Feasibility Study of a Zero-Emission High-Speed Hydrogen Fuel Cell Ferry (SF-BREEZE)

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SF-BREEZE:
San Francisco Bay Renewable Energy Electric Vessel with Zero Emissions
A progressive maritime passenger transportation company offering sightseeing cruises, ferries and charter service.

We are concerned about the effect of our vessels, and that of all maritime vessels, on the environment and on human health.

SF-BREEZE was inspired by DOT/MARAD and the work of Sandia National Labs.

We see this project as making a “stew.” We are not using meat, potatoes or carrots, but proven and commercially available technologies. Our hydrogen and equipment suppliers have been in business for decades.

“The taste of our “stew” will be zero pollution and I will drink the exhaust.” -- Tom Escher, President R&W Fleet
Sandia’s Hydrogen Program: Created in the 1960’s

 Hydrogen Production
 Develop concentrated solar power for large-scale, renewable production of hydrogen

 Hydrogen Storage
 Provide fundamental understanding of the phenomena limiting solid-state hydrogen interactions

 Hydrogen Delivery
 Identify pathways for reducing cost of steel hydrogen pipelines without compromising reliability and integrity

 Safety, Codes and Standards
 Facilitate safe deployment of hydrogen technologies with science-based codes and standards

 Fuel Cells
 Develop new membrane systems for enhanced electrochemical performance

 Systems Engineering
 Demonstrate innovative engineering solutions to harness clean energy technologies
Hydrogen 101

$H_2$ molecules barely interact at all

- Is typically a gas, but can be a liquid ($LH_2$) if made very cold (20 K).
- $LH_2$ evaporates very fast (4,000 gallons will evaporate in ~7 seconds)
- More buoyant than helium. Goes straight up at ~40 mph.

Overall, it is very similar to natural gas (which is ~ 90% methane, CH$_4$).

$H_2$ is NOT a Greenhouse Gas, unlike natural gas which is a potent GHG.

$H_2$ can be ignited given a ignition source and the right $H_2$/air mixture.

Hydrogen safety follows the same approach as natural gas: eliminate ignition sources and leaks.

**Storing hydrogen as $LH_2$ is the best way to minimize weight**
Liquid Hydrogen (LH$_2$) Has Been Used for Decades

A typical trailer can deliver 4000 kg (~15,000 gallons) at a time. (1 kg LH$_2$ = 3.72 gallons)

Trailer LH$_2$ tanks are DOT-approved, and the SF-BREEZE LH$_2$ tank is designed to the same durability spec.
The SF-BREEZE Employs Commercially Available 120 kW Proton Exchange Membrane (PEM) Fuel Cell Power Racks

\[ \text{H}_2 + \text{O}_2 (\text{air}) \rightarrow \text{H}_2\text{O} + \text{electricity} + \text{waste heat} \]
Goal of the Feasibility Study

To determine the technical feasibility, regulatory acceptance and economic impact of a high-speed, zero-emission hydrogen fuel-cell passenger ferry and associated fueling facility.

Result:

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<tbody>
<tr>
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**Project Concept**

**High-speed H₂ Ferry**
- Zero-emission Hydrogen Fuel Cell Power
- 150 passenger, 35 knots

**Dockside H₂ Station**
- Serving vessels, cars, buses and trucks
- 2,500 kg/day capacity & 80% base utilization

Engineering model of the SF-BREEZE

Existing dockside hydrogen station in Hamburg, Germany
Near-Term and Long-Term Impacts of Bringing $H_2$ Fuel-Cell Technology to Maritime Propulsion Power

- Eliminates diesel emissions (both GHG and criteria) and fuel spills.
- Dramatically decreases noise from the vessel, providing health benefits for operators, a better experience for the public and protects marine life from noise injury.
- Extends U.S leadership in hydrogen technology into the maritime application.
- Growth of U.S. shipbuilding capability and clean tech marine jobs.
- Large reliable customer jump-starts low-cost high-availability $H_2$ for both marine and ground transportation markets.
Our Project Team Integrates Ship Designers, Regulators, H₂ Experts and End Users

USCG MSC and Design and Eng. Stds.
USCG Sector San Francisco
USCG Liquid Gas Carrier NCOE
American Bureau of Shipping
Select a Demanding Route for the Feasibility Study: Vallejo-to-SF

- 23 nm one-way, 35 kts top speed
- Each round trip uses about 400 kg LH₂
- Daily logistics:
  - Two morning round trips
  - Refuel in less than 1 hr at noon
  - Two afternoon round trips
  - Refuel again at night
- Designing the ferry to meet the long distance of the Vallejo-SF route gives it maximum flexibility in eventual route choice.
Current SF-Breeze Design: Built to Subchapter T Specs

Design generated by Elliott Bay Design Group
Current SF-Breeze Design: Catamaran Hull Design

Upper Deck

Main Deck

Hulls
SF-BREEZE By The Numbers

- LOA 109’ x Beam 33’ x Depth 11.25’
- Full Load Draft ~ 4.6’
- Full Load Displacement ~133 LT
- Passengers: 150
- Service Speed: 35 knots
- Tonnage: 79.86 GRT
- LH₂ tank located on centerline (>B/5 from side)
- Propulsion power 4.4 MW, installed power 4.92 MW

**Emissions: ZERO**

**Fuel Spills: ZERO**
SF-BREEZE Weight

Total vessel weight: 297,977 lb
Refueling with Liquid Hydrogen (LH$_2$)

1,200 kg (~4,800 gallons) LH$_2$ tank

The ferry uses LH$_2$ because it is currently the lightest and most compact method to store large amounts of hydrogen, and operates at low pressure.

LH$_2$ bunkering will look a lot like current LNG bunkering because the fuels are so physically similar.
SF-BREEZE Eliminates Criteria Pollution. GHG Emissions Dramatically Reduced Using Renewable LH₂

Criteria emissions prevented for each trip (assuming Tier 4 Diesel Technology):

- 0.21 kg of PM
- 7.11 kg of NOₓ
- 1.14 kg of HC

--- criteria pollutants eliminated regardless of source of LH₂

All SF-Breeze GHG emissions are due to LH₂ production path; the SF-Breeze is Zero Emissions at the point of use.
North American LH$_2$ Production and Distribution Infrastructure is Sufficient for SF-BREEZE

- US and Canada liquid hydrogen production: 295 metric tons/day
- SF-BREEZE consumption: 2 metric tons/day

We need renewable LH$_2$ to achieve the GHG reduction goals

$H_2$ suppliers can provide renewable LH$_2$ to support the SF-BREEZE
“There is evidence that the greatly increasing use of the fossil fuels, whose material contents after combustion are principally $H_2O$ and $CO_2$, is seriously contaminating the earth’s atmosphere with $CO_2$. Since $CO_2$ absorbs long-wavelength radiation, it is possible that this is already producing a secular climatic change in the direction of higher average temperatures. This could have profound effects both on the weather and on the ecological balances.”

-- M. King Hubbert

-- from “Energy Resources”, a 1962 Report to the Committee on Natural Resources of the US National Academy of Sciences, page 96
The world population was 1.75 billion in 1910, compared to today’s population of 7.3 billion.

We need deep, deep cuts in GHG emissions to impact the global climate change problem.

-- increases in global temperature date back to ~ 1910
Pier 54 is Preferred by the Port of SF for a Refueling Station Serving Both the SF-BREEZE and Fuel Cell Cars
Co-location with Hydrogen Vehicle Fueling Station Gives Synergistic Benefits

Benefits to the vessel
- Zero wasted hydrogen – cool down hydrogen captured for vehicle use
- Funding of station possible from “vehicle” funding initiatives.

Benefits to the vehicles
- Potentially lower-cost hydrogen for the vehicle (10%-20%) due to large vessel H₂ demand.
- Jump starts renewable hydrogen nationwide

Linking maritime and land transportation modes achieves maximum technical, economic, and zero emission benefits.
SF-BREEZE is Undergoing Regulatory Review

- EBDG submitted design package to USCG and ABS on February 18, 2016.
  - Design Study Report
  - General Arrangement
  - Hazardous Zones
  - Bunkering Procedure
  - Risk Assessment
  - Speed and Powering, Weight Estimate, Tonnage
- ABS status: Approval in Principle issued on 4/13/16. POC: Emil Shtaygrud
- USCG status: under technical review. Design comments are imminent.

Approval in Principle Letter issued by ABS, no show-stopping problems identified.
Summary of Feasibility

- SF-BREEZE can meet 35 kts speed target and the 23 nm range target while carrying 150 passengers.
- H₂ Station serving SF-BREEZE and FCEV can be placed on Port of SF Property at Pier 54. Port of SF enthusiastically endorses H₂ station.
- USCG and ABS have identified no show-stopping regulatory issues with the SF-Breeze design.
- Large reductions in GHG emission possible using renewable H₂.

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Next Steps

For Sandia:

- Review pending USCG input from design review.
- Determine the optimal SF-Breeze design, size, speed and route to reduce per passenger energy use, GHG emissions and cost.
- Explore usage of fuel cell technology in other maritime applications.
- Provide assistance to commercial partners in H₂ technology use.

For Red and White Fleet and other Partners:

- Secure funding for the SF-BREEZE and H₂ Station.
- Build the SF-BREEZE and H₂ Station in collaboration with SF Port.
- Operate the SF-BREEZE and H₂ Station.
Core Project Team

L-R: Joe Pratt (Sandia, project lead), Kelly Sonerholm (EBDG), Tom Escher (RWF), Lennie Klebanoff (Sandia), Curt Leffers (EBDG), John Waterhouse (EBDG), Russ McComb (EBDG), Joe Burgard (RWF).

Special thanks to Cadet Dave Kramer of the US Naval Academy, summer intern at Sandia
An extra special Thank You to Sujit Ghosh and the US DOT / Maritime Administration (MARAD) for supporting the SF-BREEZE feasibility study.
Thanks to our sponsor, support network and friends!
(137 people from 47 organizations)
You are invited to the Ribbon Cutting Ceremony of the SF-BREEZE on March 17, 2018, 10:00am at Pier 54, the Port of San Francisco

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