

A close-up photograph of several bright green leaves on a thin brown branch, set against a blurred background of more green foliage and a light blue sky. The leaves are in sharp focus, showing their veins and serrated edges.

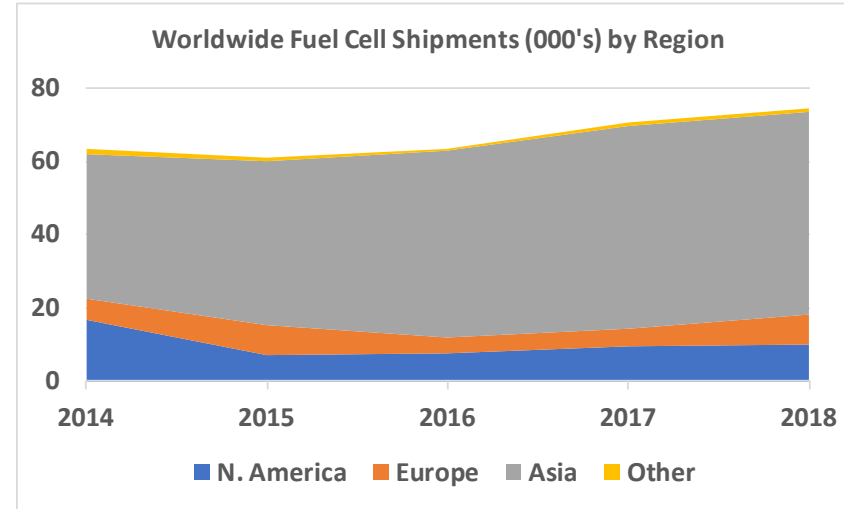
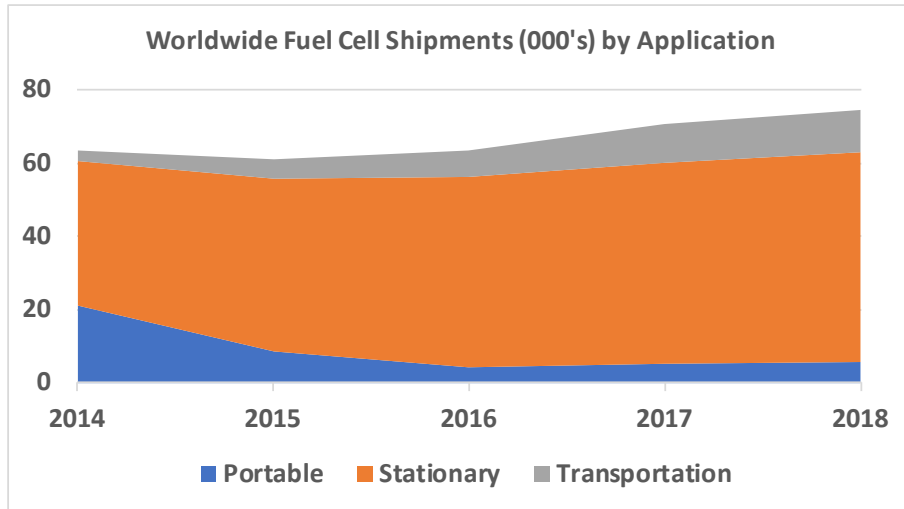
# **Market Progress: Fuel Cells for Port Applications**

**Presented at NEDC 2019 Partner Meeting  
June 11, 2019**

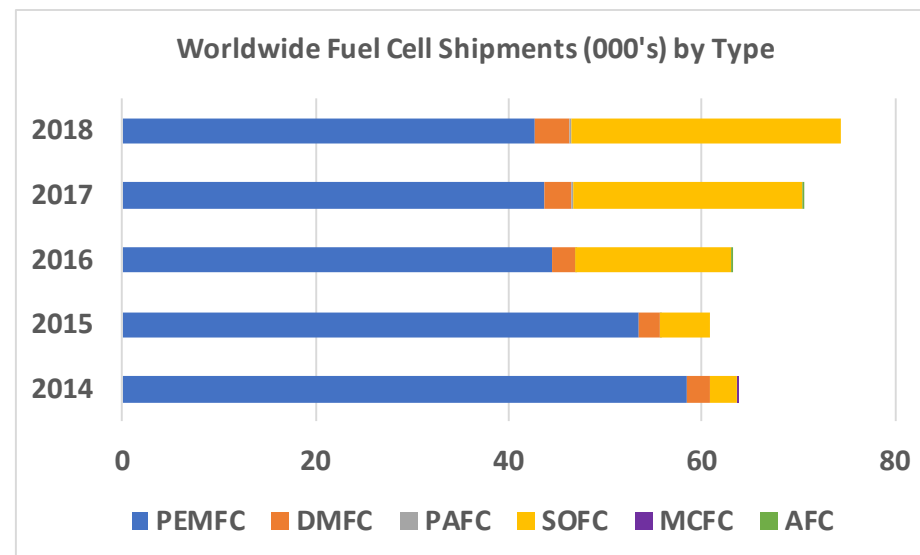
**Presented by Gregory Wilcox**



# Worldwide Fuel Cell Market Status



Source: *The Fuel Cell Industry Review, 2018, E4Tech*



# Fuel Cell Benefits for Port Applications

- 2-3 times more energy efficient than combustion power sources
- Zero vehicle/equipment emissions
  - Criteria pollutants
  - Air toxic pollutants
  - GHG Emissions
- Potential lifecycle (WTW) emission reductions compared to traditional power sources
- Lower noise emissions
- Potentially lower maintenance costs

# Remaining Market Challenges for Fuel Cell in Port Applications

- High upfront capital costs
- High delivered hydrogen fuel price
- Limited hydrogen fuel supply infrastructure in some regions
- Pre-commercial system development status for many applications
- End use market familiarity/understanding

# Market Status: Forklifts

- **Pre-commercial/commercial: Over 20,000 in service, mostly lighter forklift classes**
- **Platform Approaches: Battery box fuel cell replacement in lighter classes; integrated fuel cell hybrid systems in heavier classes.**
- **Manufacturers: Raymond, Hyster-Yale, Toyota, Taylor, Kalmar**
- **In lighter applications, direct lifecycle benefits relative to battery-electric options**
  - Lower operational costs
  - Increased productivity
  - Lower warehouse footprint



# Market Status: Drayage Trucks

- **Pre-commercial: HyARC reports over 30 fuel cell-powered heavy-duty drayage trucks deployed or soon to be deployed over the next several years. Key upcoming demonstrations in California.**
- **Fuel cell dominant and range extender hybrid platforms**
- **Manufacturers: Toyota/Kenworth, Transpower, U.S. Fuel Cell/ U.S. Hybrid/International, Ballard/BAE Systems/Kenworth, Hydrogenics/Transpower/Navistar**
- **Limited experience indicates comparable performance and much higher fuel efficiencies than baseline diesel.**



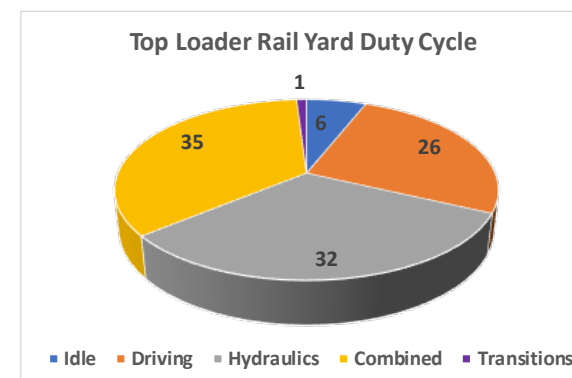
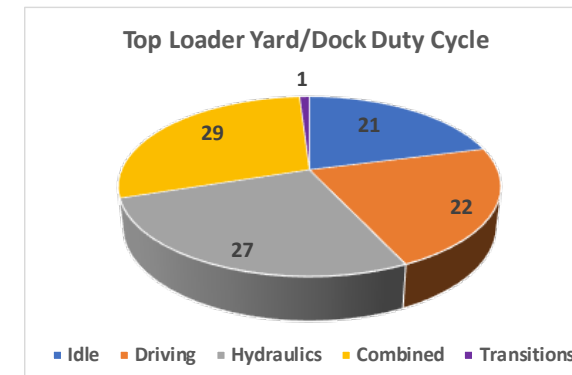
# Market Status: Yard Tractors/Container Handlers

## Yard Tractors

- Pre-commercial: Multiple vehicles in active or planned port demonstrations.
- Fuel cell dominant and range extender hybrid platforms
- Example system: 85 kW PEMFC, 20 kg H<sub>2</sub> (350 bar), 31.8 kWh of li-ion battery,
- Manufacturers: Ballard Power Systems/BAE Systems/Capacity and Loop Energy/Transpower

## Container Handlers

- Pre-commercial: Upcoming demonstration at POLA
- Manufacturer: Nuvera/Hyster-Yale Group
- Research platform: 90 kW Nuvera PEMFC, 20 kg H<sub>2</sub> storage (350 bar), 200 kWh lithium ion battery pack
- Wireless battery charging – 3 – 5 min per charge
- Lower energy costs
- Reduced maintenance
- Higher productivity



# Market Status: Marine Vessel

## Domestic

- **San Francisco Passenger Ferry: Projected completion in late 2019**
  - Hydrogenics, BAE Systems, Incat Crowther, Bay Ship & Yacht Company, Red & White Fleet, Port of San Francisco, and Sandia National Laboratories.
  - 70-foot, 84-passenger catamaran, dual BAE Systems 300 kW electric motors, 360 kW Hydrogenics PEMFC stack and 100 kWh of Li-ion battery packs.
  - Onboard 264 kg of compressed hydrogen storage (250 bar)



## International

Euro Project	Vessel Type	System	Fuel Cell Application	Timeframe	Fuel
E4Ships - RiverCell	Inland River Cruise	250kW HTPEMFC	Baseload Hybrid Propulsion and Auxiliary Power	Phase 2: 2017-2022	Methanol
E4Ships - Elektra	Inland Push/towboat	Two 100 kW HTPEMFC	Baseload Hybrid Propulsion and Auxiliary Power	Phase 2: 2017-2024	Hydrogen
FLAGSHIPS - CFT	Inland Push/towboat	400 kW PEMFC	Hybrid Propulsion and Power	2021	Hydrogen



# Market Status: Stationary Power

## Stationary Power Applications

Cost Components	System 1	System 2	System 3	System 4	System 5
Fuel Cell Type	PEMFC	SOFC	MCFC	PAFC	MCFC
Capacity (kW)	0.7	1.5	300	400	1,400
Total Cost (\$)	\$15,400	\$34,500	\$3,000,000	\$2,800,000	\$6,400,000
Cost per kW	\$22,000	\$23,000	\$10,000	\$7,000	\$4,571
O&M Costs (\$/MWh)	\$60	\$55	\$45	\$36	\$40

Source:  
Assessment of  
Fuel Cell  
Technologies  
to Address  
Power  
Requirements  
at the Port of  
Long Beach,  
UC-  
Irvine, 2016)

## Combined Heat & Power (CHP) Applications

Parameter	Fuel Cell Systems	Reciprocating Engine	Steam Turbine	Gas Turbine	Microturbine
Electric Eff (%)	30 - 65	27 - 41	5 - 40	24 - 36	22 - 28
Net CHP Eff (%)	55 - 90	77 - 80	~80	66 - 71	63 - 70
Typical Capacity (MW)	0.2 - 2.8	0.005 - 10	0.5 - 100	0.5 - 300	0.08 - 1
Power Density (kW/m <sup>3</sup> )	5 - 20	35 - 50	> 100	20 - 500	5 - 70
CHP Installed Cost (\$/kW)	\$5000 - 6000	\$1500 - 2900	\$670 - 1100	\$1200 - 3300	\$2500 - 4300
Availability (%)	> 95	96 - 98	72 - 99	93 - 96	98 - 99
Start-up Time	mins - days	secs - mins	hr - day	mins - hr	secs - min

# Contact Information

---

**Greg Wilcox**  
**Eastern Research Group**  
**(703) 841-0354**  
**(339) 223-1223**  
**[Greg.Wilcox@erg.com](mailto:Greg.Wilcox@erg.com)**



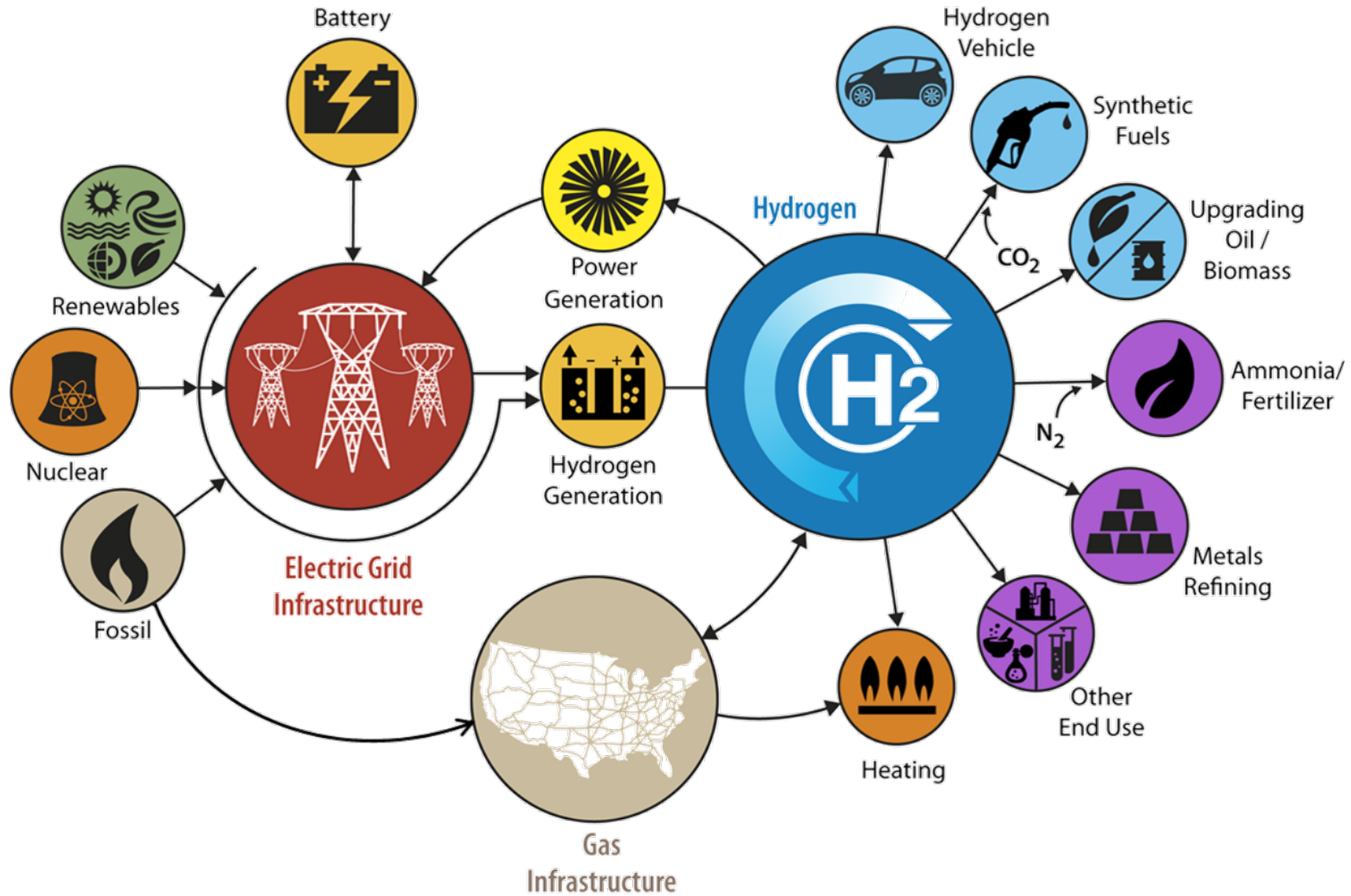
*Massachusetts  
Hydrogen  
Coalition*

# Maritime Hydrogen Port Cluster

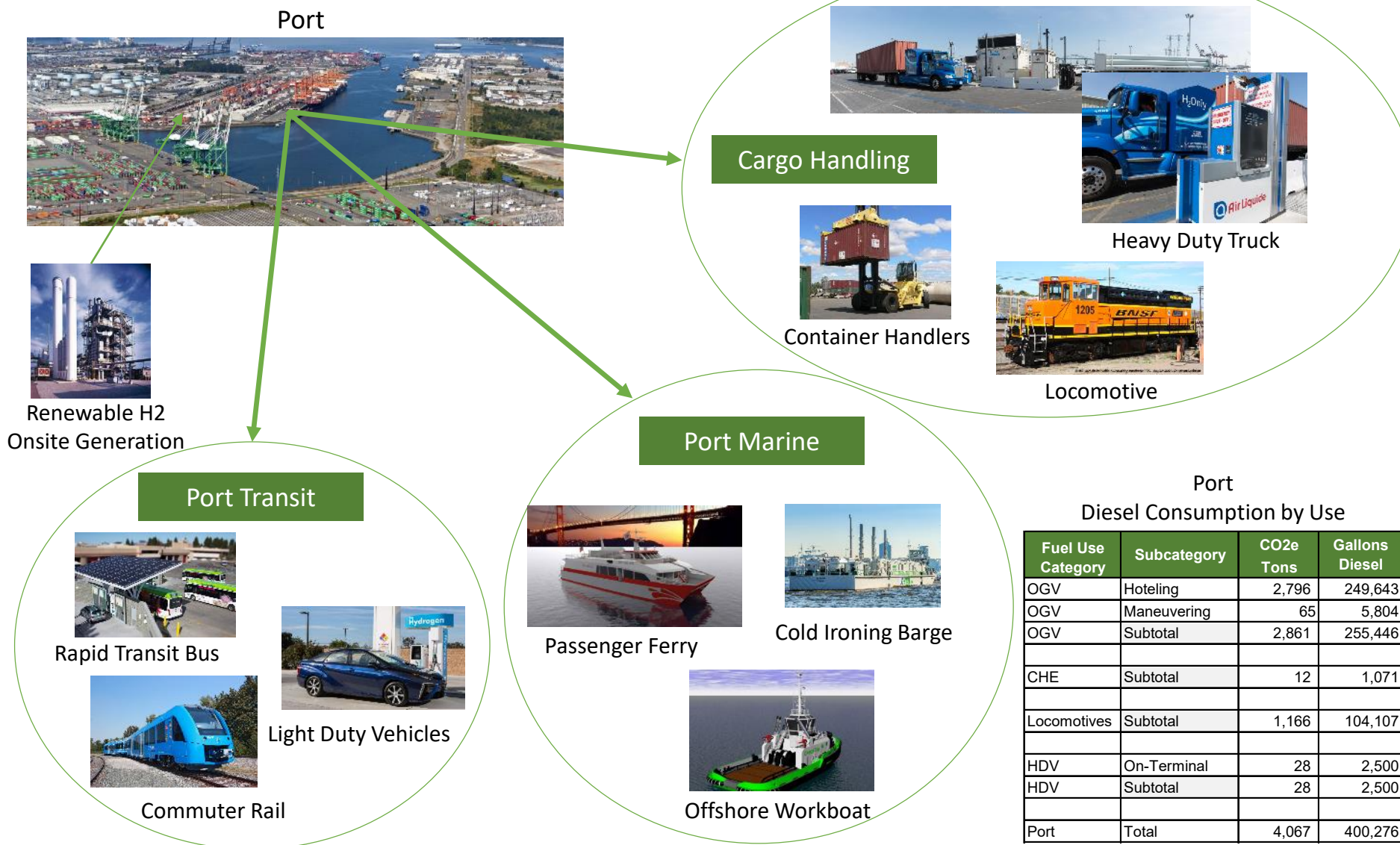
Charles Myers

July 11, 2019

# DOE H2@Scale Program



# Port Cluster Concept



# Port Terminal Container Handling Fuel Cell Options

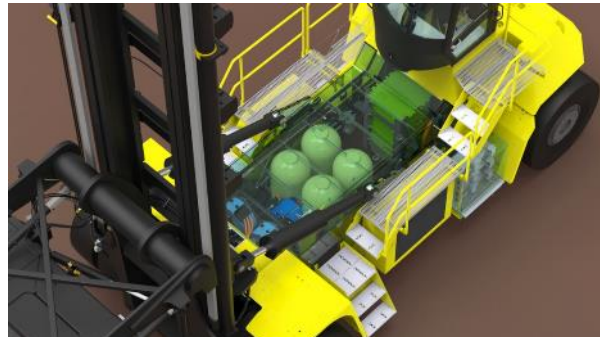
Hyster Yale  
Container Handler



Hyster Yale  
Reach Stacker



Kalmar  
Fork Lift



# Port Terminal Equipment Hydrogen Use



RTG Crane  
45 kg/day



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



Reach Stacker  
33 kg/day

	Average H2 Kg per Day/Unit	Port of NY / NY			Port of Long Beach			Port of Los Angeles		
		# 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



Straddle Carrier  
46 kg/day



Yard (Terminal) Tractor  
21 kg/day



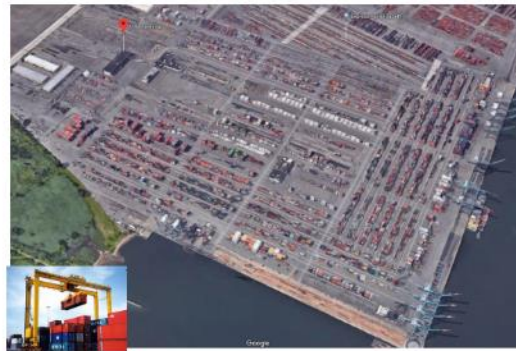
Forklift  
5 kg/day

# NY / NJ Port Terminal Equipment Fuel Use

Port operator equipment strategy drives fuel consumption and equipment numbers. APM on the surface appears to be the most efficient. Maher, the #2 volume operator, uses straddle carriers as does Ports of America. Staten Island and Red Hook rely on container handlers.

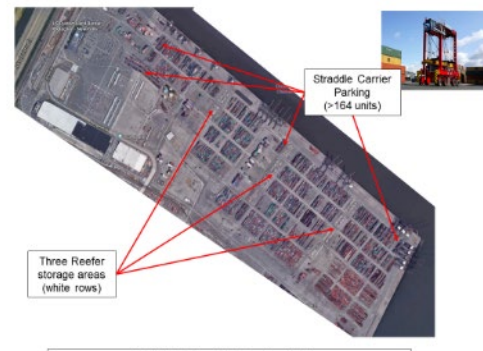
	APM Terminals		Maher Terminals		Ports of America		Port of NY Staten		Red Hook	
	# of Units	H2 Kg per Day	# of Units	H2 Kg per Day	# of Units	H2 Kg per Day	# of Units	H2 Kg per Day	# of Units	H2 Kg per Day
RTG Crane	23	1300	0	0	0	0	2	113	0	0
Forklift		0	0	0	0	0	0	0	0	0
Container Hdlr Empty	25	746	18	537	7	209	18	537	1	30
Container Hdlr Loaded	12	535	13	579	6	267	8	357	3	134
Reach Stacker		0	0	0	3	99	2	66	12	395
Straddle Carrier	0	0	210	9643	98	4500	0	0	0	0
Yard (Terminal) Tractor	118	1882	41	654	17	271	49	781	54	861
Fuel Truck	3	0	3	0	3	0	1	0	0	0
Daily Hydrogen Use (kg)		4463		11414		5346		1854		1419

APM Terminals, Elizabeth, NJ (Bunkering A Container Ship At Berth)



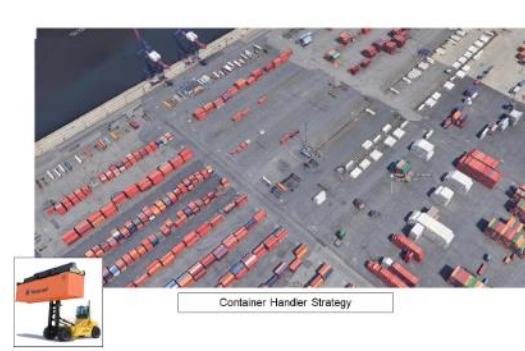
Rubber Tired Gantry (RTG) Port Operation Strategy

Maher Terminals, Elizabeth, NJ



Straddle Carrier Port Operation Strategy

Port of New York Container Terminal Staten Island



Container Handler Strategy

Draft – Subject To Review



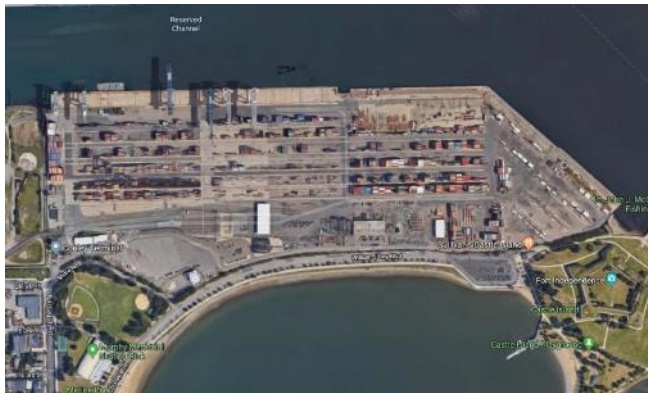
# Port of Boston Terminal & Intermodal Fuel Use

Port operator equipment strategy drives fuel consumption and equipment numbers. Connelly Terminal uses Yard Tractors to move containers from Ship-to-Shore (STS) Cranes then uses Rubber Tired Gantry (RTG) Cranes to stack containers. Container handlers are used for reefer and empty container storage.

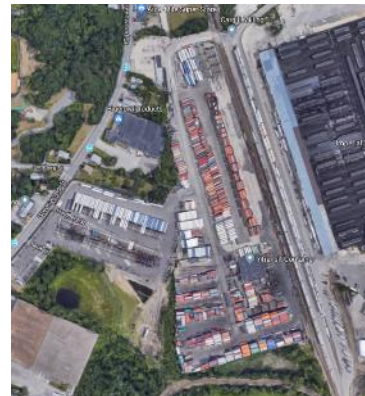
The ICI intermodal yard relies on container handlers while the CSX intermodal yard relies on RTG's. Container movement is done by the drayage truck as it moves containers in and out of the intermodal site.

	Boston		ICI Transit		CSX Worcester	
	# of Units	H2 Kg per Day	# of Units	H2 Kg per Day	# of Units	H2 Kg per Day
RTG Crane	8	452	0	0	3	170
Forklift	2	10	0	0	0	0
Container Hdlr Empty	4	119	1	30	1	30
Container Hdlr Loaded	2	89	1	45	0	0
Reach Stacker	3	99	6	197	0	0
Straddle Carrier	0	0	0	0	0	0
Yard (Terminal) Tractor	46	734	8	128	10	159
Fuel Truck	0	0	0	0	0	0
Daily Hydrogen Use (kg)		1503		399		359

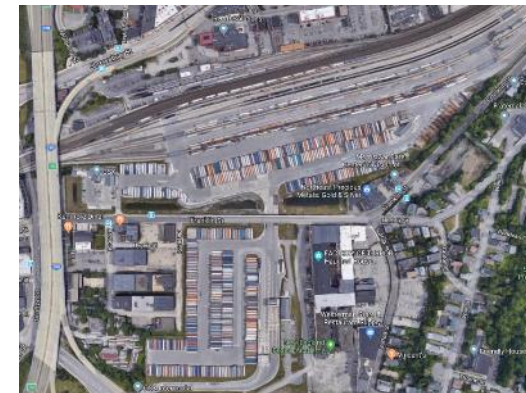
Port of Boston (Connelly Terminal)



ICI Transit Intermodal



CSX Worcester Intermodal



Draft – Subject To Review

# Port Terminal Refueling Strategies

## Equipment Ranked by Units

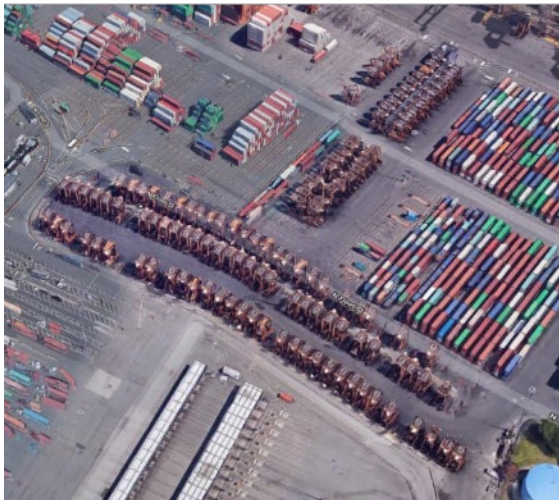
- 1) Yard Tractors
- 2) Straddle Carriers
- 3) Container Handlers (All)

Equipment when not in use is parked in rows in designated areas. Refueling is done from an oil tank truck that drives up and down the rows of parked equipment.

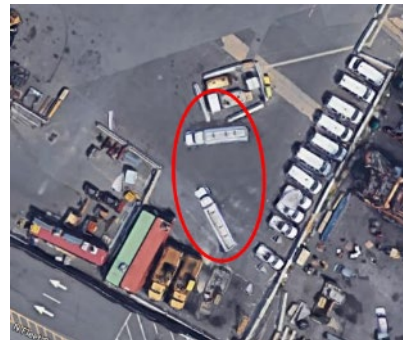
### Notes:

- Port real estate exists for siting hydrogen facilities.
- Need a mobile refueling solution for high volume hydrogen dispensing.
- Need industry agreement on dispense & storage pressure.
- Need mobile refueling protocol & safety Code development.

Straddle Carriers



Diesel oil refueling trucks parked.



APM Terminals, Elizabeth, NJ (Yard Dog and Container Handler Parking)



Port of New York Container Terminal Staten Island (Equipment Parking)



# Fuel Cell Port Drayage Truck Program



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

## Kenworth Model T680



Nikola Model One

Port	Drayage Total H2/Day
POLA	438731
POLB	335562
New York	98882

# Fuel Cell Maritime

GG Zero Marine  
Keel laid – November 2018



Reefer Power  
Young Brothers - Hawaii



Brodrene Aa – MANCRAFT  
Norway



Viking Lady  
Onboard FC Hotel Load



Port terminals, drayage trucks and maritime together create a hydrogen cluster.

Port profiling work is underway to identify use patterns, fuel needs and refueling strategies.

- Port terminal visits and discussions are underway
- Drayage truck manufacturers are sharing fuel and use profiles

Maritime vessel & ferry operators are looking at fuel cell technologies for both hotel load and main propulsion.

Thank You

Charlie Myers

(508) 380-1759

[cmyers@massh2.org](mailto:cmyers@massh2.org)