Massachusetts Hydrogen Coalition

AAPA Environmental Committee Hydrogen and Fuel Cells At Ports

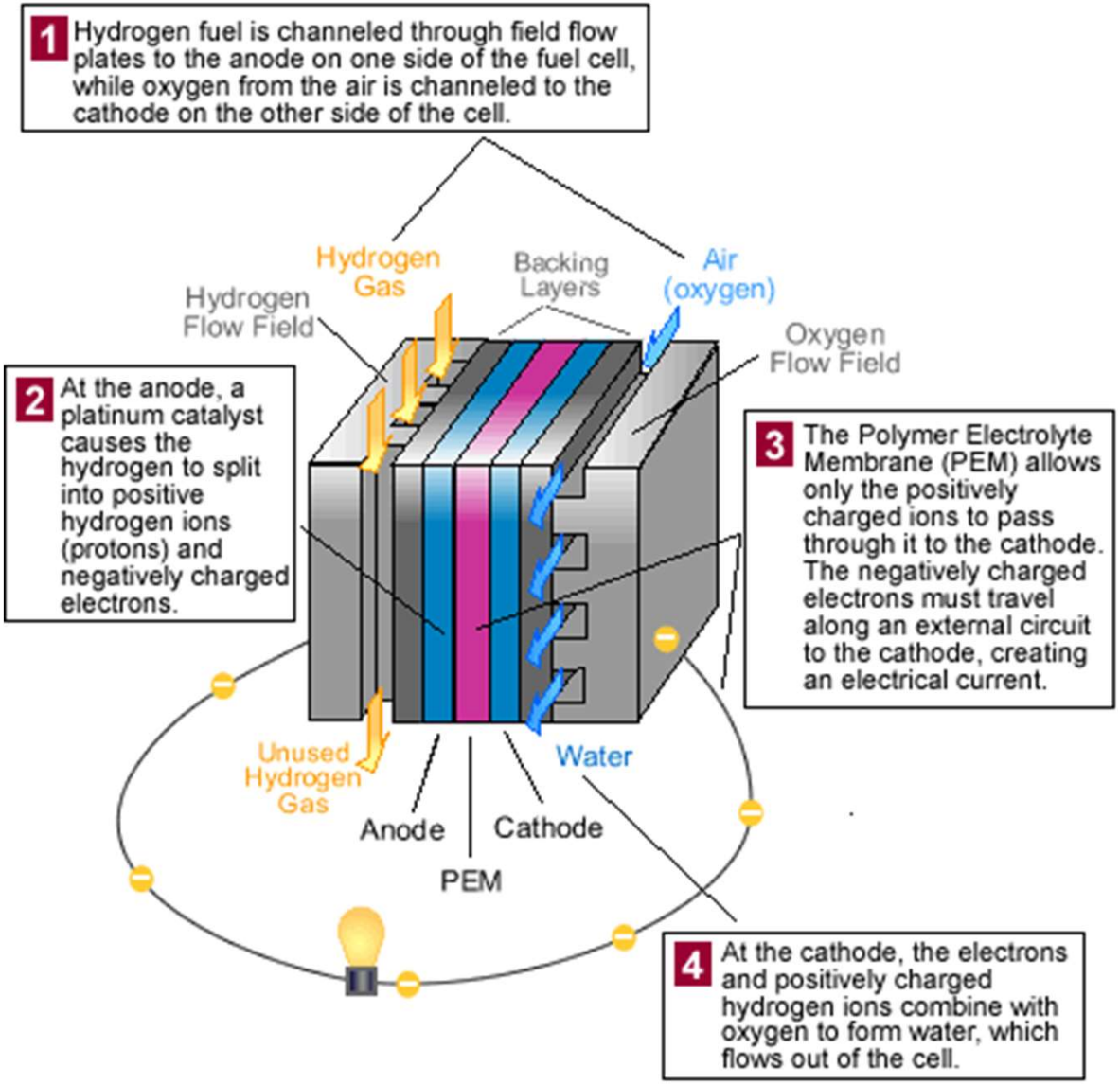
Charles Myers, MPM

May 3rd, 2022

Hydrogen (H_2) – What is it?

- A gas at ambient conditions
- Is 14 times lighter than air, which means it rises and diffuses quickly when released
- Has no odor
- Has no color
- The energy content of 1 kg of H2 is approximately equal to 1 gallon of gasoline (in BTU's)
- Flammability range: 4.1% to 74%
- Flame temperature (^oF): Hydrogen 4010; Natural Gas 3562; Gasoline 3591
- Hydrogen is a cryogen, existing as a liquid at -423^oF (-253^oC)
- Volumetric ratio of liquid to gas is 1:848
- Liquid hydrogen can be stored at relatively low pressure (50 psi)

Fuel Cell 101



Hydrogen Fuel Cell Port Equipment & Drayage Trucks

Container Handling Equipment

Container Handlers

RTG (Rubber Tired Gantry Cranes)

Reach Stackers

Fork Lifts

Yard Dogs

Capacity (Hyster Yale)

Gaussin (Plug Power)

Terberg (Plug Power)

Toyota

Drayage Trucks

Port of Long Beach Class 8 Drayage Truck H2 Station

Toyota / Kenworth

Hyundai

Hyzon

Port Equipment Hydrogen Use Per Day - Examples

RTG Crane
45 kg/day

Container Handler
Loaded 56 kg/ day - Empty 25 kg/day

Reach Stacker
33 kg/day

		Port of NY / NY			Port of Long Beach			Port of Los Angeles		
	Average H2 Kg per Day/Unit	# of Units	H2 Kg per Day/Unit	H2 Kg Class/Day	# of Units	H2 Kg per Day/Unit	H2 Kg Class/Day	# of Units	H2 Kg per Day/Unit	H2 Kg Class/Day
RTG Crane	51	53	57	2996	60	52	3126	96	46	4369
Forklift	5	200	5	1045	104	5	482	117	5	632
Container Hdlr Empty	22	68	30	2030	13	12	156	21	25	632
Container Hdlr Loaded	59	39	45	1738	195	63	12263	217	70	15258
Reach Stacker	33	52	33	1710						
Straddle Carrier	46	308	46	14143						
Yard (Terminal) Tractor	23	471	16	7511	564	28	15563	845	26	22058
			Total	29463		Total	31591		Total	59250

Data is based on the 2017 Emissions Inventory published by each respective Port.

Straddle Carrier
46 kg/day

Yard (Terminal) Tractor
21 kg/day

Forklift
5 kg/day

Class 8 Hydrogen Fuel Cell Powered Drayage Trucks

Fuel Cell Electric Kenworth Model T680 developed in collaboration with Toyota refueling at Toyota's Port of Long Beach Terminal

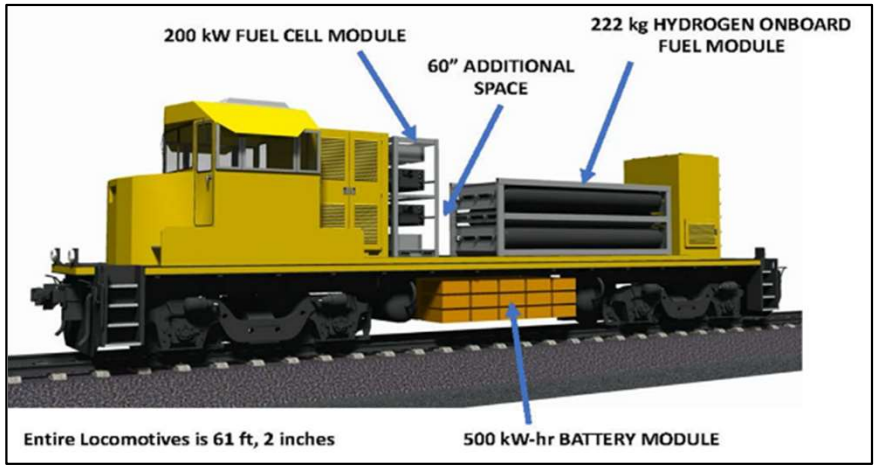
Kenworth Model T680

Hyundai Xcient

Nikola

Daily Use (kg)	Drayage	CHE	Total / Day
New York	98,883	29,896	128,779

Hydrogen Fuel Cell Switcher & Freight Locomotives



Sierra Northern California CEC Port

Wabtec GM Genesee Wyoming Program

Canadian Pacific Ballard Project

Containerized H2 Maritime Power MARAD & DOE Demo

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 Sandia

Shore Power System – on demonstration at Scripps Institute, North San Diego

Hydrogen refueling from IGX mobile trailer.

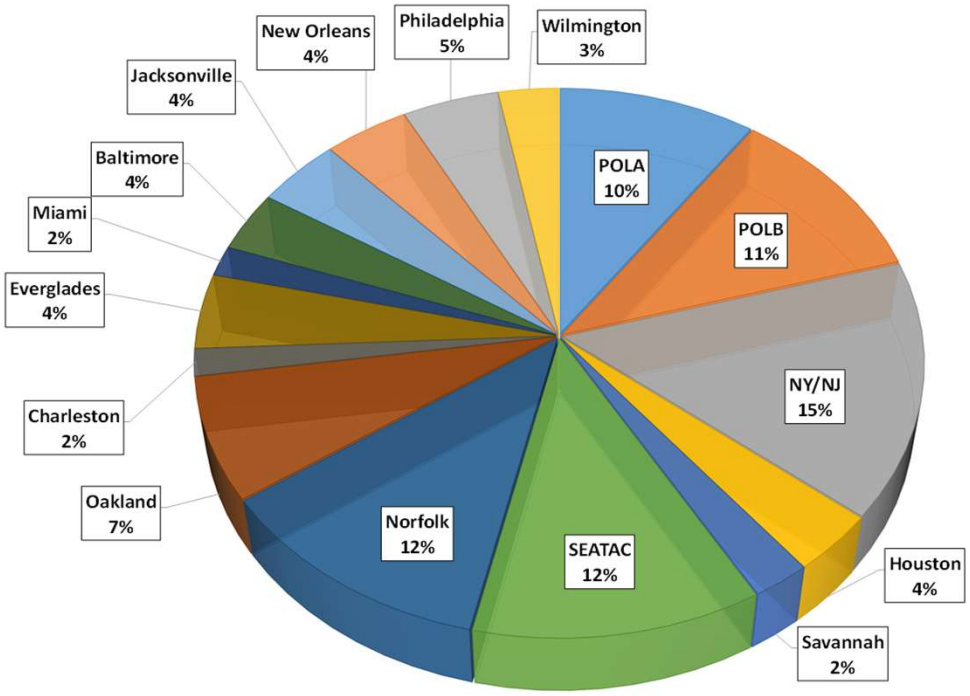
Containership Hoteling "At Berth" H2 Demand

	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**

- H2 demand varies by TEU class and the number of reefers onboard
- Modular fuel cell APU advantages – berthing flexibility, amount of power required

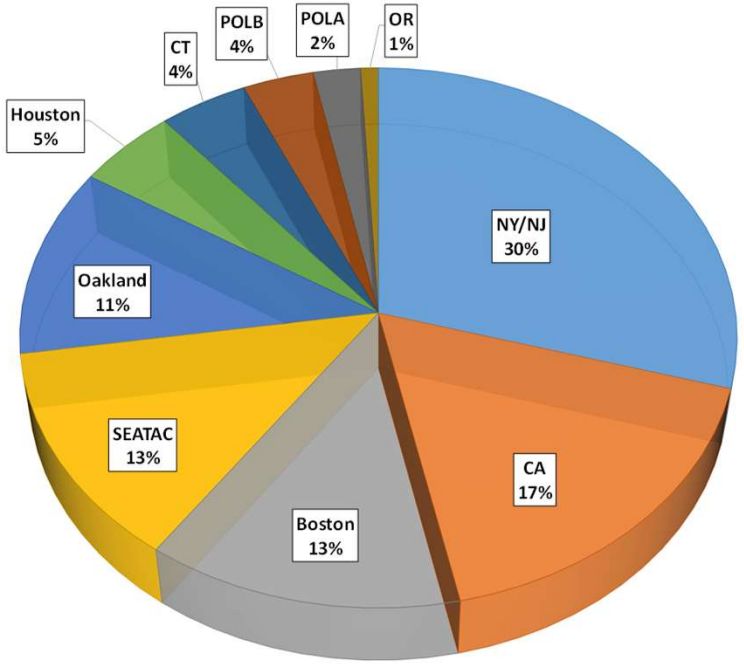
Source: L Steele, PNNL & C Myers, ORNL

Tugboat Daily H2 Demand



Total kg H_2 = 52,527

Ferry Daily H2 Demand



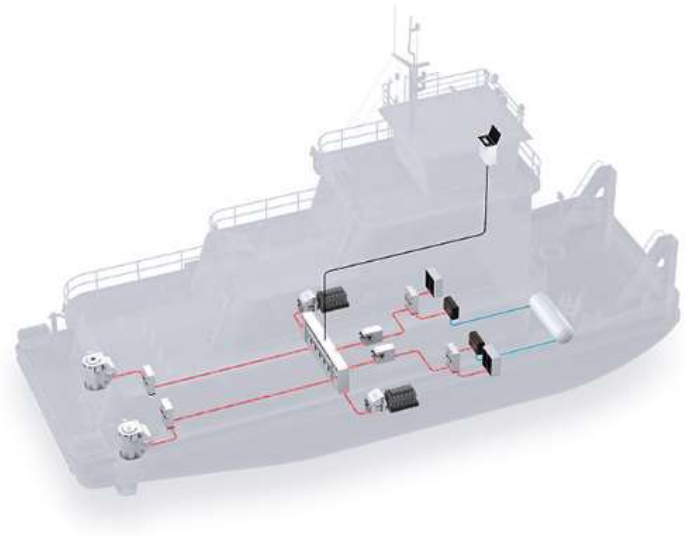
Total Daily kg H_2 = 530,278

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

Source: L Steele, PNNL & C Myers, ORNL

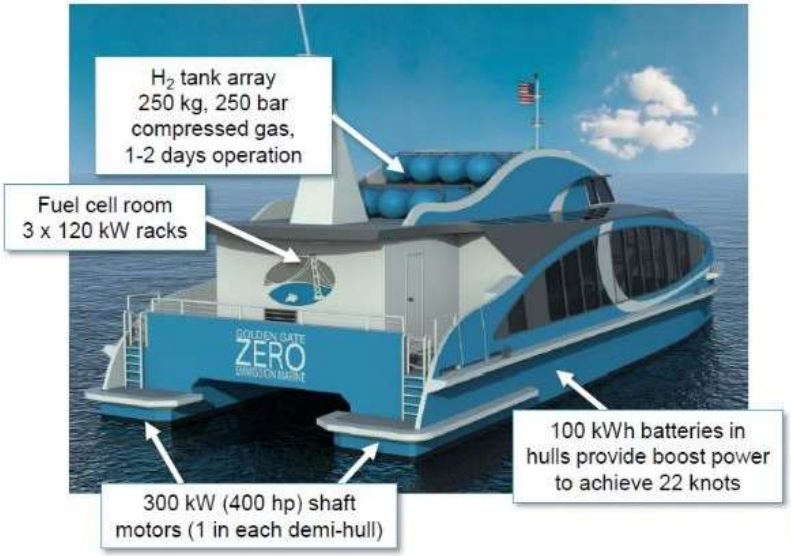
Hydrogen Push Boat & Barges

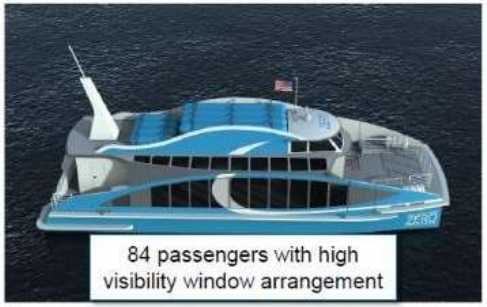
LMG Marin/Ballard / ABB
Fuel Cell River Push Boat

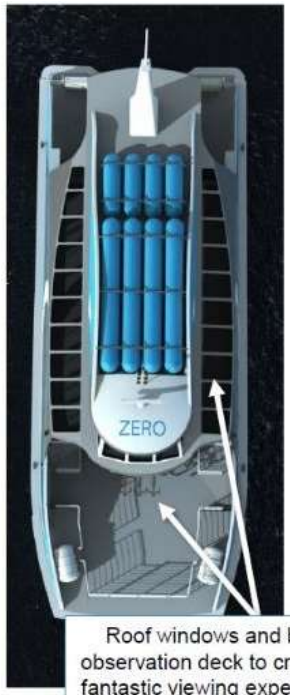


Liquid Hydrogen Barges
Stennis Space Center

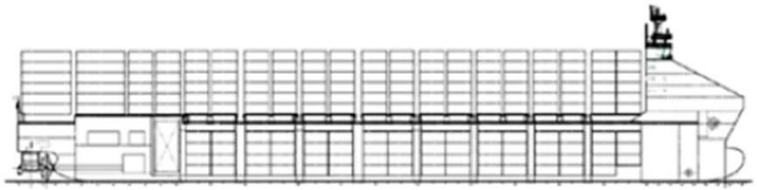
Sea Change Hydrogen Fuel Cell Ferry – San Francisco







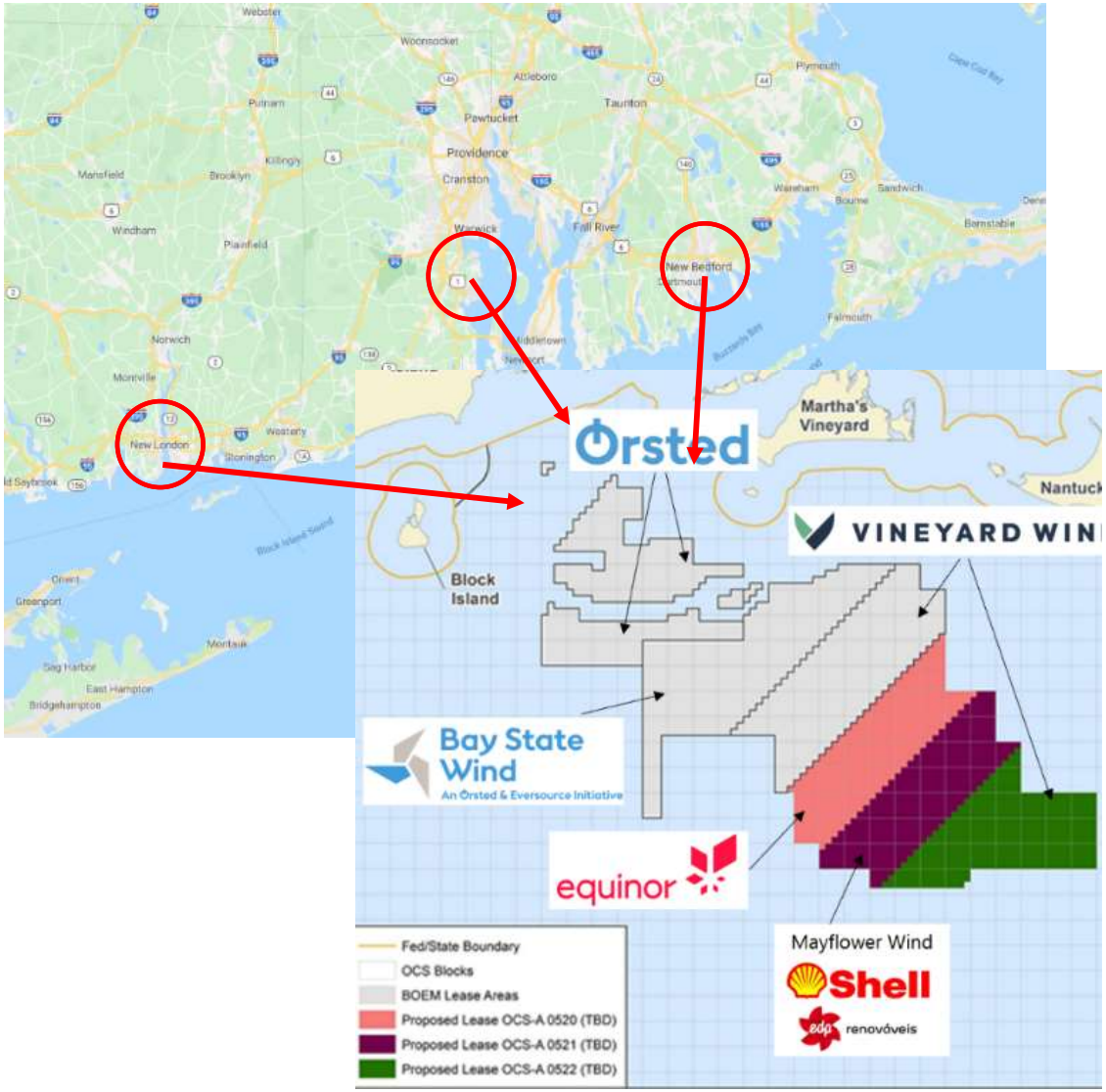
ABS – 2,000 TEU FC Containership Concept



Capacity:	**2,000 TEU (Feeder Class)**
Fuel Cell Power Profile:	**Main Propulsion 6.3 MW** **Auxiliaries 3.5 MW** **Total 9.8 MW**
Actual Fuel Cell Concept:	**Use Four (4) 2.5 MW fuel cells**
Propulsion:	**One 3.8 MW electric motor conventional shaft propeller** **One 2.5 MW steerable pod**
Battery Capacity:	**6.3 MWh used for power conditioning and dynamic energy stability.**
Hydrogen Storage: **Hydrogen Tank:**	**1,200 m3 cyrogenic liquid hydrogen** **Membrane**
Range:	**2,000 nautical miles**
Design Speed:	**16 knots (2 knots slower than current generation feeder ship)**

ABS Report: Setting the course for low carbon shipping, 2019, page 62.

Conceptual Offshore Wind CTV and Research Vessels



Design and deploy fuel cell powered offshore wind crew transfer vessel (CTV). Three possible ports – New London, Quonset, New Bedford.

Catamaran diesel CTV in transit to Block Island wind farm

Wind CTV in position at work against an offshore wind turbine.

NOAA Class 3 Research Vessels are of similar design to above CTVs.

Hydrogen Bunkering

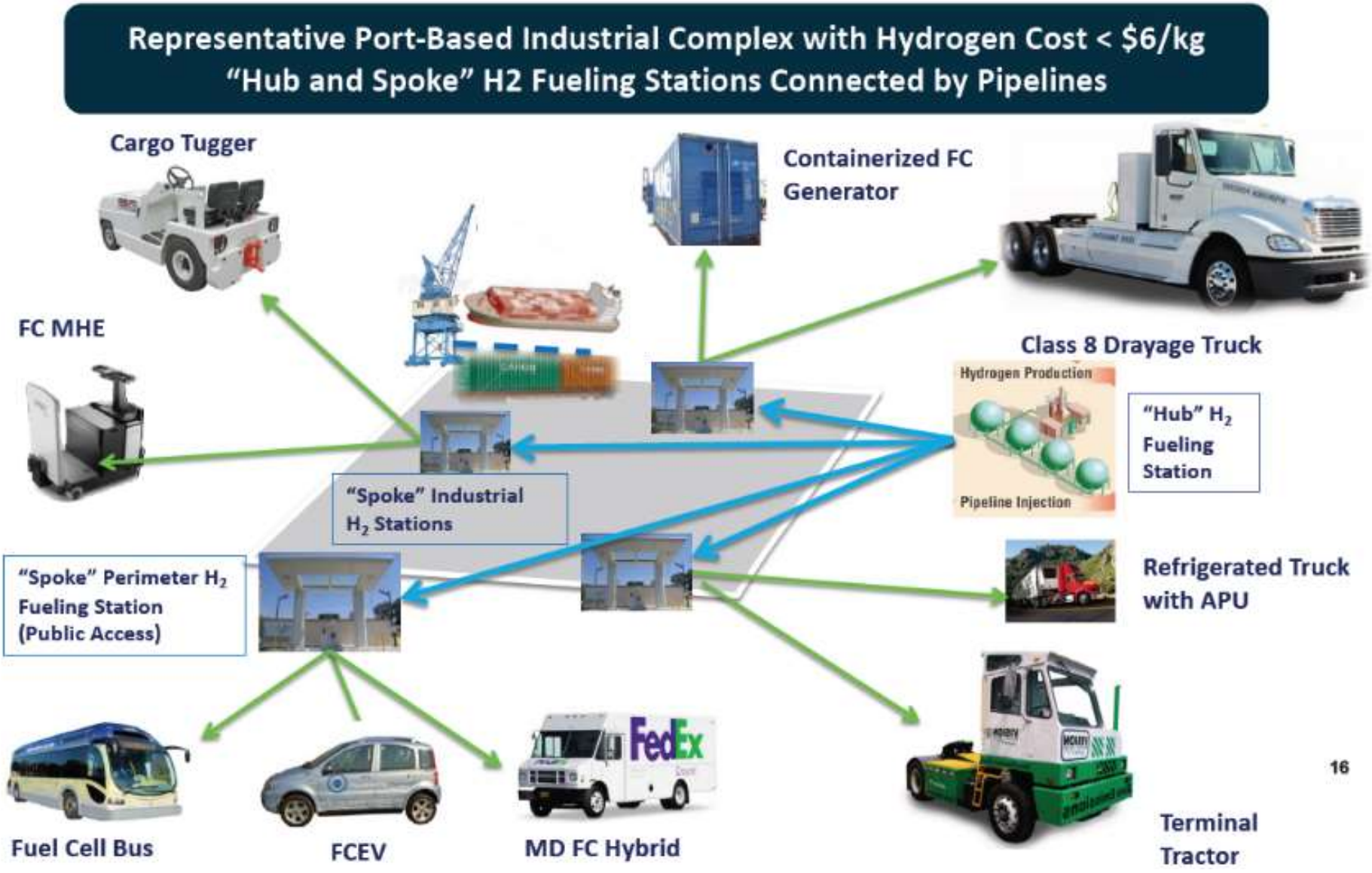
Iwatani Refueling Yanmar Research Vessel (Japan)

Sea Change Ferry Pierside Fueling

Suiso Frontier Loading Hydrogen In Australia

CMB Tech Combination Hydrogen Fueling (Europe)

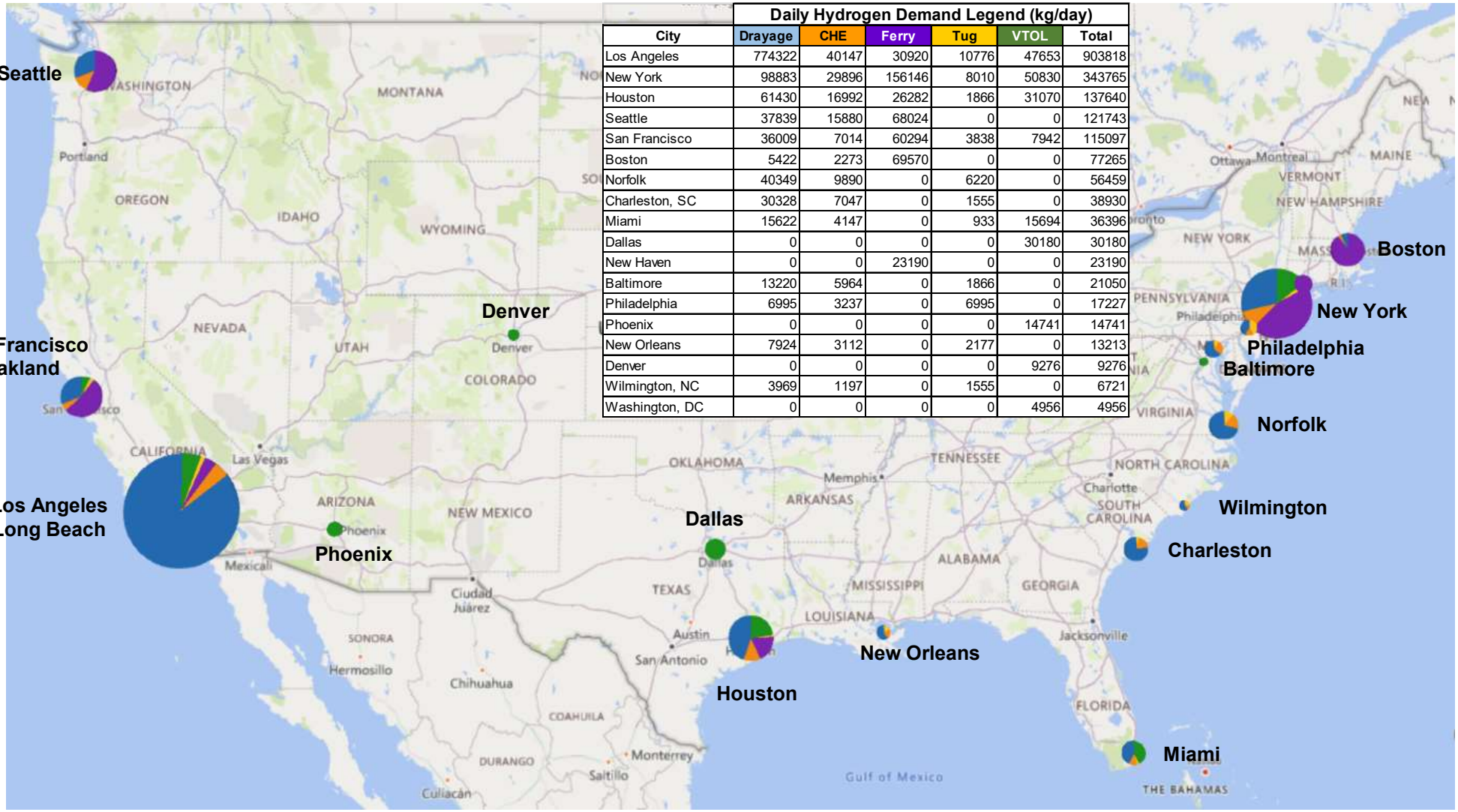
“Clustering” H2 Demand At and Around Ports



NY/NJ Port Authority Hydrogen Demand Example

Fuel Use Category	Subcategory	CO2e Metric Tons	Gallons Diesel Used (%)	H2 Equiv (kg) Annual	Gallons Diesel Used (%)	Prior Year	2017 CO2e/TEU	2016 CO2e/TEU	% Change
	TEU	6711000				6252000			1.0734
OGV	Containership	113253	11,146,421	12,435,181	75%	152312	0.0169	0.0244	-0.307
OGV	Subtotal	150696	14,831,581	16,546,423	24%	188102	0.0225	0.0301	-0.254
	Engines Main	30381	2,990,114	3,335,834		71792	0.0045	0.0115	-0.606
	Engines Auxiliary	76845	7,563,126	8,437,582		74316	0.0115	0.0119	-0.037
	Boilers	43470	4,278,341	4,773,007		41994	0.0065	0.0067	-0.036
	Transt	51982	5,116,096	5,707,624		93907	0.0077	0.0150	-0.484
	Dwelling	98715	9,715,583	10,838,909		94196	0.0147	0.0151	-0.024
Harbor Craft	Subtotal	26627	2,620,644	2,923,645	4%	24197	0.0040	0.0039	0.025
CHE	RTG Crane	9960	980,269	1,093,608	9%	10213	0.0015	0.0016	-0.091
CHE	Forklift	3473	341,815	381,335	3%	3574	0.0005	0.0006	-0.095
CHE	Container Hdlr Empty	6749	664,240	741,040		6996	0.0010	0.0011	-0.101
CHE	Container Hdlr Loaded	5778	568,674	634,424	5%	6627	0.0009	0.0011	-0.188
CHE	Straddle Carrier	47016	4,627,340	5,162,358	43%	47818	0.0070	0.0076	-0.084
CHE	Yard (Terminal) Tractor	24967	2,457,266	2,741,377	23%	25459	0.0037	0.0041	-0.086
CHE	Other Primary Equip	5685	559,521	624,213	5%	6523	0.0008	0.0010	-0.188
CHE	Ancillary Equip	6596	649,182	724,241	6%	5792	0.0010	0.0009	0.061
CHE	Subtotal	110225	10,848,404	12,102,707	17%	113001	0.0164	0.0181	-0.091
		12527	1232914.051	1,375,465					
Locomotives	Switching	11961	1,177,208	1,313,318	53%	11283	0.0018	0.0018	-0.012
Locomotives	Line Haul	10732	1,056,249	1,178,374	47%	11123	0.0016	0.0018	-0.101
Locomotives	Subtotal	22693	2,233,457	2,491,692	4%	22406	0.0034	0.0036	-0.056
HDV	On-Terminal Driving	16947	1,667,933	1,860,781	5%	16028	0.0025	0.0026	-0.015
	OT Auto	41				37	0.0000	0.0000	0.032
	OT Container Terminals	16604				15689	0.0025	0.0025	-0.014
	OT Warehouses	1667				302	0.0002	0.0000	4.142
HDV	On-Terminal Idling	21674	2,133,167	2,379,806	7%	20623	0.0032	0.0033	-0.021
	OT Auto	1167				1112	0.0002	0.0002	-0.022
	OT Container Terminals	19142				18145	0.0029	0.0029	-0.017
	OT Warehouses	1365				1366	0.0002	0.0002	-0.069
HDV	On-Road	281089	27,664,930	30,863,577	88%	275083	0.0419	0.0440	-0.048
	NJ - Union - Elizabeth	93471				50563	0.0139	0.0081	0.722
	NJ - Essex - Newark	78474				88123	0.0117	0.0141	-0.170
	NY - Staten Isl - Richmond	1597				1108	0.0002	0.0002	0.343
	NY - Red Hook - Kings	1525				12418	0.0002	0.0020	-0.886
HDV	Subtotal	319711	31,466,128	35,104,273	51%	311734	0.0476	0.0499	-0.045
Port	Total	629952	62,000,213	69,168,740		659440	0.0939	0.1055	-0.110
			Tons H2 per Year	76,245					
			Tons H2 per Week	1,466					
			Tons H2 per Day	209					
			Kg H2 per Day	190,024					

H2@Scale Port Hydrogen Demand



	Daily Hydrogen Demand Legend (kg/day)					
City	Drayage	CHE	Ferry	Tug	VTOL	Total
Los Angeles	774322	40147	30920	10776	47653	903818
New York	98883	29896	156146	8010	50830	343765
Houston	61430	16992	26282	1866	31070	137640
Seattle	37839	15880	68024	0	0	121743
San Francisco	36009	7014	60294	3838	7942	115097
Boston	5422	2273	69570	0	0	77265
Norfolk	40349	9890	0	6220	0	56459
Charleston, SC	30328	7047	0	1555	0	38930
Miami	15622	4147	0	933	15694	36396
Dallas	0	0	0	0	30180	30180
New Haven	0	0	23190	0	0	23190
Baltimore	13220	5964	0	1866	0	21050
Philadelphia	6995	3237	0	6995	0	17227
Phoenix	0	0	0	0	14741	14741
New Orleans	7924	3112	0	2177	0	13213
Denver	0	0	0	0	9276	9276
Wilmington, NC	3969	1197	0	1555	0	6721
Washington, DC	0	0	0	0	4956	4956

Source: PNNL and ORNL

Hydrogen Export / Import

Hydrogen export/import relationships established or in discussion.

Suiso Frontier – Australia to Japan

Port of Kobe Japan

Department of Energy H2 Matchmaker

https://www.energy.gov/eere/fuelcells/h2-matchmaker

Thank You

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