The SF-BREEZE: Can a Zero Emission Hydrogen Ferry Really Work in the San Francisco Bay?

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Red and White Fleet

Propeller Club Northern California

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Red and White Fleet

Thomas C. Escher,
Owner and President

- Founded in 1892, the historic Red and White Fleet today offers over 5,000 sightseeing trips/yr under the Golden Gate Bridge.
- Fleet: 4 passenger vessels, steel mono hulls, 350 to 600 pax.
- Under the visionary leadership of Mr. Escher, we are committed to providing our services with the highest level of environmental responsibility.
- We run 6 Tier III engines and 10 Tier II engines across our fleet, but it is clear that these incremental criteria emissions reductions are insufficient to respond to near term threats.
- In 2014, Mr. Escher made a commitment to providing our services on a zero emission vessel.

Sandia National Laboratories

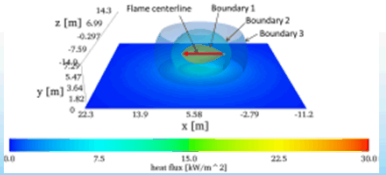
"Exceptional service in the national interest"

- Largest National Lab in U.S.
  - U.S. Department of Energy (DOE)
  - ~12,000 employees
  - ~US$2.3B/yr from DOE, other federal agencies, and private industry
  - H_2 Program in Livermore, CA (HQ in Albuquerque, NM)




- Hydrogen program: 60+ years technical depth in a wide range of areas, which we apply to enable impactful clean energy solutions
- Zero Emission Maritime Program
  - SF-BREEZE ferry
  - ZERO/V coastal-class research vessel
  - Maritime Fuel Cell Generator
  - Development of IMO H_2 regulations
  - Zero Emission Hydrogen Vessel Working Group





Project Concept

High-speed H_2 Ferry

Engineering model of the SF-BREEZE

Dockside Fueling Station

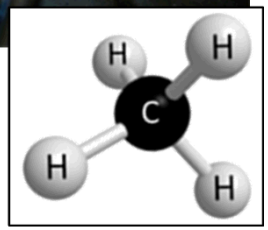
Example existing dockside hydrogen station in Hamburg, Germany

Technically Possible? ***Accepted by Regulators?*** ***Commercially Viable?***

Hydrogen is a combustible fuel, very similar to natural gas, but does not contain *carbon.*

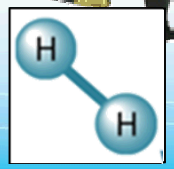
H_2O
CO
CO_2

Natural gas



H_2O

Hydrogen

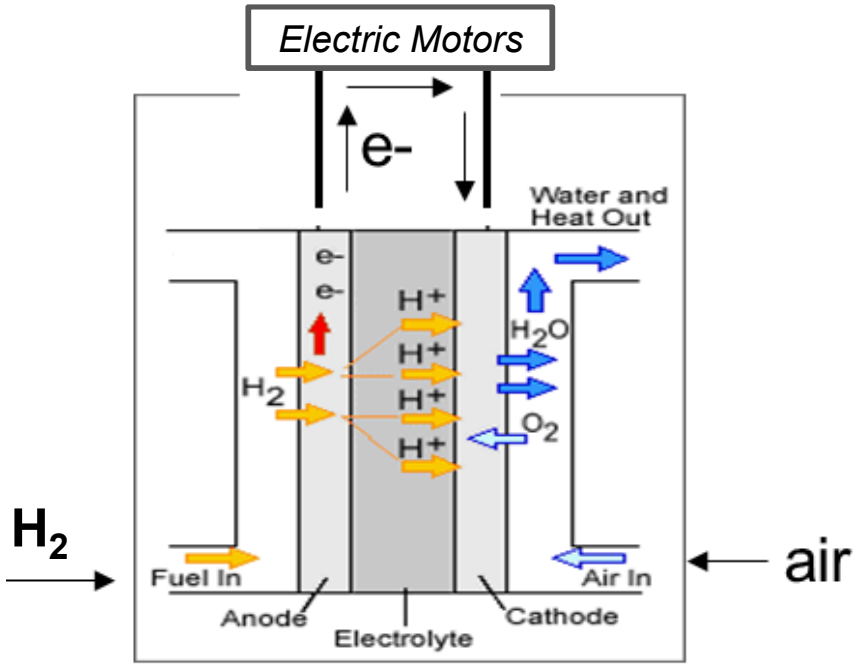


Hydrogen is the lightest gas

NG H_2

When hydrogen is used in a *Fuel Cell* it produces ZERO pollution or greenhouse gas

Hydrogen Fuel Cell



$2\ H_2 + O_2 \rightarrow 2\ H_2O$

Photos Courtesy Ryan Sookoo, Hydrogenics

Going In:

H_2 and air

Going Out:

Electricity
Waste Heat
Warm humidified air

Ways to Store Hydrogen

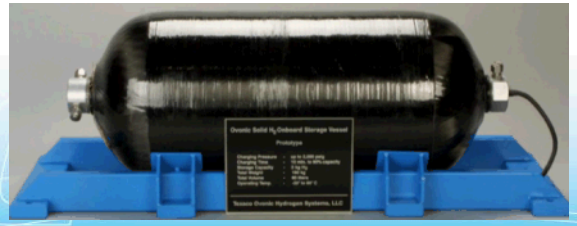
Gaseous tanks

~2,000 psi steel or aluminum

5,000-10,000 psi carbon fiber composite assemblies

Liquid hydrogen

Metal Hydride



Liquid hydrogen is the lightest option for the SF-BREEZE

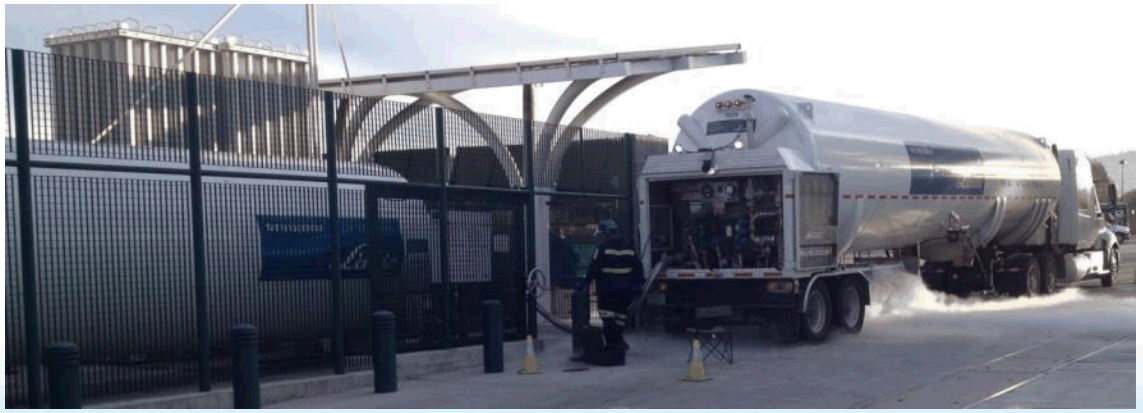
LH_2 is a lot like LNG. Both fuels have been safely transported and used for decades.

LH_2 Storage Tank

LNG Storage Tank

NASA's LH_2 transport barge

More than 50 LH_2 trucks for every Space Shuttle launch



LH_2 transfer operation at AC Transit in Emeryville, CA

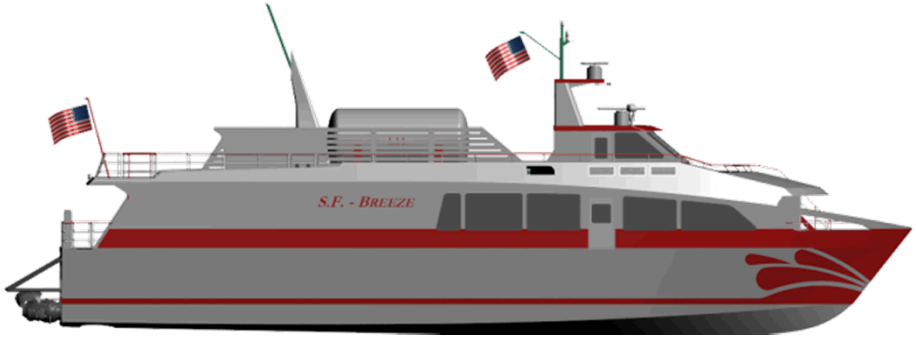
SF-BREEZE Requirements

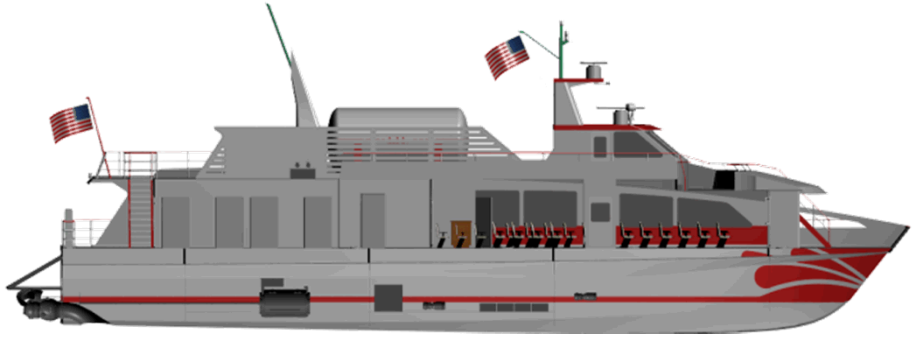
- High-speed commuter ferry in an ocean bay environment
- Must be competitive with other modes of transportation (car, bus, train, other ferries)
- 35 kts top speed, 23 nm one-way
- Daily logistics:
  1. Two morning round trips (~100 nm)
  2. Refuel in less than 1 hr at midday
  3. Two afternoon round trips (~100 nm)
  4. Refuel again at night
- Each round trip uses about 400 kg LH_2

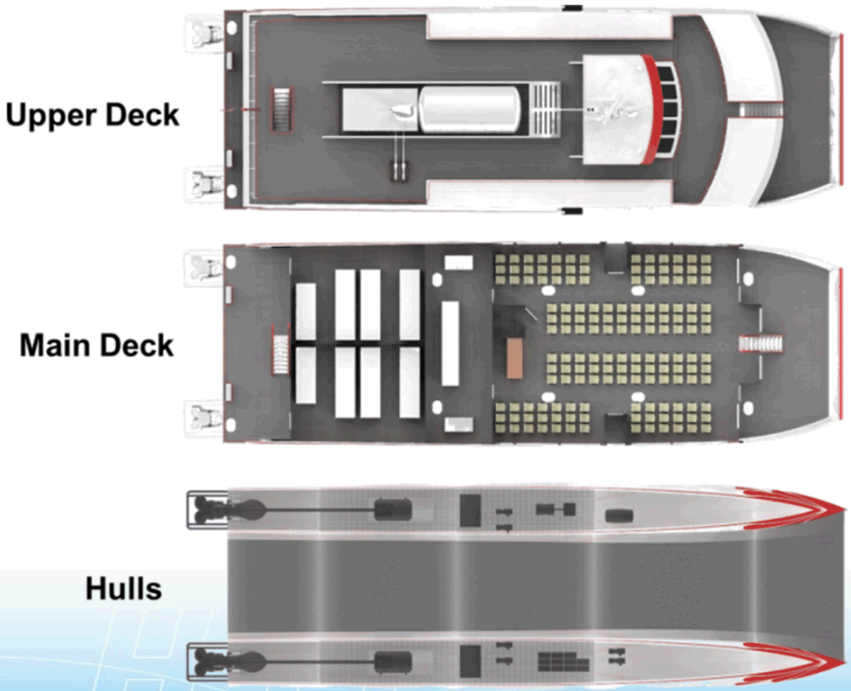
SF-BREEZE Design

Elliott Bay Design Group Naval Architecture by Elliott Bay Design Group

SF-BREEZE Design



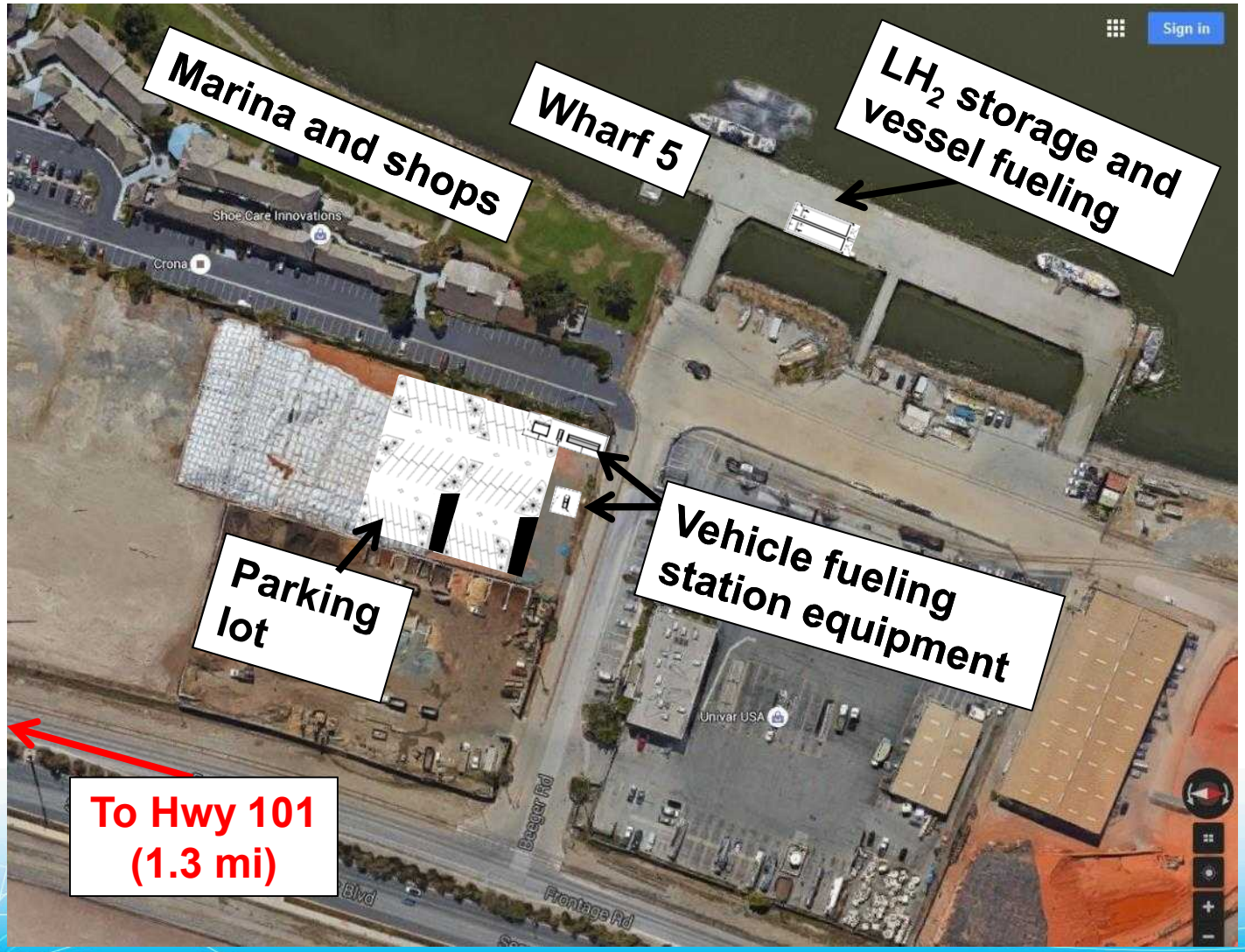




- LOA 109’ x Beam 33’ x Depth 11.25’
  Full Load Draft ~ 4.6’
- Full Load Displacement ~ 133 LT
- Tonnage: 79.86 GRT
- Passengers: 150
- Service Speed: 35 knots
- Propulsion power 4.4 MW, installed: 4.92 MW
- Fuel: Renewable LH_2
- **Low noise, no diesel fumes or odor**
- **Faster response time than diesel**
- **ZERO Emissions on the water**
- **ZERO Fuel Spills on the water or on land**

The Port of San Francisco prefers Pier 54 for fueling both the SF-BREEZE and fuel cell electric vehicles.

The Port of Redwood City identified Wharf 5 and nearby lots as ideal for fueling vessels and vehicles.



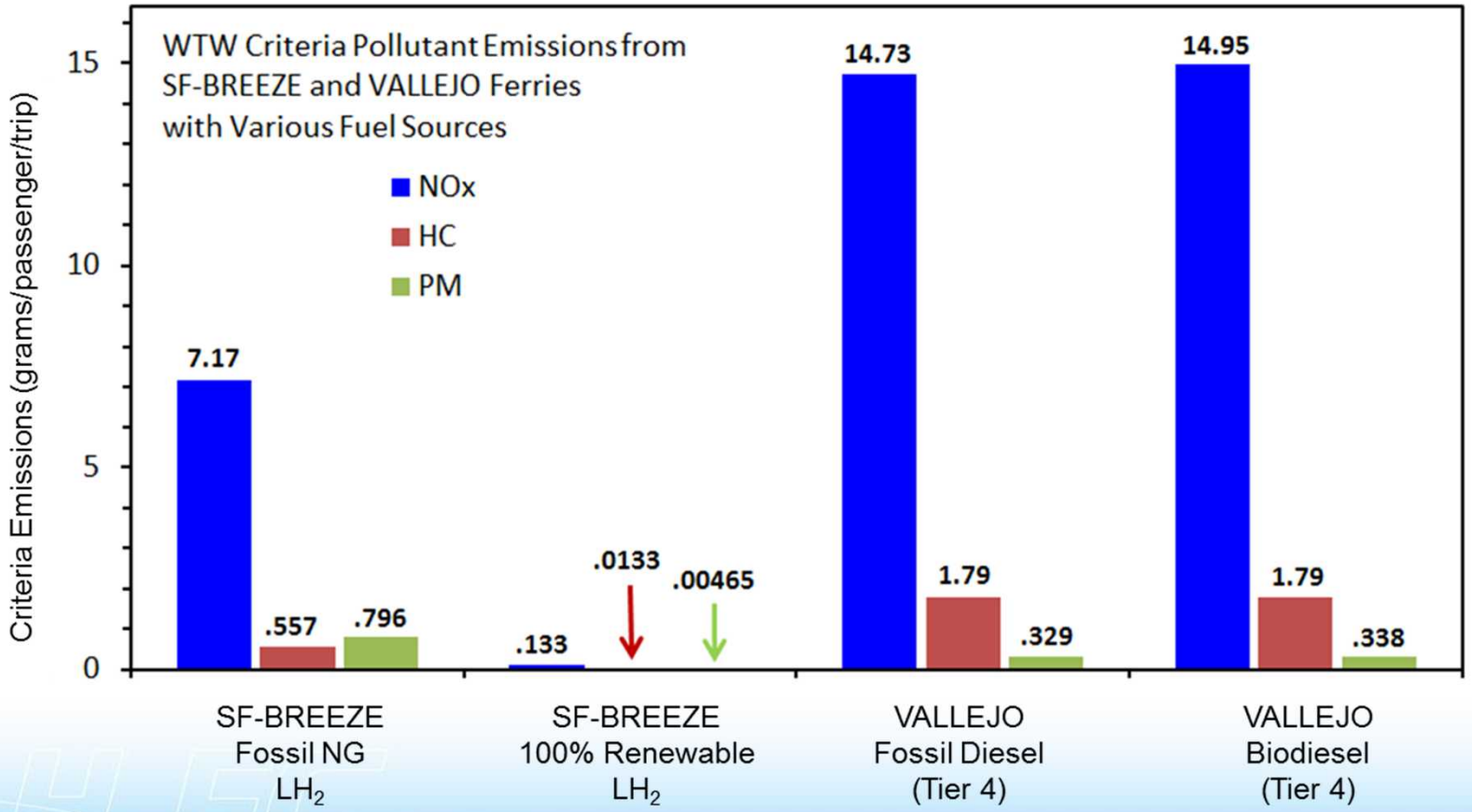
Air Emissions: Analysis, with comparison to the existing, similar sized ferry on the same route

SF-BREEZE
Top Speed: 35 knots
Power Plant: PEM fuel cells
Fuel: Liquid Hydrogen
Passenger Capacity: 150

Vallejo
Top Speed: 35 knots
Power Plant: Diesel engine
Fuel: Ultra low sulfur diesel
Passenger Capacity: 300

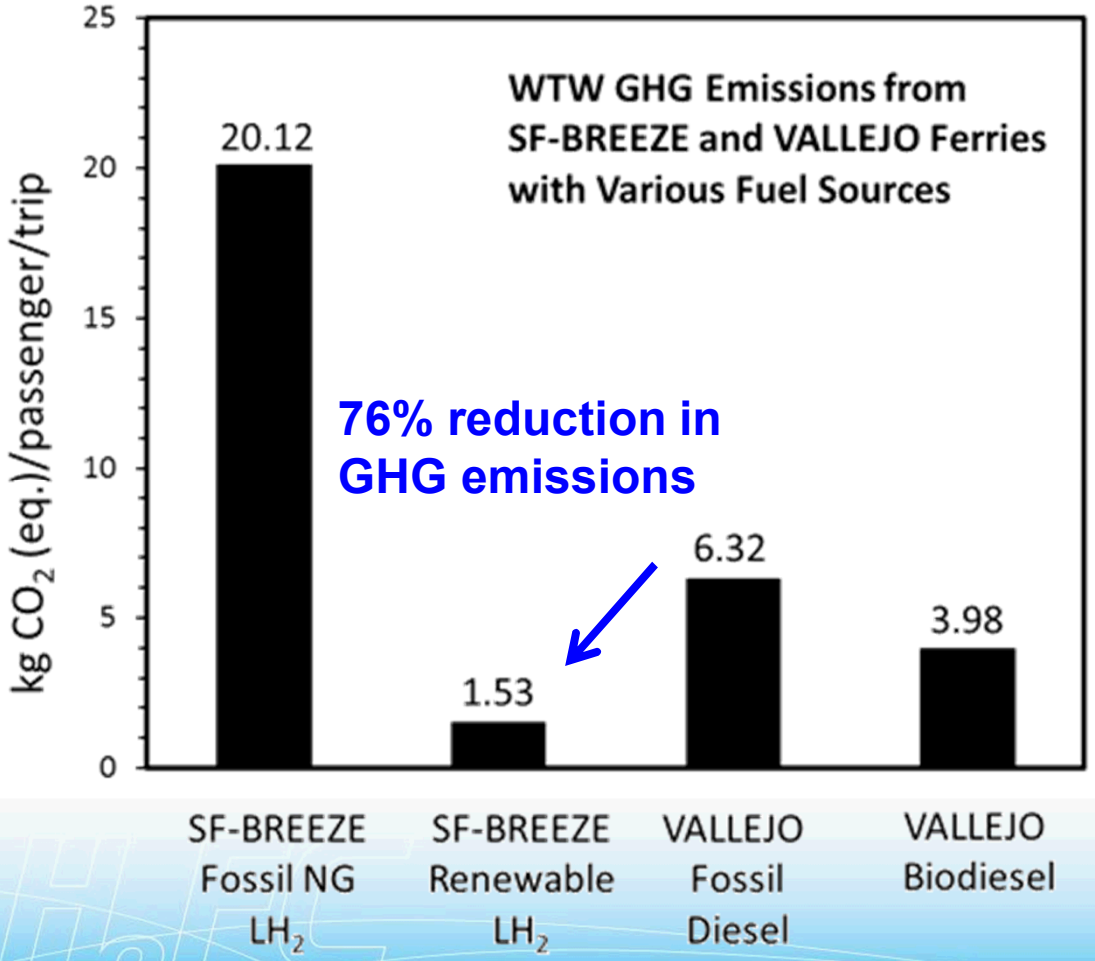
For this comparision, assume a "new-build" Vallejo diesel vessel held to Tier 4 criteria pollutant emission constraints.

The SF-BREEZE drastically reduces "Well-to-Waves" pollutant emissions compared to the most advanced (Tier 4) marine diesel ferries.



The SF-BREEZE has <u>zero</u> criteria pollutant emissions at the point of use

SF-BREEZE can achieve dramatic Well-to-Waves greenhouse gas (GHG) reduction with *renewable* LH_2



All SF-BREEZE emissions are due to the LH_2 production path; the SF-BREEZE is zero emission at the point of use

Renewable liquid hydrogen is available

Renewable methane

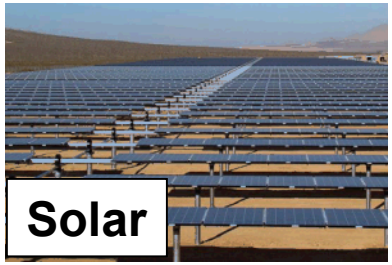
→ Reformation

H_2 ↓

Liquefaction → Renewable liquid hydrogen

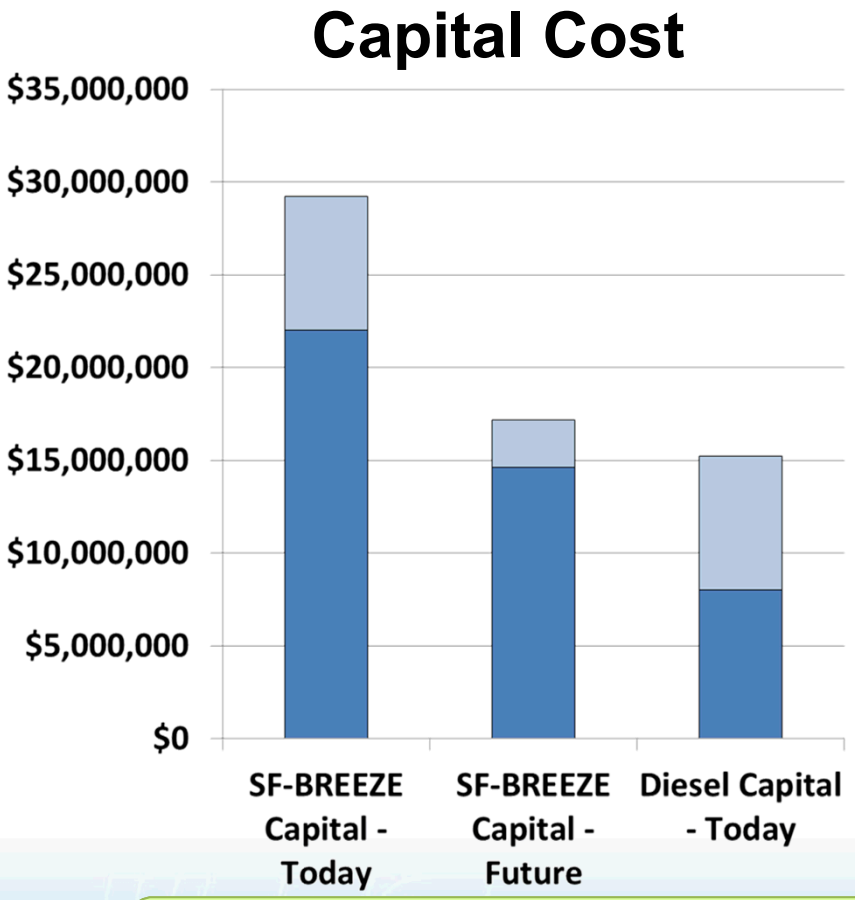
H_2 ↑

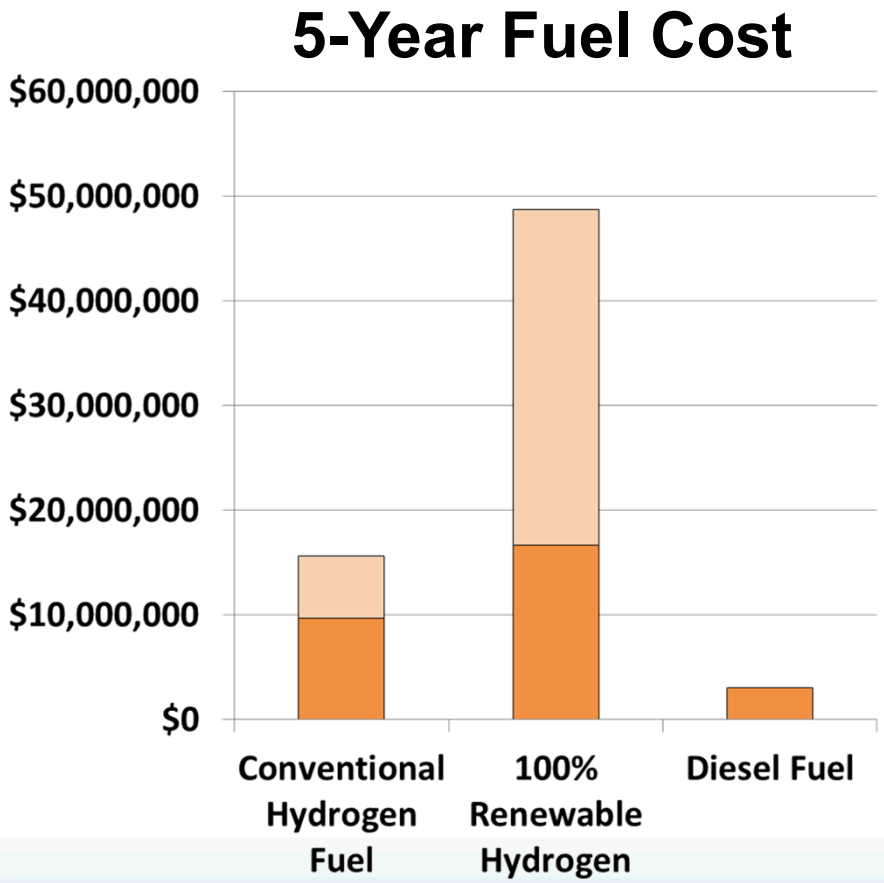
Renewable electricity



→ Electrolysis

The costs are currently higher than diesel with projected cost decreases ahead



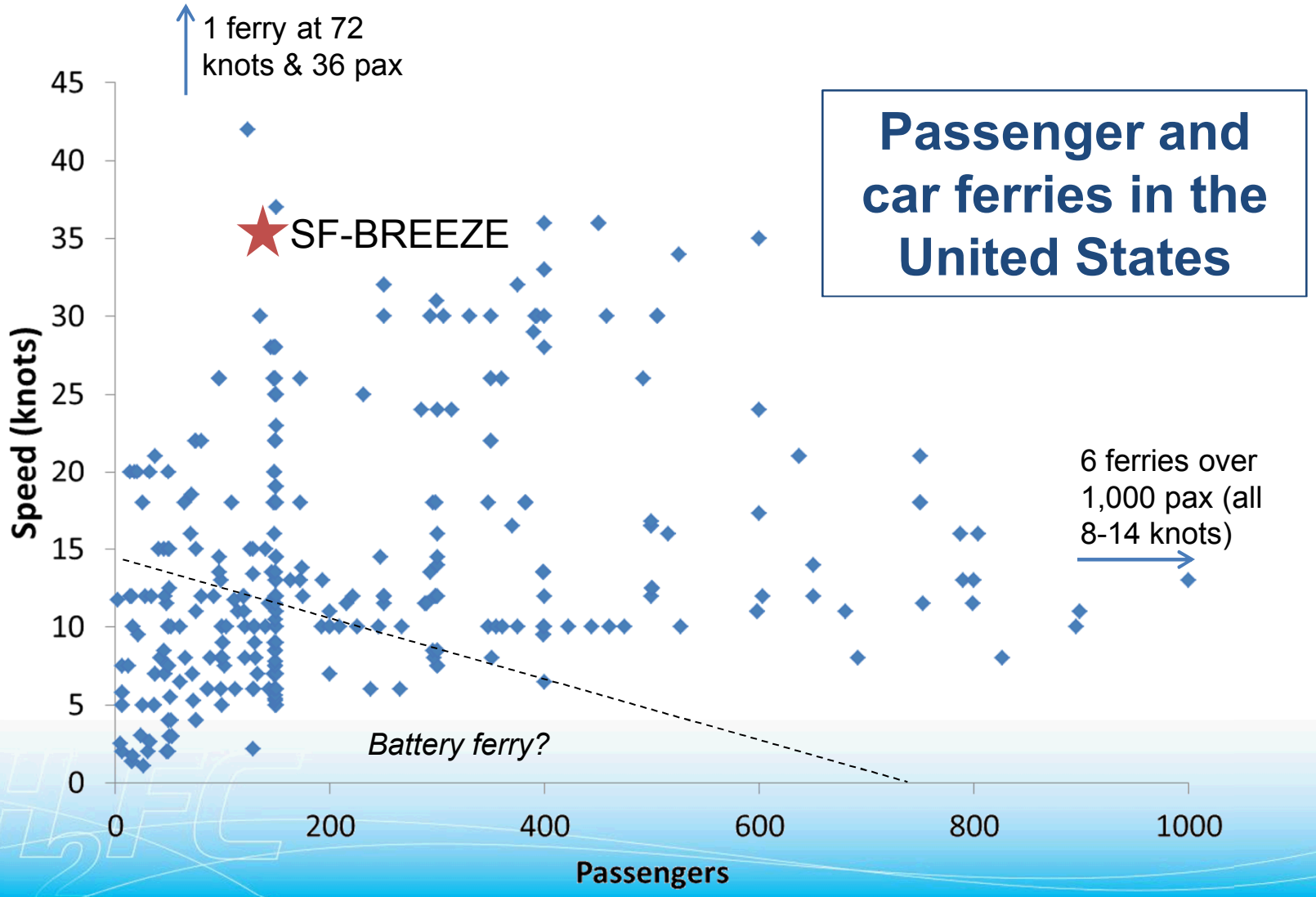


The decreased health risks and lower environmental impact saves our region **$2.6M - $11M** for each SF-BREEZE ferry built instead of a Tier 4 diesel ferry.

Summary

	Ferry	Hydrogen Station
Technical	✓	✓
Regulatory	✓	✓
Economic	*Higher than conventional now, today's market acceptance to be determined*	

What is the best type of zero emission ferry to build today?



Next Steps

Five project phases

Phase 1: Feasibility study (complete)*

Phase 2: Optimization of the vessel (starting)*

Phase 3: Detailed design of the H_2 ferry and station

Phase 4: Build the H_2 ferry and station

Phase 5: Operate the H_2 ferry and station

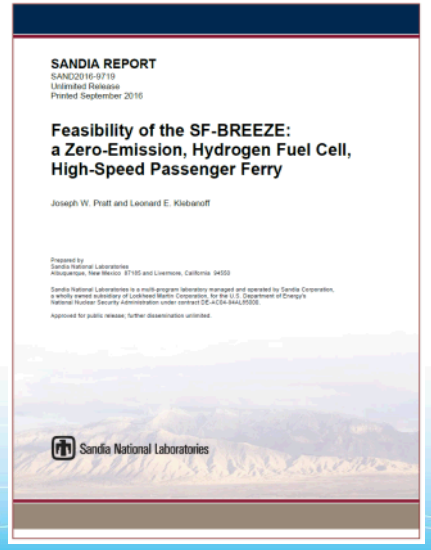
Phase 6: Extend to H_2 cars, buses and trucks

*Phases 1 and 2 funded by US DOT / Maritime Administration

Thank you!

SF-BREEZE Feasibility Study Final Report - Download from: **maritime.sandia.gov**

- All ferry design documents and drawings
- LH_2 fuel assessment (with comparison to LNG)
- Emissions
- Regulations
- Bunkering
- Economics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