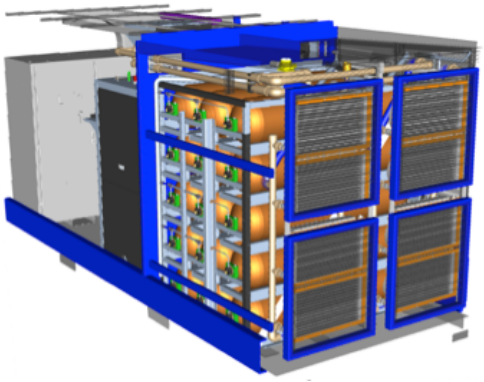
# Maritime Hydrogen Fuel Cell

## Safety Features Integrated into Design and Use of System

### Safety is the First Priority

The project team completed a number of overlapping safety methods to assure the safety of individuals operating and in proximity to the hydrogen fuel cell including:

- Failure Mode Effects Analysis (FMEA) which identifies potential failure points and devises ways to mitigate them (engineered and administrative/operational controls).
- Independent review and approval of the design by the Hydrogen Safety Panel and the US Coast Guard, and informational review by the American Bureau of Shipping.
- Special consideration of how Young Brothers, Ltd. intends to use the generator.



*The fuel cell generator's design has been independently reviewed and approved by the US Coast Guard and the Hydrogen Safety Panel.*

### Generator Safety Features

Using the FMEA results, a number of safety features or engineered controls were built into the final design based on these core principles:

1. Not allowing accumulation of a hazardous amount of hydrogen.
2. Minimizing stored energy and ensuring releases are non-hazardous.
3. Preventing damage by external events.

The generator's safety features are listed below *(with the design principle(s) addressed in parenthesis)*.

- Redundant hydrogen and smoke detectors shut down the system and sound a loud audible alarm if a leak or fire is detected. These detectors can be left on when the generator is not running. (1)
- Everytime the generator is started, multiple automated hydrogen leak checks occur. The system shuts down if leaks are detected.(1)

*One safety feature of the generator is to have redundant hydrogen sensors, including the one shown here, which automatically shut down the generator and close all hydrogen tanks as soon as a hydrogen leak is detected.*

- Constant forced-air ventilation throughout the generator room with automatic shutdown in case of ventilation failure. (1)
- Automated hydrogen tank valves require power to open. Any power failure or emergency stop causes these valves to immediately close. (1)
- Two open sides and a slanted roof in the hydrogen storage area provide passive ventilation and dissipation of leaks. (1,2)
- Fire-wall separation of the hydrogen storage from the generator room. (1, 2)
- Five fail-closed valves must be open before hydrogen can reach the fuel cell. (1,2)
- Flow-restricting orifice reduces hydrogen leakage in case of pipe breakage. (1,3)
- Minimized high pressure hydrogen piping, including zero high pressure piping in the generator room. (2)
- Redundant pressure safety devices prevent high pressure from reaching the low pressure piping or the generator room. (2)

- Hydrogen tanks have thermal pressure relief devices that open if a fire is detected, eliminating possibility of tank explosion. (2)
- Ultracapacitor is automatically discharged whenever the unit is turned off. (2)
- Hydrogen releases are directed upward and away from personnel. (2)
- The operator interface is on the far end away from the hydrogen storage area. (2)
- The hydrogen storage tanks are the same used in hydrogen fuel cell cars / buses and built to withstand impact. (3)
- Reinforced sides reduce the chance of a forklift piercing the container wall. (3)
- The container's fork pockets are closed and the container must be mounted on a platform or handled with a top-pick. (3)

## Operational Safety Controls

Leveraging Sandia's expertise in hydrogen system risk analysis coupled with Hydrogenics' commercial product design experience, a safety plan for use and handling of the fuel cell generator was defined. This plan identified operational scenarios specific to Young Brothers, Ltd. including: damage to the generator by forklift, blockage of the ventilation system by other containers, and discharge of hydrogen out the relief valve vents.

Site-specific administrative controls were added to the safety plan including these controls:

- Handling with a forklift is acceptable, handling with a top-pick is preferred as it will reduce the likelihood of damage that results in equipment downtime.
- Allow at least two feet of separation between the generator's access door side and adjacent container or structure when operating.
- Workers can transit the zone of potential hydrogen release (see chart and table) but if individuals need to linger within the zone then the generator should be re-oriented.
- In the case of fire in or around the generator, workers should not enter the zone of potential hydrogen release.

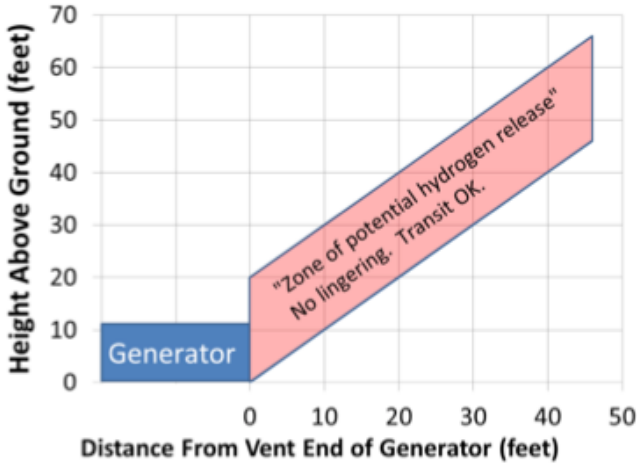



*Chart showing the zone of potential hydrogen release from the end of the container with the relief valve vents.*

| If someone is lingering this far away from the container… | They should be lower than… | Or higher than… |
|---|---|---|
| 0 feet | should not linger under the vent openings | 20 feet |
| 10 feet | 10 feet | 30 feet |
| 20 feet | 20 feet | 40 feet |
| 30 feet | 30 feet | 50 feet |
| 40 feet | 40 feet | 60 feet |
| 50 feet | N/A | N/A |

*Table showing recommended locations for personnel lingering directly off the relief vent end of the generator.*

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