

# San Francisco Bay Area Renewable Energy Electric Vessel with Zero Emissions (SF-BREEZE) Feasibility Study: *Regulatory, Fueling, and Economic Aspects*

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Sandia National Laboratories  
Passenger Vessel Association  
Green Waters Conference  
Washington, DC  
January 24, 2016



# Regulatory



# The project team includes designers, regulators, national experts, and class society working together.



*USCG MSC and Design and Eng. Stds.*



*USCG Sector San Francisco*



*USCG Liquid Gas Carrier NCOE*



*American Bureau of Shipping*



# Recent developments in LNG shipping are helping – In general, LNG and liquid hydrogen (LH<sub>2</sub>) are similar



**INTERNATIONAL  
MARITIME  
ORGANIZATION**

**E**

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MARITIME SAFETY COMMITTEE  
95th session  
Agenda item 22

MSC 95/22/Add.1  
19 June 2015  
Original: ENGLISH


**REPORT OF THE MARITIME SAFETY COMMITTEE ON ITS  
NINETY-FIFTH SESSION**

Attached is annex 1 (Resolution MSC.391(95) – Adoption of the International Code of Safety for Ships Using Gases or other Low-Flashpoint Fuels (IGF Code)) to the report of the Maritime Safety Committee on its ninety-fifth session (MSC 95/22).

**IMO IGF  
Code**

**U.S. Department of  
Homeland Security**


**United States  
Coast Guard**



Commandant  
United States Coast Guard


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Washington, DC 20583-7509  
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16715  
CG-OES Policy Letter  
No. 02-15  
**FEB 19 2015**

From:  R.E. Bailey, CAPT  
COMDT (CG-OES)

To: Distribution

Subj: GUIDANCE RELATED TO VESSELS AND WATERFRONT FACILITIES  
CONDUCTING LIQUEFIED NATURAL GAS (LNG) MARINE FUEL TRANSFER  
(BUNKERING) OPERATIONS



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GUIDE FOR

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**PROPULSION AND AUXILIARY SYSTEMS FOR GAS  
FUELED SHIPS**

**ABS Guidance**

**USCG Policy Letters**

**... and many others!**

# Design Basis

Principle regulation governing the design of the vessel:

## ➤ 46 CFR Subchapter T – Small Passenger Vessels

Other documents are used as guidance, since no official regulations yet exist which specifically apply to a hydrogen powered, high speed, aluminum ferry.

- ✓ IMO MSC 95/22/Add.1 (Adopted IGF Code)
- ✓ IMO CCC 2/3/1 (IGF Code with Fuel Cell Additions)
- ✓ ABS Guide for Propulsion and Auxiliary Systems for Gas Fueled Ships
- ✓ ABS Rules for Building and Classing High-Speed Craft
- ✓ IEC 60092-502 Electrical Installations on Ships
- ✓ IEC 60079-10 Electrical Apparatus for Explosive Gas Atmospheres
- ✓ 46 CFR Subchapter J – Electrical Engineering
- ✓ 46 CFR Subchapter F – Marine Engineering
- ✓ ASME B31.12 Hydrogen Piping and Pipelines
- ✓ ANSI/CSA America FC1-2004 Stationary Fuel Cell Power Systems

## Despite all of these resources, some areas are not appropriately addressed for aluminum, LH<sub>2</sub> ferries.

Some areas of the design appear to be non-compliant:

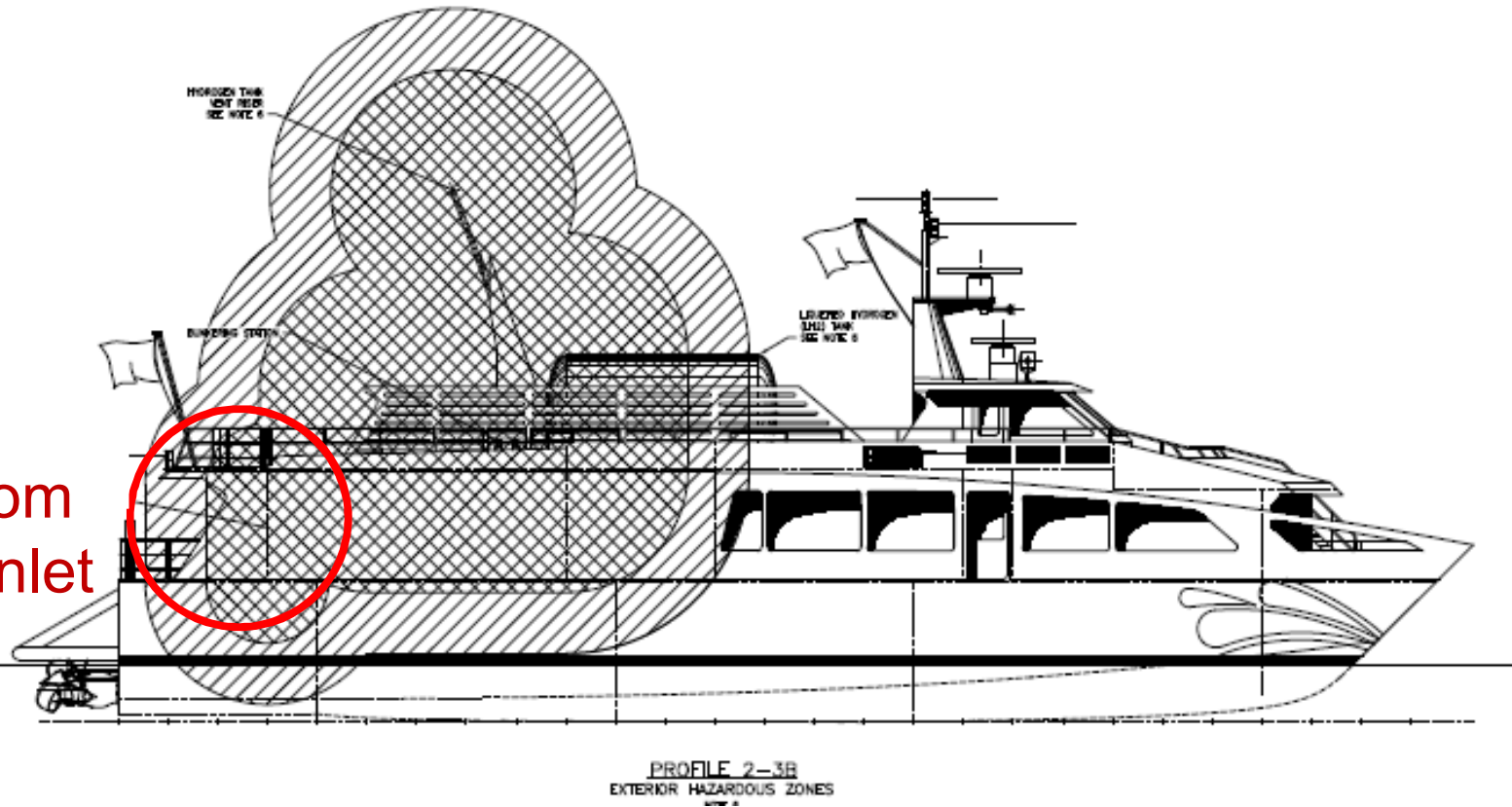
- Hazardous Zones
- Structural Fire Protection
- Hydrogen Piping

The design team is working with the regulators to allow these exceptions based on:

- The differences between LNG and hydrogen
  - Existing guidance considers LNG and/or bulk cargo
- The application (small passenger ferry in inland waterways).
  - Existing guidance based on SOLAS-type – ocean-going, single screw ships

**The goal of everyone involved is to establish what makes sense for this and future LH<sub>2</sub> vessels**

## Example: Hazardous Zones

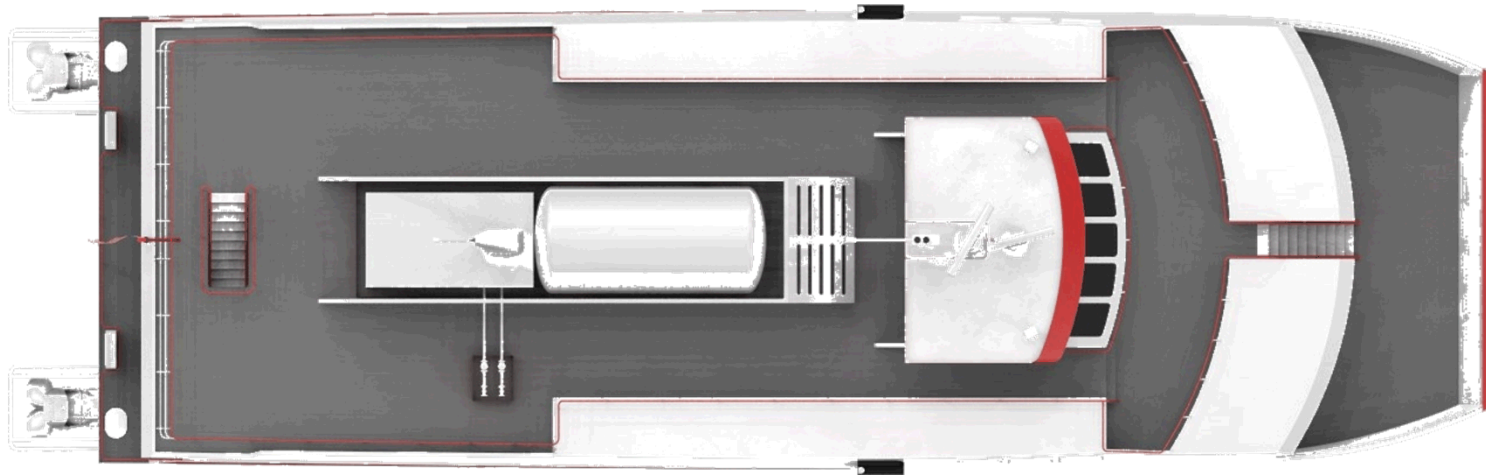


Fuel cell room  
ventilation inlet  
location in  
conflict with  
IGF 13.3.5

Based on the buoyant and evaporative properties of hydrogen, it isn't practical for the hazardous zones from equipment on the upper deck to extend down to the main deck.

## Example: Structural Fire Protection

IGF Code requires boundaries to be shielded with A60 class divisions. This adds a burden on the ferry's weight.



Analysis shows that if the entire contents of the hydrogen tank were spilled and ignited, the resulting fire would be in the air above the deck and would last for less than 10 seconds. The aluminum deck would actually become cooler in the process.

The A60 requirement is not necessary in this case.

**8. These effects are due to the unique properties of hydrogen.**

# Regulatory Gap Analysis

The gap analysis looked at 68 different design aspects. Of those:

- 11 are addressed by the current Sub T regulation (all others are addressed by the other guidance documents mentioned above)
- 62 areas are fully compliant with the full range of design basis documents
- 3 areas have been identified for recommended changes specific to hydrogen

Through teamwork, no regulatory issues have become show-stoppers. Regulators have been proactively helping to resolve issues with future hydrogen vessels in mind.

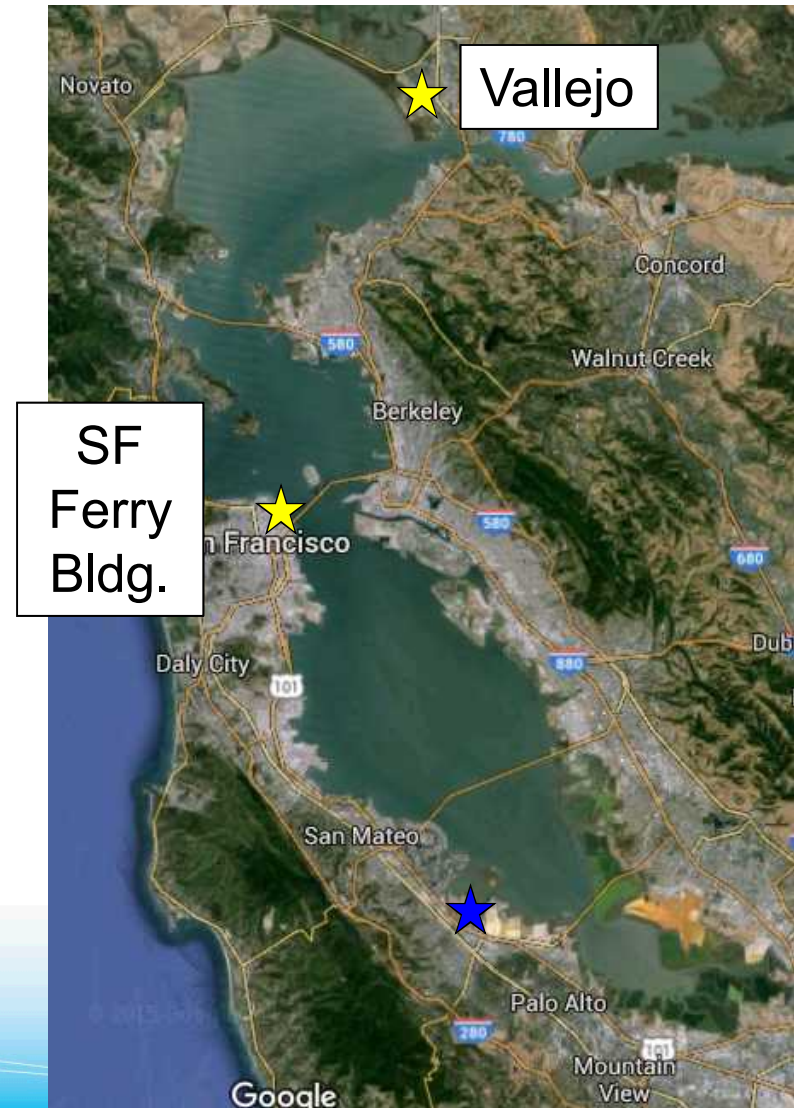


# Fueling



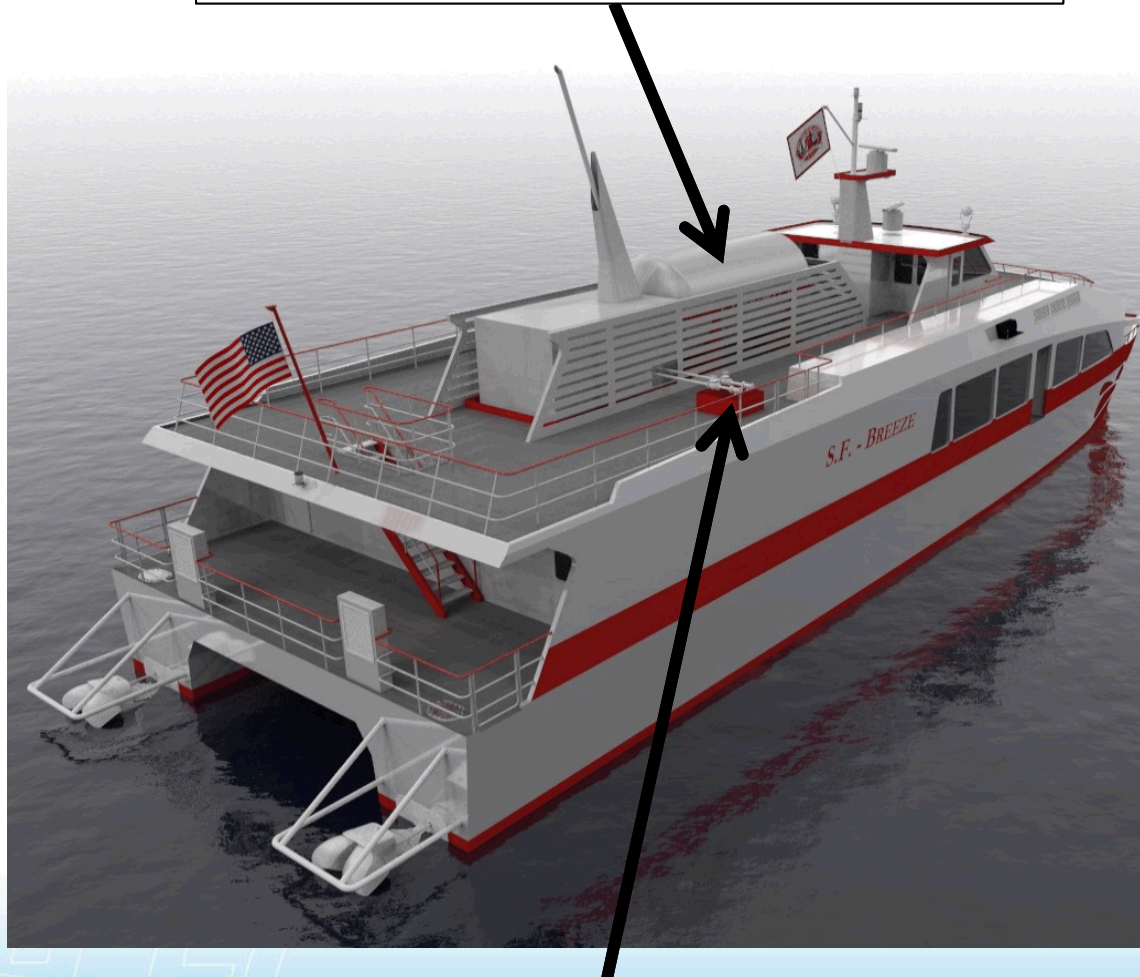
# Operating logistics

- 23 nm one-way
- Each round trip uses about 500 kg LH<sub>2</sub>
- Daily logistics:
  1. Two morning round trips
  2. Refuel in less than 1 hr.
  3. Two afternoon round trips



# Ferry Fueling Characteristics

1,200 kg (~4,800 gallons) LH<sub>2</sub> tank



Bunkering connection

*The ferry uses **liquid** hydrogen because it is currently the **lightest and most compact** method to store hydrogen, and operates at low pressure*

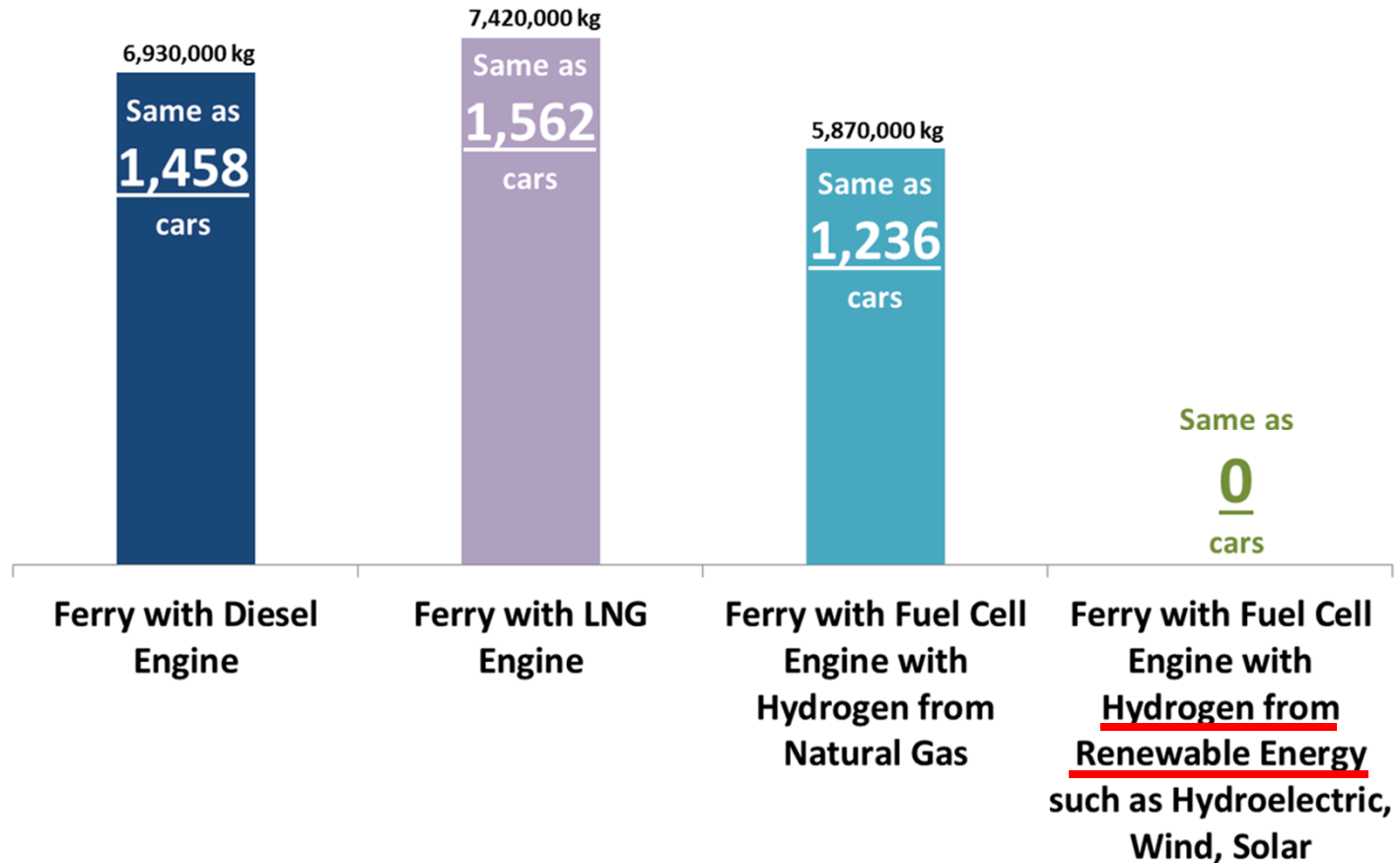
# LH<sub>2</sub> has been routinely handled and transferred between tanks for decades



Project team witnessing local LH<sub>2</sub> transfer (by Linde)

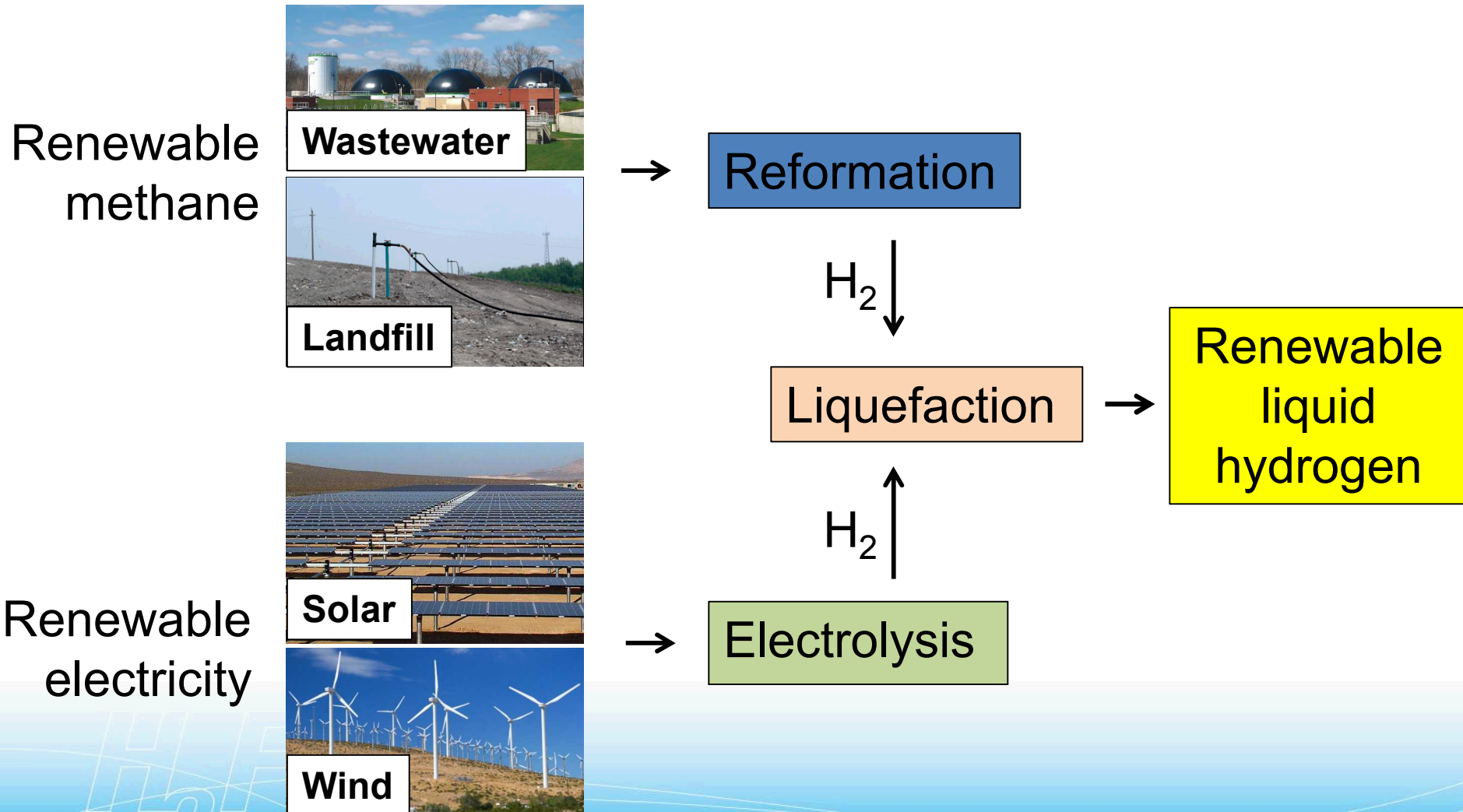
# Use of *renewable* hydrogen can completely eliminate the greenhouse gas emissions from vessels

Yearly Greenhouse Gas Emissions from one ferry with the same power and energy use as the SF-BREEZE, operating 300 days/year

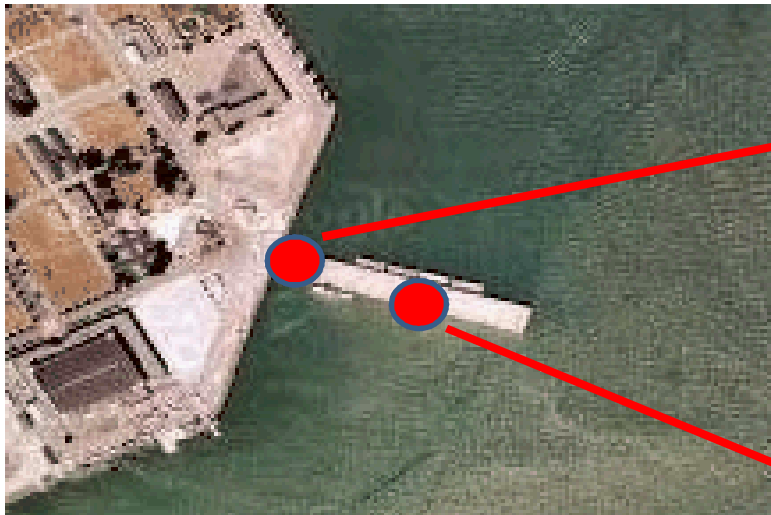


A ferry with a Fuel Cell Engine also has zero pollutant emissions (NO<sub>x</sub> (smog), SO<sub>x</sub> (sulfur/acid rain), particulate matter (soot), carbon monoxide)

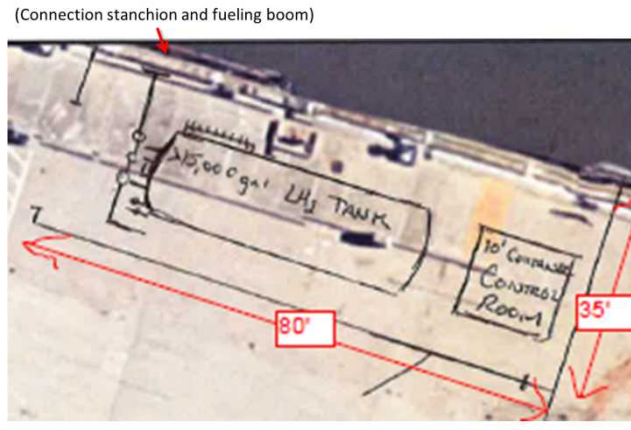
# Renewable liquid hydrogen is available. The cost is higher than non-renewable hydrogen.



# Layout of the fueling facility is flexible and can be adapted to the site.



For refueling fuel cell cars, buses and trucks (400 kg/day)



For refueling the SF-BREEZE ferry (2,000 kg/day)

The station's high throughput can reduce the hydrogen cost for the ferry and the vehicles.

All facility components are commercially available.

## Process will be similar to LNG bunkering



(1) Shoreside storage tank (or refuel directly from truck).

(2) Piping and connecting the fueling arm



(3) Transferring the fuel

(4) Underway



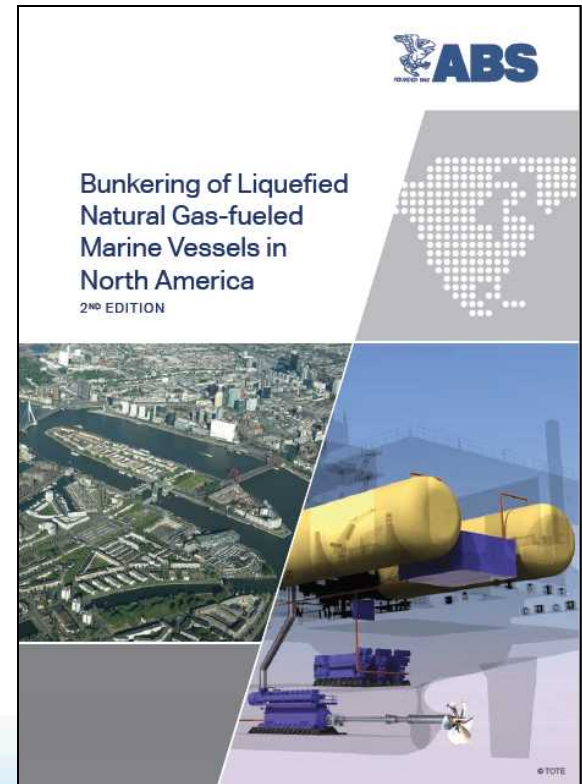
See complete video at:  
[youtu.be/oZWuTWtp5Rs](https://youtu.be/oZWuTWtp5Rs)

### Important difference between LH<sub>2</sub> and LNG:

Hydrogen is non-toxic and is not a greenhouse gas. If vented or spilled it quickly and completely evaporates with no harm to personnel or the environment.

# Regulations are only indirectly related; guidance notes for LNG bunkering are used along with LH2 supplier expertise

1. ABS, "LNG Bunkering: Technical and Operational Advisory".
2. ABS, "Bunkering of Liquefied Natural Gas-fueled Marine Vessels in North America".
3. USCG, "Guidance Related to Vessels and Waterfront Facilities Conducting Liquefied Natural Gas (LNG) Marine Fuel Transfer (Bunkering) Operations".
4. USCG, "Guidelines for Liquefied Natural Gas Fuel Transfer Operations and Training of Personnel on Vessels Using Natural Gas as Fuel"
5. 46 CFR 154 - Safety Standards for Self-Propelled Vessels Carrying Bulk Liquefied Gases



# Economics



## Factors being considered in the economic analysis: *Ferry*

- Ferry design and build cost
  - Similar to high speed aluminum diesel vessels, with increase due to higher cost of LH<sub>2</sub> and fuel cell systems.
  - Determined by designer and builder
- Ferry operating cost
  - Estimated from existing operations including any difference between diesel engine and fuel cell O&M.
- Ferry revenue
  - Estimated from existing route/fare structures in the SF Bay



# Factors being considered in the economic analysis: *Hydrogen Fuel*

- Hydrogen station design and build cost
- Hydrogen fuel cost

## Variables:

- Type of hydrogen (conventional or renewable)
- Hydrogen supply arrangement
  - Project builds and maintains the station, pays for LH<sub>2</sub> deliveries
  - Hydrogen Purchase Agreement: third party owns and operates the station, delivers LH<sub>2</sub> into ferry tanks with an “all-in” cost.



Existing dockside hydrogen station in Hamburg, Germany

## **Factors being considered in the economic analysis: *Grants, Loans, and other financial assistance***

- Federal grants for public transit agencies
- The Federal Ship Financing Program (Title XI)
- State (CA) grants for clean emissions, off-road passenger transport
- State (CA) grants for hydrogen infrastructure development
- State (CA) loans for clean energy project
- Private sector funding

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## Interested in Zero Emission Hydrogen Vessels?

Be a part of the growing community!

Join us in February for the

Inaugural **Zero Emission  
Hydrogen Vessel Workshop.**

To be notified of the event or  
become part of the working group,  
contact Tom or Joe.



A special Thank You to the US DOT / Maritime  
Administration (MARAD) for funding the feasibility study