Maritime Fuel Cells for Port Emissions Reduction and Fuel Cost Savings

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Fuel Cells and Hydrogen for Maritime and Harbour Applications: Current Status and Future Perspectives in the EU

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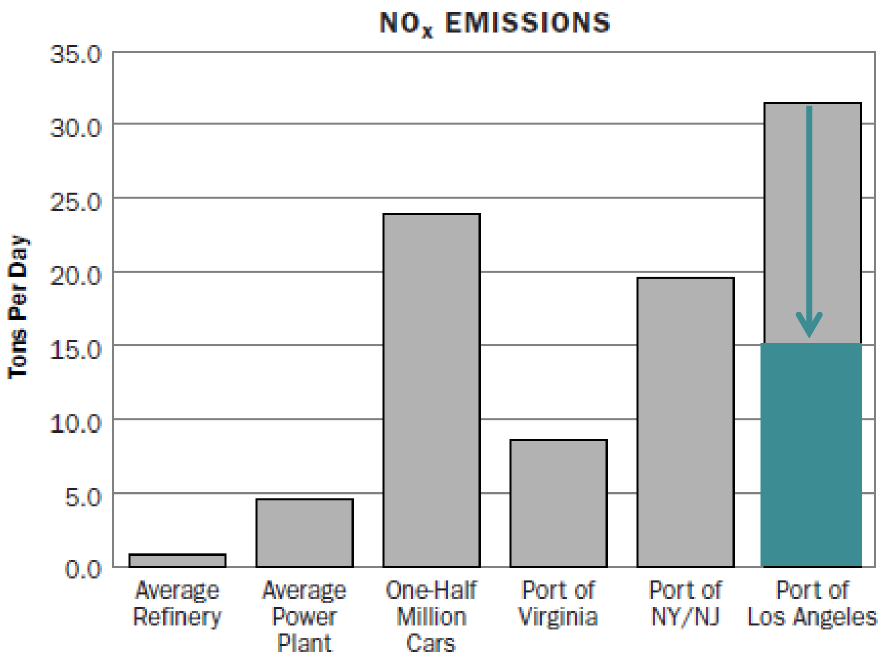
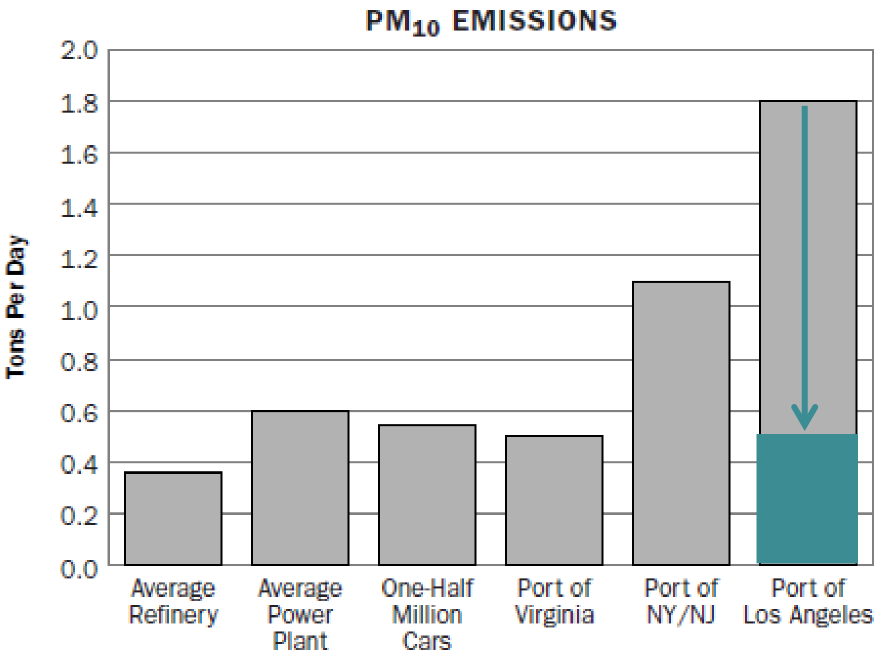
Daily pollution from a single port can exceed that of 500,000 cars.

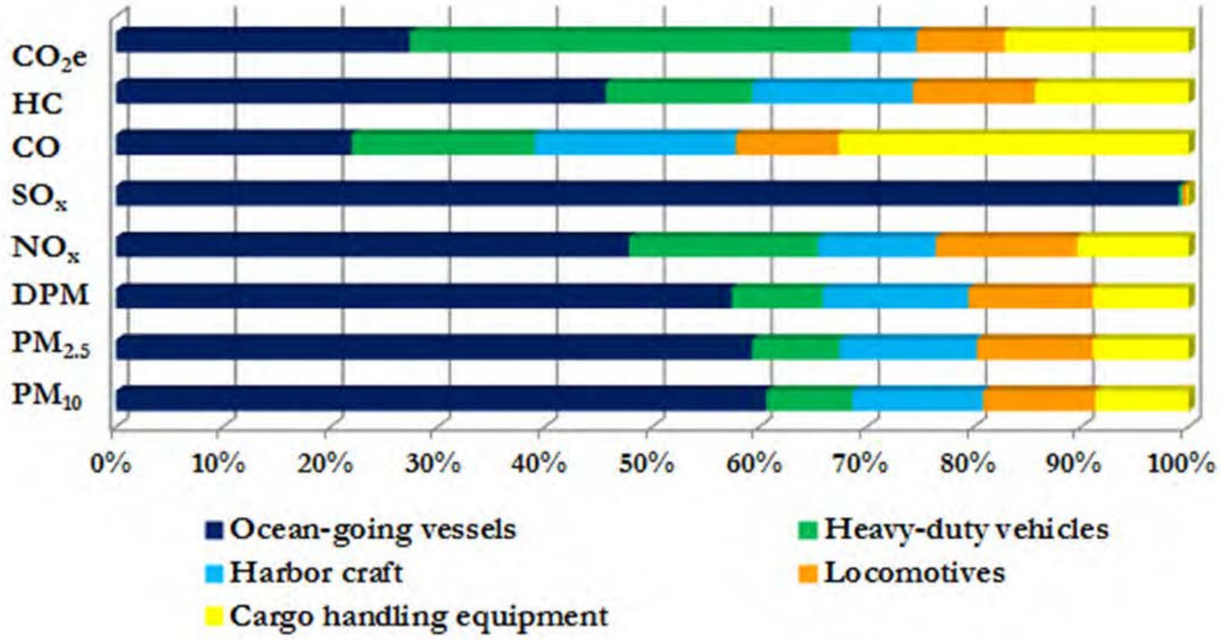




Original port data from 2002. Arrows show that, from 2005 to 2011, the Port of Los Angeles reduced NOx by 51% and PM_{10} by 73%.

Sources: National Resources Defense Council, "Harboring Pollution, Strategies to Clean Up U.S. Ports," 2005 and Port of Los Angeles, "Air Quality Report Card 2005 - 2011," 2012.

Ocean-going vessels account for roughly half of port emissions.



Approximately one-third to one-half of the emissions from ocean-going vessels is due to running auxiliary engines for electrical power at berth

Source: Starcrest Consulting Group, LLC, "The Port of Los Angeles Inventory of Air Emissions for Calendar Year 2011," 2012.

U.S. and international regulations are increasing the fuel cost for fleets.

Applicability	Date	Fuel Type	Sulfur Content	Current Fuel Cost ($/kg)*	Agency
U.S. flag carriers: • Propulsion engines for small vessels • Auxiliary engines of large vessels	Since 2007	LSD	500 ppm	No longer available	EPA
	July 2012	ULSD ('red dye' diesel)	15 ppm	$1.10	EPA
All vessels, within 200 nm of shore: • Propulsion engines of all large vessels • Auxiliary engines of international vessels	Since 2010	IFO	10,000 ppm (1%)	$0.70	IMO/ EPA
	Jan. 2015	MGO	1,000 ppm (0.1%)	$1.02	IMO/ EPA

Bottom line is being affected

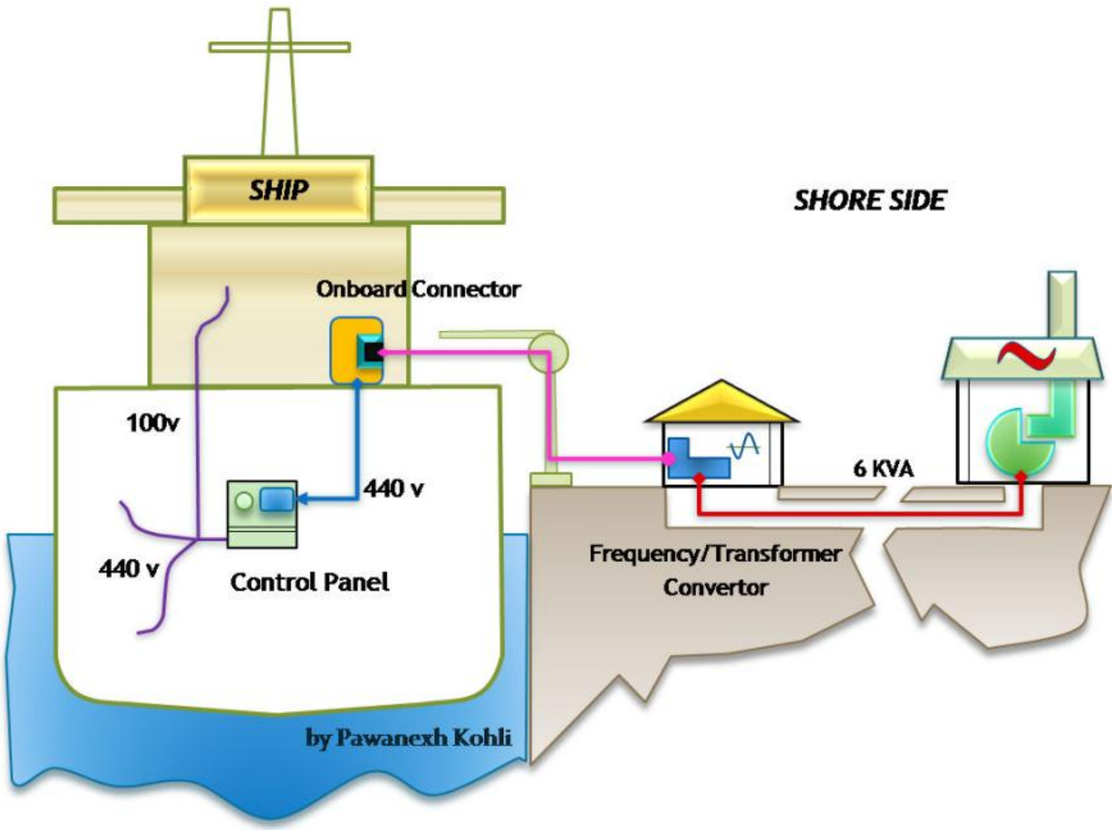
46% increase

*Bulk cost at the terminal as of December 10, 2012, from www.wilhelmsen.com.

IMO: International Maritime Organization EPA: [US] Environmental Protection Agency
LSD: Low Sulfur Diesel ULSD: Ultra-low Sulfur Diesel IFO: Intermediate Fuel Oil MGO: Marine Gas Oil

Cold-ironing is one option to eliminate vessel emissions and reduce maritime fuel cost while at berth.

Image from Wikipedia



Grid-connected cold-ironing schematic

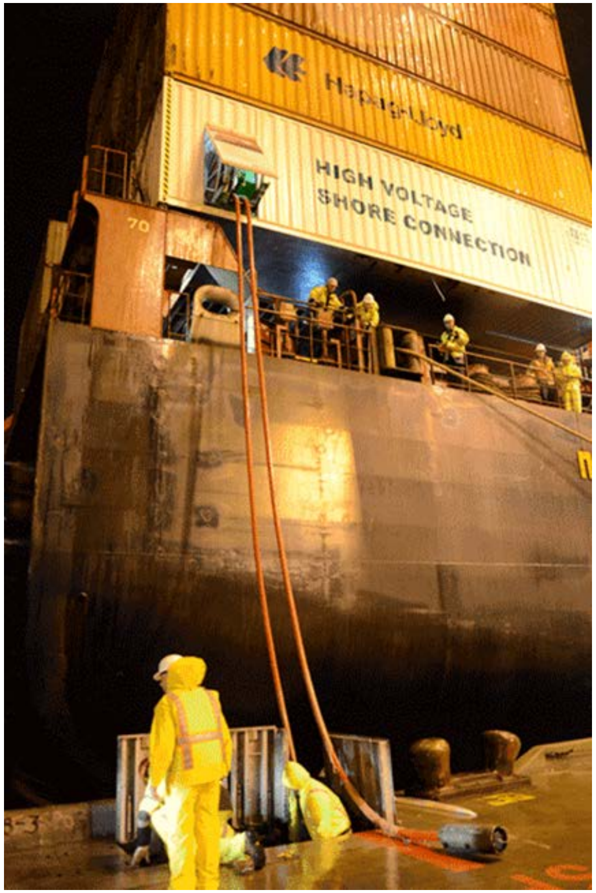


Image from www.portofoakland.com

Cold-ironing a container ship at the Port of Oakland.

A pier-side and/or barge fuel cell system provides power with added advantages

Fuel cell advantages:

- Typically cleaner electricity than the grid; potentially 100% renewable.
- Reliable, high-quality power.
- No dock-side grid infrastructure required.
- Can compete with grid on cost/kWhr in many locations.
- Can replace diesel gensets powering refrigerated cargo.

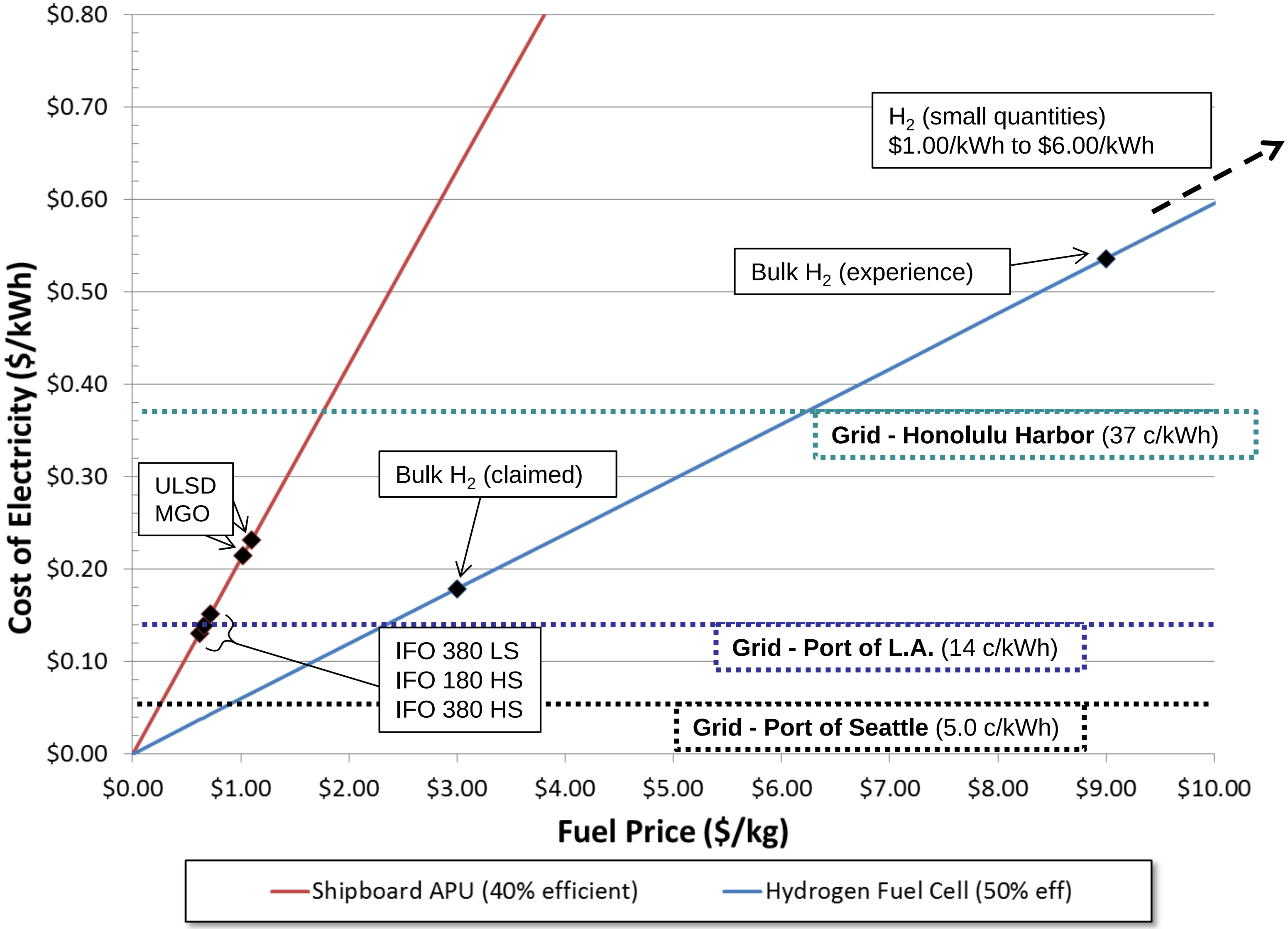
Barge advantages:

- Ability to power vessels at any berth – or at anchorage.
- Allows small craft to stay on station without running engines.

Port of Los Angeles Shore Power Barge

Images from the Port of Los Angeles

Electricity supplied by hydrogen can be cost-competitive with maritime fuels and the grid.



The path to highest environmental impact and fuel savings begins with small-scale demonstration and commercialization.

< 200 kW

> 1 MW

Dockside

Small Demo
- Verify FC-to-reefer concept
- Solves local H_2 issues (availability, price, permitting)
- FCs in maritime environment

Large Demo
- Ship interface.
- Many reefers (via ship electrical).
- Large scale containerized FC.

Large Commercial
- Critical service
- Fuel cost savings
- Infrastructure savings
- Wider applicability

Barge

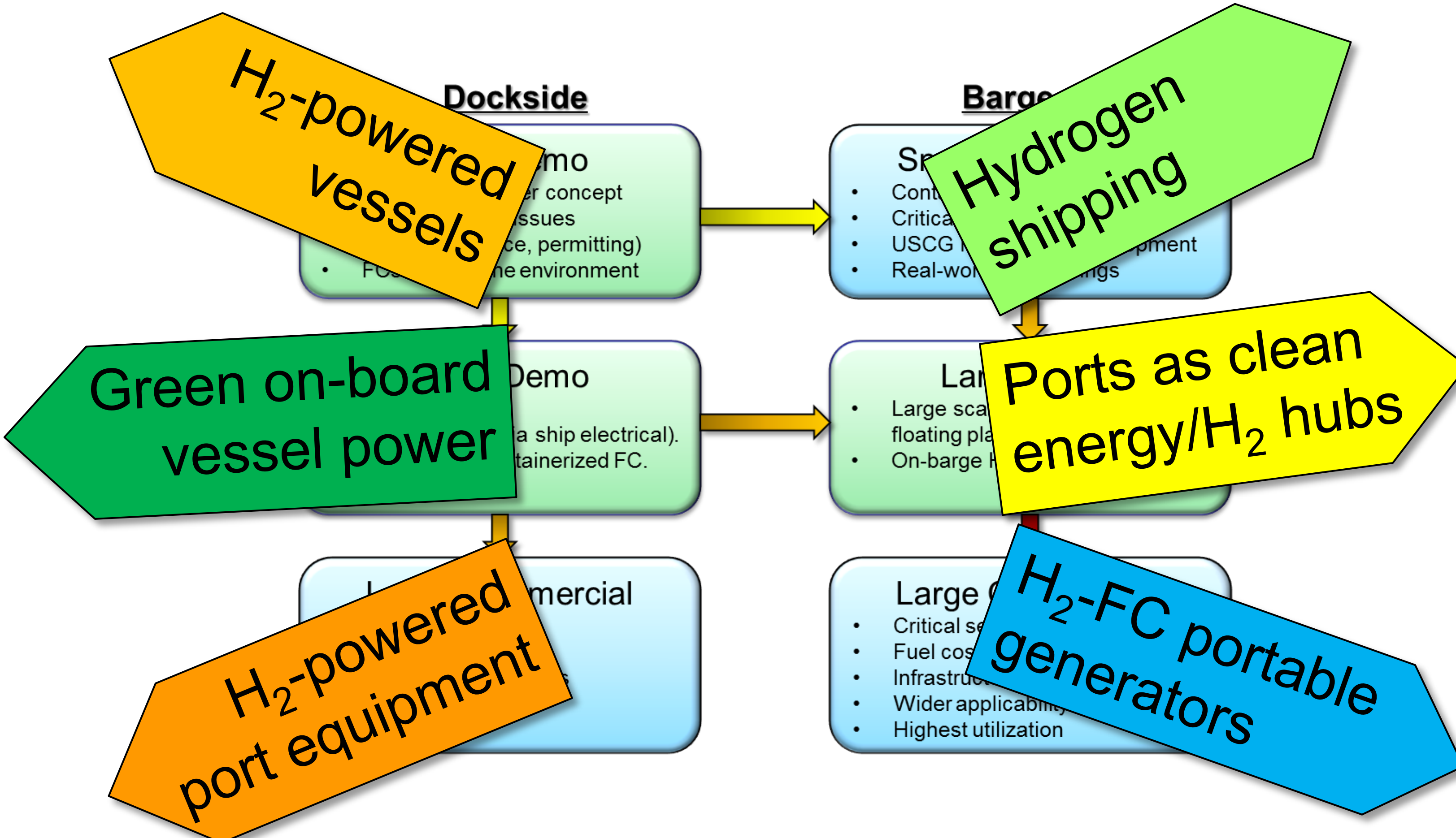
Small Commercial
- Containerized FC and H_2
- Critical service
- USCG H_2 protocol development
- Real-world cost savings

Large Demo
- Large scale FC and H_2 on floating platform.
- On-barge H_2 refueling.

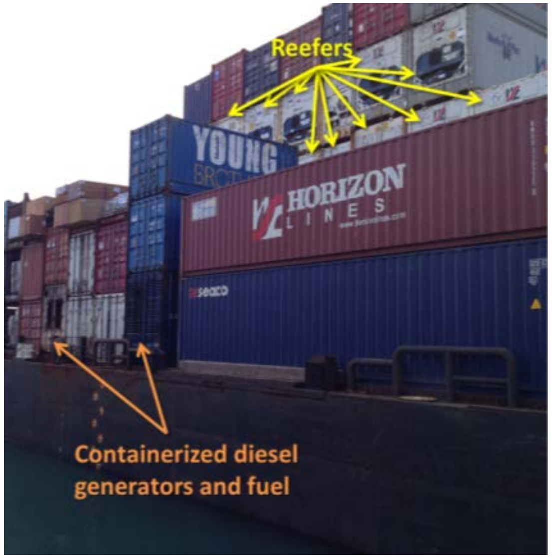
Large Commercial
- Critical service
- Fuel cost savings
- Infrastructure savings
- Wider applicability
- Highest utilization

Reefer: Refrigerated shipping container

These activities could have an impact beyond that of reefer power or cold-ironing.



Refrigerated container power for Hawaiian inter-island transport is a recommended small-scale demo-to-commercial project.



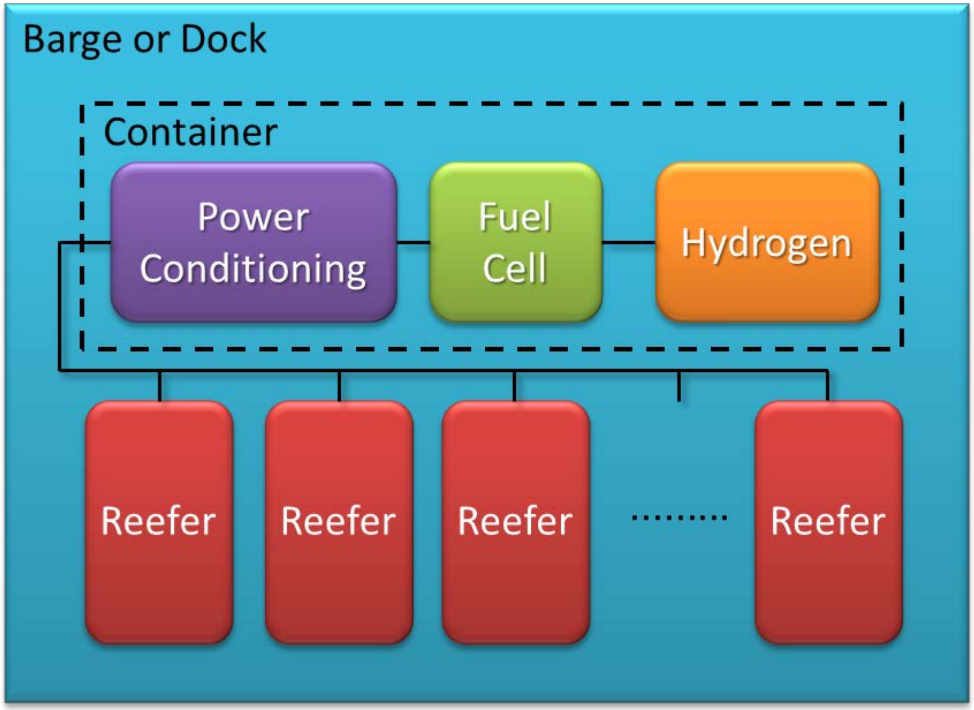
Demonstration Project Attributes

- Supplants diesel generators, saving fuel cost.
- Daily use.
- On-site PV available to provide H_2 via electrolysis
- Non-maritime spin-off potential.

Project Scope (6-month demo)

- Containerized PEMFC plus H_2 supply and storage provides power for refrigerated containers.
  - ~100 kW PEMFC.
  - Single 20-ft. ISO container.
  - On-site H_2 storage.
  - SNL tech support & mgmt.
  - Data collection.

Implementation is technically viable, with mobile, self-sufficient containers housing both the power module and hydrogen.

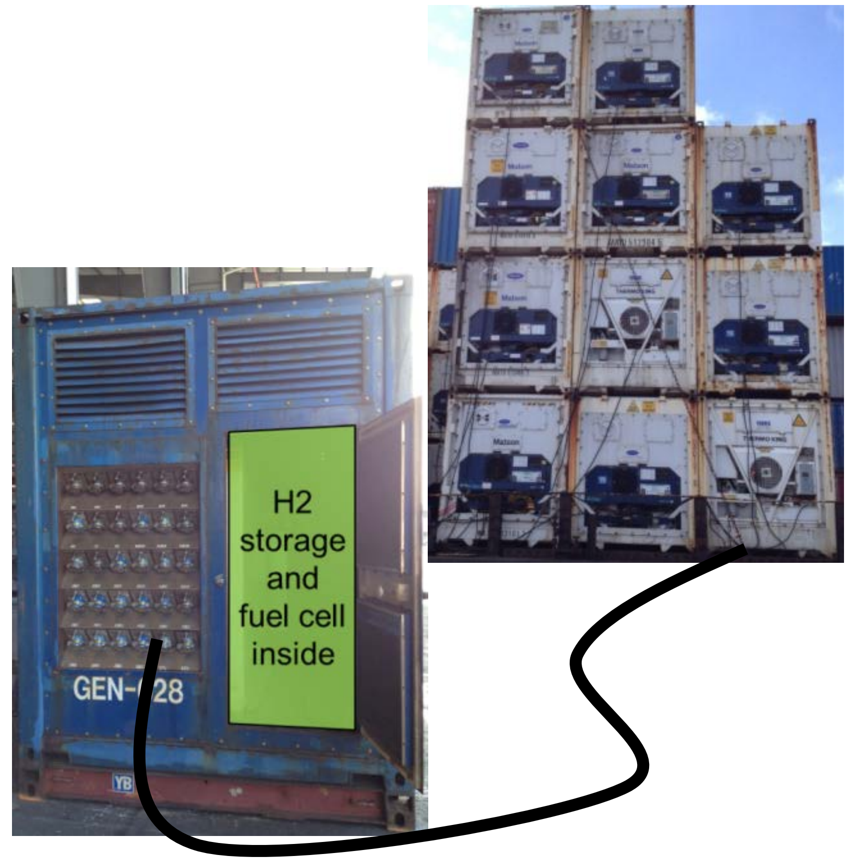


Design Considerations

- **Container size and weight.**
- **Power and storage capacity.**

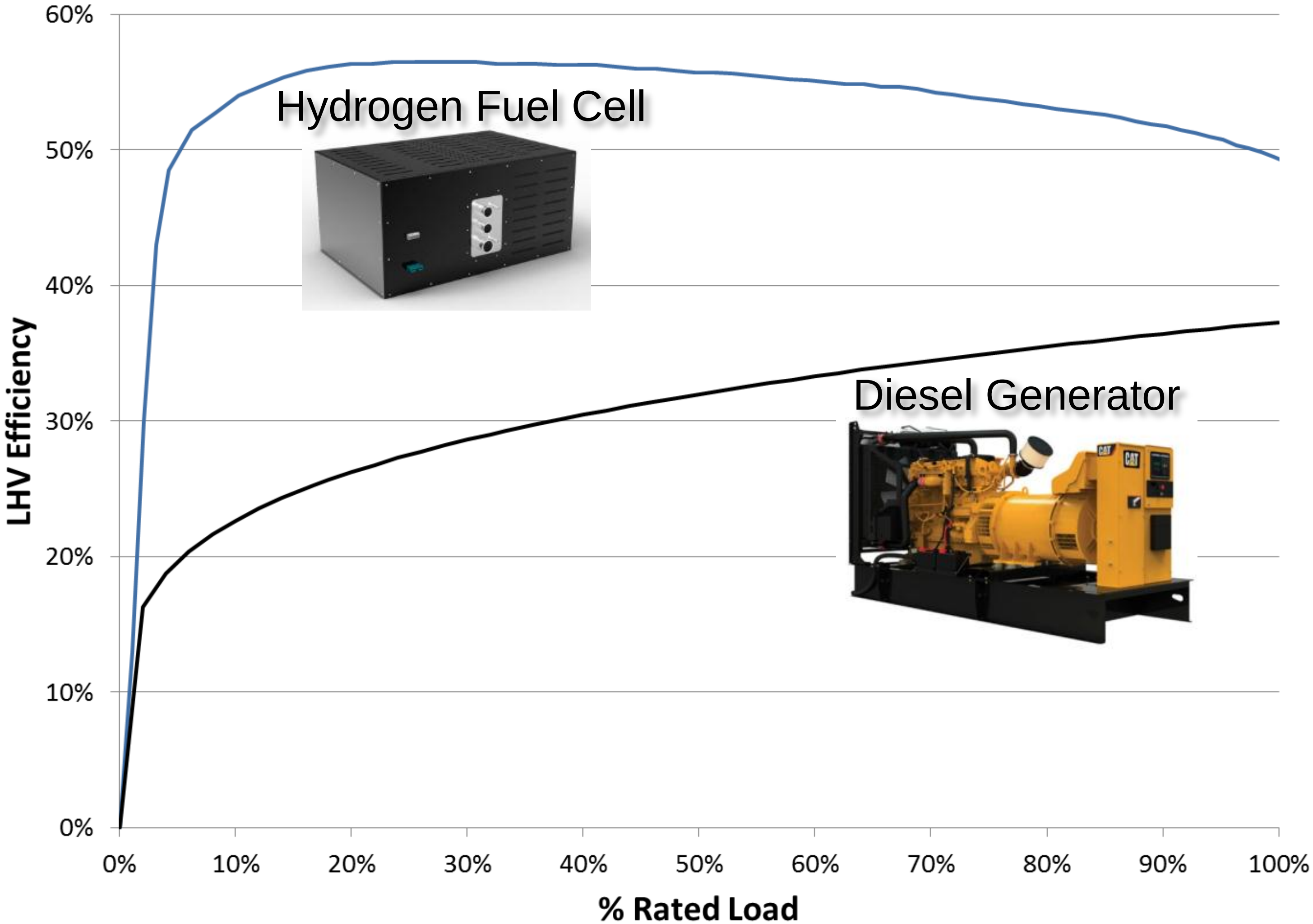
On the outside, the fuel cell power unit would look the same and perform the same function as the diesel power unit.

Current situation at Hawaii site



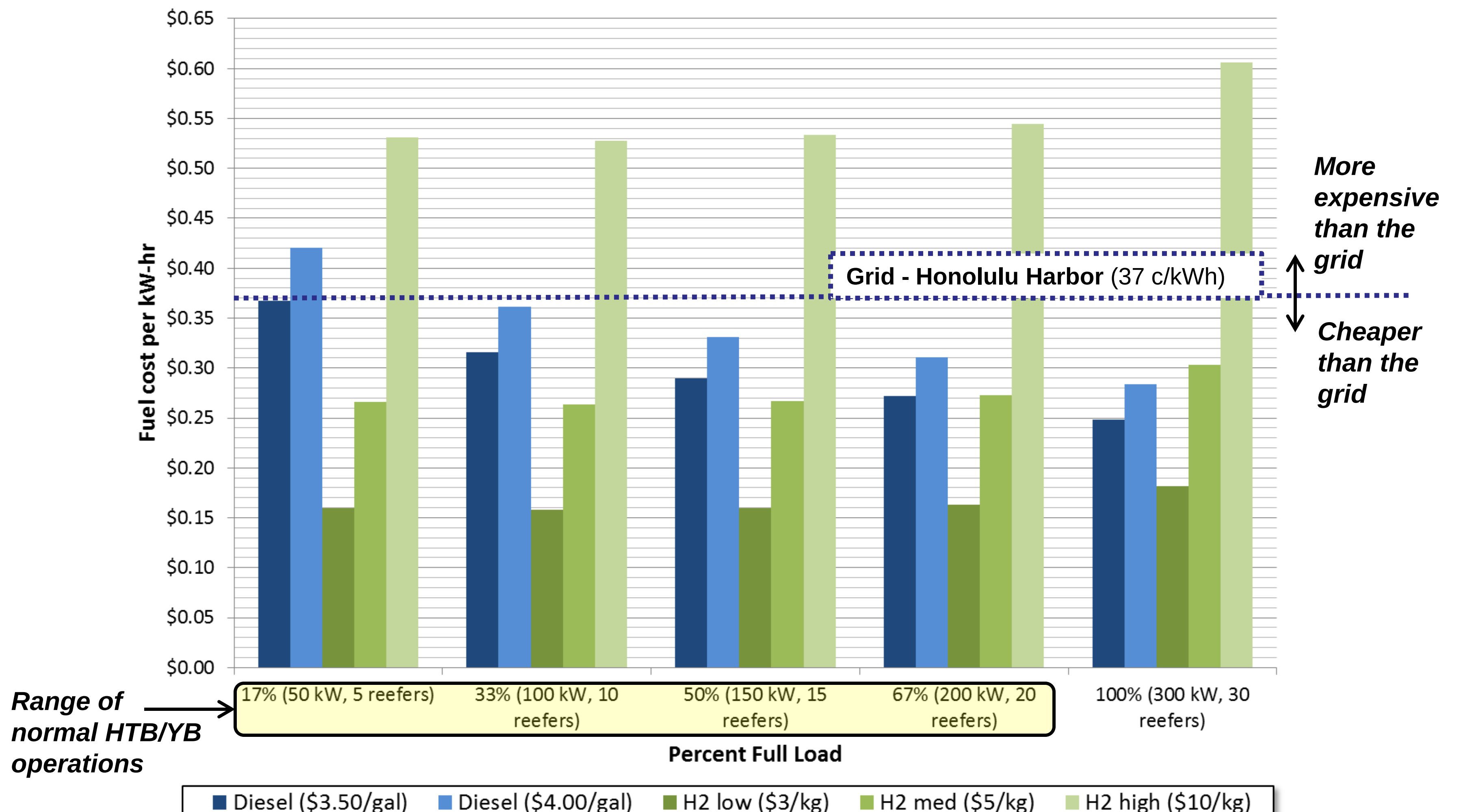
Proposed fuel cell implementation

Fuel cells have higher efficiency and perform better at part loads than diesel gensets.



Higher efficiency = Less fuel burned

Fuel cost per kilowatt hour is relatively constant for fuel cells, but increases at part load for diesel gensets.



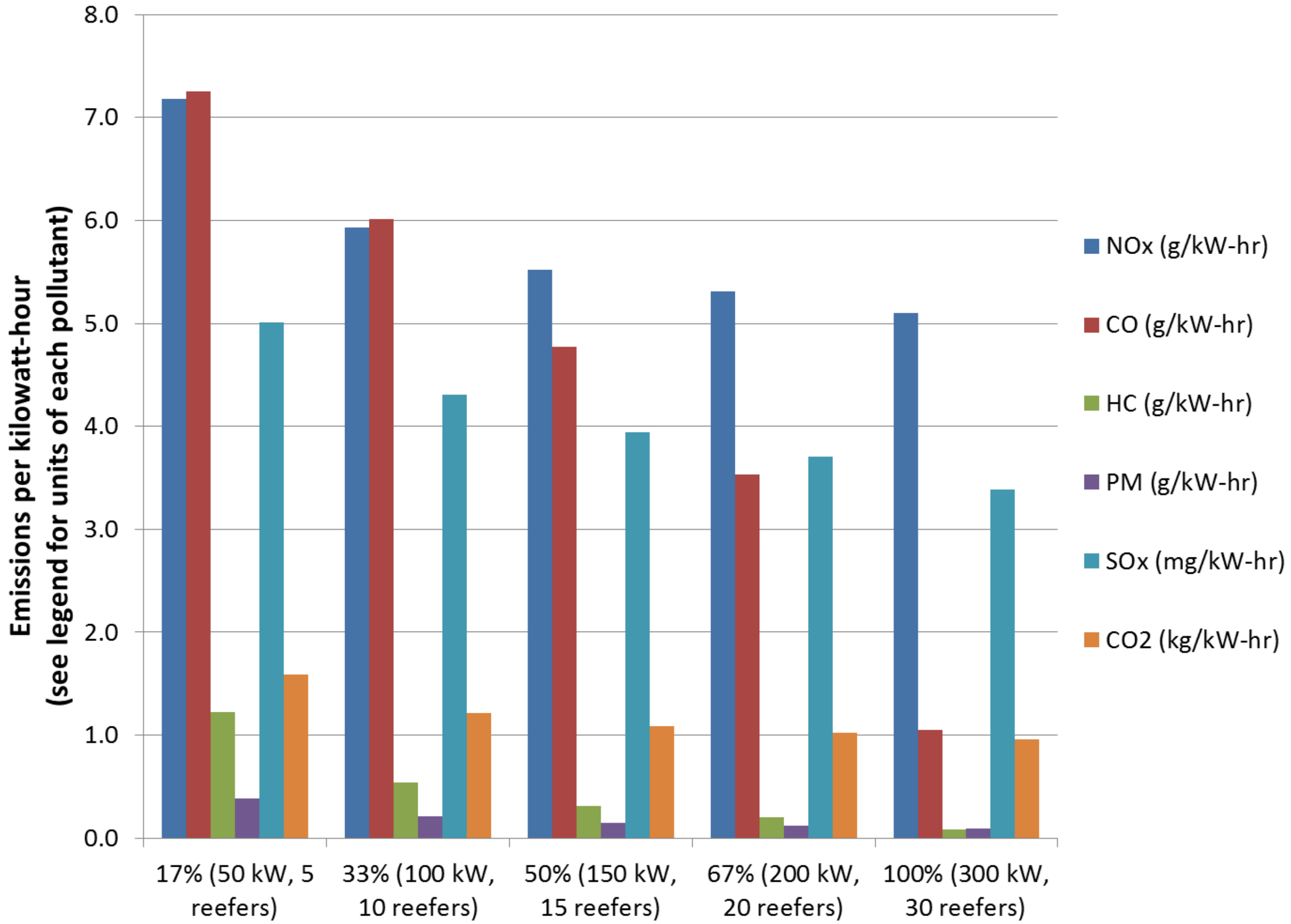
Part-load operation of diesel gensets also leads to more maintenance problems.

Each of these issues increases maintenance frequency and cost, reduces time between overhauls, and shortens engine life:

- Hydrocarbon build-up
- Rings sticking
- Glazed piston and cylinder walls
- “Slobbering” or “wet-stacking” (oil droplets in exhaust)
- Burning oil

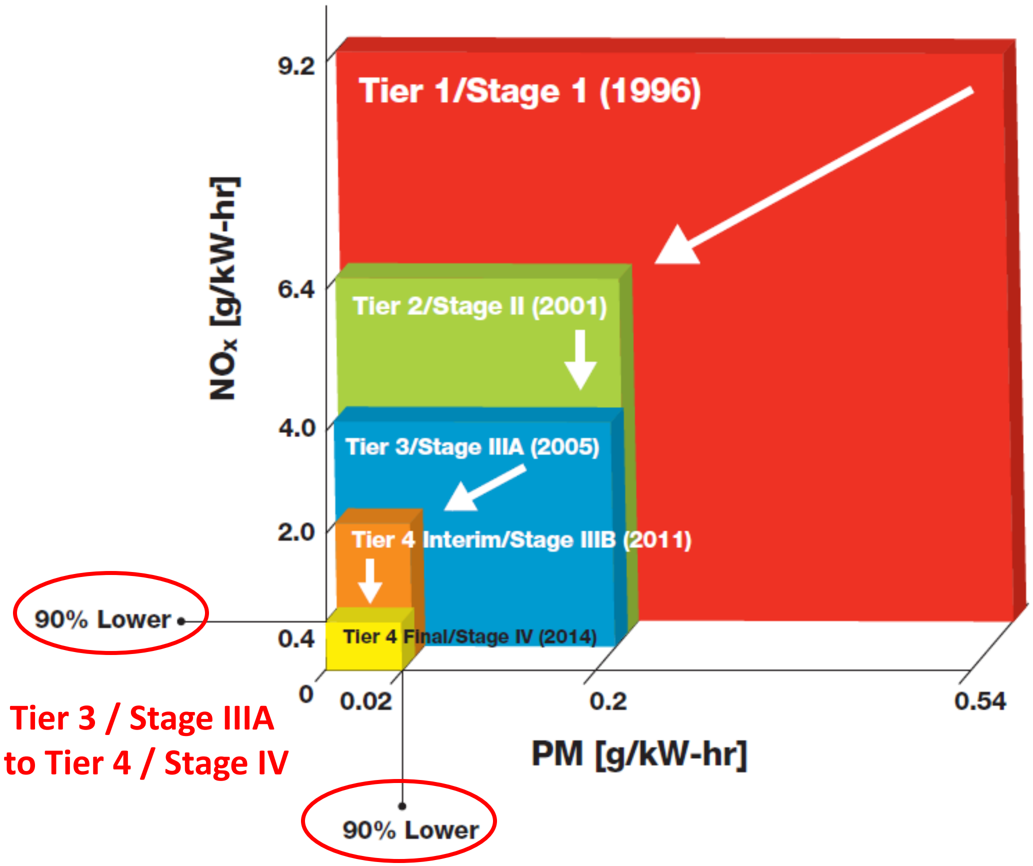
Part load operation has no adverse effects on fuel cell operation, and usually leads to *longer* fuel cell lifetime.

Diesel engine emissions are also worse at part load.



Emissions data, except SOx, from a Caterpillar C15 350 kW genset meeting EPA Tier 3 standards. SOx data assumes all fuel sulfur (15 ppm for ULSD) converted to SOx per EPA guidelines.

Ever-tightening off-road diesel emission regulations increase engine costs. Fuel cells inherently meet EU and EPA regulations.

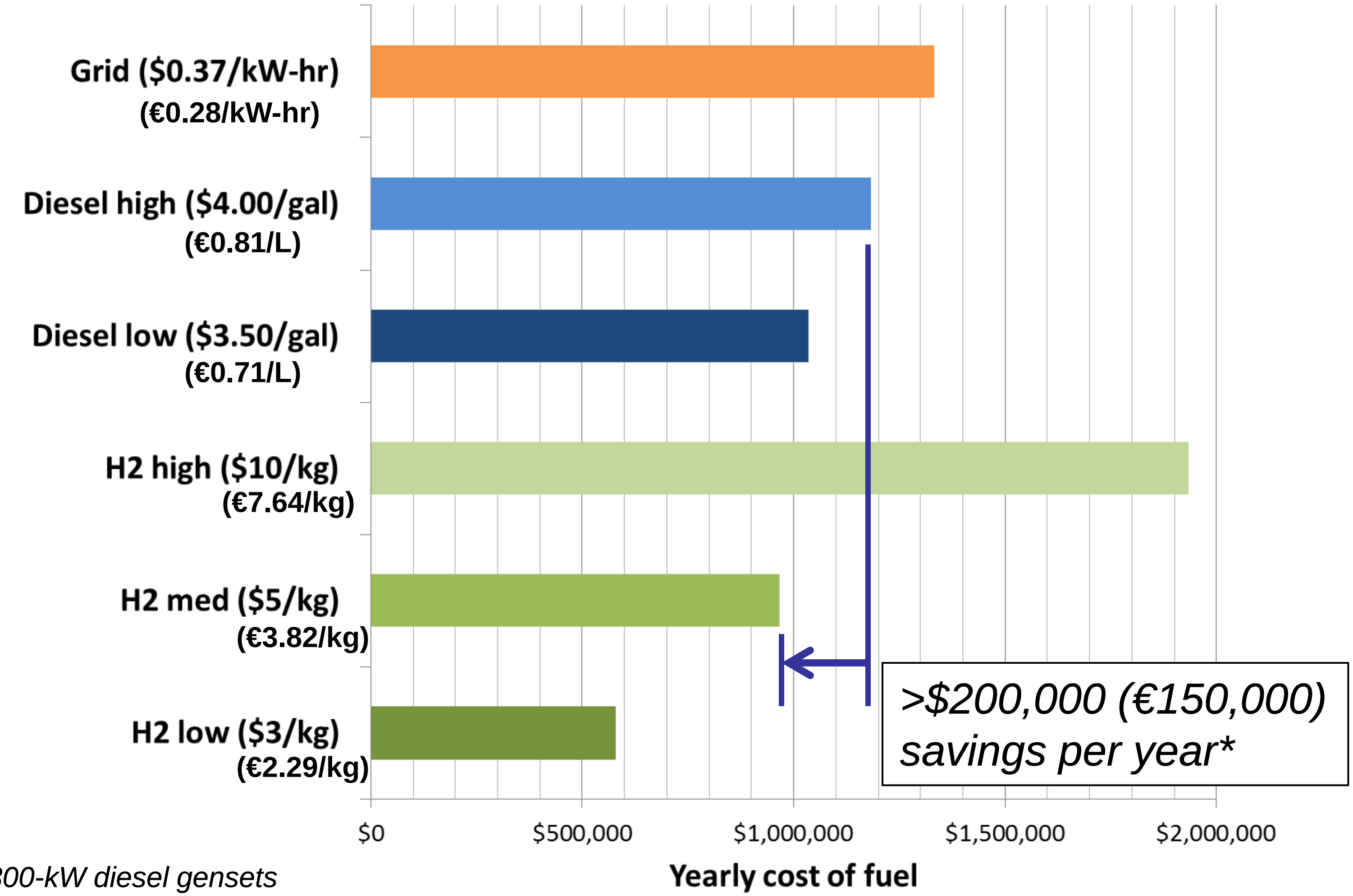


Graphic by *Cummins Emissions Solutions*

<u>Notes:</u>

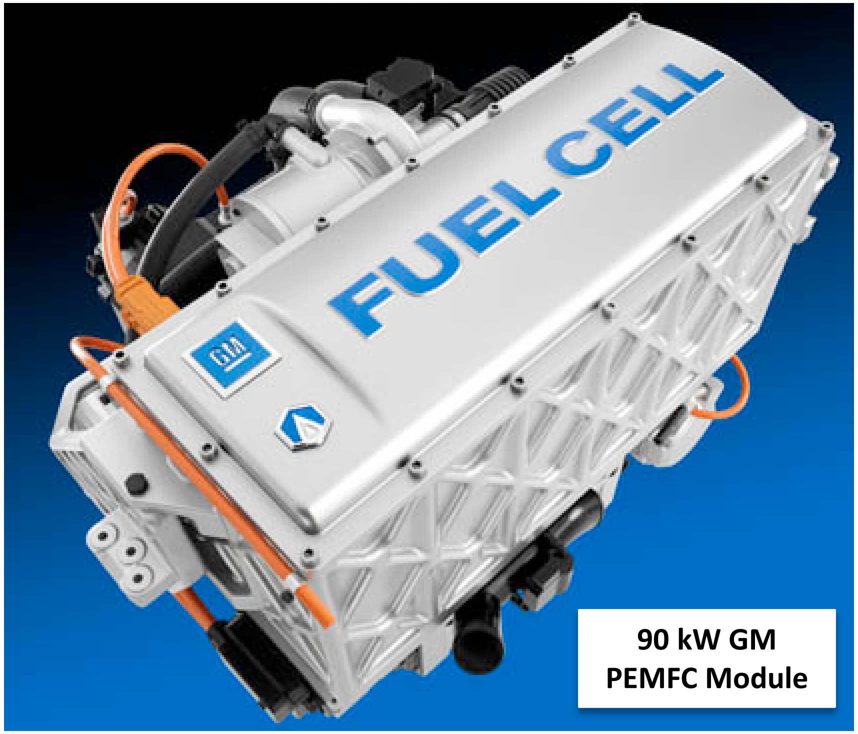
- EU Stage IV standard for PM is 0.025 g/kW-hr (vs. 0.020 g/kW-hr for US EPA)
- Tier IV / Stage IV graphic represents the 56-560 kW engine range. Prior to Tier IV / Stage IV, emissions regulations are shown for the 130-560 kW range – for lower powers the regulations were slightly more relaxed.
- Chart is a simplification and does not completely represent various compliance options available to manufacturers.

The site's fuel cost analysis showed the fuel cell is cost effective if hydrogen can be purchased for $5/kg (€3.82/kg) or less.

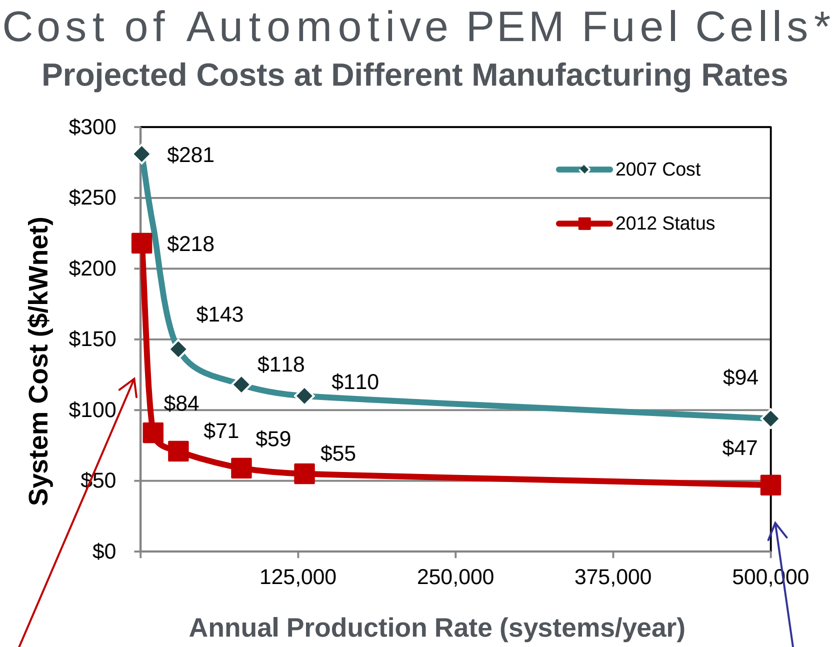


*Replacing six 300-kW diesel gensets

The ~100kW fuel cell size directly leverages the automotive market for mass production and cost reduction.



90 kW GM PEMFC Module



**Based on state-of-the-art lab scale technology projection to high-volume manufacturing (500,000 units/year).- Strategic Analysis*

DOE high-volume cost target: $30/kW

Estimated cost of a similar 90 kW stack today: >$2,000/kW

$100-$150/kW for auto PEM fuel cell at 10,000 units year

Summary

- Environmental concern, regulatory compliance, and rising fuel cost is driving increased support for maritime fuel cell applications.
- Small-scale demonstration at the HTB/YB facility
  - Good proving ground for:
    - Fuel cell ability to provide sufficient and reliable reefer power.
    - Operation in typical marine environment (weather, handling, etc.).
    - Hydrogen supply logistics and cost.
- Ultimate goal is a fuel cell barge powering a container ship at berth.
  - Use the Hawaii project as a stepping stone.
  - Challenging on many levels, yet technically do-able with potential commercial opportunity.
  - Worldwide impact.