

U.S. Hydrogen and Fuel Cell Overview

Dr. Sunita Satyapal, Director - Fuel Cell Technologies Office
U.S. Department of Energy

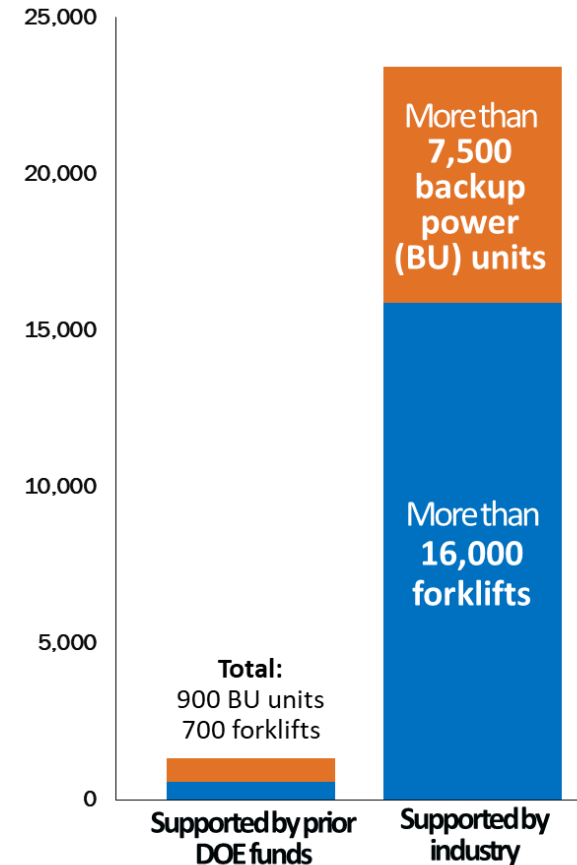
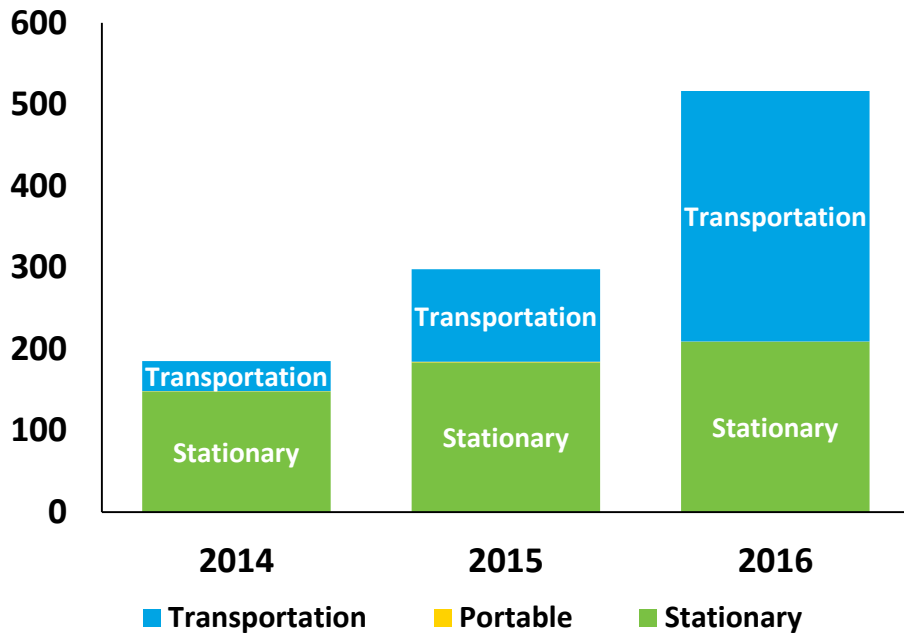
IPHE Forum, Yokohama, Japan

May 8, 2018



Unprecedented Growth in the Fuel Cell Industry

Total power (in MW) shipped by application
Growth in Transportation



500 MW fuel cell power shipped worldwide

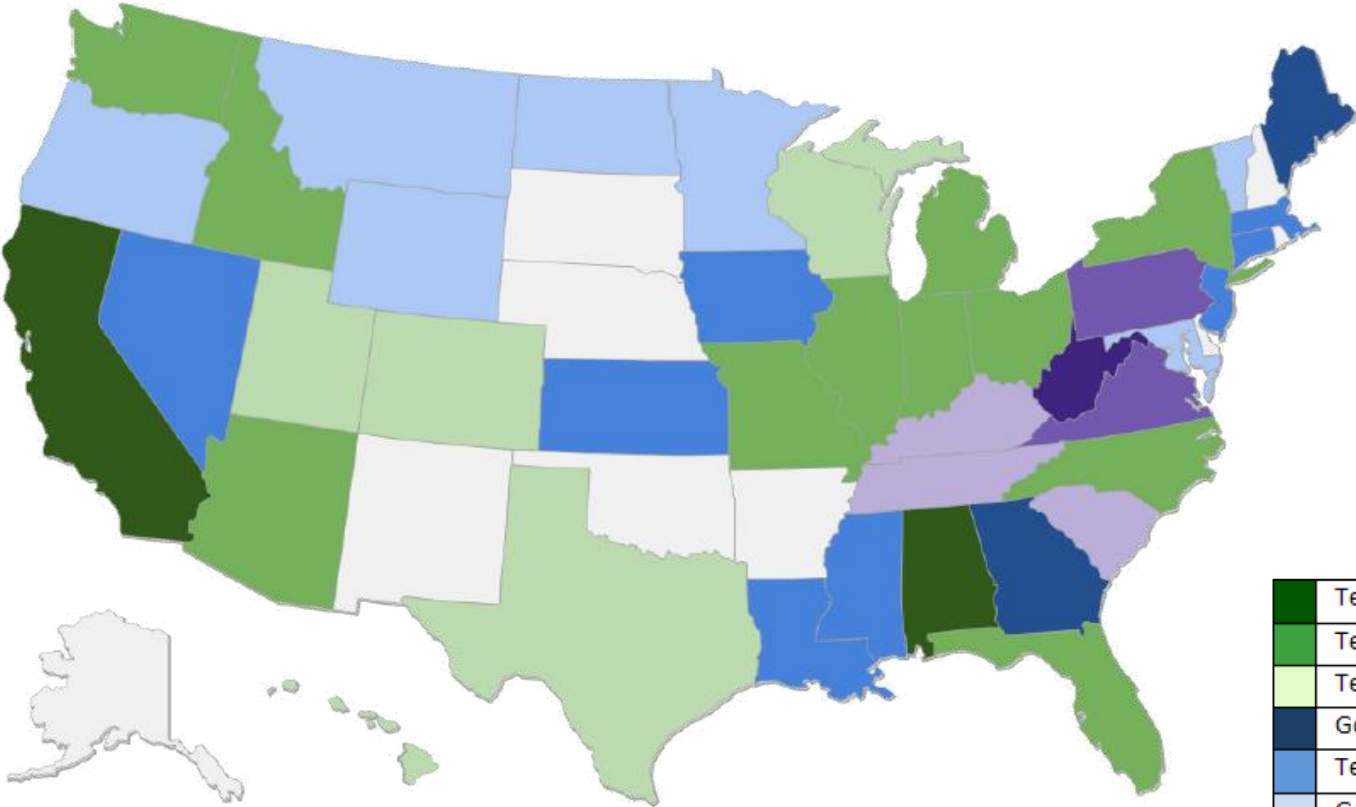
62,000 fuel cell units shipped worldwide

Approximately **\$1.6 Billion** fuel cell revenue

Source: DOE Fuel Cell Technologies Market Report. Available at: <https://energy.gov/eere/fuelcells/market-analysis-reports>

Fuel cells operating all over the U.S.

Fuel cells used for backup power in more than 40 states



Over 235MW
in stationary
fuel cell power
installed

Over 8,000 backup power units
deployed or on order

Dark Green	Telecom, Government, Railroad, Utility sites
Green	Telecom, Government, Railroad sites
Light Green	Telecom and Government sites
Dark Blue	Government, Railroad, Utility sites
Blue	Telecom sites
Light Blue	Government sites
Dark Purple	Railroad sites
Dark Blue-Gray	Utility sites
Medium Purple	Government and Railroad sites
Light Purple	Telecom and Railroad sites

Source: DOE State of the States: Fuel Cells in 2016 Report

Forty years later for the first time in history....



Honda Clarity

Nearly **4,500** | **sold or leased**
in the United States



As of Dec 2017

Hyundai Tucson Fuel Cell SUV

Commercial fuel cell electric cars are here

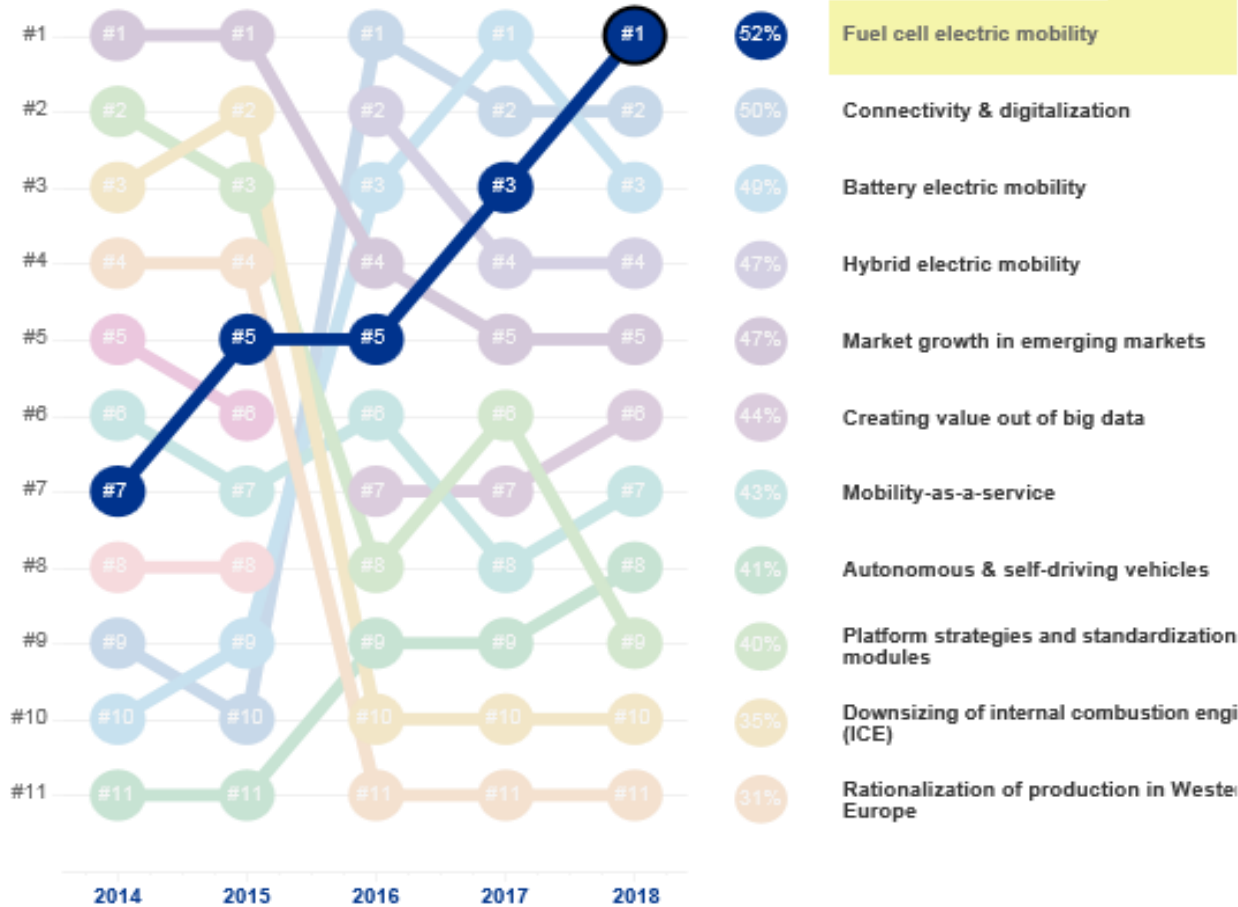


Toyota Mirai

- ✓ No petroleum, no pollution
- ✓ Refuels in minutes
- ✓ More than 360 mi driving range
- ✓ Over 60 mpgge

Global Automotive Executive Survey Results

Global Automotive Executive Key Trends until 2025



- Fuel cell electric mobility
- Connectivity & digitalization
- Battery electric mobility
- Hybrid electric mobility
- Market growth in emerging markets
- Creating value out of big data
- Mobility-as-a-service
- Autonomous & self-driving vehicles
- Platform strategies and standardization modules
- Downsizing of internal combustion engi (ICE)
- Rationalization of production in Weste Europe

Fuel Cell Electric Mobility ranked #1 key trend among executives

■ OEM captive financing and leasing ■ Innovative urban vehicle design concepts

Note: Percentage of executives rating a trend as extremely important

Source: KPMG's Global Automotive Executive Survey 2018 | © KPMG Automotive Institute

	2014	2015	2016	2017	2018
n=	200	200	800	953	907

Source: KPMG Global Automotive Executive Survey 2018

Heavy Duty Vehicle Applications Emerging

Fuel cell delivery and parcel trucks starting deliveries in CA and NY



Industry demonstrates first heavy duty fuel cell truck in CA



Fuel cell buses in CA surpass 17M passengers

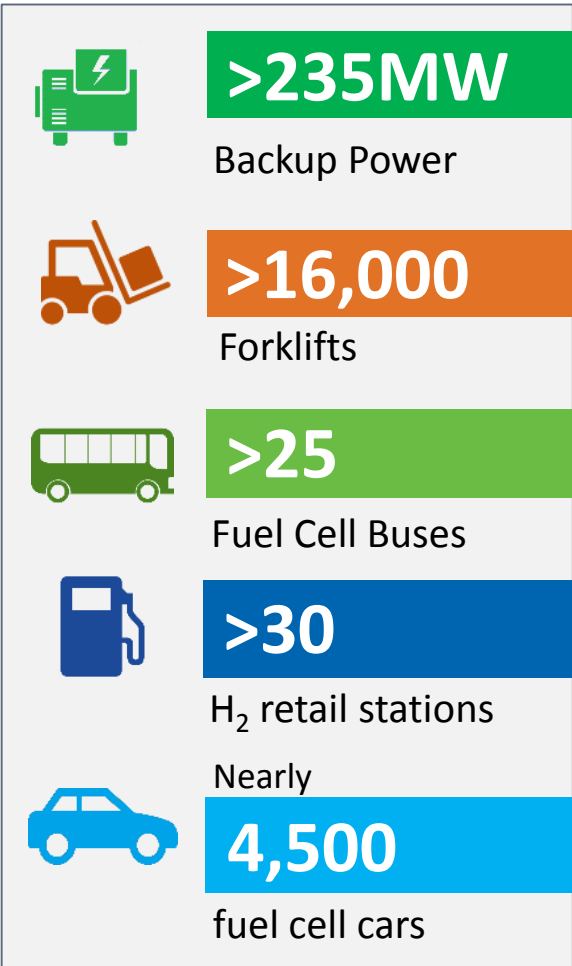


ZH2: U.S. Army and GM collaboration First of its kind

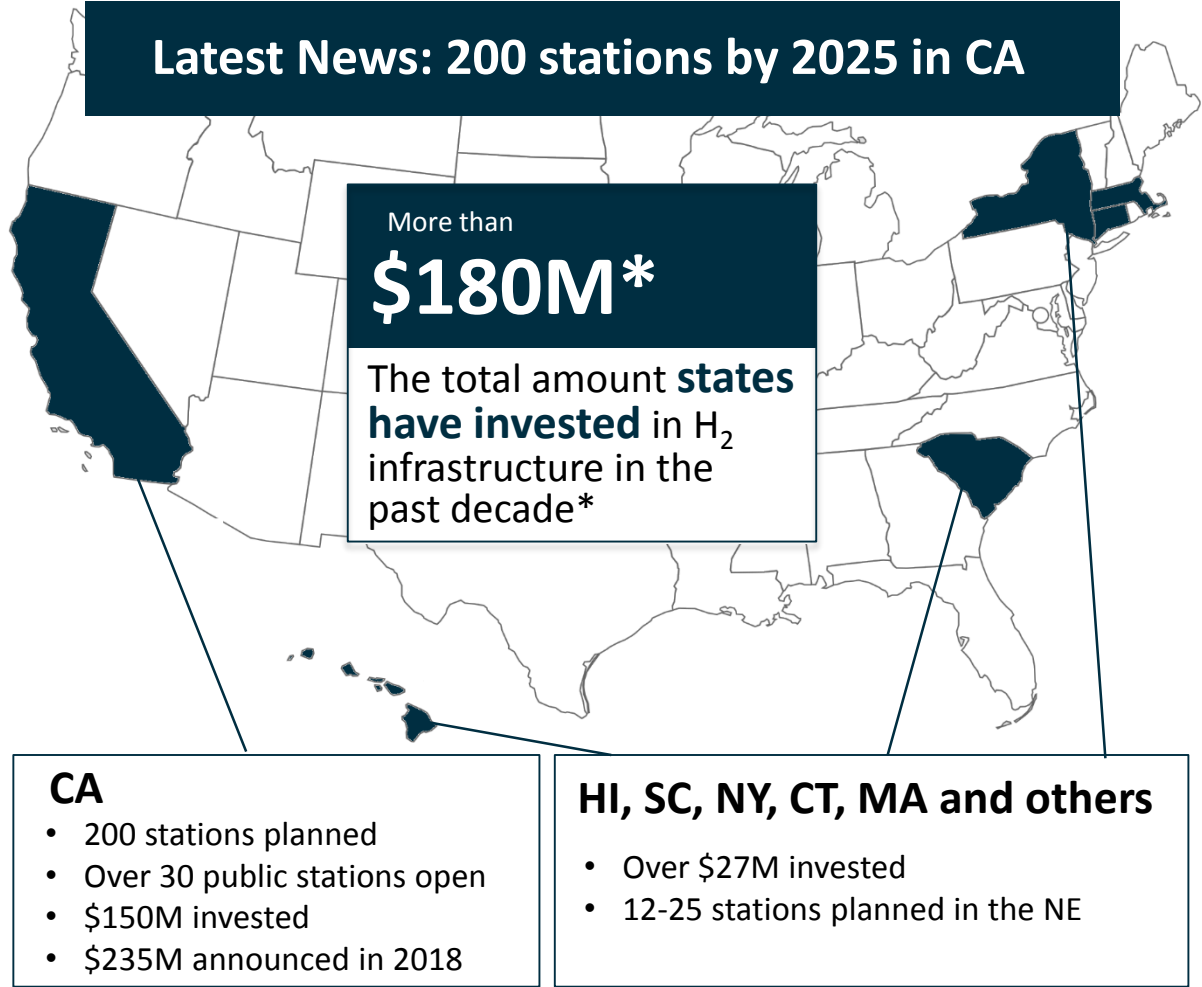


Hydrogen and Fuel Cell Applications in the U.S.

U.S. Snapshot



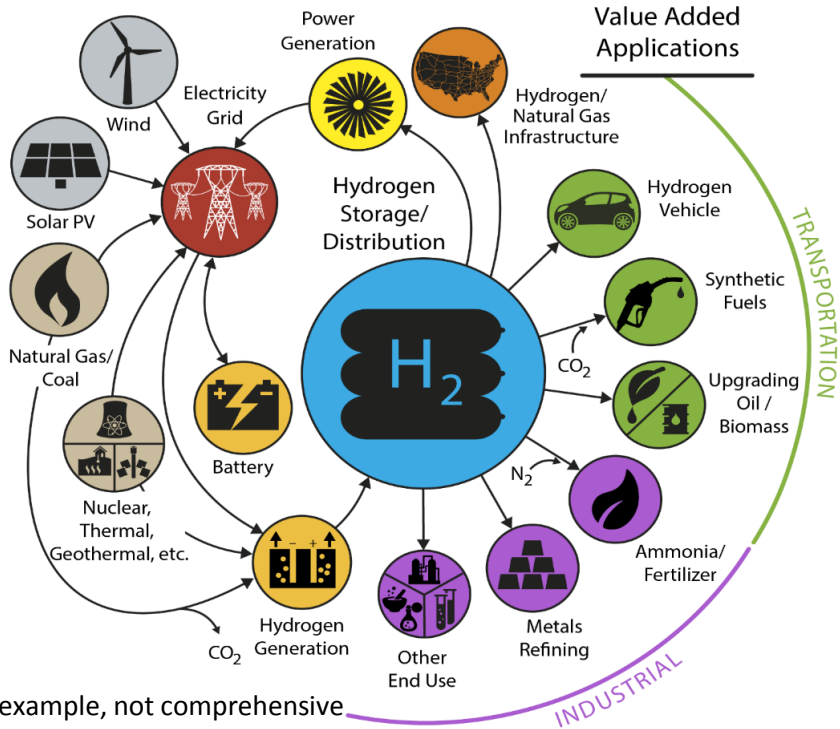
Cumulative State Funding



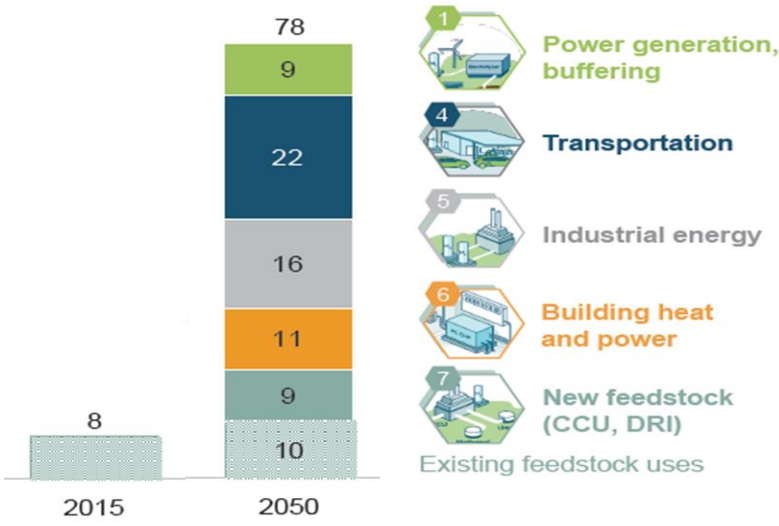
*Excludes recent announcement from CA to invest \$235M in electric vehicles

Focus: H2@Scale & Alignment with U.S. Priorities

Hydrogen can enable use of diverse domestic resources and address priorities of energy security, energy storage, resiliency and economic prosperity. R&D is required. Aligns with national & DOE priorities.



Potential for Global H2 Demand
10-fold increase by 2050



Global energy demand supplied with hydrogen, EJ

Source: Hydrogen Council

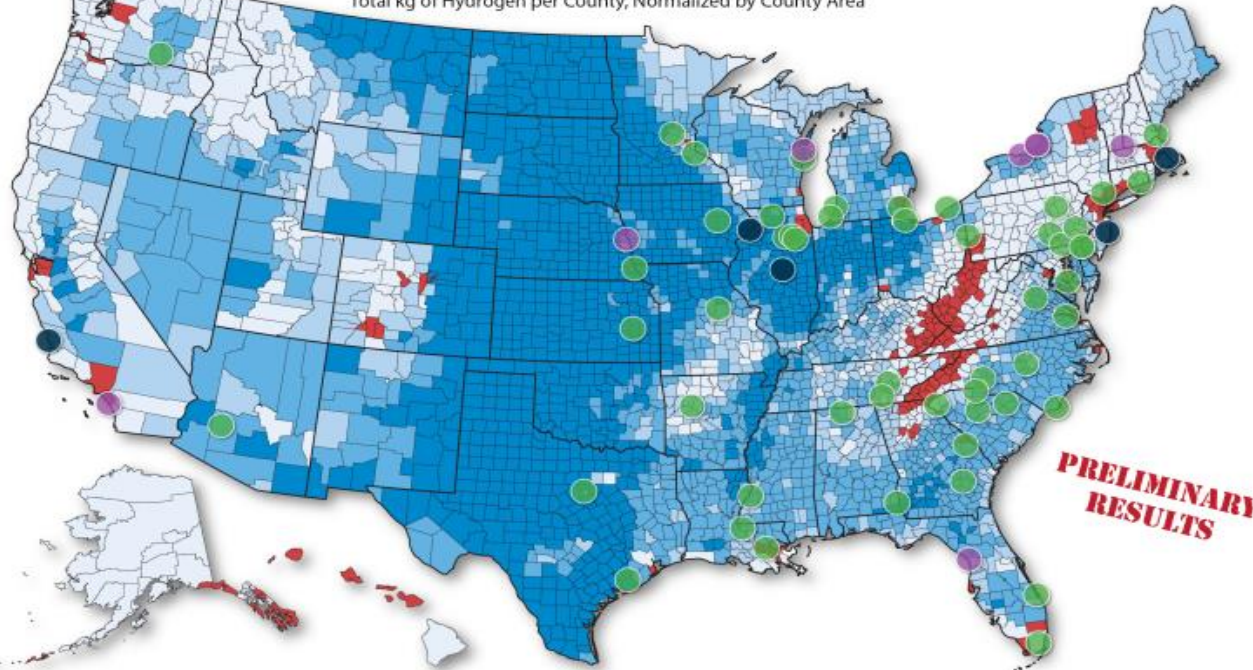
*Illustrative example, not comprehensive
Source: NREL

“Agencies should invest in early-stage, innovative technologies that show promise in harnessing American energy resources safely and efficiently.”

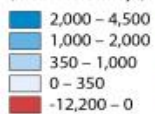
-Aug. 17, 2017 OMB/OSTP Memo

H2@Scale: Nationwide Resource Assessment

Hydrogen Potential From Photovoltaic and Onshore Wind Resources Minus
Total Hydrogen Demand for the Industrial & Transport Sectors
Total kg of Hydrogen per County, Normalized by County Area



Hydrogen
(metric ton/m²/yr)



Nuclear Energy Plants



This analysis represents potential generation from utility-scale photovoltaics and onshore wind resources minus total hydrogen demand from the industrial sector: refineries, biofuels, ammonia and natural gas systems (metals are not included) and the transport sector: light duty vehicles and other transport. The data has been normalized by area at their respective spatial scales, and then summarized by county.

Data Source: NREL analysis
Robson, A. Preserving America's Clean Energy Foundation. Retrieved March 23, 2017, from <http://www.thirdway.org/report/preserving-americas-clean-energy-foundation>

This map was produced by the
National Renewable Energy Laboratory
for the U.S. Department of Energy.
Nicholas Gilroy, March 27, 2017



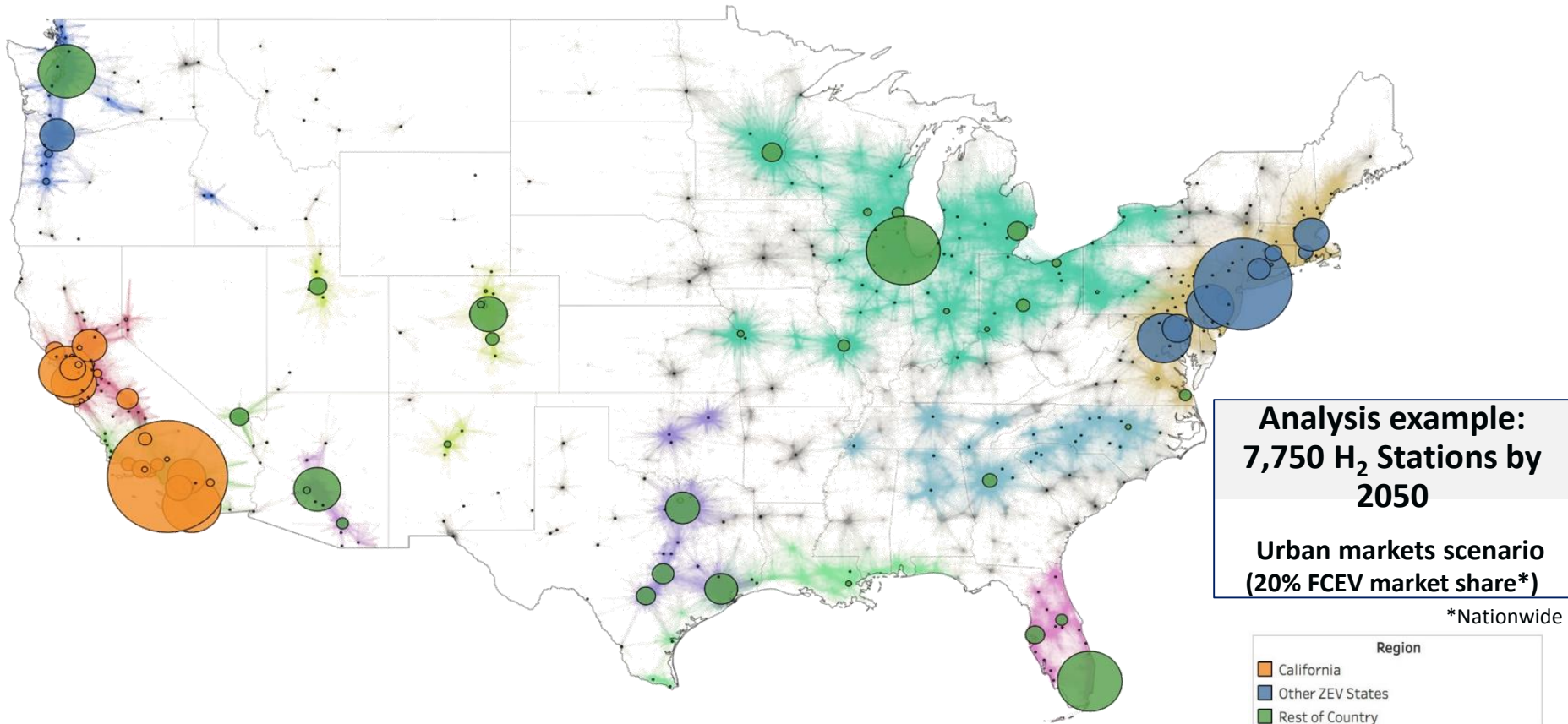
Labs assess
resource
availability. Most
regions have
sufficient
resources.

Red: Only regions where
projected industrial &
transportation demand
exceeds supply.

Lab PIs: Mark Ruth, Bryan Pivovar, Richard Boardman, et al

Hydrogen Station Analysis - Example

NREL's Station Rollout Scenario Analysis in support of H₂USA



Examples of variables considered in scenarios:

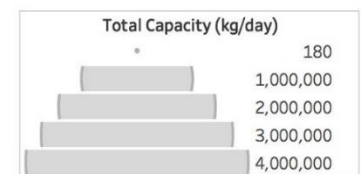


Consumer adoption



Station Expansion Network

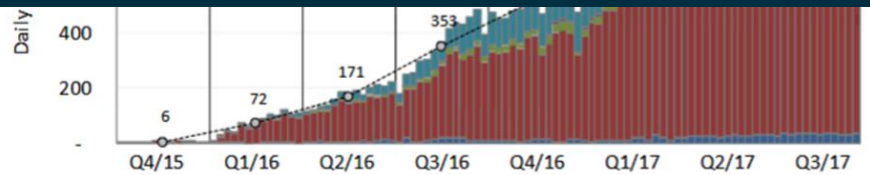
Source: Marc Melaina, et al, NREL



Growing Demand for Hydrogen: FCEVs



Hydrogen demand for FCEVs has steadily increased since 2015.



Source: NREL



Over 30 retail stations in California
4 stations built in Northeast



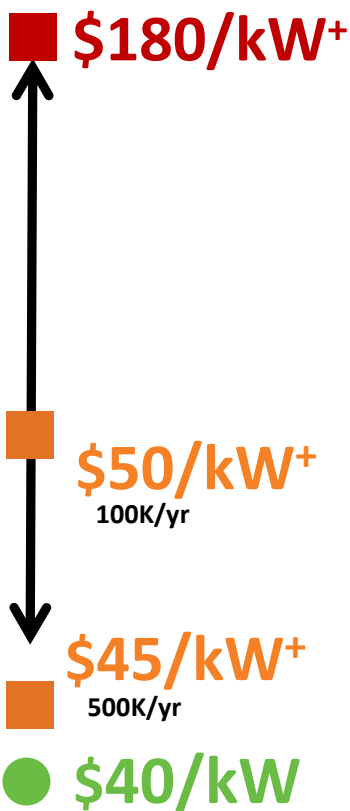
- Retail stations currently reach **80% utilization in average of 5 years.**¹
- High-throughput hydrogen fueling stations (e.g. **1,000 kg/day**) of interest.
- **Over 2,000 tonnes/year of renewable hydrogen needed by 2022** to satisfy FCEV demand.¹
- Emergence of **medium- and heavy duty fleets would bolster demand.**

¹<http://www.energy.ca.gov/2017publications/CEC-600-2017-011/CEC-600-2017-011.pdf>

DOE Cost Status and Targets for R&D

Fuel Cell R&D

System

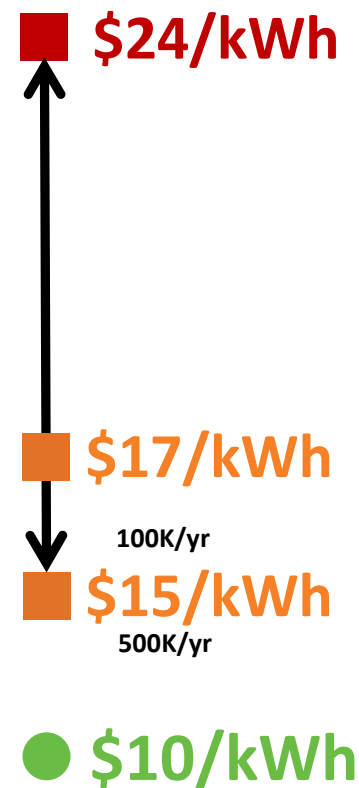


Hydrogen R&D

Production, Delivery & Dispensing



Onboard Storage (700-bar compressed system)



● **Targets**

■ **High-Volume Projection**

■ **Low-Volume Estimate**

*Based on Electrolysis **Based on NG SMR + Preliminary, updates underway
 Onboard storage cost status from DOE Program Record 15013

Note: Graphs not drawn to scale and are for illustration purposes only.
 Data through 2017

Examples of Areas Requiring R&D

Fuel Cells

Bipolar Plates
Membranes
BOP
MEA
Frames/Gaskets
GDLs



Focusing on...



**Low and Non PGM Catalysts,
Alkaline Membranes**

H₂ Station

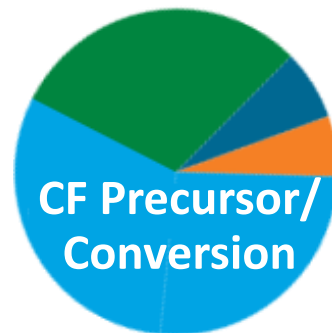
Storage
Cooling
Dispensing
Other



**Advanced Compression
Alternate Approaches**

H₂ Storage

BOP/Assembly
Other processing
Resin



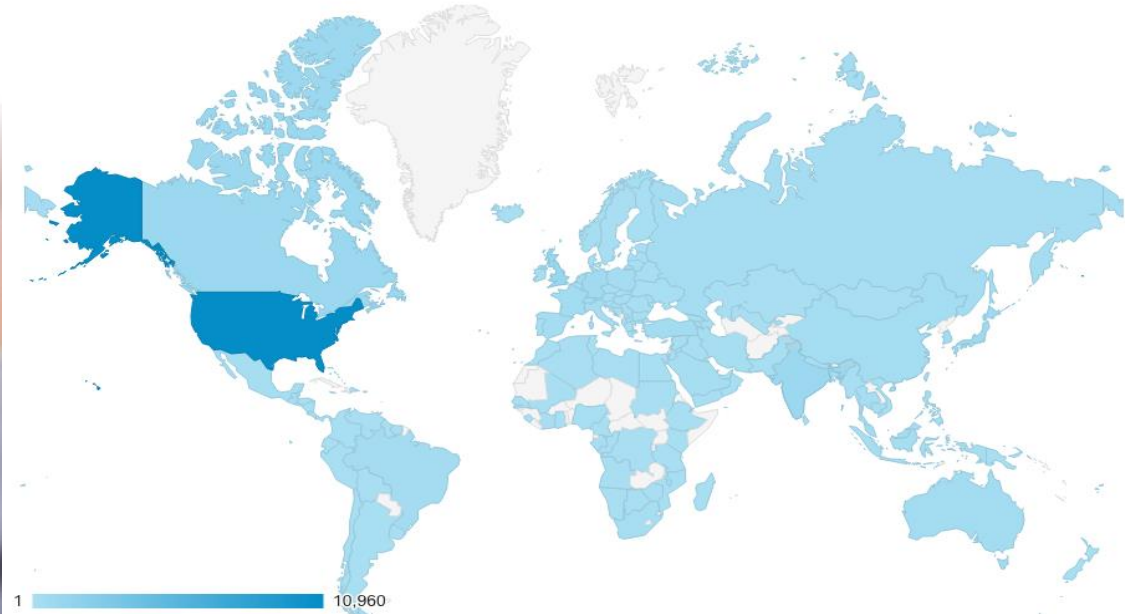
**Low Cost Carbon Fiber (CF)
Long term Materials Approaches**

Collaboration Tools: H₂ Safety Information Sharing

H₂Tools.org : A one stop resource for hydrogen safety



h2tools.org



- Includes resources on **safety** best practices, **first responder training**, and **H₂ codes & standards**
- Site visit tracking shows a **global reach: 50% of visits have been international after launch**
- Roughly **300,000 site visits**
- Training resource **translated into Japanese. Interest in other languages.**

First time ever Multiple Agencies at Annual Merit Review (AMR) and National Hydrogen and Fuel Cell Forum

June 12-15, 2018
Washington, DC
www.hydrogen.energy.gov

Plans

- **Identifying priorities for reducing barriers to deployment of infrastructure**
- **Identifying resources for H₂**
- **Roadmap and goal-setting underway in FY18-19**
- **Continue early-stage R&D and leverage partnerships**

Thank You

Dr. Sunita Satyapal

Director

Fuel Cell Technologies Office

Sunita.Satyapal@ee.doe.gov

energy.gov/eere/fuelcells

Life-cycle Petroleum Use- Today's Cars

Low, Medium & High Petroleum Energy/Mile for 2015 Technology



Fuel Cell Electric



Battery Electric



Extended-Range Electric

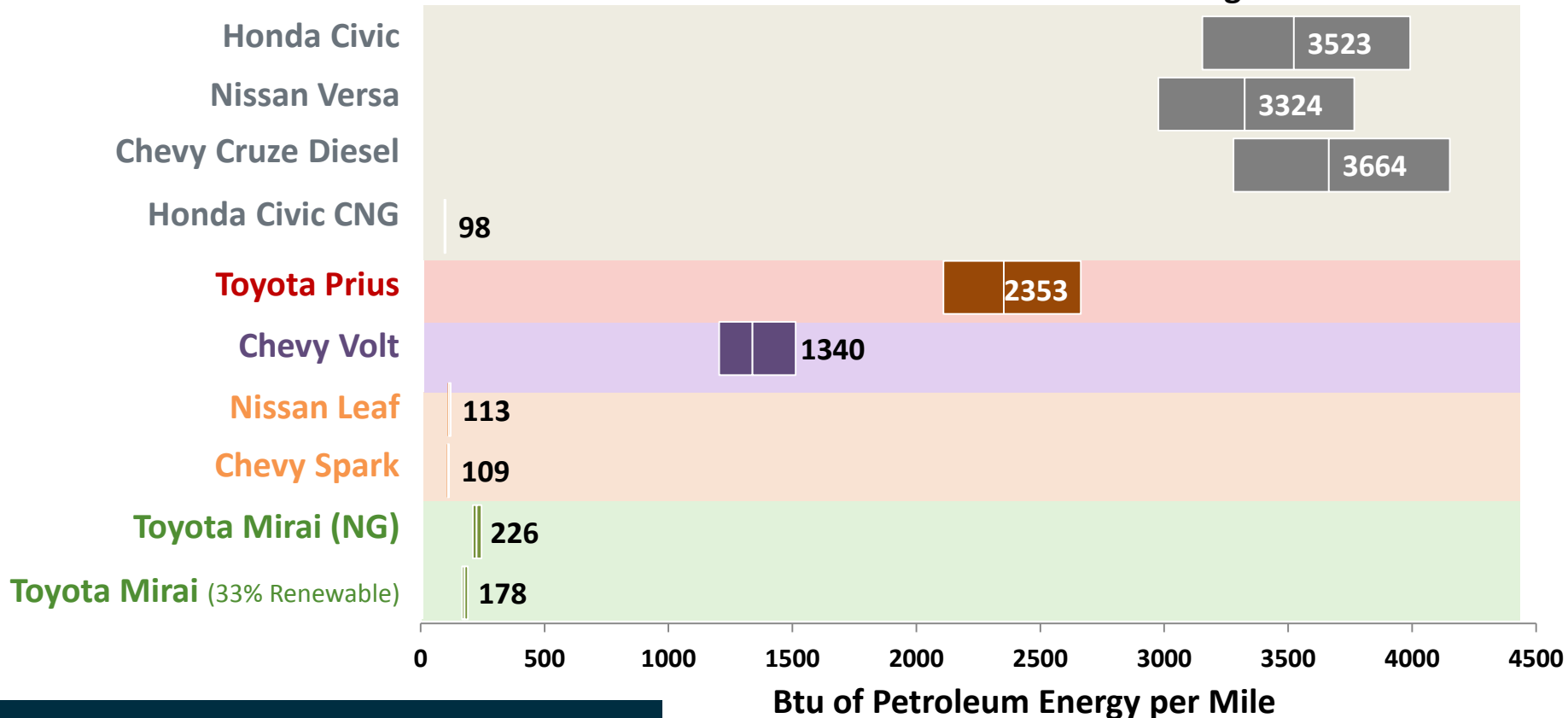


Hybrid Electric



Internal Combustion Engine

Current gasoline ICEV: 4300



DOE cross office analysis example

Source: Program Record 16004 (https://www.hydrogen.energy.gov/pdfs/16004_life-cycle_ghg_oil_use_cars.pdf)

Life-cycle Emissions- Today's Cars

Low, Medium & High Emissions/Mile for 2015 Technology



Fuel Cell Electric



Battery Electric



Extended-Range
Electric

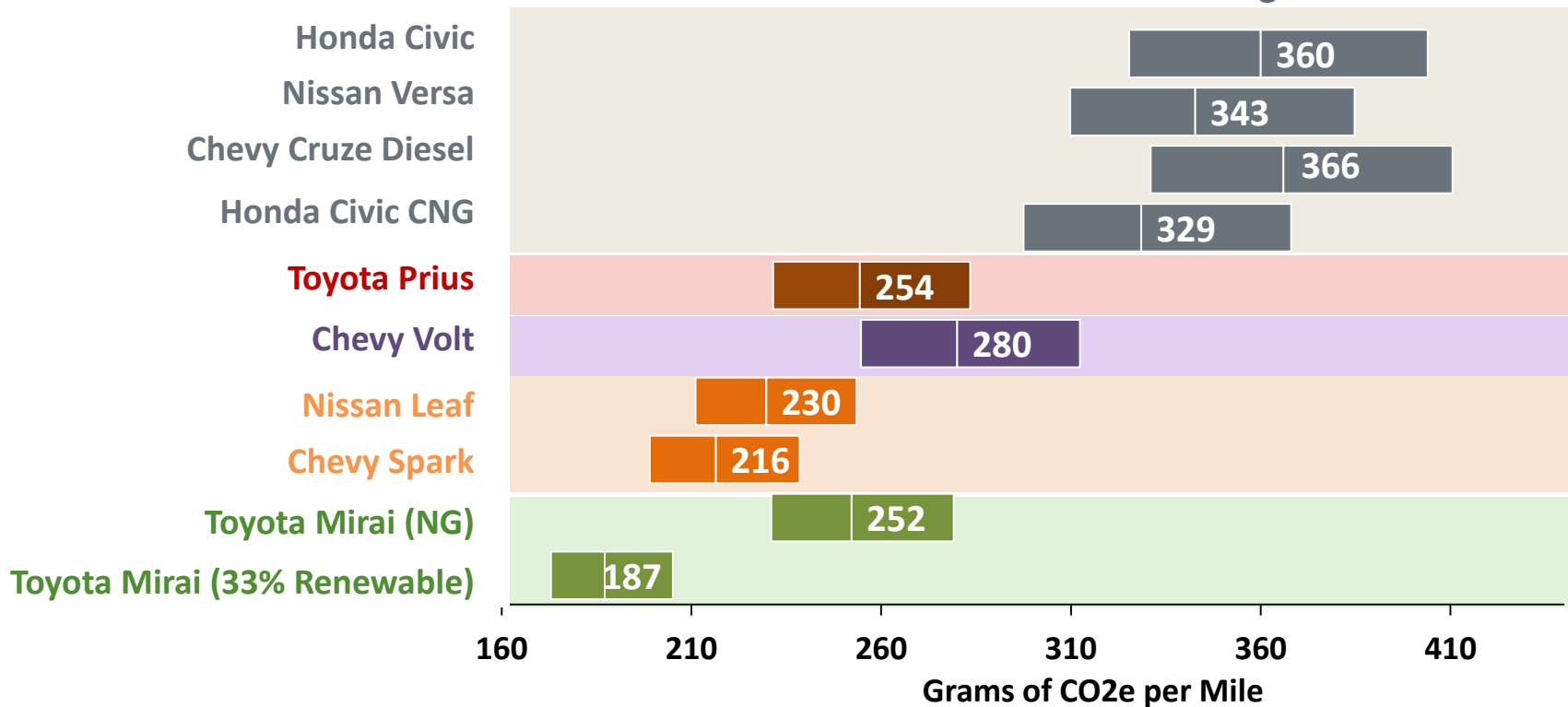


Hybrid Electric



Internal Combustion Engine

Current gasoline ICEV: ~450



DOE cross office analysis example

Source: Program Record 16004
https://www.hydrogen.energy.gov/pdfs/16004_life-cycle_ghg_oil_use_cars.pdf