U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

The Case for Hydrogen in Ports and Maritime

California Hydrogen Business Council

Hydrogen and Fuel Cells in the Ports and Shipping Workshop 2018

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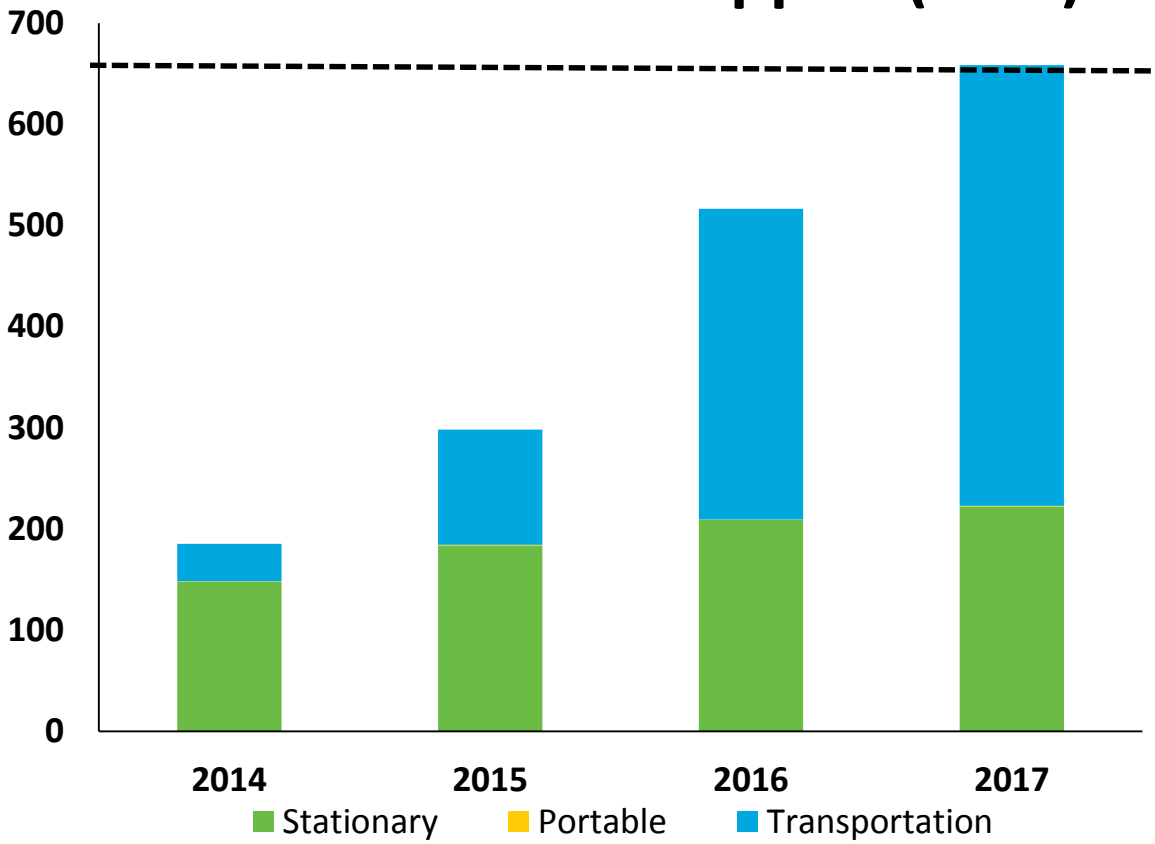
Los Angeles, CA - October 10, 2018

Overview at Glance

1. Hydrogen and Fuel Cells Progress
2. Focus, Research Targets, Results
3. H2@Scale
    1. Vision
    2. New R & D and Demand Assessments

1. Progress

Upward trend with global fuel cell shipments



650 MW
fuel cell power
shipped worldwide

70,000
fuel cell units
shipped worldwide

Approximately
$2 Billion
fuel cell revenue

Source: DOE and E4Tech

Electrolyzers: Over 100MW/year estimated global sales

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

Stationary Power Applications Emerging – Examples

Fuel cells provided backup power during Hurricane Sandy in the U.S. Northeast

Fuel cells used to power new World Trade Center in NYC

Fuel cell power for maritime ports demonstrated in Honolulu, Hawaii

Over 235 MW of fuel cell stationary power installed across more than 40 US states

Photo Credit: Fukuoka Pref.

Heavy Duty Vehicle 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

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

Real World Applications – Abroad

Hydrogen fuel cell powered drones and UAVs

Photo Credit: MMC

Fuel cell cab fleet launched in Paris, France

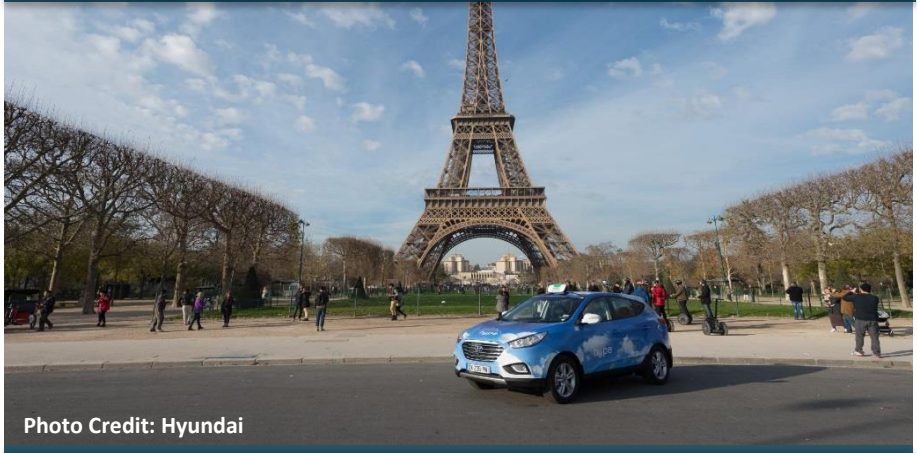


Photo Credit: Hyundai

A town in in Fukuoka, Japan running on hydrogen

Photo Credit: Fukuoka Pref.

World's first hydrogen fuel cell train in Germany

Photo Credit: Hydrogenics and Alstom

Hydrogen Fuel Cell Electric Vehicles are Here

Hyundai Tucson Fuel Cell SUV

Toyota Mirai

Honda Clarity

- **High fuel efficiency:** Over 60 mpgge*
- **Long Range:** More than 360 mi.
- **Quick Refueling:** 3-5 mins.
- **High torque, pollution-free**
- **Over 5,000 cars on U.S. roads** [+]

* miles per gallon of gasoline equivalent
[+] as of Jun 2018

Projected cost (at volume) for driving fuel cell car:

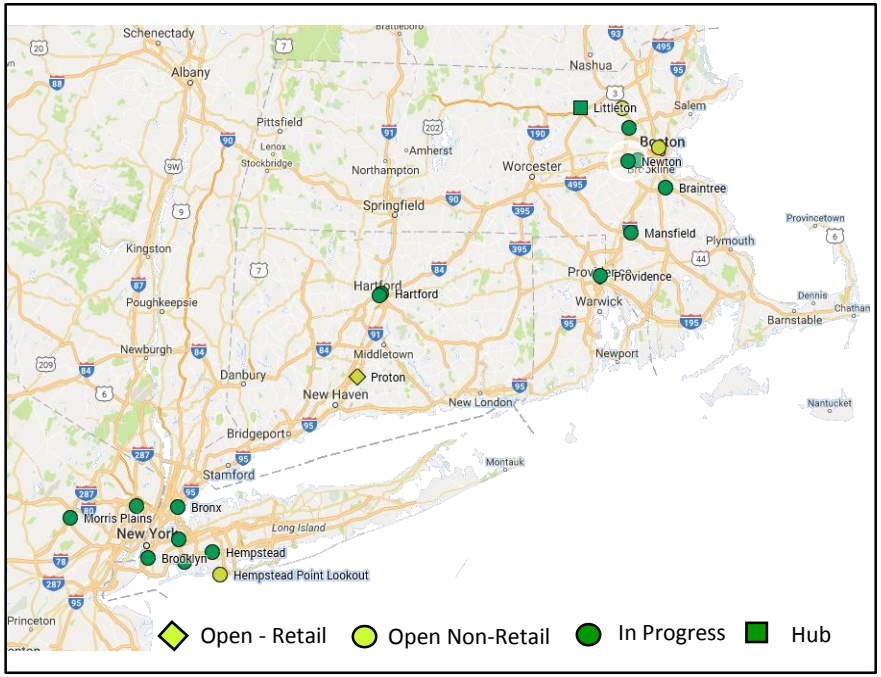
Today	Ultimate Target
$0.39 per mile	**$0.27 per mile**

U.S. Hydrogen Refueling Stations

California

Over 30 open retail

Funding for 200



Northeast

Approx. 12 to 25 stations planned

Others with interest: Hawaii, Ohio, Texas, Colorado, South Carolina, and others

2. Focus, Targets, Results

U.S. Dept. Of Energy H_2 and Fuel Cells R&D Focus

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

- PGM- free catalysts
- Durable MEAs
- Electrode performance

Hydrogen Fuel

- Production Pathways
- Advanced materials for storage

Infrastructure R&D

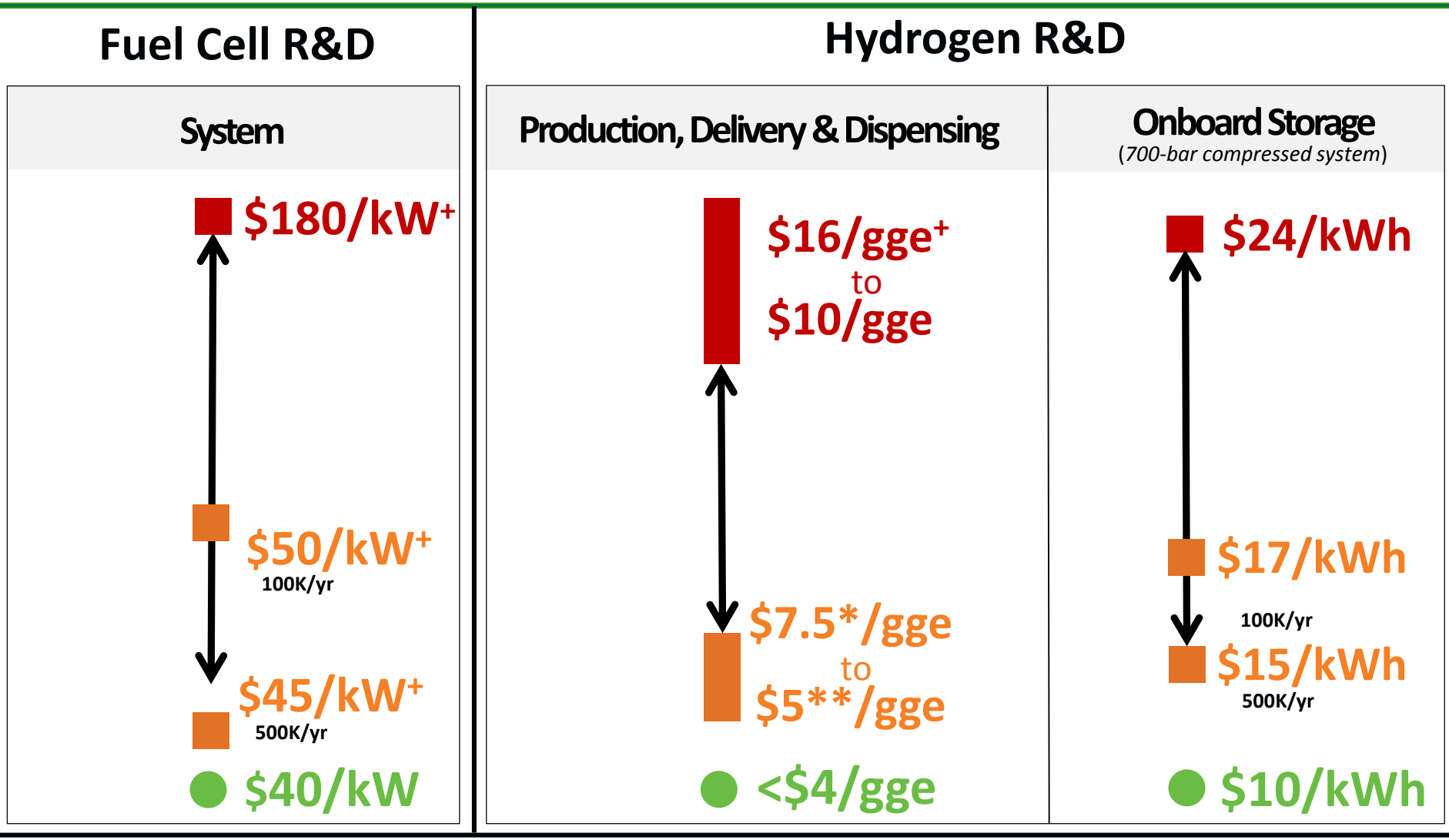
- Safety
- Manufacturing
- Delivery components
- Others

PGM = Platinum group metals
MEA = Membrane Electrode Assembly

Enabling

H2@Scale℠
U.S. Department of Energy

DOE Cost Status and Targets



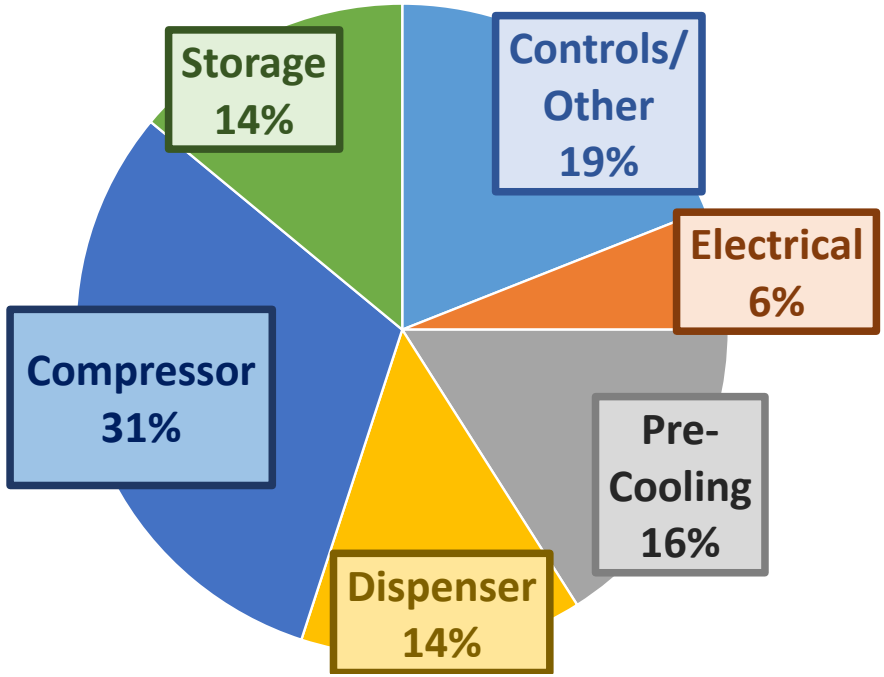
*Based on Electrolysis **Based on NG SMR + Preliminary, updates underway
Onboard storage cost status from DOE Program Record 15013

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

Hydrogen Delivery Infrastructure is a Key Challenge

Delivery cost goal: <$2/kg** (includes dispensing at the station)

Cost by Component
Tube Trailer Delivery Example



Early Stage R&D Examples

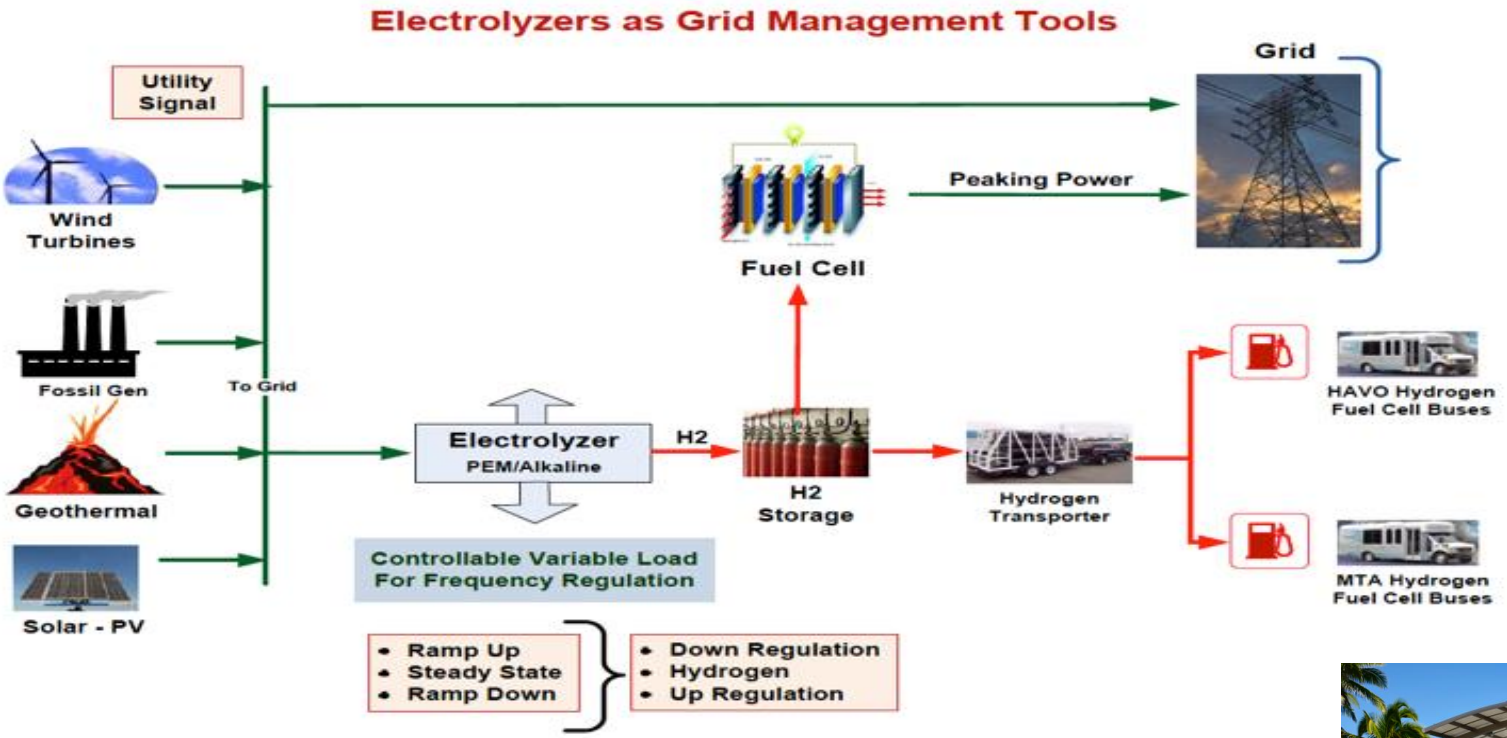
Innovative concepts on:

- Gaseous & Liquid Delivery
- Compressors
- Storage
- Dispensers
- Materials Compatibility
- Liquefaction
- Pipeline & joining materials
- Other innovations (e.g. liquid carriers, etc.)

**gge = gallon of gasoline equivalent

Hydrogen Energy Systems as a Grid Management Tool

An electrolyzer can be used as a variable controllable load that can be reduced/increased in order to maintain the total load balance and frequency stability.



Built and deployed a containerized hydrogen fuel cell generator for reefer power on land and sea.

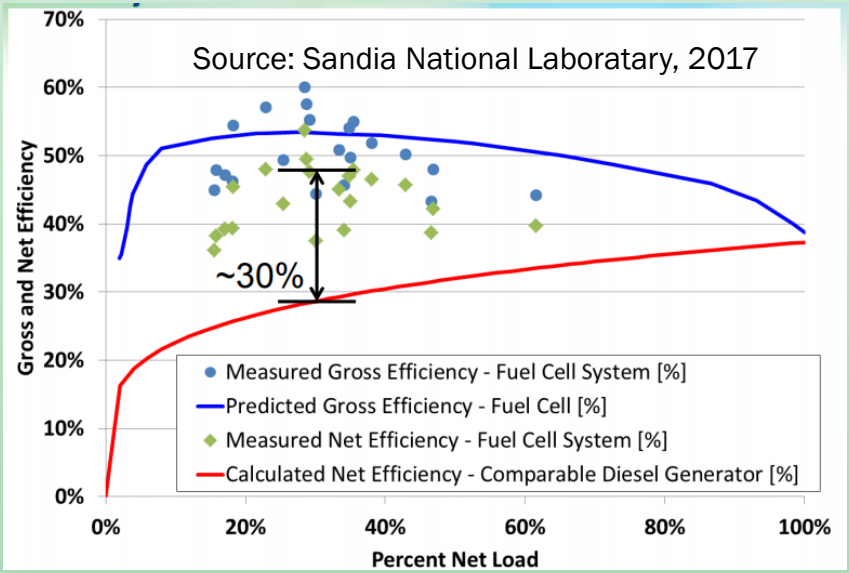
Project Scope

Design, build, and deploy a containerized fuel cell system to supply portable power for refrigerated containers ("reefers").

- 100 kW (net) fuel cell and H_2 storage inside a 20-foot container,.
- 9-month deployment on land and over the ocean. (Honolulu-Kahului)
- Strategic set of project partners, encompassing both the H_2-fuel cell and maritime communities.

Photo by Sandia

Photo by Author



Accomplishments & Next Steps

- Data shows up to ~30% efficiency gain over diesel engine at part loads
- Fuel cell unit was able to replace diesel generators to meet the power requirements of the reefers, at the same time reducing fuel cost and emissions.
- Upgrade the MarFC, re-deploy at new site

Vessel Cold-Ironing Using a Barge Mounted PEM Fuel Cell: Project Scoping and Feasibility

Objective:

- Determine the technical feasibility of a barge-mounted hydrogen-fueled PEM fuel cells system's potential to reduce emissions and fossil fuel at ports
- Examines specific options on the U.S. West Coast for deployment practicality and potential for commercialization.

6,000 TEU containership at Port of Tacoma

Source: Sandia Natiional Lab

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

Most technically viable and commercially attractive deployment options:

- 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

Examples of fuel cell vehicle technology demo's:

Heavy Duty Vehicles

Full-size buses

Drayage Trucks

Medium Duty Vehicles

Shuttle buses

Baggage Tow Tractors

Delivery Vehicles

Light Duty Vehicles

Commercial Vans

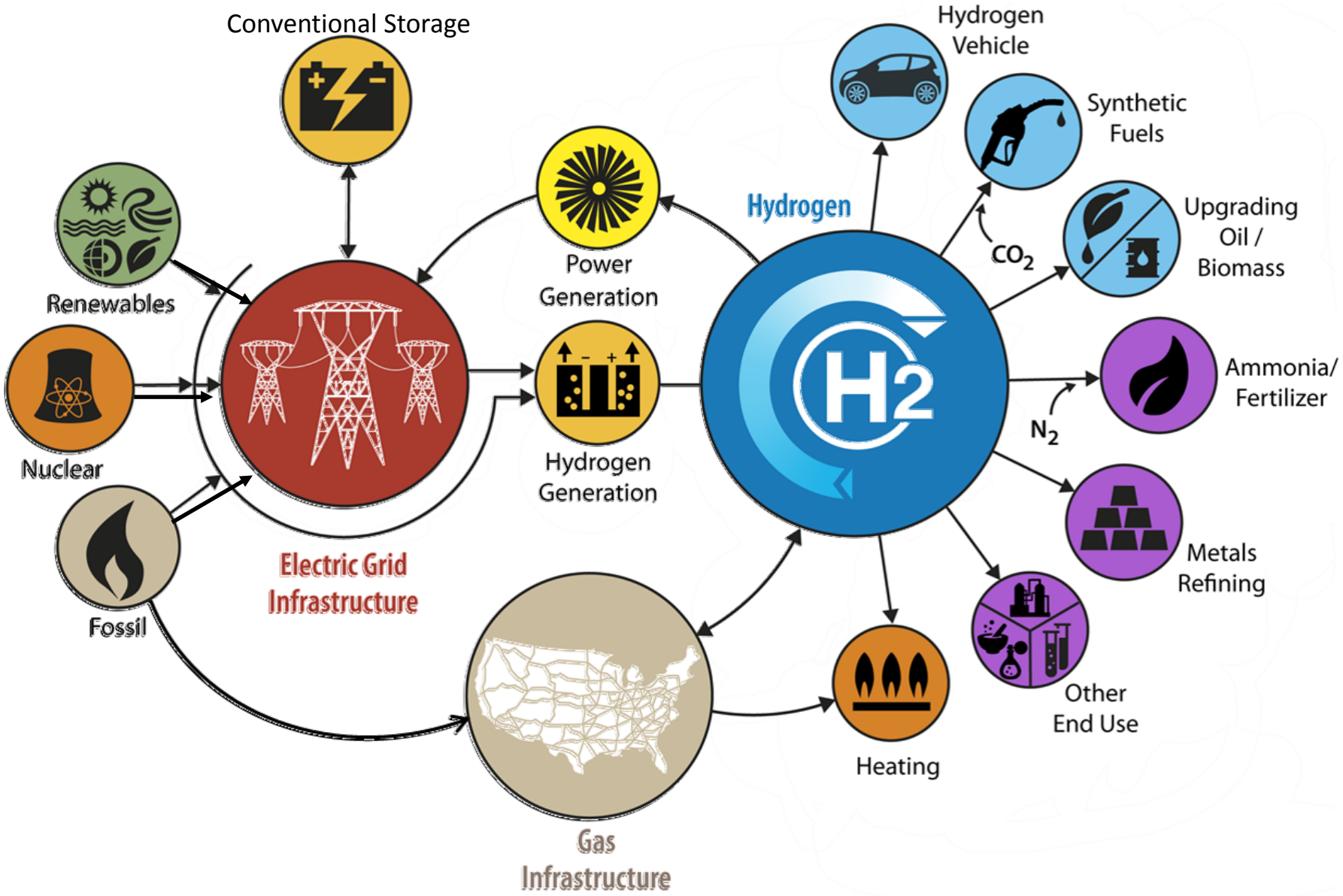
Tactical Vehicles

3. H_2@Scale concept

Vision

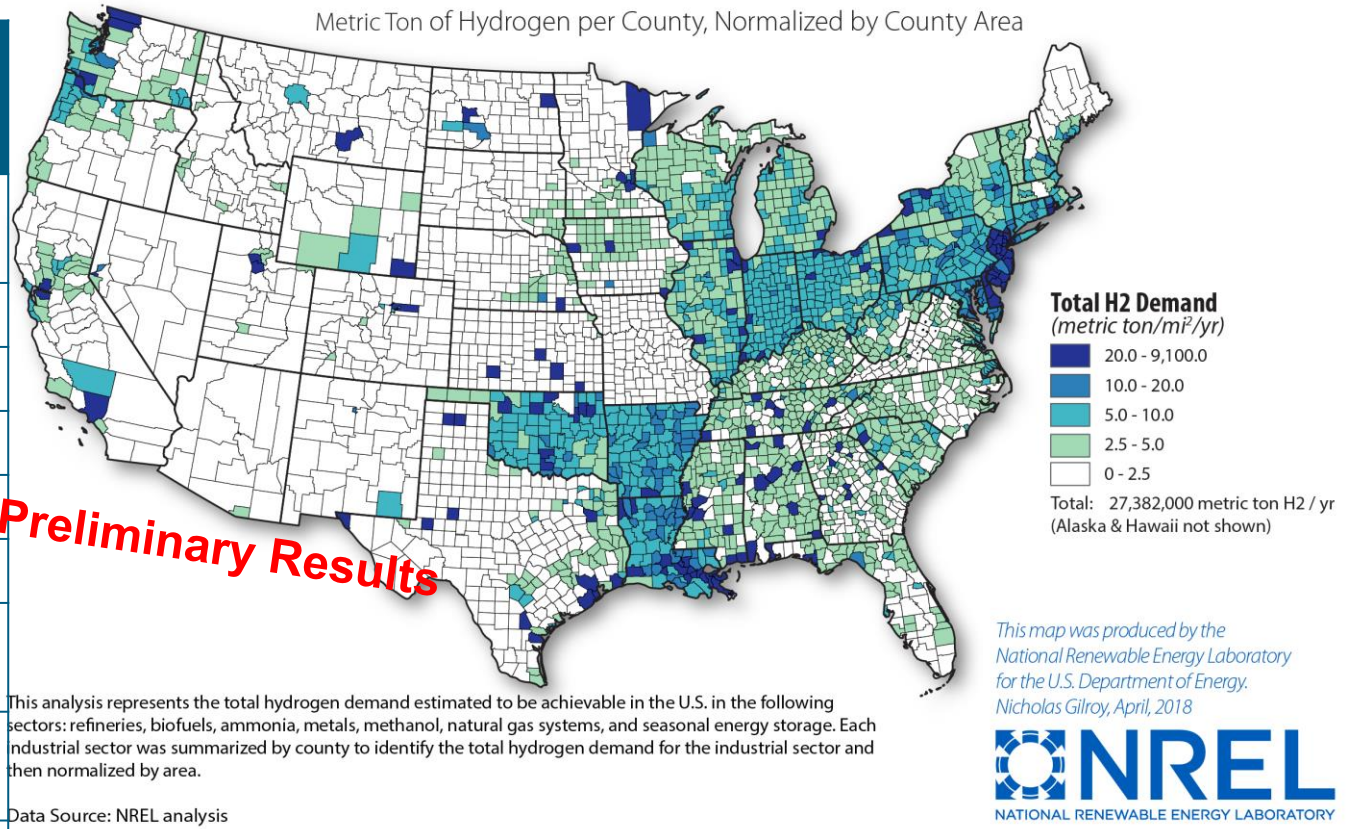
Enable affordable, reliable, clean and secure energy across sectors

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



H2@Scale Analysis: Estimated Technical Potential Hydrogen Demand

Demand	Technical potential (MMT* / year)
Refineries & CPI§	8
Metals	6
Ammonia	5
Methanol	1
Biofuels	1
Natural Gas	7
Light Duty Vehicles	28
Other Transport	3
Electricity Storage	28
Total	87



This analysis represents the total hydrogen demand estimated to be achievable in the U.S. in the following sectors: refineries, biofuels, ammonia, metals, methanol, natural gas systems, and seasonal energy storage. Each industrial sector was summarized by county to identify the total hydrogen demand for the industrial sector and then normalized by area.

Data Source: NREL analysis

Technical Potential Demand: 87 MMT/yr

Current U.S. market: ≈ 13 MMT/yr

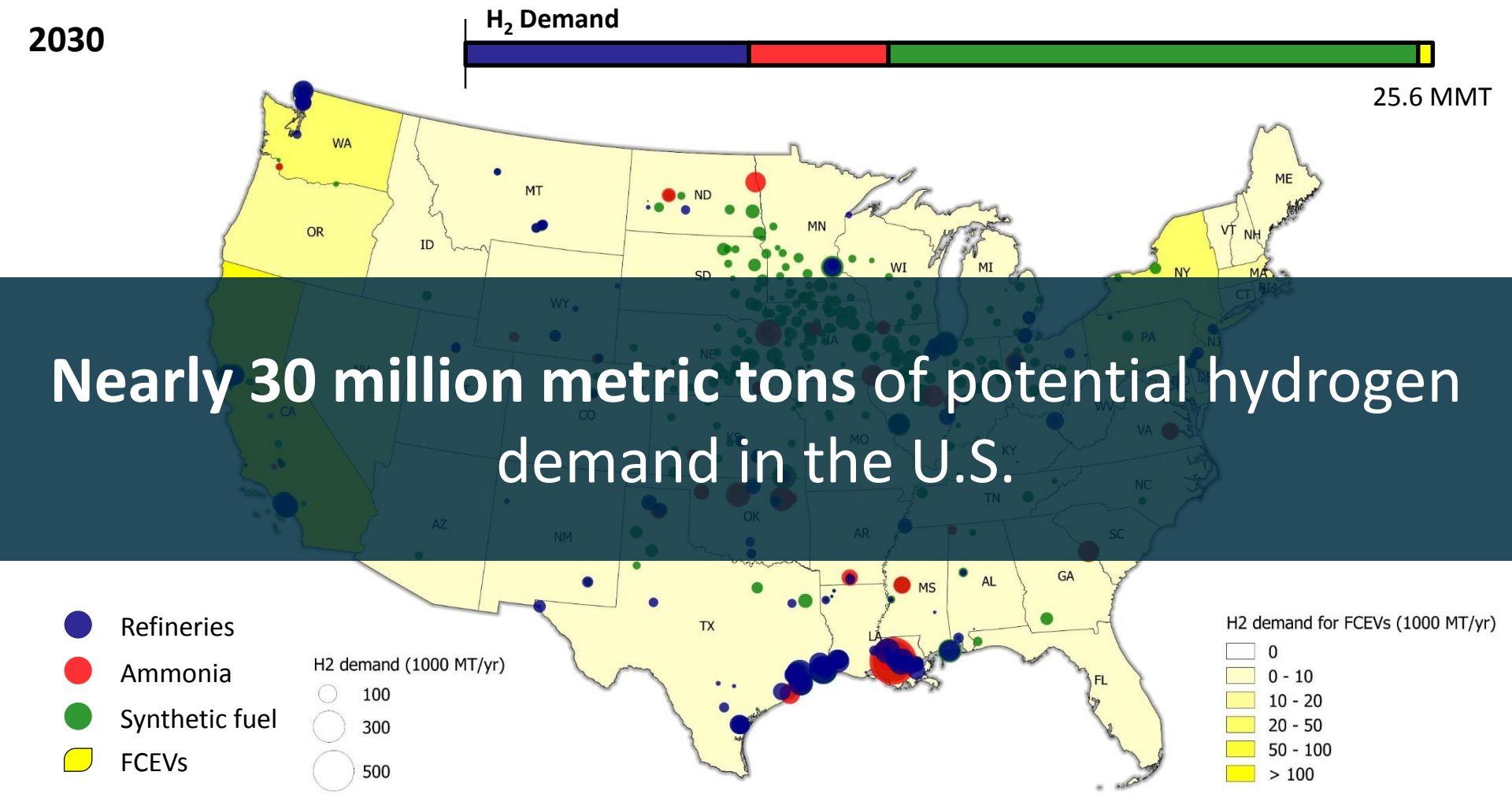
Including captive generation for ammonia and refining

* MMT: Million metric tonnes

§ CPI: Chemical Processing Industry not including metals, ammonia, methanol, or biofuels

Light duty vehicle calculation basis: 190,000,000 light-duty FCEVs from http://www.nap.edu/catalog/18264/transitions-to-alternative-vehicles-and-fuels

Hydrogen Demand Potential



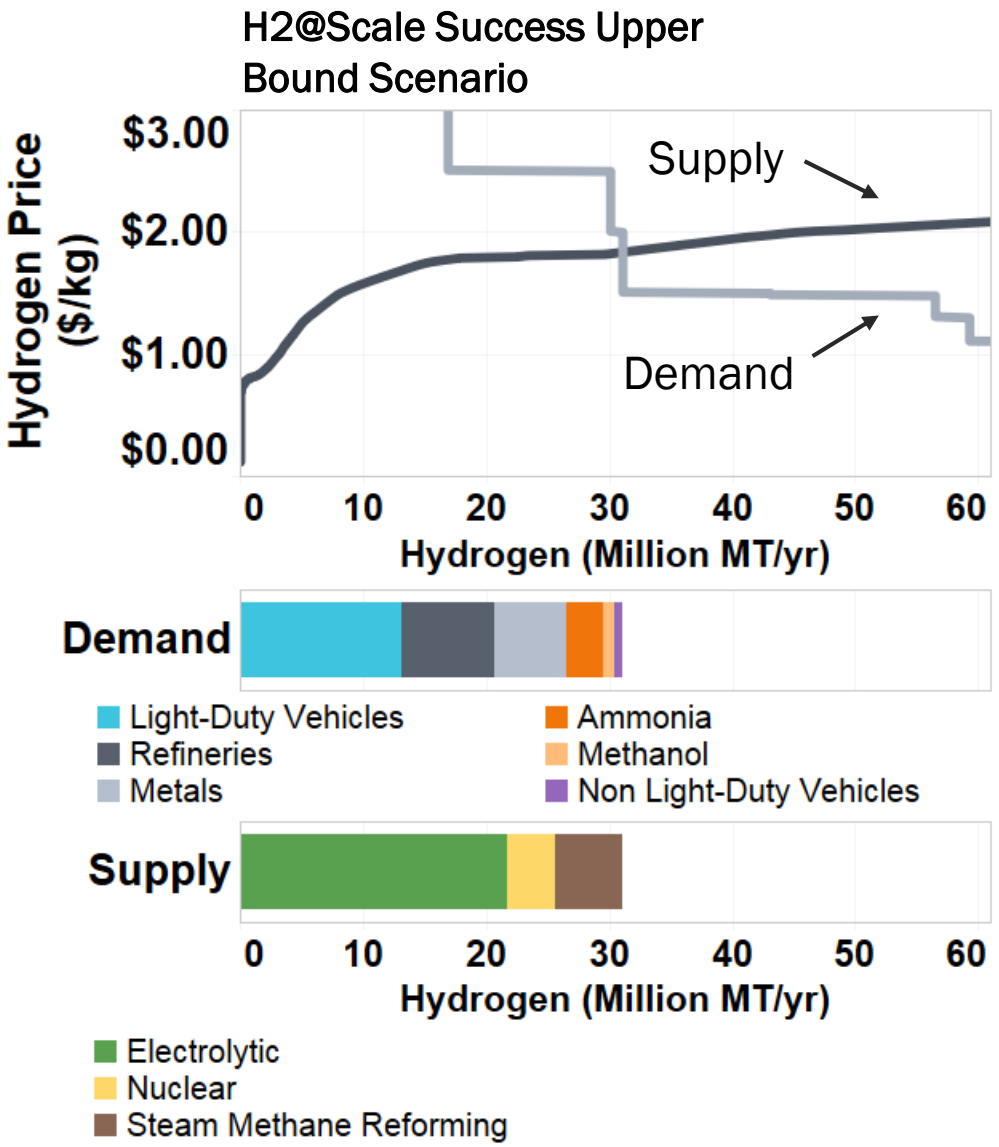
Nearly 30 million metric tons of potential hydrogen demand in the U.S.

Source: Elgowainy, et al, ANL

Approach for the techno-economic analysis of H2@Scale

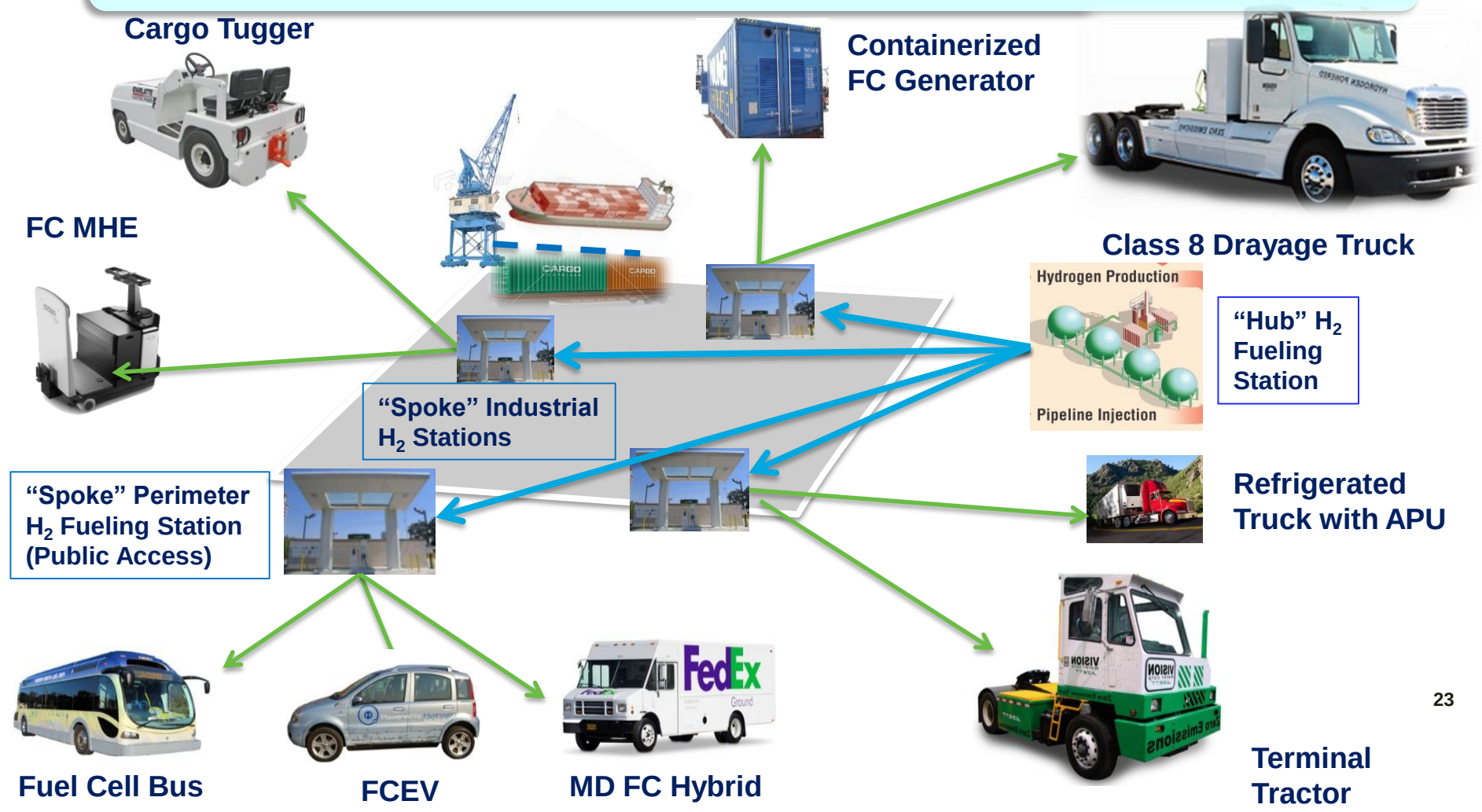
Developed hydrogen supply and demand scenarios with national labs and stakeholders

- Hydrogen supply growth developed using natural gas prices and curtailed resources of wind, solar and nuclear energy. (NREL)
- Hydrogen demand growth assessed (ANL)
  - Growth in FCEVs
  - Future gasoline and diesel demand
  - Ammonia production
  - Synthetic fuel growth
- Assessed the hydrogen supply from nuclear generation assets in conjunction with the Office of Nuclear Energy. (INL)



“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



Port of Tacoma Hydrogen Use

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

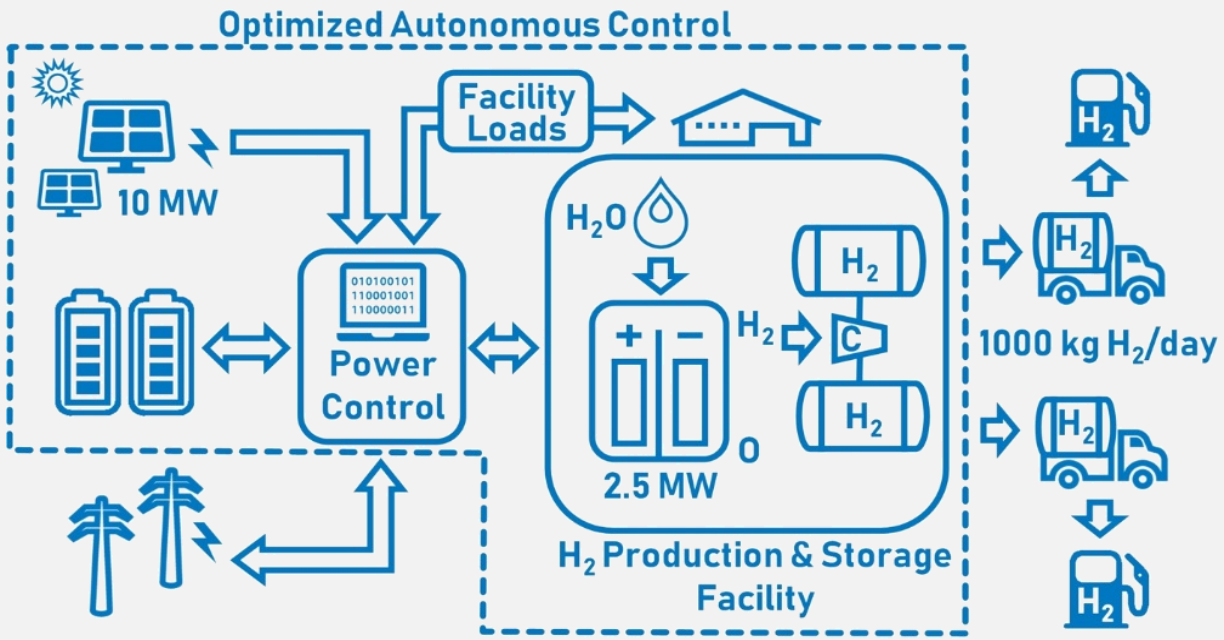
Offshore Workboat

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

Integrated control & dispatch of renewable hydrogen

Goal: Demonstrate a 100% renewable hydrogen end-to-end supply chain



System integrates:

1. **Autonomous controlled hydrogen export terminal**
2. **Frequency regulation and demand response** through control and dispatch of electrolyzer and battery systems
3. **Optimized dispatch of electricity** to meet customer demand.

Impact: Reduced operating costs, increased renewable H_2 production from highly integrated projects

Hydrogen Demand Assessments

Conduct R & D, analysis, and demonstrations of hydrogen and fuel cell technologies and share information to guide early-stage R&D needs for emerging areas in seaport & rail propulsion applications.

Maritime

- Collaboration with DOT Maritime Admin
- Assess potential H2 applications and determine hydrogen demand and societal benefits for seaport applications including:
  - Forklifts
  - Drayage trucks
  - Cranes
  - Yard dogs
  - Cold ironing

Rail

- Collaboration with DOT Federal Railroad Admin
- Assess technical and economic potential of hydrogen use for prime propulsion and auxiliary power of railway locomotives in various operations scenarios
  - Shunt/switch yard
  - Long line haul
  - Regional passenger transit.

IPHE: International Partnership for H_2 and Fuel Cells in the Economy

- **Share** information on H_2 and fuel cells, lessons learned, best practices
- **Increase** international **collaboration to accelerate progress**

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United States

Launched 2003 and includes 18 countries and the European Commission

Save the Date

Request for Information to Enable H2@scale

Opportunities to facilitate widespread hydrogen adoption – closes Oct. 31

www.energy.gov/eere/fuelcells/h2-scale

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