U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

H2@Scale and H2@Rail: Progress, Opportunities and Needs

Dr. Sunita Satyapal – Director, Fuel Cell Technologies Office

H2@Rail Workshop

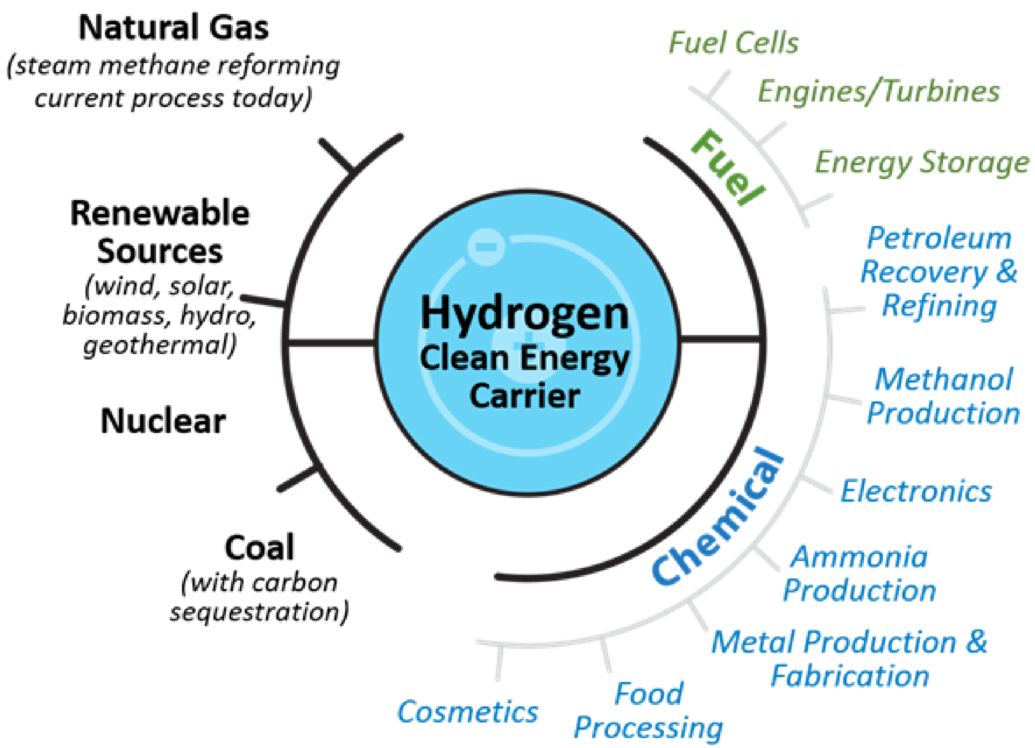
Lansing, MI – March 26, 2019

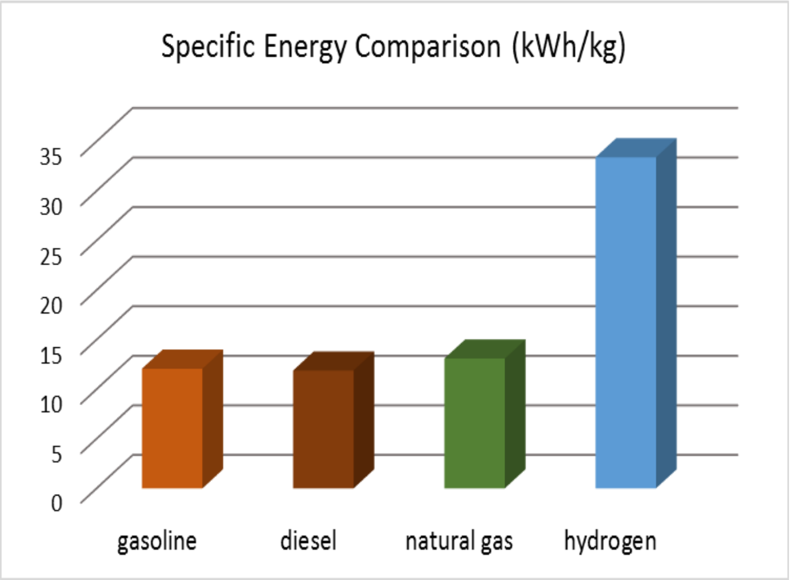

Hydrogen is Part of an All of the Above Portfolio

H_2 can be produced from diverse domestic sources

Many applications rely on or could benefit from H_2

Very High Specific Energy



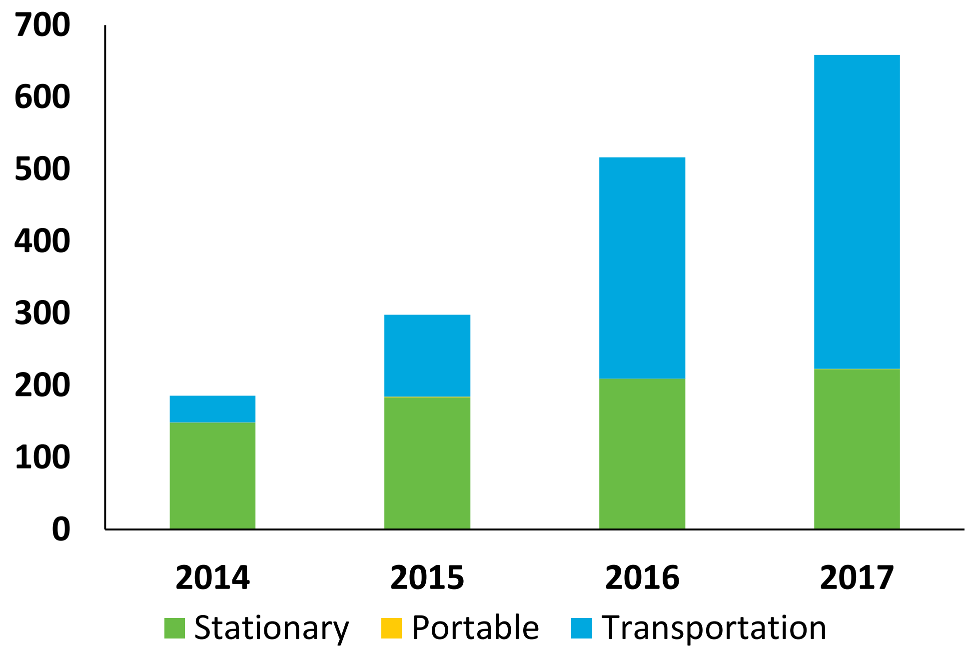


About *three times* more energy by mass than gasoline. But worse in terms of volume.

Clean , sustainable, versatile, and efficient energy carrier

An exciting time for hydrogen and fuel cells

650 Fuel Cell Power Shipped (MW) worldwide in 2017*



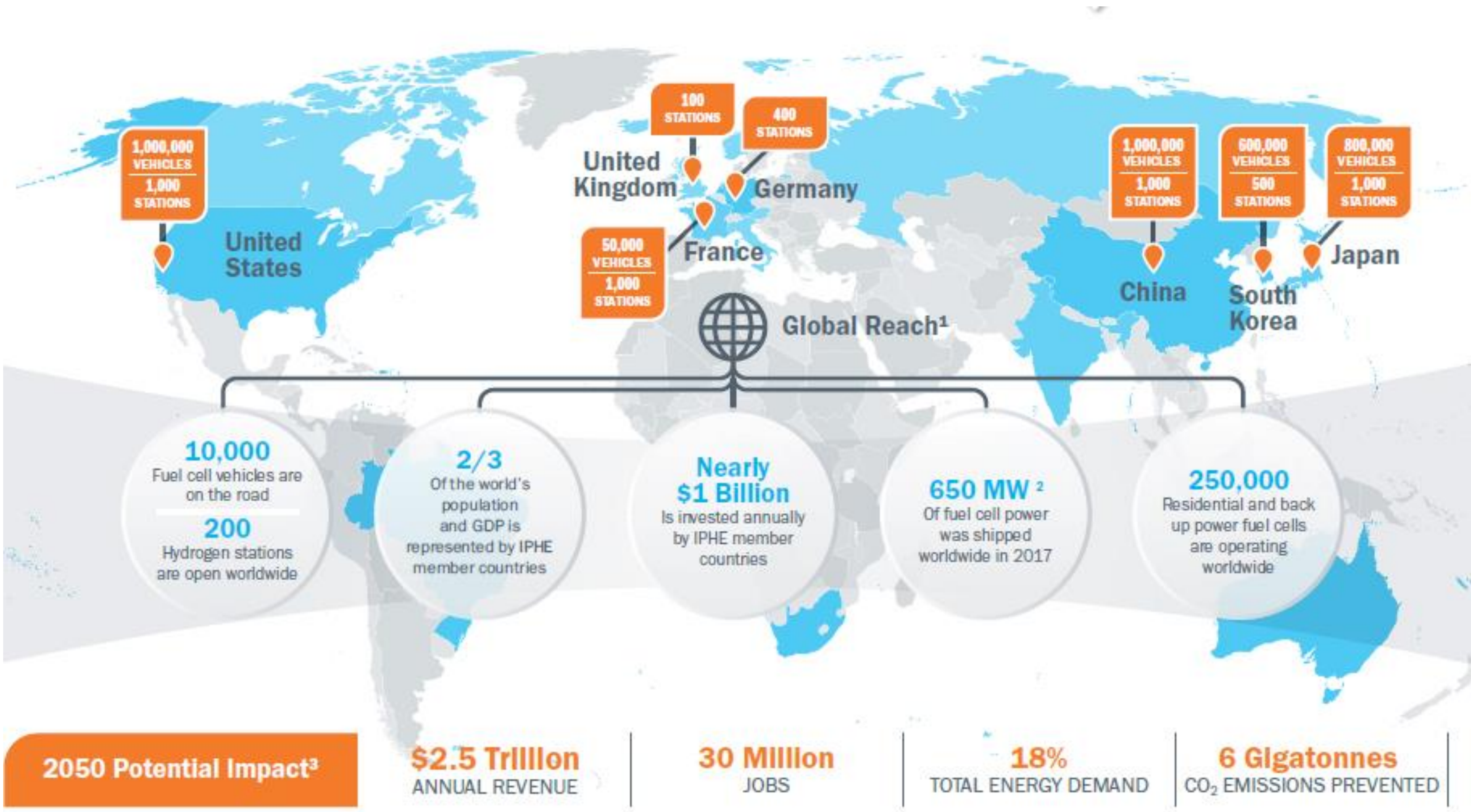
Sales in 2017

- 70,000 fuel cell units shipped*
- Global sales for electrolyzers estimated at over 100MW/year**

*DOE and E4tech
**Courtesy of NOW, E4tech and partners: A collaborative effort to assess electrolyzer market potential

Over 6,500 fuel cell cars sold or leased in the United States. Over 360 mi driving range.

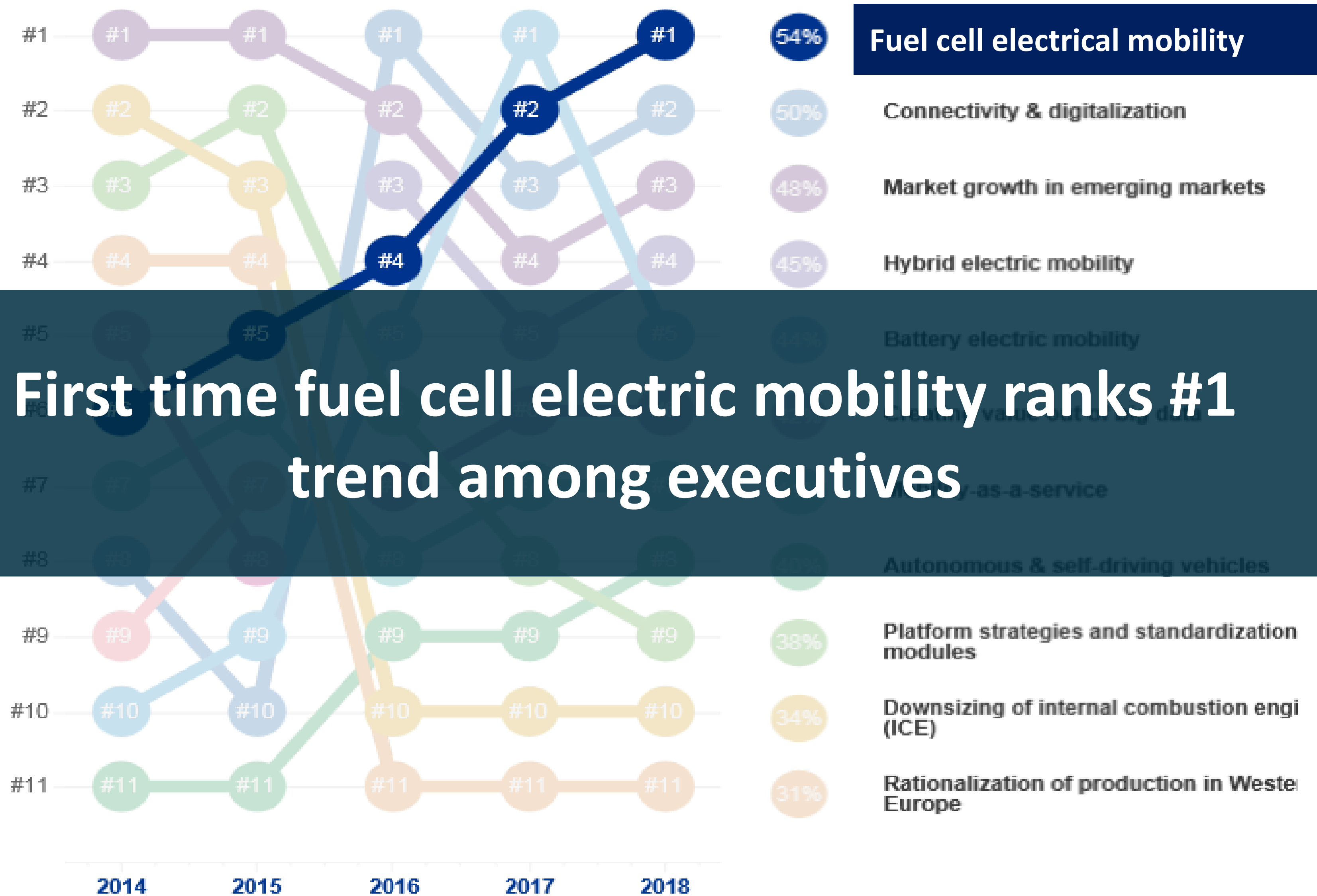
International Commitment Ramping Up



[1] IPHE Country Updates [2] U.S. Department of Energy, E4tech. 2018 [3] *Hydrogen Scaling Up*. Hydrogen Council, 2017

Source: IPHE

Automotive Executives Survey Results



First time fuel cell electric mobility ranks #1 trend among executives

Source: KPMG Global Automotive Executive Survey 2018

Long-Range, Heavy Duty Applications Emerging

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

Fuel cell buses in CA surpass 19M passengers

Industry demonstrates first heavy duty fuel cell truck in CA

Material Handling Equipment Applications

More than **25,000 forklifts**

Over **16 million refuelings**

Examples of fuel cell activities for rail applications

Alstom iLint Coradia

German, 2017

CRRC Fuel Cell Tram

China, 2015

BNSF Fuel Cell Shunter

California, 2008

FC Tram Locomotive

Spain, 2011

FC Mining Vehicle

South Africa, 2012

FC Hybrid Railcar

Japan, 2006

Emergence of Hydrogen and Fuel Cells in the U.S.

Examples of Application in the United States

Over
>240MW
Backup Power

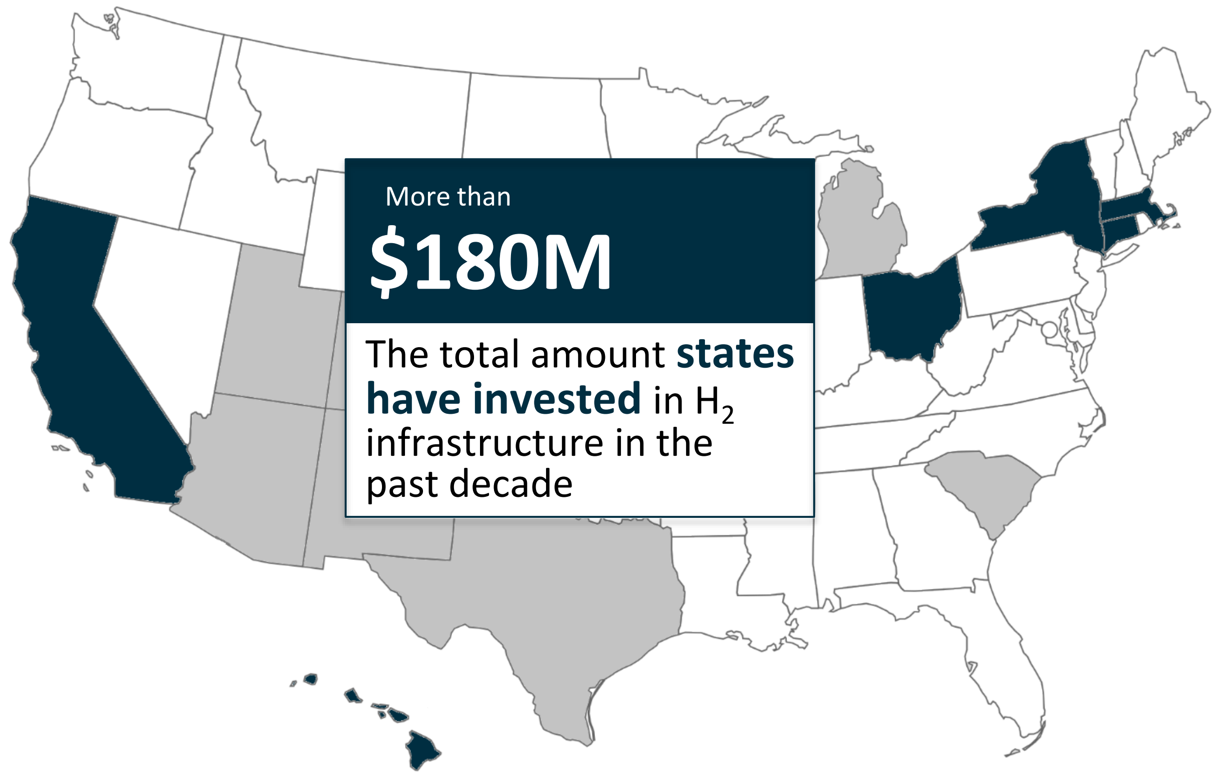
More than
~25,000
Forklifts

More than
~35
Fuel Cell Buses

~40
H_2 Retail Stations

Over
>6,500
Fuel Cell Cars

States with Growing Interest



More than
$180M
The total amount **states have invested** in H_2 infrastructure in the past decade

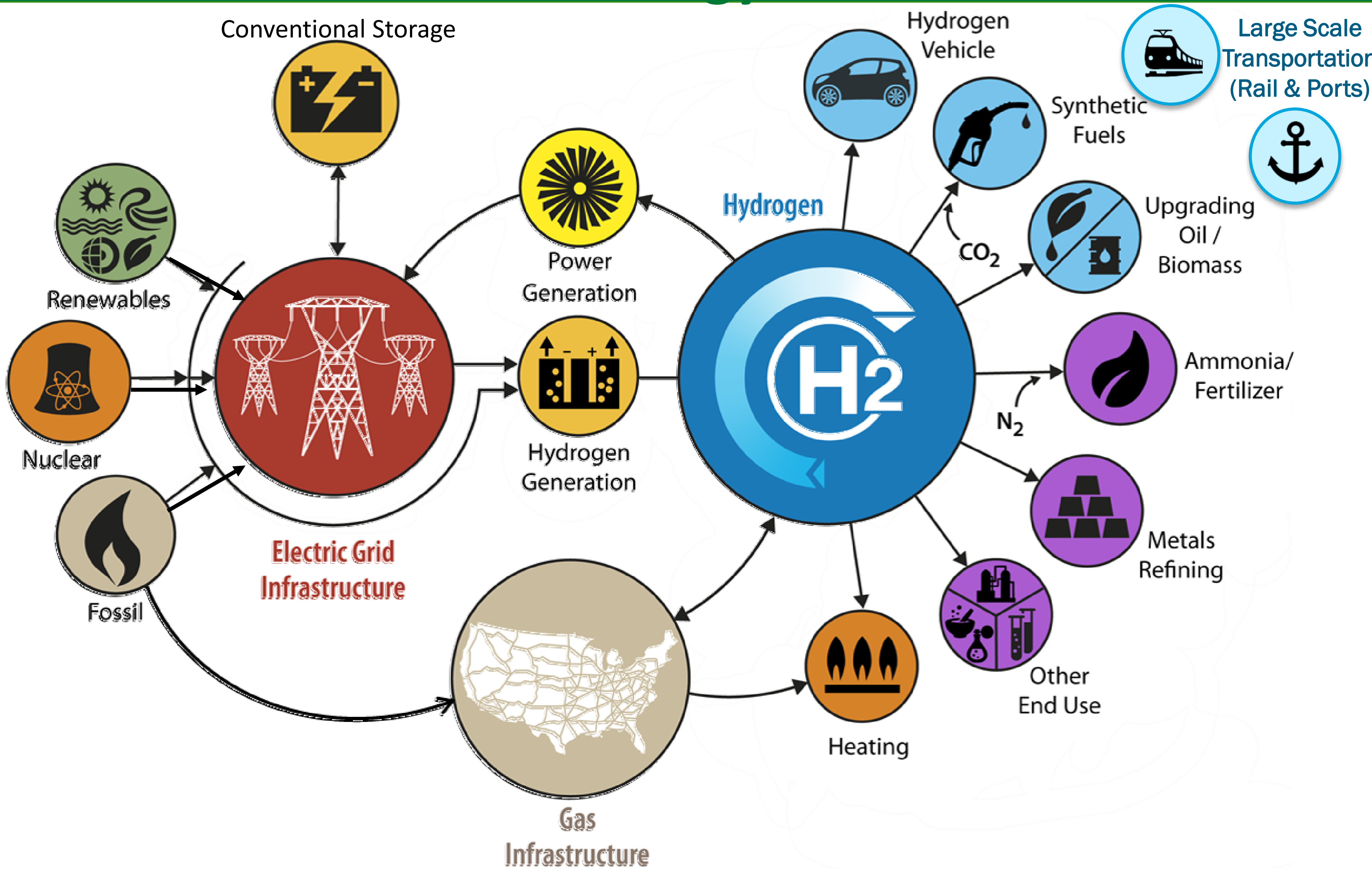
Hydrogen Stations: Examples of Plans Across States

California
1,000 stations by 2030

Northeast
12 – 20 stations planned

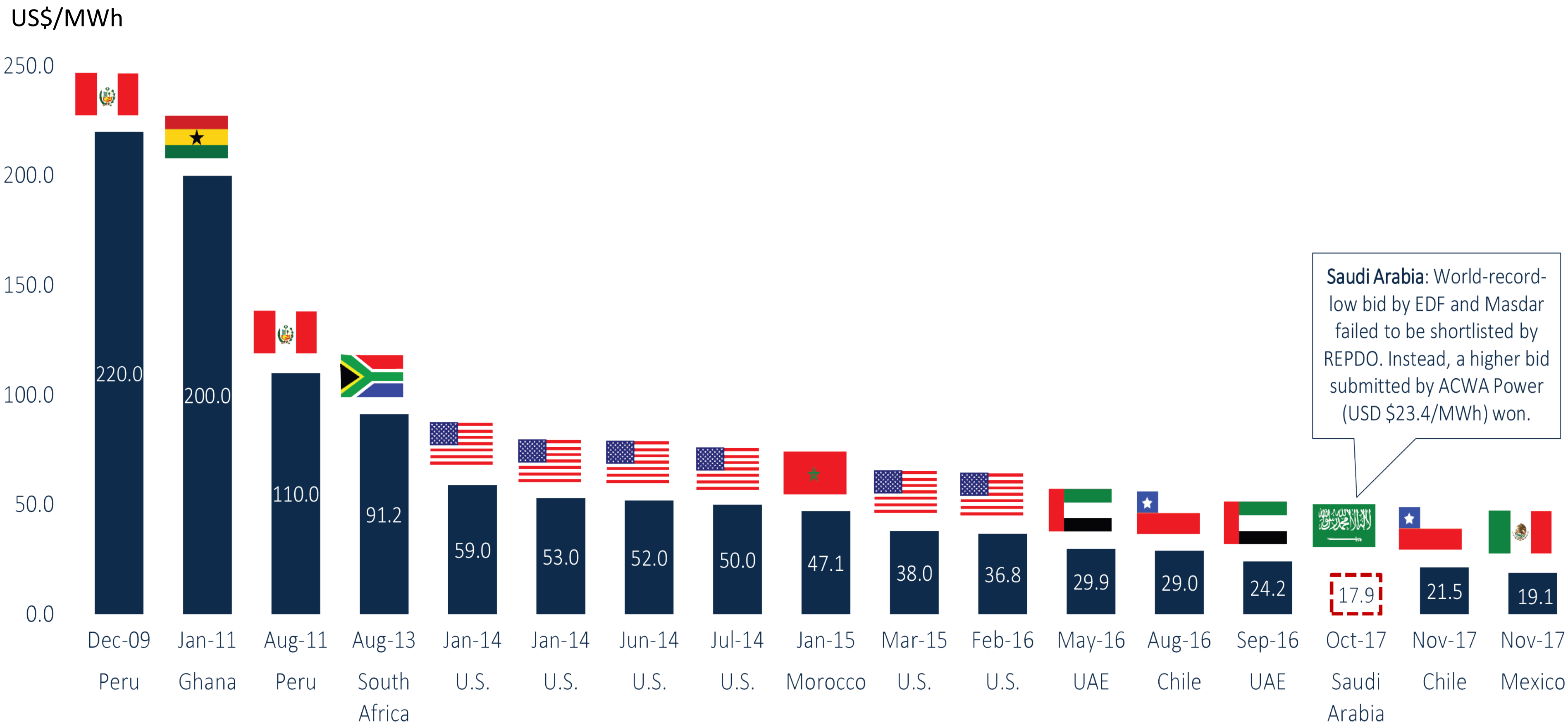
HI, OH, SC, NY, CT, MA, CO, UT, TX, MI, and others
with interest

H_2@Scale: Enabling affordable, reliable, clean, and secure energy across sectors



What is different now?

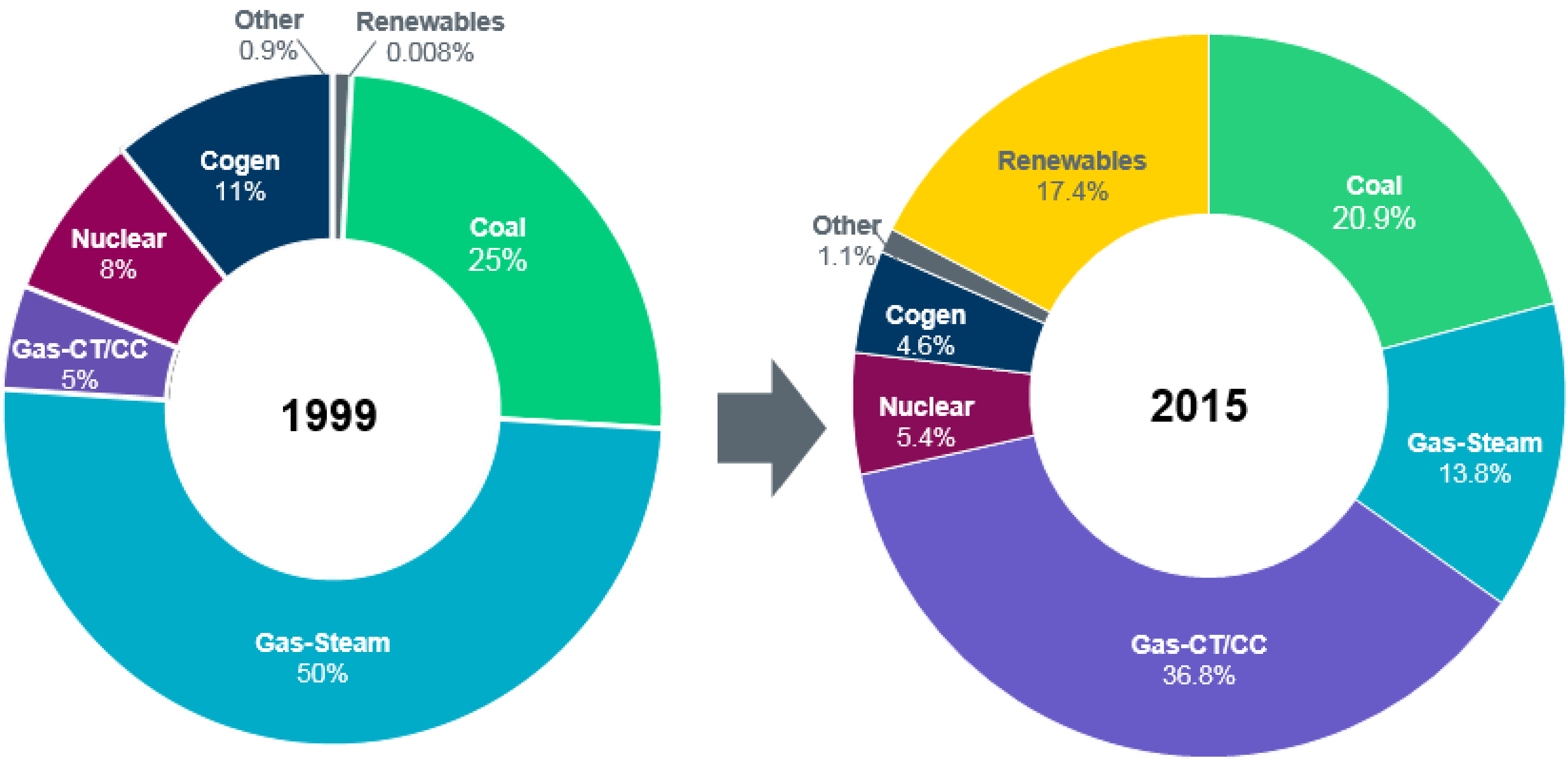
Record-Low PPA Prices for Utility-Scale Solar



Source: GTM, DOE Solar Technologies Office

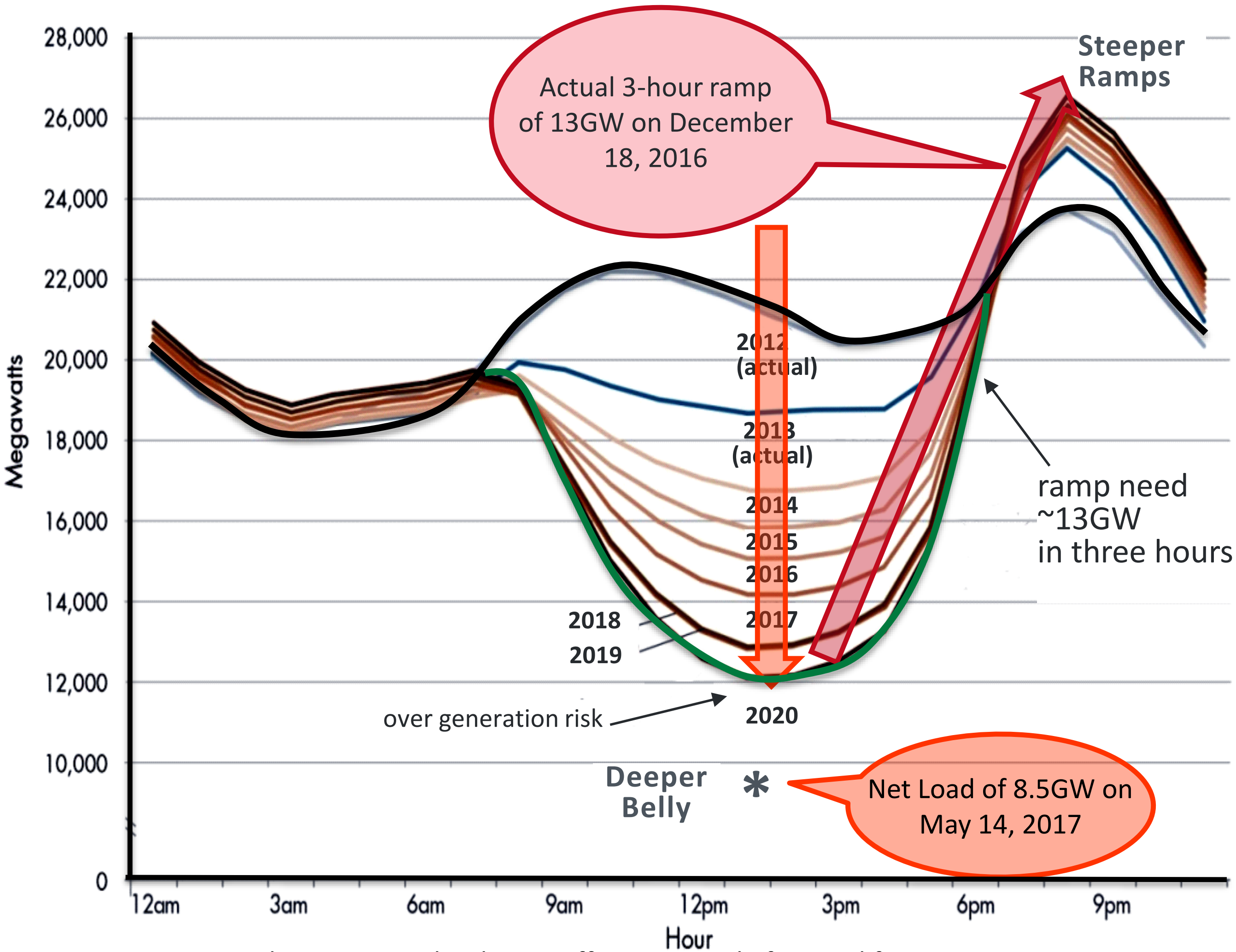
Electricity Mix Landscape is Changing

Example: Installed Capacity in Texas



Source: ERCOT, DOE H2@Scale Workshop, TX

Utilities are facing Challenges: Duck Curve Example



Source U.S. DOE Solar Energy Technologies Office – example from California

Two Concerns:

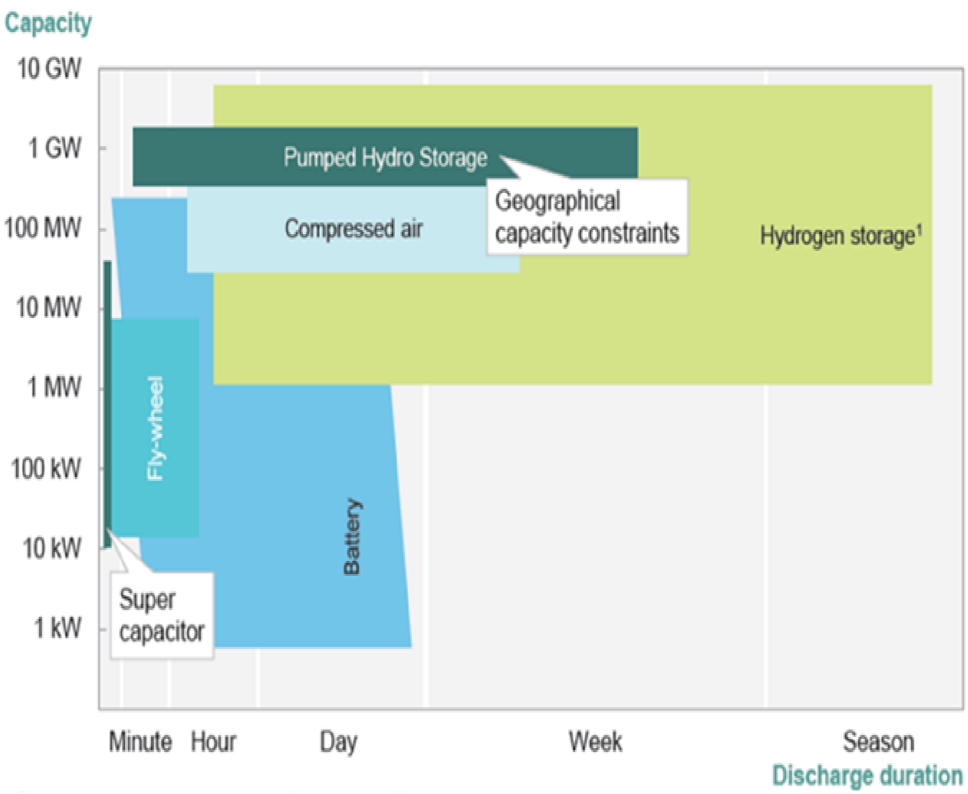
- **Low Net Load:** flexibility to reduce baseload generation resources is limited
- **High Ramp Rates in Evening:** flexibility of other generation to ramp up is limited

Can be addressed by

H2@Scale℠ U.S. Department of Energy

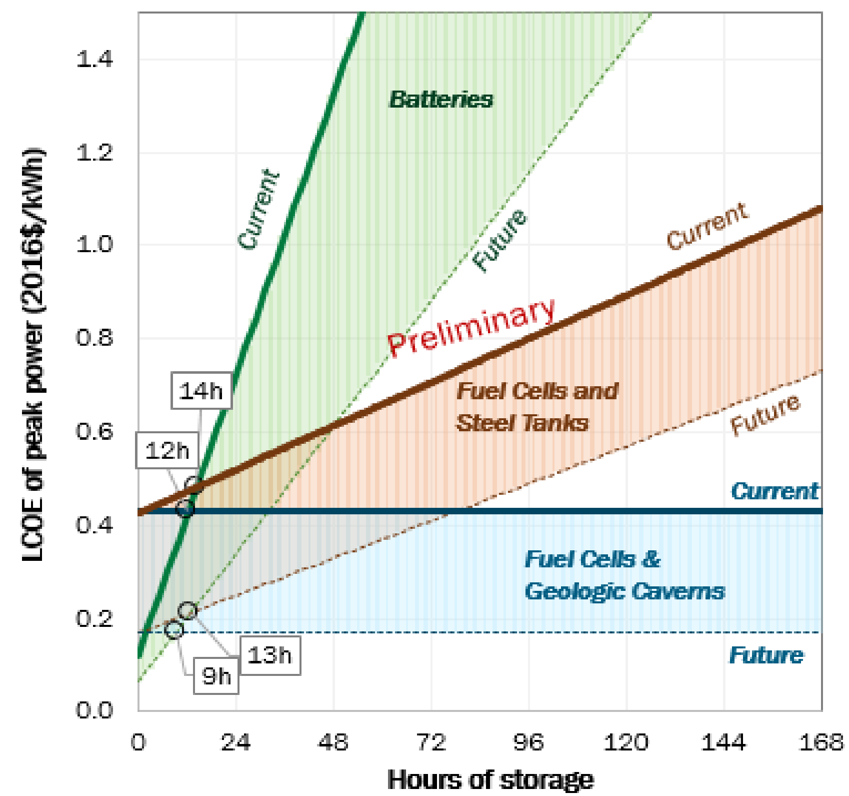
Opportunity for Energy Storage

- **Hydrogen can offer long duration and GWh scale energy storage**



Source: Hydrogen Council

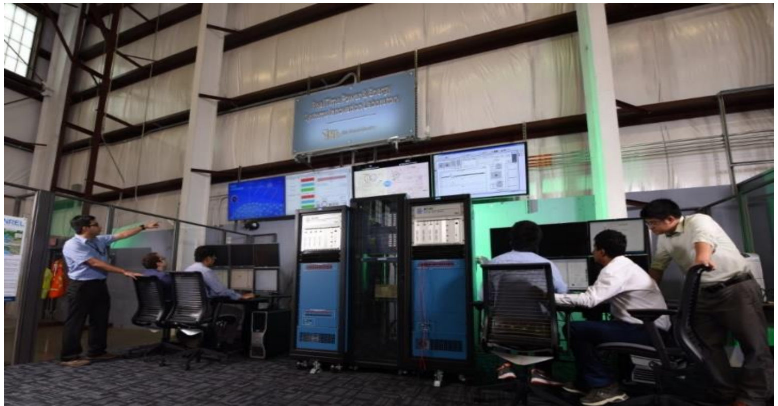
- **Analysis shows potential for hydrogen to be competitive at > 10 hours**



Source: NREL (preliminary)

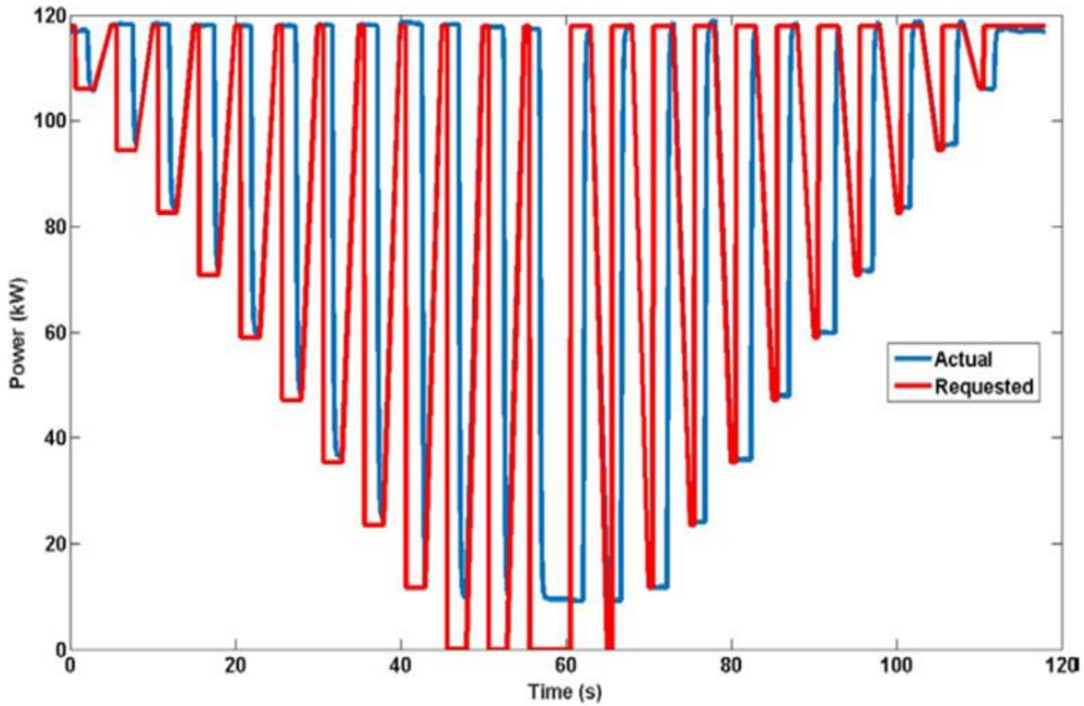
Lab testing shows value of electrolyzers for ancillary services

First Ever Validation of Frequency Regulation with Electrolyzers



Idaho National Lab (INL)

National Renewable Energy Lab (NREL)

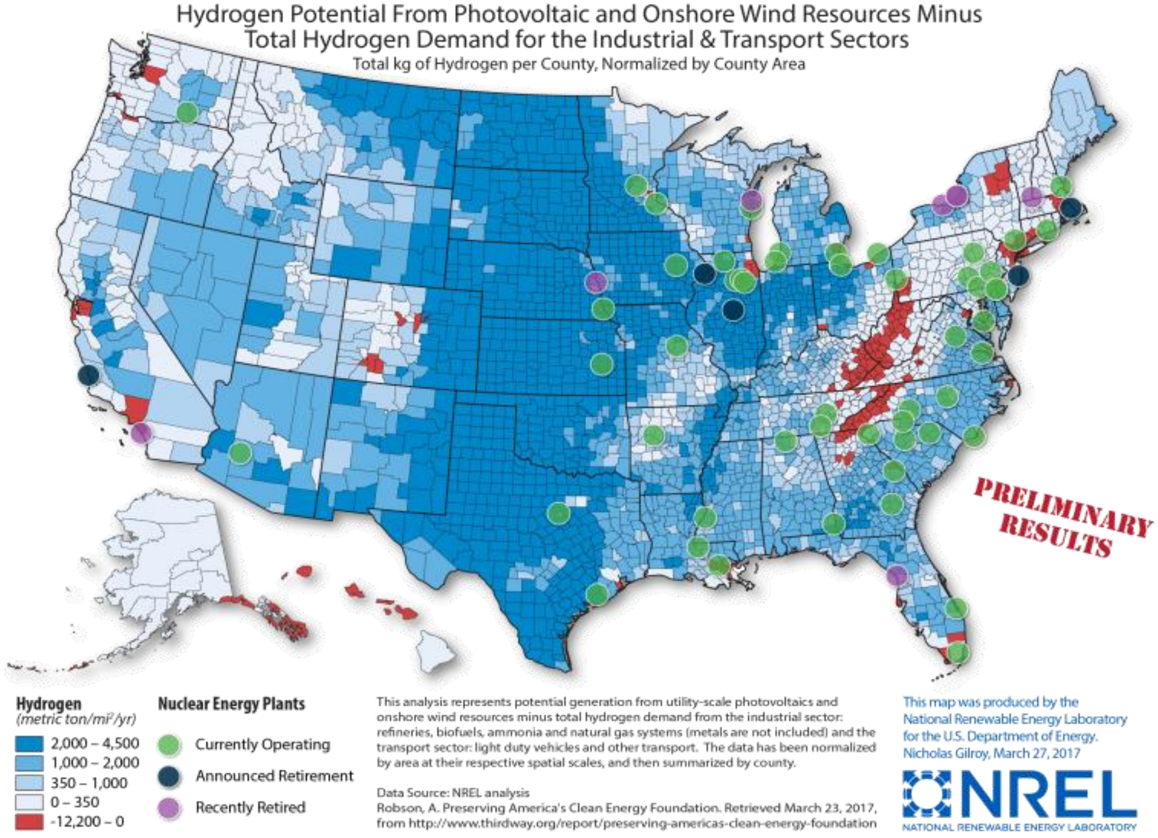


Lab testing shows dynamic response within seconds and potential for grid services

H_2@Scale: Nationwide Resource Assessment

Assessing resource availability. Most regions have sufficient resources.

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

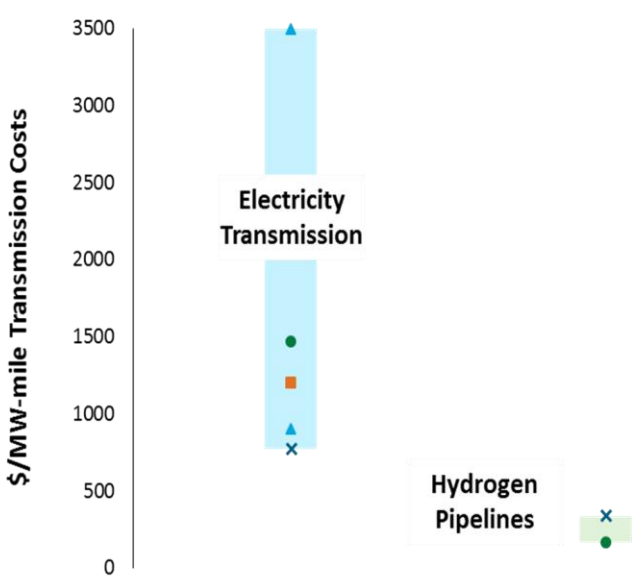


Assessing cost of H_2 vs electricity transmission

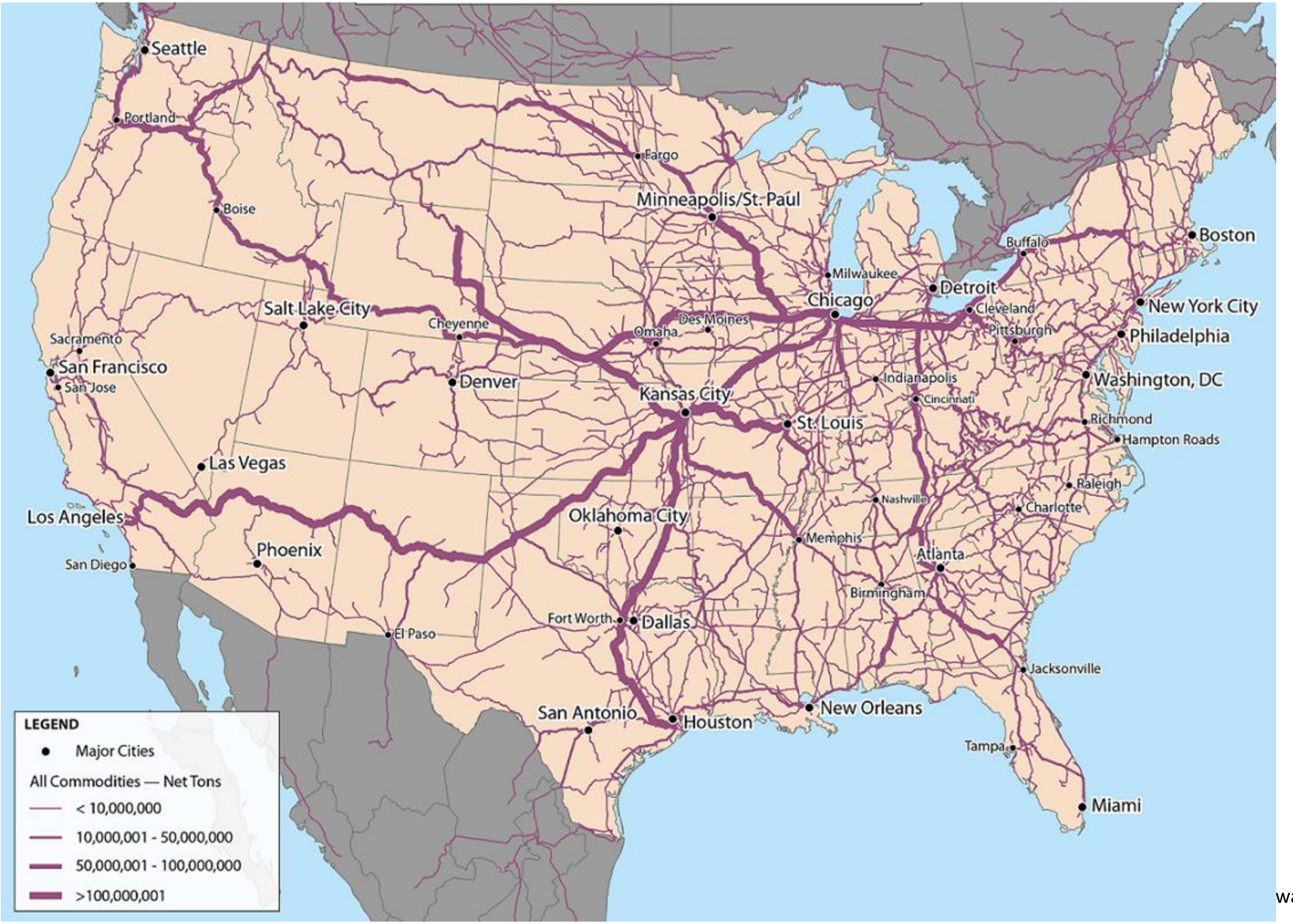
(in process)

Electricity:
~$600-$3,500 per MW-mile

Hydrogen Pipeline:
~$200-400 per MW-mile

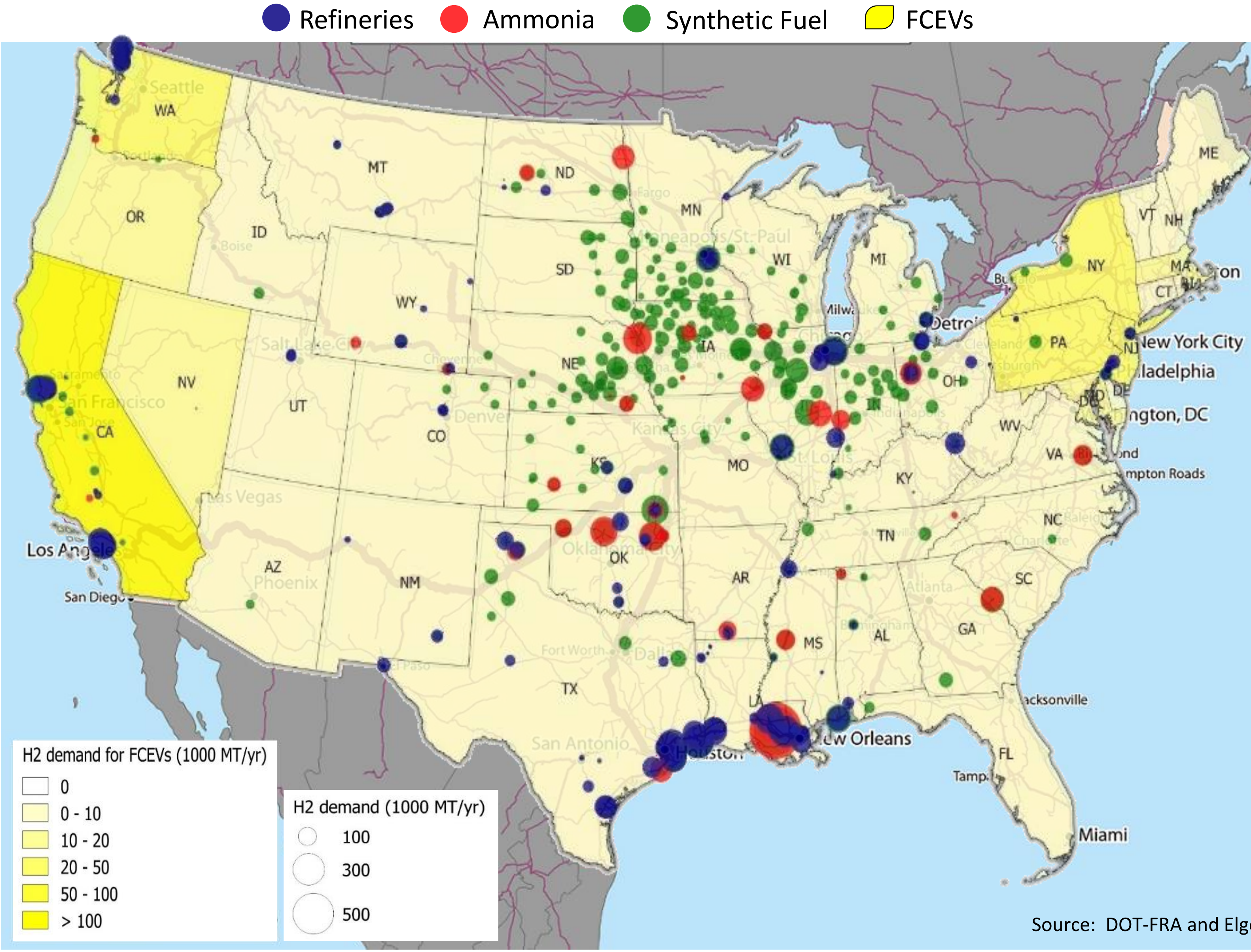


Freight Routes by Region



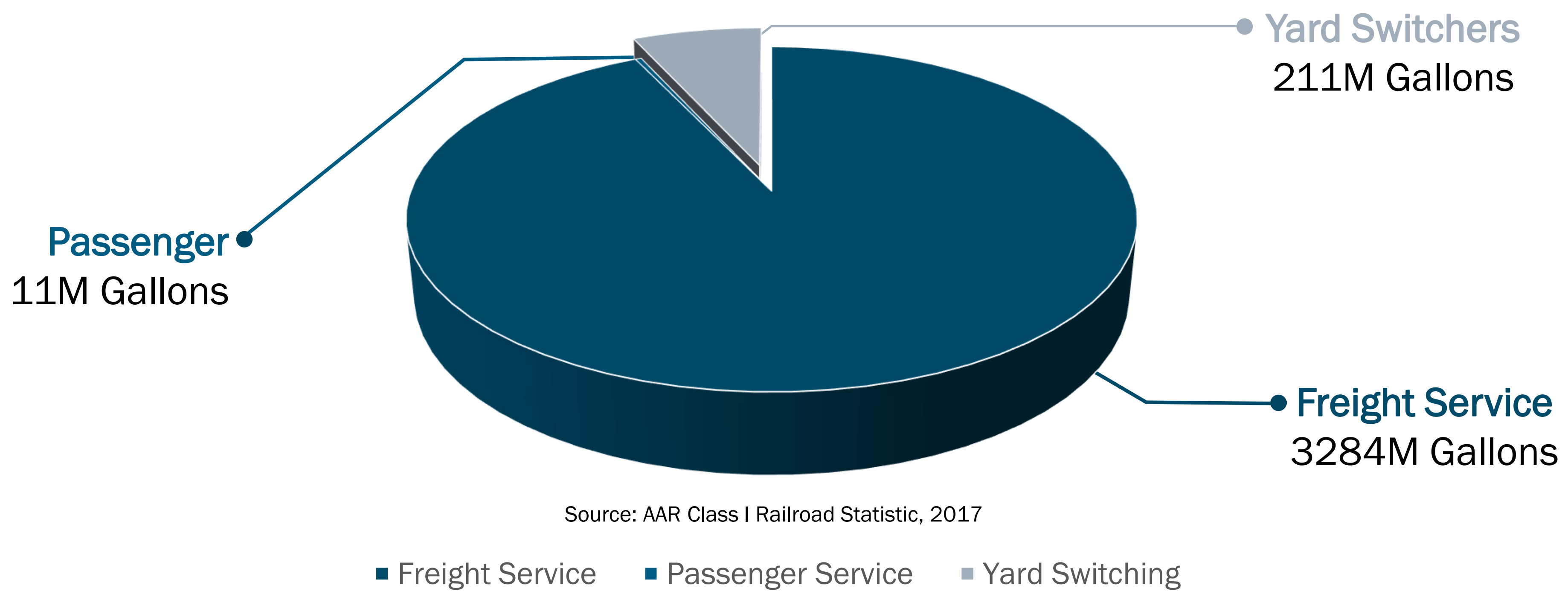
wainy, et al, ANL

Hydrogen Demand Forms Regional Clusters



Source: DOT-FRA and Elgowainy, et al, ANL

Diesel Consumption in the Rail Sector



Top 3 Diesel Consumption in the Rail Sector

1. Freight

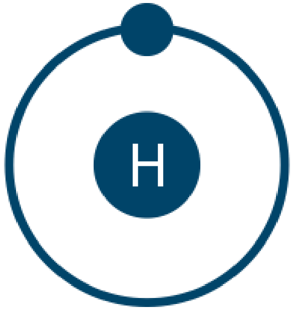
2. Yard Switchers

3. Passenger


Maximum Potential Hydrogen Demand

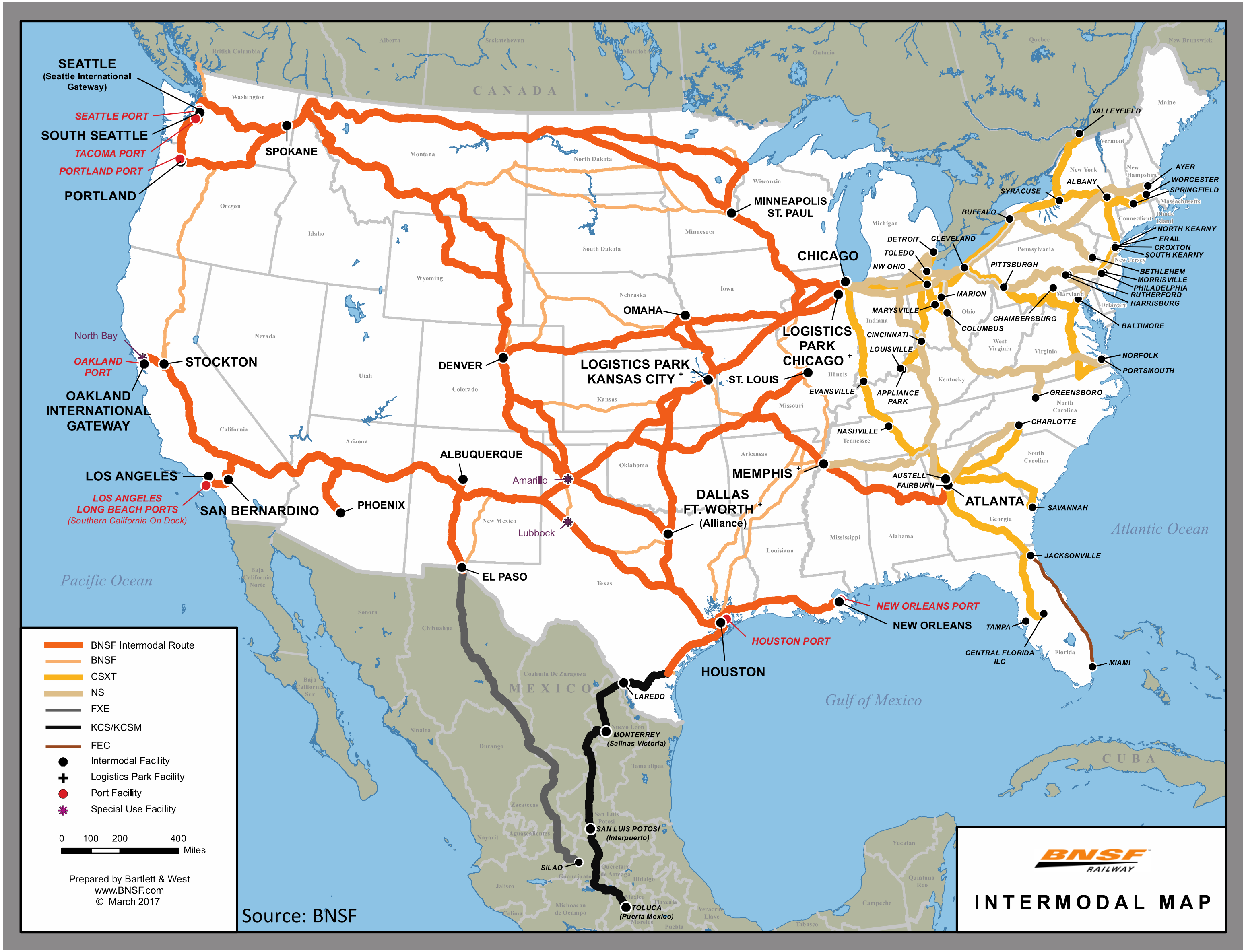
>3.5M

metric ton/year*



*assumes 1 kg H_2 is ~ 1 diesel gallon energy equivalent and full fleet conversion

Examples of Intermodal Routes in the U.S.



Source: BNSF

H_2@Rail and H_2@Ports Initiatives

- Collaboration with:
  - DOT-Federal Railroad Administration
  - DOT-Maritime Administration
- Conduct R&D to assess the technical and economic potential of hydrogen use for:
  - **Prime propulsion & auxiliary railway locomotives**
  - **Maritime applications**

Scale: Simple Example

How much hydrogen for 1 automobile?

1 passenger car uses ~ 5 kg H_2 for over 300 mile range

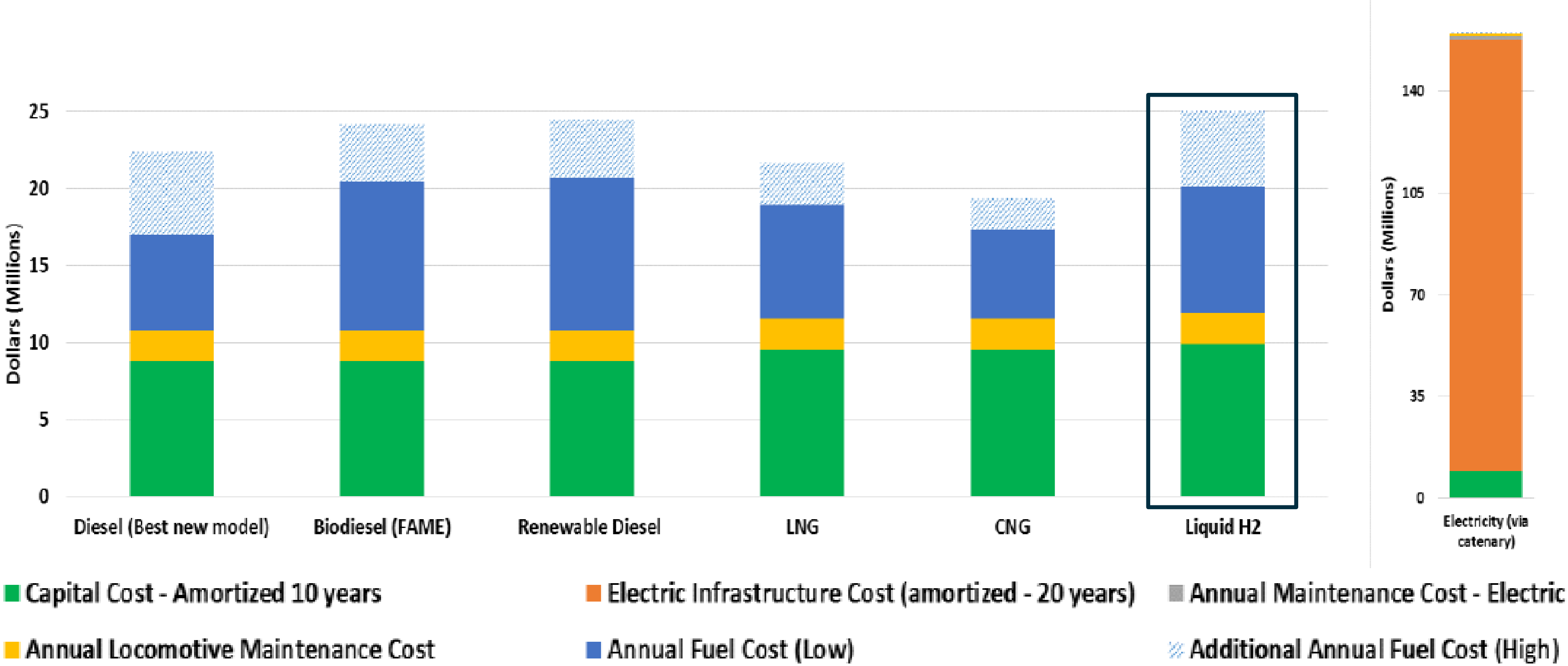
How much hydrogen for rail?

Smallest Example: 100 kg H_2 = 20 automobiles
Potential for several hundred cars worth of H_2

Key Driver - Affordability

Annual Costs Example: Passenger Rail – UC Davis Study

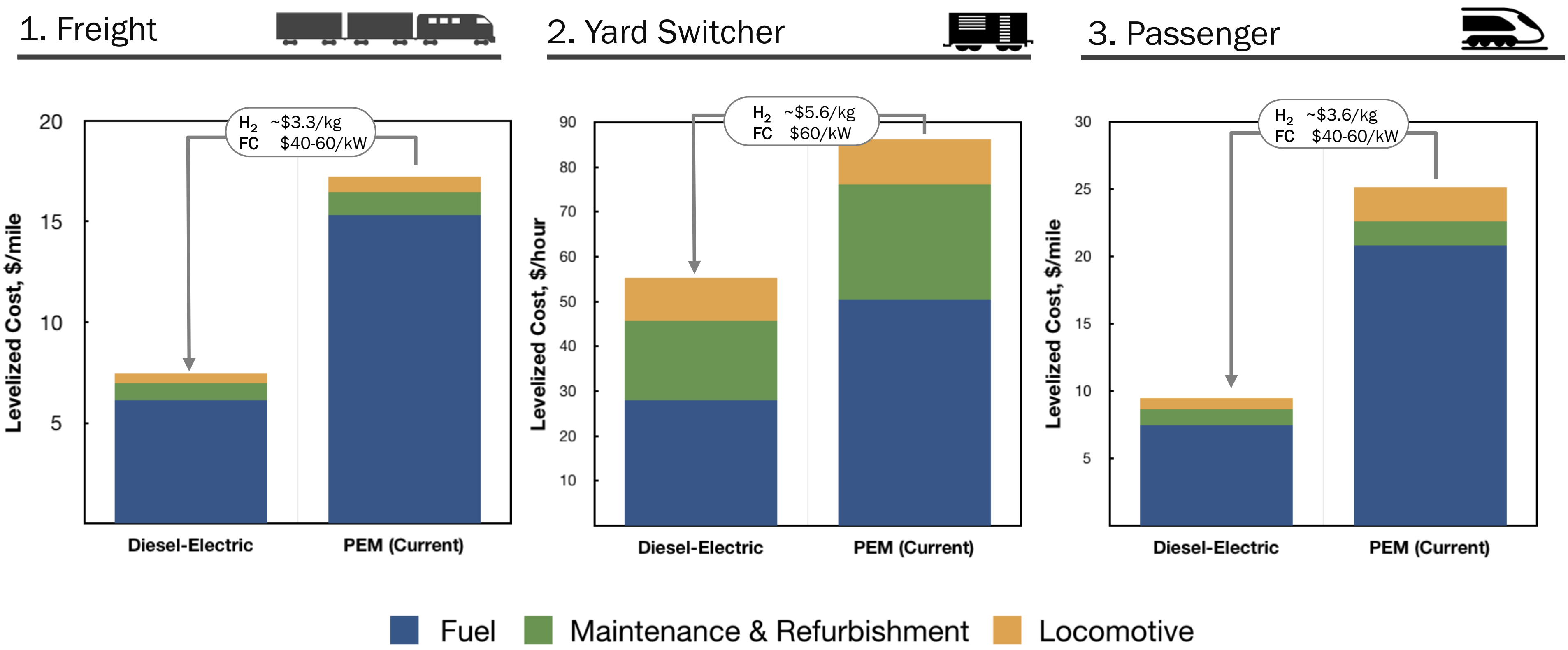
Hydrogen fuel technology cost is slightly higher than the diesel, LNG, and biodiesel, but much less than catenary electric technology



Assumptions:
Liquid Hydrogen Cost: $5.16-$9.03/gallon
Vehicle Cost: $8.05-$9.95 million/locomotive + Tender car

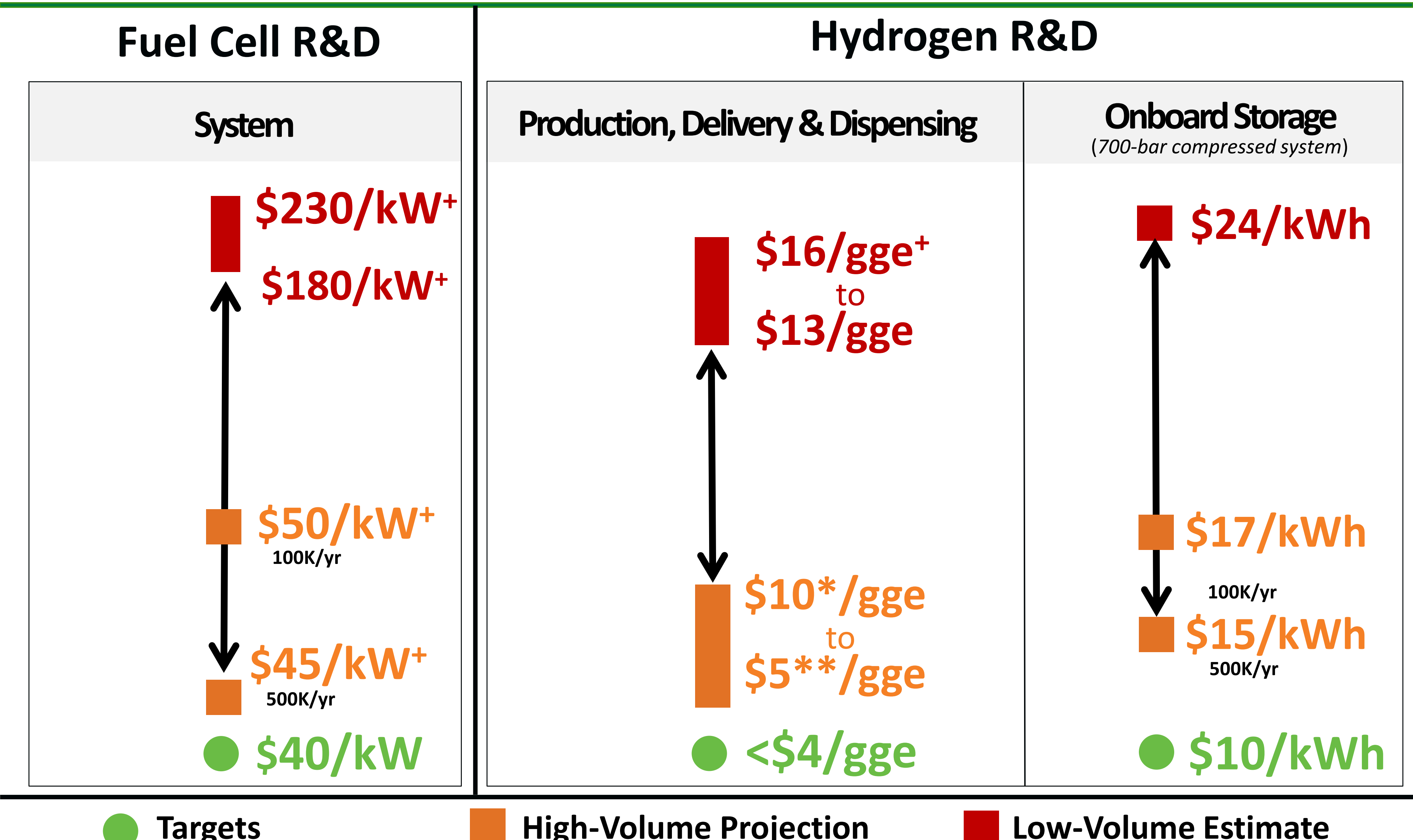
Source: Isaac, Raphael et al. UC Davis (2016)

Preliminary Argonne TCO results



If fuel cell and hydrogen technology performance and cost targets are met, they could compete with diesel rail power for various rail applications.

Cost Status vs Targets – Automotive Application

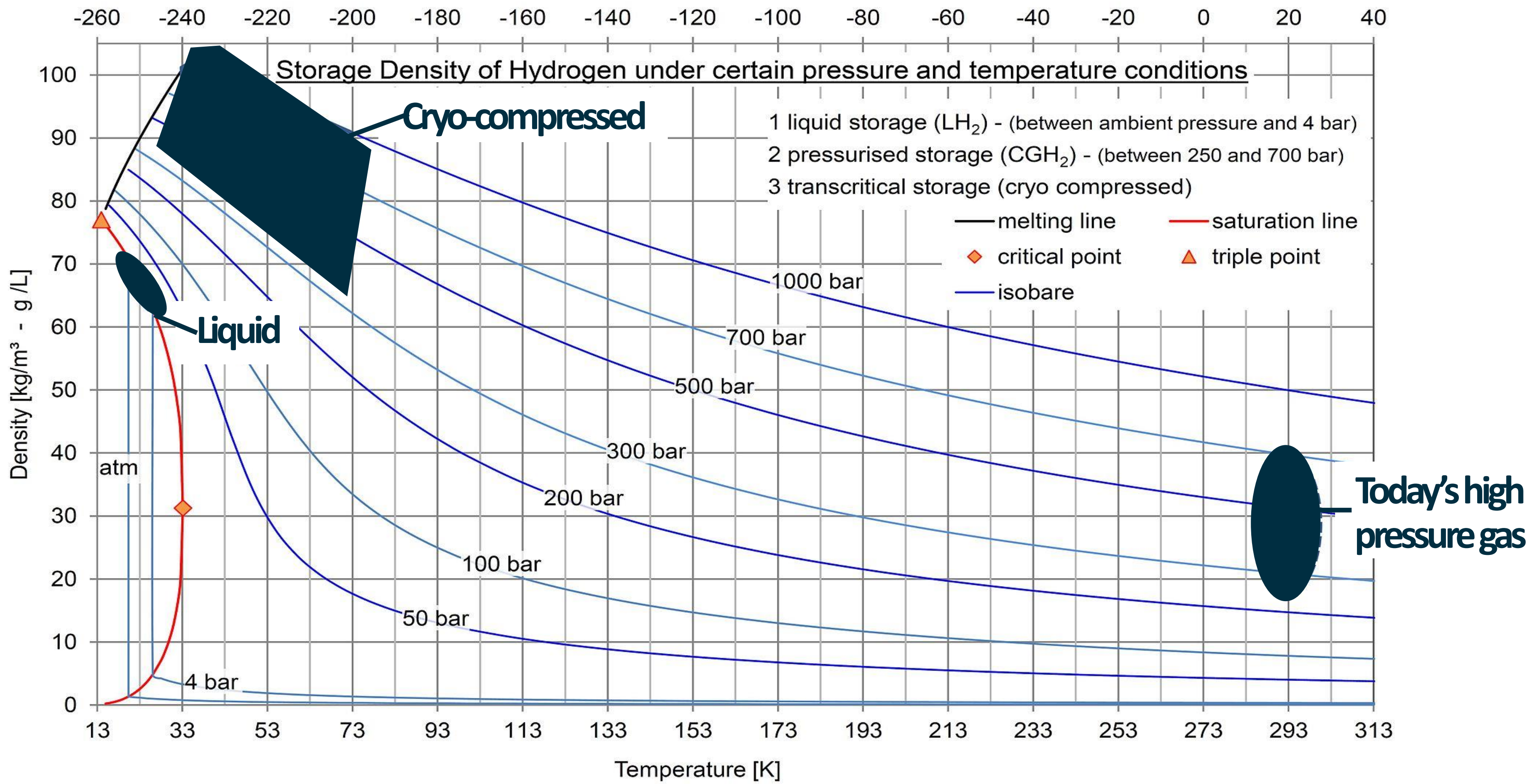


*Based on Electrolysis **Based on NG SMR + Preliminary, updates underway
Onboard storage cost status from DOE Program Record 15013

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

Example of Alternate Hydrogen Storage Options

Cryo-compression can offer densities higher than liquid hydrogen



ANL analysis (preliminary) shows potential for:

- 90-200% storage capacity increase
- 25% less cost (at 5,000 units/yr)
- 46% less carbon fiber composite

Collaborations and Next Steps

IPHE: International Partnership for H_2 and Fuel Cells in the Economy: www.iphe.net

Government partnership to **share** information and **increase** international **coordination** and **collaboration** to **accelerate progress**

Working Groups
Education & Outreach
Regulations, Codes, Standards & Safety

- 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

Launched 2003 and includes 18 countries and the European Commission

Collaboration: New H_2 Safety Partnership

Leverages new partnership to promote collaboration on safety

U.S. DOE's

Pacific Northwest
NATIONAL LABORATORY

AIChE

CENTER FOR
Hydrogen
SAFETY

HYDROGEN
Safety Panel

HYDROGEN
Emergency Response
Training Resources

April 1-2, AICHE Meeting, LA

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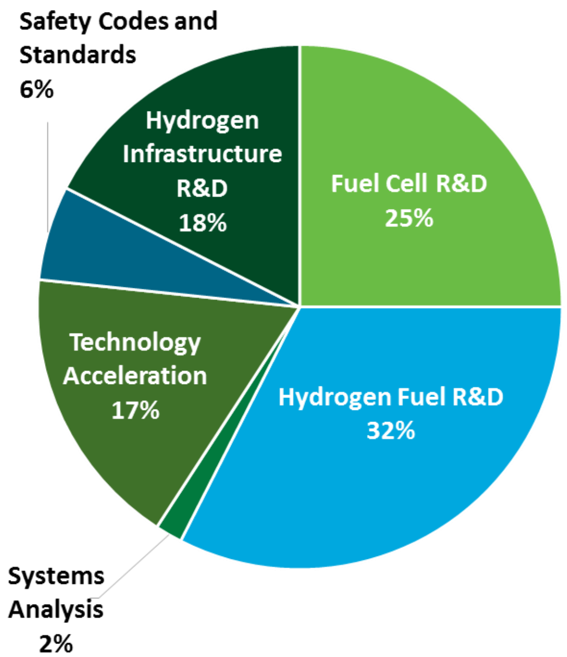
Funding

Distribution of FCTO FY19 Funding: $120 M



Office	FY 2018 ($ in thousands)
EERE (FCTO)	115,000
Science (Basic/xcut)	19,000
Fossil Energy (SOFC)	30,000
Total	~164,000

FCTO Appropriations

Key Activity	FY 2017	FY 2018	FY 2019
	($ in thousands)		
Fuel Cell R&D	32,000	32,000	30,000
Hydrogen Fuel R&D	41,000	54,000	39,000
Hydrogen Infrastructure R&D	-	-	21,000
Systems Analysis	3,000	3,000	2,000
Technology Acceleration	18,000	19,000	21,000
Safety, Codes and Standards	7,000	7,000	7,000
Total	101,000	115,000	120,000

FY19 Request: New Infrastructure R&D Subprogram in Budget

Just Announced: Funding for H_2@Scale and Trucks

H2@Scale - Up to $31M

H_2 production, storage and utilization concepts

Concept Papers due 4/8

Full Apps due 5/29

Trucks – Up to $15M

H_2 storage, refueling technologies and fuel cell R&D

Concept Papers due 3/29

Full Apps due 5/15

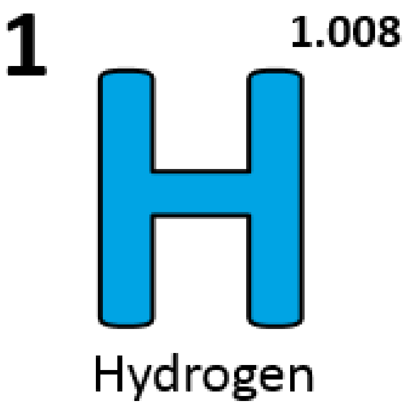
More information on the **EERE Exchange Website** or **Grants.gov**

Opportunities for outreach and to increase awareness

Celebrate National Hydrogen & Fuel Cell Day

October 8 or 10/08

(Held on its very own atomic- weight-day)



Information and Training Resources to Increase Awareness

H2tools.org

INCREASE YOUR H_2IQ

Download for free at:
energy.gov/eere/fuelcells/downloads/increase-your-h2iq-training-resource

Learn more at: energy.gov/eere/fuelcells

Save the Date and Sign up for Our Newsletter

All relevant DOE offices and other federal agencies working on hydrogen and fuel cell technologies at Annual Merit Review (AMR)

2019 AMR – April 29 – May 1

Crystal City, VA

www.hydrogen.energy.gov

Sign up to receive hydrogen and fuel cell news and updates

www.energy.gov/eere/fuelcells/fuel-cell-technologies-office-newsletter

Summary and Next Steps

- Using H_2 for large scale applications across sectors aligns with H2@Scale and can enable energy security, economic value and environmental benefits. Rail and marine applications can play a role.

Joint DOE-DOT FRA Project

- Conduct analysis on H_2 and fuel cells rail applications.
  - TCO, impact potential (petroleum, emissions reductions, etc.)
- Develop technical and cost targets.
- Identify barriers and opportunities for RD&D and collaborations to help define future plans.

Workshop Objectives

- Assess the state of the art on electric rail power propulsion using fuel cells
- Discuss requirements and lessons learned from early fuel cell rail projects
- Identify technology gaps, R&D needs and potential collaborative opportunities

Solicit feedback from stakeholders to help guide future activities

Thank You

Dr. Sunita Satyapal
Fuel Cell Technologies Office

energy.gov/eere/fuelcells

EERE Fuel Cell Technologies Office (FCTO)

Early R&D Focus	Applied research, development and innovation in hydrogen and fuel cell technologies leading to:	• Energy security • Energy resiliency • Strong domestic economy

Early R&D Areas

Fuel Cells	Hydrogen Fuel	Infrastructure R&D
• PGM- free catalysts • Durable MEAs • Electrode performance	• Production Pathways • Advanced materials for storage	• Safety • Manufacturing • Delivery components • Others

PGM = Platinum group metals

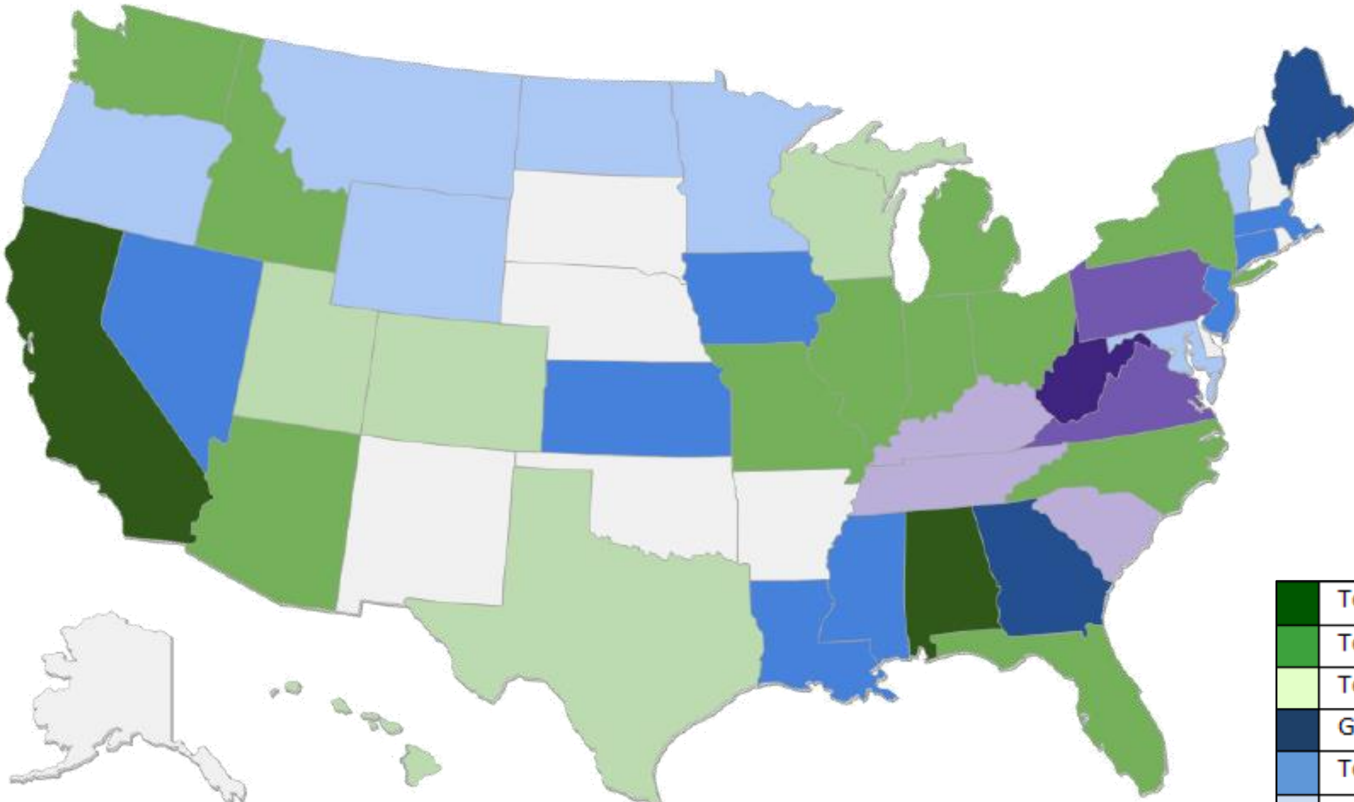
MEA = Membrane Electrode Assembly

Enabling

H2@Scale
U.S. Department of Energy

Fuel cells operating all over the U.S.

Fuel cells used for backup power in more than 40 states



Over 240MW
in stationary fuel cell power installed

Over 8,000 backup power units
deployed or on order

	Telecom, Government, Railroad, Utility sites
	Telecom, Government, Railroad sites
	Telecom and Government sites
	Government, Railroad, Utility sites
	Telecom sites
	Government sites
	Railroad sites
	Utility sites
	Government and Railroad sites
	Telecom and Railroad sites

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

Rail transport is the **second largest** diesel consumer in the US transportation sector, making up **~8% of total diesel use**

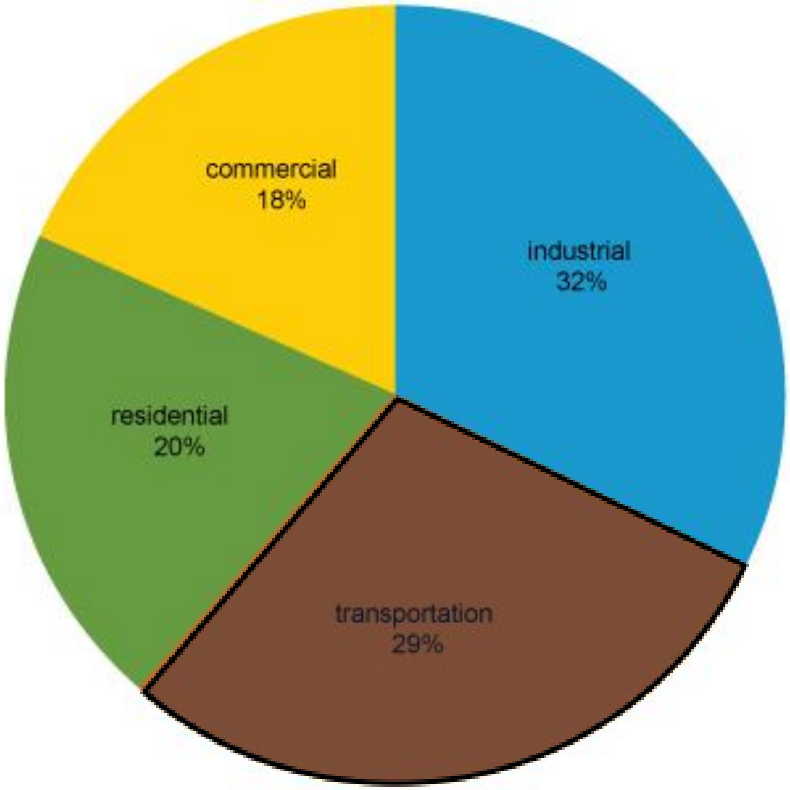
Transportation Sector Mode	Total Consumed (Trillion BTU's)	Percent of Total
Freight Trucks	4,917.6	75.1%
Rail Transportation	**513.1**	**7.8%**
• Freight Rail	490.9	7.5%
• Passenger Rail	22.2	0.3%
Waterways Shipping	453.7	7.0%
Light Duty Cars and Trucks	330.1	5.0%
Buses	186.4	2.9%
Military	96.0	1.5%
Recreational Boats	51.2	0.7%
Total Diesel Consumed	6548.1	100.0%

Source: EIA Transportation Sector Energy Use by Fuel Type Within a Mode, 2016

The Big Picture: Where is the energy consumption?

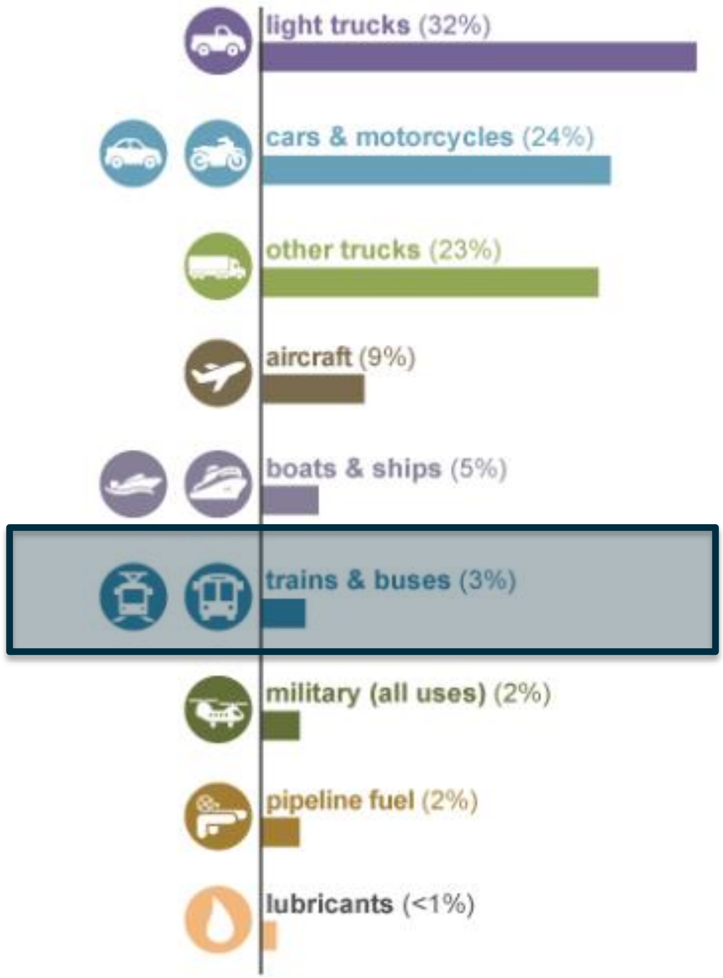
Total U.S. Energy Consumption by End-Use Sector, 2017

Total: 97.7 quadrillion BTUs



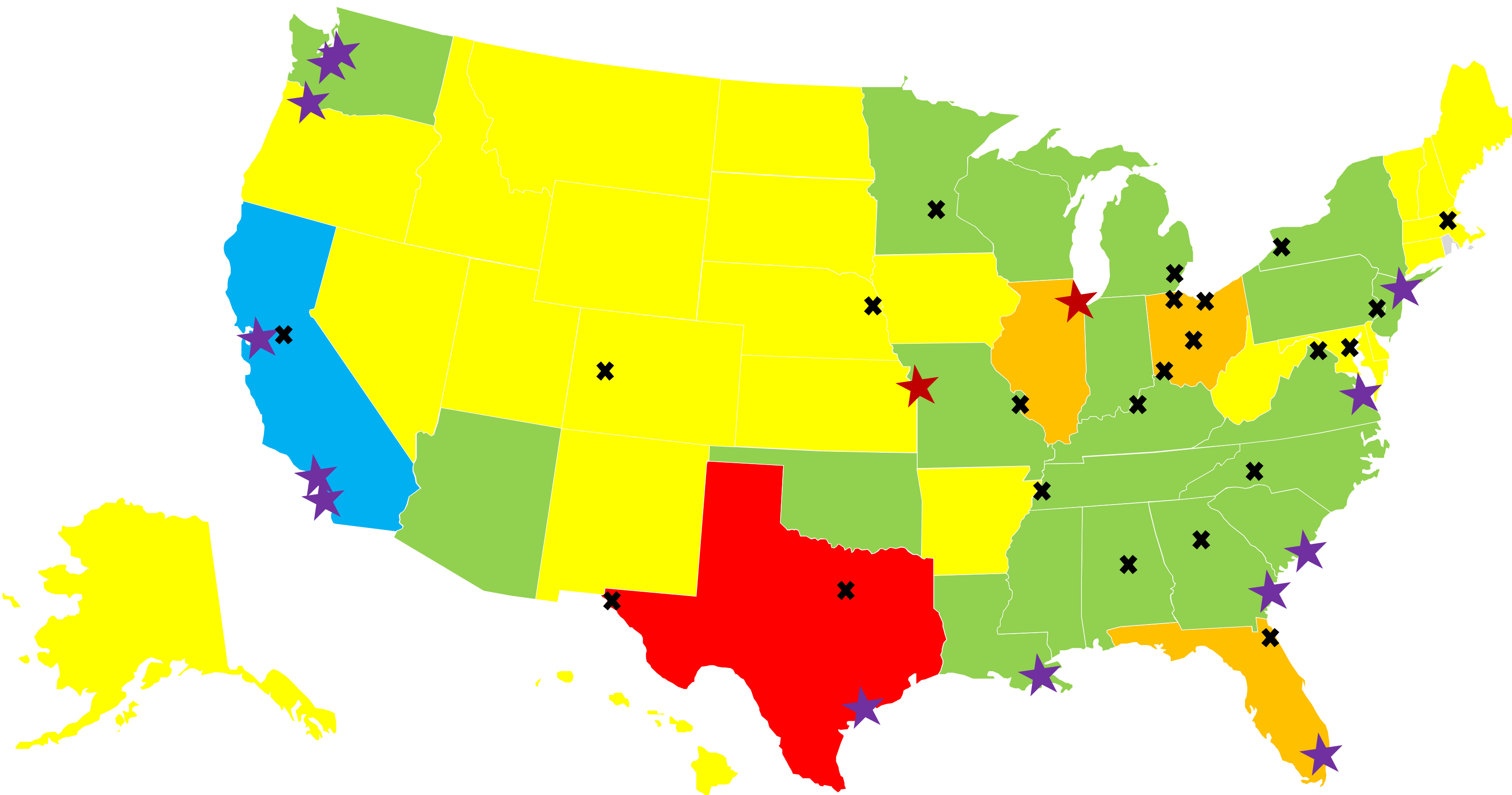
Source: EIA

Transportation Energy Use by Type



Largest U.S. Intermodal Rail Yard Locations

★ Container Port Intermodal Facility ★ Logistics Park Intermodal Facility ✖ Inland Intermodal Facility Supporting At Least Two Railroads



2016 Diesel Energy Consumption by State [Trillion Btu's]	
Yellow	< 100,000
Green	100,000-200,000
Orange	200,000-400,000
Blue	400,000- 800,000
Red	> 800,000

trade-daily/commentary/americas-top-intermodal-facilities