	$20M to $25M
Fossil Energy, SECA	$25M
ARPA-E[3]	$33M

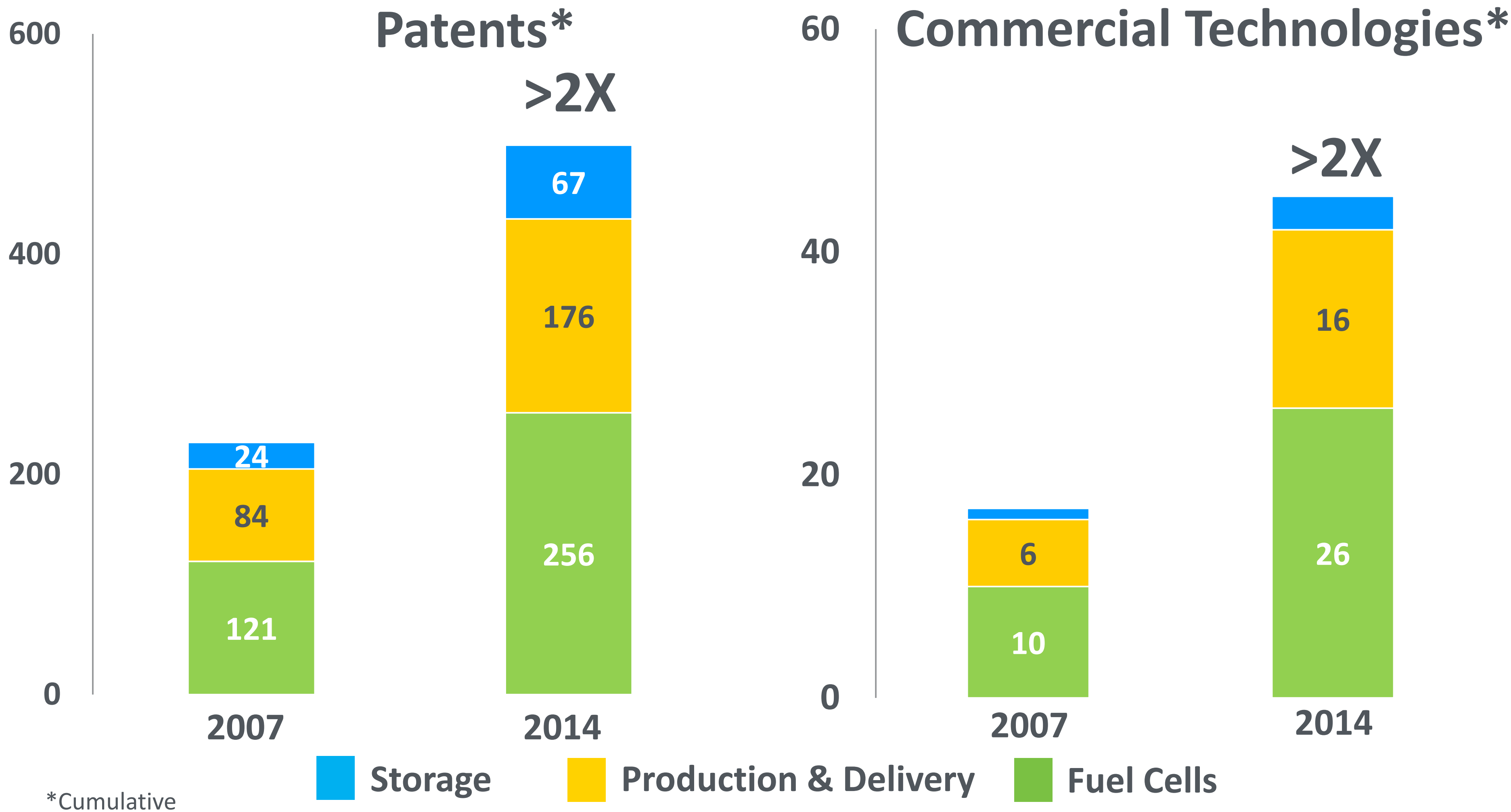
FY14 DOE Total: ~$175M

Consistent R&D funding request and appropriations in recent years

Hydrogen and Fuel Cell Summary FY15 Senate and House Language

SENATE	HOUSE
Total recommendation: $93,000,000	**Total recommendation: $100,000,000**
• DOE should analyze, research and make suitable investments in order to transform the size, cost, scalability (including modular stations), and interoperability of new retail hydrogen stations. • DOE should focus on consumer acceptance and strategic locations.	Technology Validation: • $5,000,000 of funding above the request is for testing and analysis of fuel cells as industrial-scale energy storage devices, with validation and testing using full-scale testing and demonstration capabilities. • Recommends that DOE leverage national laboratory, university, and regional stakeholder partnerships and capabilities, including at-scale grid infrastructure, modeling expertise, extreme environment testing capabilities, and public-private partnerships.
No specific direction on allocation of $93M (consistent with request).	Advanced demonstration and deployment: • $2,017,000 above the request is for demonstration and deployment activities that validate commercial viability, including material handling equipment, ground support equipment, refrigerated trucks, auxiliary power units, and associated hydrogen infrastructure.
H2USA: Committee is encouraged by the collaborative approach reflected in H2USA.	No direction.

Technology Innovation and Commercialization

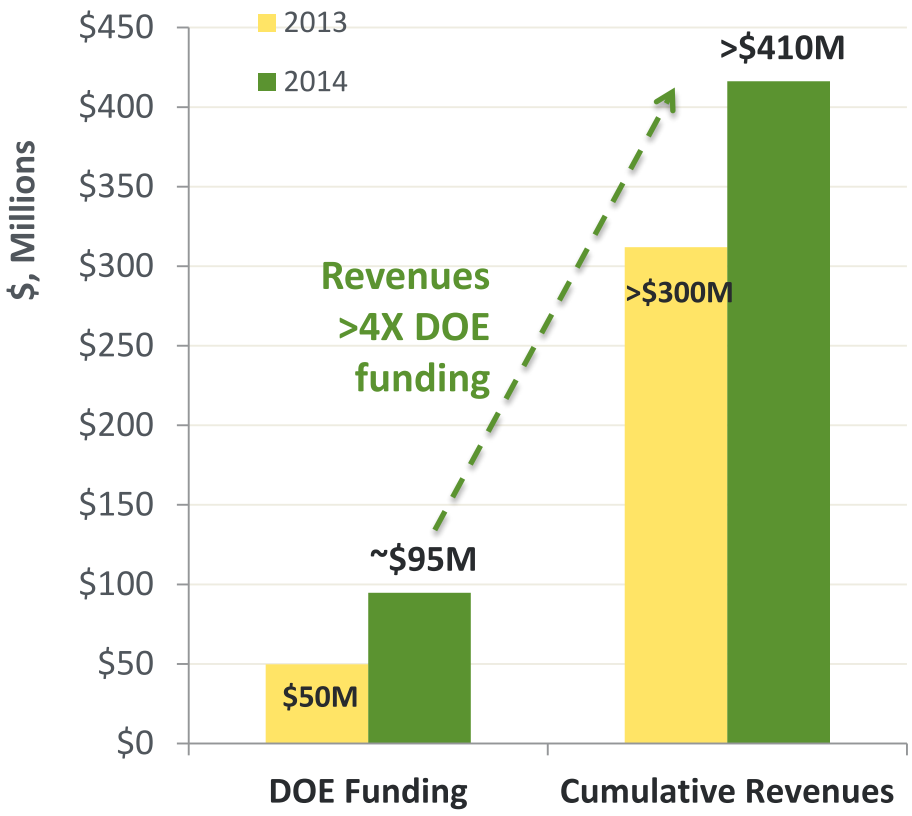


*Cumulative

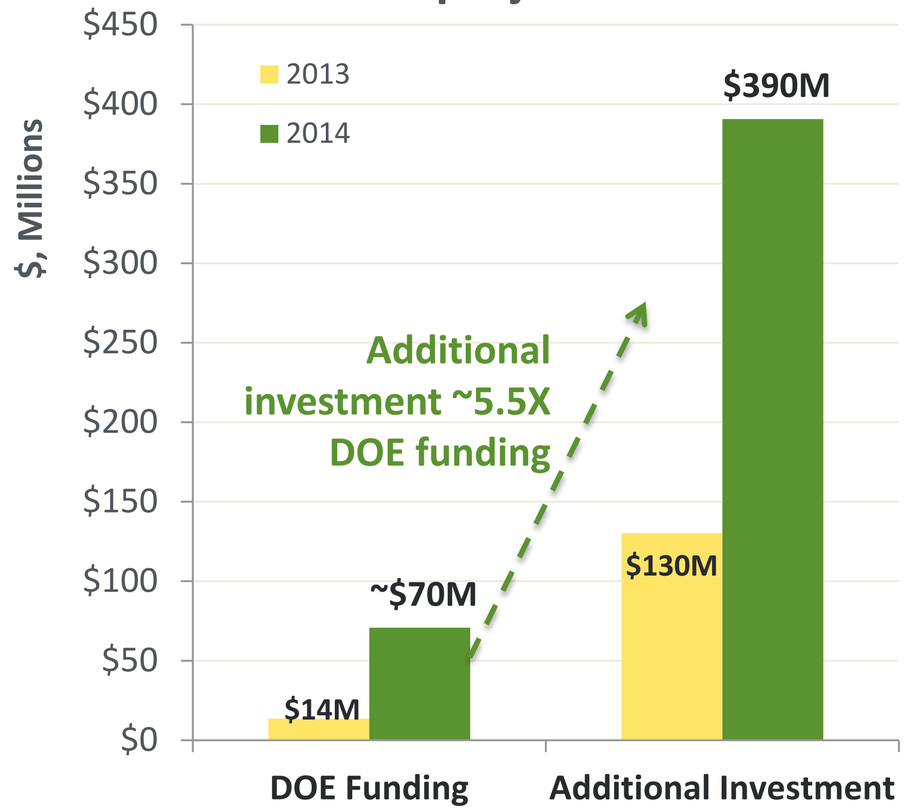
DOE funding has led to ~500 patents and 45 commercial technologies

"Tech to Market"
Assessing the Impact of DOE Funding

Example: Revenues resulting from DOE funded projects*



Example: Private investment resulting from DOE funded projects*

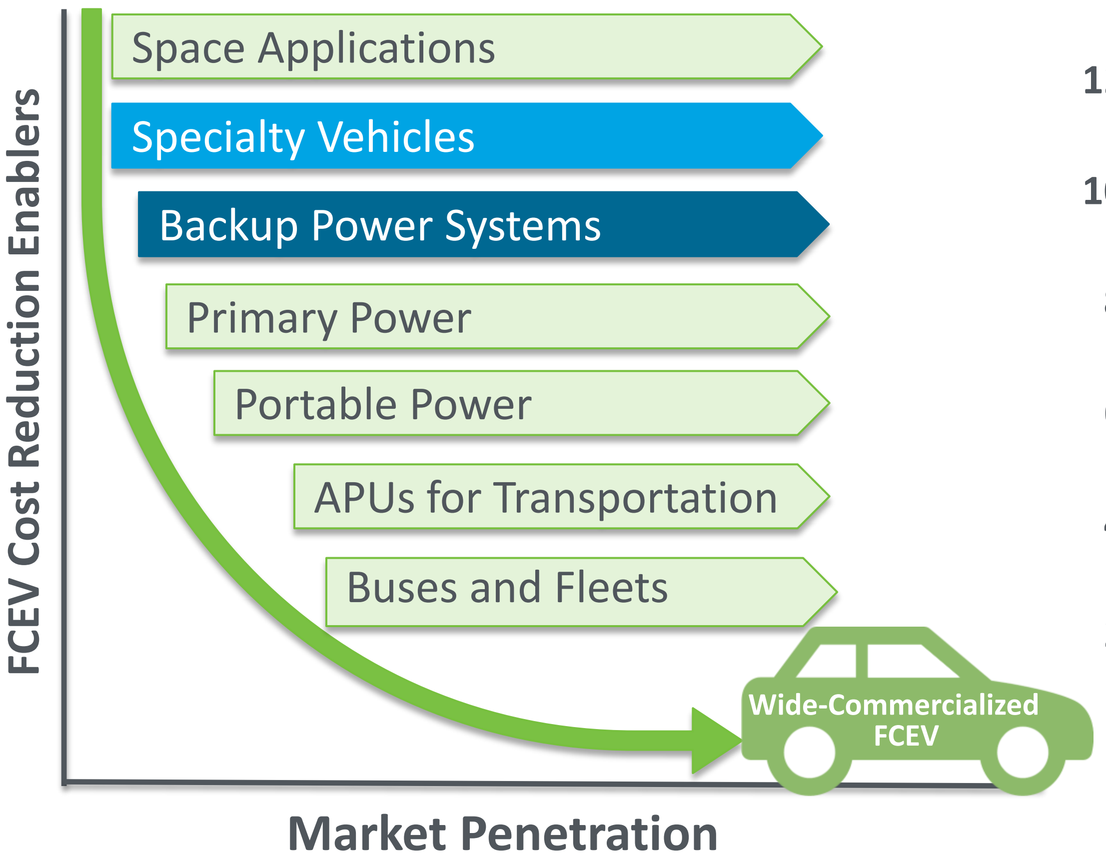


Revenues include estimates based off number of units sold.
*July 2014 rev.

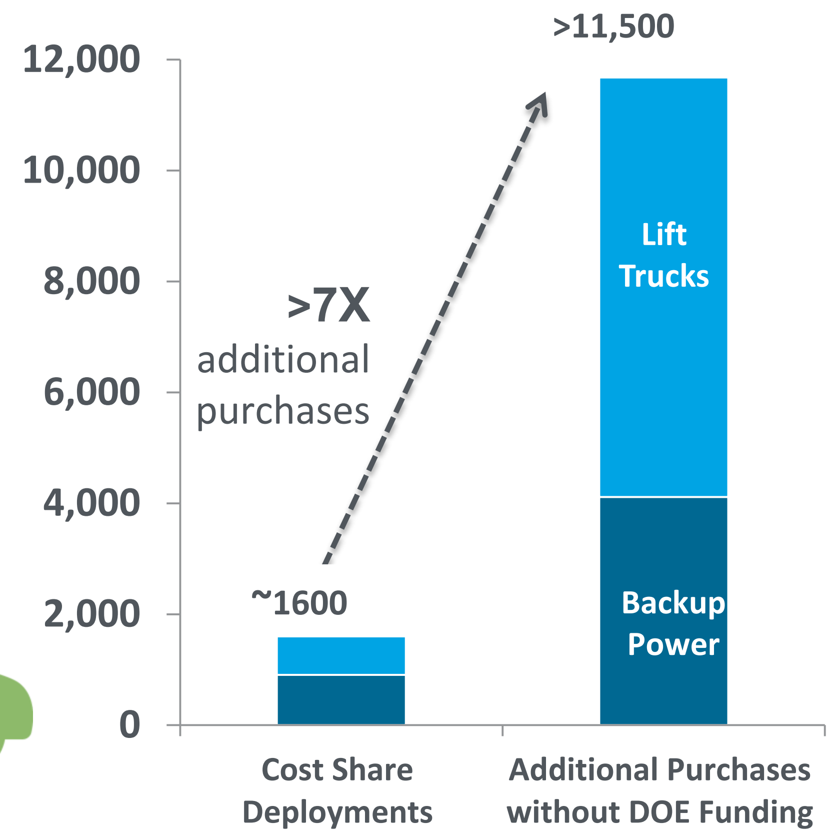
Revenues and additional investment valued at >4X and >5X the DOE investment.

DOE Funding Impact on Early Market Purchases

FCEV Commercialization Strategy



DOE Cost-Shared Deployments and Additional Purchases



Catalyzing early markets enables broader commercialization of FCEVs

Fuel Cell Cost Reductions Enabled by R&D

Fuel Cell Cost Reductions

50% from 2006
Fuel Cell
30% from 2008

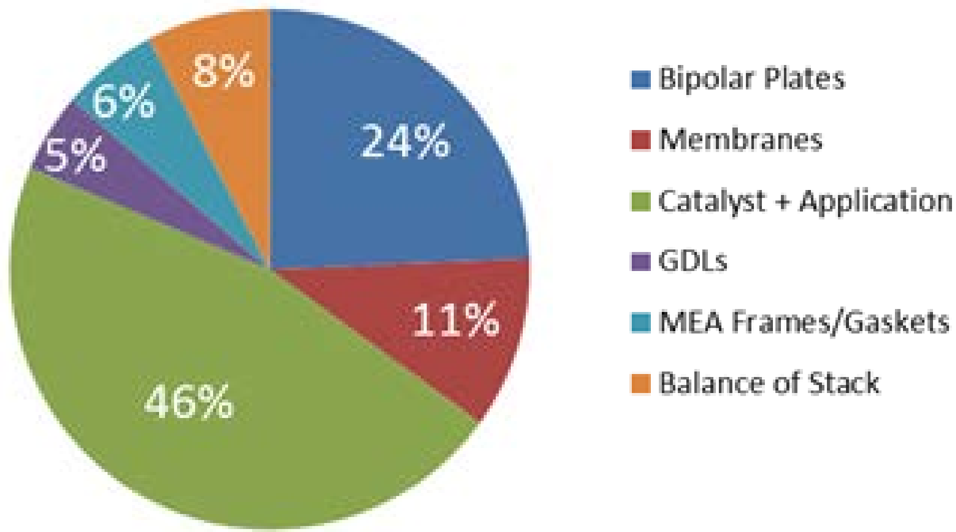
5X Platinum Catalyst

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

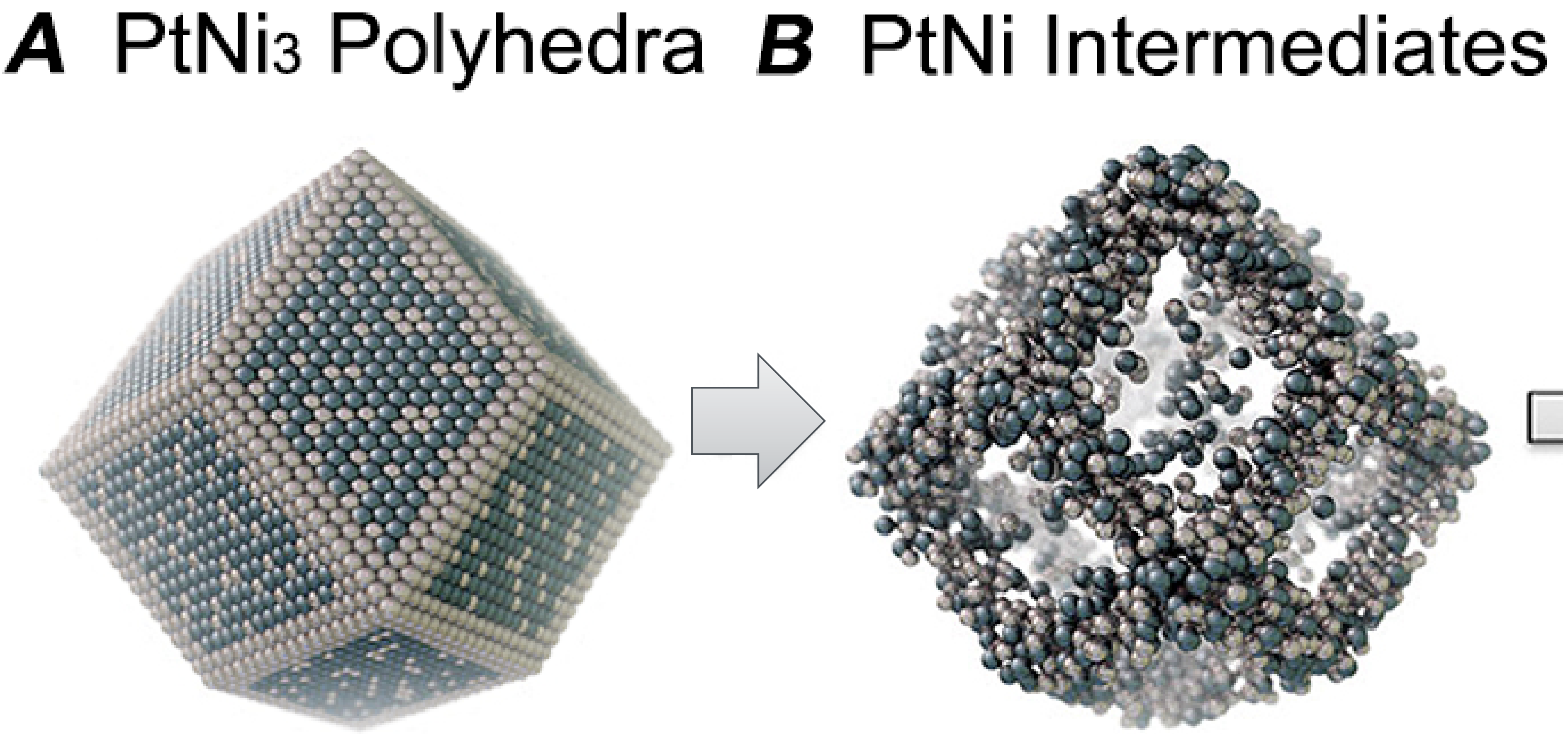


Catalyst accounts for **>45%** of total system cost

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

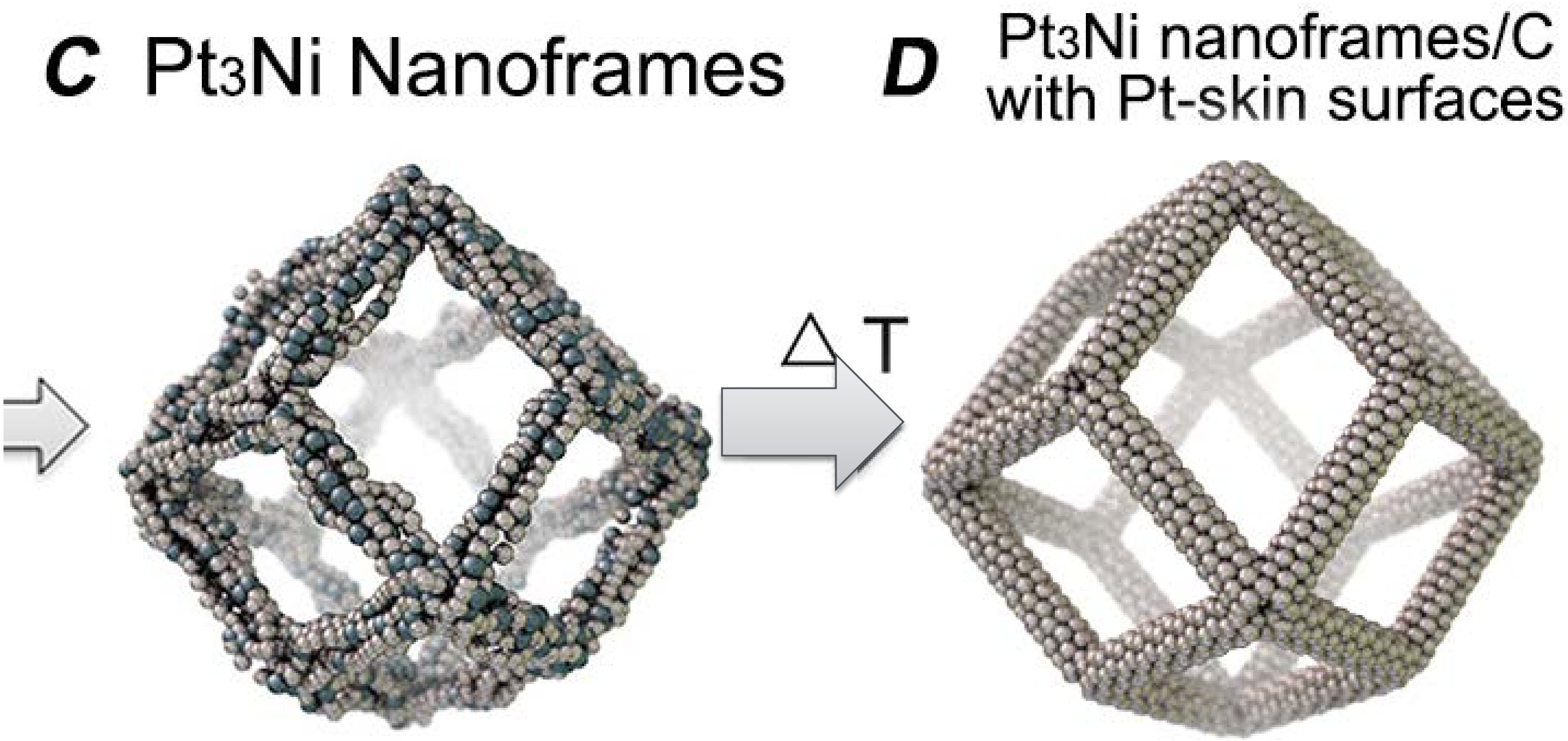
Catalyst remains key challenge and opportunity to lower cost

Synthesis & Evaluation of Nanoframes



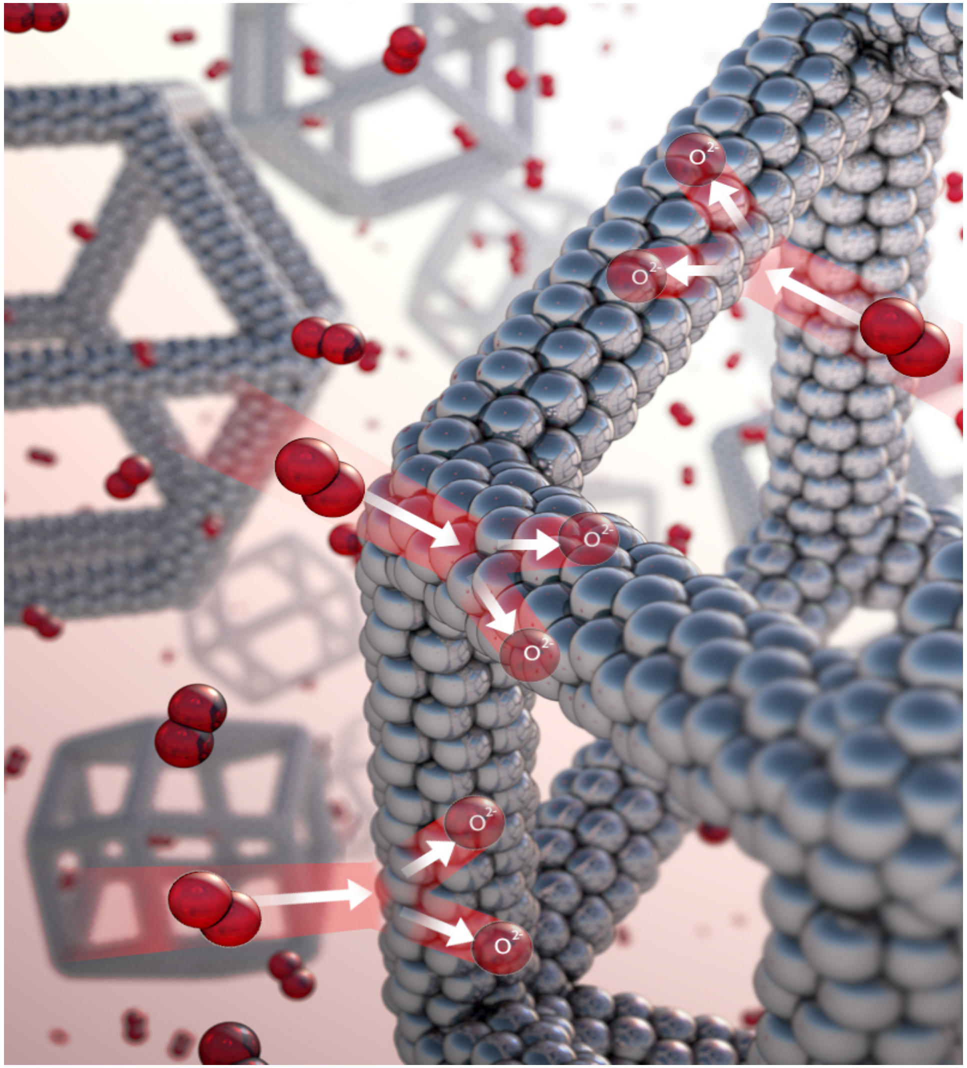
ANL and UC Berkeley scientists develop a high-mass activity nanoframe

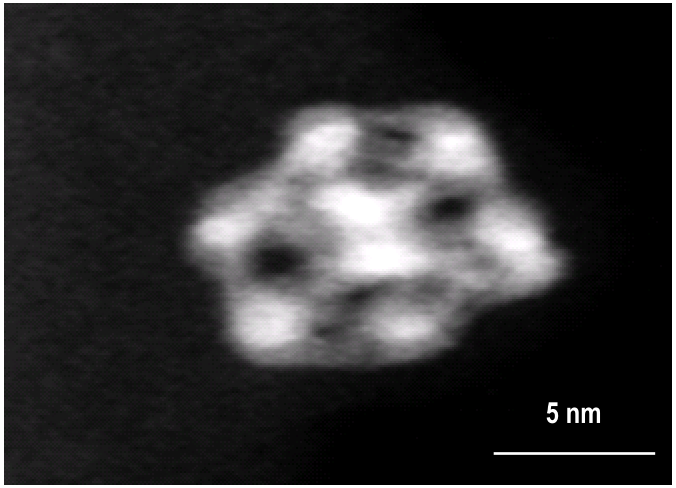
Synthesis & Evaluation of Nanoframes

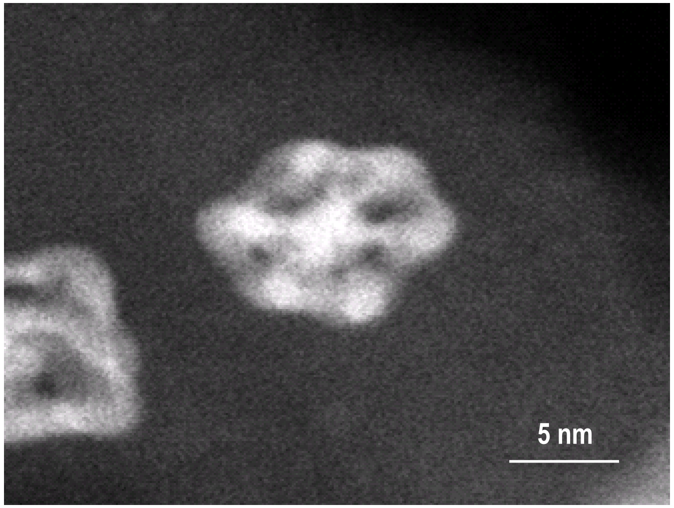


Dispersible cathode catalyst with extended thin film catalyst properties

Synthesis & Evaluation of Nanoframes



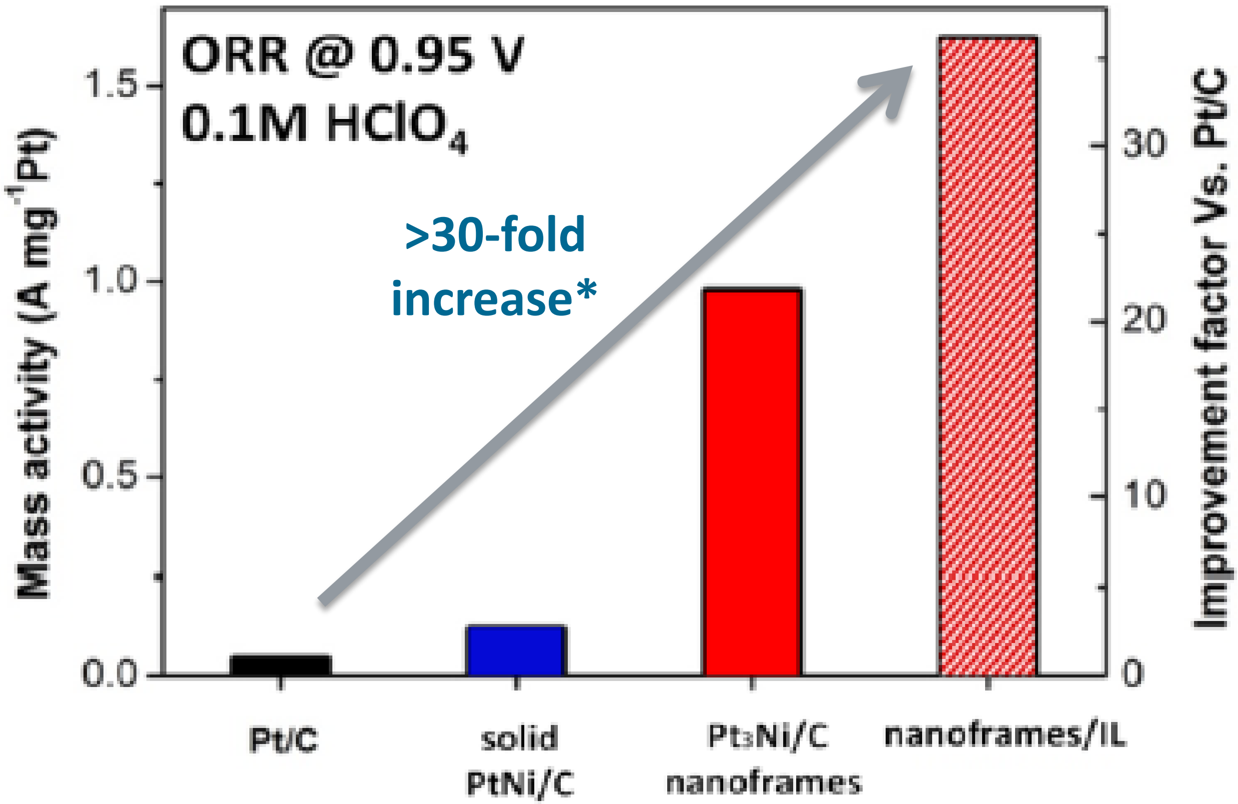




TEM- Karen Morre, ORNL

Microscopy demonstrates nanoframe hollow structure

Synthesis & Evaluation of Nanoframes



*Catalyst only in RDE tests

Future plans: Demonstrate MEAs

Reference:
"Highly Crystalline Multimetallic Nanoframes with Three-Dimensional Electrocatalytic Surfaces"
Vojislav Stamenkovic (ANL) & Peidong Yang (LBNL/UCB)
Science, 343 (2014) 1339

Catalyst mass activity >30X higher than conventional Pt/C

H_2 Infrastructure Development and Status

Nationwide

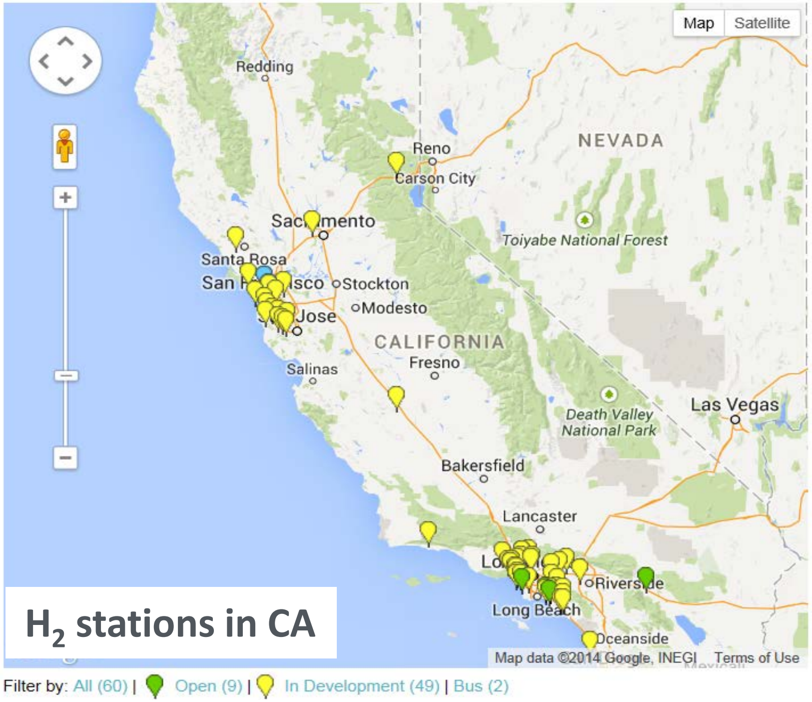
- **1500 mi.** of H_2 pipeline
- **>9M** metric tons produced/yr
- **~50 stations** (~10 public)

Other States

- **8-State MOU Members:** CA, CT, NY, MA, MD, OR, RI and VT
- **MA, NY, CT:** Preliminary plans for H_2 infrastructure and FCEVs deployment in metro centers in NE states.
- **Hawaii:** Public access refueling infrastructure on Oahu by 2020

California

- **100 stations** - Goal
- **>~$70M** awarded
- **~$100M** planned through **2023**



H_2 stations in CA

California, NE States and Hawaii have H_2 infrastructure efforts underway

H_2USA Public-Private Partnership to address H_2 Infrastructure Challenges

H_2 USA

U.S. DEPARTMENT OF ENERGY
The Great Seal of the State of California
GlobalAutomakers
NESCAUM
Fuel Cell & Hydrogen Energy Association
AGA American Gas Association

California Fuel Cell Partnership – Driving for the Future
GM
HONDA The Power of Dreams
HYUNDAI
Mercedes-Benz
NISSAN
TOYOTA
VW

AIR LIQUIDE
arc:HYDROGEN
Argonne National Laboratory
50%
EDTA Electric Drive Transportation Association
HNEI
HYDROGENICS Advanced Hydrogen Solutions

Intelligent Energy
ITM POWER Energy Storage | Clean Fuel
KOBELCO Kobelco Compressors (America), Inc.
The Linde Group – Linde
Massachusetts Hydrogen Coalition
NACS

NREL National Renewable Energy Laboratory
NUVERA Making hydrogen make sense.
Pacific Northwest National Laboratory
PDC
plugpower
PROTON The leader in on site gas generation.

Sandia National Laboratories
SRNL Savannah River National Laboratory
SCRA
CHRYSLER

3X increase in partners and growing since 2013

Hydrogen Fueling Infrastructure Research Station Technology

$1.4M DOE Funding
Leveraging Expertise of National Labs

NREL NATIONAL RENEWABLE ENERGY LABORATORY & Sandia National Laboratories

H_2FIRST In Support of H_2USA and tasked to deliver

Reference Station Design

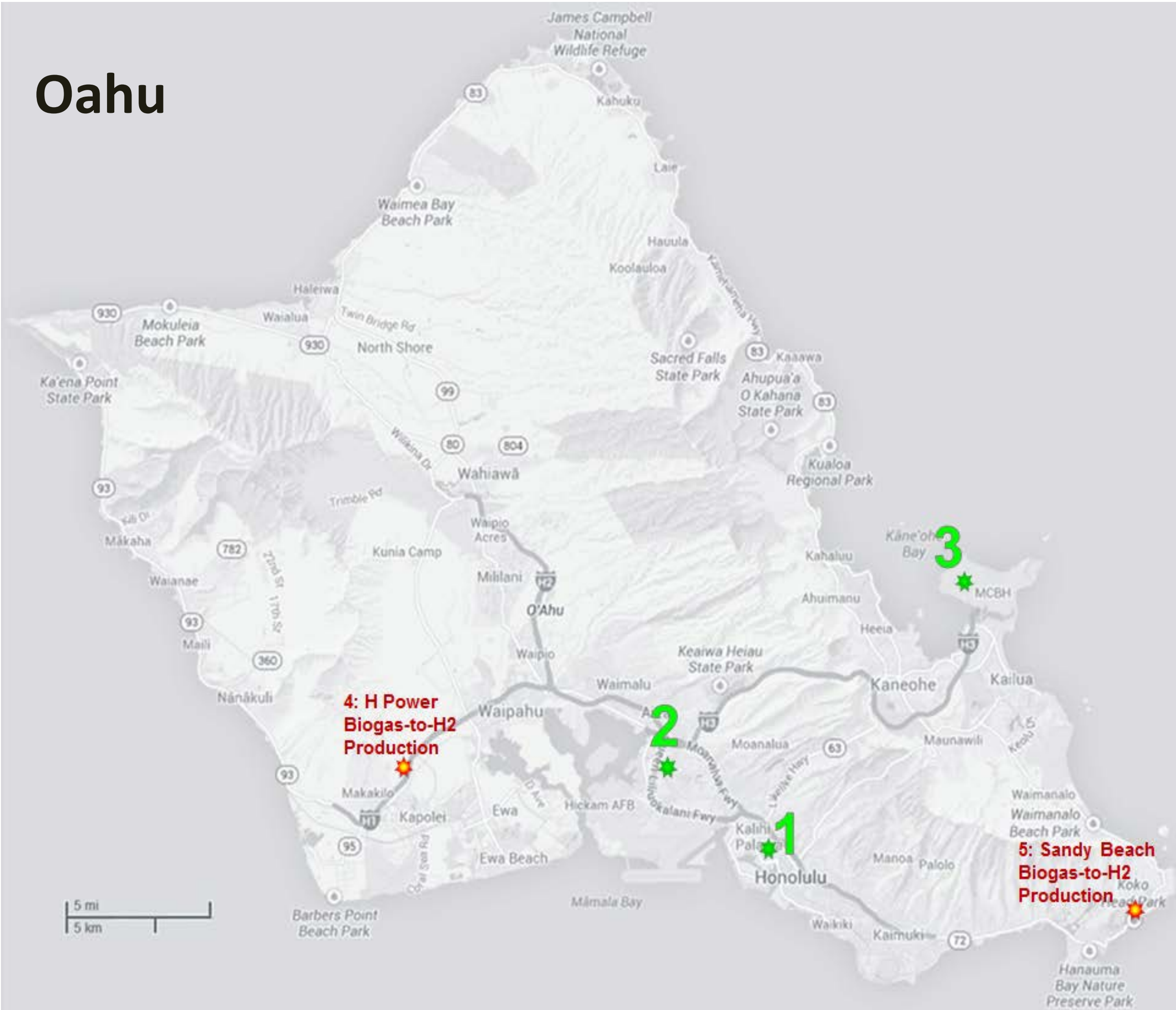
Fuel Contaminant Detection

HyStEP Device

- H_2 Station Equipment Performance Device
- H_2First Inaugural Task
- HyStEP will help reduce time required to place H2 stations in service

DOE's H_2FIRST project supports H2USA goals to address infrastructure

Infrastructure Options at Government Sites



1. GSA Fort Armstrong (65 kg/day):

- New greenfield site using 1.45 acre fed parcel

2. Hickam AFB (65 kg/day):

- Electrolyzer behind fence, mobile refueler source only

3. K-Bay USMC:

- Hookup Capacity

4. H-Power:

- Government owned with excess power, possibly electrolysis (LFG power)

5. Sandy Beach:

- WWTP with potential for SMR – H_2 plant

DOE is assessing H_2 infrastructure options in Hawaii

H-Prize Announcement

H2refuel
U.S. Department of Energy

$1 million competition for on-site home and community-scale H_2 fueling systems.

1st Year — Teams form and submit designs

2nd Year — Selection of finalists and testing

Late 2016 — Technical and cost analysis to select winner

Award — $1M

Promoting H_2 fueling system development in the community
Visit http://hydrogenprize.org/

International Partnership for Hydrogen and Fuel Cells in the Economy

- **Representatives from 17 member countries & the European Commission**
- **Facilitates international collaboration and a forum for advancing policies education**
- **Recent Activities:**
  - Infrastructure workshops, data-sharing, tank testing

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
    - New Task on Hydrogen Safety being defined

Strong International Collaboration on Safety

6th International Conference on Hydrogen Safety

October 19-21, 2015 in Kawasaki/Yokohama, Japan (Hosted by Technova)

IA HySafe Research Priorities Workshop

Facilitate knowledge sharing among international research activities in the field of hydrogen safety

International Hydrogen Infrastructure Workshop

The workshop, held in Torrance, CA in May 2014, was organized by NEDO, NOW, CaFCP, and DOE and included ~70 participants from Japan, the United States, Germany, Scandinavia, and the EU. Toyota and Honda were hosts and sponsors.

Objective: ***To continue international collaboration from the workshop held in 2013 on infrastructure challenges in four key areas: Refueling, Hydrogen Quality, Metering, and Hardware Reliability.***

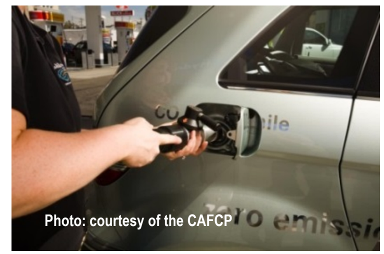


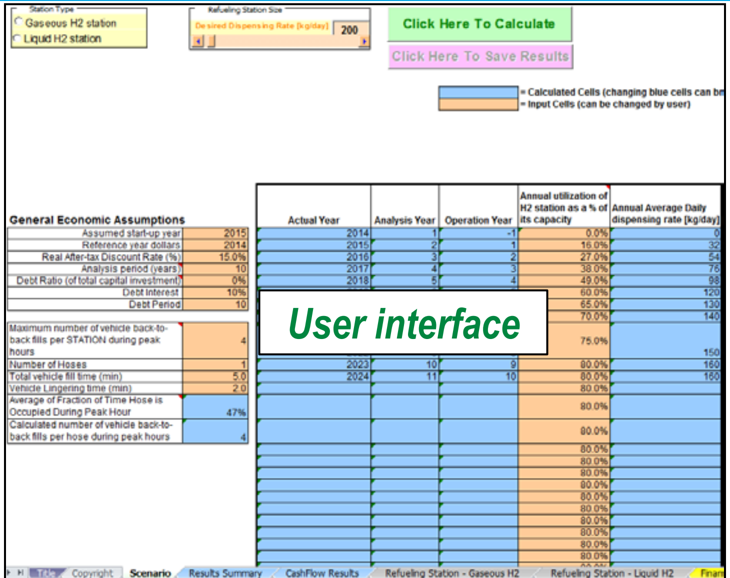
Photo: courtesy of the CAFCP

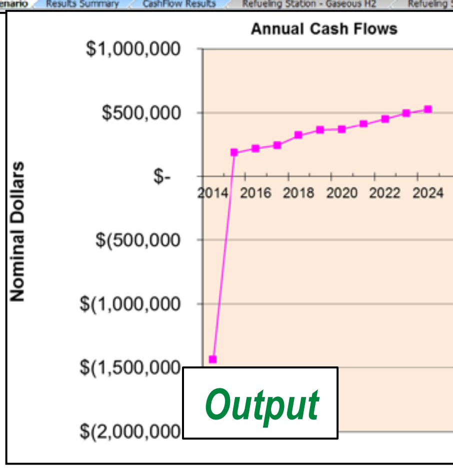
Key outcomes:

- **Refueling:** Need for internationally standardized methods and devices to validate fueling station performance. Regional initiatives are underway.
- **H2 Quality:** Need for low-cost inline test devices to supplement spot-checks. Fuel quality certification guidelines, best practices for hydrogen production and supply, and a risked-based approach to selection of chemical species that must be analyzed were particular concerns.
- **Metering:** Metering guidelines must be standardized internationally with the Weights and Measures community. Standards should be developed regionally and then proposed to the international community through the OIML[1] and NIST.
- **Station Hardware:** Key concerns included the reliability of compressors, cost of storage, understanding of storage reliability, along with the user-friendliness and durability of hoses.

1.International Organization of Legal Metrology

Hydrogen Refueling Station Analysis Model (HRSAM)





Developed at Argonne National Laboratory (ANL)

Economic

Primary inputs:

- Analysis period (years)
- Debt-to-equity ratio
- Debt interest and real after-tax discount rate
- Capital and operating costs of equipment (compressors, storage, dispensers, refrigeration, etc.)*
- Projected annual utilization

* Default values are based on early market data

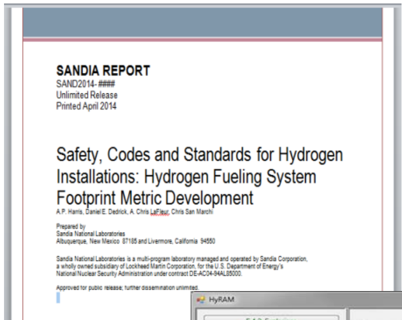
Station Performance

- Mode of hydrogen delivery (tube trailer vs. pipeline, liquid vs. gas)
- Number of consecutive fills station can complete
- Number of dispensers
- Station size (kg/day)

Uses discounted cash flow analysis to estimate cost ($/kg) of H_2 dispensing at a given station based on equipment costs.

Safety Codes and Standards Updates

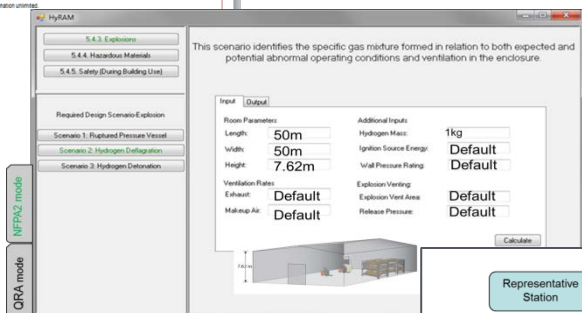
Examples of Key Activities


SANDIA REPORT
SAND2014-####
Unlimited Release
Printed April 2014

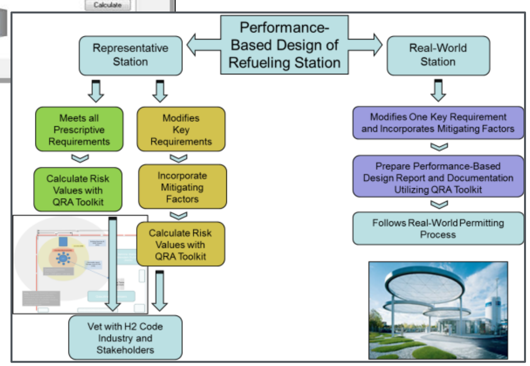
Safety, Codes and Standards for Hydrogen Installations: Hydrogen Fueling System Footprint Metric Development

Station Footprint Reduction – Reduced critical separation distances by **~50% for GH2 due to supported SCS R&D efforts** and direct participation in code development of NFPA 2 Hydrogen Technologies Code.

New Effort in FY14: Initiating LH2 release behavior experiments to address separation distances in partnership with NFPA 2/55 committees.



Develop tools for stakeholders to understand Risk – HyRAM (Hydrogen Risk Assessment Models) is being developed to enable an integrated approach of probabilistic and deterministic modeling including all relevant hazards and H2 phenomena.



Accelerate deployment of Hydrogen infrastructure by informing local AHJs –

- Develop a performance-based approach for the design of a hydrogen fueling station to increase the number available sites. (NFPA 2, Chapter 5)
- Develop a national permitting template in support of H2USA.

R&D supports development of codes & standards and facilitates domestic and international harmonization

- **Trained > 30,000 first-responders and code officials on hydrogen safety and permitting through on-line and in-classroom courses**
- **Developed H2Tools portal**

Hydrogen Tools APP for iPad/iPhone (1,130 downloads as of 11/2014)

www.eere.energy.gov/hydrogenandfuelcells/codes/

Implementing safety practices and procedures to ensure the safe operation, handling, and use of hydrogen and fuel cell technology

FCEVs are Here!

Available for Public Purchase soon….

Toyota Fuel Cell Electric Vehicle

Now Leasing…

Hyundai Tucson Fuel Cell SUV

In Auto Shows…

Honda Fuel Cell Electric Vehicle

OEMs bringing fuel cells to showrooms and driveways

Outreach and Communication Efforts

- **Publications** - **~80/yr.**
  - **Monthly Newsletter**
  - **Success Stories**
  - **News Alerts**
  - **Blogs**
- **Investor Days**
  - NYC and CA
- **House Senate Caucus Events**
- **Annual Merit Review & Peer Evaluation**
  - June 2014- 1,800 attendees
- **Ride-n-Drives**

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

Increasing public awareness and understanding about fuel cells and H_2

Hyundai Fuel Tucson Ride-n-Drive

"As part of the President's all-of-the-above energy strategy, the Department funds research, development and demonstration activities that are helping to put fuel cell electric vehicles like the Tucson on the road....

...The efforts of the Office of Energy Efficiency and Renewable Energy have helped cut fuel cell costs in half and double durability in the last several years, supporting the emerging domestic fuel cell electric vehicle industry and enabling the development of technologies that will reduce greenhouse gas emissions."

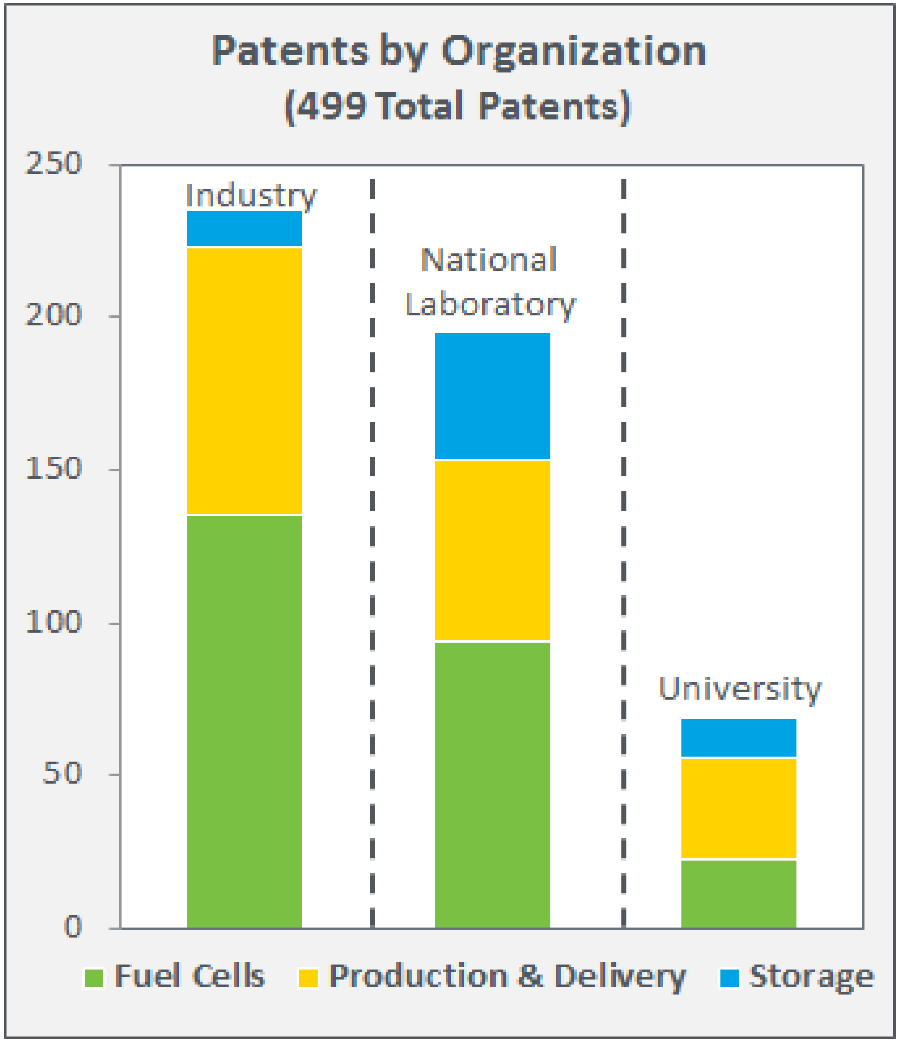
**- Deputy Secretary of Energy,
Daniel B. Poneman during Hyundai Fuel Cell Tucson Ride-n-Drive at DOE Headquarters**

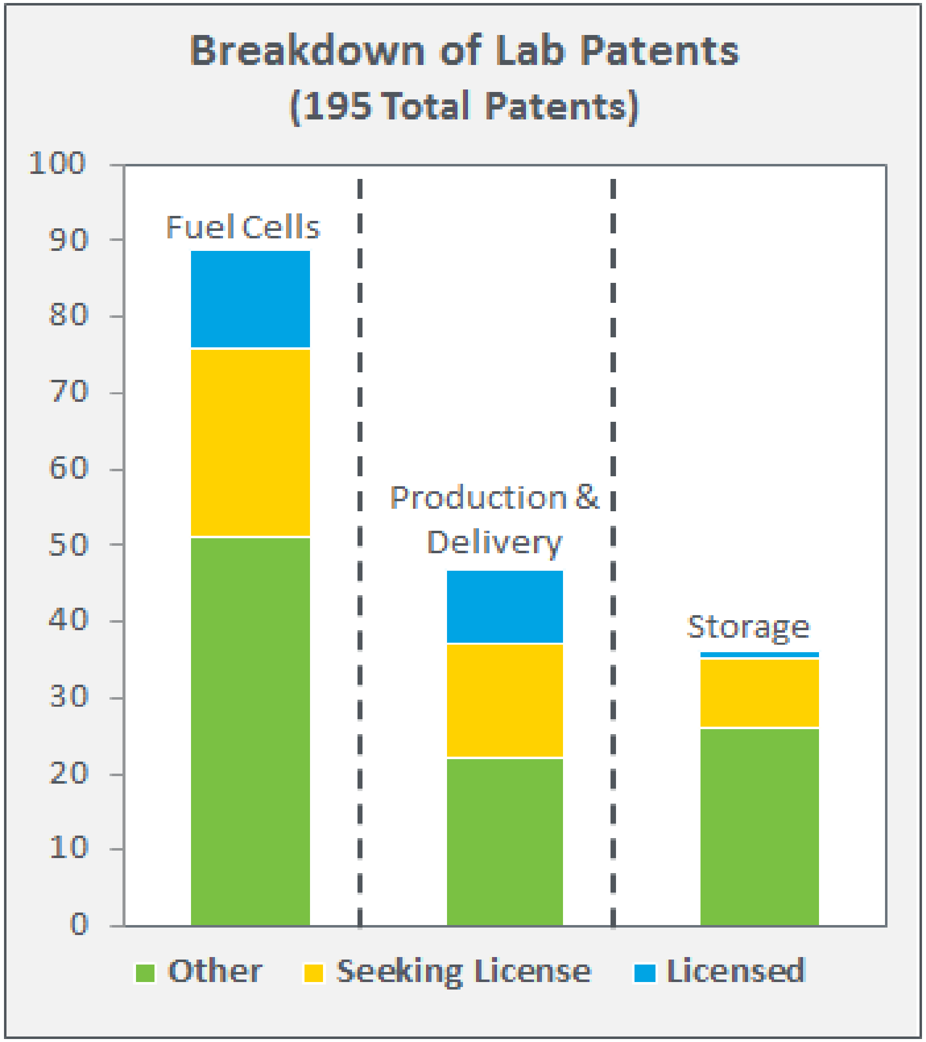
Committed to…

- EERE-National Lab Guiding Principles
- Long-term and committed relationship with National Labs
- Impact on industry
- Lab brand and identity

EERE Assistant Secretary David Danielson launches one of EERE Lab Impact Initiative key component– ***The Tech-To-Market (T2M) Approach***

DOE-Funded Patents



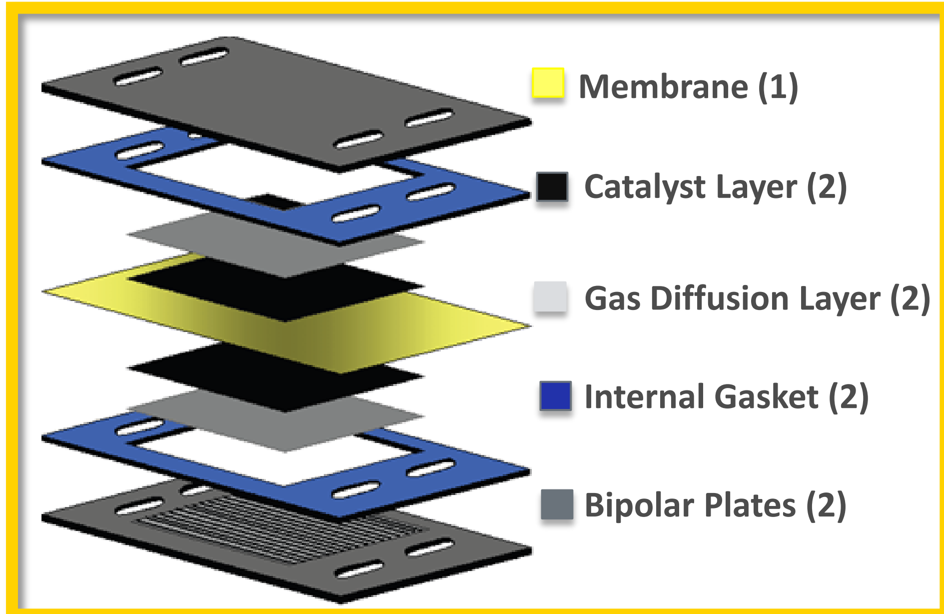


DOE has enabled nearly 500 patents, ~200 from labs

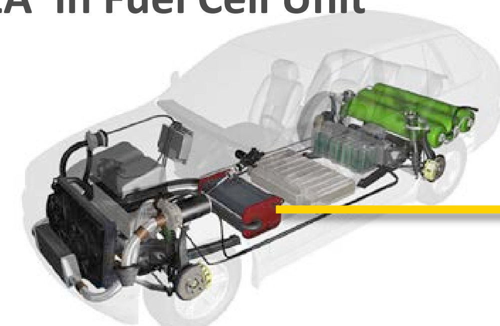
Examples of DOE-Led Fuel Cell Technology Breakthroughs

- **Ionomer-Impregnated Catalyzed Gas Diffusion Electrodes-** *US Pat 4,876,115 (1989)*
  "**ELAT**" – Electrode, Los Alamos Type
- **Catalyst-Coated Membranes-**
  US Pats 5,211,984 and 5,234,777 (1993)
- **Microporous Film on Gas Diffusion Layers-** *US Pat 5,641,586 (1997)*
- **Thermoset Composite Bipolar Plates-**
  US Pat 6,248,467 (2001)

Los Alamos NATIONAL LABORATORY EST. 1943



MEA in Fuel Cell Unit



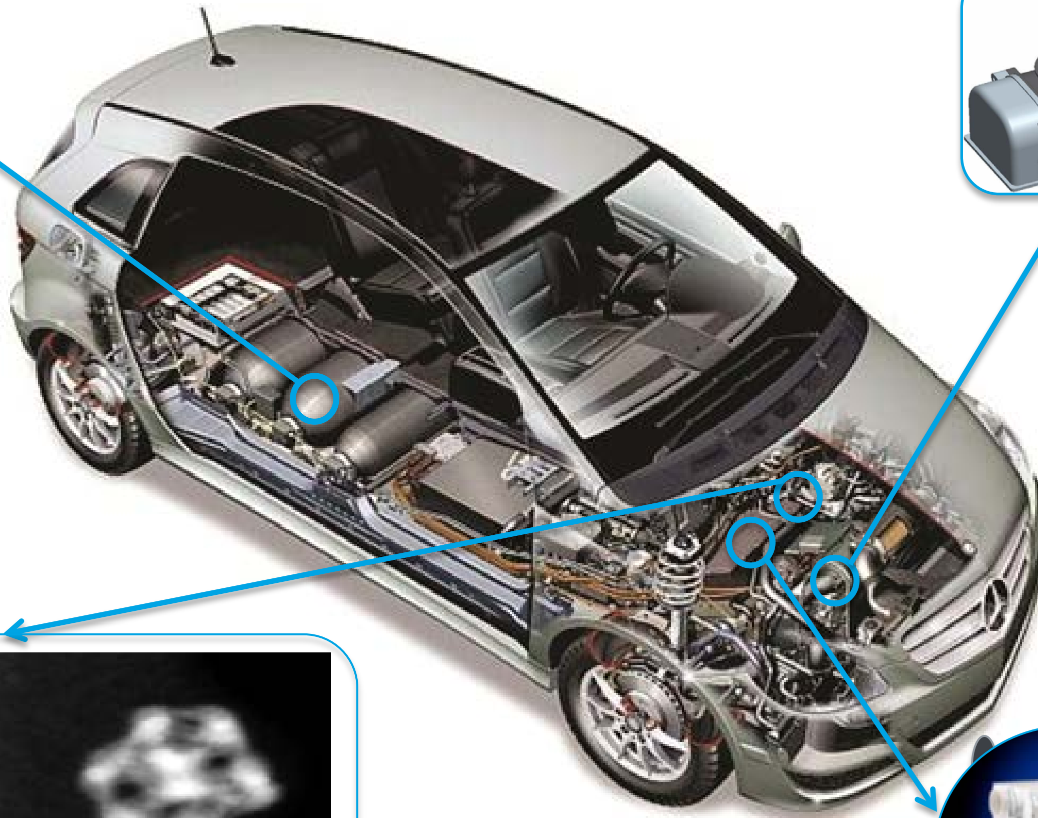
Fuel Cell Car

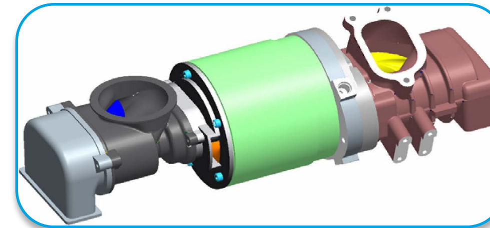
Fuel Cell Stack

Innovation from LANL can be found in most fuel cells today

FCEV Technology Advancements

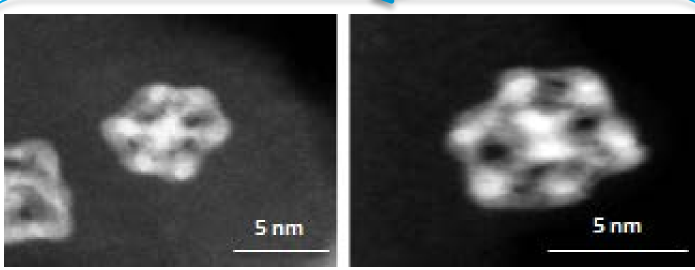
700 bar composite overwrapped pressure vessels





Compressor Expander Motor Module for Air Compression System

ORNL microscopy imaging



TEM- Karen Morre, ORNL

Module for Humidifier

DOE funded R&D has advanced the state of technology for FCEV systems

Fuel Cells Tech-to-Market (T2M) Strategy

T2M Strategy

Activities

Increase Industry Contact
- Business-to-Business Product Theater (Eleven Labs)
- Manufacturing Road Show

Listen to the Voice of the Customer
- Key Staff Exchange with Industry

Develop Technology Transfer Skills
- Business Plan Development Training
- Lab Corps

Increase Market Understanding

Improve Private Sector Relationships

Improving technology transfer and targeted impact from lab to market

T2M Activities at the Fuel Cell Seminar and Exposition (FCS&E)

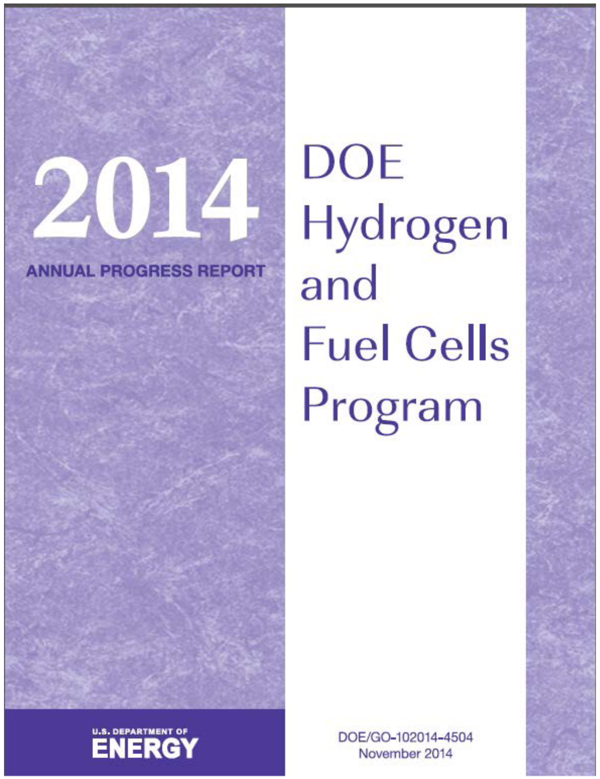
- **Tools**
  - Workshop sessions
  - Business-to-business product theaters
- **Key Questions**
  - How do I work with the National Labs?
  - Why should I work with the National Labs?
- **Objective**
  - Collaboration and understanding between national labs and industry

FCTO's ad on T2M Showcase Activities for the FCS

DOE sponsored several T2M events during FCS&E- Nov 11th, 2014

Just Published…

2014 DOE Hydrogen and Fuel Cells Program Annual Progress Report (APR)



- **~1,000** pages documenting DOE progress

2013 Fuel Cell Technologies Market Report

- ~ **$1.3** billion industry
- **>35,000** units shipped worldwide

APR documents DOE progress and Market Report provides update on fuel cell industry

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

HTAC Input Requested:

- Feedback on Goals (Draft) for H2USA Working Groups
- Location Roadmap
  - Determine number of vehicles planned for 2015-2020 launch and the number, location and capacity requirements for station rollout for at least two states by Q4 2015.
- Financing/Investment
  - Develop and disseminate refueling station business case studies, identify at least 3 (X) optimal payback scenarios and strategies for risk mitigation, and secure financing or investment by Q4 2016.

Draft goals continued

- **Station Technology**
  - **Develop and demonstrate critical enabling technologies for station rollout including station performance validation device and validate fueling protocols for at least 5 stations by 4Q 2016.**
- **Communication and Outreach**
  - **Increase H2USA partnership by factor of 5 since launch, develop communication and outreach materials and disseminate to at least 10,000 by 4Q 2015.**

Subgoals (examples)

- **Hold H2USA infrastructure financing and investment workshop.**
- **Develop online tool to calculate station payback and disseminate through webinar and conferences to key retail station owners and investors.**

Thank You

Dr. Sunita Satyapal

Director

Fuel Cell Technologies Office

Sunita.Satyapal@ee.doe.gov

hydrogenandfuelcells.energy.gov

Additional Information

Recent Webinars

- **Wide Bandgap Semiconductor Power Electronics for Hydrogen and Fuel Cell Applications** (Oct 21, 2014)
- **SAE Hydrogen Fueling Standardization** (Sep 11, 2014)
- **Hydrogen Energy Storage for Renewables** (Aug 19, 2014)
- **Hawaii Hydrogen Activities** (Jul 29, 2014)
- **Overview of Hydrogen Fueling for FCEVs** (Jun 24, 2014)
- **NREL's Fuel Cell Contaminant Database** (May 27, 2014)
- **Fuel Cells at NASCAR** (Apr 17, 2014)
- **National Fuel Cell Technology Evaluation Center** (NFCTEC) (Mar 11, 2014)
- **Additive Manufacturing for Fuel Cells** (Feb 11, 2014)
- **Energy 101: Fuel Cells Discussion** (Jan 16, 2014)
- **Hydrogen Student Design Contest** (Nov 6, 2014)
- **H2FIRST Overview** (Nov 18, 2014)

Recent Workshops

- **Contaminant Detection at the Forecourt** (June 12th, 2014)
- **Energy Storage Workshop** (May 2014)
- **2nd International Workshop on Hydrogen Infrastructure** (May 8-9th, 2014)
- **Hydrogen Safety Resource Tools** (April 2014)
- **Infrastructure Financing Workshop** (April 2014)
- **Electrolytic Hydrogen Production** (February 27-28th, 2014)
- **Hydrogen Transmission and Distribution Workshop** (February 25-26th, 2014)

Hydrogen Production Strategies

Current Technology

- Natural Gas (D/C)
- Electrolysis (D)

Near to Mid-Term:

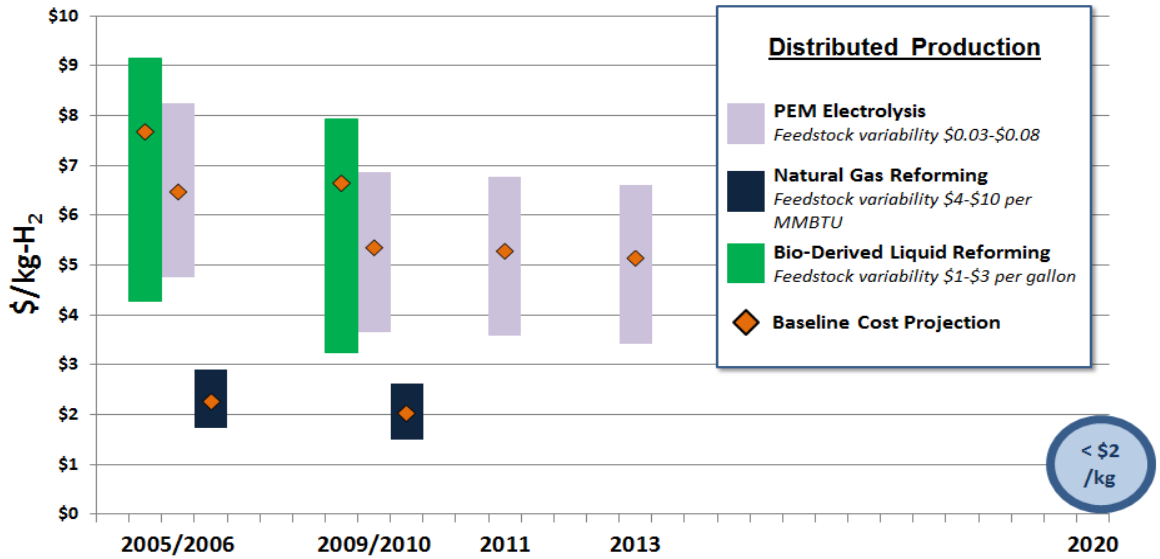
- Electrolysis- Wind and Solar Powered (D/C)
- Bio-derived Liquids (D/C)
- Fermentation (D/C)

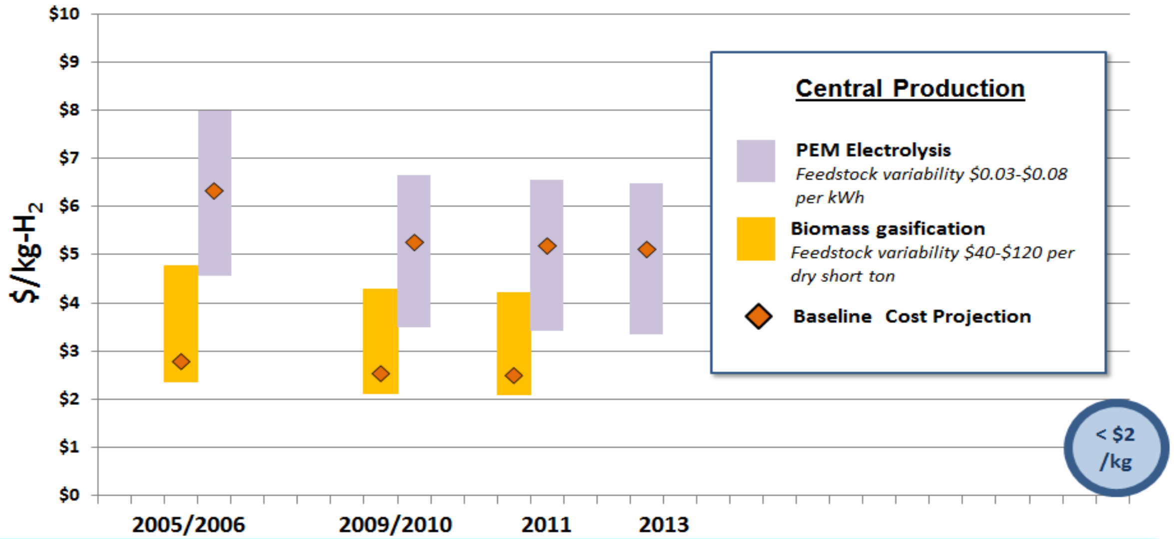
Long-Term (not shown):

Central Renewable H_2

- Solar-based water splitting
- Photolytic Bio-hydrogen

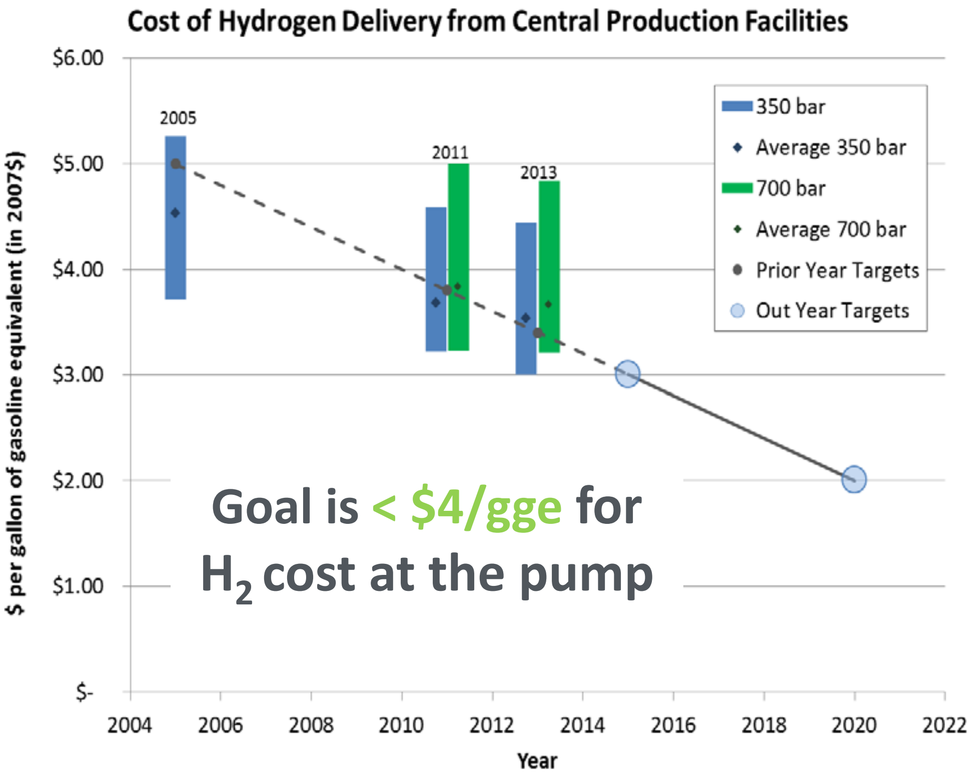
D- Distributed **C- Central**





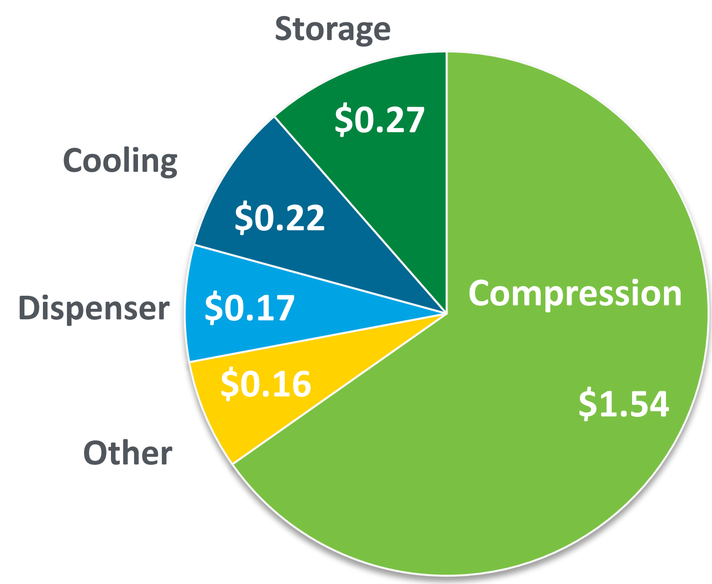
H_2 from natural gas is available now while H_2 from renewables is a longer-term focus.

Hydrogen Delivery Cost Reductions



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

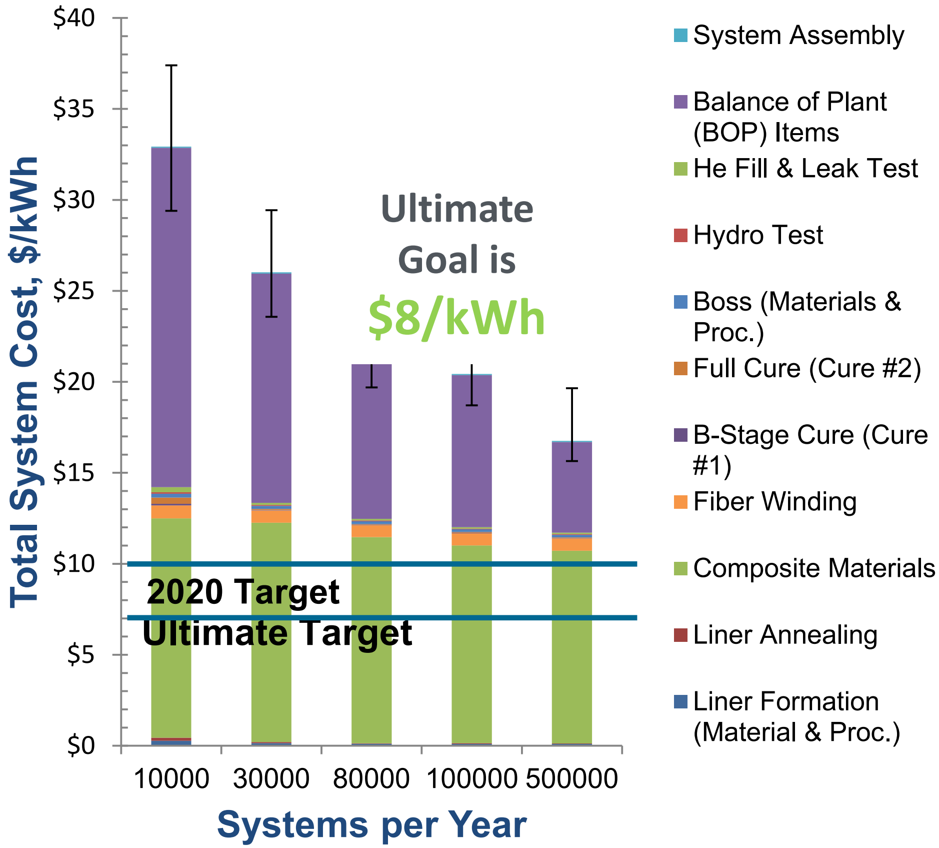
* Details for the high volume cost projection assumptions can be found in Record 13013

**Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs Record

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

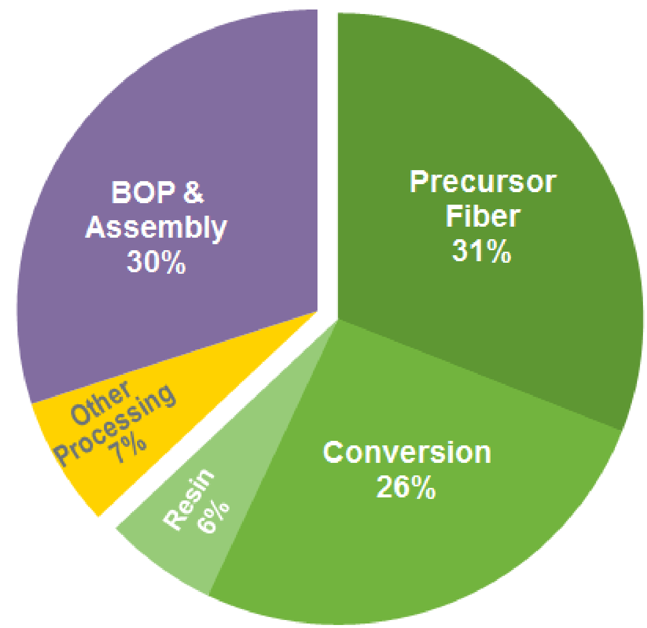
H_2 Storage System Critical Costs

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

700 bar compressed H_2 is the immediate strategy for FCEV rollout, however cost reductions are needed and carbon Fiber is the key.

New Selections for Hydrogen Production RD&D

6 selections, $13.3 M in federal funds

FuelCell Energy Inc. ($900k), Danbury, CT

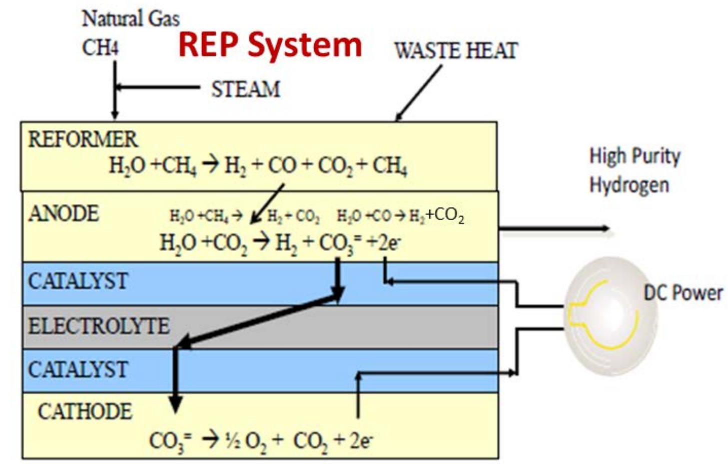
- Novel reformer-electrolyzer-purifier (REP) system

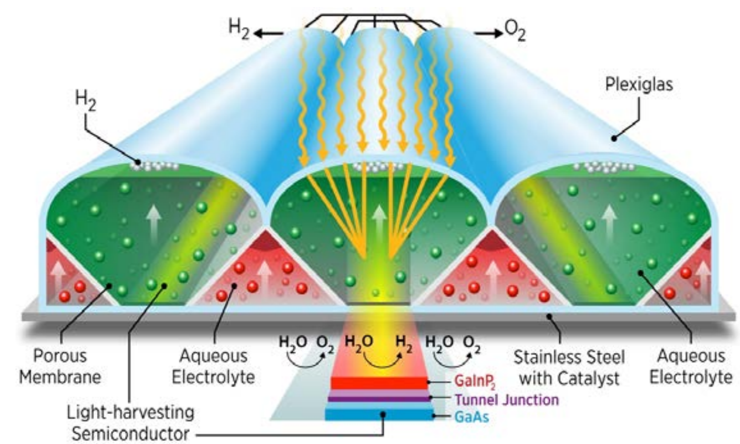
Pacific Northwest National Laboratory ($2.2M Richland, WA

- 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.





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

New Selections for Hydrogen Production RD&D

6 selections, $13.3 M in federal funds

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

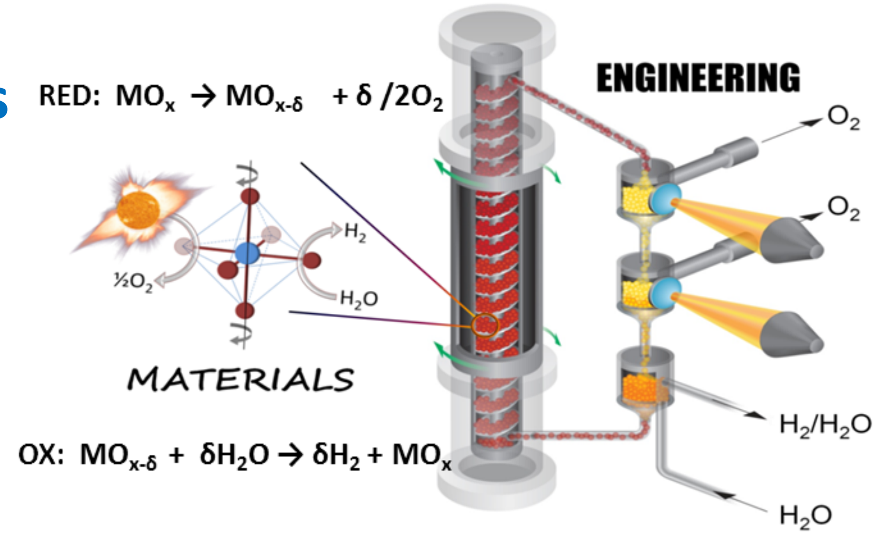
- Photoelectrodes based on novel wide-bandga thin-films for direct solar water splitting.

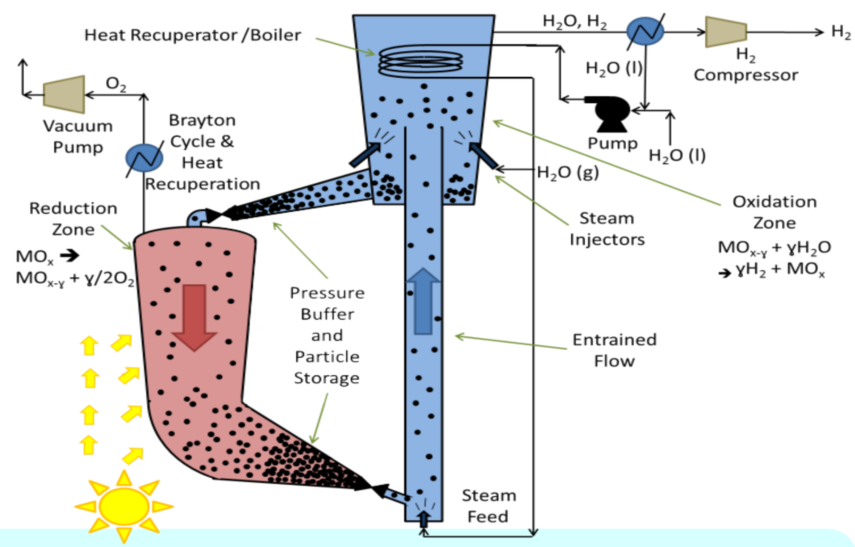
Sandia National Laboratories ($2.2M) Livermore, CA

- 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.





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

New Selections for Hydrogen Delivery RD&D

3 Awards, $6.8 M in federal funds

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

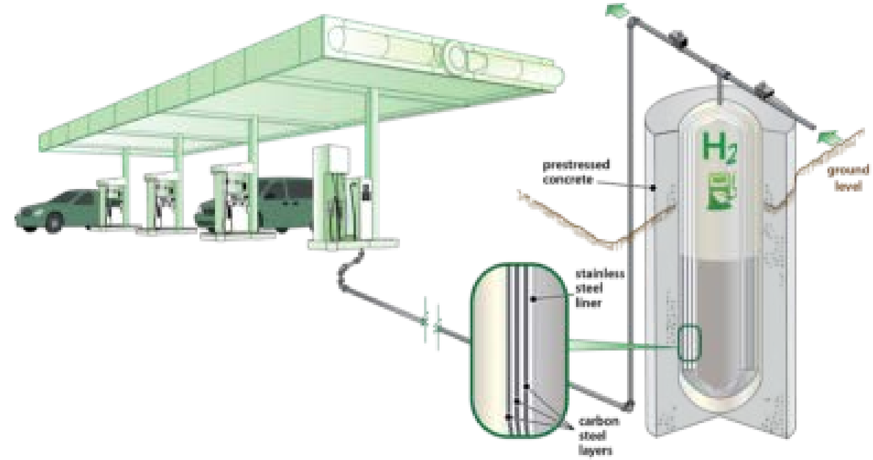
- Linear motor reciprocating compressor for forecourt H_2 compression

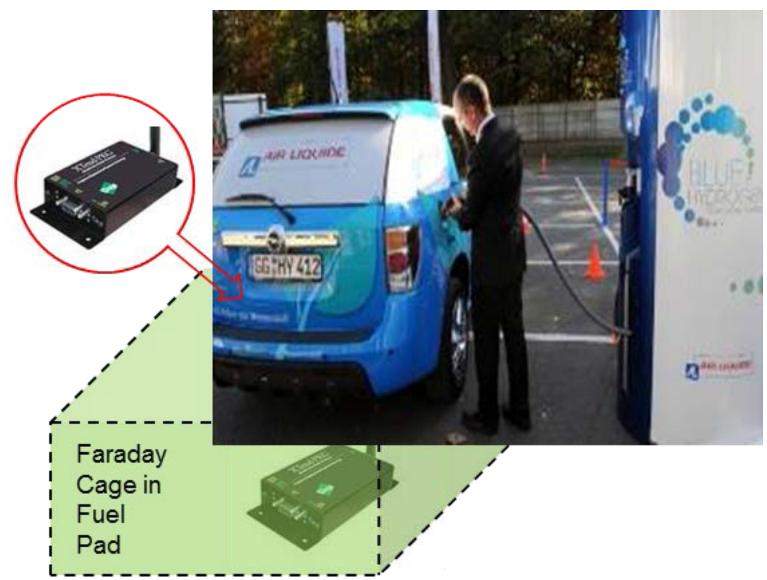
Oak Ridge National Laboratory ($2.0M), Oak Ridge, TN

- 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.





Innovative technologies for forecourt compression, storage and dispensing

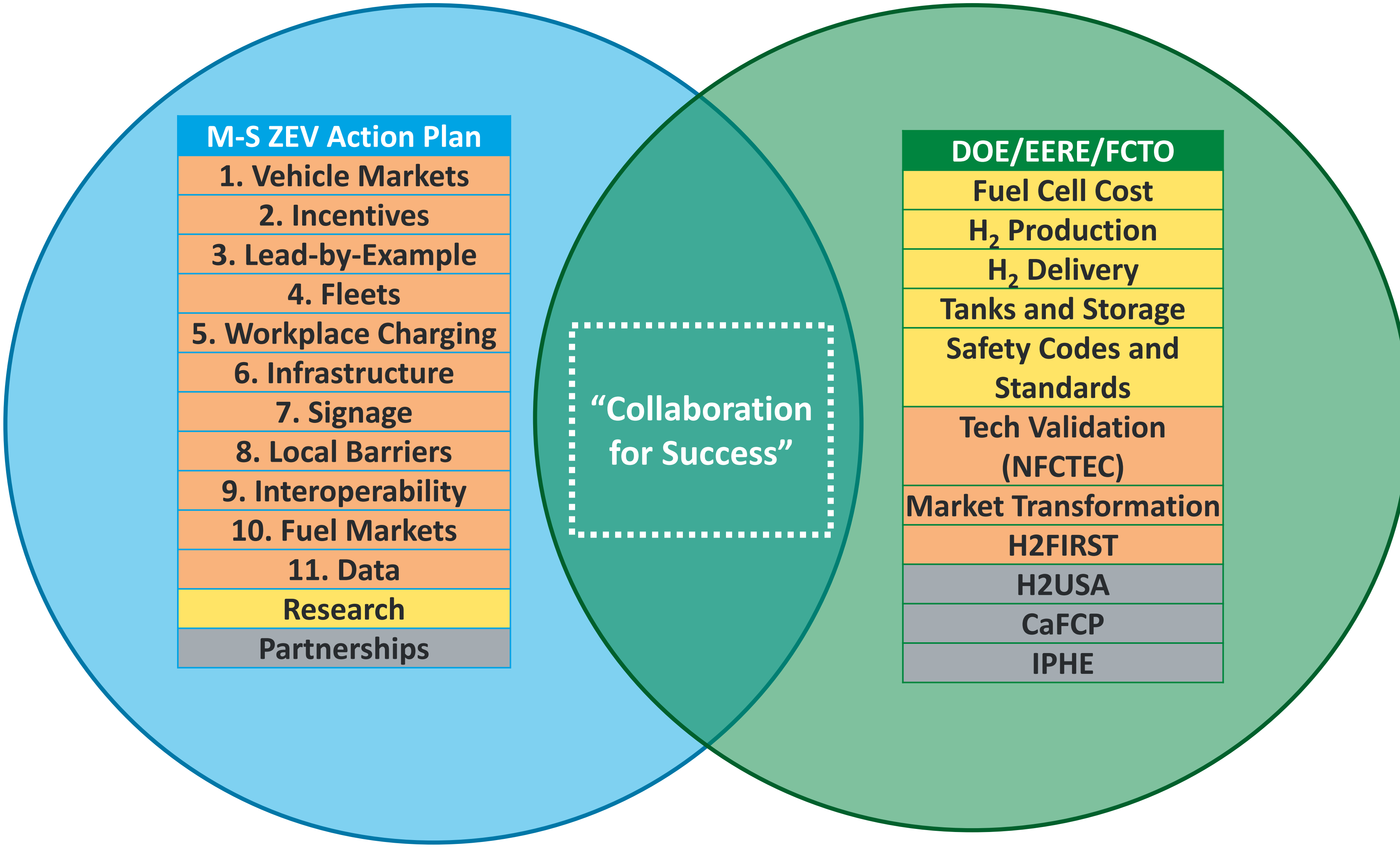
New Selections for Hydrogen Storage RD&D

6 Selections, $8M in federal funds

- **Materia ($2M), Pasadena, CA**
  - Demonstrate novel resin system and vacuum assisted resin transfer manufacturing process to reduce the cost of high pressure storage tanks.
- **PPG Industries ($1.2M), Greensboro, NC**
  - Demonstrate novel high strength glass fiber with tensile strengths equal or greater than the carbon fibers used today at half of the cost.
- **Sandia National Laboratories ($1.2M), Livermore, CA**
  - Systematically screen low-cost alternative steel alloys for use in balance of plant components for hydrogen storage systems.
- **Ardica ($1.2M), San Francisco, CA**
  - Develop and scale-up a low-cost process for the commercial production of aluminum hydride (alane), a high-capacity hydrogen storage material.
- **HRL Laboratories ($1M) Malibu, CA**
  - Develop high-capacity reversible hydrogen storage materials that have properties needed for practical hydrogen storage applications.
- **Lawrence Livermore National Laboratory ($1.2M) Livermore, CA**
  - Use a combined computational/experimental approach to improve the kinetics and properties of magnesium borohydride for practical hydrogen storage

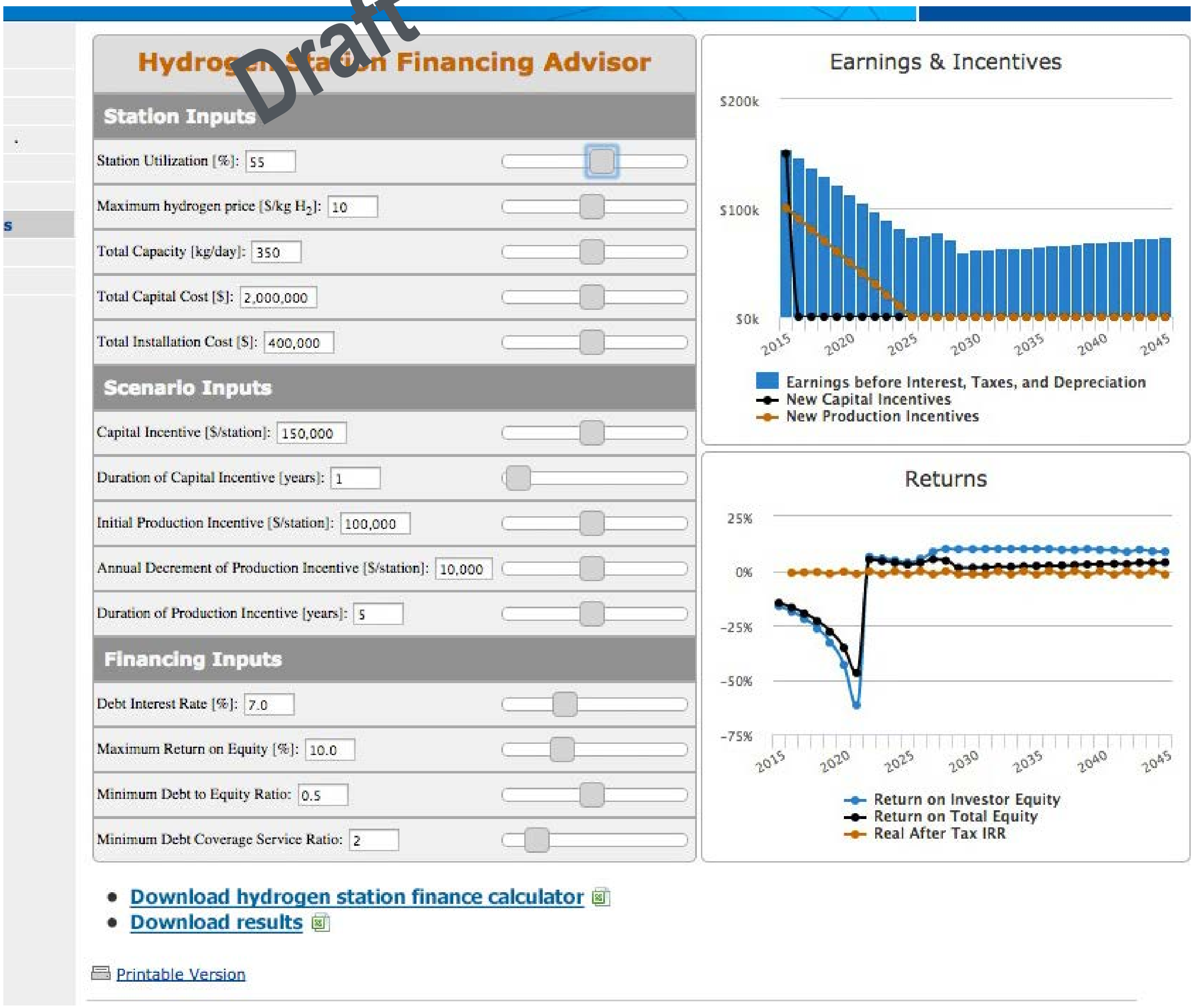
Examples of Activities Supporting ZEV Action Plan

ACTION | RESEARCH | PARTNERSHIPS

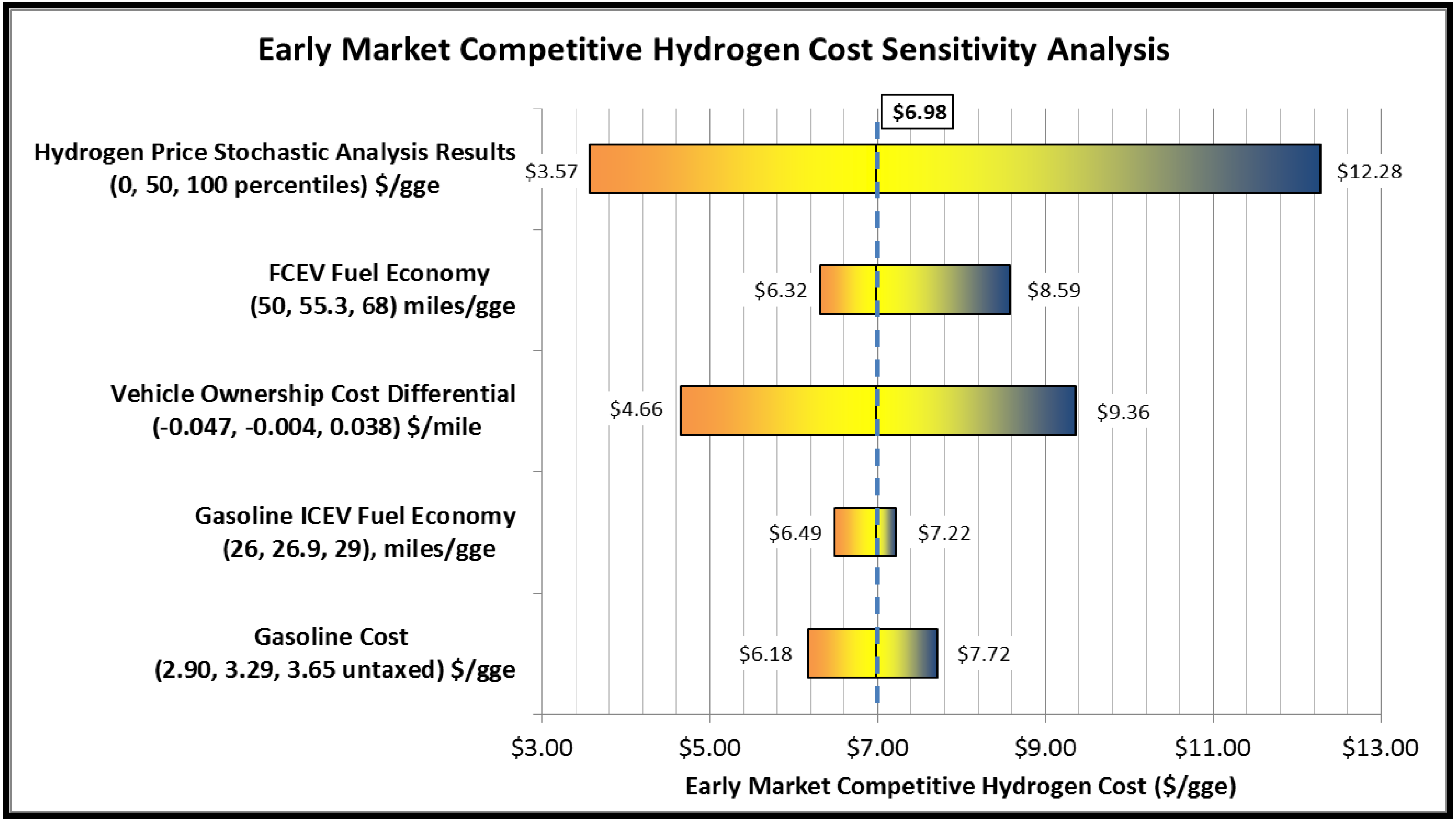


Online cost calculator (NREL)

- H2FAST (Financial Advisor Scenario Tool)
- Developed by NREL with inputs from ANL's HRSAM (H_2 refueling station analysis model)
- Beta testing coming soon



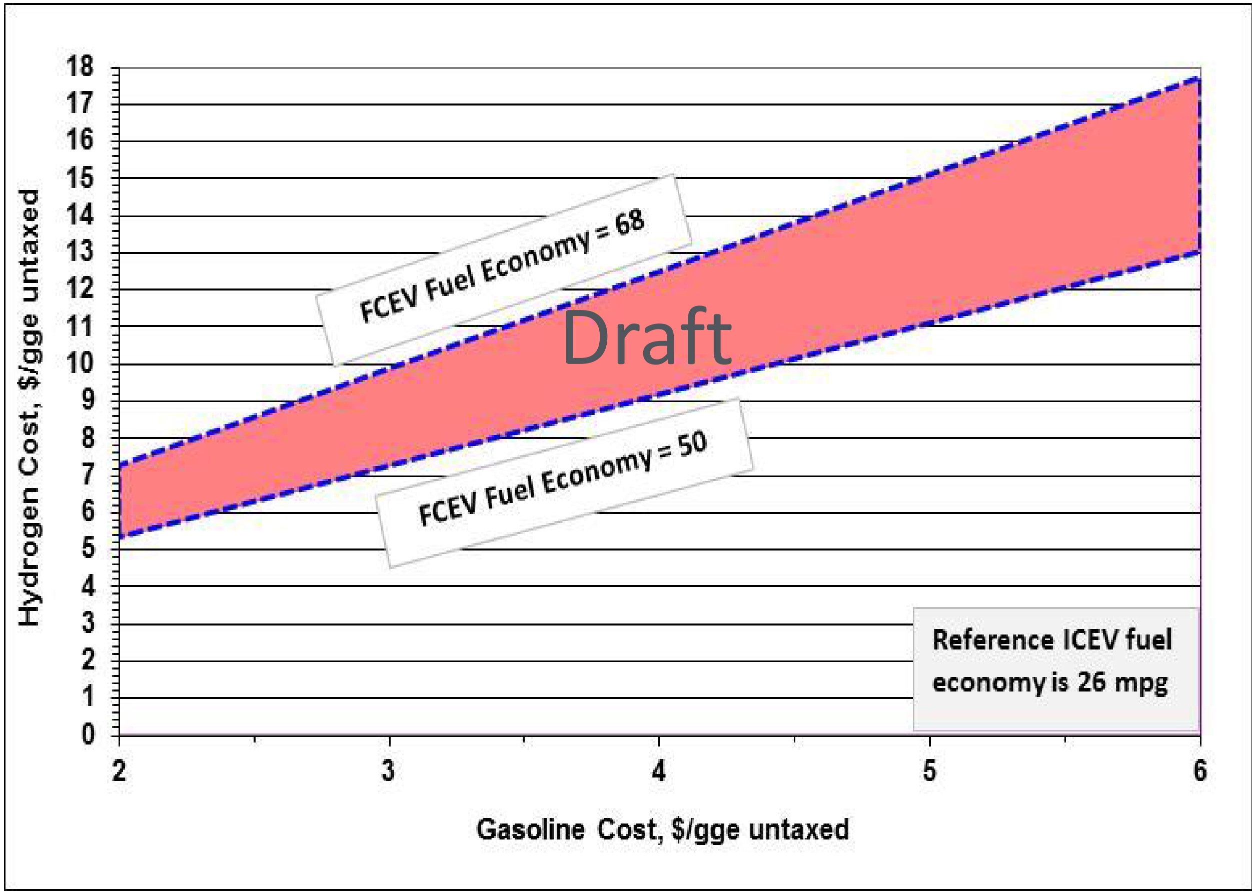
Interim H_2 Cost Target Analysis



H_2 would be competitive with gasoline at a cost of ~$7.00/gge in the early markets.

Interim H_2 Cost Target Methodology

- "top-down" analysis of the cost at which H_2 in the early market would be competitive.
- Target is pathway independent.
- Measure for assessing technology in regions of California and New York where early fuel cell electric vehicle penetration will occur
- FCEV is referenced to the gasoline ICE.



Establishing interim H_2 cost target for early market applications

SOFC Program – Industry Teams

➢ Current Status

- 20 to 60 kWe Stack Tests - Completed
  - Degradation rates of 1.0 to 1.5% per 1,000 hrs
  - Supplemental heating
  - TRL 5

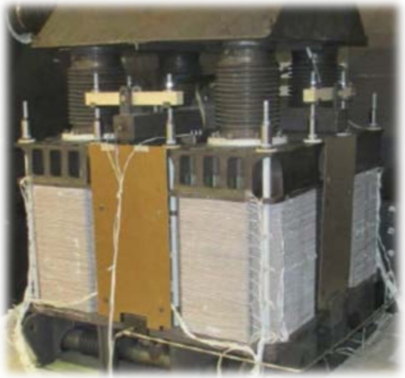
➢ In-progress

- 60 kWe-class Stack Tests
  - Thermally self-sustaining
  - Expected degradation rate <0.5% per 1,000 hrs
  - Planned operation ≥ 1,000 hrs
  - TRL 6

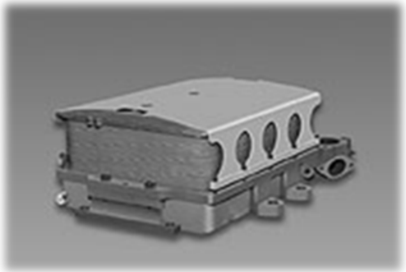
➢ Planned (Two new awards FY2014)

- 125 kWe-class System Tests
  - Thermally self-sustaining
  - PNG, AC to grid
  - Planned operation >2,500 hrs
  - Commercial-scale sub-systems
  - TRL 7

~20 kWe Stack
(~300 cells)
LGFCS



60 kWe Stack
(~400 cells)
FCE



7 kWe Gen 4 Stack
(38 cells)
Delphi

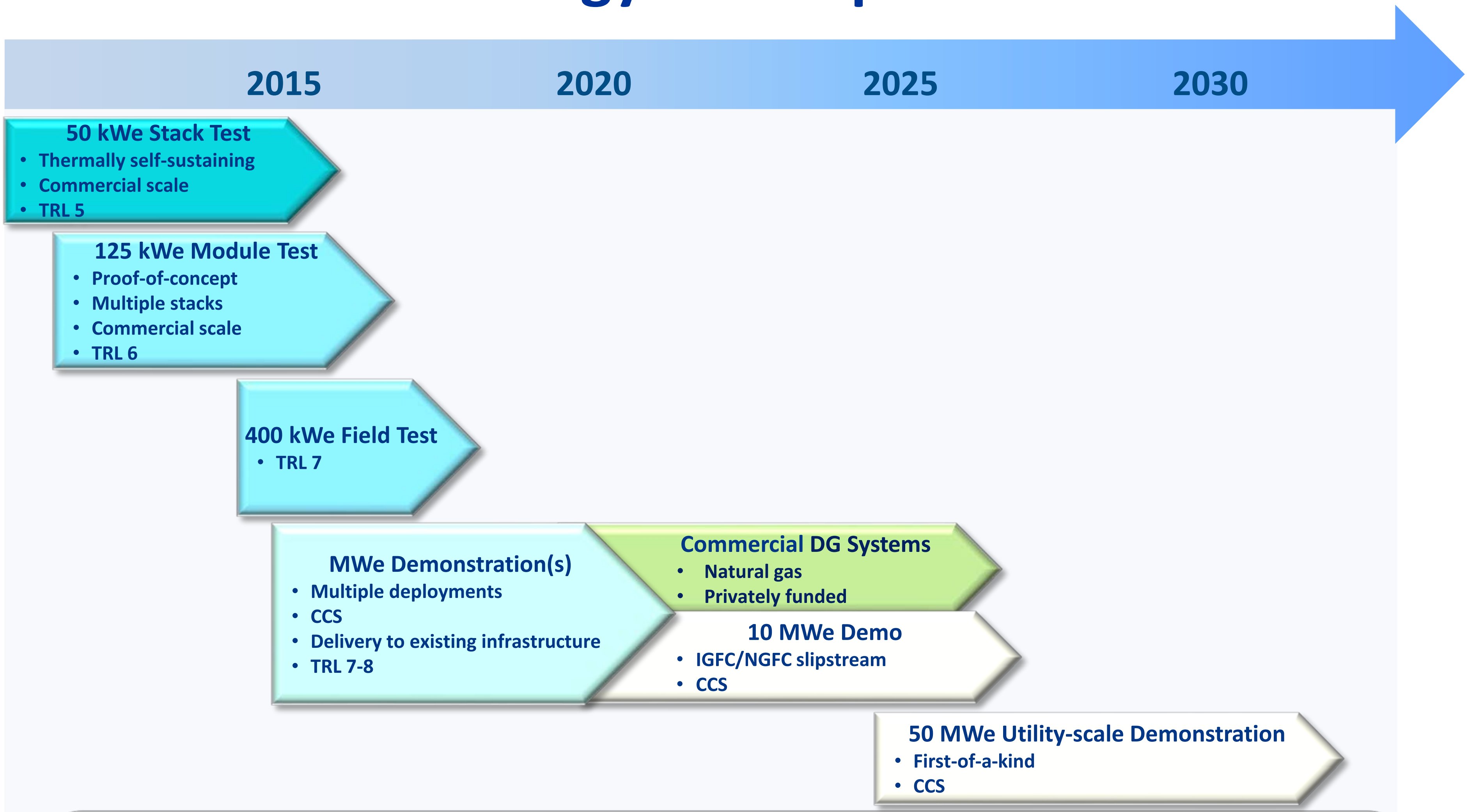
Industry Teams are validating stack technology through progressively larger stack and system tests

NETL

FY14 SOFC Program Update

- Two competitive solicitations
  - 11 projects selected
  - 2 Industry Teams, 9 Core Technology
- Increased emphasis on system level testing
- Increased emphasis on Industry Team – Core Technology collaboration
- Peer Review of 7 Projects
- Updated NETL and SOFC Program website
- Web-based SOFC Program Portfolio
- Three new SBIR projects

SOFC Technology Development Timeline



Natural gas fueled DG systems will establish the manufacturing and operational experience necessary to validate and advance the technology for both natural gas and gasified coal-based central power generation

NETL

SOFC Program - In Summary

- Emphasis on cost reduction and increased reliability
- Focused on system-level testing
- Facilitating Industry Team - Core Technology collaboration
- Taking advantage of revolutionary advances in materials and manufacturing processes
- Issued an RFI on October 31, 2014 for a 400 kWe prototype system test – responses due November 28

A technically and economically viable SOFC system will create market-pull for natural gas distributed generation applications in the 2020 timeframe

Reliable Electricity Based on ELectrochemical Systems (REBELS)

Intermediate temperature operation enables load-following fuel cells for distributed generation applications and grid support

Nearer-term to market

Longer-term to market

FUEL CELL	FUEL CELL + BATTERY MODE	FUEL CELL + FUEL PRODUCTION
REDOX (Redox Power Systems, LLC)		
SAFCell		
Oak Ridge National Laboratory		
United Technologies Research Center		
	Si Energy Systems, LLC (An Allied Minds Company)	FuelCell Energy (Ultra-Clean, Efficient, Reliable Power)
Colorado School of Mines (Earth • Energy • Environment)		
	University of South Carolina	MSRI (Materials and Systems Research, Inc.)
parc (Palo Alto Research Center)		
Georgia Tech	UCLA	Argonne National Laboratory

Duration of stored energy →

Nanoframes with 3D Electrocatalytic Surfaces

Scientific Achievement

Nanoframe architecture with controlled surface structure, compositional profile and surfaces with three dimensional molecular accessibility

Significance and Impact

Superior electrocatalytic properties of highly crystalline multimetallic nanoscale materials

Research Details

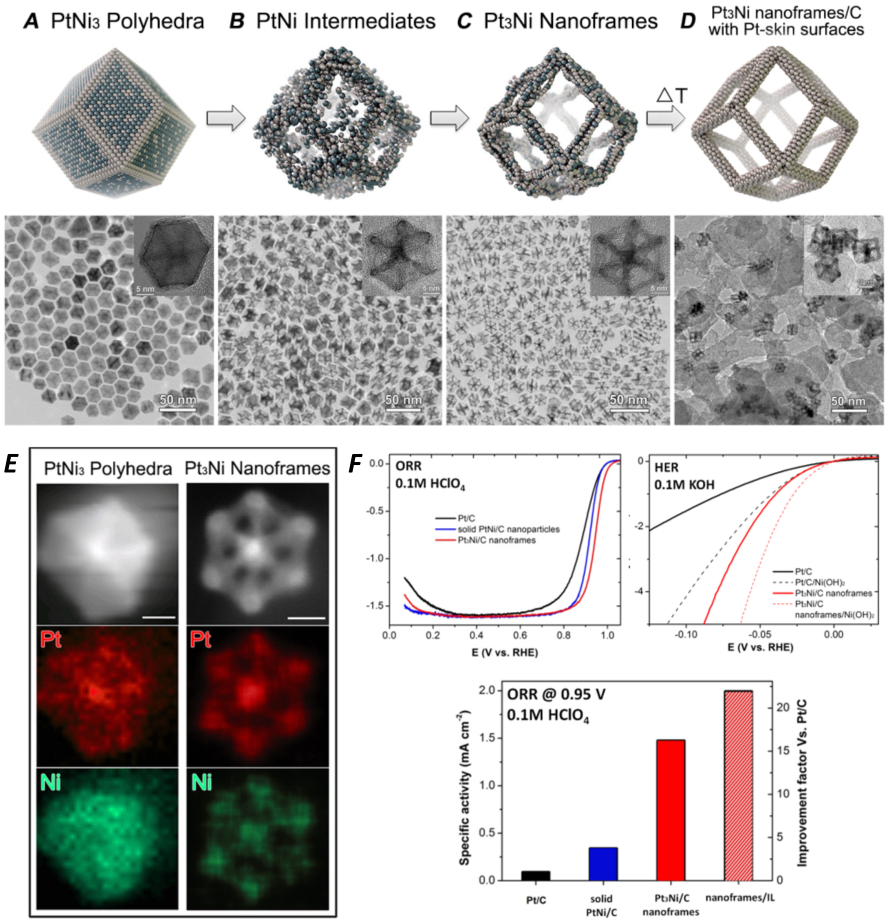
–Structural evolution from $PtNi_3$ solid bimetallic polyhedra to Pt_3Ni hollow nanoframes

–Surface is tuned to form desired Pt-Skin structure

–Superior catalytic activities for the oxygen reduction and hydrogen evolution reactions have been achieved for highly crystalline multimetallic nanoframes

–Collaborative effort between Lawrence Berkeley National Laboratory and Argonne National Laboratory

C. Chen et al., "Highly Crystalline Multimetallic Nanoframes with Three-Dimensional Electrocatalytic Surfaces", **Science** ***343***(2014) 1339-1343
DOI: 10.1126/science.1249061



Multimetallic nanoframes with 3D surfaces:
Structural evolution of nanoparticles from: **(A)** polyhedra, **(B)** intermediates, **(C)** nanoframes and **(D)** nanoframes with multilayered Pt-Skin structure; **(E)** elemental mapping and **(F)** superior electrochemical activities for ORR and HER

U.S. DEPARTMENT OF ENERGY | Office of Science

Work was performed at Lawrence Berkeley and Argonne National Laboratories

BERKELEY LAB | Argonne NATIONAL LABORATORY

Leaky TiO_2-stabilized Photoanodes for Solar Fuel Production

Scientific Achievement

JCAP researchers devised a new method to protect common semiconductors from corrosion in basic aqueous solutions, while still maintaining excellent electrical charge conduction to the surface.

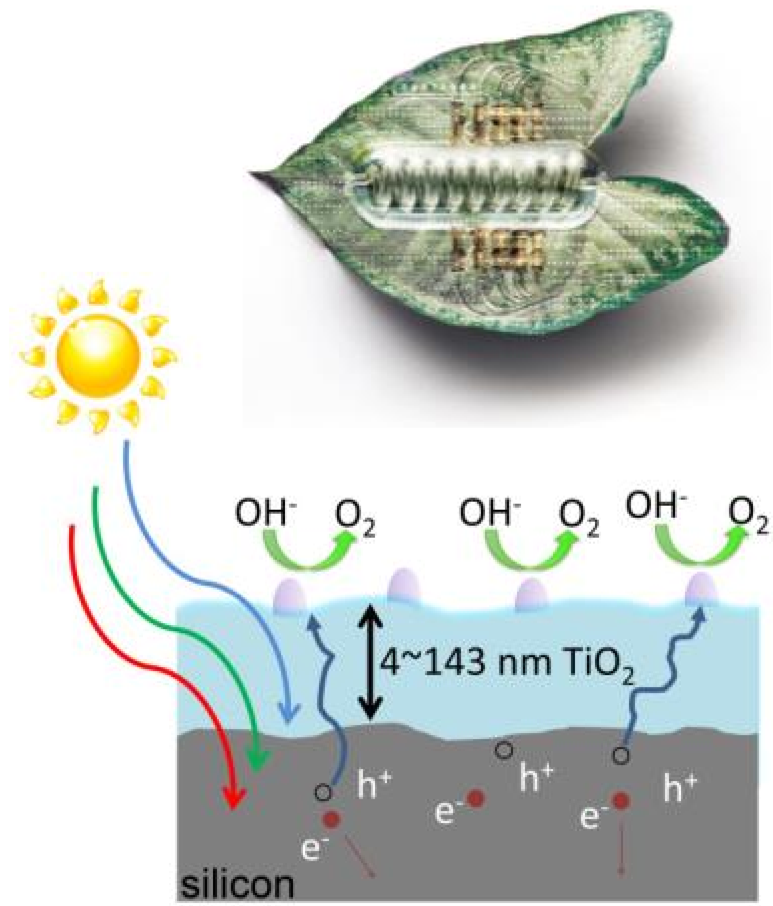
Significance and Impact

Highly light-absorbing semiconductors like silicon and gallium arsenide, which corrode when unprotected, can now be incorporated in photoanodes for solar fuel generators.

Research Details

– Semiconductors are protected by an electronically defective layer of ~100 nm thick, unannealed TiO_2 using atomic layer deposition

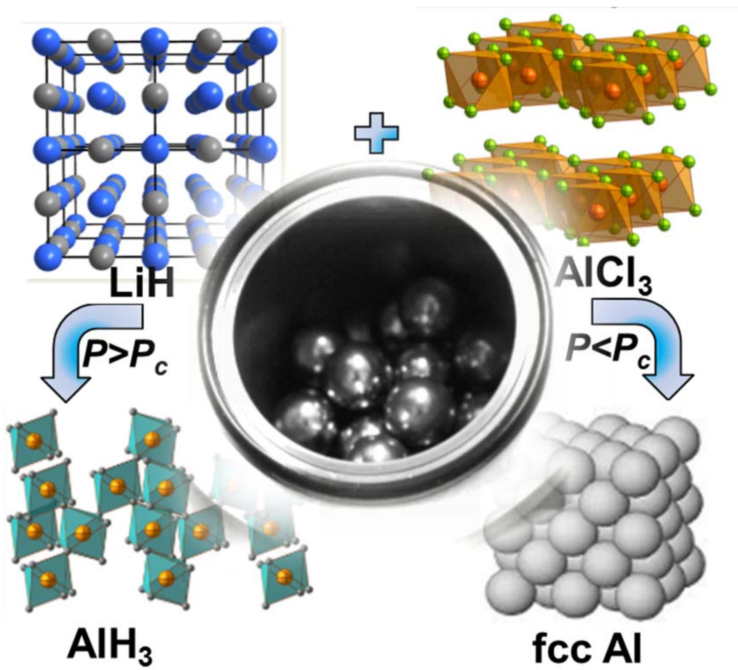
– In conjunction with islands of nickel oxide electrocatalysts, protected Si can continuously and stably oxidize water for over 100 hours at photocurrents of >30 mA cm^{-2} under 1-sun illumination



Photoanode stabilized against corrosion in an aqueous KOH electrolyte by a thick, electronically defective layer of unannealed TiO_2 produced by atomic layer deposition.

Hu, S., *et. al*, *Science*, 344, 1005-1009 (2014). DOI: 10.1126/science.1251428

Mechanochemical preparation of Alane (AlH_3): Exploiting the non-equilibrium pathways



Ball-milling LiH and $AlCl_3$ at pressures (P) exceeding a critical pressure (P_c) leads to the formation of AlH_3

Ball-milling LiH with $AlCl_3$ at pressures below P_c leads to conversion of nearly all aluminum to the metal

I.Z. Hlova, S.Gupta, J.F.Goldston, T.Kobayashi, M.Pruski and V.K.Pecharsky, "Dry Mechanochemical Synthesis of Alane from LiH and $AlCl_3$" *Faraday Discuss.*, 2014, DOI: 10.1039/C3FD00161J

Work was performed at Ames Laboratory, Iowa State University.

Scientific Achievement

A successful strategy for the solvent-free, room temperature mechanochemical synthesis of AlH_3 via a solid state metathesis reaction of LiH and $AlCl_3$ has been developed.

Significance and Impact

The course of mechanochemical reactions and, hence, the final products can be controlled by gradual addition of reactants and gas pressure, thus opening up possibilities to access new materials by mechanochemistry.

Research Details

- **By adding $AlCl_3$ to LiH in three steps and applying gas pressure, quantitative yield of AlH_3 – an important energetic material – has been achieved.**
- **Using x-ray diffraction, solid state NMR, and temperature programmed desorption analyses established the mechanism of mechanochemical transformation: $3LiH + AlCl_3 \rightarrow 3LiCl + AlH_3$.**