APPENDIX D. HYDROGEN QUICK RESPONSE GUIDE

D.1 Overview of Spill Characteristics, Properties, Behaviors, and Hazards

Table D-1, Table D-2, and Table D-3 provide a high-level overview of hydrogen spill characteristics, properties, behaviors, and hazards.

Table D-1. Hydrogen spill characteristics (Kass et al., 2021).

Behavior when Spilled	Dissipation or Degradation Rate	Ecological Impacts	Flammable / Explosion Risk	Toxicity	Air Displacement and Suffocation Risk to Crew	Spill Cleanup
Will form a cold cloud on the water surface	Fast	No long term impacts, but marine life at the water surface in the spill zone may suffocate or become chilled	High	Low	Possible	Will dissipate before cleanup can begin

Table D-2. Summary of key hydrogen properties and behaviors (ITOPF, 2024c).

	Properties	Behavior
Boiling Point	-253 °C	At ambient conditions, hydrogen is a gas.
Liquid Specific Gravity (@ -253 °C)	0.071	Hydrogen is approximately 14 times less dense than water; therefore, as a liquid, liquid H_2 will float if spilled on water.
Gas Specific Gravity (@ -253 °C)	1.34	Saturated vapor is heavier than air and will remain close to the ground until the temperature rises.
Vapor Specific Gravity (@ ambient temp)	0.067	Vapors of hydrogen at ambient conditions are significantly lighter than air (buoyant) and will easily disperse in open or well-ventilated areas.
Solubility	Insoluble	Hydrogen will not mix with water (run-offs) or seawater.
Flammability Range	4.0 - 75 (v/v) %	Hydrogen/air vapor mixture has an extremely large flammability range.

Table D-3. High-level overview of hazards associated with hydrogen (ITOPF, 2024g).

State		Longevity in the Environment	Toxicity to Humans	Health & Safety: Main Concerns	Protracted Response to Recover Pollutant
Under Ambient Conditions	During Transport				
Gas	Liquid (cryogenic), or pressurized gas	Hours	Non-toxic	Significant risks linked to flammability & explosivity	Unlikely

D.2 Responder Safety Considerations

Hydrogen, whether stored as a compressed gas or cryogenic liquid, presents hazards that require specialized response protocols. It is colorless, odorless, and burns with a nearly invisible flame, making detection and hazard recognition challenging during an incident.

Responders must conduct operations from upwind, with continuous atmospheric monitoring in place.

Responders should use flame detection systems or thermal cameras to locate active fire zones.

Principal hazards include:

- Flammability and explosion risk: Hydrogen has a very wide flammability range (4 - 75% by volume in air) and a very low ignition energy, making it prone to ignition from static discharge or minimal heat sources.
- Asphyxiation risk: High concentrations of hydrogen in enclosed or low-lying areas can displace oxygen and lead to suffocation.
- Cryogenic exposure (liquid hydrogen): Contact with liquid hydrogen or supercooled surfaces can result in severe frostbite and material embrittlement.
- Invisible flame hazard: Hydrogen flames emit little to no visible light, which may lead to accidental entry into burning zones.

Personal Protective Equipment (PPE):

- Thermal protective clothing and self-contained breathing apparatus (SCBA).
- Mandatory use of intrinsically safe equipment.

Training in hydrogen-specific hazards is essential, especially regarding safe approach techniques, early signs of cryogenic injury, and monitoring of confined spaces. First responders will need specialized training for responding to incidents involving hydrogen.

D.3 Detection and Monitoring

Table D-4 shows how effective existing detection methodologies are for identifying hydrogen.

Table D-4. Summary of detection methodologies for hydrogen (Kass et al., 2021).

Visible	Radar	Infrared	Fluorescence	Chemical Analysis
Yes, will form a cold cloud on the water surface that will quickly dissipate	No	Potentially yes, depends on temperature reduction of ship and water surface	No	Yes, but only by sampling surface airspace

Due to hydrogen's physical properties, detection relies heavily on gas-specific sensors and optical detection systems. Conventional gas detectors (e.g., catalytic bead sensors) are insufficient alone due to hydrogen's wide flammability range and low ignition threshold. Electrochemical and thermal conductivity sensors are better suited for hydrogen-specific monitoring.

Hydrogen flames are not visible in daylight and, while potentially more visible at night, may require ultraviolet/infrared (UV/IR) flame detectors or thermal imaging cameras to locate fires. Portable hydrogen detectors should be deployed at varying heights to identify accumulation zones, particularly in roof spaces or enclosures where hydrogen may rise and concentrate.

Continuous air monitoring is essential in enclosed or partially enclosed spaces. Uncrewed aircraft systems (UAS) equipped with thermal and gas sensors can support hazard zone mapping. All readings must be used to inform exclusion zones and safe approach strategies.

D.4 Fire Fighting

Hydrogen fires require both a passive and defensive approach. In most cases, the safest method is to isolate the fuel source and allow the hydrogen to burn off in a controlled manner. If the fuel flow can be stopped safely, the fire may self-extinguish.

- Small hydrogen fires – use dry chemical extinguishers.
- Large hydrogen fires – dry chemical extinguishers not typically effective. Apply water spray to cool surrounding equipment/structures but must not be directed at hydrogen leak source due to vapor cloud expansion risk.

Concerns/considerations:

- Responders must assume the flame is invisible unless confirmed extinguished via thermal imaging.
- Fire crews must maintain communication with command and use designated entry points monitored by safety officers.

D.5 Spill Response

Hydrogen spill response is primarily atmospheric in nature due to its gaseous state at ambient conditions. In the case of cryogenic hydrogen release, response must also address risks associated with extreme cold and potential for rapid phase transition.

Immediate actions include establishing exclusion zones, securing ignition sources, and conducting atmospheric monitoring to track plume movement. Since hydrogen rises rapidly, outdoor releases will typically disperse upward unless trapped under structures or within enclosed spaces.

In cases involving liquid hydrogen, responders should anticipate localized pooling and rapid vaporization upon contact with surfaces or seawater. This may generate pressure waves or physical damage due to rapid phase transitions.

Ventilation should be maximized in any structure that may trap gas. Indoor spills require immediate evacuation and atmospheric clearance verification before reentry. Emergency shutoff valves should be activated to prevent further fuel discharge.

Mechanical containment is not feasible. As hydrogen disperses quickly, response efforts should focus on risk isolation and hazard area control rather than fuel recovery.

D.6 Environmental Impacts

Hydrogen poses minimal long-term environmental impact. It is non-toxic, does not bioaccumulate, and reacts quickly in the atmosphere to form water vapor. There is no known adverse effect on aquatic ecosystems from gaseous hydrogen release.

In the event of a liquid hydrogen release into seawater, localized freezing and thermal shock may affect marine organisms, similar to the cryogenic hazards posed by LNG. However, due to the rapid vaporization and upward dispersion of hydrogen, the duration of environmental exposure is short.

The main environmental concern is the potential for fire or explosion, not chemical contamination. Infrastructure exposed to liquid hydrogen may experience structural damage due to cold embrittlement or pressure wave impacts from rapid expansion.

Environmental monitoring following an incident is generally limited to confirmation of system integrity and, if applicable, evaluation of infrastructure damage. Restoration actions are not likely to be required.