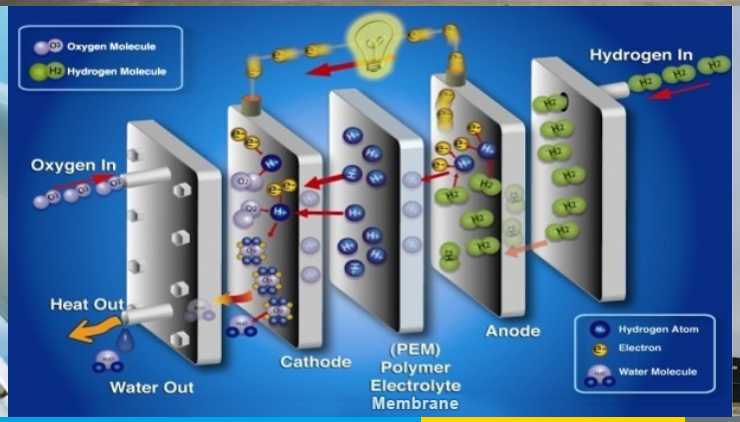
U.S. Department of Energy
Fuel Cell Technologies Office

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



BOP Workshop Introduction

Elyria, OH

March 31, 2017

Dr. Sunita Satyapal

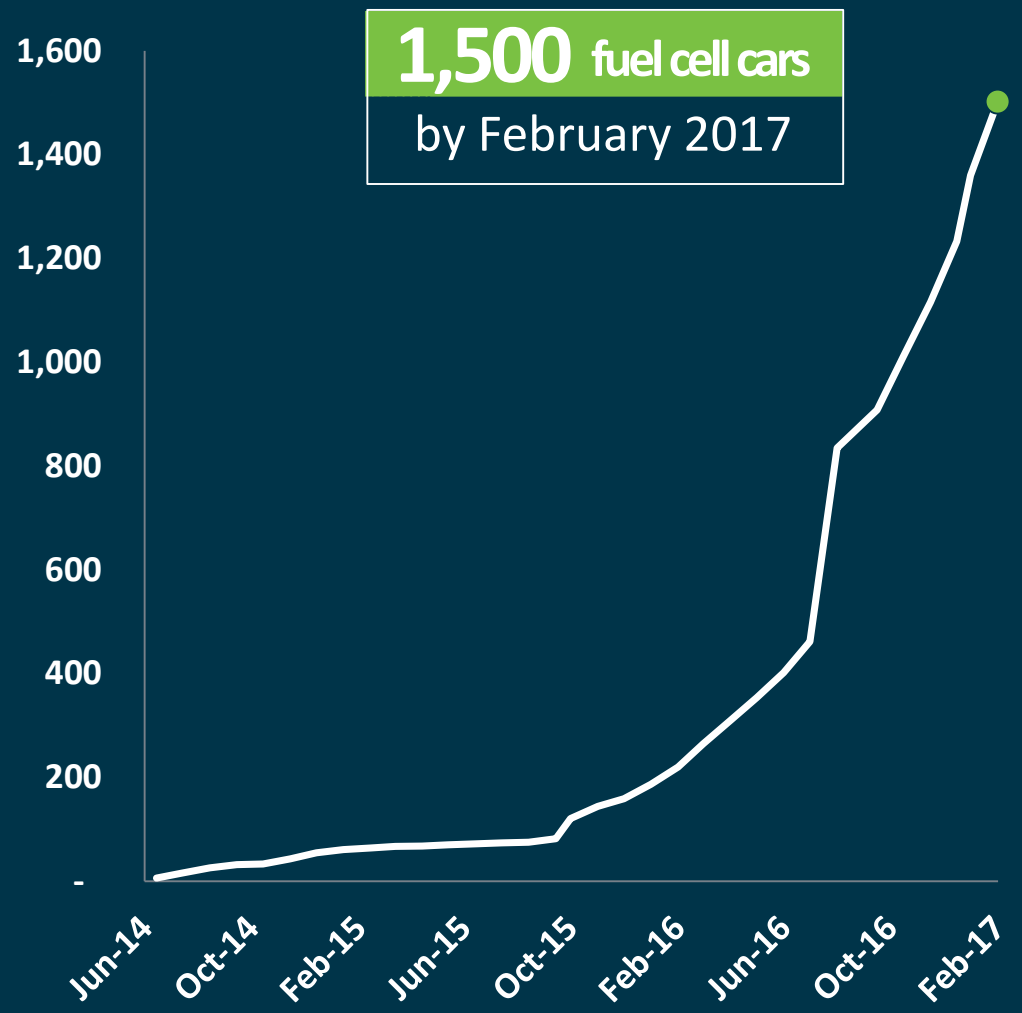
Director
Fuel Cell Technologies Office
U.S. Department of Energy

Key Messages

1. Hydrogen and fuel cells gaining momentum in multiple applications

Commercial Fuel Cell Cars are Here

Fuel Cell Cars Sold/Leased in the U.S



Note: Cumulative number of vehicles sold/leased. Source: hybridcars.com


Hyundai Tucson


Toyota Mirai

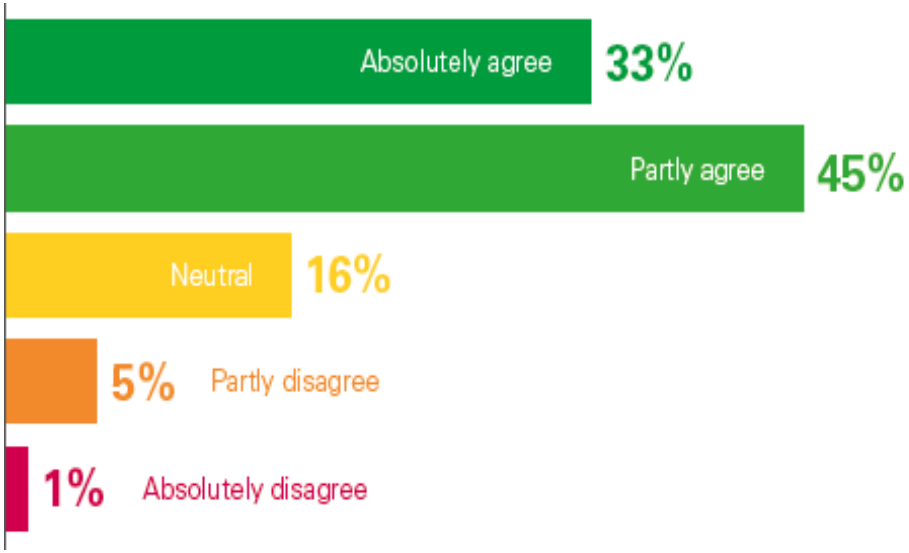

Honda Clarity

Executive Opinions Worldwide- Jan 2017

Fuel Cell Electric Vehicles (FCEVs)

78% of executives

Absolutely or partly agree that **FCEVs will be the real breakthrough for electric mobility**



Source: KPMG, Global Automotive Executive Survey 2017 (Jan. 2017)

Fuel Cells: Recent Progress

Fuel cell buses surpass 15 million passengers

Fuel Cells: Material Handling Growth

Over 10,000 fuel cell forklifts

~ 5 million H_2 refuelings

Fuel Cells: New Applications Demonstrated

1st fuel cell tow trucks at U.S. airport

Fuel Cells: New Applications Demonstrated

Fuel cells for back up and emergency power for hospitals, telecommunications towers, supermarkets and more!

Stationary Fuel Cells- Opportunities Emerging

Data centers require non-stop electrical power

Reliable power is vital at hospitals

Supermarkets- growing interest for reliable power

Fuel Cell Stationary Power in the U.S.

Installations

More than
235 MW
in at least
43 states

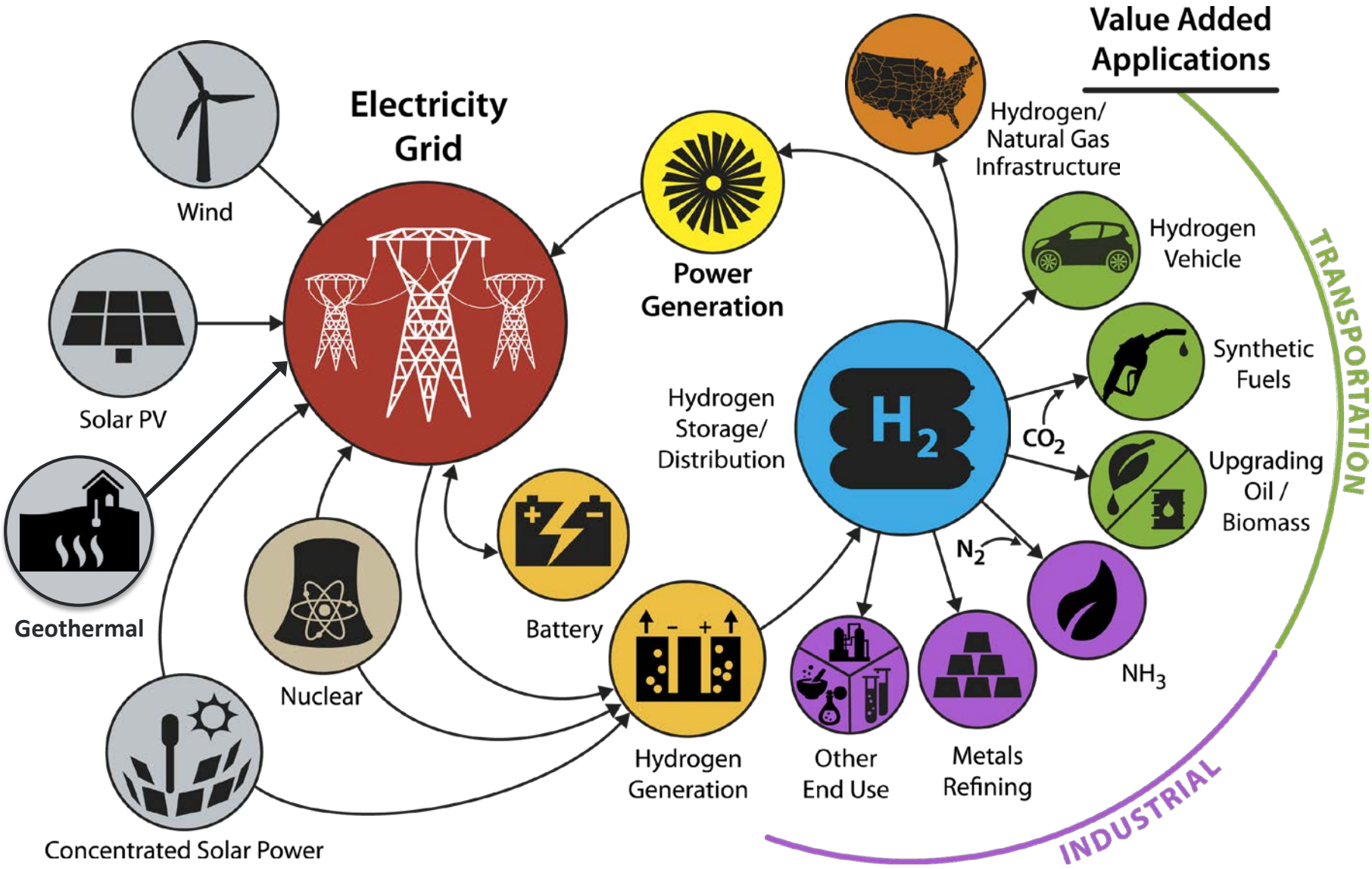
Top States

- **By unit size:** DE (30 MW) and CT (14.9 MW)
- **By number of units** CA (480 systems)

Source: DOE Fuel Cell Technologies Office. State of the States Report (2016)

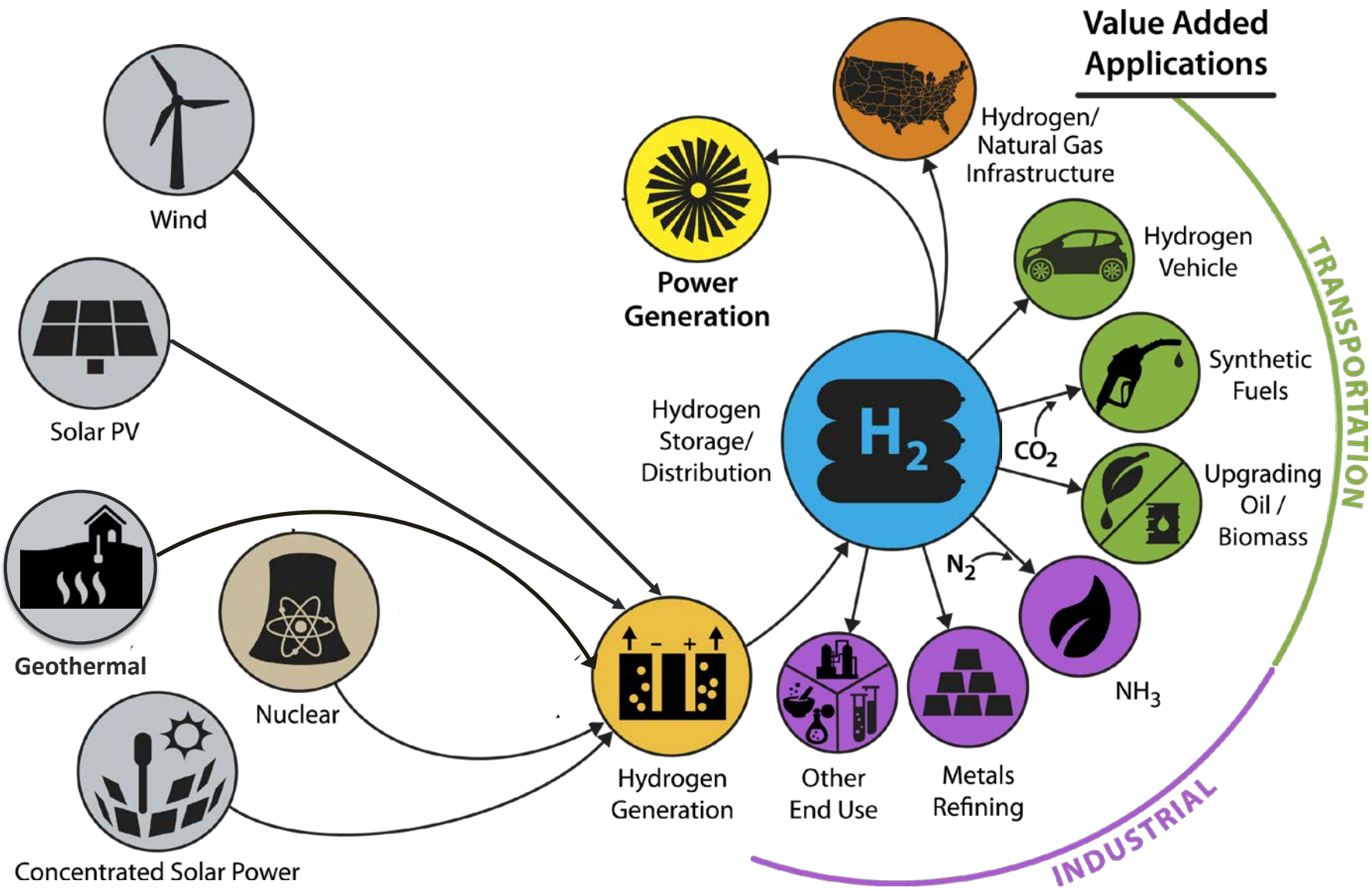
New World Trade Center using fuel cells

Conceptual H_2 at Scale Energy System



*Illustrative example, not comprehensive
Source: NREL

Conceptual H_2 at Scale Energy System



The Hydrogen Council: A Global Initiative

Launched in 2017

Position **hydrogen among the key solutions** of the energy transition at a global level by:

- **Showcase hydrogen technology and benefits** to the world
- **Accelerate investment** in the industry
- **Engage key stakeholders**

Commitment

$10.7 Billion
in the hydrogen and fuel cells

Formed by 13 companies

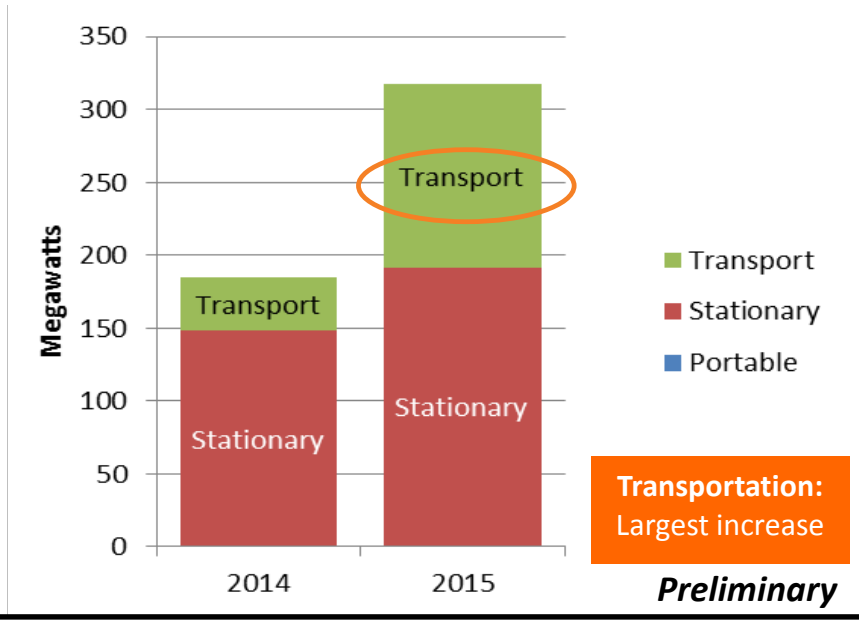
Air Liquide (co-chair) · ALSTOM · AngloAmerican · BMW GROUP · DAIMLER · ENGIE · HONDA · HYUNDAI · Kawasaki · Shell · THE LINDE GROUP · TOTAL · TOYOTA (co-chair)

Revenues of $1 Trillion

More information: [Hydrogen Empowers the Energy Transition- 2017 Report](http://hydrogeneurope.eu/)

Asia and Transportation Applications: Rapid Growth Areas

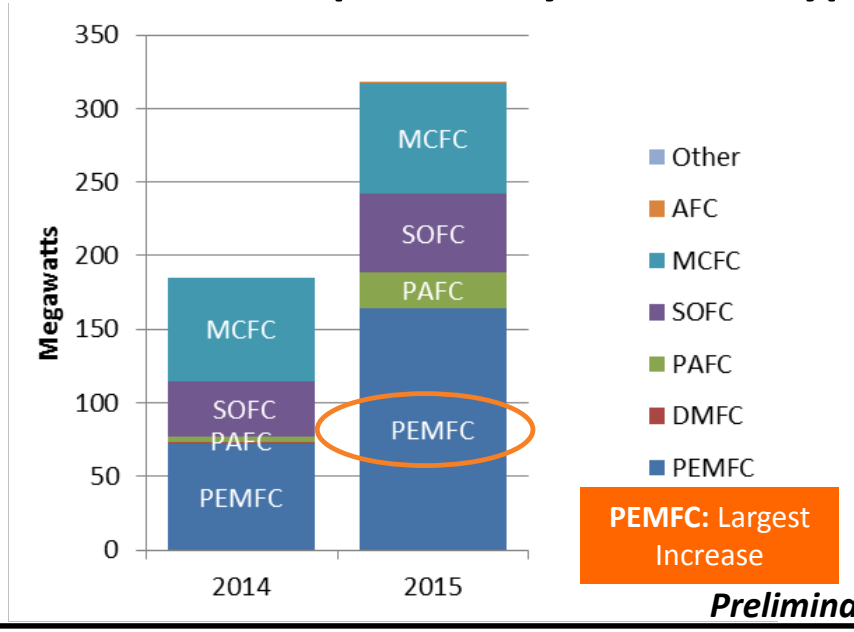
Worldwide Shipments by Application



Transportation: Largest increase

Preliminary

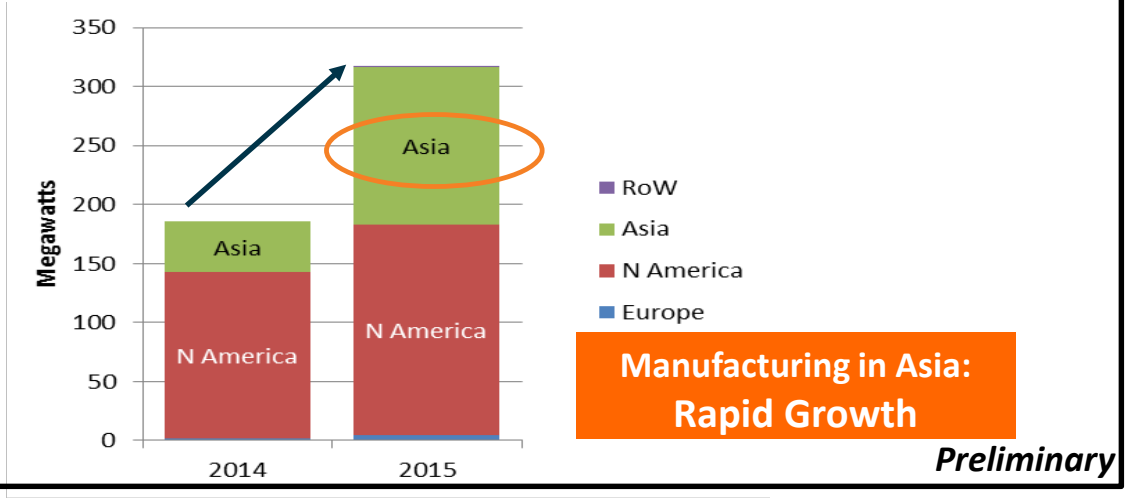
Worldwide Shipments by Fuel Cell Type



PEMFC: Largest Increase

Preliminary

Worldwide Shipments by Region of Manufacture



Manufacturing in Asia: Rapid Growth

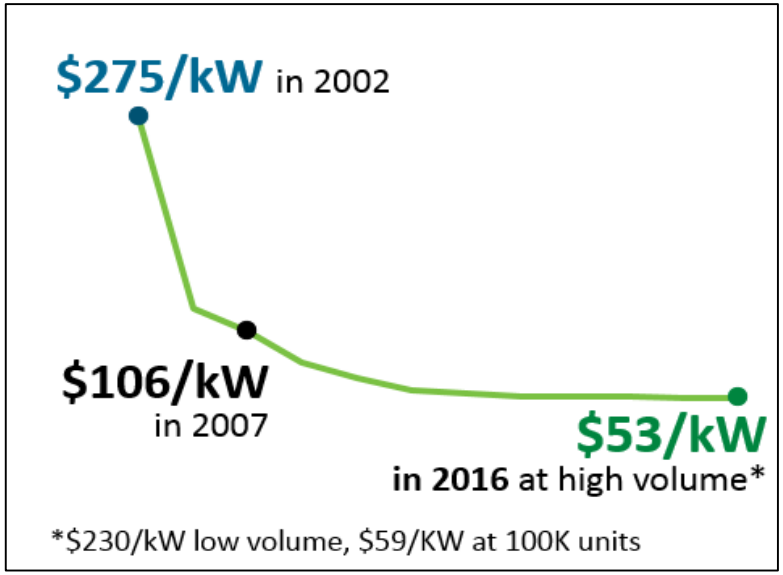
Preliminary

2. Focus on research and development that enables technology breakthroughs and maintains **domestic competitive advantage**

The Role of the Government Enabling Progress

Technology Innovation

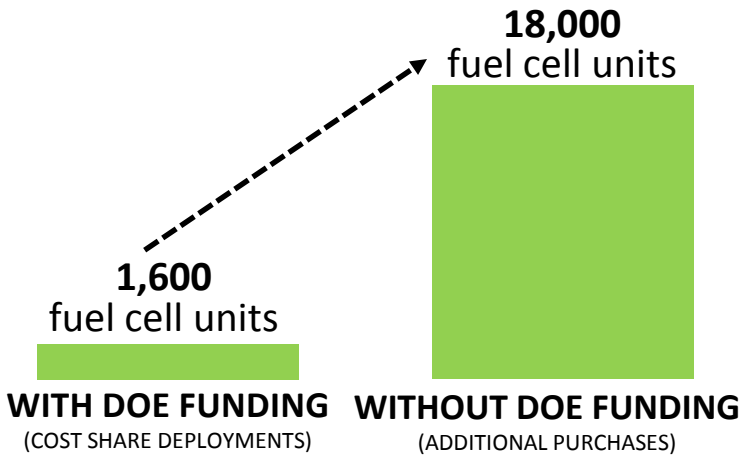
- **Cut fuel cell cost by 80%**



- **Quadrupled fuel cell durability**
- **Validated Research Advances**
  - More than **220 fuel cell cars**
  - Driving over **6 million miles**
  - **>360 mi** range, >**2X** efficiency of gasoline vehicles

Market Impact

- **Jumpstarted early markets by magnitude of more than 11X**



- **Catalyzed Additional Private Investment**

DOE Hydrogen and Fuel Cells Impact

Innovation

More than H_2 and fuel cells **580 patents**

enabled by FCTO funds

Market Impact

More than **30** Technologies available in today's market

enabled by FCTO funds

FCTO: Fuel Cell Technologies Office

Job Potential*

Jobs

360,000 to **675,000**

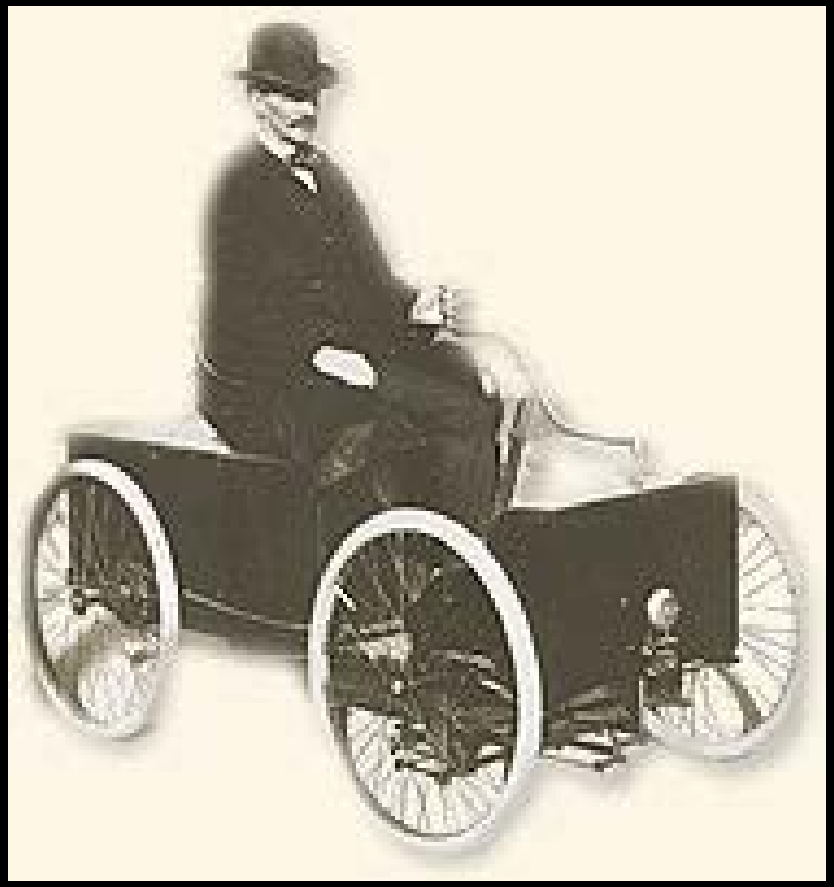
in fuel cells and hydrogen

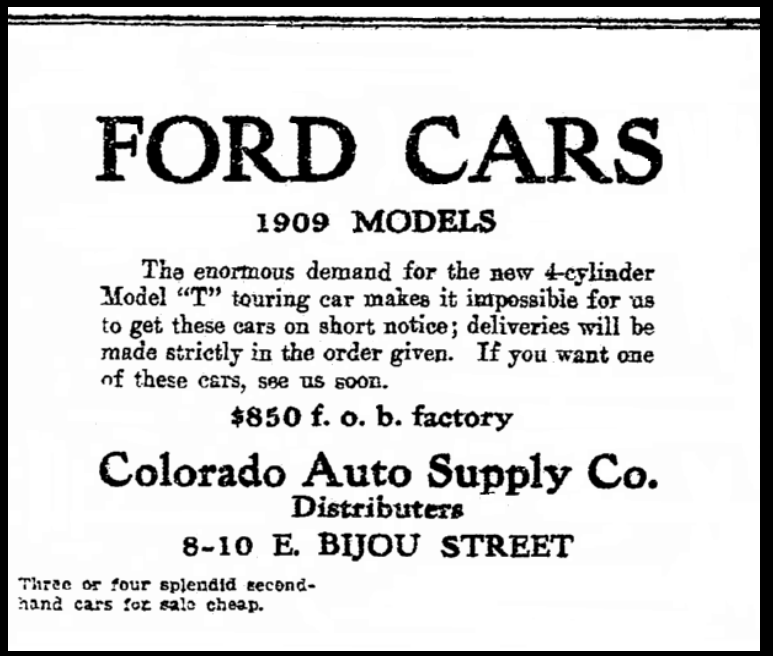
Job gains across **41 industries**

*2008 DOE Employment Study currently being updated

What can we learn from history?

Henry Ford's Quadricycle in 1896 to Model T in 1908





FORD CARS

1909 MODELS

The enormous demand for the new 4-cylinder Model "T" touring car makes it impossible for us to get these cars on short notice; deliveries will be made strictly in the order given. If you want one of these cars, see us soon.

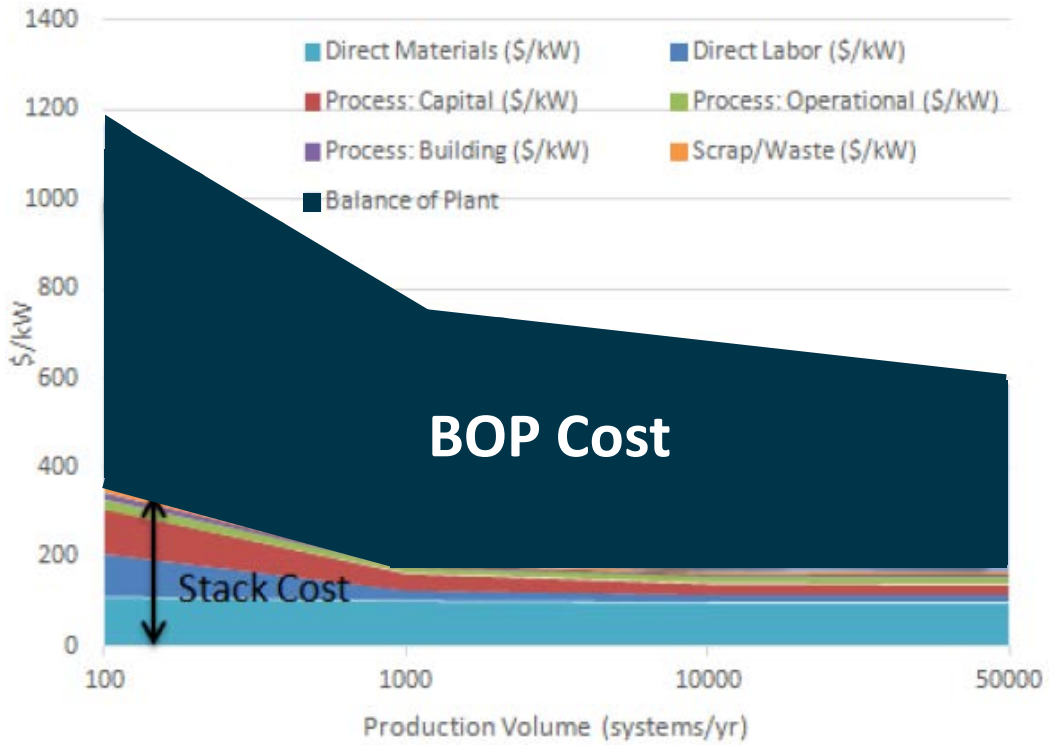
$850 f. o. b. factory

Colorado Auto Supply Co.
Distributers
8-10 E. BIJOU STREET

Three or four splendid second-hand cars for sale cheap.

Combined Heat & Power (CHP) System – SOFC

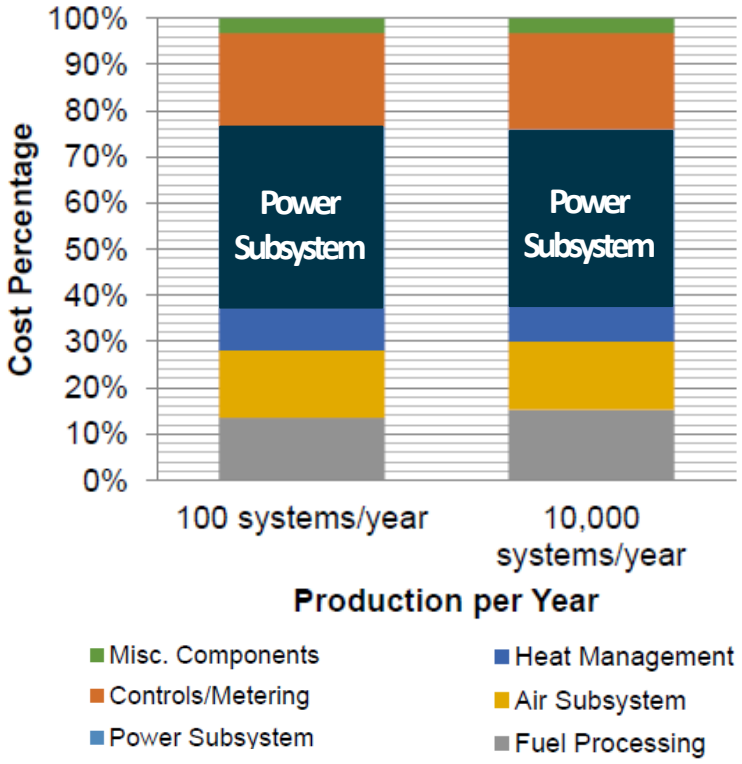
Overall CHP System Cost Breakdown (100 kWe CHP System- SOFC)



Over 60% of overall system cost

- At lower sizes, BOP portion increases with volume
- At higher sizes, BOP portion remains fairly stable

BOP Cost Breakdown (100 kWe CHP System- SOFC)



40% of BOP cost

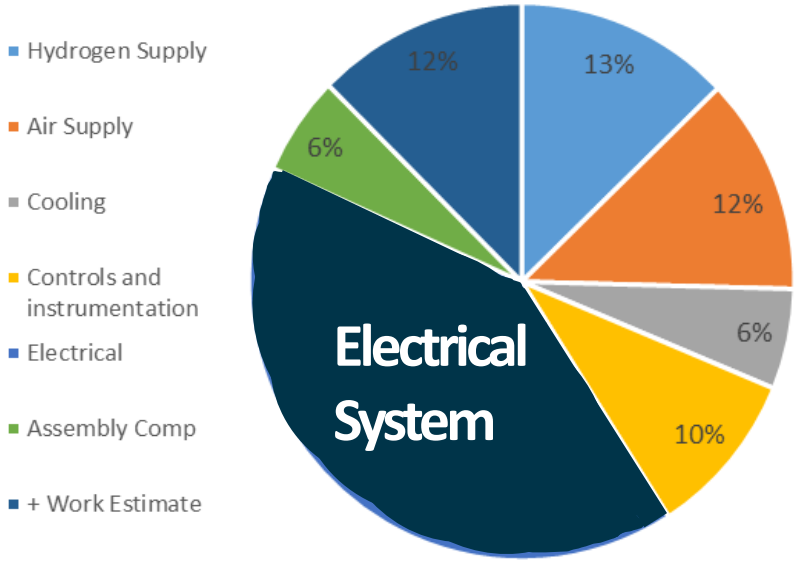
- Power inverter is largest portion (85%) of power subsystem cost
- Controls/Metering #2 largest BOP cost

Reference: LBNL, A Total Cost of Ownership Model for Solid Oxide Fuel Cells in Combined Heat and Power and Power-Only Applications (Dec. 2015)

Stationary PEM Fuel Cell System BOP Costs

Back Up Power System

BOP Cost Breakdown (10 kW, 1,000 units/yr)

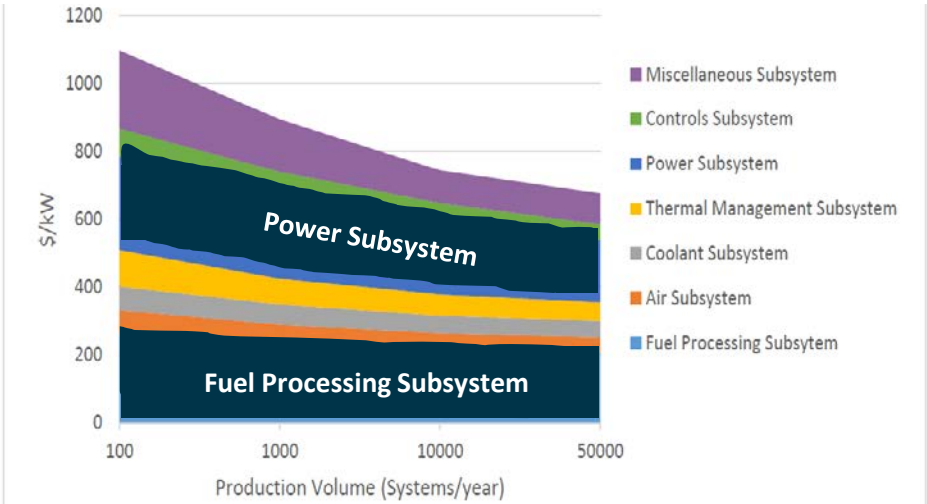


Over 40% of BOP cost
due to electrical system, primarily the DC/DC converter

Reference: Battelle, Manufacturing Cost Analysis of PEM Fuel Cell Systems for 5- and 10-kW Backup Power Applications (October 2016)

Combined Heat and Power System

BOP Cost Breakdown (100kW)



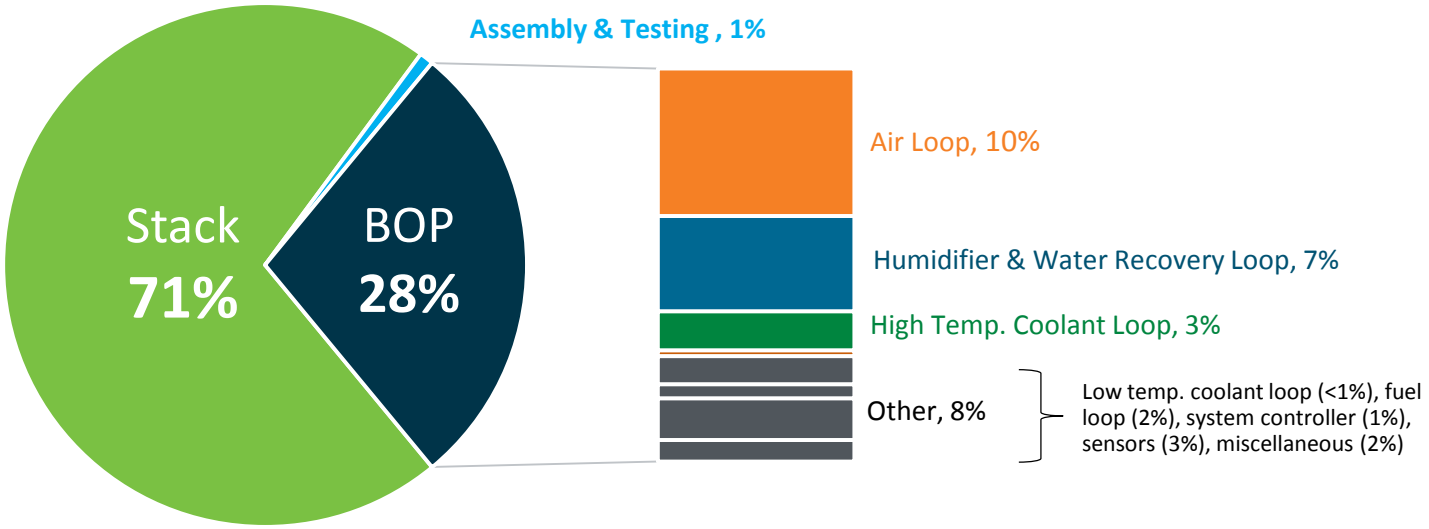
Power and Fuel Processing Subsystems are
60% of total BOP costs

Reference: LBNL, A Total Cost of Ownership Model for Low Temperature PEM Fuel Cells in Combined Heat and Power and Backup Power Applications (2017 Update)

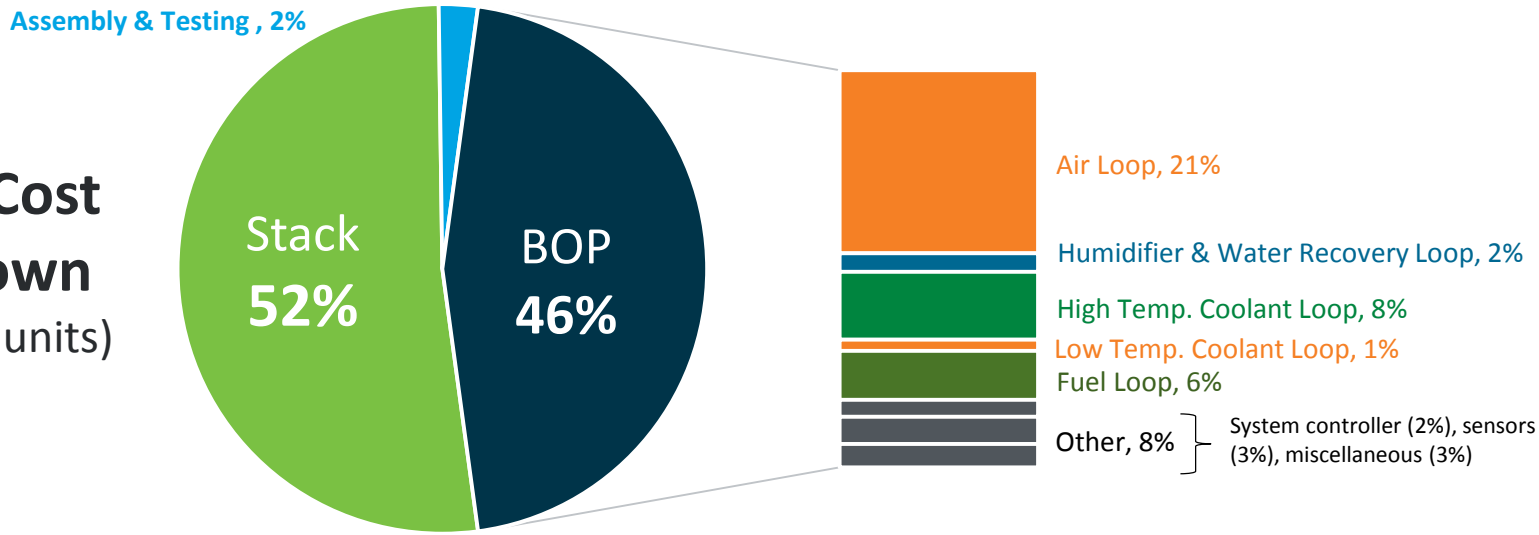
BOP is 40-60% of the overall stationary fuel cell system cost

Automotive Fuel Cell System- PEM

System Cost Breakdown
(at 1,000 units)



System Cost Breakdown
(at 500,000 units)



At high volume BOP is almost half of total system cost and the air loop is the largest BOP cost

Reference: SA, Mass Production Cost Estimation of Direct H2 PEM Fuel Cell Systems for Transportation Applications: 2016 Update

3. Collaboration is key to identify synergies and solutions to challenges

New DOE Efforts to enable robust supply chain

Integrated Network of Regional Technical Centers

OFCC
OHIO FUEL CELL COALITION

Activities
(Examples)

- Hold supply chain exchanges
- Promote cooperation between suppliers & developers, and standardization of component specifications

Locations

- East Coast (CCAT)
- Midwest (OFCC)
- Central States (NREL)
- West Coast (UC Irvine)

Global Competitiveness Analysis
including:

- Global Cost Breakdown
- Design for Manufacturing & Assembly
- Value Stream Mapping

GLWN.org

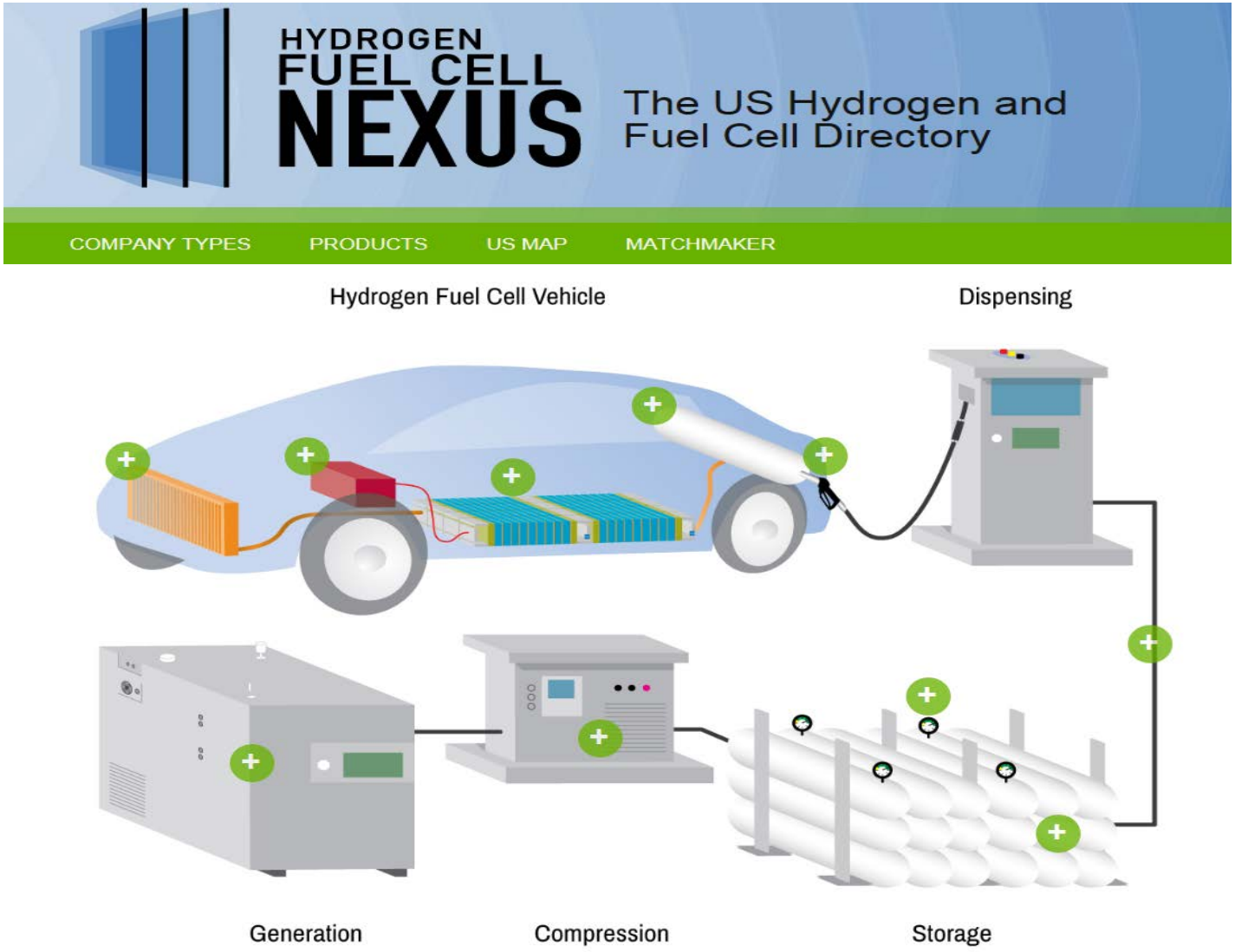
Fuel Cell and H_2 Opportunity Center

- Comprehensive **online database**
- **Project activities include:**
  - Encourage **supplier engagement**
  - Release and maintain **public directory**
  - Conduct **outreach campaign** (social media. etc.)

Virginia Clean Cities

JAMES MADISON UNIVERSITY

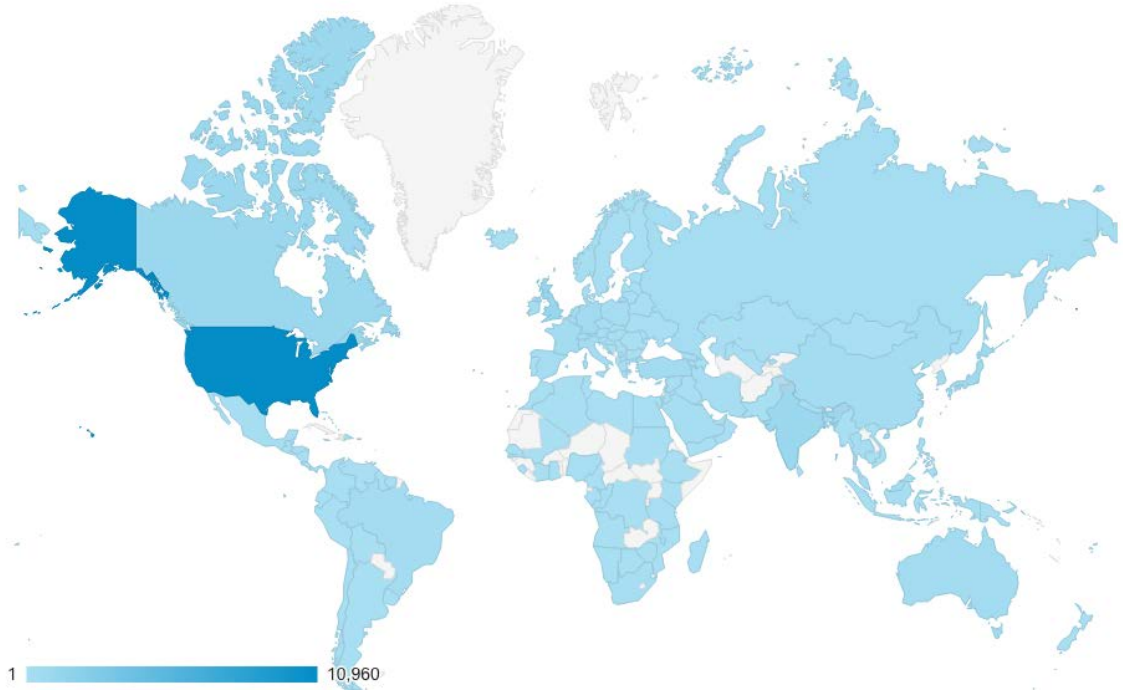
Tools, Models and Databases Online



www.HFCnexus.com

Supplier engagement & collaboration & information readily and publicly accessible

H_2Tools: One-stop for H_2 safety knowledge



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

- Site visit tracking shows a **global reach: 50%** of visits are **international!**
- Over **31,000 site visits** in the first year alone
- Training resource **translated into Japanese**

Enabling dissemination of safety information around the world

Military and Veterans Outreach

Activities

- **Engagement** with potential candidates and military leadership
  - Job transition events
  - Web based resources
  - Information transfer
- **Coordination** with other agencies
  - Dept. of Defense
  - Veterans Affairs

Findings

- **More than 100,000 qualified candidates** identified
- **Unique skill set** identified
  - Disciplined and well trained
  - Dedicated, mission oriented, team players
  - Follow instructions and orders
  - Keen interest in renewable energy
- **Translating military qualifications into civilian positions** is critical

Military and Veterans: superior talent pool, untapped human resource

Workshop Objectives

- Identify **synergies between fuel cell systems with a focus on Balance of Plant (BOP)**
- Enable a **robust supply chain**
- Identify research & development **needs for BOP components and systems**

Save the date: Annual Merit Review (AMR)

June 5-9, 2017- Washington DC

2018 Summer: AMR + Industry Expo!

Thank You

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