Hydrogen Fuel Cell Applications in Ports:

Feasibility Study at Multiple U.S. Ports

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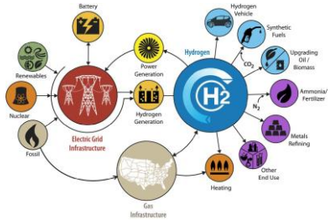
Why Ports?

- **Energy consumption - 28% commercial transportation, 4% U.S. ports[(a)]**
- **Pollution - 29% U.S. CO_2 emissions from transportation[(b)]**
- **Initiatives to decarbonize transportation of freight (global)**
  - Need to consider new technologies and alternative fuels to achieve emission reduction targets
- **Ports are an ideal location for hydrogen-powered transport**
  - Many uses of transport-related equipment in a localized/central space – “cluster”
  - Explores the potential for wide-scale hydrogen production and adoption in diverse industries
  - Works to identify market opportunities, partnerships, and project funding
- **Feasibility study of fuel cell applications at multiple ports nationwide (diesel ⇨ hydrogen)**
  - Collect information on inventory of equipment used by port and terminal tenants
  - Associated annual/daily usage, power, and fuel consumption
  - Information collected from port administrators and port tenants (reports and/or specific data)
  - Analysis of satellite imagery to verify/confirm port equipment profiles



(a) https://www.eia.gov/energyexplained/use-of-energy/transportation-in-depth.php
(b) https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions

Methodology/Port Operations

Port Side	Ship Side
Cranes	Ocean Going Vessels (OGV)
Rubber Tire Gantry Crane (RTG)	Harbor Craft
Straddle Carrier	Ferries
Container Handlers	Vessel Ship-to-Shore Power (hotel, reefers, pumps, lighting)
Container Reach Stackers	
Yard Tractors	
Drayage Trucks	

Equipment Fuel Use Information Sources

Port Emissions Inventory Reports

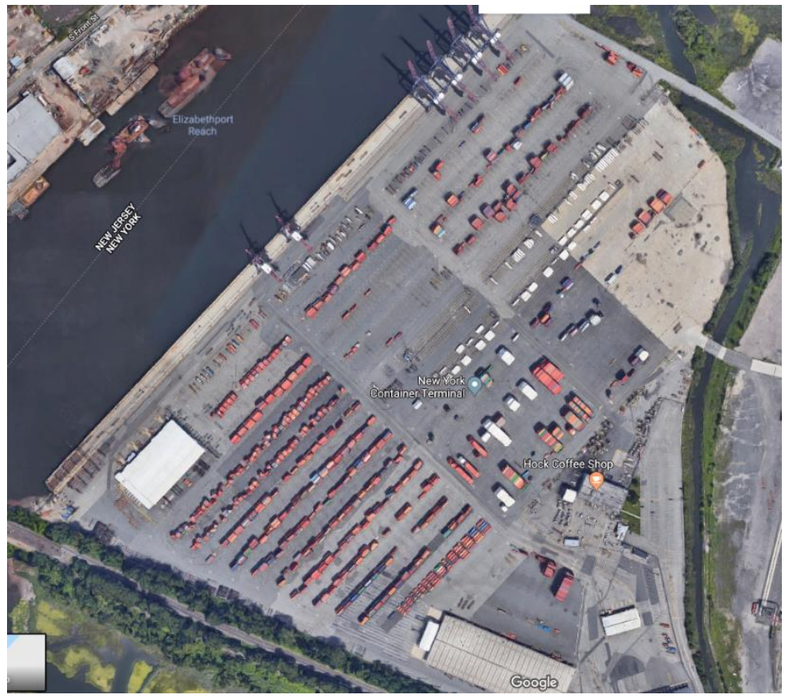
- Puget Sound (SEATAC), New York/New Jersey, Oakland, Long Beach, Los Angeles, Houston

Port Authorities and Terminal Operators

- Visit ports to obtain specific details on terminal equipment and port terminal operations

Satellite/Aerial Imagery Analysis

- Verify or check equipment inventories or unpublished port equipment inventories



Estimate Port Inventory Fuel Use from Emissions

- **Determine fuel use for each equipment type – diesel**
  - **Estimate from emissions data or known fuel consumption rates**

- **Convert CO_2 emissions to diesel using U.S. EIA emissions coefficients[(a)]**
  - **22.4 lb CO_2 released per gallon of diesel**

- **Diesel fuel conversion to hydrogen fuel equivalent**
  - **1 gallon low sulfur diesel = 1.125 kg H_2[(b)]**
  - **1 ton = 2,000 lb = 907.185 kg**
  - **1 tonne = 2205 lb = 1.1023 ton**

(a) *https://www.eia.gov/environment/emissions/co2_vol_mass.php*
(b) *https://h2tools.org/hyarc/hydrogen-data/energy-equivalency-fuels-lhv*

Port Terminal Equipment kg/day H_2

RTG Crane
45 kg/day

Forklift
5 kg/day

Straddle Carrier
46 kg/day

Container Handler
56[L] 25[E] kg/day

Reach Stacker
33 kg/day

Yard Tractor
21 kg/day

SEATAC Emissions Inventory to Fuel Conversion

- **Estimate Hydrogen Use in Port of Seattle/Tacoma/NWSPA**
- **22 million kg H_2 per year = 22,000 tonnes**

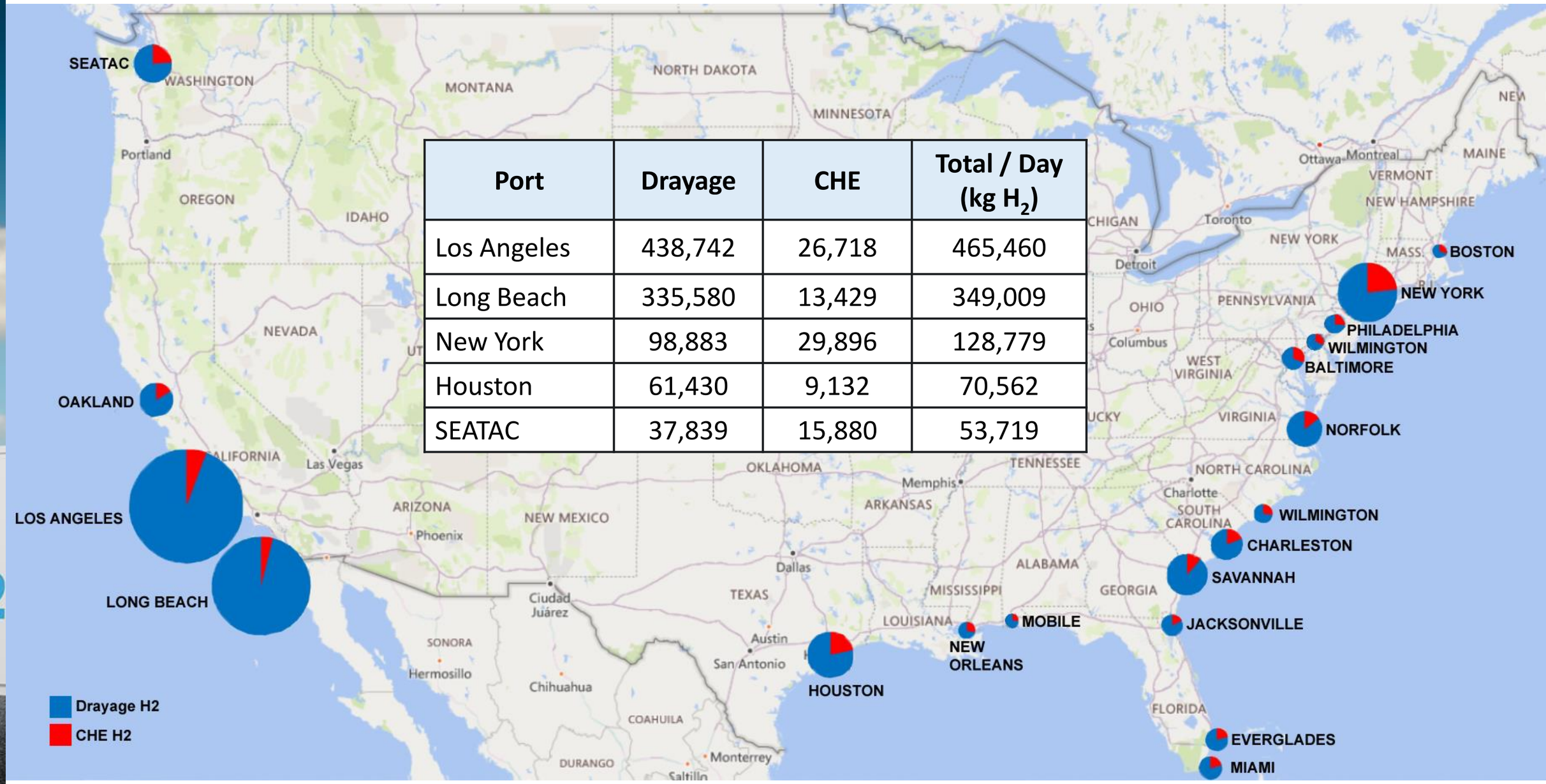
TOTAL SEATAC (Annual)			
Source Category	**CO_2 (tonnes)**	**Diesel (gals)**	**H_2 Equivalent ULS diesel (kg)**
OGV, hoteling	82,721	7,385,804	8,306,343
OGV, maneuvering	7,957	710,446	798,994
Harbor vessels	24,194	2,160,179	2,429,415
Recreational vessels	739	65,982	74,206
Locomotives	41,957	3,746,161	4,213,069
Cargo-handling equipment	44,215	3,947,768	4,439,803
Heavy-duty vehicles	16,824	1,502,143	1,689,365
Fleet vehicles	995	88,839	99,912
Total	219,602	19,607,321	22,051,107

Note: Approximately 900 Tonnes H_2 Fuel Dispensed in U.S. 2018[(a)]

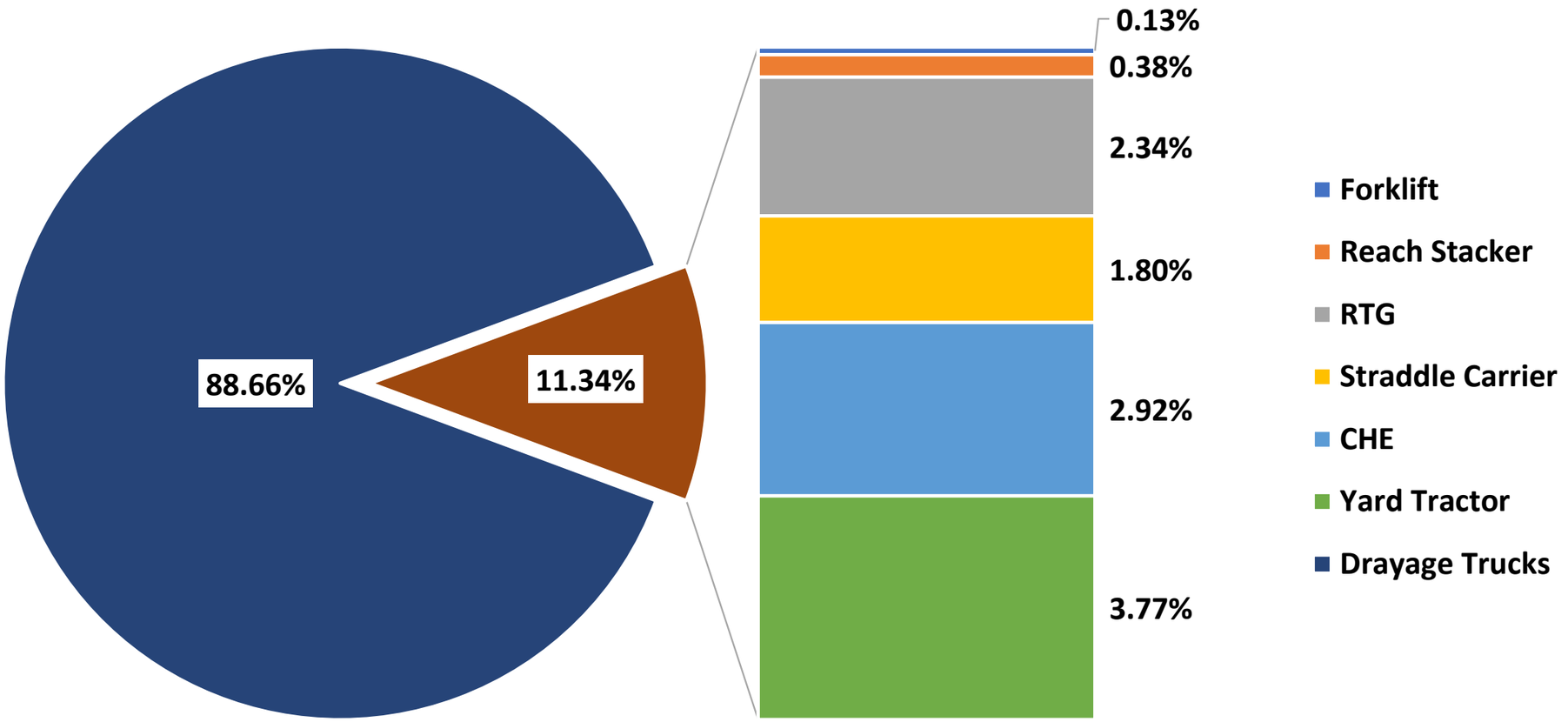
(a) https://www.nrel.gov/hydrogen/infrastructure-cdps-retail.html

Potential Hydrogen Demand at U.S. Ports

Port	Drayage	CHE	Total / Day (kg H_2)
Los Angeles	438,742	26,718	465,460
Long Beach	335,580	13,429	349,009
New York	98,883	29,896	128,779
Houston	61,430	9,132	70,562
SEATAC	37,839	15,880	53,719

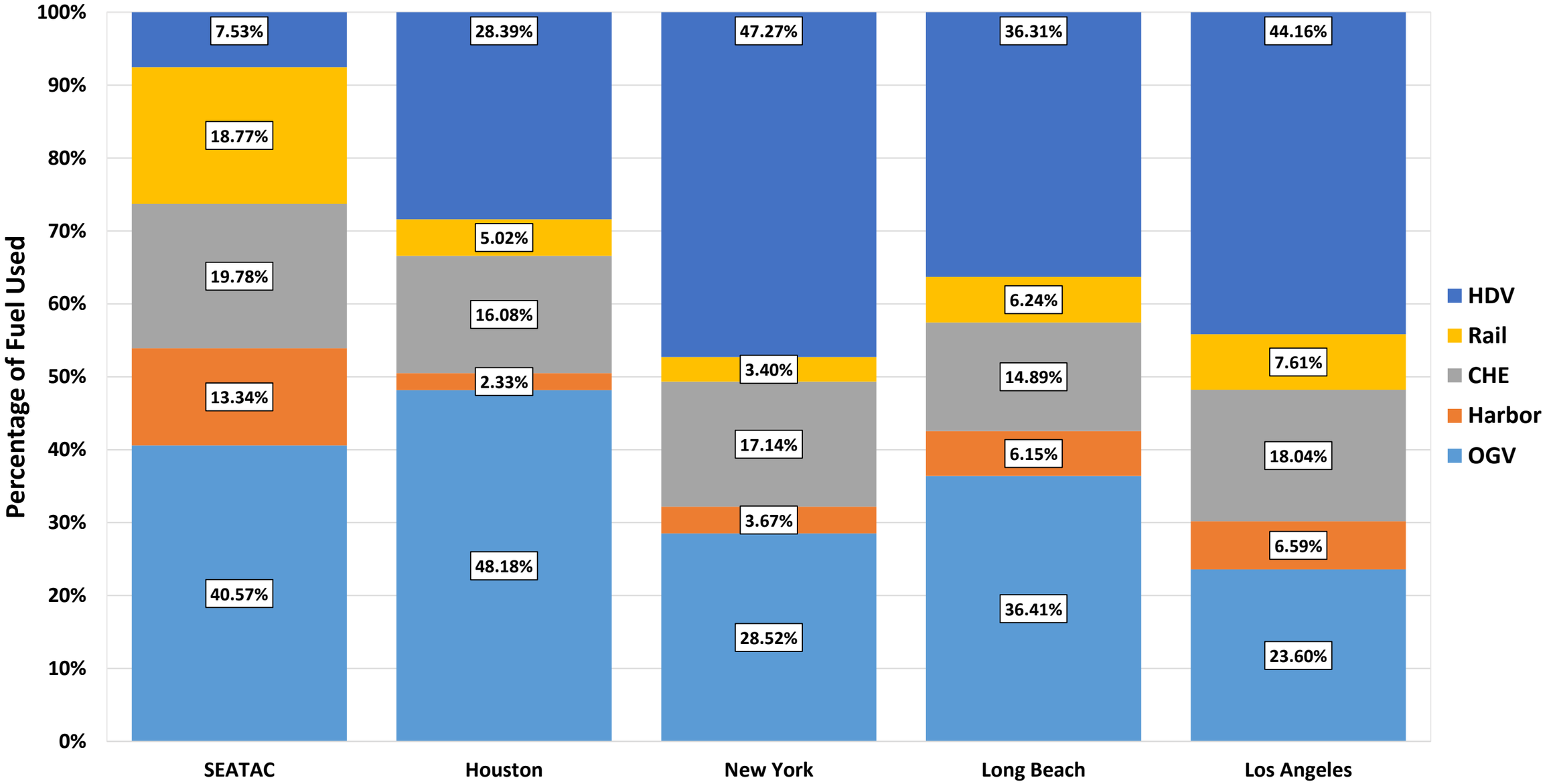


Potential Daily H_2 Demand Percentage by Equipment Type for U.S. Ports

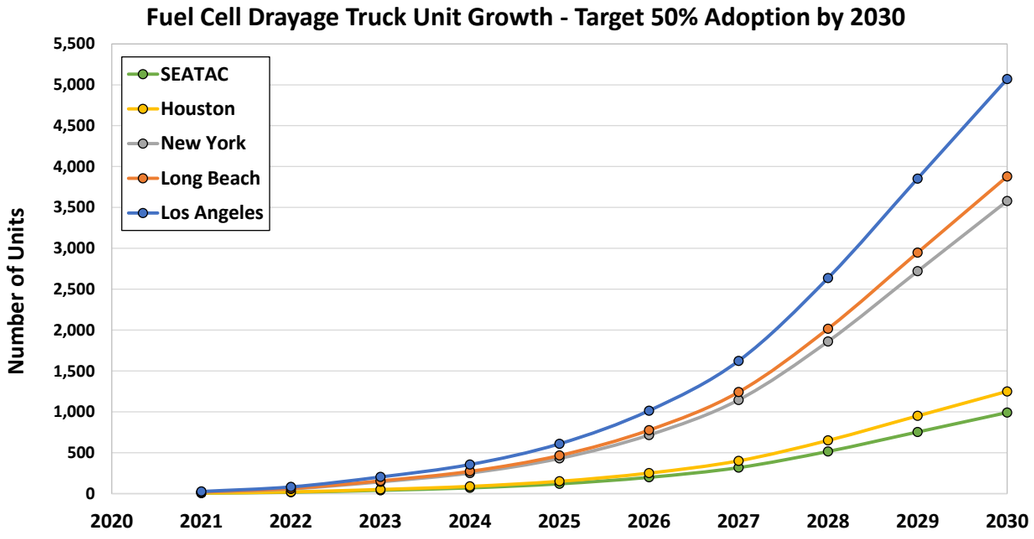


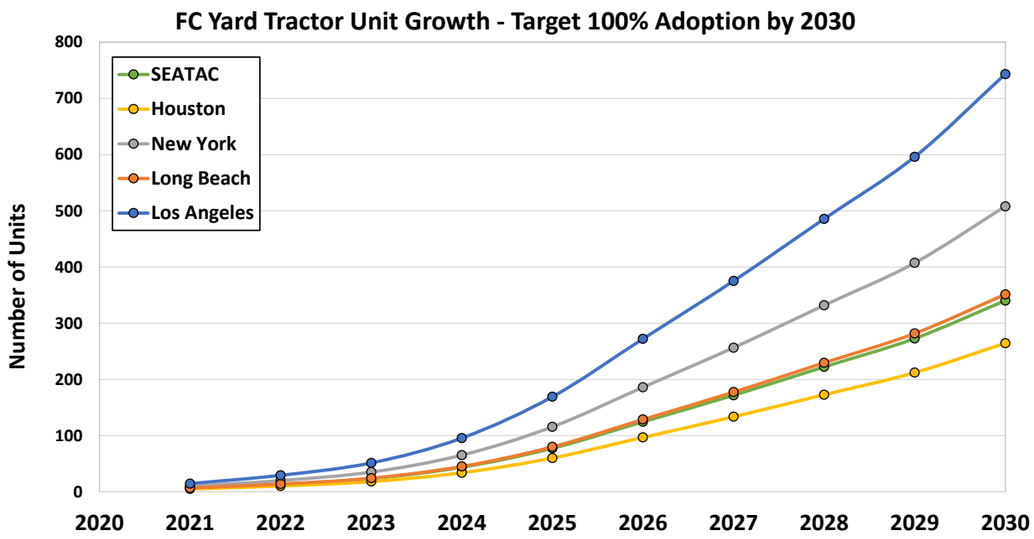
Total Potential H_2 Demand = 1,385 tonnes per day (19 U.S. Ports)

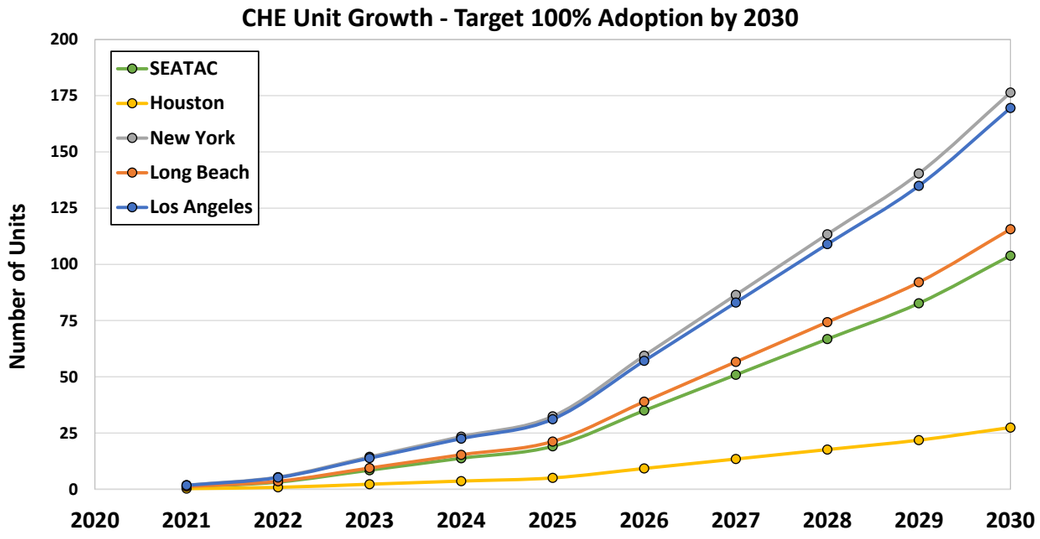
Equipment Type Fuel Use by Port

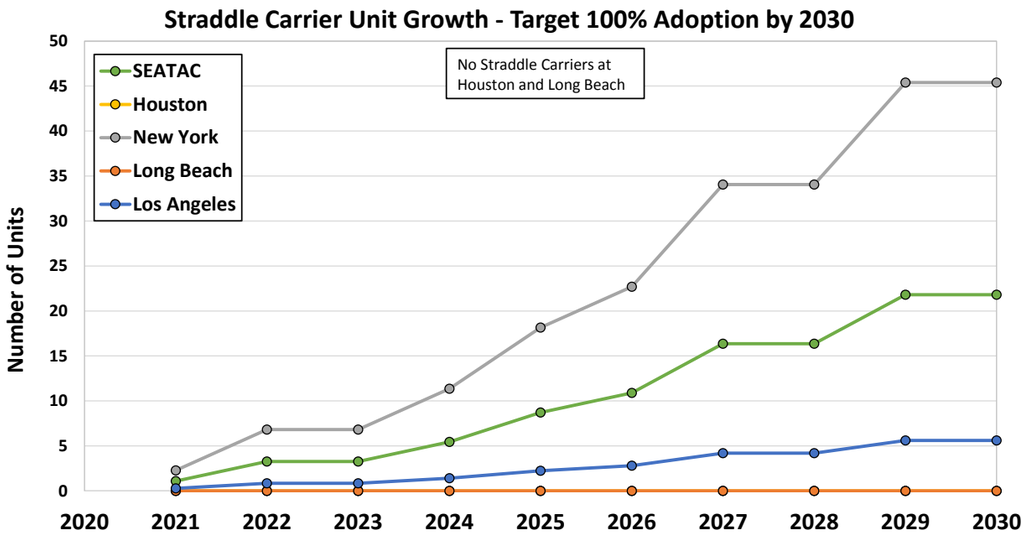


Port Side Related Equipment Fuel Cell Adoption Rates







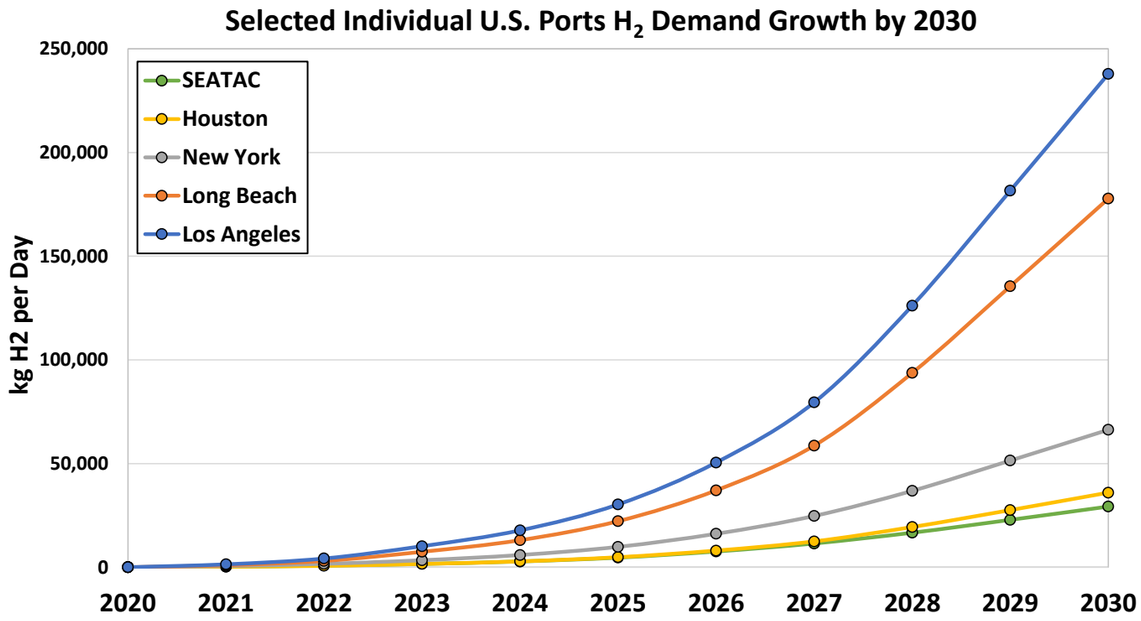


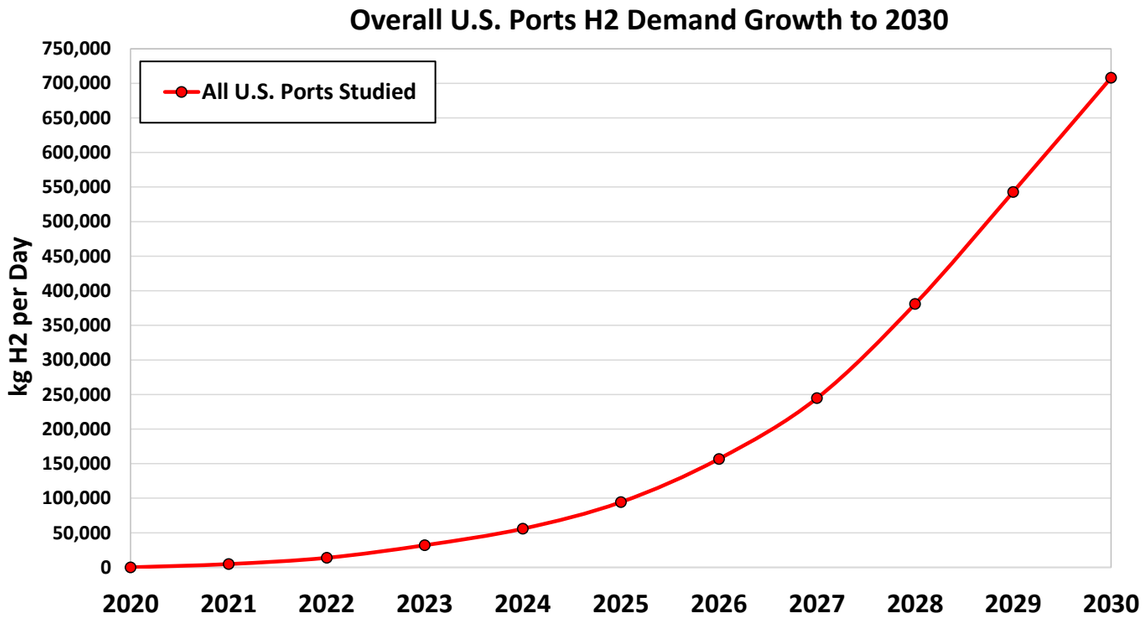
- 50% adoption of existing fleet by 2030, all new drayage trucks are ZEV starting 2022
- Yard tractor, CHE, and straddle carrier growth based on port and terminal operator fleet purchase dynamics

H_2 Demand in U.S. Ports - Summary

- Individual port H_2 demand at lowest adoption rates justifies pipeline over truck delivery
- Drayage trucks represent the largest H_2 use associated with port container operations
- 2nd highest H_2 demand is yard tractors and container handling equipment
- Adoption rates can be matched to H_2 generation capacity growth for optimal utilization and lower H_2 fuel cost

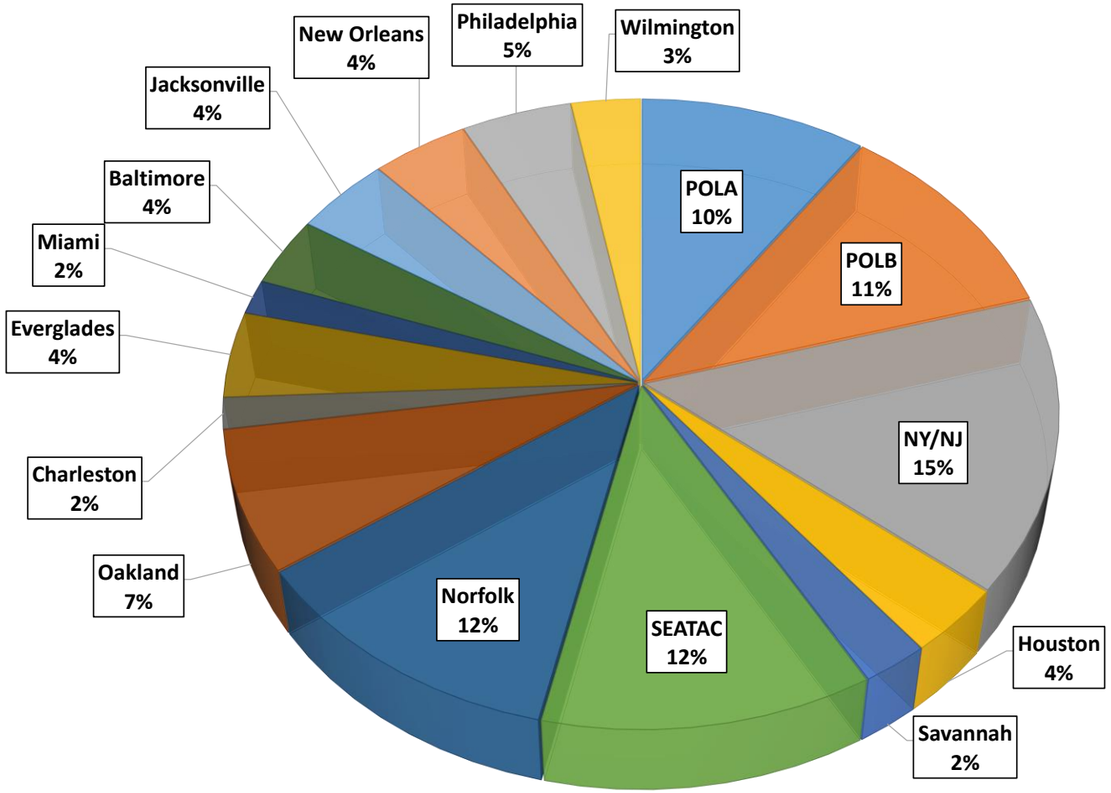
H_2 Demand in U.S. Ports





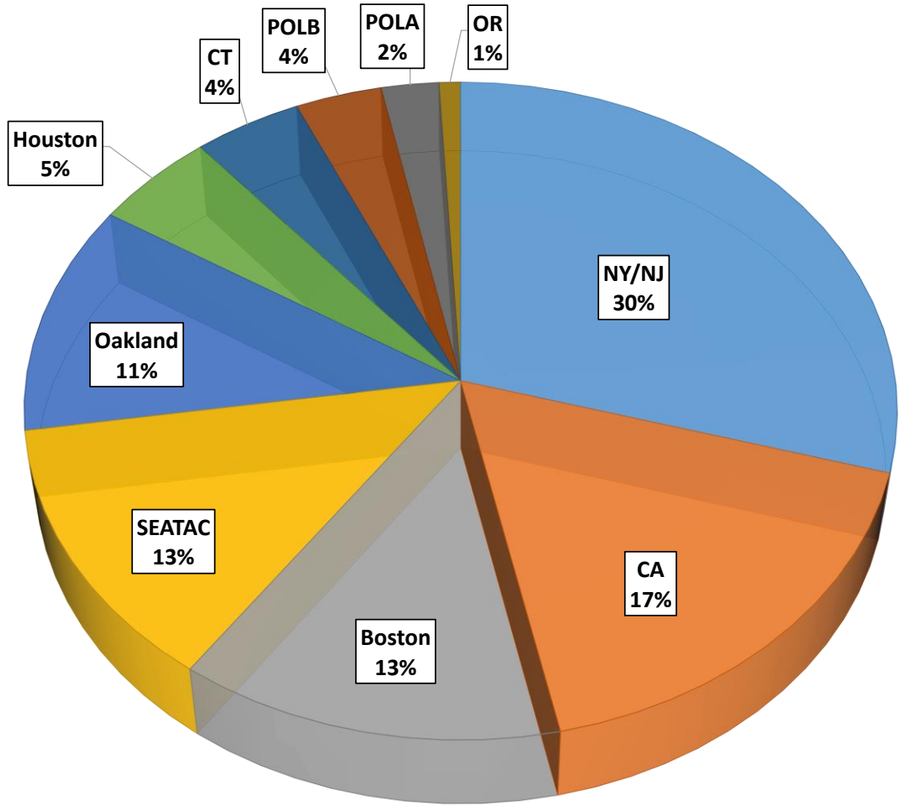
- **Individual port H_2 demand range 25,000–250,000 kg per day**
- **Overall port H_2 demand for U.S. ports studied is over 700,000 kg per day**

Tugboat Daily H_2 Demand U.S. Ports



Total kg H_2 = 52,527

Ferry Daily H_2 Demand U.S. Ports and State Data



Total Daily kg H_2 = 530,278

Port	Tug (Units)	H2/Tug/Day (kg)	Total Tug H_2/Day (kg)	Annual H_2 (kg)
NY/NJ	31	258	8,010	2,923,535
Norfolk	20	311	6,220	2,270,300
SEATAC	20	311	6,220	2,270,300
POLB	14	406	5,678	2,072,365
POLA	14	364	5,098	1,860,890
Oakland	21	183	3,838	1,400,719

Containership Hoteling “At Berth” Hydrogen Demand

	Los Angeles		Long Beach		PUGET	
OGV TEU Class	Per Hotel Use H2 (kg)	Annual Hoteling H2 (kg)	Per Hotel Use H2 (kg)	Annual Hoteling H2 (kg)	Per Hotel Use H2 (kg)	Annual Hoteling H2 (kg)
1000	No Data		2,083	237,451	2,509	288,491
2000	1,704	313,621	5,157	417,745	2,167	195,039
3000	1,313	6,563	2,368	139,711	2,555	112,409
4000	2,223	484,505	4,610	590,126	3,437	470,860
5000	2,627	231,157	7,937	198,426	4,368	663,980
6000	3,245	808,037	6,069	424,846	4,495	476,520
7000	8,823	538,227	10,174	20,348	4,969	258,407
8000	3,652	544,160	6,892	1,647,084	5,461	901,134
9000	3,791	178,167	3,154	195,537	4,420	123,758
10000	7,171	337,050	7,503	525,226	5,401	437,493
11000	6,451	238,684	15,360	691,179	5,285	10,570
12000	6,974	27,894	19,042	76,167		
13000	6,041	277,905	13,732	810,210		
14000	6,091	115,720	37,056	37,056		
Total		**4,101,689**		**6,011,112**		**3,938,662**

- **H_2 demand varies by TEU class and the number of reefers onboard**
- **Modular fuel cell APU advantages – berthing flexibility, amount of power required**

Overall Port Side and Ship Side H_2 Demand

- Individual port side H_2 demand potential range 10,000–100,000 tonnes per year
- Total potential port side H_2 demand for U.S. ports studied > 250,000 tonnes per year
- Tugboat potential H_2 demand for U.S. ports studied > 15,000 tonnes per year
- Ferry potential H_2 demand from port and U.S. DOT data > 190,000 tonnes per year
- Containership hoteling potential H_2 demand > 15,000 tonnes per year (based on 3 ports)

U.S. maritime H_2 demand could exceed ½ million tonnes per year

Potential Future Activities

Container Terminals (Operators, Ports, Drayage)

- Engage with port operators, authorities, drayage operators, container handling equipment manufacturers, and fuel cell equipment stakeholders to expand data set, discuss challenges, and identify first actions
- Engage with hydrogen fuel cell and hydrogen infrastructure industry stakeholders to develop terminal equipment and drayage truck refueling solutions
  - On-terminal mobile hydrogen equipment refueling solution
  - High volume throughput drayage truck hydrogen fueling station

Containership (<4000 TEU), Tugs & Ferry Operators

- Engage with operators to confirm which systems are best for fuel cell technology phase in and determine the current operating cost and performance metrics
  - What role can converting auxiliary power systems play in the adoption of fuel cell/hydrogen technology on containerships?
- Develop fuel cell use profile for auxiliary power systems that includes all forms of hoteling load
- Identify associated ship design standards for onboard fuel cell systems, hydrogen storage, and hydrogen bunkering

Hydrogen Infrastructure (Industrial Gas Companies)

- Determine the optimal size of a hydrogen generation plant or plants to support a port hydrogen cluster
  - Explore the maintenance cycle typical of these plants so that supply is uninterrupted
- Determine what hydrogen bunkering options and challenges exist to support containerships, tugs, and ferries
- Develop a roadmap for hydrogen generation and distribution to the various component locations of a port cluster and identify the technology development needs

Urban Hydrogen Cluster

- Hydrogen Port Clusters (H_2PC) will typically be part of a broader urban environment. Include stakeholders from the urban cluster to broaden hydrogen demand roadmap
- Stakeholders could include nearby airport(s) authorities, commuter rail supporting the urban environment, mass transit bus authorities, and advanced mobility vehicle (AMV) developers

Thank you

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