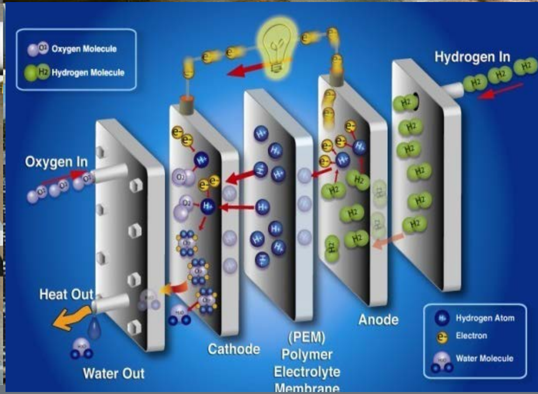
U.S Department of Energy Fuel Cell Technologies Office Overview

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



IEA Electrolysis Meeting

Herten, Germany

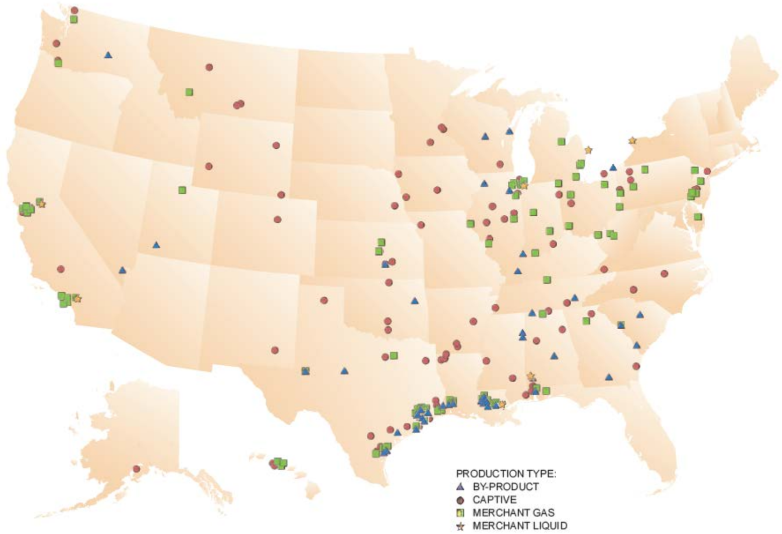
April 21-22, 2015

Bryan Pivovar

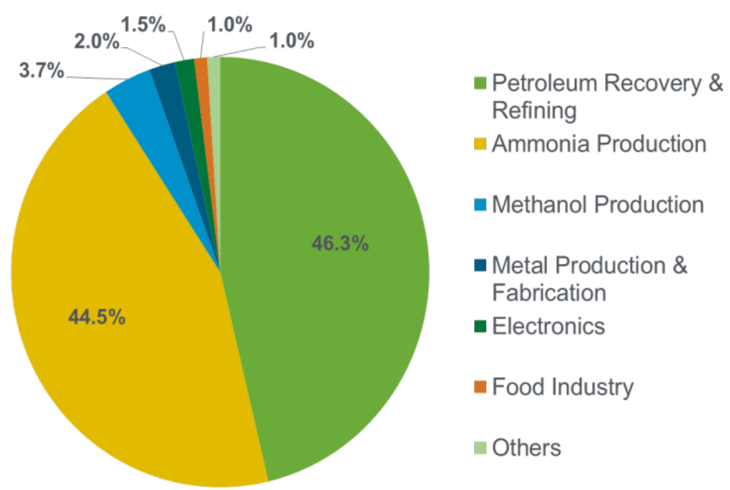
National Renewable Energy Lab

Hydrogen Current Status

- **~10 million tonnes H_2 from NG reforming for petroleum refining, ammonia production, etc. today**
- **NG can provide near-term cost-competitive H_2 at scale:**
  - <$2/gge produced ($4.50/gge delivered)
- **>1,500 miles of H_2 pipeline**
- **~ 50 H_2 stations (10 public)**
- **Plans for H_2 stations:**
  - 100 in CA; 100 each in Germany, Japan (1,000 each by 2025)
- **Growing demand for electrolyzers for renewable H_2 at scale:**
  - >$5/gge produced ($7.50/gge delivered)



Existing centralized hydrogen production facilities



2010 hydrogen consumption market share by application

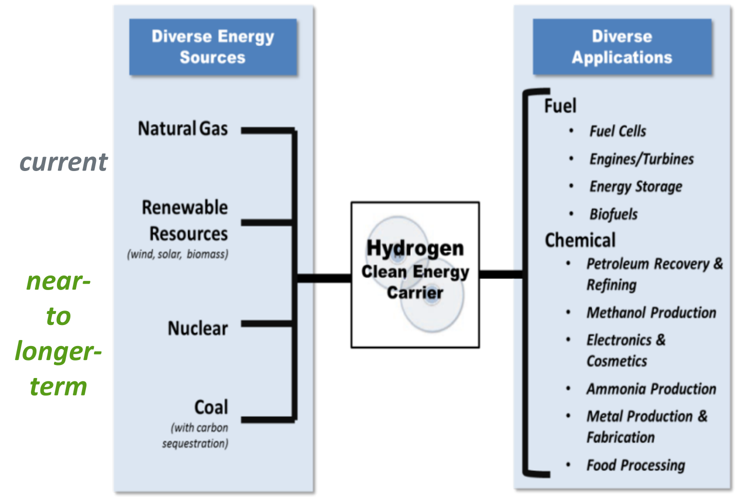
Note: NG reforming with CCS is another near-term low-carbon option

Hydrogen Challenges and Opportunities

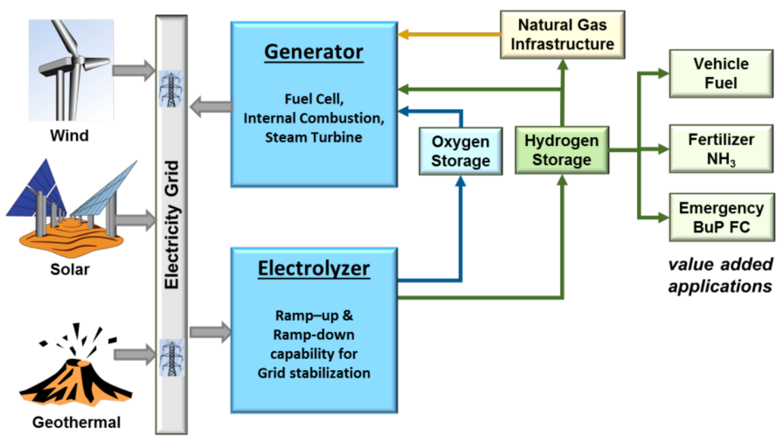
- **Major challenges:**
  Reduce the cost of producing and delivering H_2 from renewable/low-carbon sources for FCEV and other uses (capex, O&M, feedstock, infrastructure, safety, permitting, codes/standards)

- **Factors driving change in the technologies:**
  - FCEVs are driving requirements (e.g. high P tanks)
  - Need to reduce cost of 700 bar refueling stations for near-term FCEV roll-out

- **Where the technology R&D needs to go:**
  - Materials innovations to improve efficiencies, performance, durability and cost, and address safety (e.g. embrittlement, high pressure issues)
  - System-level innovations including renewable integration schemes, tri-generation (co-produce power, heat and H_2), energy storage balance-of-plant improvements, etc.
  - Cost reductions in H_2 compression, storage and dispensing components
  - Continued resource assessments to identify regional solutions to cost-competitive H_2



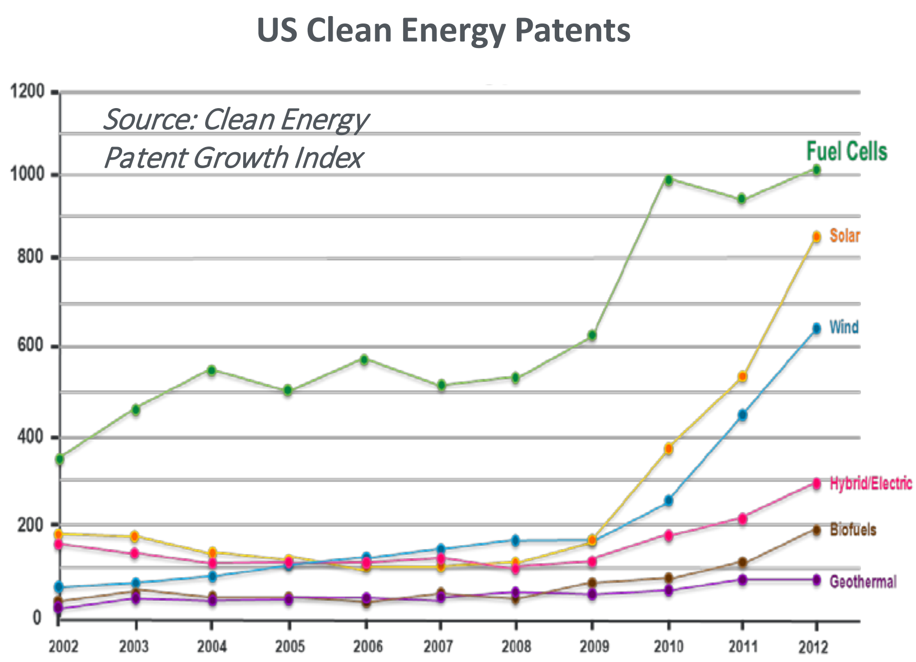
H_2 offers important long-term value as a clean energy carrier

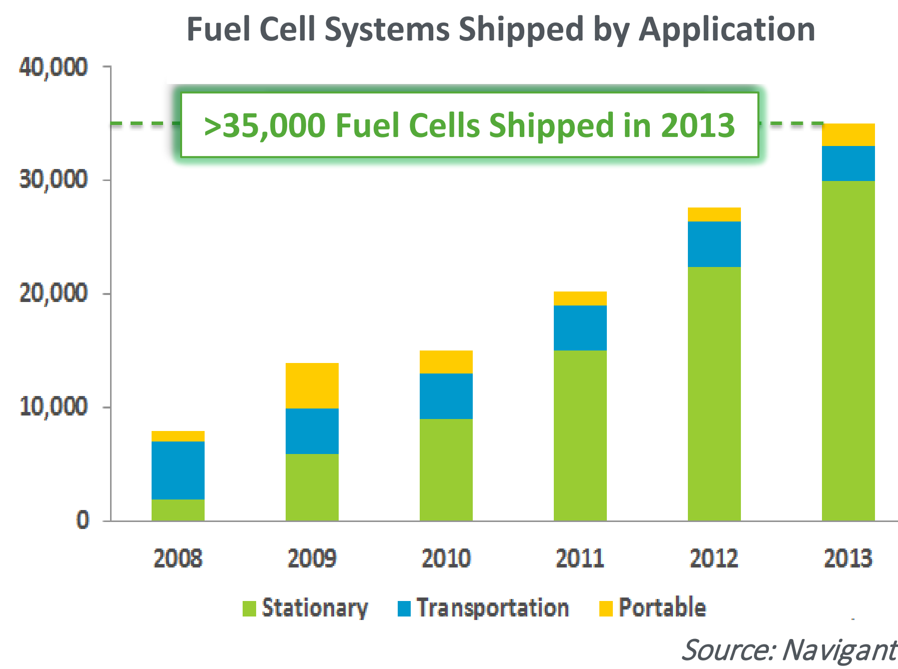


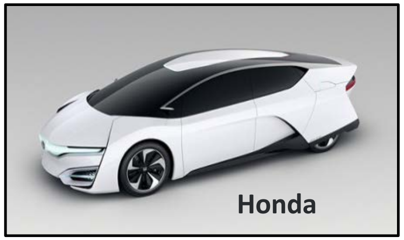
Renewable energy integration options with hydrogen

Note: H2 storage on-board FCEVs is addressed in Ch. 9

Fuel Cells- An Emerging Industry







Recent FCEV announcements- 2013-2014

- Consistent **30%** annual growth since 2010
- Global market potential in 10–20 years:
  - 14 – $31 billion/yr for stationary power
  - $11 billion/yr for portable power
  - $18 – $97 billion/yr for transportation

FCTO Overview

Mission

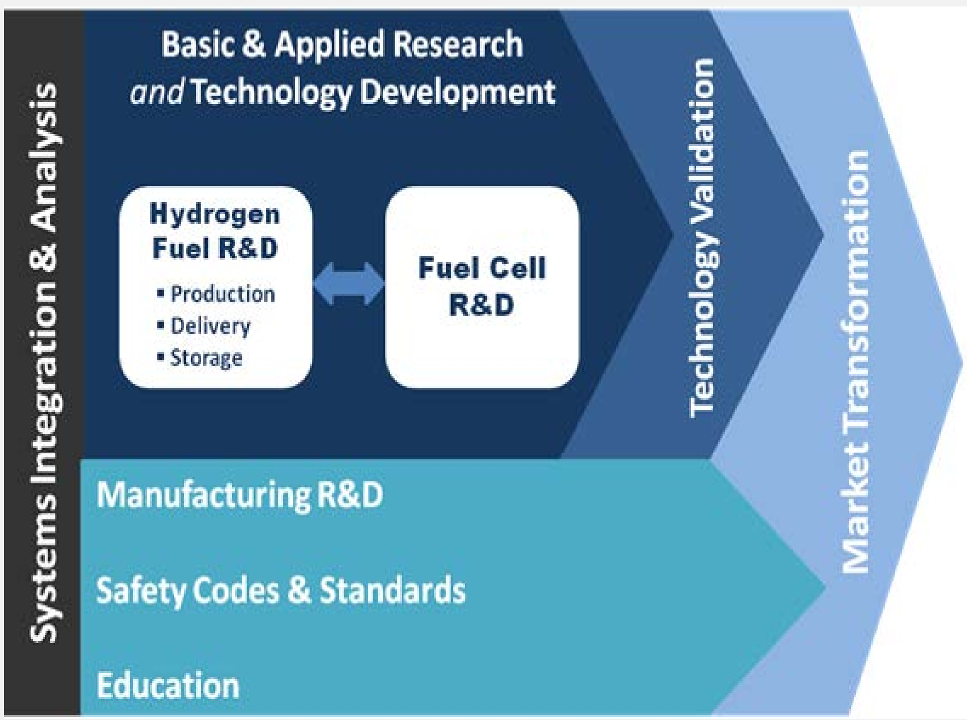
To enable the **widespread commercialization** of hydrogen and fuel cell technologies, which will reduce petroleum use, greenhouse gas (GHG) emissions, and criteria air pollutants, and will contribute to a more diverse energy supply and more efficient use of energy.

Impact

2-4 million barrels per day petroleum reduction by 2050

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

Strategy and Approach



2020 Targets

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

FCEVs Reduce Greenhouse Gas Emissions

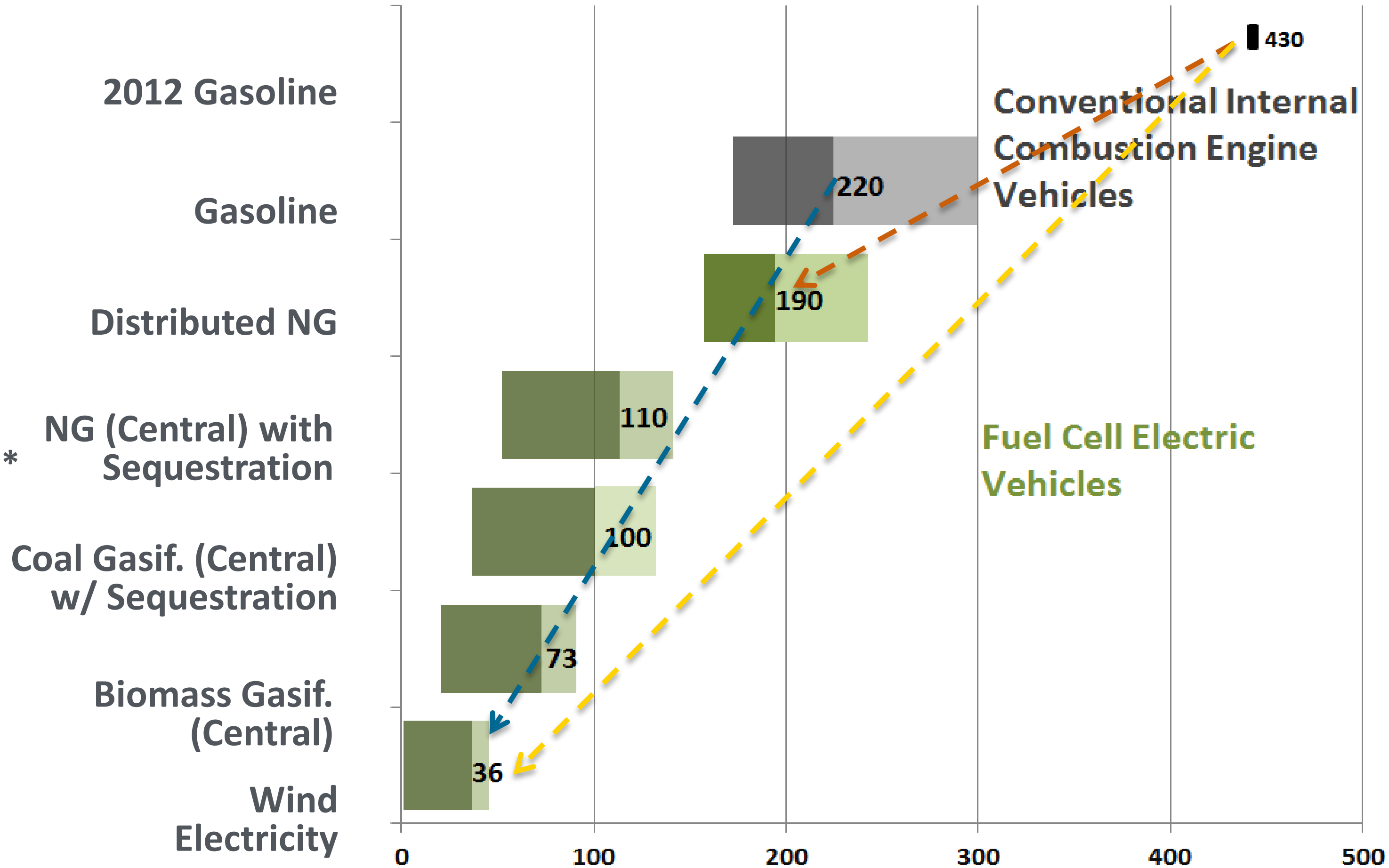
>50% from Distributed Natural Gas*

>80% from Renewables** (Wind)

>90% from Renewables* (Wind)

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

Well-to-wheels CO_2 emissions/mile



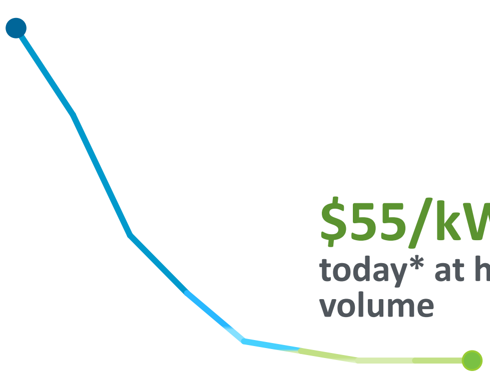
Substantial GHG reductions with H_2 produced from renewables

DOE Activities Span from R&D to Deployment

1. Research & Development

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

$124/kW in 2006



$55/kW
today* at high volume

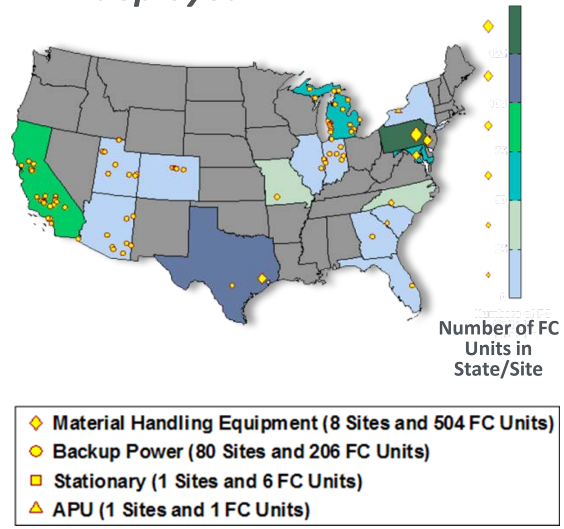
*$280/kW low volume

2. Demonstration

- ***>180* FCEVs**
- ***25* stations**
- ***3.6* million miles traveled**
- ***World's first tri-gen station***
- ***Early markets- Airport baggage tractor, back-up power***

3. Deployment

- ***Government Early Adoption*** *(DoD, California, etc.)*
- ***DOE Recovery Act & Market Transformation Deployments***
- ***~1,600* fuel cells deployed**



Fuel Cell Cost Reductions Enabled by R&D

Fuel Cell System Cost Reductions

50% reduction since 2006

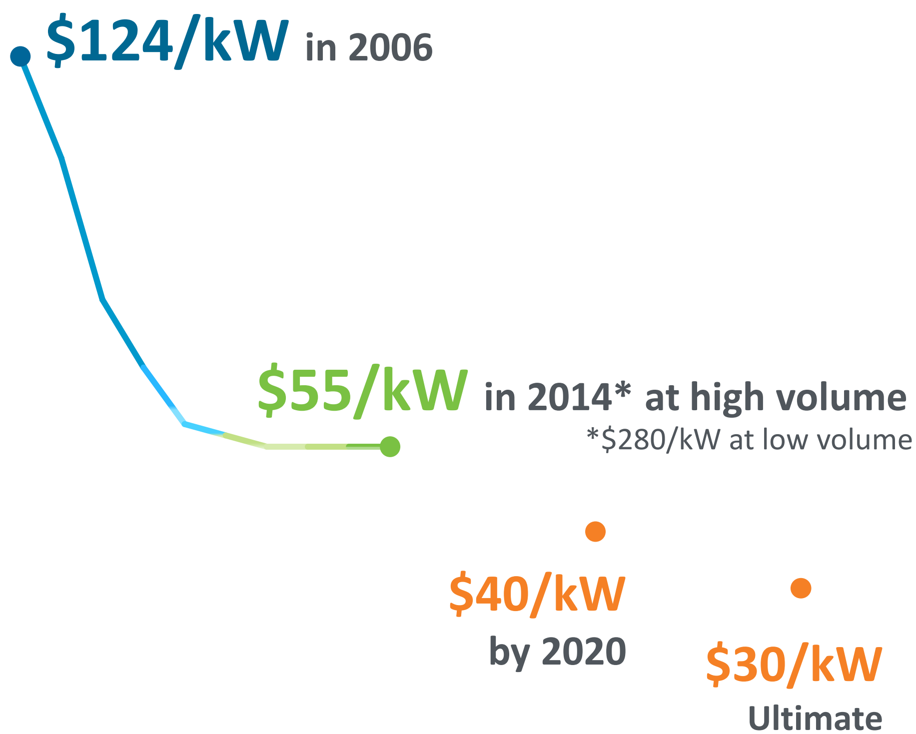
30% reduction since 2008

5X ↓ In Platinum Loading

Fuel Cell Cost Status

- **$55/kW*** for high volume
- **~$280/kW†** for low volume

Fuel Cell System Cost* Status and Targets

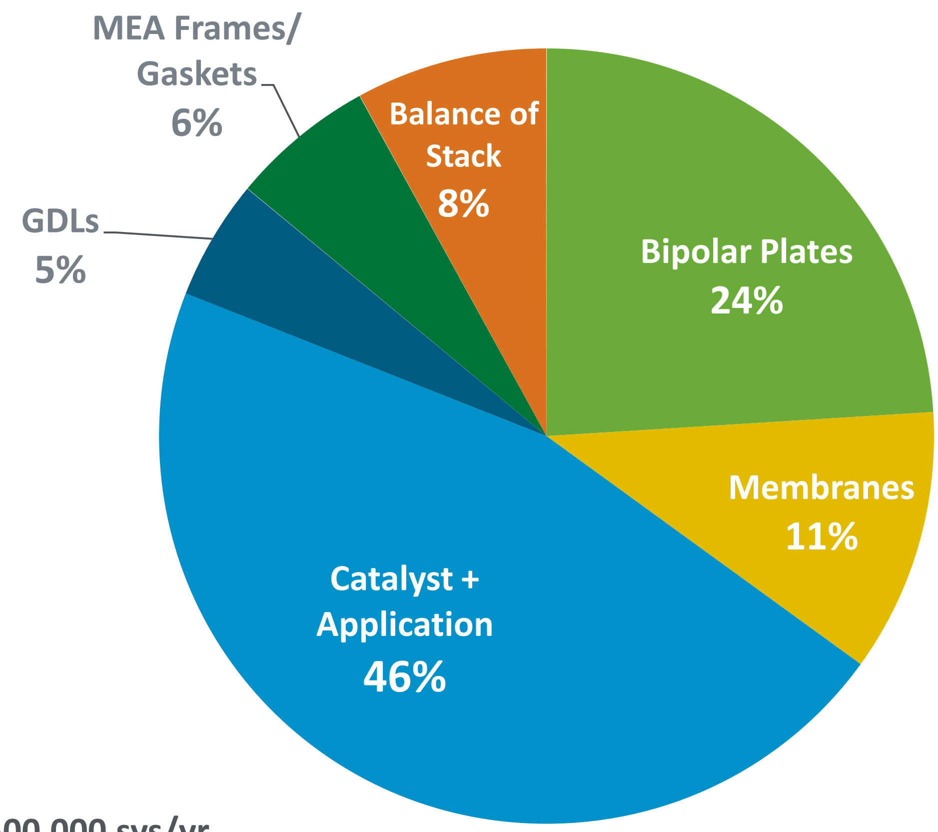


†ORNL, top-down analysis based on OEM input, 20,000 sys/yr. with current technology.
*SA, bottom-up analysis of model system manufacturing cost, 500,000 sys/year with next-gen lab technology.

Cost is shown as $/kW-net.

50% fuel cell system cost reduction through DOE R&D since 2006

PEMFC Stack Cost Breakdown*



*500,000 sys/yr

- 2020 target for PEMFC cost is **$40/kW**
- **Catalyst** is the largest cost

Catalyst remains key challenge and opportunity to lower cost

Hydrogen Production Strategies

Current Technology

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

Near to Mid-Term:

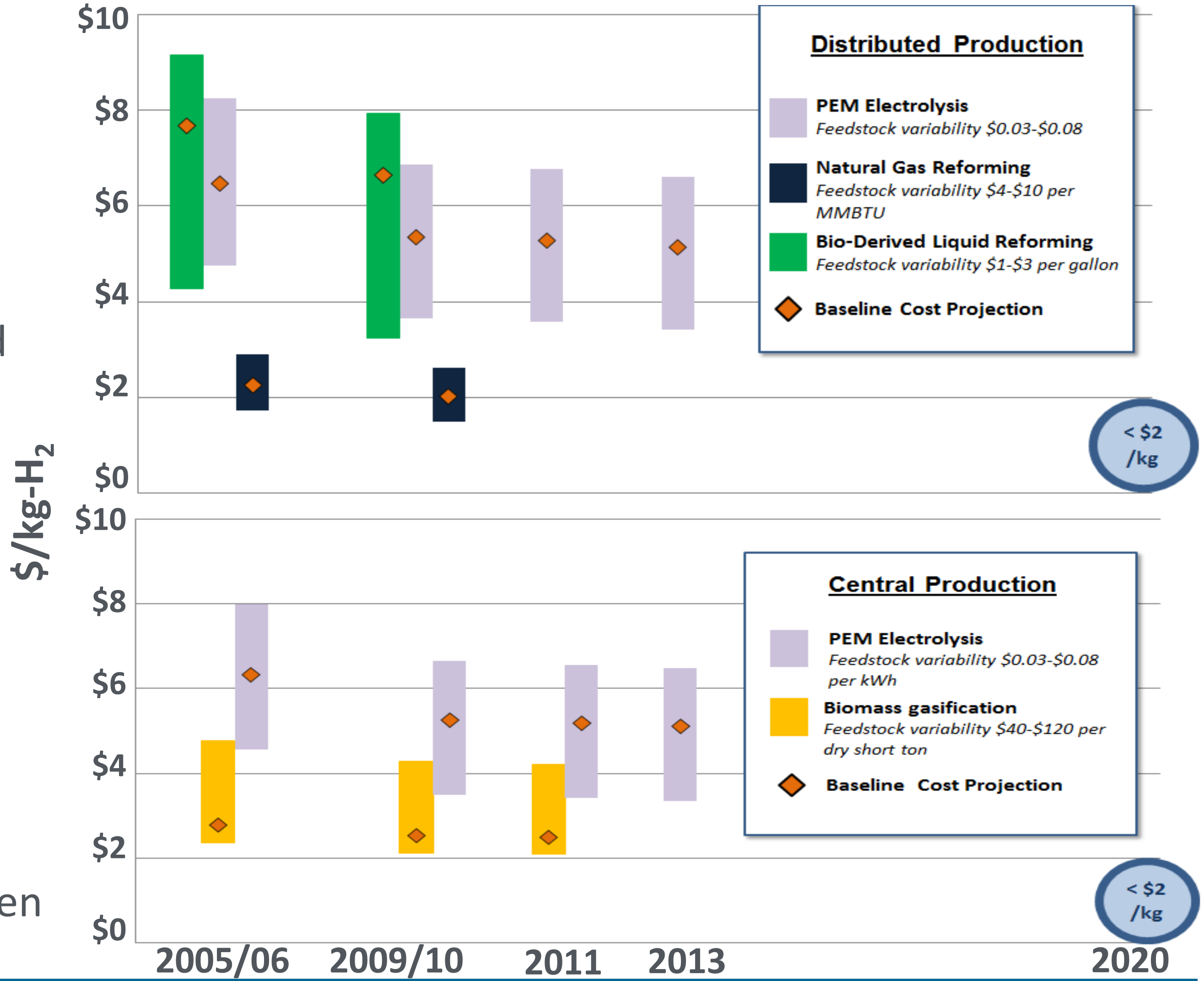
- Electrolysis- Wind and Solar Powered (D/C)
- Bio-derived Liquids (D/C)
- Fermentation (D/C)

Long-Term (not shown):

Central Renewable H_2

- Solar-based water splitting
- Photolytic Bio-hydrogen

D- Distributed **C- Central**



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

Hydrogen Challenges & Strategy

Materials durability, efficiency improvements, and capital cost reductions are key challenges for all production and delivery pathways

Challenge	Strategies	RD&D Focus	Key Areas
Reduce the cost of sustainable low-carbon hydrogen production & delivery while meeting safety and performance requirements • Feedstock costs • Capital costs • O&M costs	***Near-term*** Minimize cost of 700 bar hydrogen at refueling stations ***Long-term*** Improve performance and durability of materials and systems for production from renewable sources	• Technoeconomic analysis • Reliability and cost of compression, storage and dispensing • Renewable integration • Advanced materials and systems for H_2 delivery • Innovations in materials, devices and reactors for renewable H_2 production • Improved balance of plant for P&D systems	***Delivery*** • Polymers & composites for delivery technologies • Liquefaction technologies • Compressor reliability • Low cost onsite storage ***Production*** • Advanced electrolysis • Biomass/biogas conversion • Hybrid fossil/renewable approaches • Solar water splitting: PEC, STCH, biological

Hydrogen Analysis and Research Goals

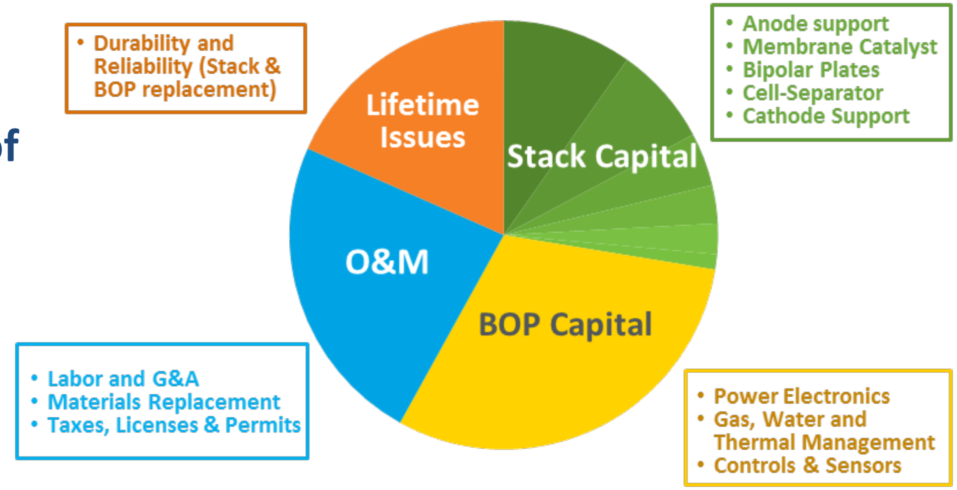
- **Reduce the cost of H_2 from renewable and low-carbon domestic resources to achieve a delivered & dispensed cost of <$4/gge** **(Note: 1 kg H_2 ~ 1 gge)**

  Pathways:
  - Electrolysis, high temperature thermochemical (solar/nuclear), biomass gasification/bio-derived liquids, coal gasification with CCS, biological & photoelectrochemical

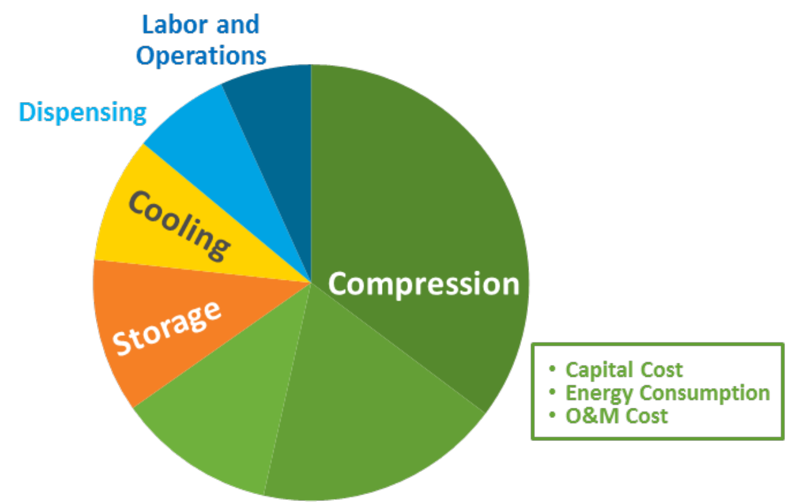
- **Need R&D in materials and components to improve efficiency, performance, durability, and reduce capital and operating costs for all pathways**
  - For many pathways, feedstock cost is a key driver of H_2 cost

- **Need strong techno-economic and regional resource analysis**

- **Opportunities for energy storage (e.g. curtailed wind for electrolyzing water)**



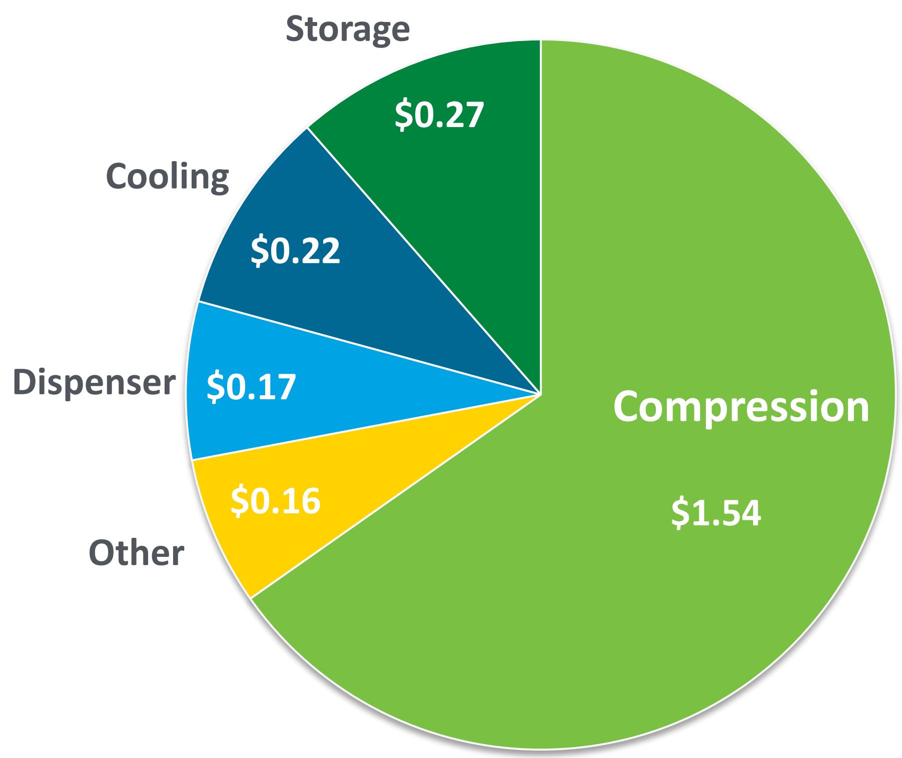
H_2 Production Example- Cost Breakdowns for PEM electrolysis, (excluding electricity feedstock costs)



H_2 Delivery Example- Compression, Storage and Dispensing (CSD) Cost Breakdown for the Pipeline Delivery Scenario

Hydrogen Delivery Critical Costs

H_2 Compression, Storage and Dispensing (CSD) Cost Breakdown



Total Cost: $2.36

*Based on the pipeline scenario

- 2020 goal for H_2 cost at the pump is **<$4/gge** *(production and delivery cost included)*
- **Compression** and **storage** are **75%** of the cost of H_2 station dispensing costs.

Compression is a key challenge for the cost of delivering and dispensing H_2

H_2 Infrastructure Development and Status

Nationwide

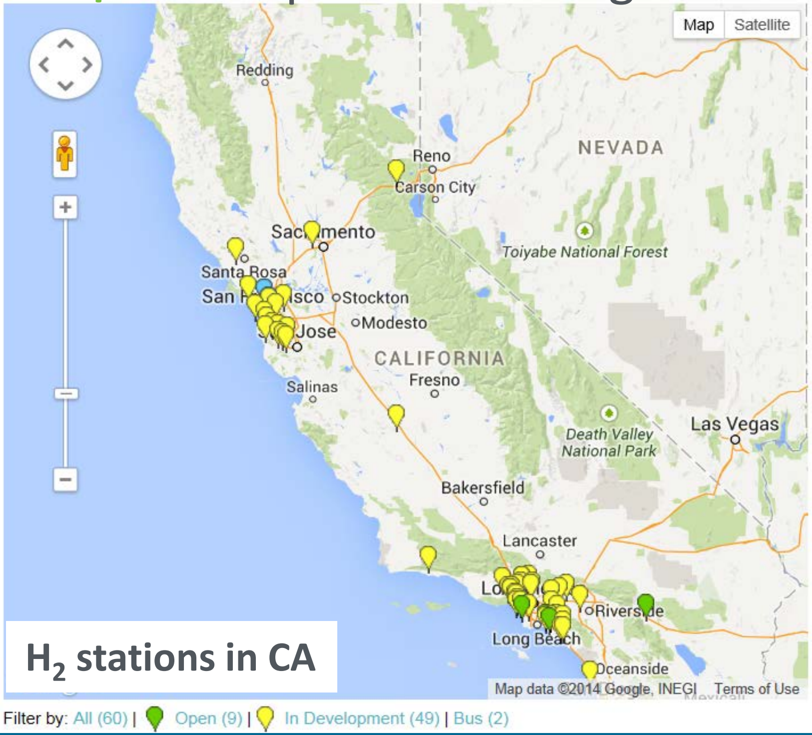
- **1500 mi.** of H_2 pipeline
- **>9M** metric tons produced/yr
- **~50 stations** (~10 public)

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

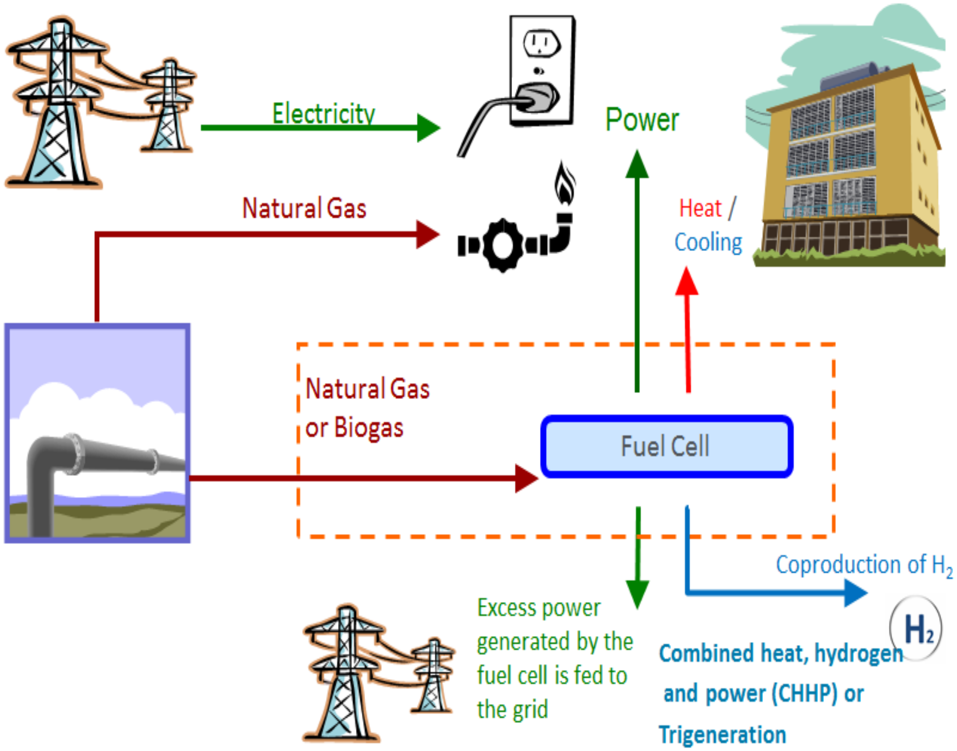
NE states, California and Hawaii have H_2 infrastructure efforts underway

H_2 Delivery Options for Infrastructure

- H_2 delivered from central site:
  - **<$1M** would be the cost of low-volume* stations
  - **$7/gge** for H_2
- **Distributed production** (e.g. natural gas, electrolysis)
- **H_2 from waste** (industrial, wastewater, landfills)

*~200-300 kg/day

- **Trigeneration**

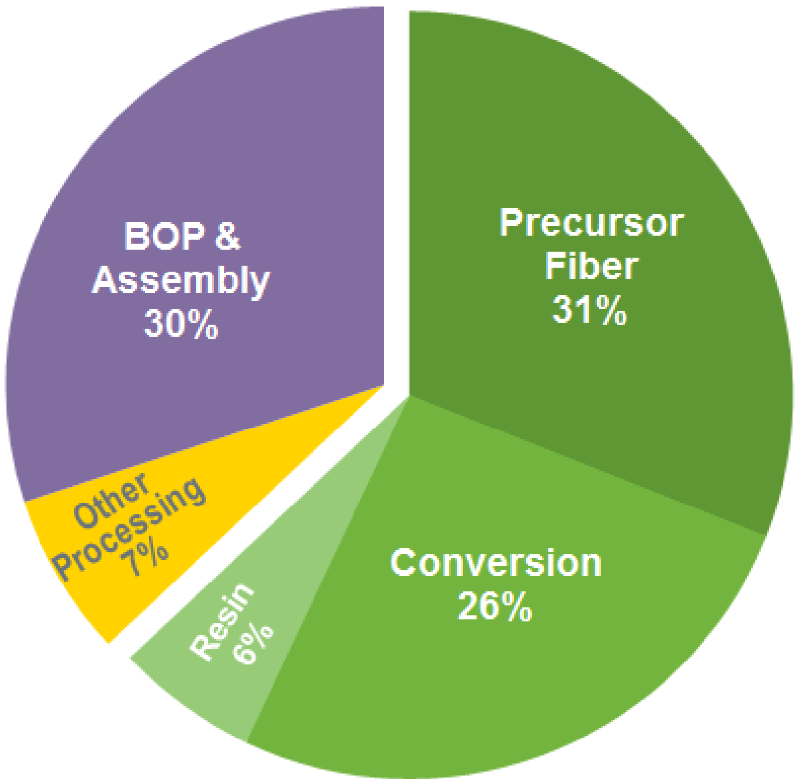


= **Power** + **Heat** + **H_2**

H_2 delivery options present opportunities for expanding H_2 infrastructure

Compressed H_2 Storage System Critical Costs

Cost breakdown for 700-bar H_2 Storage Tank*



- 2020 goal for H_2 storage is **$10/kWh**
- **Carbon fiber** precursor is the **largest** single cost contributor

*Single tank holding 5.6kg H2 total, cost in 2007$, 500,000 systems/yr

Carbon fiber cost reductions are critical for 700-bar compressed H_2

The Path Going Forward

- Continue to promote and strengthen R&D
- Selectively demonstrate strategic, innovative technologies
- Conduct key analyses to guide RD&D
- Leverage partnerships to maximize impact of efforts

R&D, demonstrations, analysis and partnerships lead the path forward

Thank You

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