North Sea Energy

Report on offshore structural integrity and safety performance of H2 production, processing, storage and transport

As part of Topsector Energy:
TKI Offshore Wind & TKI New Gas

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1 Executive summary

The purpose of this study is to give an overview of the additional functional safety of hydrogen production offshore in comparison to hydrocarbon production. The relevant properties of hydrogen with respect to leak and flame detection have been investigated before venturing into the HAZID report, which is the primary focus of this text.

In the literature search suitable sensors for the detection of hydrogen gas and hydrogen flames have been identified. For the detection of the presence of hydrogen gas catalytic bead type detectors are most suited. For the detection of hydrogen flames multi-spectrum IR detectors are most suited.

The HAZID has been performed on a hypothetical situation of offshore hydrogen production on a manned platform. The HAZID workshop was held at TNO Utrecht and consisted of a multidisciplinary group chaired by Yokogawa. The full HAZID report is attached to this report as an appendix.

In the HAZID study, 49 recommendations have been formulated for the chosen scenario and lay-out. Some recommendations are very practical: minimise the hydrogen inventory, install proper gas and flame detection for hydrogen, and if a hydrogen leakage is burning do not extinguish the fire as the consequence of an explosion could be worse than a localised fire.

Other recommendations are related to further studies that need to be performed: vent studies for hydrogen and oxygen, radiation study for hydrogen vent.

Other topics to be investigated are: the effect of hydrogen flame temperature on the structural steel, TR (Temporary Refuge) and ESD (Emergency Shut Down) valves, the need of additional training of personnel, ensure that the structure has sufficient strength for the remainder of the lifetime.

Methods to study structural integrity and safety for off shore hydrogen production, storage and transport exist. One of these methods, the HAZID method, has been applied on a hypothetical scenario of hydrogen production on an existing, stripped platform. Interesting results have been obtained, which are generally applicable. No major show stoppers for hydrogen production offshore were found regarding safety concerns. In order to gain more detailed results, more information/process details is/are needed as input to get a better view on the issues/challenges related to structural integrity and safety.

2 Introduction

Background
With an ever-increasing percentage of intermittent energy from renewable sources in the energy mix, the need for grid stabilization and storage become more important. One proposed technology for grid stabilization and storage is so-called power-to-gas conversion, where (excess) electrical power is used to create e.g. hydrogen through water electrolysis.

In the Dutch continental shelf of the North Sea the areas included in the roadmap 2023 [1] have wind farms already running or are being developed. These areas will be fully developed by 2023 and will bring the total capacity of offshore wind energy up to 4.5 GW. Towards 2030 there are plans to further increase this capacity to 11.5 GW. Using power-to-gas technologies on existing oil and gas platforms, hydrogen can be produced, stored and transported to shore through existing gas infrastructure. Besides solving power grid stability and storage challenges this would also extend the useful lifetime of oil and gas platforms. Studies have been performed with regard to the technical and economical feasibility of power-to-gas offshore [2]; however, no studies have been performed regarding functional safety of offshore hydrogen production.

Aim of study
In this study we take the first step in studying functional safety of offshore hydrogen production by performing a hazard identification study (HAZID).

Methodology
Yokogawa together with TNO drafted four scenarios relevant to the North Sea Energy consortium. The scenarios are as follows:

1. Offshore hydrogen production on an (un)manned operating platform that produces natural gas.
2. Offshore hydrogen production on an (un)manned stripped electrified platform without natural gas production.
3. Offshore hydrogen production on an (un)manned stripped platform that processes and stores CO_2 subsurface, but has no natural gas production.
4. Offshore hydrogen production on an energy island.

These scenarios were presented and ranked by NSE consortium partners during the mid-term review on the 9th of July 2019. Scenario 4 topped the vote closely followed by scenario 2. As energy islands are a further into the future solution compared to scenario 2, it was decided to perform a HAZID study for the manned version of scenario 2. For this scenario a process flow chart was designed and embedded on an existing platform as a basis of the study. The surface area of the platform was estimated at roughly 1000 m^2, which makes an electrolyser of 100 MW possible [2]. During the HAZID a concern was raised due to the additional weight to the topside of the structure; however from [2] it is concluded that the available surface area not the weight is the limiting factor for electrolyser placement on existing platforms. The process flow chart can be found in the HAZID report in appendix A.

The emphasis of the HAZID is on the differences between a typical gas platform and the intended change-over to a hydrogen producing platform.

In addition to the HAZID study, a literature search has been performed on available methods for hydrogen leak and flame detection. The results of the literature study are shown in section 3. Section 4 describes the HAZID process and the results are given in section 5. The conclusion is written in section 6.

3 Hydrogen leak and flame detection

Hydrogen is not present on current offshore gas or oil platforms; therefore, all gas and flame detectors are based on detecting hydrocarbons. For our “hydrogen production on a stripped platform” scenario personnel will be working in an environment where hydrogen is produced making hydrogen gas and fire detection very important. In this document we will investigate through a study of existing literature the dangers of hydrogen and the detection methods required.

Properties of Hydrogen

Hydrogen is the smallest molecule; as such the probability for leaks is greater than for hydrocarbons. Furthermore, it is colourless, odourless and tasteless making it impossible to detect by human senses. It forms an explosive mixture with air in concentrations from 4-75% (5-15% for methane) and burns with a pale blue flame which is nearly invisible, especially during daytime, and has low radiant heat. Its minimum ignition energy is 0.02 mJ (0.21 mJ for methane) making hydrogen far more sensitive to ignition than most other gaseous or vaporised flammable materials. Autoignition occurs at 585°C (methane 580°C) [3].

Figure 1 - Hydrogen fire **[4]***: Left picture – Ignited hydrogen only visible with a thermal camera, thermal radiation falls off sharply around the flame. Right picture – Experiment with a hydrogen vehicle fire. Flare at the hydrogen vehicle (700 bar), visible part of the flame is small most of the flame is invisible.*

Detection Methods

On current gas production platforms several types of gas and flame detectors are used e.g. ultrasonic gas leak detector, open path gas detector, IR (InfraRed) gas detector, IR flame detectors. All these detectors are primarily designed for detecting hydrocarbon gas leaks or fires; therefore, these detectors are not suited for an environment with hydrogen production and will need to be replaced. However, detectors suitable for hydrogen gas do exist.

Gas detection technologies

Gas detection represents the first line of defence in the case of a hydrogen release. Ideally, actions can be taken to stop the hydrogen release before a flame or explosion. Two of the common technologies for combustible gas detection are infrared and catalytic bead. Both are discussed below and their suitability for hydrogen is checked.

An infrared gas detector responds to gases that absorb IR radiation – such as methane and propane (hydrocarbons). However, hydrogen cannot absorb IR radiation, thus IR gas detectors will not detect it and should not be used.

This leaves the catalytic bead type detectors for detecting hydrogen at lower flammable limit (LFL) levels. In fact, a catalytic bead sensor detects any combustible gas that combines with oxygen to make heat. If the gas can burn in air, this detector will sense it. This property makes it suitable for hydrogen detection.
The catalytic gas sensor usually consists of a matched pair of platinum wirewound resistors, one of which is encased by a bead of ceramic. The active catalytic bead is coated with a catalyst; the reference catalytic bead remains untreated. This matched pair is then enclosed behind a flameproof sinter, or porous filter. In operation, the beads are resistively heated. When a combustible gas comes in contact with the catalytic surface, it is oxidised. Heat is released, causing the resistance of the wire to change. The reference bead, or passive bead, maintains the same electrical resistance in clean air as the active bead, but does not catalyse the combustible gas. The sensor compares the currents. If the current is different, the detector can alarm. If there is no gas cloud, both beads will have the same current.

The catalytic bead sensors do have shortcomings, however. For example, they don't annunciate when they fail. Also, they are susceptible to poisoning and dying from chemicals such as silicones – common chemicals in industrial environments. In these cases, the porous filter gets clogged so that the active bead cannot sense gas and becomes the same as the reference bead. If the active bead cannot sense gas, the operator back in the control room won't know. Periodic testing is required to ensure proper sensor operation.

In placing the gas detectors, consider that hydrogen is the lightest gas and floats up quickly and disperses easily. Make sure the gas sensor is close to and above the location where a leak might occur. For example, a gas detector could be located above a valve stem. [5]

Flame detection technologies

Hydrogen presents several flame-detection challenges. Hydrogen burns a very pale blue to nearly invisible flame. Technologies to detect hydrogen flames include flame detectors that sense the non-visible spectrum of electromagnetic radiation, which includes ultraviolet (UV) and IR radiation.

Manufacturers have developed technologies such as thermal detectors, UV flame detectors, and multispectral IR flame detectors. All three types will be discussed below.

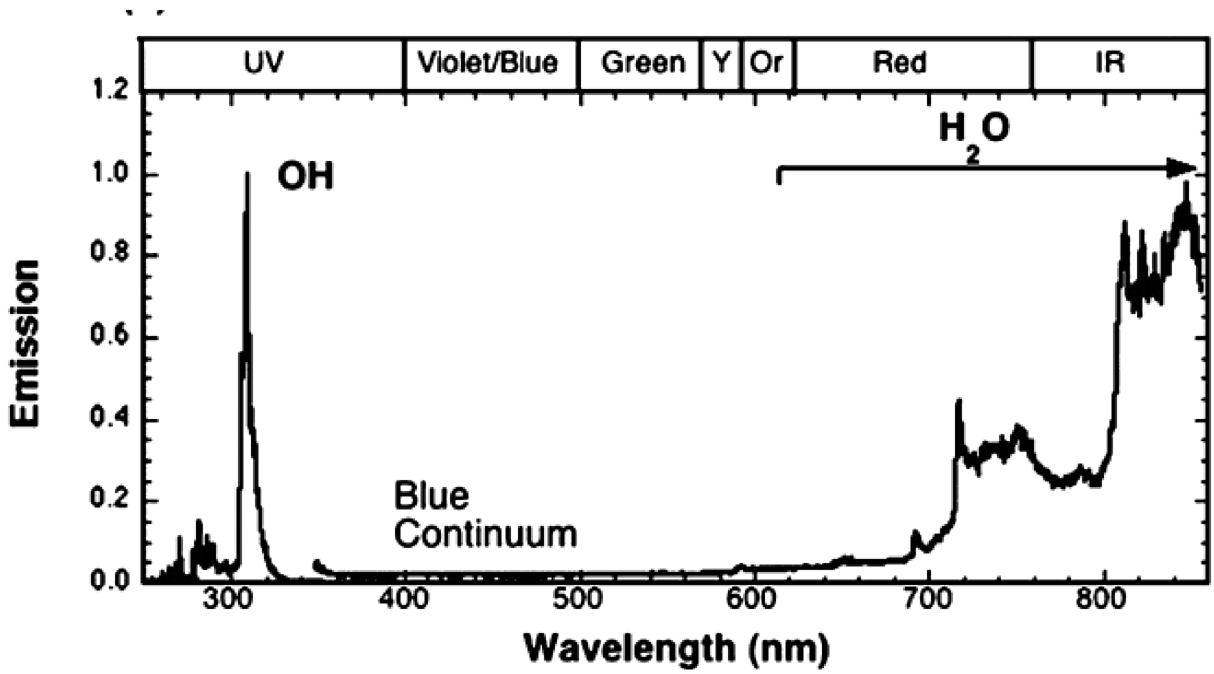
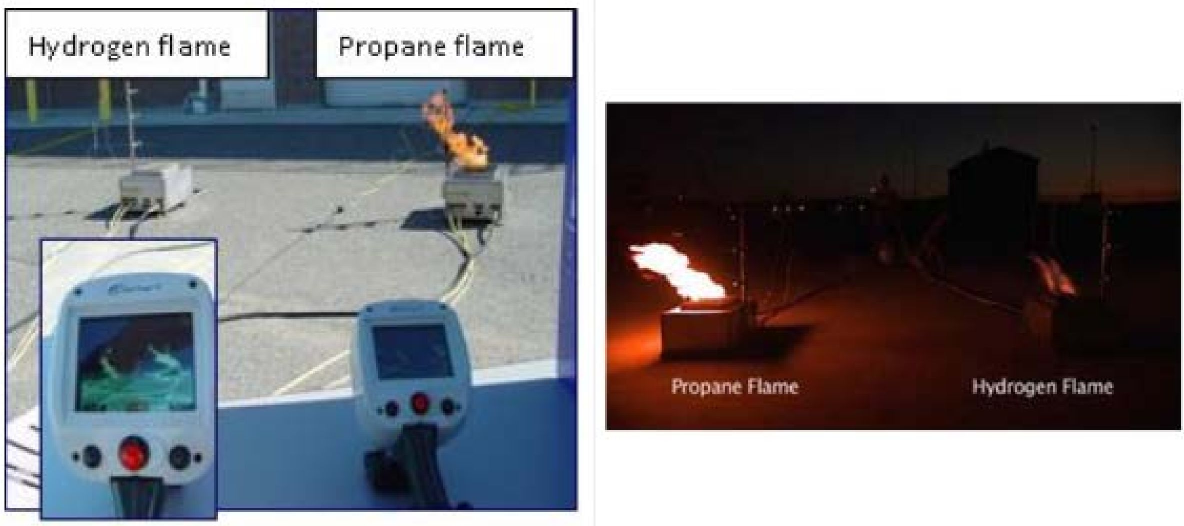


Figure 2 - pre-mixed H2-air jet flame showing measured spectral peaks from ultraviolet to near infrared **[5]**

The first type to be discussed are the thermal detectors [6]. A thermal detector will only give an alarm if it feels the heat. For this reason, positioning a thermal detector directly above the possible site of a hydrogen flame seems logical. However, the source of the hydrogen leak might create a flame that is directed away from the detector. The hydrogen flame's low IR radiation may not be enough to set the radiant heat detector into alarm. Thermal detectors are helpful, but proper positioning is the biggest challenge.

The second type of detectors are the UV detectors. UV detectors use basic anode/cathode Geiger-Muller-type vacuum tubes to sense UV radiation emitted by a flame [6] [7]. UV radiation enters the vacuum tube through a quartz window and strikes the cathode. The energy from the UV photon releases a photo electron and creates an electrical impulse as it travels to the anode. This is a basic technology that dates to the beginning of the 20th century.

Hydrogen flames, compared to hydrocarbon flames, emit little visible light and little IR radiant heat (*Figure 3*). Instead, energy is radiated primarily in the UV band. Therefore, without doubt, UV detectors excel at detecting hydrogen flames. In addition, they have a good detection range and can see a 24-inch plume flame up to 50 feet away.



Hydrogen and Propane Flames in Daylight (Photo courtesy of HAMMER)

Hydrogen and Propane Flames at Night (Photo courtesy of ImageWorks)

Figure 3 – Hydrogen and propane flames in daylight and at night.

UV detectors, however, are sensitive to arcs, sparks, welding, lightning, and other UV-rich sources. When those relatively safe conditions are present, UV detectors could go into alarm condition. False alarms can be expensive and can reduce people's sensitivity to potential hazards. Therefore, users should match the appropriate technologies to the applications they face.

UV detectors, with their very fast response time and good detection range, are best suited for applications where the false-alarm sources can be controlled, such as in enclosed rooms. But keep in mind that most enclosed rooms have ventilation ducts that can reflect UV from lightning and welding – thus causing UV detectors to alarm.

The last type of flame detectors to be discussed are the multispectral IR detectors. These multispectral IR flame detectors use a combination of IR sensor filters and software analysis to both see the flames and reduce false alarms. Some multispectral IR detectors have been designed specifically to detect the low-level IR radiation of hydrogen flames using a unique set of IR filters.

These special multispectral IR flame detectors have a very good detection range with a good response time to the low levels of IR from hydrogen flames, but do not incur false alarms for arcs, sparks, welding, and lightning. In addition, the multispectral IR detector has complete solar resistance and is insensitive to artificial lights and most “blackbody” radiation, which plague other detection technologies.

By selecting the optimum IR filter set, some available detectors have doubled the UV range and can detect a 24-inch plume flame at 100 feet. The result is increased flame sensitivity with discrimination of non-flame sources in situations where traditional flame detectors are unsuitable.

The multispectral IR detectors do have limits, however. For example, their detection range is reduced with the presence of water or ice on the lens. To mitigate the problem, some detectors are manufactured with lens heaters that melt ice and accelerate the evaporation of water. [4] For most applications, indoors and out, multispectral IR flame detection has become the preferred choice for detecting hydrogen flames. [7]

4 HAZID

A hazard identification study (HAZID) is a qualitative study used as the first step in a process used to assess risk, where risk is defined as a combination of the frequency of occurrence of harm and the severity of that harm (IEC 61508 / IEC 61511). A HAZID is performed in order to identify potential hazards in an early stage and reduce any adverse impact that could injure personnel, damage property, damage the environment or the reputation of a company. The result of a hazard analysis is the identification of different type of hazards and a list of necessary actions to mitigate such risks.

The generic study method is a combination of identification, analysis and brainstorming by the HAZID team members. Guide words are used in order to identify potential hazardous effects as well as threats. The HAZID team is a multi-disciplinary team consisting of:

- Chairman – leads the HAZID workshop
- Scribe – documents the HAZID workshop
- Process engineer
- Safety/environmental specialist
- Expert on standards

A HAZID was performed for the North Sea Energy consortium for the scenario of offshore hydrogen production on a manned platform. For the full report see Appendix A.

ENVID

The ENVID (Environment Identification) specifically looks at the planned impacts of the project on the environment. The workshop examines specific activities and determines what aspect of the environment could be affected. The ENVID is also concerned with accidental impacts, which are primarily defined in the HAZID.

The purpose of the ENVID process is for the early identification of aspects that can potentially impact the environment. Another key element of the process is the identification of proposed measures to prevent, control or mitigate the potential environmental hazards identified. Furthermore, alternative measures and monitoring schemes are provided where necessary.

The major benefit of this process is to provide essential input that may influence the subsequent project design phases. The results are also used to inform the development decision process that is intended to lead to safer and more cost-effective design and execution of the operation.

The ENVID process comprises of the following:

Identifying and describing environmental hazards and threats at the earliest practicable stage of a development

The workshop format of an ENVID is similar to that of a HAZID and can be conducted in the same session if time allows. An ENVID was not part of the HAZID workshop described in the current report, due to time constraints and should be included in future projects.

5 Results HAZID

The HAZID resulted in 49 recommendations, which require attention for a future design, as described in the HAZID report in appendix A. The actions can be divided into three categories: investigate, check and recommend. For the full list of recommendations see the attached HAZID report. Below a selection of these recommendations is discussed.

A first recommendation is related to planned and accidental releases of process fluids like oxygen and hydrogen. In the event of an unignited hydrogen release a hydrogen cloud is formed. As a worst case situation, this cloud could result in an explosion causing structural failure or fatalities. Moreover, the (planned) release of oxygen can result in an oxygen rich environment leading to increased flammability of all materials resulting in fires where one normally would not expect them, which again, can result in structural failure or fatalities. Therefore, the HAZID group recommends performing dispersion studies for both hydrogen and oxygen, this will also provide information on the placement of vessel, helicopter, escape pod etc, and on blowdown scenarios.

Furthermore, the oxygen rich environment will lead to higher corrosion rates. For this reason, the HAZID group also recommends including corrosion in the vent study. Additionally, the design of the vent piping needs to be checked for sufficient strength to withstand a hydrogen fueled explosion in the vent piping.

During operations it may be required to vent and/or flare hydrogen. The thermal radiation from hydrogen is different than that from natural gas; therefore, the HAZID group recommends performing a radiation study on the hydrogen vent.

In the case of a process fluid release in the form of an ignited flammable gas release, the identified hazard is that of fires and jet fires. The worst possible credible consequence is structural failure and/or fatalities. There is a deluge system in place as a safeguard; however, the HAZID team recommends to not use the deluge system on hydrogen fires as the gas release can become unignited and form a cloud, which can lead to an explosion with possibly worse consequences than a localised (jet) fire.

In the event of a process fluid release in the form of either ignited or unignited hydrogen gas another risk is that of unsuitable gas leak and flame detection devices. Therefore, the HAZID group recommends the installation of leak and flame detection suitable for hydrogen. For the difference between hydrocarbon and hydrogen detection see chapter 3. Moreover, a release of oxygen can result in an oxygen rich environment which increases flammability of all materials potentially resulting in fires in normally unexpected locations. Therefore, the HAZID group recommends investigating O_2 detection.

In the event of a release of ignited flammable hydrogen gas, which can lead to structural failure and fatalities, one of the safeguards currently used is H60/J15 steel as a passive fire protection (PFP). As hydrogen fires burn at a higher temperature the HAZID group recommends investigating the effect of the temperature of a hydrogen fire on structural steel and TR and ESD (riser) valves and whether or not the installed PFP is sufficient.

Hydrogen gas and fires behave differently from that of hydrocarbon fires. Currently offshore personnel is trained for hydrocarbon fires, but has no experience with hydrogen fires. Therefore, the HAZID group recommends investigating additional training of personnel for hydrogen fire detection and firefighting.

Once an area has been identified as hazardous it should be classified into zones based on the frequency and persistence of the potentially explosive atmosphere. This then determines the controls needed on potential sources of ignition that may be present or occur in that area. These controls apply particularly to the selection of fixed equipment that can create an ignition risk; but the same principles may be extended to control the use of mobile equipment and other sources of ignition that may be introduced into the area (for example, matches and lighters) and the risks from electrostatic discharges. For gasses, vapours and mists there are three zones:

1. Zone 0: A place in which an explosive atmosphere consisting of a mixture with air of dangerous substances in the form of gas, vapour or mist is present continuously or for long periods or frequently.
2. Zone 1: A place in which an explosive atmosphere consisting of a mixture with air of dangerous substances in the form of gas, vapour or mist is likely to occur in normal operation occasionally.
3. Zone 2: A place in which an explosive atmosphere consisting of a mixture with air of dangerous substances in the form of gas, vapour or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

Since the production of hydrogen introduces new equipment and processes to the offshore platform one may run into non compliances with engineering codes and standards and with safety measures and regulations. As such the HAZID group recommends checking whether or not the area classifications are still suitable for hydrogen.

To minimise the risks from process fluid releases in the form of unignited hydrogen gas the HAZID group recommends minimizing the hydrogen inventory.

With platforms being repurposed for hydrogen production additional weight will be added due to new equipment, in particular electrolysers which will take up most of the space on the platform [2]. This can lead to collapse due to fatigue, design, materials or corrosion; therefore, the HAZID group recommends ensuring the structure has sufficient strength for the intended lifetime.

The HAZID was performed on a simplified process flow chart for offshore hydrogen production. For future HAZIDs a more detailed design and process should be made available to get better and more project and site specific results.

6 Conclusion

In the sections above a study has been made on safety aspects of hydrogen production on an existing platform. A literature search into gas and flame detectors has been performed. And a HAZID study has been made for the chosen scenario of hydrogen production on a manned platform.

In the literature search suitable sensors for the detection of hydrogen gas and hydrogen flames have been identified. For the detection of the presence hydrogen gas catalytic bead type detectors are most suited. For the detection of hydrogen flames multispectral IR detectors are most suited. Different detection methods have different strengths and vulnerabilities as such a combination of different type of detectors is particularly effective because they are complementary [7].

In the HAZID study 49 recommendations have been formulated for the chosen scenario and lay-out. Some recommendations are very practical: minimise the hydrogen inventory, install proper gas and flame detection for hydrogen, and if a hydrogen leakage is burning do not extinguish the fire as the consequence of an explosion could be worse than a localised fire.

Other recommendations are related to further studies that need to be performed: vent studies for hydrogen and oxygen, radiation study for hydrogen vent.

Other topics to be investigated are: the effect of hydrogen flame temperature on the structural steel, TR and ESD valves, the need of additional training of personnel, ensure that the structure has sufficient strength for the remainder of the lifetime.

Methods to study structural integrity and safety for offshore hydrogen production, storage and transport exist. The HAZID method has been applied to a hypothetical scenario of hydrogen production on an existing, stripped platform. Interesting results have been obtained. No major show stoppers for the offshore production of hydrogen were found with regards to safety concerns. In order to obtain more detailed results, more information on process details are needed as input to get a better view on the /challenges related to structural integrity and safety.

7 References

[1] J. Vermeulen, "Dutch offshore wind energy developments: roadmap 2023, roadmap 2030," [Online]. Available: https://offshorewind.rvo.nl/.

[2] C. J. Jepma and M. v. Schot, "On the economics of offshore energy conversion: smart combinations," 2017.

[3] J. Grummer and S. Hawksworth, "Spontaneous ignition of hydrogen - Literature review," Health and Safety Laboratory, 2008.

[4] Brandweer Nederland, "Aandachtskaarten waterstof incidentbestrijding," 2019.

[5] R. Schefer, W. Kulatilaka, B. Patterson and T. Settersten, "Visible emission of hydrogen flames," Elsevier.

[6] hazardex, "Detecting Hydrogen Gas and Flames," 2011.

[7] MSA The Safety Company, "Hydrogen Detection in Oil Refineries".

8 Appendix A

This appendix contains the results of the HAZID – Offshore hydrogen production. This appendix is available as a separate document.