U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Hydrogen and Fuel Cells Overview: Opportunities for Ports & Maritime Applications

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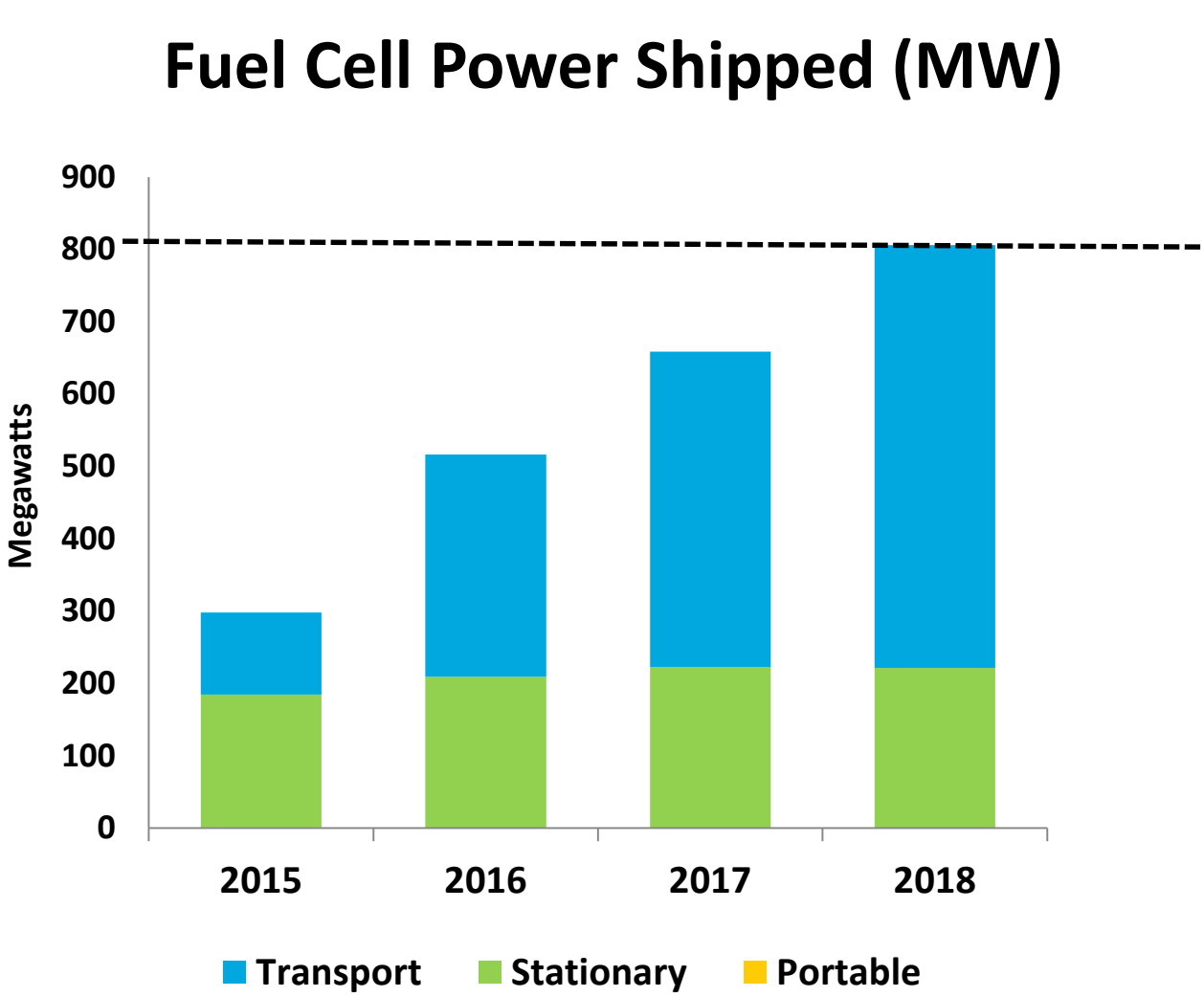
U.S. Department of Energy

CHBC & CHFCA Ports Workshop

Vancouver, Canada – May 21, 2019

Progress

Fuel Cell Shipments - Growth by Application



800 MW
fuel cell power
shipped worldwide

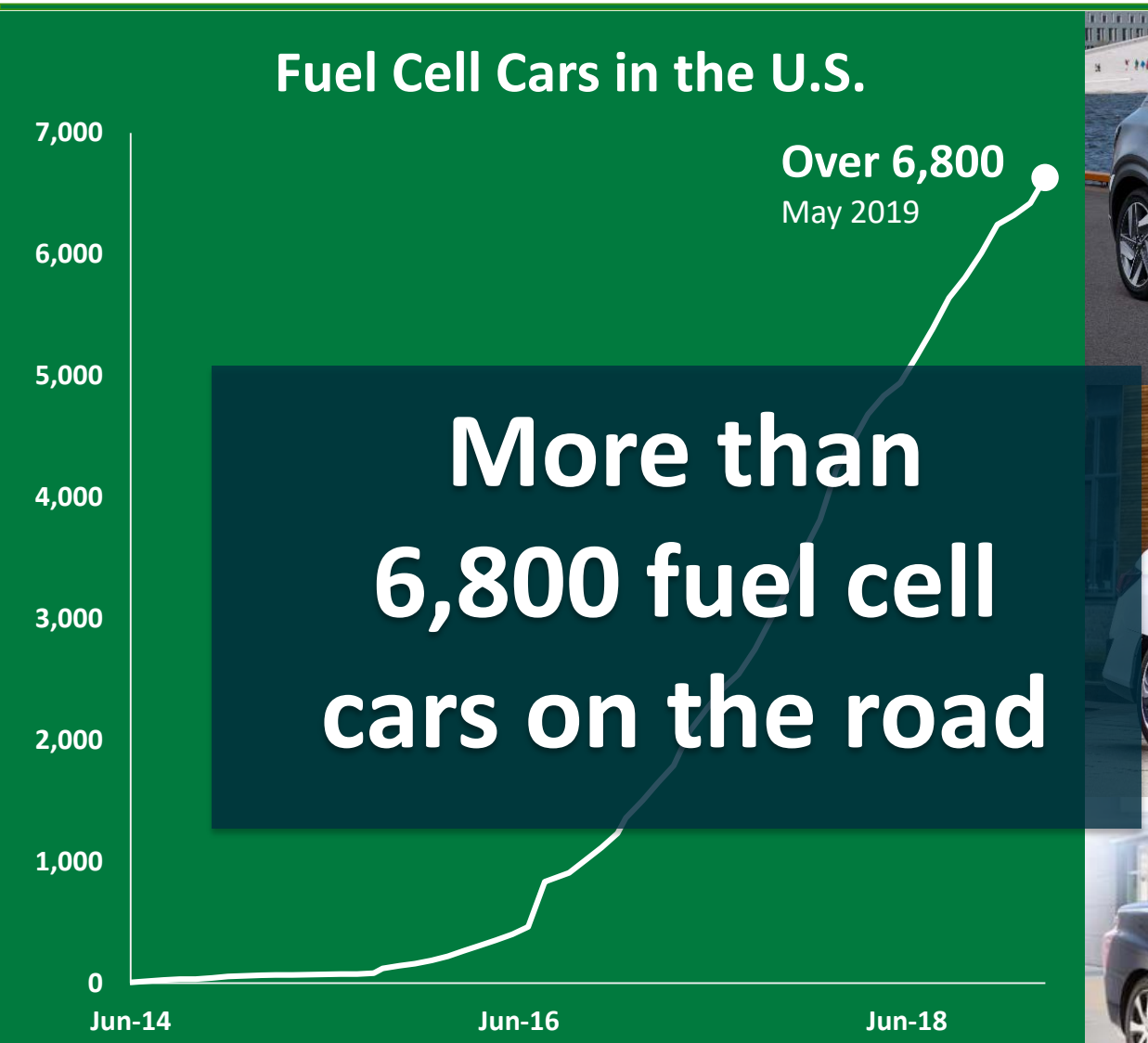
68,500
fuel cell units
shipped worldwide

Approximately
$2.3 Billion
fuel cell revenue*

* Revenue from publicly available

Source: DOE and E4Tech

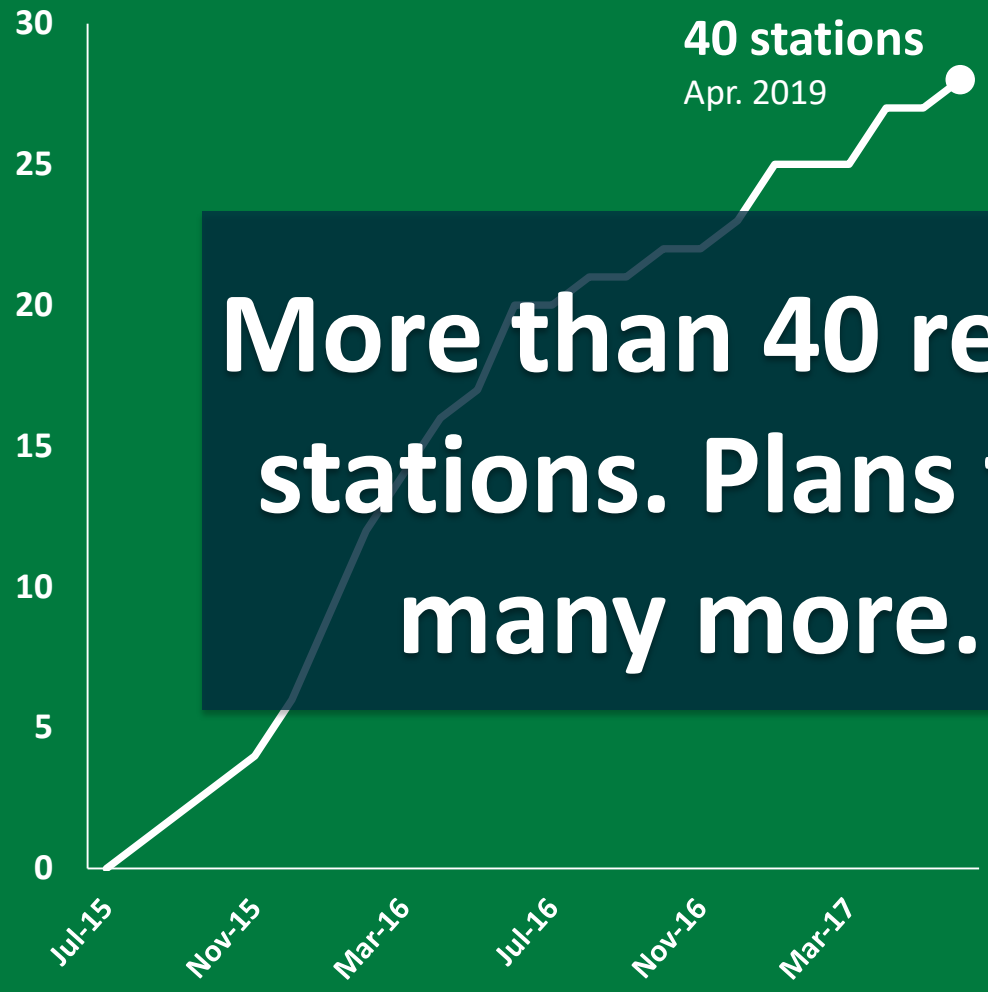
Commercial Fuel Cell Passenger Vehicles



More than 6,800 fuel cell cars on the road

Commercial Hydrogen Refueling Stations

Retail Hydrogen Stations in the U.S.



More than 40 retail stations. Plans for many more.

Real World Applications – In the U.S.

Photo Credit: UPS

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

Photo Credit: FedEx

First fuel cell tow truck fleet at airport in Memphis

World's first fuel cell for maritime ports in Hawaii

Photo Credit: Sandia National Laboratories

Real World Applications – In the U.S.

Industry demonstrates heavy duty fuel cell trucks

Photo Credit: Toyota

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

Photo Credit: General Motors

Fuel cell powered lights at Super Bowl

Fuel cell buses in California surpass 20 million passengers

Photo Credit: NREL

Real World Applications – Growing Opportunities

Hydrogen fuel cell powered drones and UAVs- markets taking off

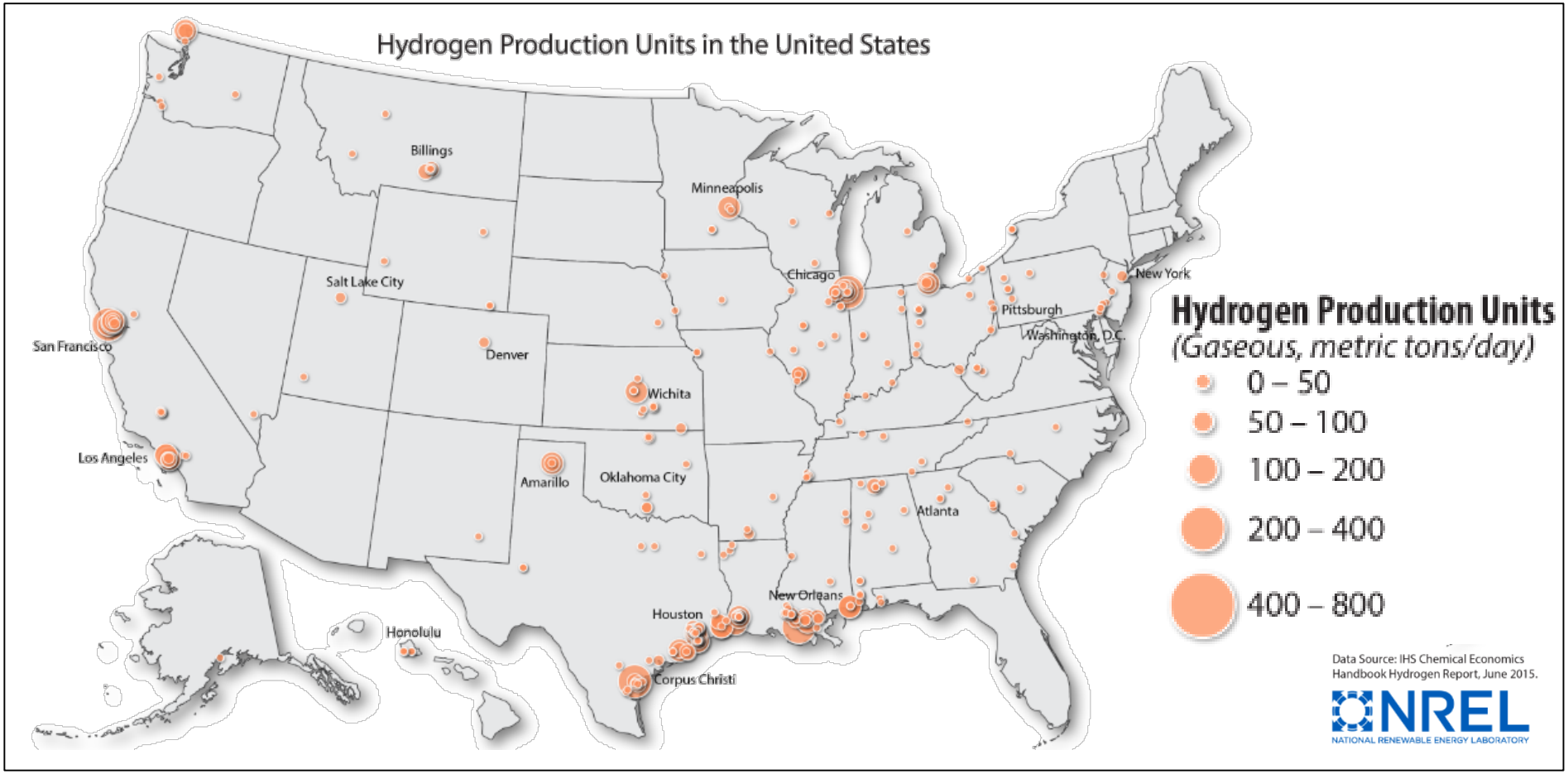
Thousands of fuel cells for backup power and stationary power for resilence

Thousands of fuel cell forklifts in warehouses and stores in the U.S.

Hydrogen fuel cell trains in passenger service in Germany

Photo Credit: Hydrogenics and Alstom

Hydrogen in the United States Today



U.S. annual hydrogen production

10 million metric tons

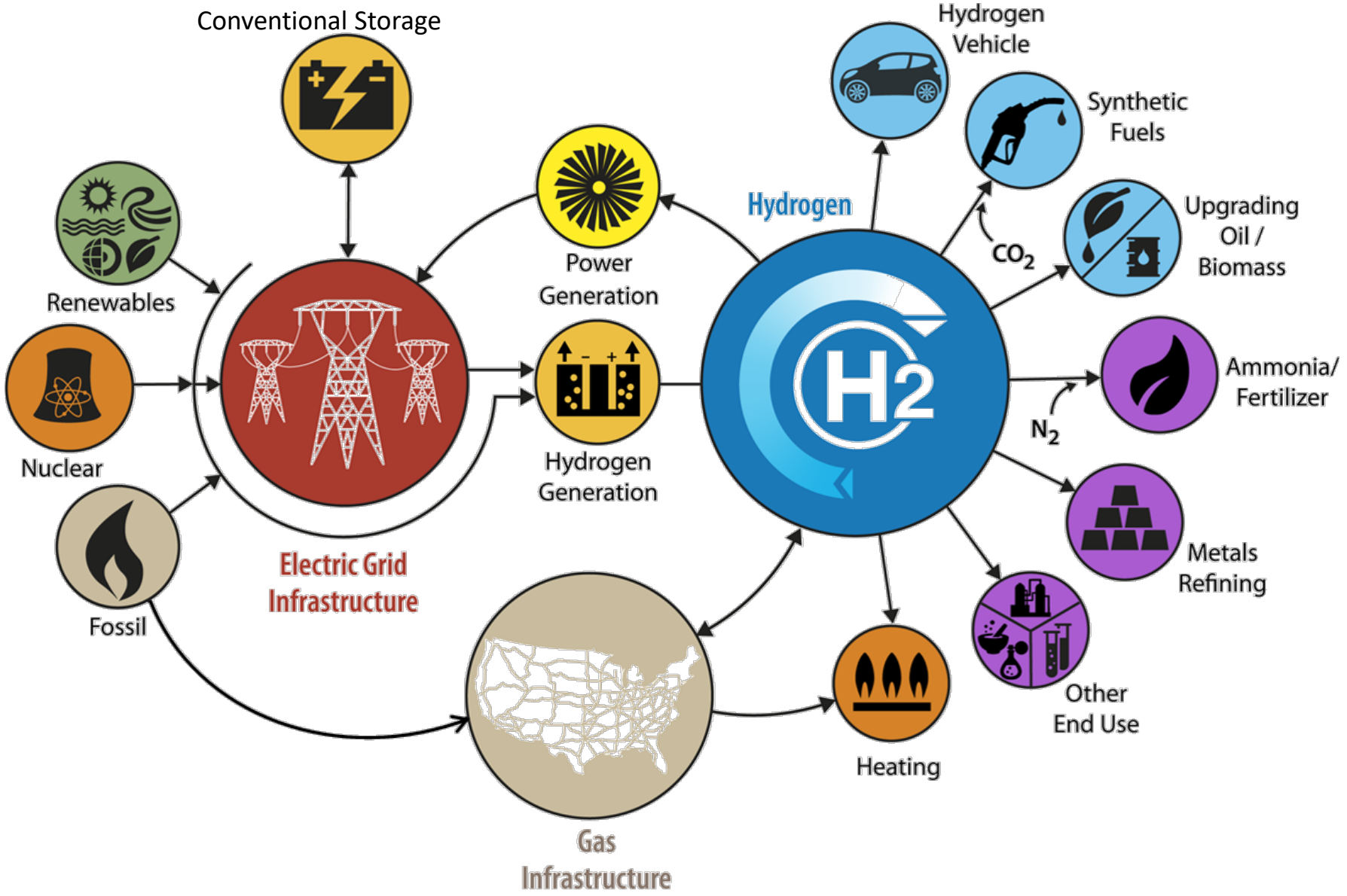
Largest Users in the U.S.

Petroleum Processing	68%	Fertilizer Production	21%

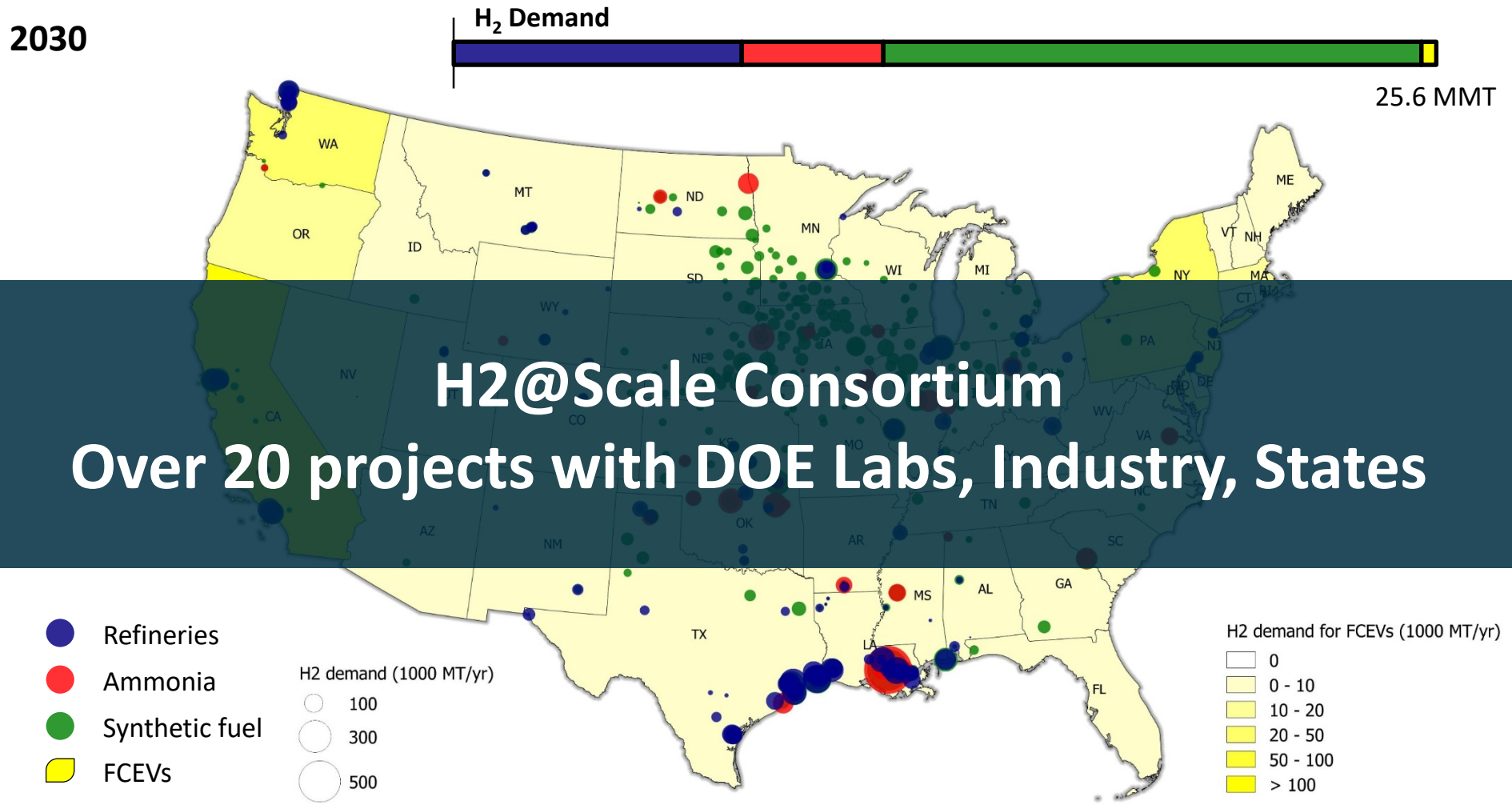
H_2@Scale concept

Enable affordable, reliable, clean and secure energy across sectors

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



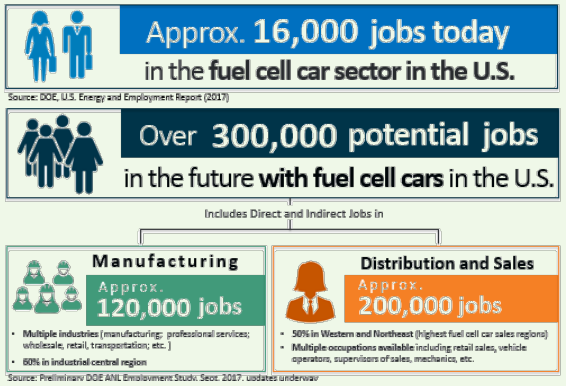
Analysis and R&D Projects Underway



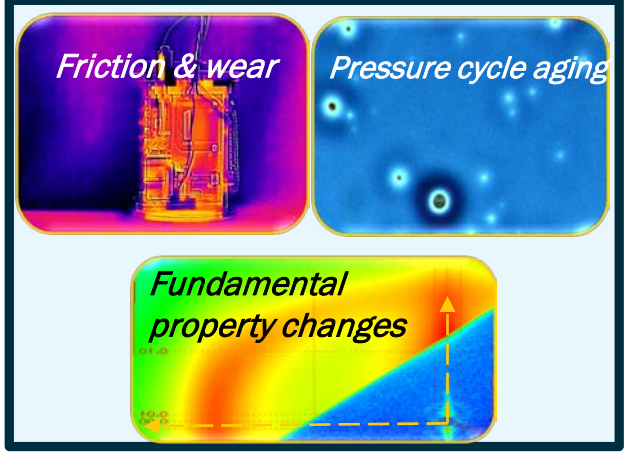
Source: Elgowainy, et al, ANL

Requests from Industry: Work with National Labs on…

Techno economic Modeling and Analysis



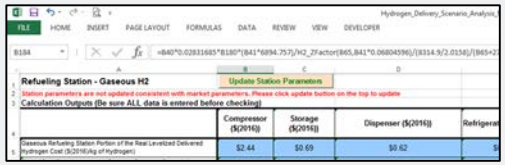
Hydrogen Materials R&D

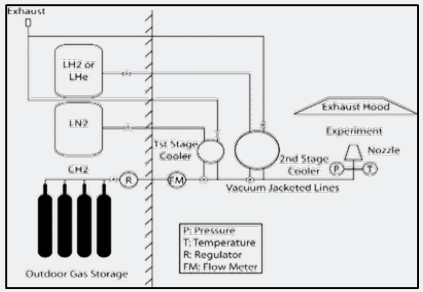


Grid simulation and Testing R&D

Safety and Infrastructure R&D

HyRAM
HYDROGEN RISK ASSESSMENT MODELS



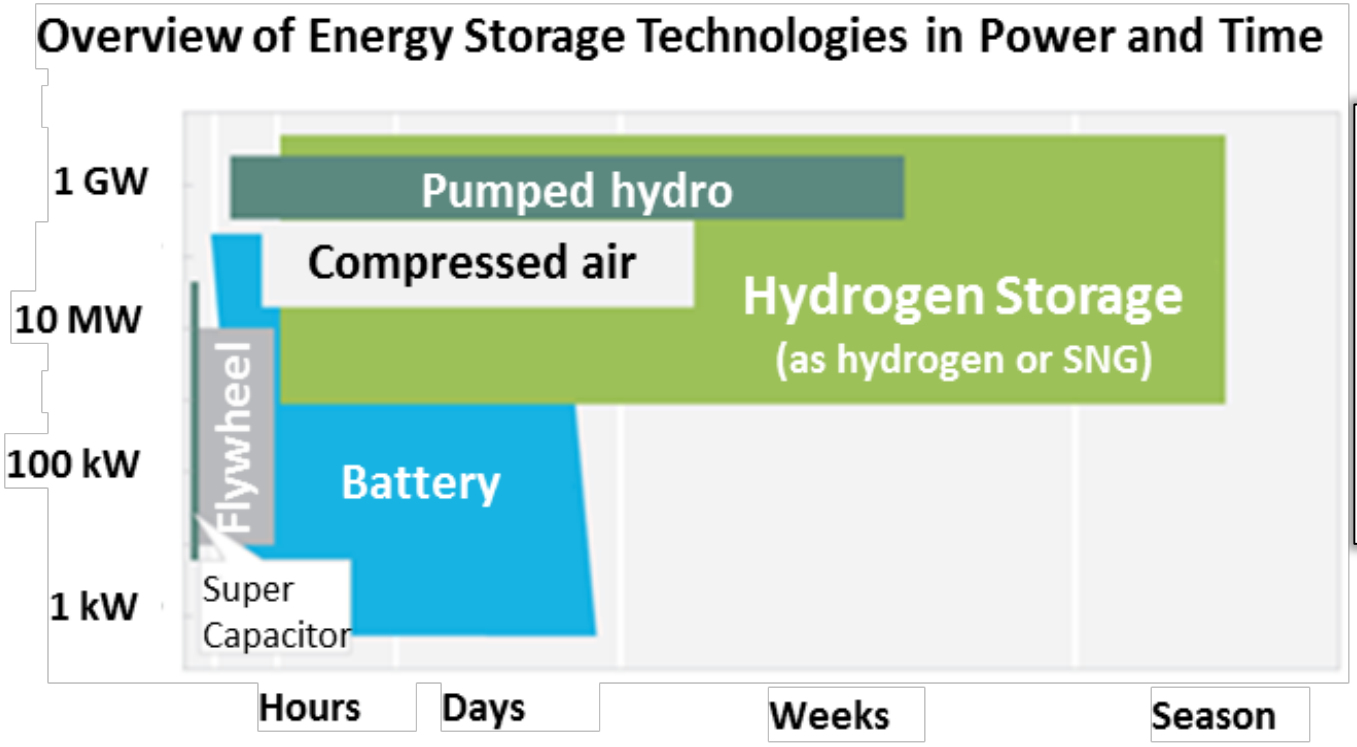


Versatility

Volume

Value Proposition

Hydrogen Energy Storage is Scalable



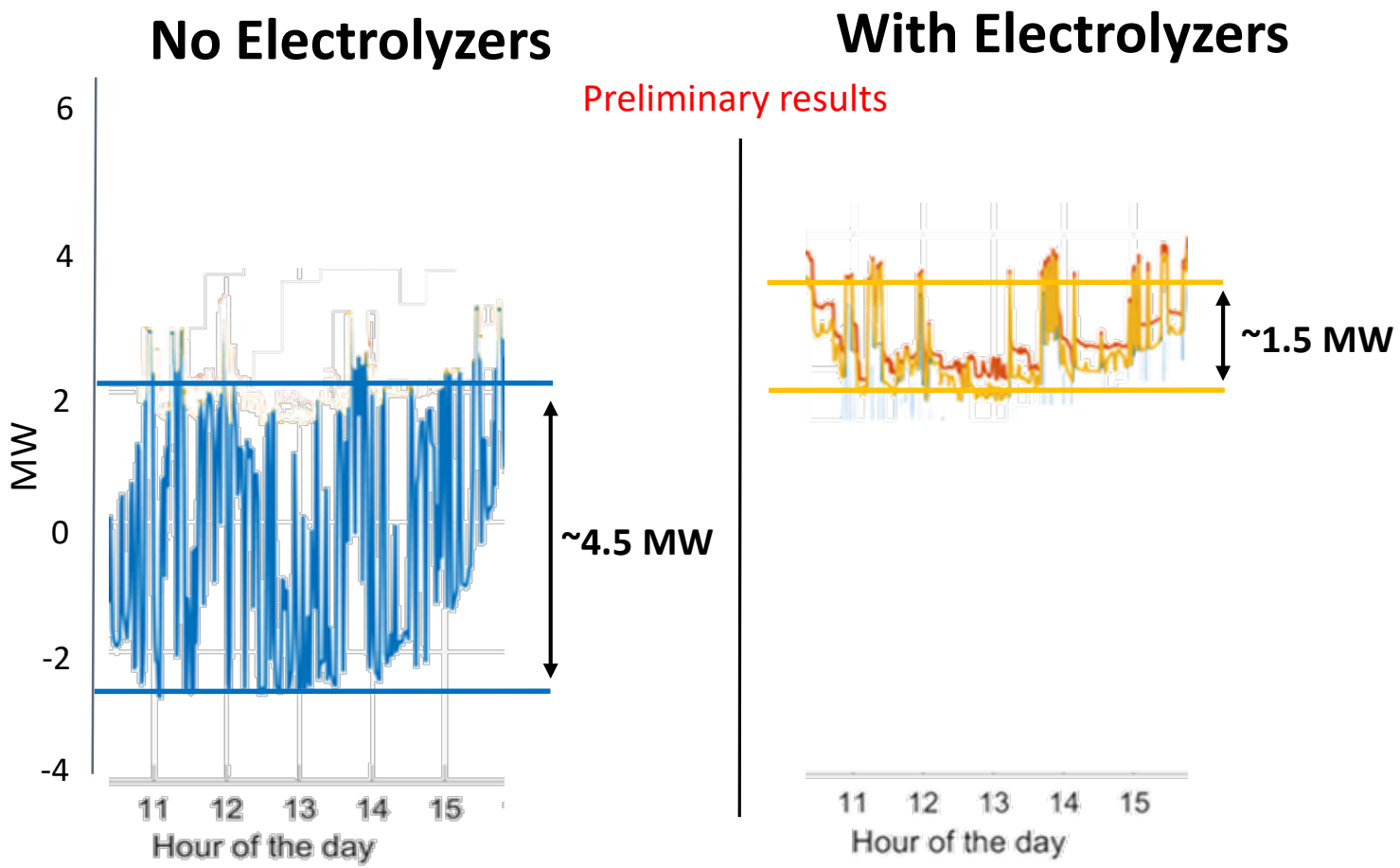
One hydrogen cavern could provide **~ 100 GWh energy storage**

Image: Hydrogen Council

Hydrogen can be used to monetize surplus electricity from the grid, or remote, off-grid energy feedstock (e.g. solar, wind) for days to months.

Example: Addressing Grid Needs

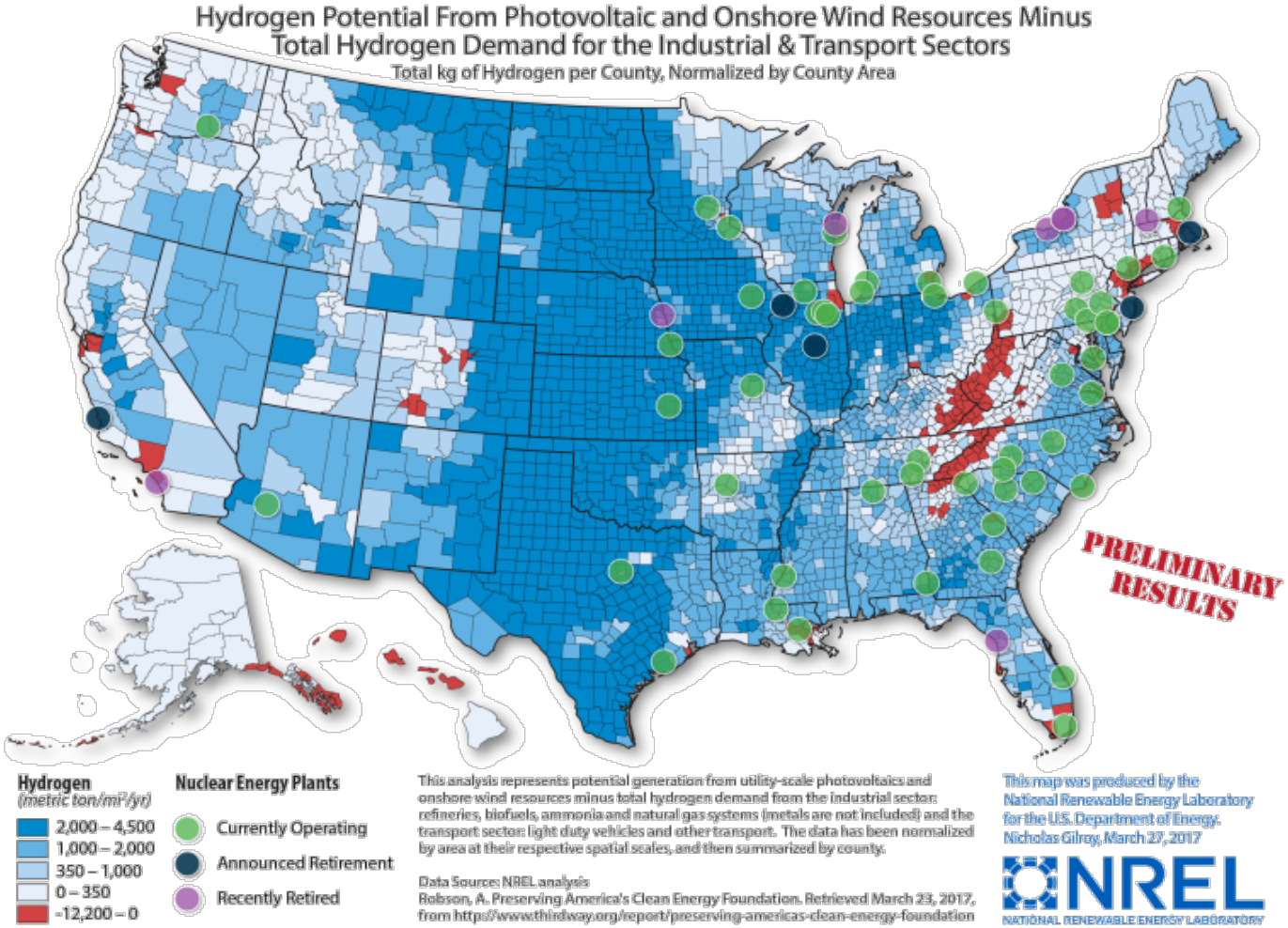
Preliminary study shows electrolyzers can reduce amplitude of power fluctuations by up to 65% in a grid with high renewables



Source: D. Murphy, et al, NREL and INL. Specific case with high solar penetration and electrolyzers used to compensate for power fluctuations

H_2@Scale: Supply and Demand Assessment

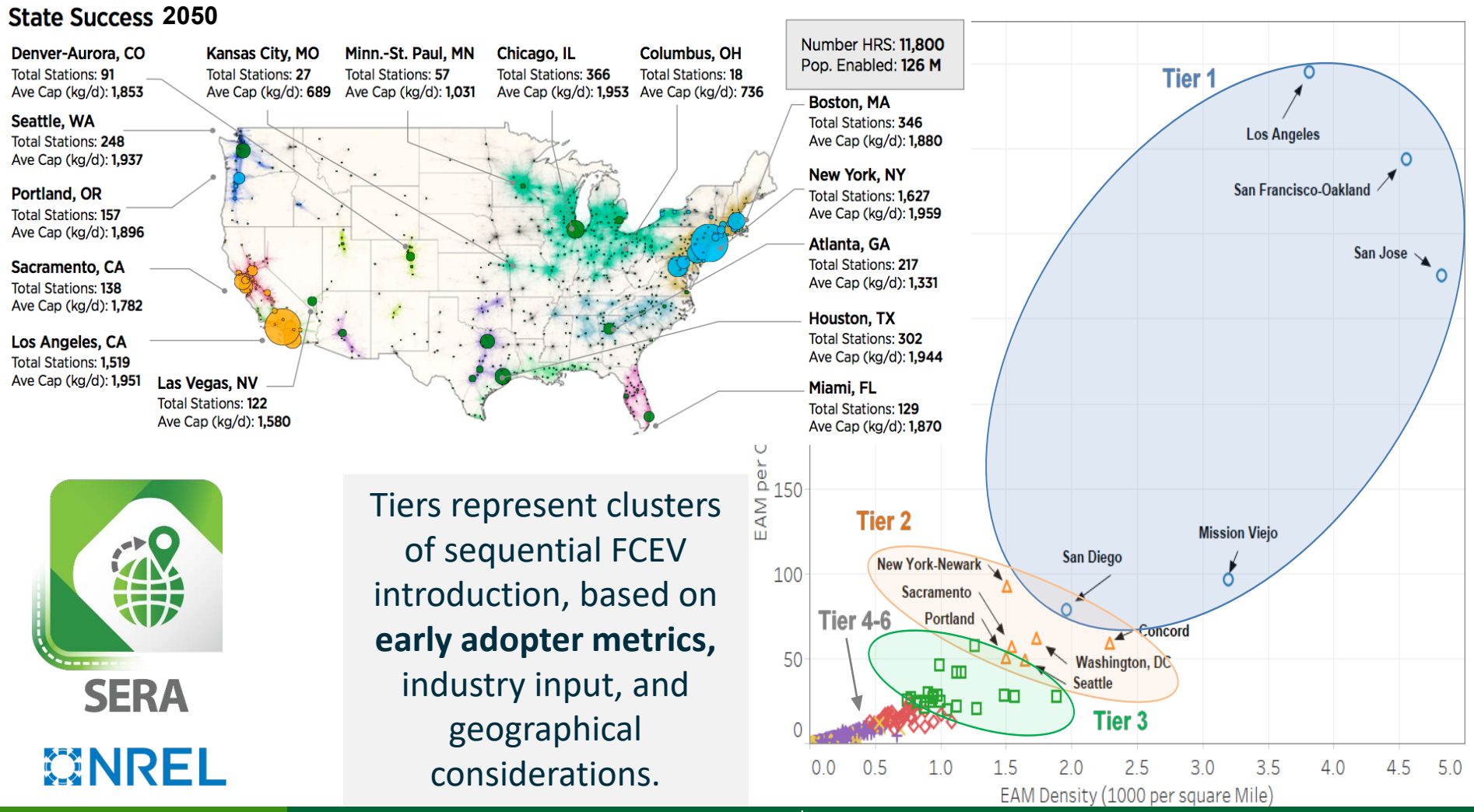
Assessing resource availability- most regions have sufficient resources



Red: regions where projected industrial & transportation demand exceeds supply for given scenario

Scenario Analysis for Hydrogen Fueling Station Rollout

Modeling the optimal size and placement of hydrogen stations over time under various scenarios



SERA

NREL

Tiers represent clusters of sequential FCEV introduction, based on **early adopter metrics,** industry input, and geographical considerations.

Source: EPA National Port Strategy Assessment, 2016; http://ad.apta.com/mc/rail/previous/2010/Papers/Demonstration-of-a-Hydrogen-Fuel-Cell-Locomotive.pdf

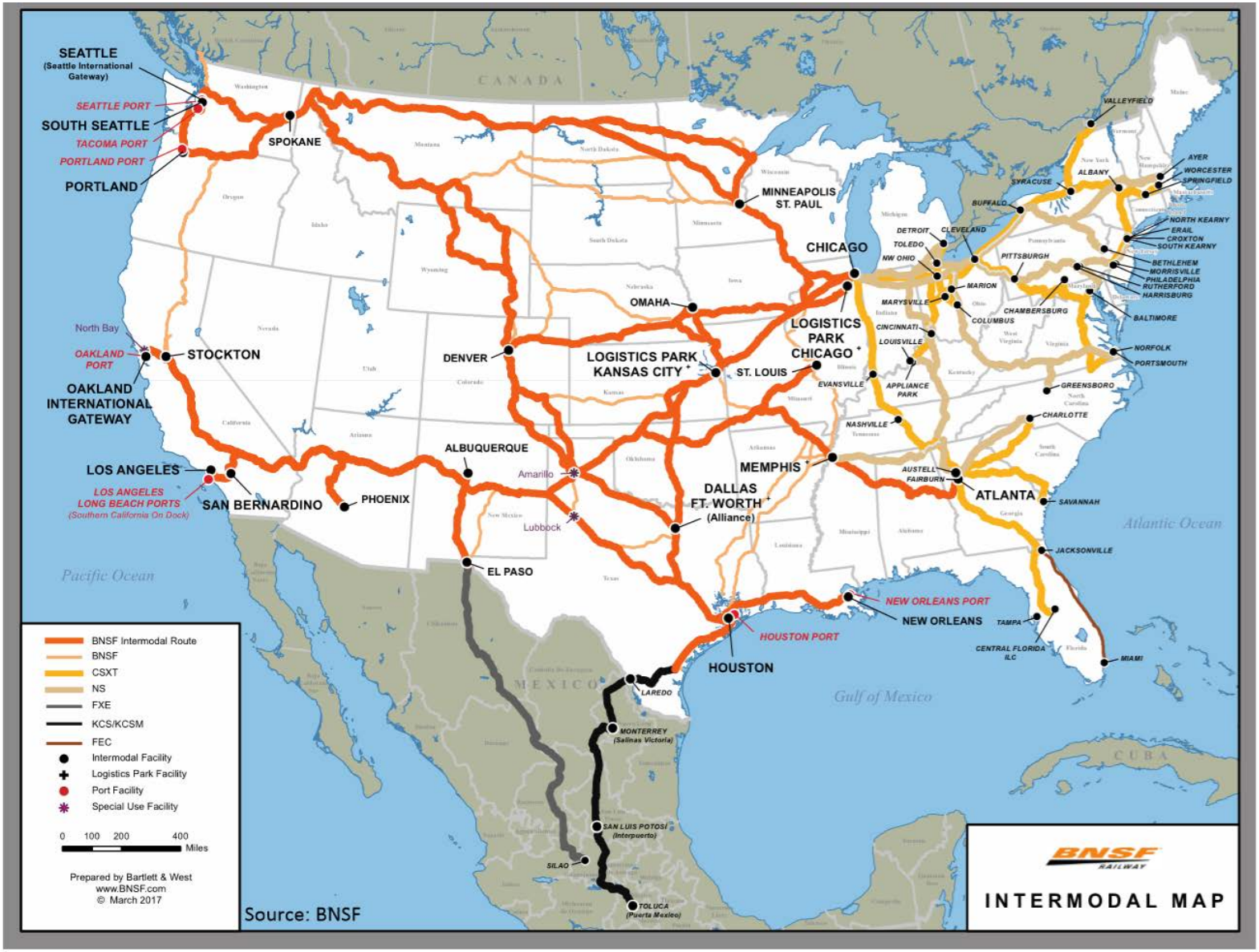
H_2@Rail and H_2@Ports Initiatives

- U.S. DOE in collaboration with:
  - Dept. of Transportation (DOT)-Federal Railroad Administration
  - DOT-Maritime Administration

Source: DOT-FRA (top) & SNL (bottom)

Data Centers and Energy Storage Applications

Examples of Intermodal Routes in the U.S.



DOE, MARAD, Industry Project: Pier-side Power

Collaboration with multiple project partners was essential to success of the project

Partner		Project Roles
(logo removed)	DOE	Sponsorship, steering
	DOT/MARAD	Sponsorship, steering, and facilitation
YOUNG BROTHERS Your Neighbor Island Partner / FOSS	Young Brothers & Foss Maritime	Site preparations, prototype operation and routine maintenance
HYDROGENICS SHIFT POWER | ENERGIZE YOUR WORLD	Hydrogenics *(sub w/ cost share)*	Design, engineer, build, commission, and support prototype unit
HNEI Hawai'i Natural Energy Institute University of Hawai'i at Mānoa	HNEI	Hydrogen supply logistics facilitation
HCATT	HCATT	Hydrogen provider
ABS	ABS	Prototype design to maritime product standards
	US Coast Guard	Review and acceptance of prototype design and operation
Pacific Northwest NATIONAL LABORATORY	PNNL H_2 Safety Program	Prototype and project safety review by HSP; Hydrogen Emergency Response Training for First Responders
Sandia National Laboratories	Sandia	Mgmt. and coord., H_2 materials, systems, risk expertise, H2 supply logistics, tech/biz data collection and analysis

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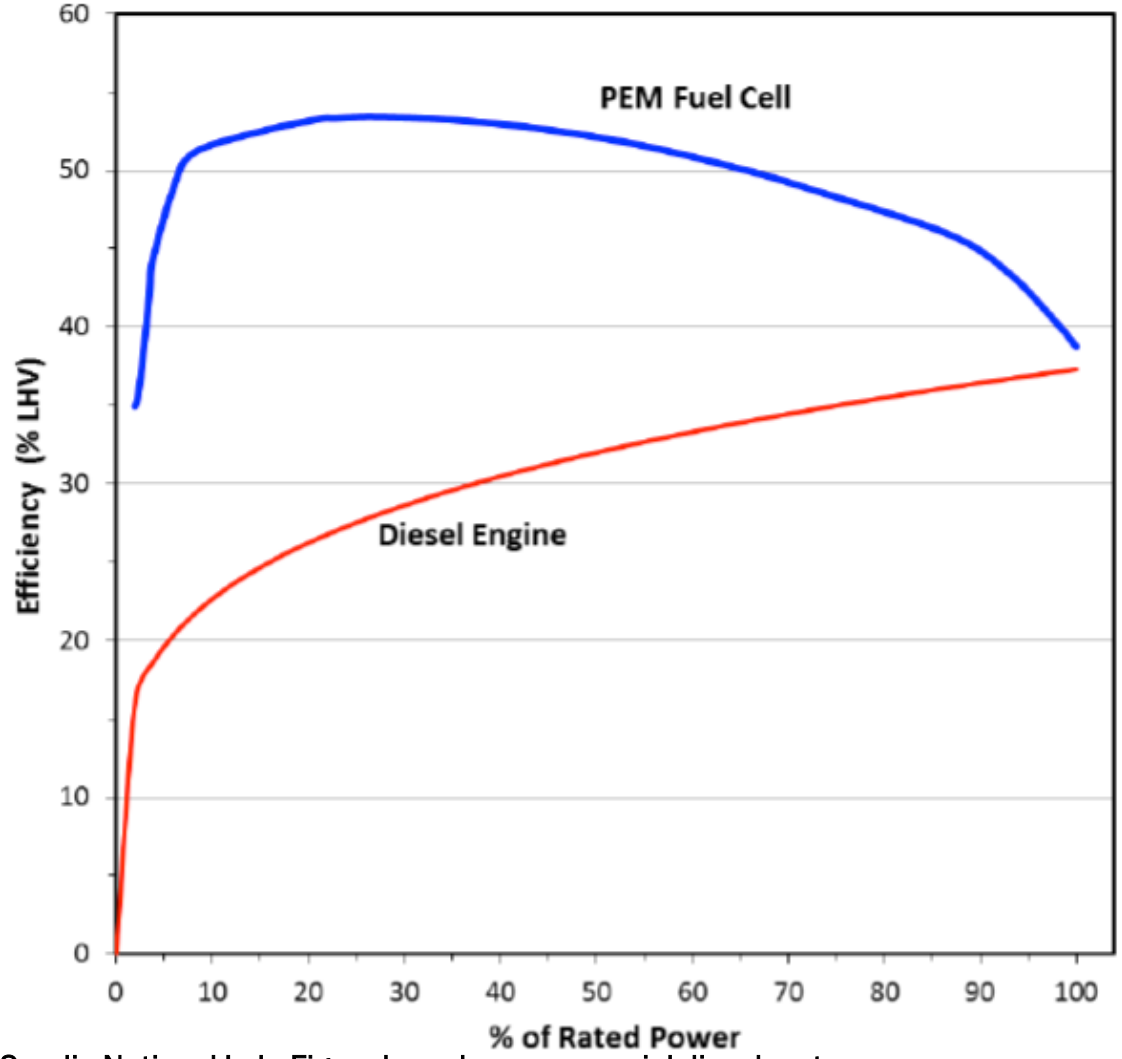
Fuel Cell and Diesel Engine Efficiency Examples

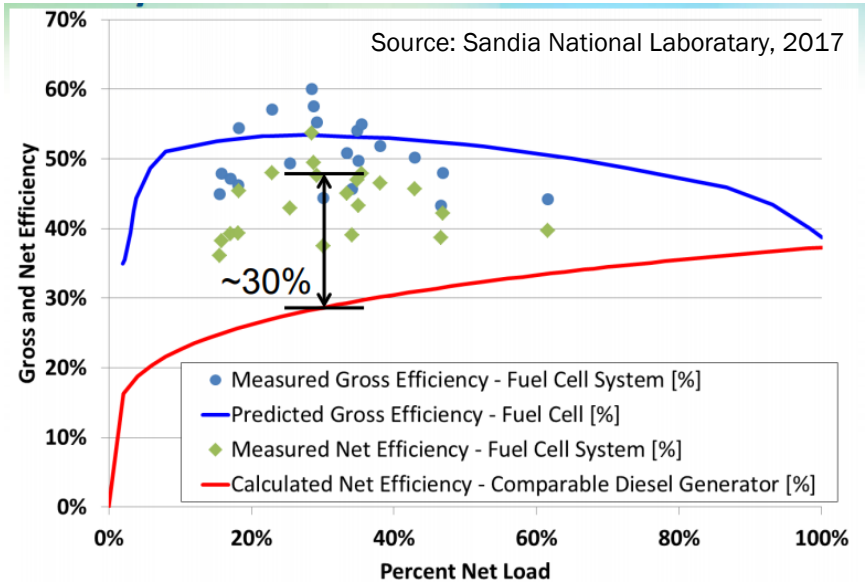


Diesel engines at ports: Typically sized for max load. Poor efficiency at part load

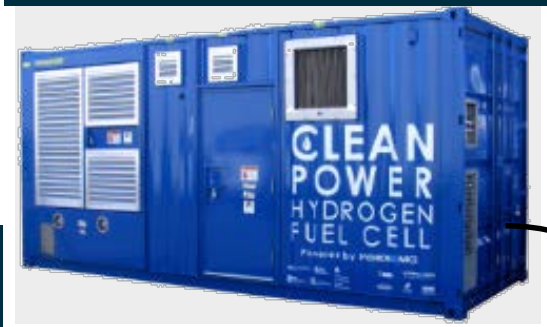
Fuel Cells: Higher efficiency, especially at part load. Zero emissions, no noise, no moving parts

Sandia National Lab. Figure based on commercial diesel system..
https://www.energy.gov/sites/prod/files/2017/07/f35/fcto_maritime_fc_generator_2017.pdf

In collaboration with U.S. MARAD, developed and tested hydrogen fuel cell power generator



Model analysis validated in field experiment testing: ~30% energy efficiency gain over diesel engine at part loads



100kW fuel cell power system

Refrigerated containers

Next Step

Maritime fuel cell generator will be field tested at Scripps Institution of Oceanography in San Diego for cold ironing application

Full report available at:
https://www.energy.gov/sites/prod/files/2017/07/f35/fcto_maritime_fc_generator_2017.pdf

Scripps location for MarFC generator

Example: Annual Fuel Cost for Port Application

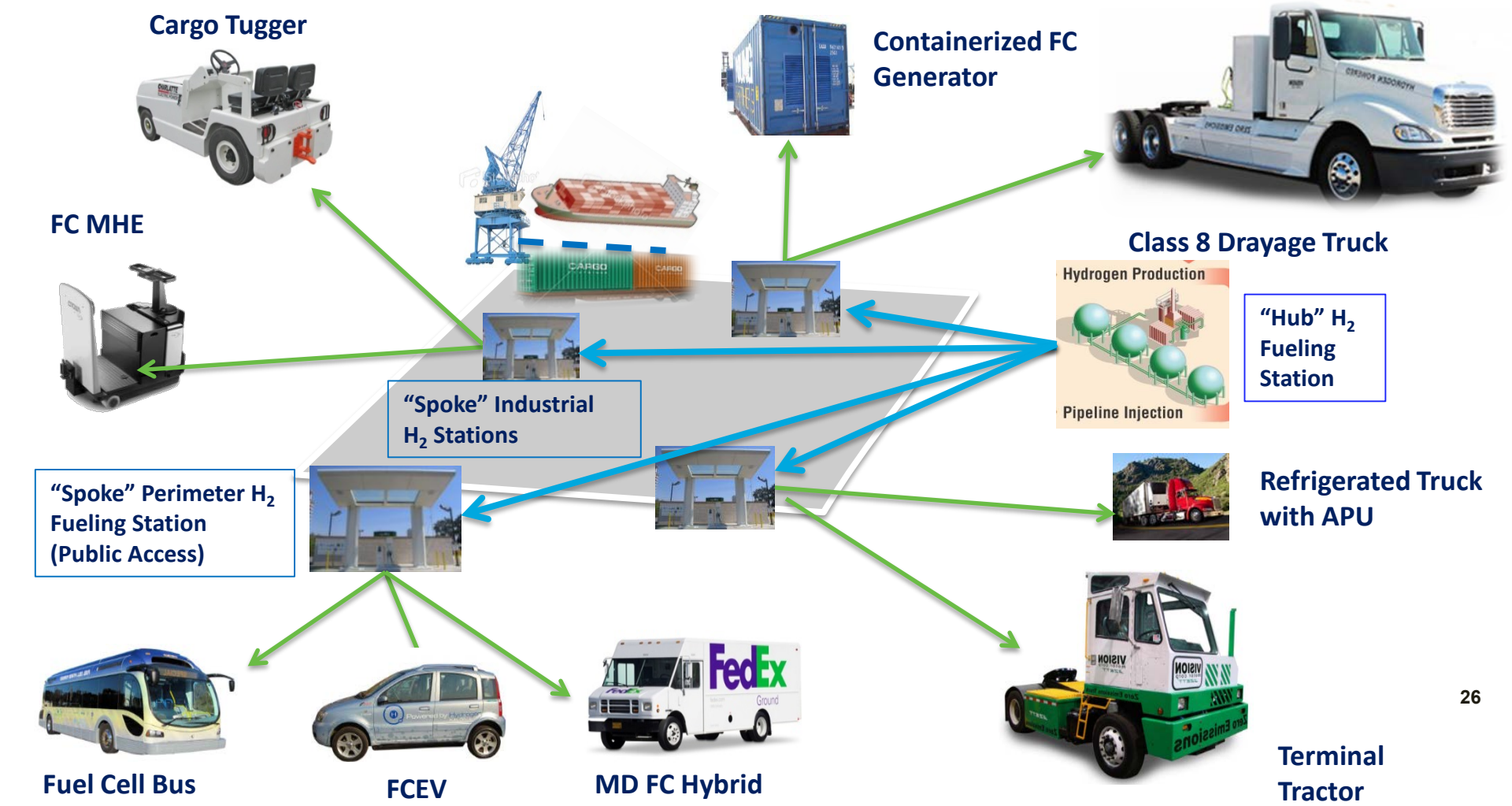
Figure 9: Yearly cost of fuel for running six 300 kW generators in a typical load profile at Young Brothers (33% of the time at 33% load, 33% of the time at 50% load, and 33% of the time at 67% load).

Annual fuel cost for six 300 kW generators in port application

Hydrogen fuel at roughly $5/kg can offer fuel savings compared to diesel and zero emissions

"Clustering" FCEVs Can Drive H2 Demand in Port-Based Distribution Complexes

Representative Port-Based Industrial Complex with Hydrogen Cost < $6/kg
"Hub and Spoke" H2 Fueling Stations Connected by Pipelines



Examples of Applications and Specifications

Vessel Type	Power Required			Run Time (hr)		
	Typical	Low	High	Typical	Low	High
Harbor Tug	100 kW	7.5 kW	410 kW	4	1	6
Tug-Barge	115 kW	-	-	N/A	-	-
Fishing Trawler	200 kW	75 kW	670 kW	continuous	48	months
Bulk	200 kW	150 kW	300 kW	48	-	-
Tanker (steam pumps)	700 kW	550 kW	800 kW	48	24	72
Auto/RoRo	800 kW	700 kW	890 kW	24	24	36
Container	1.4 MW	500 kW	8.4 MW	48	24	72
Reefer	3 MW	900 kW	5.6 MW	60	48	72
Cruise	6 MW	3.5 MW	11 MW	10	10	12
Tanker (elec. pumps)	7.8 MW	-	-	48	24	72

Examples of applications under assessment:

- Container ships at berth at the Port of Tacoma and/or Seattle
- Tugs at anchorage near the Port of Oakland
- Powering refrigerated containers on-board Hawaiian inter-island transport barges

Source: Sandia National Laboratary, 2014

Example - Hydrogen Potential at the Port of Tacoma

Port of Tacoma

Renewable H2
Onsite Generation

Cargo Handling

Heavy Duty Truck

Container Handlers

Locomotive

Port Transit

Rapid Transit Bus

Light Duty Vehicles

Commuter Rail

Port Marine

Passenger Ferry

Cold Ironing Barge

Offshore Workboat

Port of Tacoma
Diesel Consumption by Use

Fuel Use Category	Subcategory	CO2e Tons	Gallons Diesel
OGV	Hoteling	2,796	249,643
OGV	Maneuvering	65	5,804
OGV	Subtotal	2,861	255,446
CHE	Subtotal	12	1,071
Locomotives	Subtotal	1,166	104,107
HDV	On-Terminal	28	2,500
HDV	Subtotal	28	2,500
Port	Total	4,067	400,276

State and Industry Project: Hydrogen Fuel Cell Ferry to be Built Soon

Funded by the State of California Air Resources Board (CARB)

The first commercial hydrogen fuel cell ferry in the western hemisphere.

- Aluminum catamaran
- 70’ long
- 84 passenger (reconfigurable)
- 22 knot top speed
- On the waters of SF Bay Fall of 2019.

Project Lead

GOLDEN GATE ZERO EMISSION MARINE

Funding & Administration

CALIFORNIA AIR RESOURCES BOARD

BAY AREA AIR QUALITY MANAGEMENT DISTRICT

CALIFORNIA CLIMATE INVESTMENTS — Cap and Trade Dollars at Work

This project is supported by the “California Climate Investments” (CCI) program


Collaboration
&
Resources

Example of International Government Collaboration

The International Partnership for Hydrogen and Fuel Cells in the Economy

Enabling the global adoption of hydrogen and fuel cells in the economy

www.iphe.net

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

Find IPHE on Facebook, Twitter and Linkedin
Follow IPHE **@The_IPHE**

Formed 2003
Over 20 Countries

Collaboration: New H_2 Safety Partnership

New global partnership to promote collaboration on safety

www.aiche/chs

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Summary and Next Steps

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

Next Steps

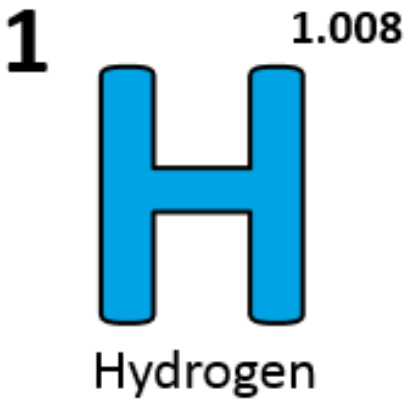
- Conduct analysis on H_2 and fuel cells maritime applications.
  - TCO, impact potential (petroleum, emissions reductions, etc.)
- Develop technical and cost targets.
- Identify barriers and opportunities for RD&D and addressing regulations, codes and standards
- Focus on global collaborations to accelerate progress.

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 H2IQ

Save the Date: May 18-21 2020
Annual Merit Review
Washington DC

Learn more at: energy.gov/eere/fuelcells

Thank You

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Fuel Cell Technologies Office
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www.hydrogen.energy.gov