Reporting Case5
Hydrogen bunkering

WP5 Veiligheidsaspecten en risico's

Dit project is medegefinancierd door TKI Nieuw Gas | Topsector Energie
uit de PPS-toeslag onder referentienummer TKI2019 WVIP

NLHydrogen

November 2023, status: TECdef/SGinf

Introduction

The objective of WVIP work package 5 “Hazard Identification Studies” is to assess potential safety risks by executing so called Hazard Identification studies (HAZID) for a number of concrete applications of hydrogen in the public domain. In particular:

1. To identify typical safety hazards and to assess safety risks of a number of concrete cases associated with the production, storage, transport and use of hydrogen.
2. To identify and assess potential risk mitigating measures in order to control safety risks of hydrogen in the public domain.

The deliverables of this work package are intended for all parties involved in the production, storage, transport, distribution and end use of hydrogen in the public domain.

The HAZID cases are selected by the TEC of WVIP and involve:

- Case 1 Hydrogen refueling station
- Case 2 Hydrogen transport by road (tubetrailer)
- Case 3 Local hydrogen production
- Case 4 Hydrogen Power Modules
- Case 5 Bunkering of hydrogen

This report covers case 5: ‘Bunkering of hydrogen’ and provides insights in typical safety risks and recommendations for risk mitigation and control.

Summary

This report covers case 5: ‘Bunkering of hydrogen’. It provides insights in typical safety risks and recommendations for risk mitigation and control. This report includes an introduction to the Hazard identification methodology (HAZID) and a narrative for bunkering of hydrogen. Bunkering of hydrogen is foreseen for harbours and to be done by harbour service providers, but can be for recreational boating or hydrogen taxis too.

The HAZID study is executed under the umbrella of the Dutch Hydrogen Safety Programme (Dutch acronym: WVIP). Uptake of the findings and recommendations of this HAZID case takes place within WVIP.

1. Introduction

The HAZID is organised in the context of the WVIP (Dutch acronym of Waterstof Veiligheid Innovatie Programma (WVIP, Dutch for Hydrogen Safety and Innovation Program). In working group 5 safety risks are assessed for typical use cases with methods and tools that are based on (inter) national standards and/or guidelines.[1] Further information can be found on the website of the WVIP, which also describes the complete WVIP scope. This scope includes:

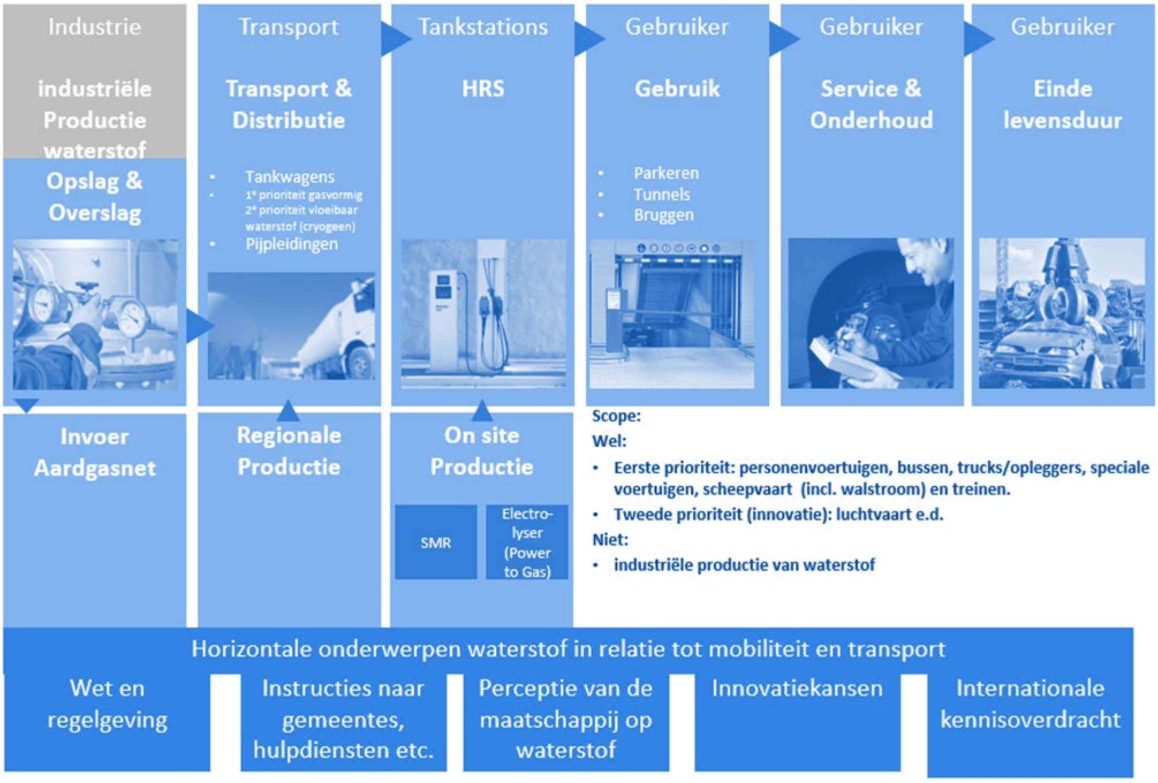

Figure 1: Scope WVIP This report contains the results and recommendations of the HAZID regarding the production of hydrogen, next to a hydrogen fuelling station

2. Narrative

A bunkering location in a harbour is foreseen. The bunkering location is during the bunkering process not accessible for public. The bunkering installation is stationary and tube trailers will be used as storage, from which feeding of hydrogen to a manifold takes place. The ship will be connected to the manifold with flexible hoses.

Assumptions made to make the case more specific are:

- Hydrogen will be in the gaseous phase
- The pressure will be 500 bar on the tube trailer side and 350 bar at the ship side. No compression on location.
- Maximum amount of hydrogen present on the location will be limited by the 'BRZO' limit and is 5000 kg (3-5 tube trailer locations)

[1] (Inter) National standards and guidelines include Publicatiereeks Gevaarlijke Stoffen (PGS) Handreiking Generieke Risicobenadering, ISO 31010 (Risk management - Risk assessment techniques) and NEN-EN ISO 17776 (Petroleum and natural gas industries - Offshore production installations - Major Accident hazard management during the design of new installations)

- The bunkering frequency is multiple times a day with a maximum of 10 times a day.
- The bunkering of ships is in the order of 200 to 400 kg per ship.
- The bunkering will be a manned action, with at least one person (onshore/offshore operator) present. The operator is responsible for the security and supervision.
- The bunkering location is meant for single purpose (no multi fuel situation)
- Existing procedures and safeguarding is taken into account.
- The following regulations (Dutch regulations) are considered relevant, already containing guidelines and regulations applicable to the case considered:
    - Wet milieubeheer/Besluit omgevingsrecht/Activiteitenbesluit milieubeheer
    - Warenwetbesluit drukapparatuur
    - Wet natuurbescherming
    - Provinciale omgevingsverordening
    - Richtlijn Industriële Emissies
    - Wet Luchtkwaliteit
    - PGS 33-2, PGS 35, PGS 15
    - BEVI
    - Omgevingswet
    - Regionale Havenverordening.
    - Binnenvaartpolitieregelement (BPR).
    - Technical Requirements for Inland Navigation vessels (ES-TRIN)
- The following other safeguarding is considered:
    - ESD (installation specific, emergency stop, emergency release coupling (ESC, hose rupture protection)), technical process safety standards, collision protection and measures to prevent floating away of the ship.
    - Procedures: ship / shore checklist, bunkering protocol, driver hand book
    - ADR
    - EIGA-standards (Home - EIGA : European Industrial Gases Association)
    - Relevant ISO/EN/NEN-standards
    - QRA, fixed safety distances, HAZOP, other safety studies
    - Evacuation- and calamity plan, entrance protocol
    - Qualified onshore-offshore operator, point of interest is the not qualified taxi/recreational boating.
    - Pressure safety valves, pressure protection.

3. Methodology, activities and meetings

3.1. HAZID team

The HAZID team consisted of the following persons, with their respective roles:

- Marcel Weeda (TNO) – Project leader HAZID; Expert and TL WG 5
- Johan van Middelaar (TNO) – HAZID Chair
- Lennart de Waart (NEN) – Scribe, co-PM WP 5
- Ruud IJpelaan (TNO) – Expert design
- Bart Koning – Brandweer Kennemerland
- Marco van den Berg – VR RR
- Leon Boetzkes – Linde Gas
- Cees Boon – Port of Rotterdam (session 1)
- Francoise van den Brink – Port of Rotterdam
- Renate Westendorf – Port of Rotterdam
- Rinus van Manen – Eneco
- John de Bont – Ekinetix
- Harold Pijnenburg - OD NZKG
- Bram Vogelaar – AirLiquide (session 2)

3.2. Meeting dates

The HAZID was conducted in 2 sessions (live) on 6 October and 3 November 2023 at NEN location Delft.

3.3. HAZID methodology

This HAZID is executed according the Terms of Reference (ToR) for this project, which includes a description of the HAZID methodology as based on (inter) national standards and guidelines, such as Publicatiereeks Gevaarlijke Stoffen (PGS) "*Handreiking Generieke Risicobenadering*" and NEN-EN-ISO 17776.

The main objectives of the HAZID study is to identify and assess potential hazards and safety risks for a typical hydrogen genset in terms of probability of occurrence and potential effect, including identification and assessment of risk mitigating measures.

Several categories are used in order to identify hazards and assess risks, including:

- Hazards related to external and environmental conditions.
- Hazards related to specific (design) aspects of the installation.
- Hazards of the activity in relation to health of workers and people in the vicinity.
- Project implementation issues; i.e. hazards or points of attention in relation to regulations, norms and standards for the activity.

The risk assessment includes four 4 sequential steps

1. Identify typical scenarios by team brainstorming and use of guidewords. Typical scenarios are derived in each hazard category, including descriptions of typical initiating (top) events.
2. Assessment of potential causes and consequences of the scenario.
3. Assessment of potential barriers.
4. Risk assessment of each scenario in terms of probability (scale A-E) and consequences for both people and the environment (scale 1-6). By use of a risk assessment matrix a relative risk level is determined (see figure 2).

Risk matrix

Consequence (Effect class)	People	Assets	Environment	Reputation		Probablity (Frequency of occurence): Scarcely – Never heard of in industry	Seldom / rarely – Has occurred in this type of industry/sector	Now and than – Has occurred in similar type of company	Regular – Has occurred several times in similar type of company	Often – Has occurred several times in a year on one location
						A	**B**	**C**	**D**	**E**
Zero	No injury Medical treatment (First Aid)	No damage < € 1.000	No / limited effect (pinhole leaks)	no	**1**	1,5	2,0	2,5	3,5	4,5
Minor	Medical Treatment case, substited work Slight health damage, no irreverse effects	Minor damage € 1.000 - € 10.000	Minor effect (small leak)	within company	**2**	1,9	2,5	3,1	4,4	5,6
Major	Major injury, Lost Time injury Irreverse health seffects	Major damage € 10.000 - € 100.000	Local effect (major leak)	local	**3**	3,8	5,0	6,3	8,8	11,3
Severe	Disability One fatality	Severe damage € 100.000 - € 1 milliion	Severe / regional effect (small equipment rupture, large leak)	regional	**4**	5,6	7,5	9,4	13,1	16,9
Very severe	More than one fatality (<50)	Very severe damage > € 1 - 10 million	Very severe / national effect (large equipment rupture, very large leak)	national	**5**	7,5	10,0	12,5	17,5	22,5
Catastropic	Many fatalities (>50)	Extensive damage > € 10 miljoen	Massive / international effect (loss of containment complete asset)	international	**6**	11,3	15,0	18,8	26,3	33,8

green	1 t/m 4	Risico behoeft geen vervolg actie
yellow	4,1 t/m 10	(Additionele) Beheersmaatregelen nodig
orange	10,1 t/m 15	risico. Altijd beheersmaatregelen nodig.
red	15,1 t/m 34	Absoluut onacceptabel. Stopzetten van werkzaamheden

Figure 2: Risk matrix used during HAZID.

4. Conclusions and recommendations

During the (live) HAZID sessions the guidewords have only partly been discussed.
All the guidewords in the category 'External and environmental hazards' have been discussed and most of the guidewords in the category 'Typical hydrogen bunkering hazards' have been discussed. The category with 'Health hazards' and 'Project implementation issues' (both not containing much guidewords) have not been discussed. These latter categories are of a more general character for hydrogen related projects and installations and will not differ much from the other HAZID cases earlier discussed.

Due to limited time and the finding that adding guidewords will not lead to new conclusion, it was decided to not further discuss the HAZID guidewords. From this conclusion follows the recommendation that a more detailed case, complete with concrete scenarios, should be developed for a better understanding of risks on a specific design level.

General insights from the discussions highlight that significant risks are often associated with new players lacking sufficient hydrogen expertise. Furthermore, the importance was underscored that in new projects, all risks are comprehensively addressed, and responsibilities and liabilities appropriately allocated. It is strongly advised that an encompassing risk analysis, such as HAZOP, shall be conducted by a qualified party for each new scenario, design or project.
While there are already numerous regulations and guidelines in place for hydrogen bunkering (see chapter 2), it is crucial to recognize that errors are always possible, especially given the difficulty of maintaining complete control over all details. In this context, hydrogen generally does not pose an immediate threat as long as strict adherence to the applicable rules is maintained. Nevertheless, it is emphasized that controlling details remains a challenge, as it is impossible to foresee and prevent all possible situations, designs, and mistakes. Therefore, it is strongly recommended to conduct a location- and design specific HAZID with a detailed focus.

Furthermore, it is advised to standardize as much as possible within the process to minimize human errors and ensure a consistent approach. A need is recognized for an updated PGS 35-2 *Hydrogen installations for delivering hydrogen to vehicles and tools* for hydrogen bunkering.

To effectively carry out a HAZID, selecting the right tools and experts is of importance. Choosing appropriate tools and experienced professionals will contribute to a thorough analysis and identification of potential risks.

4.1. Findings

The findings in this section include a summary of very high (red), high (orange) and medium (yellow) risks. The details of all risks and recommendations are recorded in the HAZID (Excel) worksheet.[2]

Very high risks (red):

- No very high risks are identified

High risks (orange):

- No high risks are identified

[2] The minutes of the HAZID are reported in an Excel format, as demonstrated in Annex 1 of this report. The complete HAZID worksheet is available on request.

Medium risks (yellow):

- 1.1.1: Extreme weather conditions, freezing and shrinking in piping/couplings/equipment leading to external leaks on gas from high pressure hydrogen tanks. Potential consequences are, leakage, frosting, fire (micro fire or jet fire) and possible delayed ignition.
- 1.1.1: Extreme weather conditions and freezing of soil lead to slippery roads, accidents, and collision of vehicle with objects or overturning of vehicle, resulting in leaks and fire (explosion not included in this scenario).
- 1.1.7: Extreme weather conditions, exposure to excessive amount of solar radiation, resulting in high temperatures and exceeding of design parameters
- 1.2.1: Overpressure or heat radiation due to H2 fire/explosion leading to leakage of hydrogen, total loss of ship of (H2) truck, damage to people and/or properties, surge on passing ships.
- 1.2.2, 1.2.4: Domino effects as result of risk 1.2.1.
- 1.2.5: Accident (collision) of H2 truck with obstacle or truck/crane with H2 filing point leading to damage/rupture of tubes, leakage of H2 with possible ignition and explosion hazard (lots of uncertainty about probability).
- 2.1.3, 2.1.xx: Improper system maintenance of installation (shore and ship) including hoses and couplings leading to possible leakage and/or fire.
- 2.2.4: Design failure (no pressure protection) leading to operation outside design window, leakage, (jet) fire.

Medium risk (yellow) as findings of previous HAZID cases:

- 2.2.5: Third party intrusion / vandalism can lead to many possible scenarios.
- 2.2.10: Failure of fittings lead to leaks, e.g. from flanges, connections.
- 2.2.14: Heat radiation due to external fire leading to various consequences and risks for people.
- 2.5.1: Fire in aggregate/hydrogen package and unavailability of a fire water system.
- 3.1.2: Large hydrogen leak leads to lack of air, suffocation, explosion/fire risk.
- 4.1.1: User company selection constraints, lack of stability and contractual conditions lead to unqualified personnel.
- 4.1.2: Legislation, governmental contracting requirements and permit requirements can be challenging to interpret and apply, especially for new players.
- 4.1.3: Additional engineering/company guidelines & standards lead to external standards which are insufficiently disseminated (to all market parties) and implemented.
- 4.2.1: Hazard studies have not been executed correctly.
- 4.2.2: Absence of Hazards and Effects Register
- 4.2.3: Absence of Q&A measures
- 4.3.2: Absence of medical support service, firefighting support, evacuation
- 4.3.3: controlled burn out of fire by firefighters lead to total loss.

4.2. Conclusions

With the proper safety barriers implemented, limited risks are expected in the use of a hydrogen bunkering facility (see 4.1).

The HAZID methodology is a useful instrument to bring possible hazards to the surface. Upon project implementation, the HAZID results should be used as input for more detailed analysis, such as HAZOP

4.3. Recommendations

The main recommendations of the HAZID analysis are:

- Strive for uniform engineering standards and instructions.
- Standard training program for hydrogen handling. Also (contractually) safeguarded when working with external parties or customers, e.g. related to connecting bundles.
- Check on engineering standards for extreme (NL applicable) weather conditions (freezing), including a check on intrusion of water and freezing.
- Check if requirements of flow limitation SAE 2601-2 for automotive purposes are applicable to bunkering too.
- A general point of attention is awareness and knowledge about safety aspects and risks about hydrogen. This applies to the entire public in general and to first responders and operators in particular.
- Design philosophy shall be: unmanned, intrinsically safe, e.g. automatic stop of flow / dead man knob in case of human failure (accident).
- Safety distances / working space for incident responders of at least 3 meter around the installation possibly fenced off, only accessible by authorized and trained personnel.
- Check if earthing of (H2-) bundles is covered in practice / regulations.
- Isolation (electrically) is not always possible. Investigate the possibilities to implement isolation for H2 applications in the future. See other recommendations with respect to earthing between ship and (on-shore) installation (e.g. the order and procedure of connecting the earthing). Metallic hoses have a low resistance (good earthing characteristics). Be aware that when connecting there will be a potential difference which can cause sparks.
- Recommendation to consider fit for purpose, strength and type of hose for risk with respect to safety. Minimize the use of couplings and ensure flexibility, fit for purpose length and good engineering practice of hoses as much as practicable with respect to safety.
- ESD Link is not standard or compatible, recommendation to look into this.
- Check if flood risk is addressed in permitting procedures, e.g. flood plains (uiterwaarden) low lying areas.
- Reconsider design criteria with respect to high temperature of bundles/tube truck and increasing pressure (climate change e.g. solar radiation).
- Recommended is not to allow bunkering with passengers /multiple people on board.
- Review recommendations of the Kjørbo incident.
- Prevent spaces where H2 can accumulate (e.g. below the quay)
- Require specific safety studies for each (type) bunkering station per location, including marine / nautical safety studies (ship collision).
- Evacuate the bunkering location in case of an incident.
- Inform the environment of the bunkering location concerning smoke and/or others hazards depending on the location (e.g. city, harbor location, remote area).
- Look into safety distances for passing ships, especially smaller ships / recreational boating.
- Check if the BPR regulation is adjusted for H2 bunkering e.g. conform LNG systematic.
- Point of attention: check to which extend the ship to shore checklist is applicable to recreational boating.
- Investigate the applicability of ATEX and possibly the revision of ATEX rules

- Recommendation: for smaller ships no persons on board during bunkering in relation to lack of emergency exits / evacuation.
- Bunker facility operator: to assess the safety of passengers / ships and take appropriate measures to ensure their safety.
- Draw up instructions, emergency, evacuation & firefighting procedures. E.g. 'aandachtskaarten'.
- General: how to handle with recognizability/labelling/register of H2 on board of recreational boating, compared to the professional boating regulations (e.g. linked to license/registration number/code).
- A critical point is the hose/coupling. The hose can be damaged both on shore or ship side with a own administrator. This is the case for the whole installation. 2 to 3 different parties depending on the way of bunkering, wall/on-shore installation, ship and H2 trailer. A gap in responsibility is present: supplier / driver of the trailer, the administrator of the bunkering installation and the captain of the ship, who is coordinating?
- Ensure design by qualified staff. Point of attention new players on market.
- No flammable materials within 30m around the trailer location. Interpretation of safety distances as mentioned in the PGS 35.

And relevant recommendation coming from other HAZID concerning the guidewords not discussed during the case 5 HAZID

- To further investigate ignition probabilities, scenario's, probabilities etc. See also knowledge gaps) WVIP WP 4. Incl. benchmark study on other gas transport scenarios.
- Verify that the hydrogen aspect is sufficiently taken into account in existing risk analysis (and in extension regulation) of (conventional) modes of transport such as shipping, aviation, drones related to 1) overflying and passing by hydrogen sites or 2) overflying or passing by by vessels / aircraft with hydrogen as fuel or cargo.
- Create an emergency plan per location. Not only emergency instructions on the emergency column also in the mind of the parties involved.
- Ensure accessibility, reserve a location for emergency services (fire brigade vehicles) near the hydrogen power module.
- Training of maintenance personnel
- Prepare maintenance philosophy (permit to work, work plans, agreements about switching of etc.)
- Explore necessity of assessment and training for key positions / mental pressure resilience of personnel.
- Organizations prepare for after care of fires exceeding 2 hrs.

Annex 1: HAZID worksheet

The HAZID worksheet is a separate Excel file with all notes and conclusions. For more information about this worksheet, please contact: energy@nen.nl