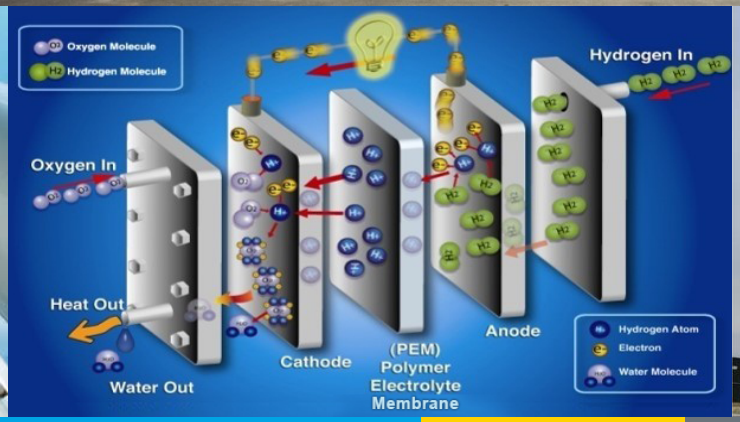
U.S. Department of Energy
Fuel Cell Technologies Office

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



Hydrogen and Fuel Cells Overview

Washington, DC

April 21, 2016

Dr. Sunita Satyapal

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

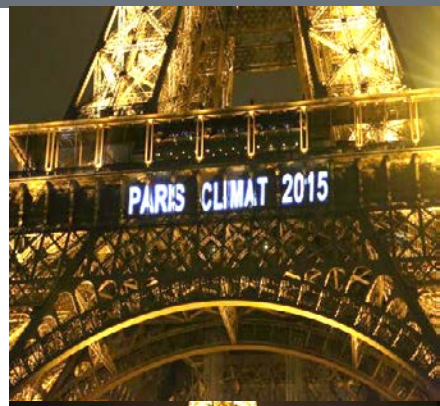
Real Climate Change Impact Requires

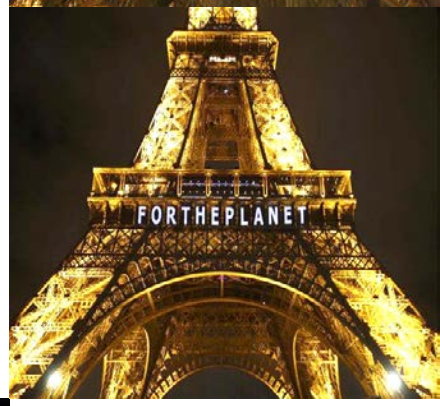
Deep Decarbonization

Key Driver- Paris Agreement at COP 21

"Let that be the common purpose here in Paris. A world that is worthy of our children. A world that is marked not by conflict, but **by cooperation**; and not by human suffering, but by human progress. A world that's safer, and more prosperous, and more secure, and more free than the one that we inherited. **Let's get to work**."

- President Barack Obama at the launch of COP21





PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

Oil Dependency is Dominated by Vehicles

- Transportation is responsible for **66%** of U.S. petroleum usage
- **27%** of GHG emissions
- On-Road vehicles responsible for **85%** of transportation petroleum usage

- **16.0M LDVs** sold in 2014.
- **240 million light-duty vehicles** on the road in the U.S
- **10-15 years** for annual sales penetration
- **10-15 years** to turn over fleet

Poses significant economic, energy and environmental risks to U.S.

Photos courtesy of Spc. Jordan Huettl, U.S. Army; U.S. Environmental Protection Agency; and M. Studinger, NASA

It takes decades of sustained effort to turn over the fleet

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

Photo Credit: Office of Prime Minister of Japan and His Cabinet

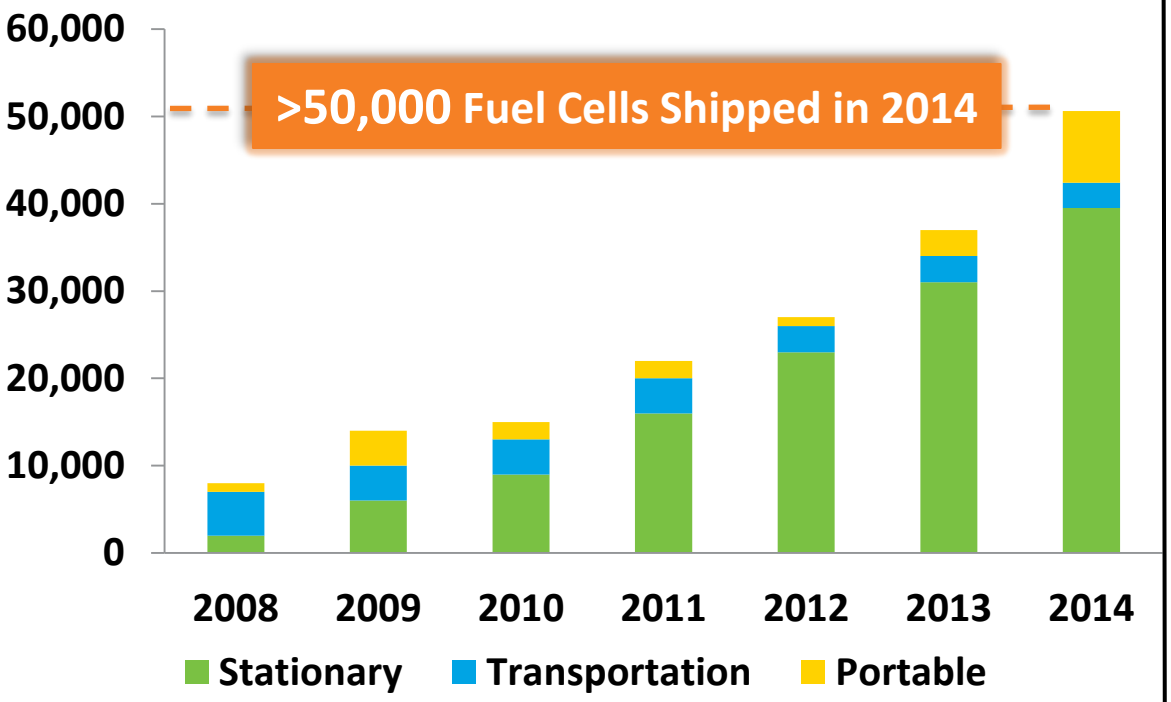

Photo Credit: Office of Prime Minister of Japan and His Cabinet

Iwatani Hydrogen Fueling Station Opening with Japan's Prime Minister (Apr, 2015)

1st station in the heart of Tokyo

Fuel Cells Market Overview

Fuel Cell Systems Shipped Worldwide by Application



Source: Navigant Research (2008-2013) & E4tech (2014)

- Consistent **~30% annual growth** since 2010
- Global Market Potential in 10- 20 years*

$14B – $31B/yr for stationary power
$11B /yr for portable power
$18B – $97B/yr for transportation

*Fuel Cell Economic Development Plan, Connecticut Center for Advanced Technology, Inc. January 2008

Fuel Cell Electric Vehicles (FCEVs) are here

Honda Clarity Fuel Cell Vehicle

DOE Activities Span from R&D to Deployment

1. Research & Development

Fuel Cells

- >50% decrease in cost since 2006
- 5X less platinum used
- >4X increase in durability

$124/kW in 2006

$53/kW in 2015* at high volume

*$280/kW low volume

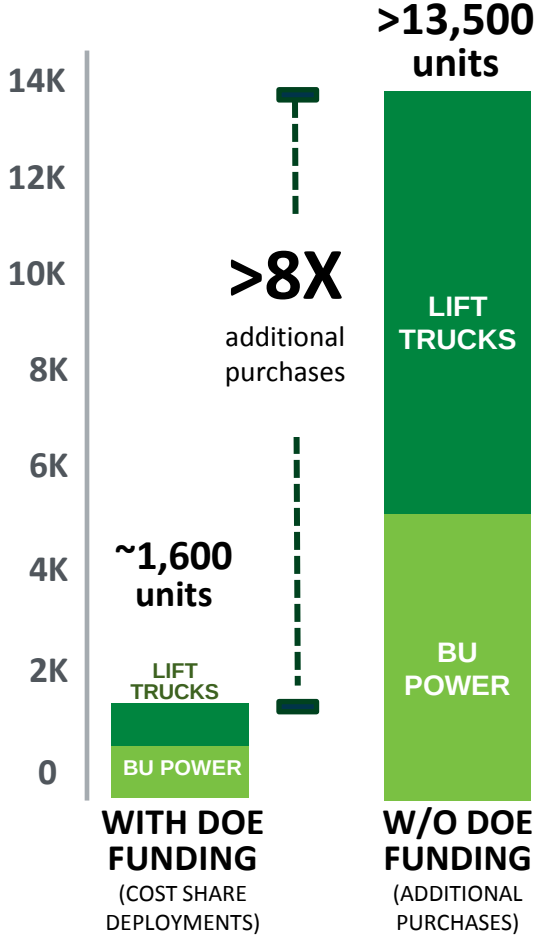
2. Demonstration

Forklifts, back-up power, airport cargo trucks, parcel delivery vans, marine APUs, buses, mobile lighting, refuse trucks

>220 FCEVs, 30 stations, 6M miles traveled

World's first tri-gen station

3. Deployment



BU: Back Up Power

H_2USA: Public-Private Partnership

H_2 USA

Partners

~ 45 Partners in 2015

Mission

To address hurdles to **establishing hydrogen fueling infrastructure**, enabling the **large scale adoption of fuel cell electric vehicles**

Structure

4 Working Groups coordinated by the **Operations** Steering Committee

H_2FIRST Coordination panel

H_2FIRST

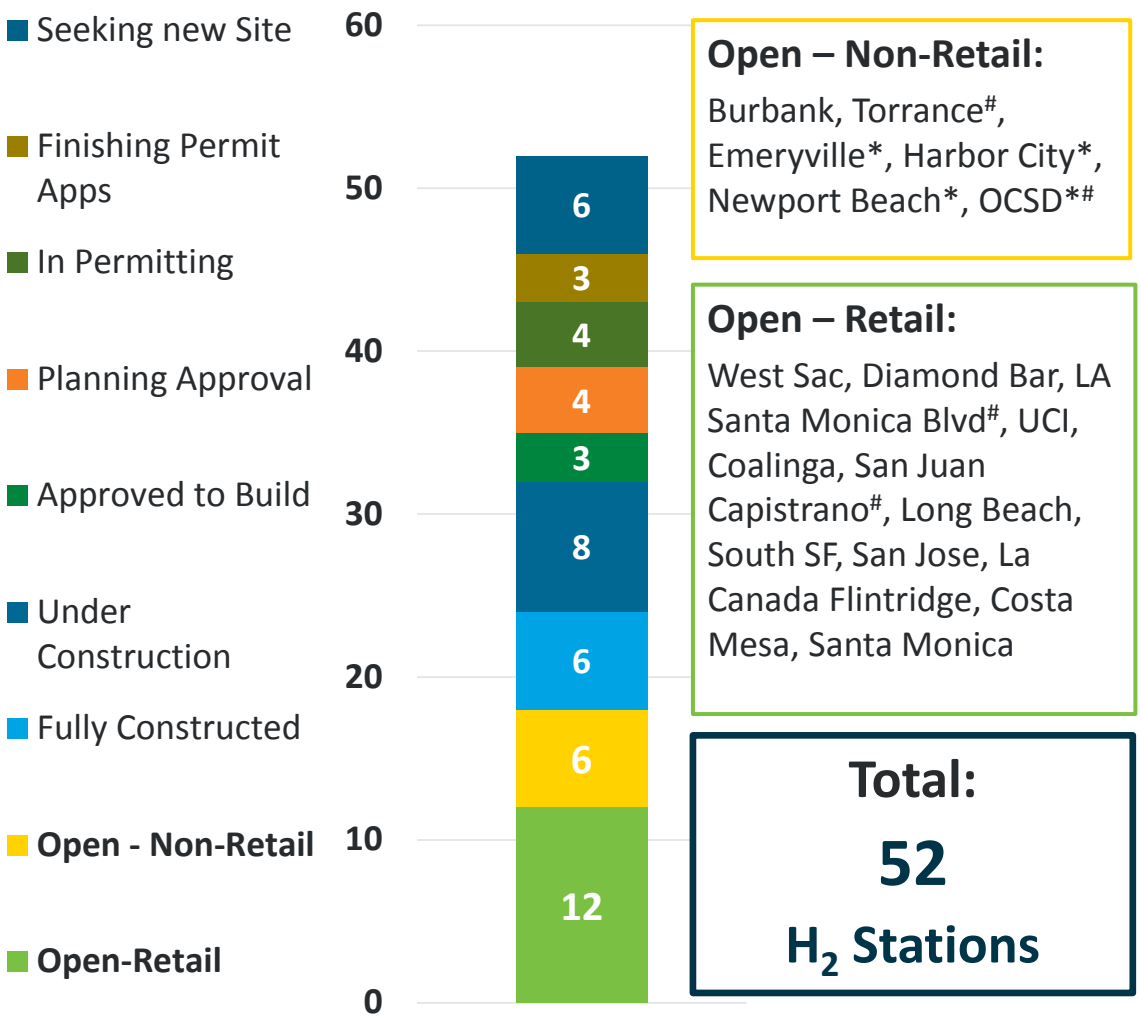
H_2USA's Working Groups

- **Hydrogen Fueling Station**
- **Locations Roadmap**
- **Financing Infrastructure**
- **Market Support & Acceleration**

More than 45 partners- Visit www.H2USA.org

Example: California- H_2 Station Status

Snapshot of Status



Open – Non-Retail:

Burbank, Torrance#, Emeryville*, Harbor City*, Newport Beach*, OCSD*#

Open – Retail:

West Sac, Diamond Bar, LA Santa Monica Blvd#, UCI, Coalinga, San Juan Capistrano#, Long Beach, South SF, San Jose, La Canada Flintridge, Costa Mesa, Santa Monica

Total:

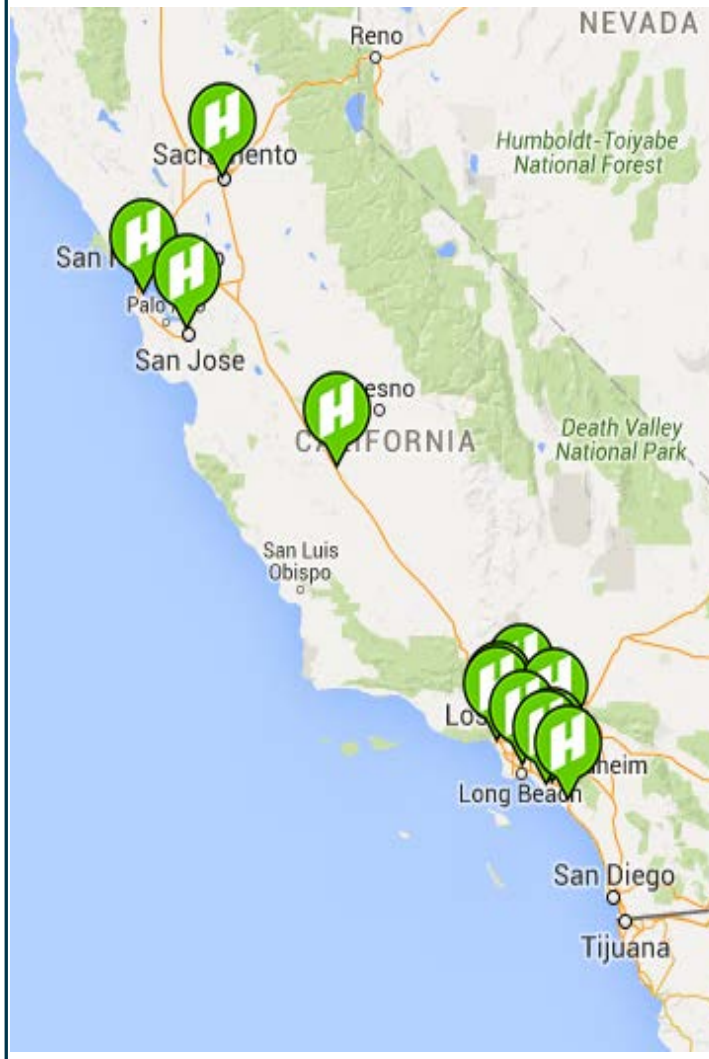
52

H_2 Stations

As of February 25, 2016 (Data from CARB). * Stations in need of extension or upgrade

Currently Torrance (H70 only), Santa Monica, San Juan Capistrano, and OCSD are offline (01/15/16 CaFCP SOSS)

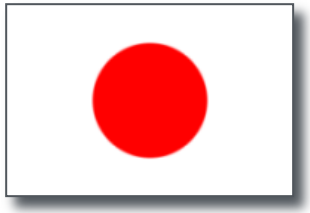
Locations



Green icons indicate Open Retail Stations

Global Infrastructure Activities

Japan



- **FCEVs: 40K by 2020, 200K by 2025 and 800K by 2030**
- **H_2 Stations: 160 by 2020, 320 by 2025 and 900 by 2030**

United States

- **FCEVs: 8 States committed to 3.3M ZEVs by 2025,** FCEVs currently available for sale and lease in CA
- **H_2 Stations: 100, ~$100M** through 2023 in CA

Denmark, Norway and Sweden

Scandinavian H_2 Highway Partnership (SHHP)

United Kingdom

UKH_2Mobility

Germany

H_2Mobility

International partnerships established to accelerate hydrogen infrastructure

Examples: US-Japan Collaboration on H_2 and Fuel Cells

- **Technology and Safety Data Sharing**

Example: Sources of H_2 Infrastructure Maintenance (out of 5,531 events)

Collaborations with:

FCEV Performance Data:

HONDA NISSAN TOYOTA

Safety & Reliability Data:

HySUT IPHE International Partnership for Hydrogen and Fuel Cells in the Economy

- **Implementing agreements** through the International Energy Agency (IEA)

iea International Energy Agency

- **Joint Research** on H_2 safety codes and standards

AIST National Institute of Advanced Industrial Science and Technology (AIST)

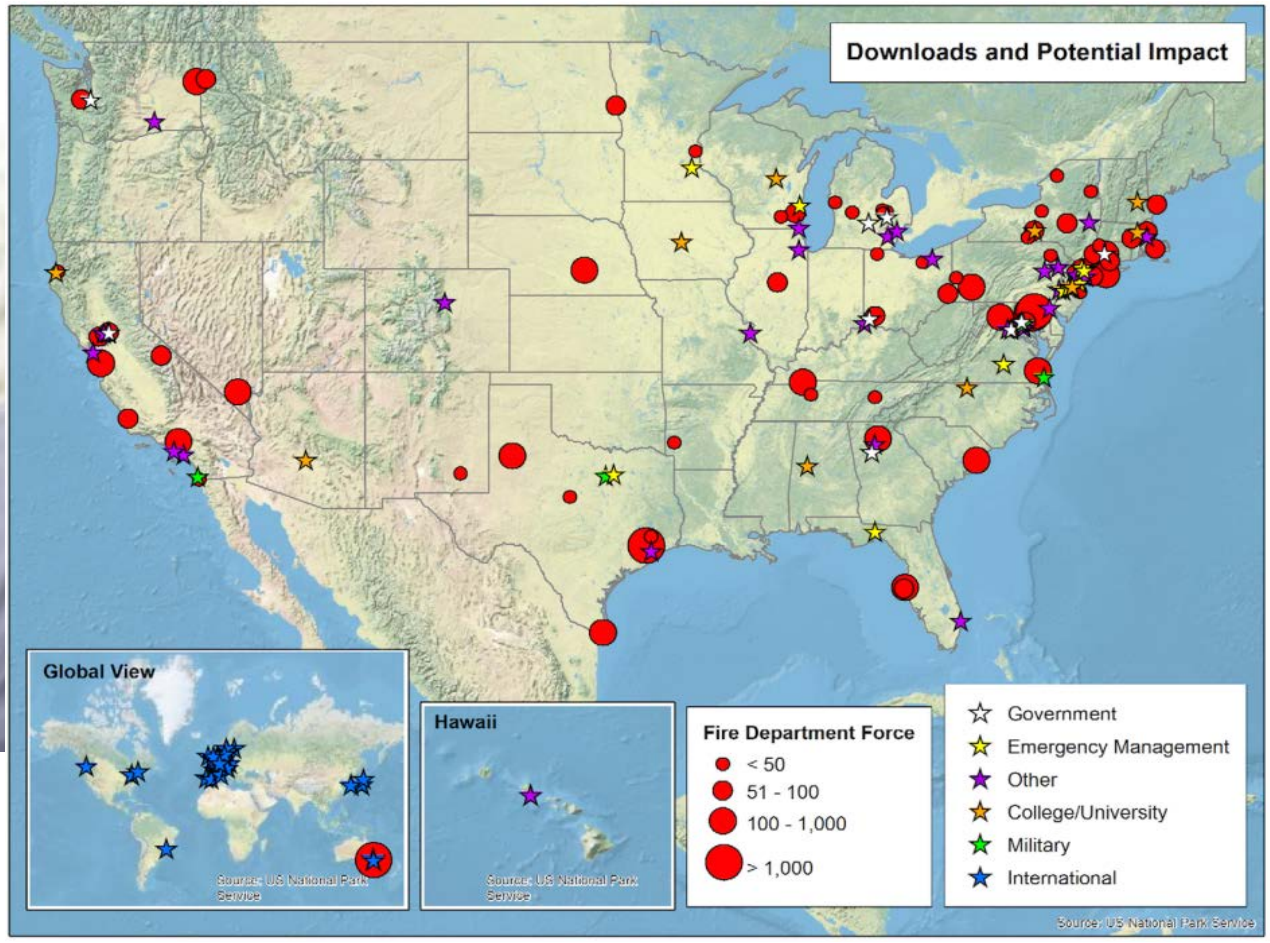
Sandia National Laboratories

I²CNER

ILLINOIS University of Illinois at Urbana-Champaign

H_2Tools: One-stop for H_2 safety knowledge

- Includes resources on **safety** best practices, **first responder training**, and **H_2 codes & standards**



- Tracked downloads from **Europe and Japan**
- Resource **translated in Japanese**
- **50%** of visits are **international!**

Enabling dissemination of safety information around the world

Japan- US Collaboration in Action!

20th Steering Committee Meeting City of Fukuoka, Japan *(left)*

2015 US DOE Annual Merit Review (AMR) Washington D.C. , USA *(lower left)*

2015 FC Expo Tokyo, Japan *(lower right)*

International Partnership

International Partnership for Hydrogen and Fuel Cells in the Economy

IPHE is an Inter-Governmental Partnership to

- **Share policy** information on H_2 and fuel cells
- **Increase** international **collaboration**
- **Share information** and lessons learned

Recent and Upcoming IPHE Events

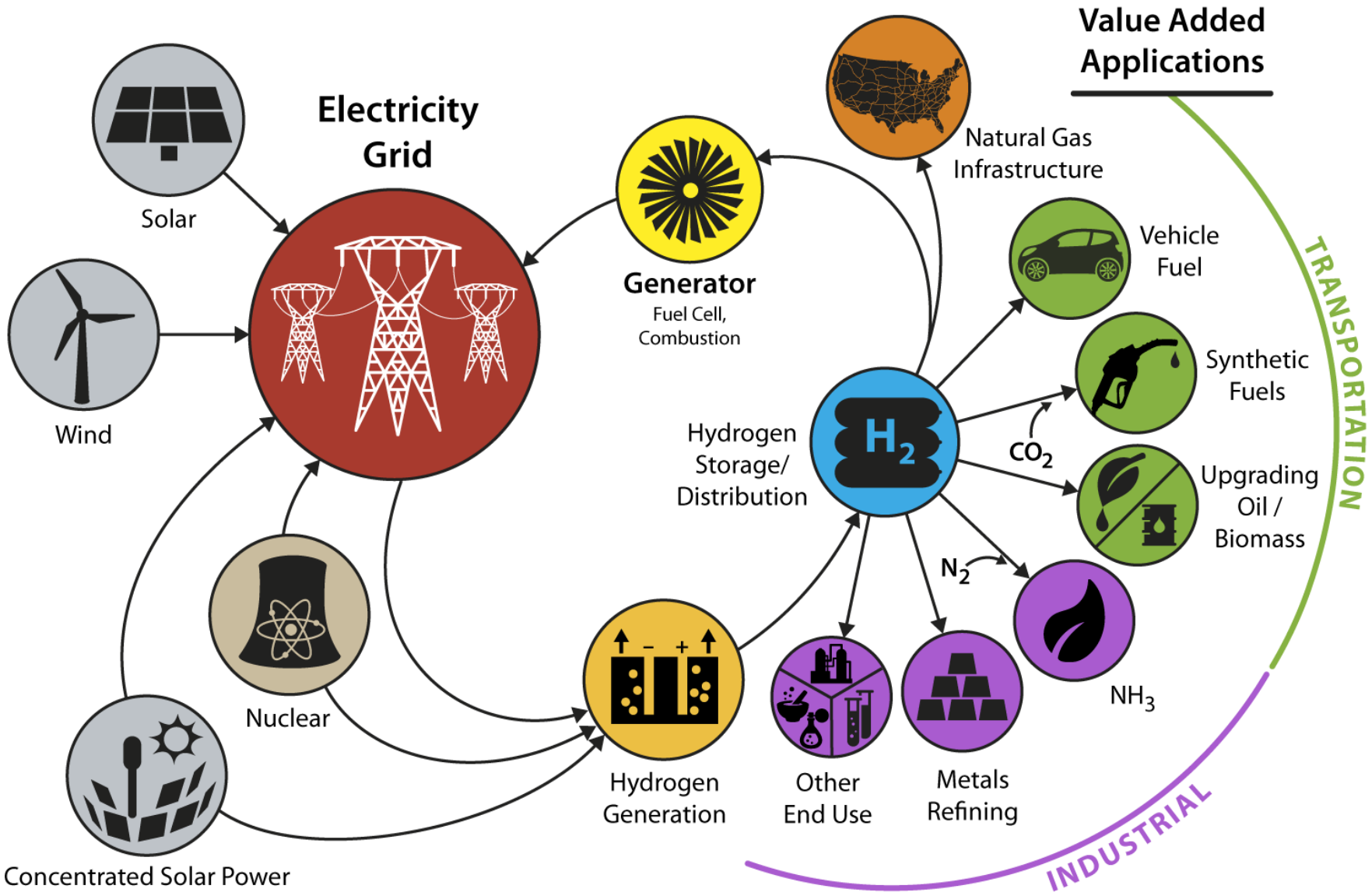
- 24th IPHE Steering Committee Dec 2015, in Grenoble France
- New: **May 20th- IPHE Stakeholder-Govt Dialogue, California**

18 members working together to advance hydrogen and fuel cell technologies

- Australia
- Austria
- Brazil
- Canada
- China
- European Commission
- France
- Germany
- Iceland
- India
- Italy
- Japan
- Republic of Korea
- Norway
- Russian Federation
- South Africa
- United Kingdom
- United States

Visit www.iphe.net for more information

H_2 at Scale Energy System



*Illustrative example, not comprehensive
Source: NREL

H_2 @ Scale Potential:

A CLEANER FUTURE

50% fewer GHG emissions than today by 2050

Reduction by Sector

75%
Grid

25%
Transportation

25%
Industrial

& MORE

Jobs
Security
Resiliency

The hardest problems of pure and applied science can only be solved by the open collaboration of the world-wide scientific community

Kenneth G. Wilson

Nobel Prize, 1982 in Physics

Thank You

Dr. Sunita Satyapal

Director

Fuel Cell Technologies Office

Sunita.Satyapal@ee.doe.gov

hydrogenandfuelcells.energy.gov

FCEV Ride-n-Drive at DOE Headquarters

Watch Secretary Moniz driving the Mirai!
http://energy.gov/eere/fuelcells/test-driving-toyota-mirai

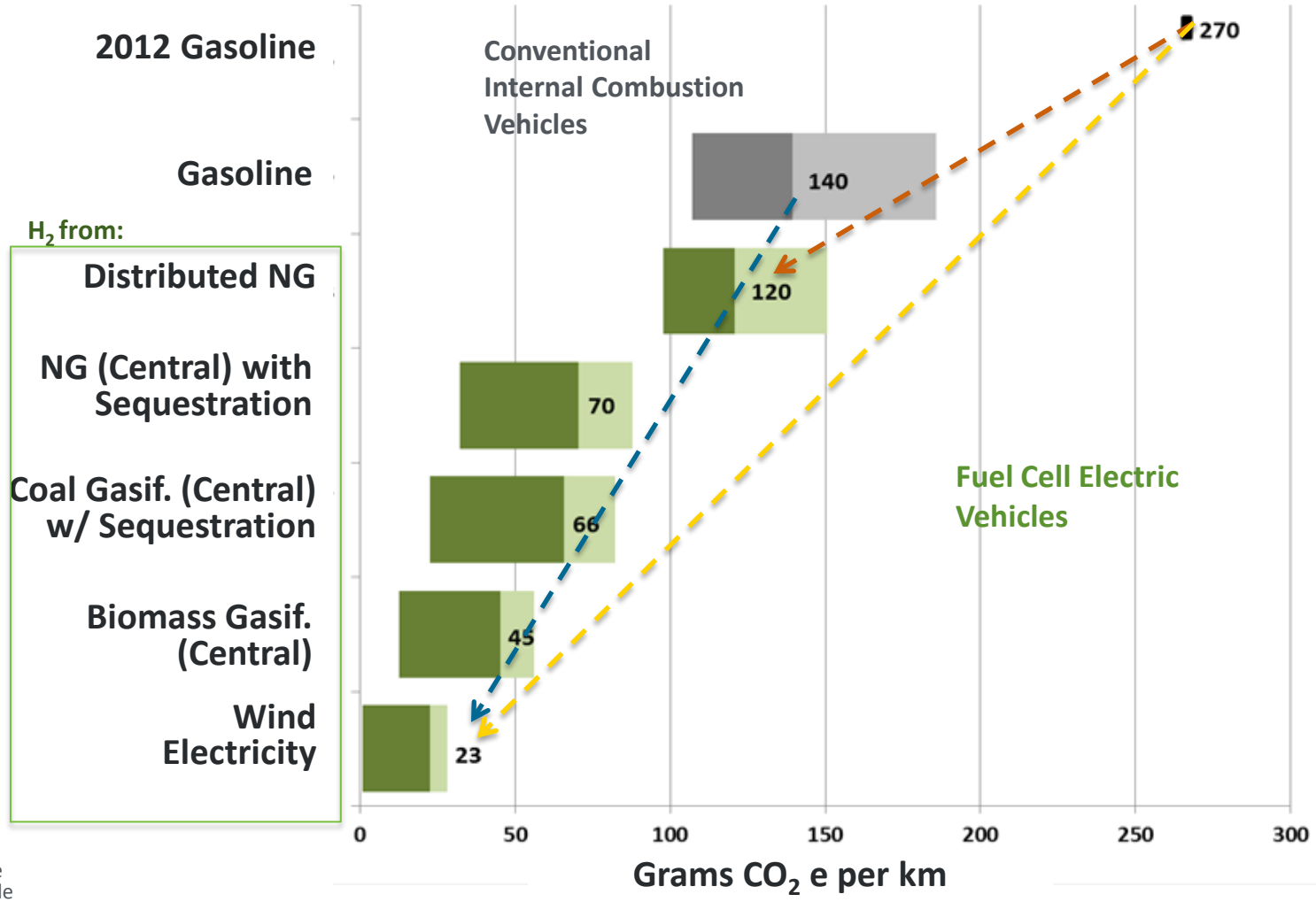
FCEVs Reduce Greenhouse Gas Emissions

>50% from Distributed Natural Gas*

>80% from Renewables** (Wind)

>90% from Renewables* (Wind)

Well-to-Wheels CO_2 Emissions (in grams per km) **for 2035 Vehicles Technologies,** *except were indicated*



*Compared to 2012 gasoline vehicle
**Compared to 2035 gasoline vehicle

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

Substantial GHG reductions with H_2 produced from renewables

“It is the long history of humankind (and animal kind, too) those who learned to collaborate and improvise most effectively have prevailed”

- Charles Darwin

Outreach and Communication Efforts

- **Publications- ~100/yr**
  - Monthly Newsletter
  - Success Stories
  - News Alerts, Blogs
- **Educated:**
  - **>12,000** teachers
  - **>35,000** code officials & first responders
- **Investor Days**
- **Congressional Caucus Events**
- **Annual Merit Review**

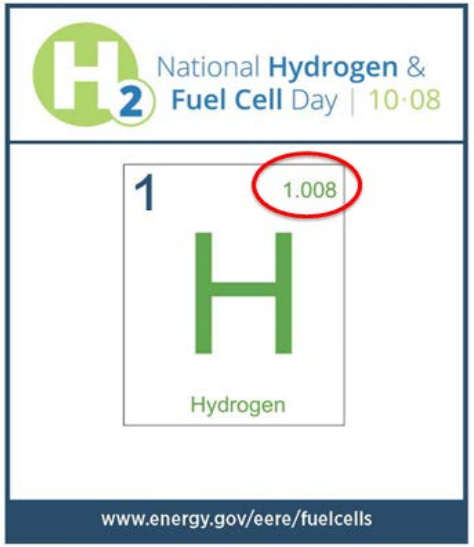
  June 2015- >1,800 attendees

- **Ride & Drives**

U.S Department of Energy Secretary Ernest Moniz test driving the Toyota Mirai

- **Events**

2015: 1st year the U.S. **to celebrate Hydrogen and Fuel Cells Day**

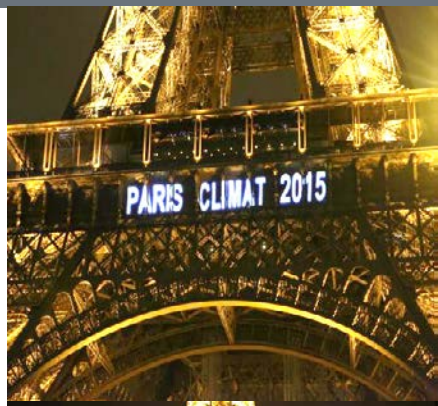


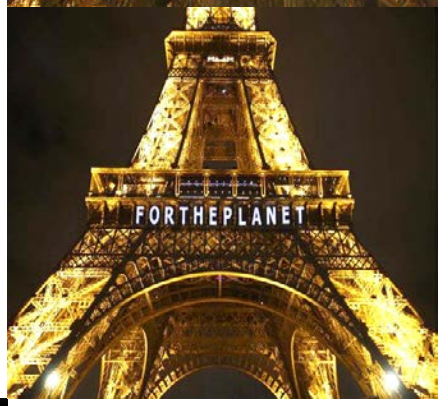
Increasing public awareness and understanding about fuel cells and H_2

Key Driver- Paris Agreement at COP 21

"Let that be the common purpose here in Paris. A world that is worthy of our children. A world that is marked not by conflict, but **by cooperation**; and not by human suffering, but by human progress. A world that's safer, and more prosperous, and more secure, and more free than the one that we inherited. **Let's get to work**."

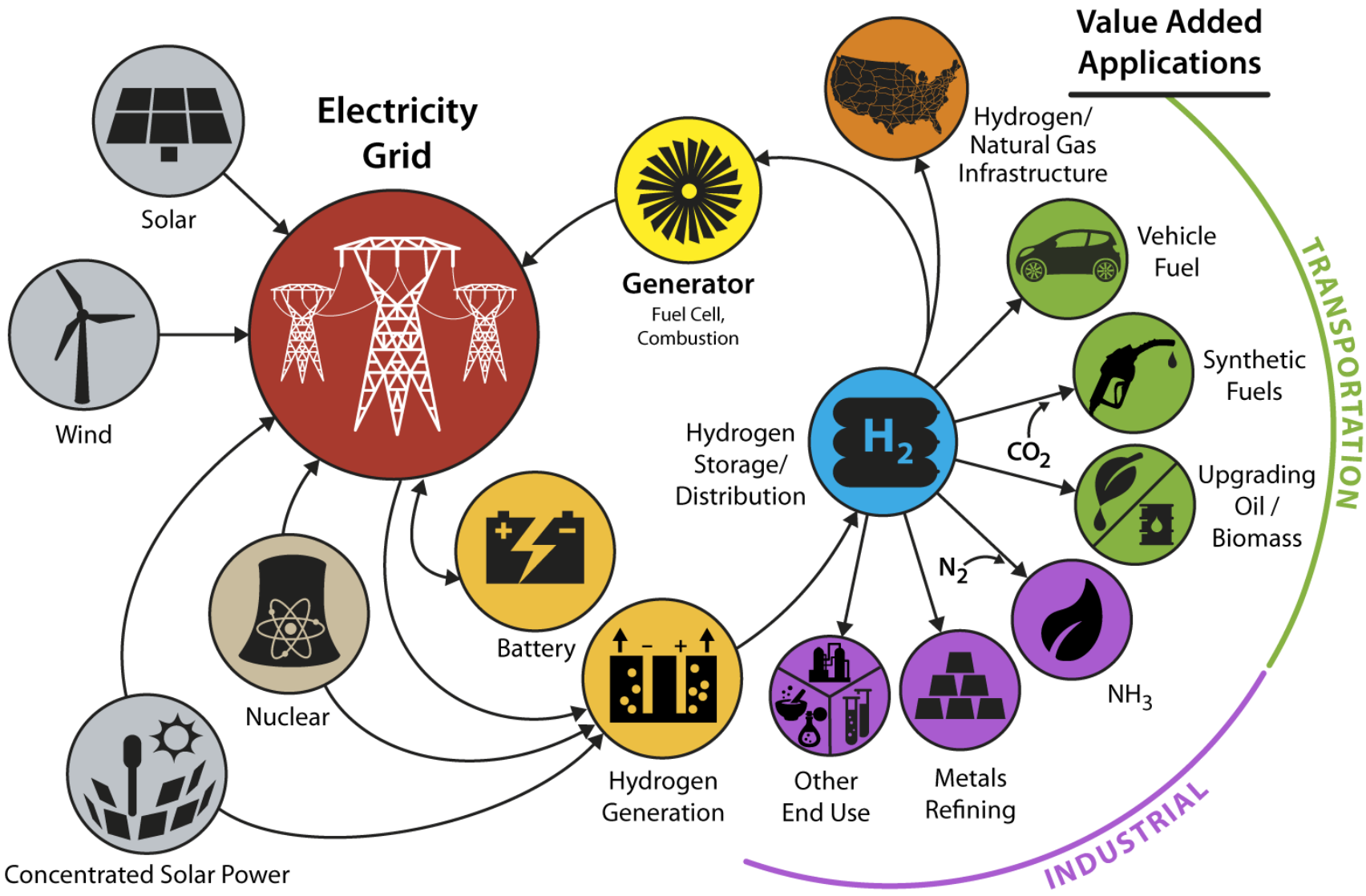
- President Barack Obama at the launch of COP21



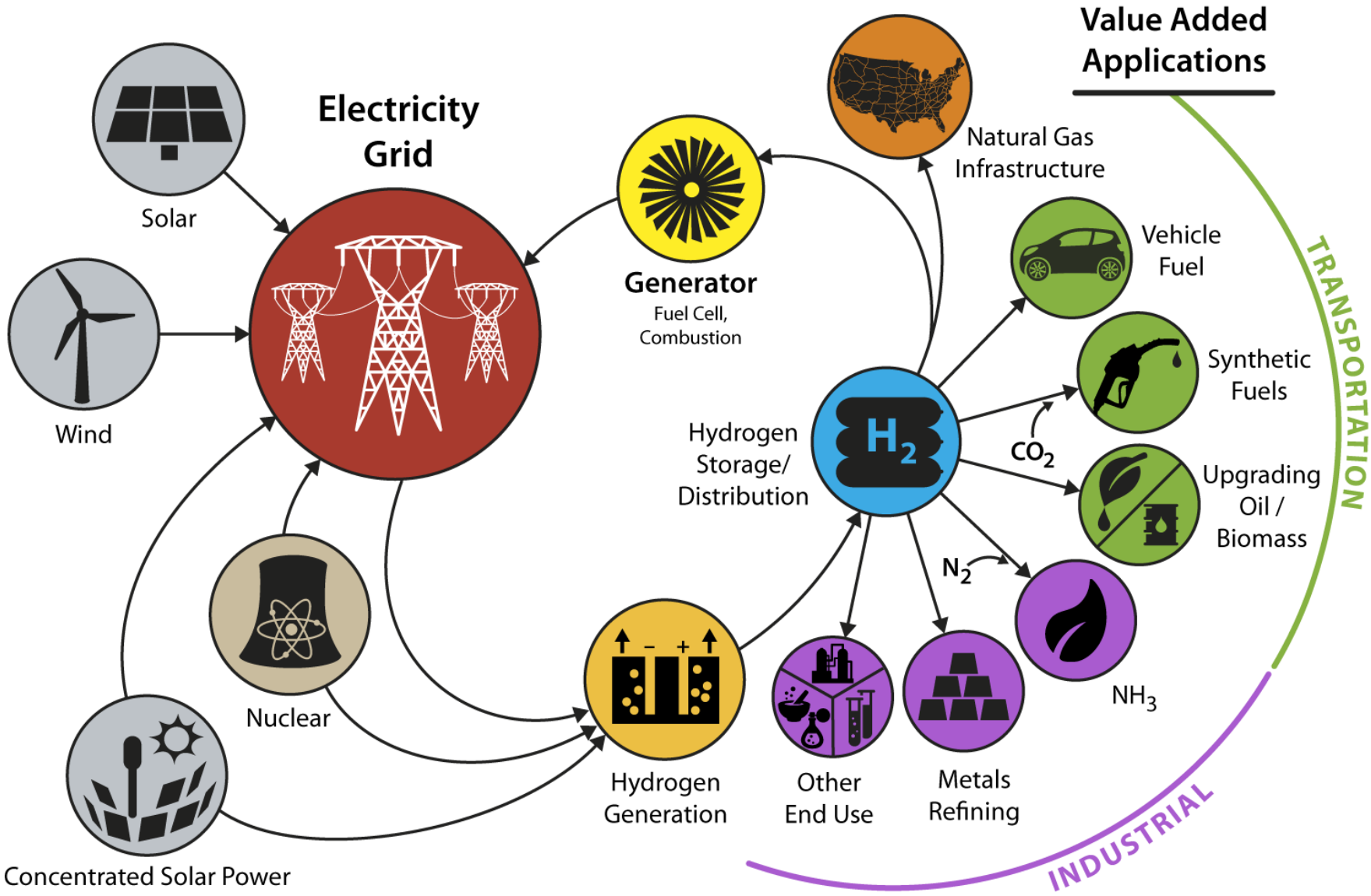


PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

H_2 at Scale as Key Part of Solution



H_2 at Scale as Key Part of Solution



Lab Consortia Approach

Activities

Consortia Core

- **Fuel Cells: FC-PAD** (Fuel Cell Performance and Durability)
- **Storage: HyMARC** (Hydrogen Storage Materials Advanced Research Consortium)
- **ElectroCat (launched)**
- **Renewable H2 Production (planned)**

Projects added through FOAs

- Companies, universities, labs
- 2-4 yrs/project
- May include seedling projects

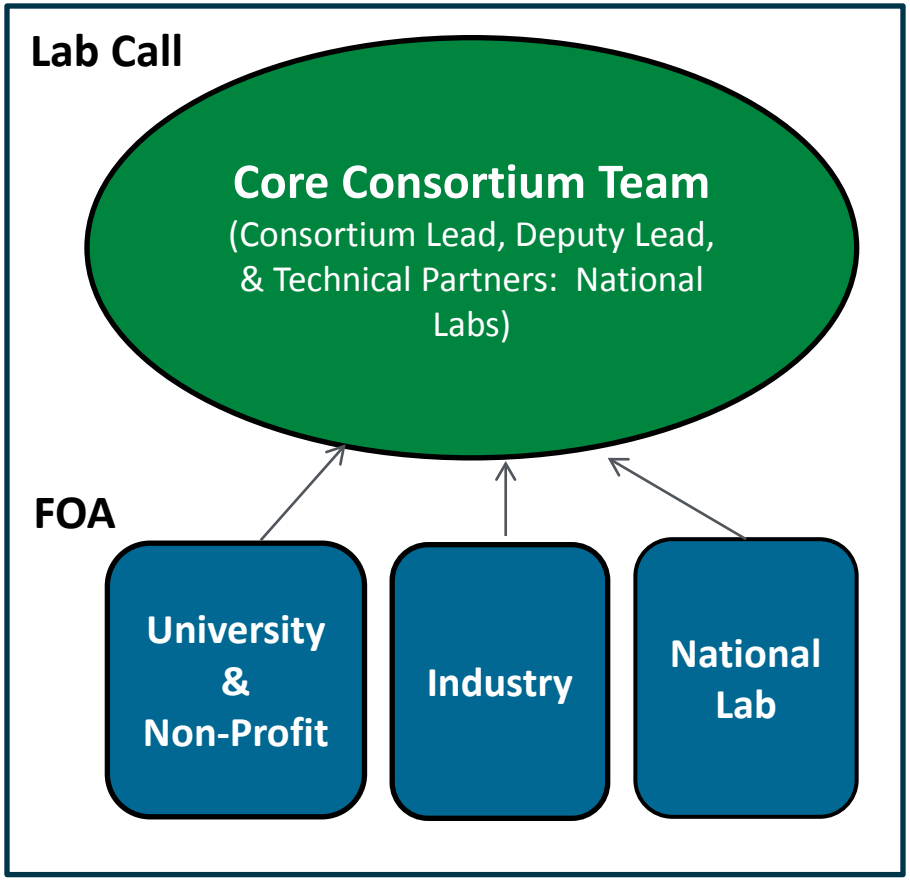
* Subject to appropriations

Potential Future Collaborations

Relevant Offices and other Agencies (e.g. Office of Science , Advanced Manufacturing Office, etc.)

Strategy and Structure

Multi-Lab team with Lab Call to competitively select core team



IPHE 24th Steering Committee Meeting- Grenoble, France

Going Forward

- **R&D and accelerate Tech to Market (Lab impact)**
  - **Key Focus: Renewable H_2**
  - **Consortia, high throughput materials, safety, fuel cells, H_2**
- **Strategic, selective demonstrations**
- **Key analyses to guide RD&D and path forward**
  - **Life cycle cost; infrastructure, economic & environmental analyses, sustainable pathways, etc.**
- **Leverage activities to maximize impact**
  - **U.S. and global partnerships, H_2USA, States**

Save the date: Annual Merit Review (AMR)

June 6-10, 2016- Washington DC

Hydrogen Fueling Infrastructure Research Station Technology

Leveraging Expertise of National Labs

H_2FIRST In support of

H_2 USA and tasked to deliver:

NREL NATIONAL RENEWABLE ENERGY LABORATORY & Sandia National Laboratories

Outstanding Partnership Award

By the Federal Laboratory Consortium (FLC) for efforts toward deployment of hydrogen fueling infrastructure

Reference Station Design

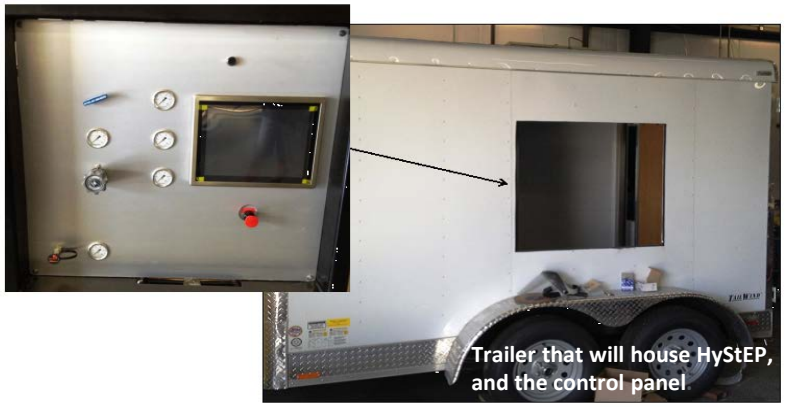
- ✓ Report Delivered with Detailed Station Designs and Cost Estimates

Fuel Contaminant Detection

- ✓ Market Survey and Gap Analysis Complete

HyStEP (H_2 Station Equipment Performance Device)

- ✓ Design Complete
- ✓ Testing Complete



DOE's H_2FIRST project supports H2USA goals to address infrastructure

FCEVs are on U.S. Roads Now!


Toyota Mirai Fuel Cell Vehicle

Available for Commercial Sale

- **$57,500 MSRP**
- 67 mi/gge
- 312 mi range, ~5 min refuel
- 114 kW stack
- US:200 2015, 3000 by 2017


Hyundai Tucson Fuel Cell SUV

Available for Lease

- **$499/month lease**
- 50 mi/gge
- 265 mi range
- 100 kW stack
- US: 70 thru May ‘15 (237 overall)

Honda Clarity Fuel Cell Vehicle

Just Announced at Auto Shows

- **$60,000 MSRP**
- **$500/month lease** for initial launch
- +300 mi range*
- 100 kW stack
- Initial launch planned for late 2016

*Preliminary range estimate determined by Honda

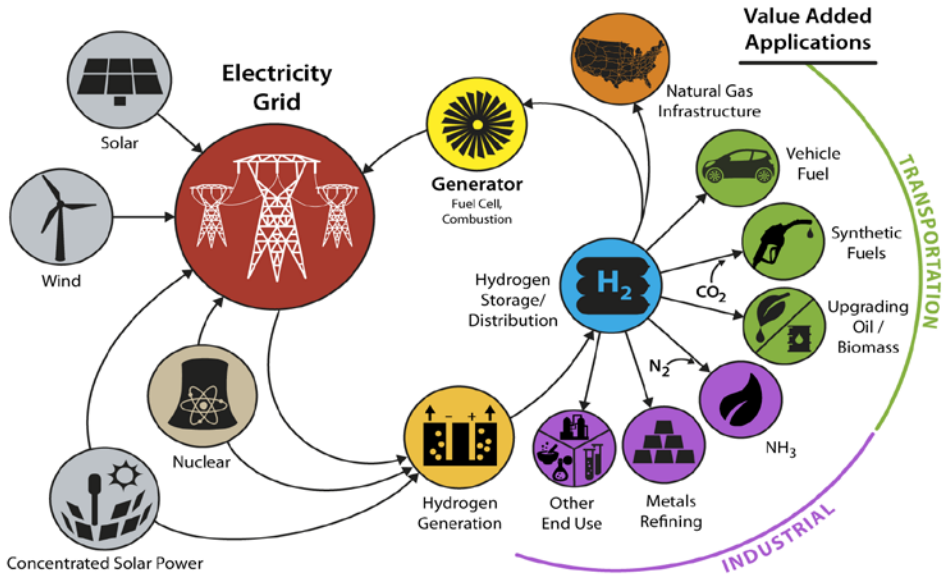
Additional OEMs planning FCEVs in soon

H_2 at Scale- Lab Big Idea Initiative

3 H_2 Focus Areas:

- Advanced **Generation**
- **Storage and Distribution**
- End use market transformation and **systems integration**

H_2 at Scale Energy System:



Outcomes:

- Increased **market penetration**
- **Lower cost H_2**
- **Decarbonized** industrial sector
- Expanded use **of other sources of energy**
- **Energy security**
- **Energy flexibility and resilience**

Partners

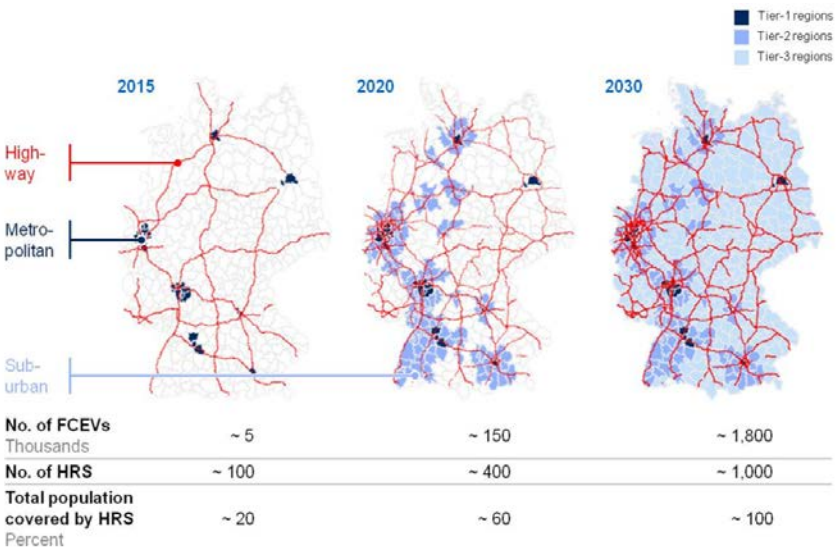
- **National Labs** (*NREL-Lead*)
- **EERE** with the Sustainable Transportation Office *(including engagement with other DOE offices)*

Develop and enable the deployment technologies that produce and utilize green, low-cost H_2

Examples of Global Infrastructure Activities

Hydrogen Supply/Utilization Technology (HySUT)

- 18 companies (3 car companies) with plans to commercialize FCEVs and build infrastructure
- **FCEVs & H_2 Stations- 40K & 160 by 2020, 200K and 320 by 225 and 800K & 900 by 2030**.

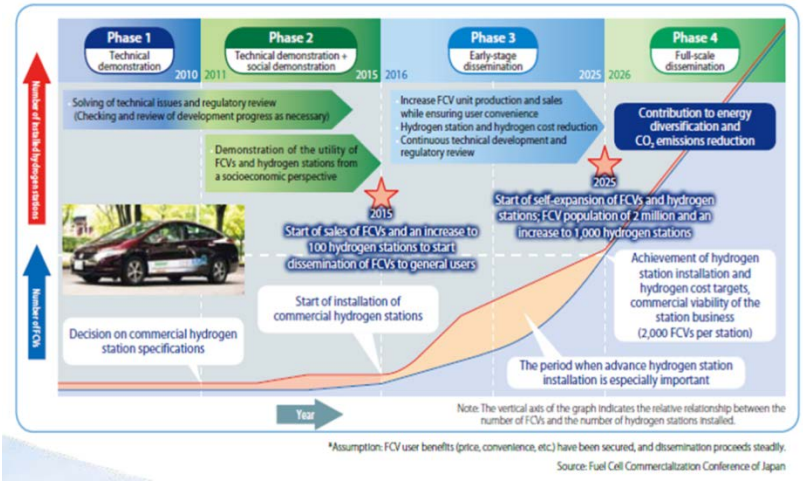


H2Mobility

- Public-private initiative for nationwide H_2 infrastructure
- **50** H_2 stations and **5,000** FCEVs by 2015

UKH2Mobility

- Evaluating anticipated FCEV rollout in 2014-2015
- Will develop action plan to make UK a leading market for FCEVs



Scandinavian H2 Highway Partnership (SHHP)

- Denmark, Norway and Sweden
- **45 H_2 stations** and a fleet of **~1K vehicles.** Projects include H2Moves Scandinavia and Next Move
- 2012 MOU with industry and NGOs for FCEVs and H_2 infrastructure introduction by 2015 timeframe

International partnerships established to accelerate hydrogen infrastructure

Hydrogen & Fuel Cells Budget

Key Activity	FY 15	FY 16	FY17
	($ in thousands)		
	Approp.	Approp.	Request
Fuel Cell R&D	33,000	35,000	35,000
Hydrogen Fuel R&D[1]	35,200	41,050	44,500
Manufacturing R&D	3,000	3,000	3,000
Systems Analysis	3,000	3,000	3,000
Technology Validation	11,000	7,000	7,000
Safety, Codes and Standards	7,000	7,000	10,000
Market Transformation	3,000	3,000	3,000
Technology Acceleration	0	0	13,000[2]
NREL Site-wide Facilities Support	1,800	1,900	N/A
Total	97,000	100,950	105,500

Office	FY 2015
EERE	$97.0M
Basic Science	$18.5M
Fossil Energy, SOFC	$30.0M

FY 2015 DOE Total: ~$150M

Number of Recipients funded from 2008-2015	
Industry	>110
Universities	>100
Laboratories	12

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

[2]Combines Manufacturing R&D, Technology Validation, Market Transformation.

Sustained, stable funding requests and appropriations

Major Administration Energy Goals

Reduce GHG emissions by 17% by 2020, 26-28% by 2025 and 83% by 2050 from 2005 baseline Climate Action Plan

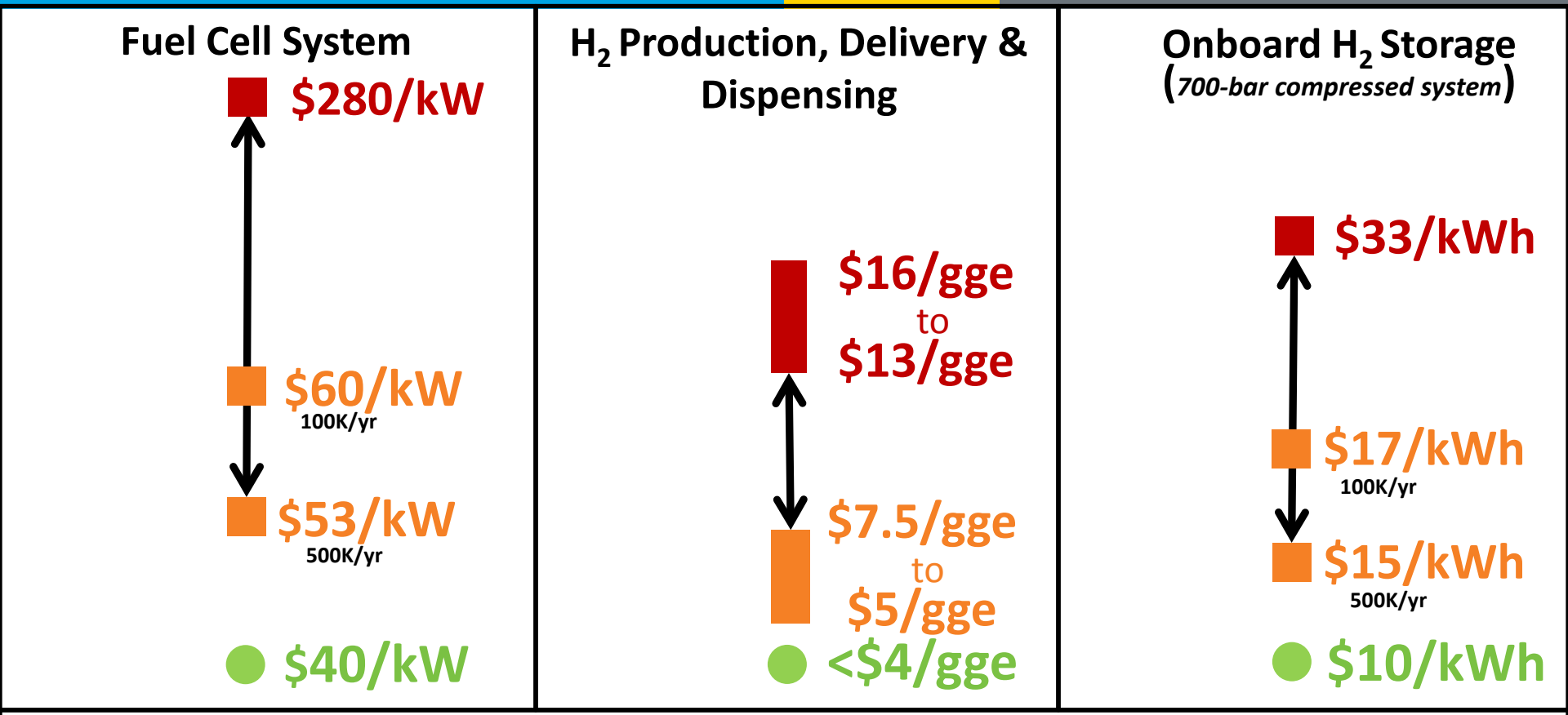
By 2035, generate 80% of electricity from a diverse set of clean energy resources Blueprint Secure Energy Future

Double energy productivity by 2030 Department of Energy

Reduce net oil imports by half by 2020 from a 2008 baseline Blueprint Secure

Reduce CO_2 emissions by **3 billion metric tons** cumulatively by 2030 through efficiency standards set between 2009 and 2016
CAP Progress Report

DOE Cost Targets and Status



Key Challenges- Examples

- PGM loading
- Catalyst and membrane durability
- Electrode performance and durability

- Efficiency and Reliability
- Feedstock and Capital Costs
- Compression, Storage and Dispensing (CSD) Costs

- Carbon fiber precursors and conversion
- Composite/resin materials
- BOP and assembly costs

Techno-Economic Analysis Guides R&D Portfolio

Fuel Cells

Bipolar Plates
Membranes
BOP
MEA
Frames/Gaskets
GDLs

Focusing on…

Low and Non PGM Catalysts,

Alkaline Membranes

H_2 Station

Storage
Cooling
Dispensing
Other

Advanced Compression

Alternate Approaches

H_2 Storage

BOP/Assembly
Other processing
Resin

Low Cost Carbon Fiber (CF)

Long term Materials Approaches

H_2 Production Pathways Cost Status

Current Technology

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

Near to Mid-Term:

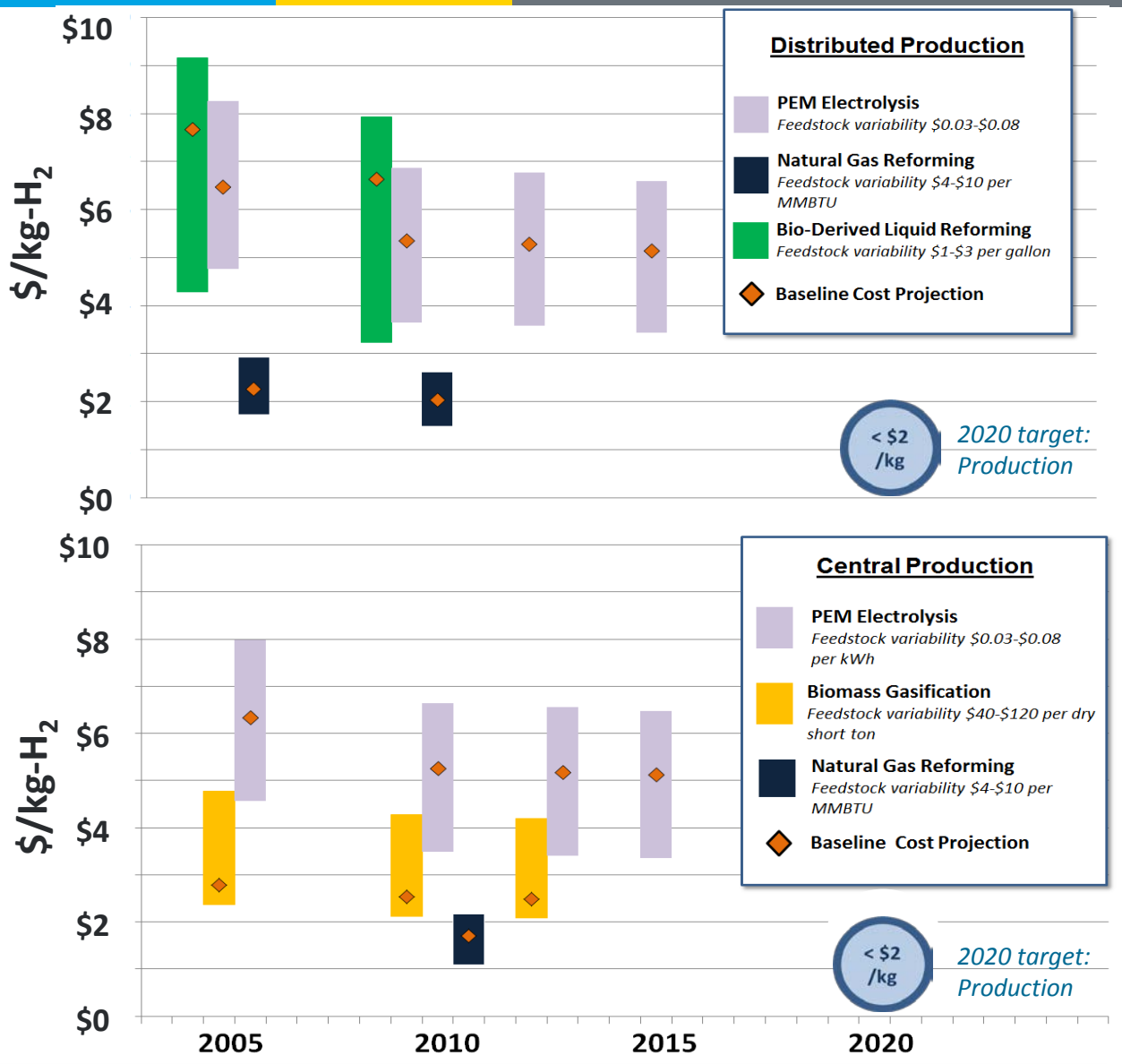
- Electrolysis- Wind and Solar Powered (D/C)
- Bio-derived Liquids (D/C)
- Fermentation (D/C)

Long-Term (not shown):

Central Renewable H_2

- Solar-based water splitting
- Photolytic Bio-hydrogen

D- Distributed **C- Central**



H_2 from NG can be competitive today - renewables is a longer-term focus

H_2 Infrastructure Status

H_2 Delivery Infrastructure

- **Current: 1,600 miles of H_2 pipeline**

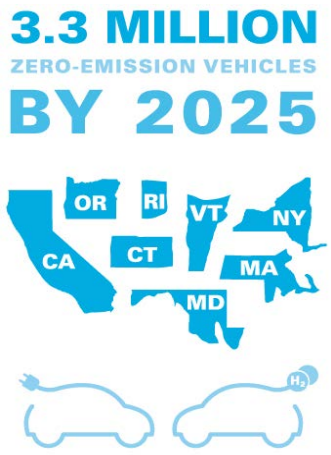
H_2 Station Options

- **H_2 from central site:**
  - **>$1-2 M** for stations*
  - **~$7-$16/gge** for H_2
- **Distributed production:**
  - Natural gas
  - Electrolysis

*~100-300 kg/day (range of cost)

H_2 Stations in the U.S.

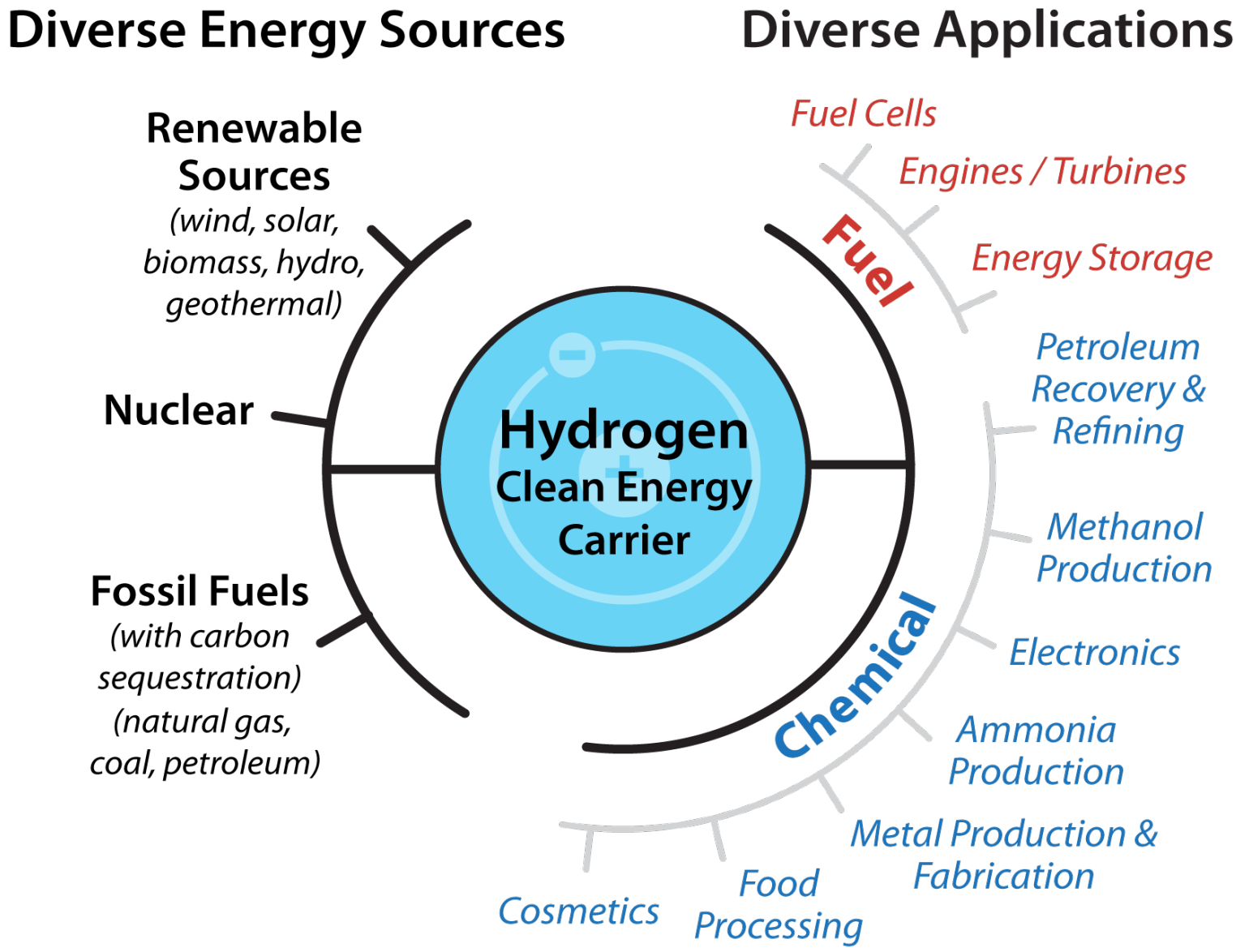
- **Current: ~50 total** (~15 public)
- **State Plans:**
  - **CA- 100 stations, ~$100M** planned through 2023
  - **Northeast States & Hawaii**
  - **8 State MOU- 3.3M ZEVs** by 2025



California
Connecticut
Massachusetts
Maryland
New York
Oregon
Rhode Island
Vermont

H_2 delivery options present opportunities for expanding H_2 infrastructure

Hydrogen- An energy carrier feedstock



Source: DOE, NREL, Hydrogen and Fuel Cell Program

H_2 Infrastructure Status

H_2 Delivery Infrastructure

- **Current: 1,600 miles of H_2 pipeline**

H_2 Station Options

- **H_2 from central site:**
  - **>$1-2 M** for stations*
  - **~$7-$16/gge** for H_2
- **Distributed production:**
  - Natural gas
  - Electrolysis

*~100-300 kg/day (range of cost)

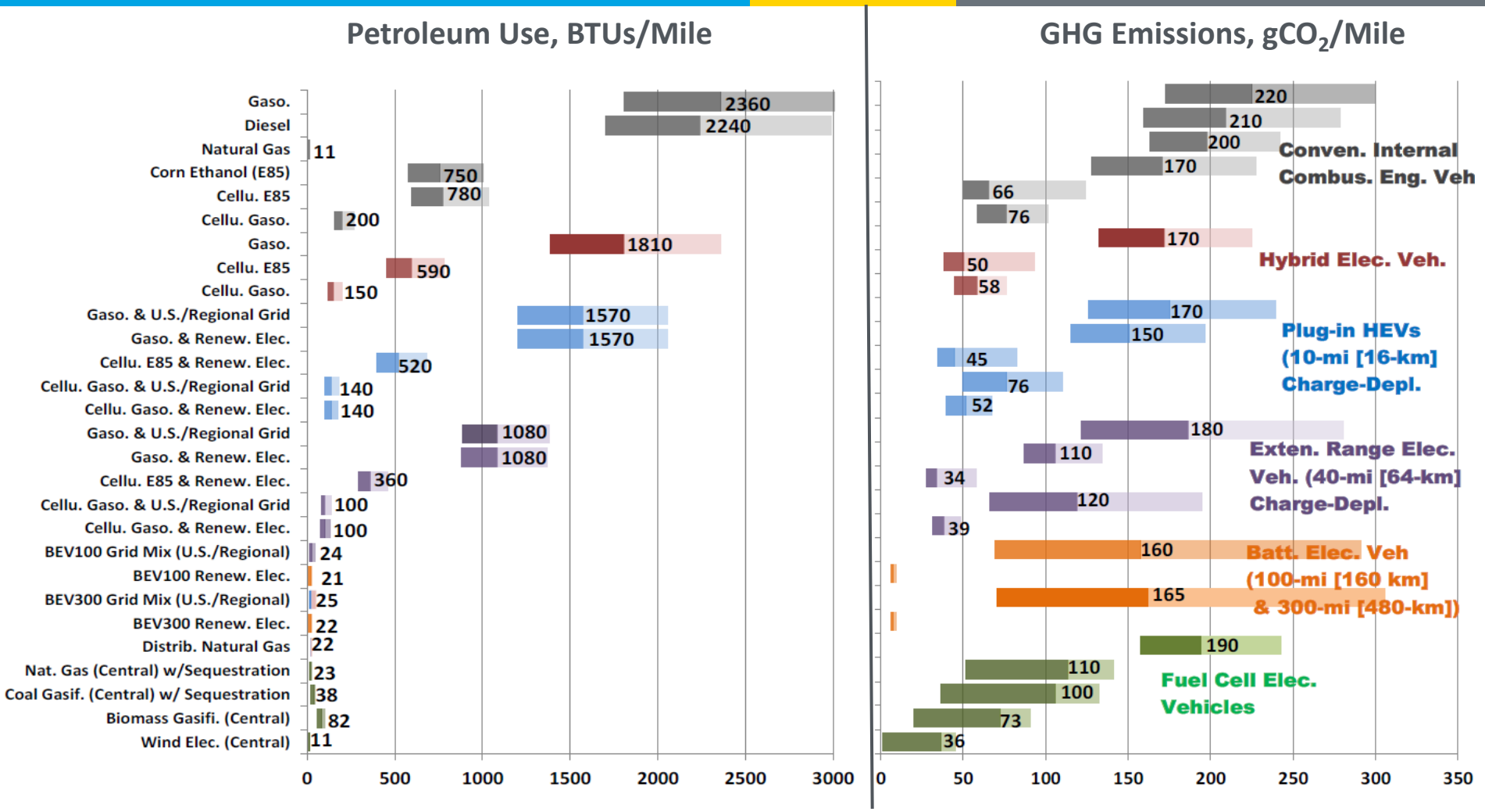
H_2 Stations in the U.S.

- **Current: ~50 total** (~10 public)
- **State Plans:**
  - **CA- 100 stations, ~$100M** planned through 2023
  - **Northeast States & Hawaii**
  - **8 State MOU- 3.3M ZEVs** by 2025

California
Connecticut
Massachusetts
Maryland
New York
Oregon
Rhode Island
Vermont

H_2 delivery options present opportunities for expanding H_2 infrastructure

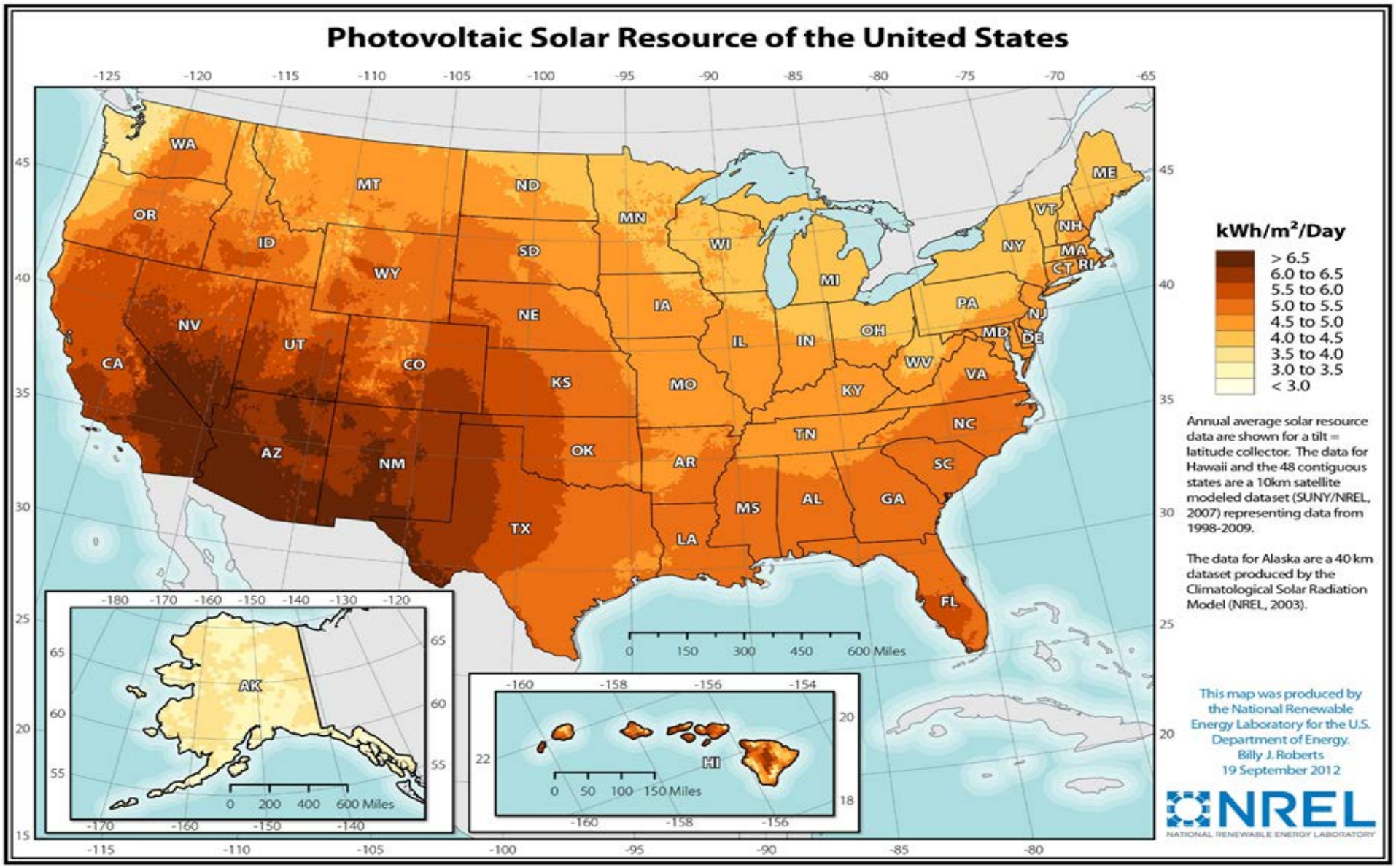
Well-to-Wheels Analysis: GHG Emissions and Petroleum Use



Program Record #13005: http://www.hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf

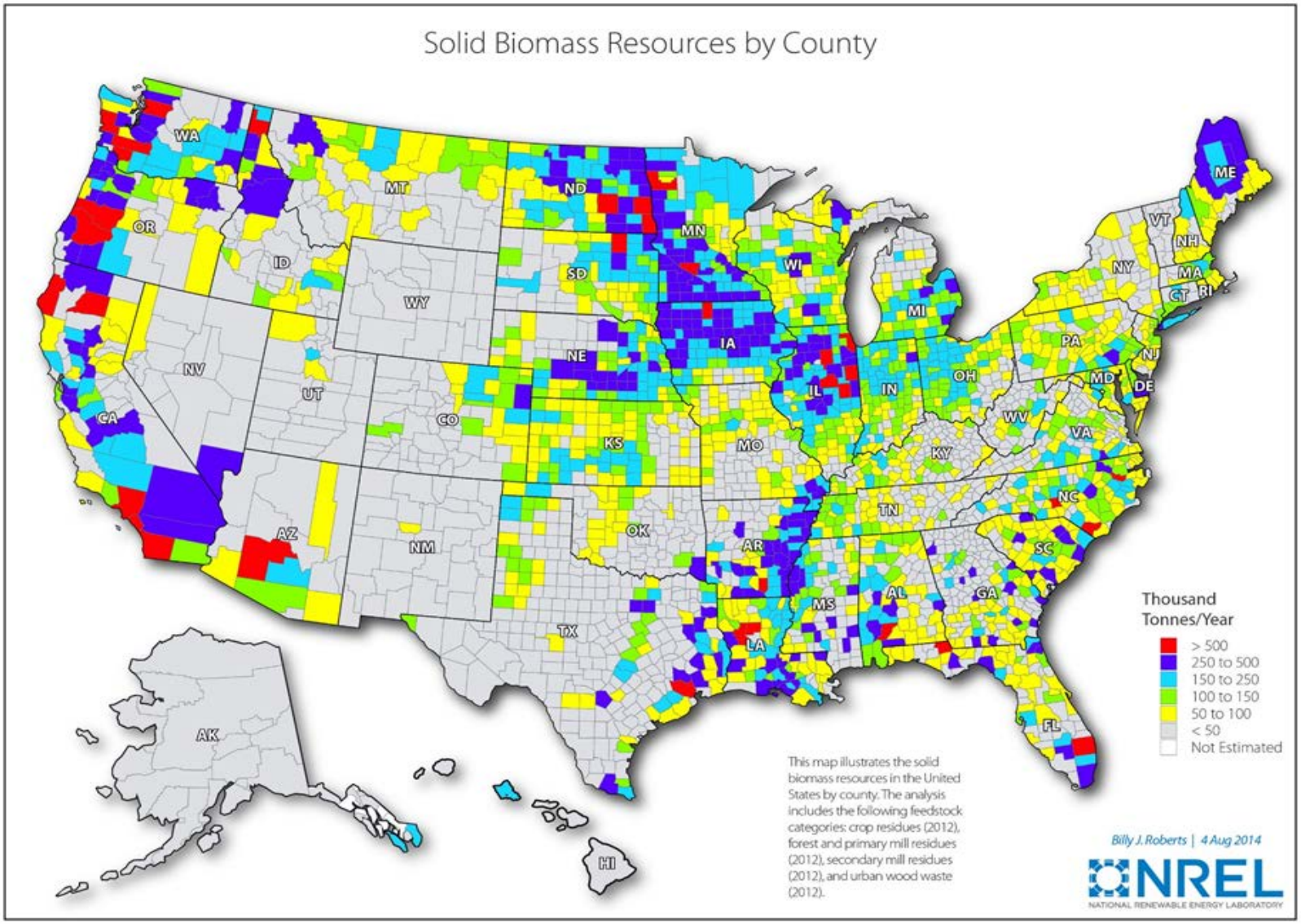
Electric Drive With Low Carbon Fuels - Pathway with lowest GHG emissions and petroleum use

Solar Sources: Opportunity for Renewable H_2



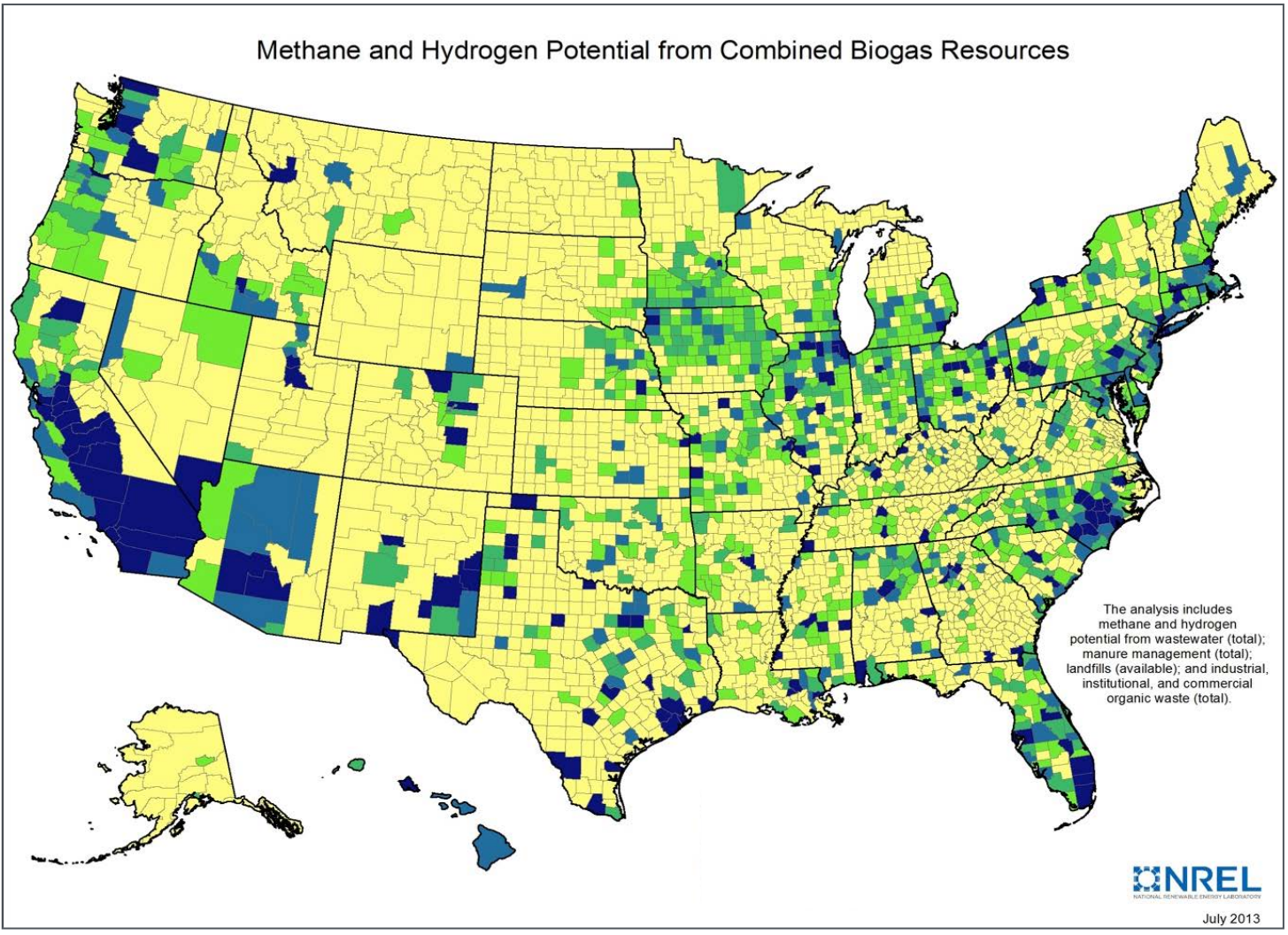
Solar water-splitting is an important longer term option

Biomass Resources: Opportunity for Renewable H_2



Bio-feedstock reforming is a near term option

Biogas Resources: Opportunity for Renewable H_2



Hydrogen from biogas already **available in some California fueling stations**

Wastewater treatment plants alone have the potential to provide enough hydrogen to support over ~1-3M FCEVs/year

H_2 Production and Delivery Broad Technology Portfolio

Production method

Central

Established Industrial Process

Natural Gas Reforming

Carbon Mitigated NG Reforming

Biomass Gasification

P&D Subprogram R&D efforts successfully concluded

FE

Coal Gasification With CCS

Electrolysis (wind)

Electrolysis (solar)

NE

High-temp Electrolysis

STCH

PEC

Photo-biological

Biomass pathways

Solar pathways

Distributed

Natural Gas Reforming

Electrolysis (Grid)

Bio-derived Liquids

Microbial Conversion

FE, NE: R&D efforts in DOE Offices of Fossil and Nuclear Energy, respectively

Near-term | **Mid-term** | **Long-term**

Delivery method

Tube Trailer Transport

- **Mobile Re-fuelers**
- **High Capacity Tube Trailers**
- **Forecourt CSD**
  - Mechanical compression
  - Station storage
  - Hose dispensers

Liquid Tanker Transport

- **Advanced Liquefaction**
- **Distribution pipelines**
  - H_2 embrittlement mitigation
- **Advanced Forecourt CSD**
  - Advanced compression
  - Intelligent dispensers

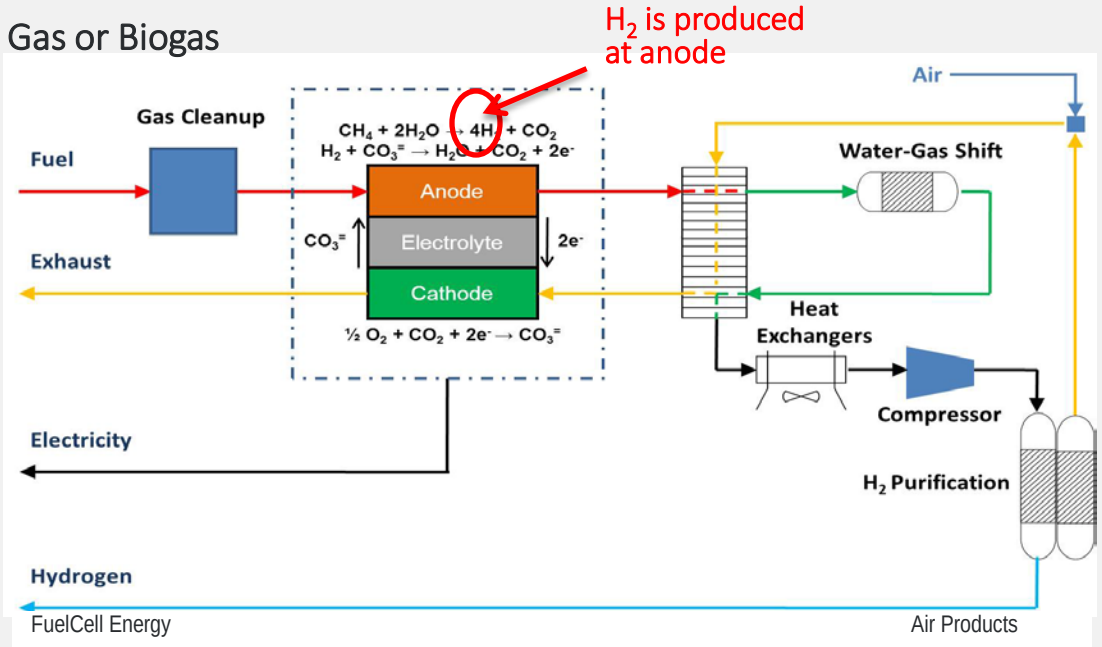
Pipeline Transport (& alternatives)

- **Fiber Reinforced Pipelines**
- **Game-changing compressors**
- **Cold GH2 delivery**

Goal to develop technologies to produce H_2 from clean, domestic resources at a delivered & dispensed cost <$4/gge by 2020 (<$2 production,<$2 delivery)

Example of Innovation: Tri-Generation

- **Demonstrated co-production of electricity and hydrogen with 54% efficiency**
- **Uses biogas from wastewater treatment plant**



Co-funded by DOE/FCT and multiple partners

Fountain Valley Demonstration Completed

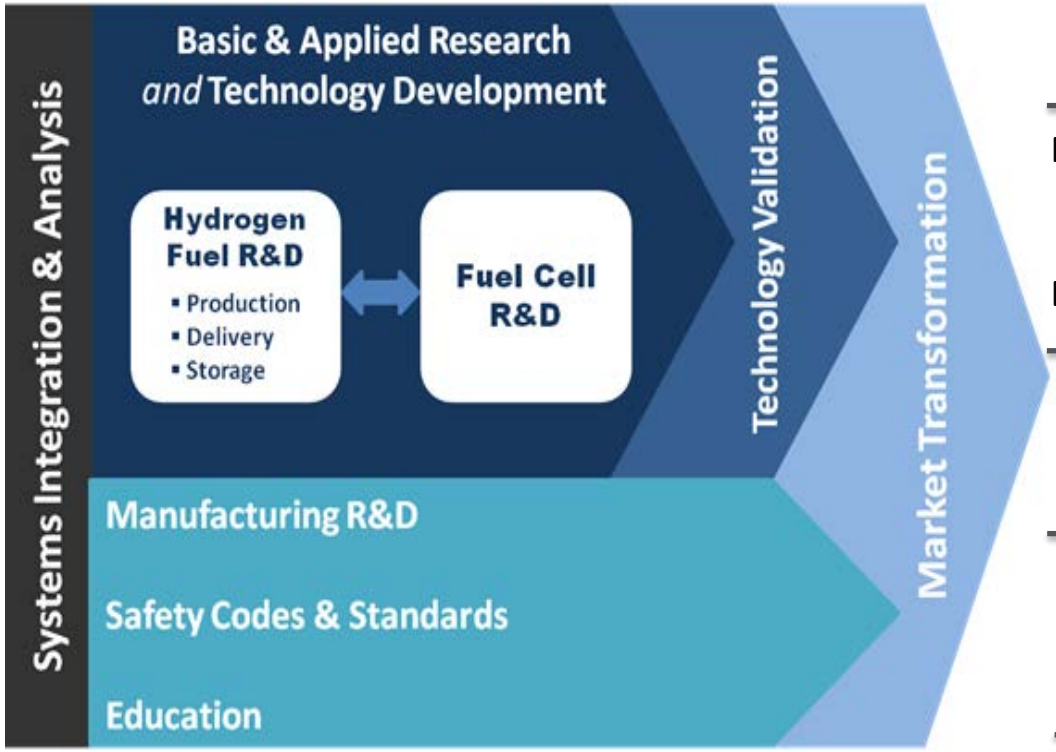
- **~250 kW of electricity**
- **~100 kg/day hydrogen capacity (350 and 700 bar), enough to fuel 25 to 50 vehicles.**

Tri-Generation co-produces power, heat and hydrogen. World's First Fuel Cell and Hydrogen Energy Station demonstrated in Orange County (DOE/FCT project)

DOE Hydrogen and Fuel Cells Program

Mission

To enable the **widespread commercialization of hydrogen and fuel cell technologies**



2020 Targets by Application

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 1.8 kWh/L, 1.3 kWh/kg	
H_2 Cost at Pump	<$4/gge <$7/gge (early market)	

*For Natural Gas
**For Biogas

Integrated approach to widespread commercialization of H_2 and fuel cells

Major Administration Energy Goals

Reduce GHG emissions by 17% by 2020, 26-28% by 2025 and 83% by 2050 from 2005 baseline Climate Action Plan

By 2035, generate 80% of electricity from a diverse set of clean energy resources Blueprint Secure Energy Future

Double energy productivity by 2030 Department of Energy

Reduce net oil imports by half by 2020 from a 2008 baseline Blueprint Secure

Reduce CO_2 emissions by **3 billion metric tons** cumulatively by 2030 through efficiency standards set between 2009 and 2016
CAP Progress Report