HYDROGEN FUELLING STATION, CEP-BERLIN – SAFETY RISK ASSESMENT AND AUTHORITY APPROVAL EXPERIENCE AND LESSONS LEARNED

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ABSTRACT

The CEP (Clean Energy Partnership) – Berlin is one of the most diversified hydrogen demonstration projects at present. The first hydrogen fuelling station serving 16 cars is fully integrated in an ordinary highly frequented Aral service station centrally located at Messedamm in Berlin. Hydro has supplied and is the owner of the electrolyser with ancillary systems. This unit produces gaseous hydrogen at 12 bar with use of renewable energy presently serving 13 of the cars involved. The CEP project is planned to run for a period of five years and is supported by the German Federal Government and is part of the German sustanaibility strategy. During the planning and design phase there have been done several safety related assessments and analyses:

- Hydro has carried out a HAZOP (HAZard and OPerability) analysis of the electrolyser and ancillary systems delivered by Hydro, Electrolysers.
- Hydro arranged with support from the partners a HAZOP analysis of the interface between the electrolyser and the compressor, an interface with two different suppliers on each side.
- A QRA (Quantitative Risk Assessment) of the entire fuelling station has been carried out.
- Hydro has carried out a quantitative explosion risk analysis of the electrolyser container supplied by Hydro Electrolysers.

The aim in the CEP-Berlin project was to follow the guidelines from the European Integrated Hydrogen Project, phase 2, (EIHP2) [1] when planning and designing a new hydrogen fuelling station. These guidelines focus on installation and operation of hydrogen refuelling stations, and were based upon best practice and knowledge from the industrial partners in EIHP 2. The explosion risk analysis for the CEP-Berlin facility demonstrated that the safety risk was acceptable if certain design modifications were carried out. Both Aral/BP and Hydro accepted the results from the quantitative risk assessments. These companies have also their own standards regarding safety acceptance criteria, which have to be complied with. The fuelling station was opened November 12 2004, and was put in normal operation during winter 2005.

1.0 INTRODUCTION

The CEP (Clean Energy Partnership) – Berlin is one of the most diversified hydrogen demonstration projects at present.

The CEP-Berlin partnership is public-private partnership comprising the Federal Government and the industrial partners Aral/BP, BMW, BVG, DaimlerChrysler, Ford, Hydro/GHW, Linde, Opel/GM, Total and Vattenfall with the common goal to demonstrate mobility with hydrogen in Berlin. The German authorities are supporting the construction and operation of the hydrogen fuelling station as well as the service station for the maintenance of hydrogen vehicles. The hydrogen fuelling station is a fully integrated part of an Aral service station. The partner's main focus has been put on the following: technology for the future, hydrogen safety and positive profiling.

The fuelling station was opened November 12th 2004, and was gradually put into normal operation during the winter of 2005. For the time being the plan is to keep the fuelling station in operation until the autumn of 2007.

The role of Hydro is to supply gaseous hydrogen and be the supplier and operator of the hydrogen producing equipment at the fuelling station. This is an electrolyser with auxiliaries placed in a container, with a production capacity of 60 Nm^3/h. The container is a "closed system" with supply of only electricity and water, and the only emission during normal operation is oxygen. The electrolyser is remotely operated from Norway. No local personnel is needed except for routine inspections and maintenance. In regular operation personnel from Hydro will not be at site earlier than after one day. Locally employed staff at the 24 hour manned service station has a limited responsibility, mainly related to daily visual inspections and some emergency operations, which have to be handled instantly.

The electricity supplied for the electrolyser is renewable hydropower with green certificates.

The CEP-Berlin partnership has designed and constructed a fuelling station in a busy city area, which is a good example of what the future might look like.

Figure 1. The CEP-Berlin fuelling station.

This is a hydrogen fuelling station fully integrated into a conventional and modern service station offering different fuels such as gasoline and diesel as well as liquid and gaseous hydrogen in a busy public area in Berlin. Among the close neighbours are a public bus terminal and a car wash. The electrolyser, the compressor and the high-pressure storage is located inside a fenced 12 x 12 meters big area in the rear courtyard of the service station. In other words, this can be seen upon as an industrial plant in a public area.

Figure 2. Hydro water electrolyser container without panels

Figure 3. The Hydro electrolyser container located in the rear courtyard

2.0 HYDRO REQUIREMENTS BASED UPON INDUSTRIAL EXPERIENCE

2.1 General

Hydro has been in the hydrogen business for about 80 years, making hydrogen with electrolysis for the production of fertilizers since the 1920ies. Hydro has been owner and operator of offshore oil and gas installations in the North Sea since the 1970ies. Light metal production and petrochemical production has also been industrial areas for decades.

Initially, water electrolysis equipment was delivered to Hydro plants only. Industrial developments in the seventies opened for external supply worldwide.

Experience both from industrial use of hydrogen as well as production of hydrogen equipment alongside with the safety demands of offshore oil and gas production has resulted in high requirements

to safety levels at a whole. The benefit of having qualified operators as well as long experience in equipment research and development together with a continued focus on personnel safety and environmental concern has led to a strong position in risk based safety management. Risk Based Safety Management can be defined as follows: “Developed from consequence based safety management by maintaining that the residual risk should be analyzed both with respect to the probabilities and the nature of hazard, hence, give information for further risk mitigation”. This implies that very unlikely events might, but not necessarily will, be tolerated. The Risk Based Safety Management system is a systematic approach, which measures safety risk through risk analysis methods and relates it to established risk acceptance criteria. This will identify design specifications or need for risk reduction measures. If risk-reducing measures are needed, either consequence reducing measures or accident probability reducing measures should be implemented. If possible, probability-reducing measures should be preferred.

This is formalized in Governing Documents as Health Safety, Security and Environment (HSE) procedures in Hydro:

- Principles of inherent safety, barriers preventing development / limiting consequences of incidents/accidents, operational instructions.

- Hazard identification and/or HSE studies shall be done. The identified hazards and/or HSE study shall form the basis for evaluating, understanding and documenting risk. These shall be updated when significant modifications are done

- The risks shall be compared with relevant established risk acceptance criteria.

- The Organisation shall make sure that all employees have appropriate competence, are familiar with the HSE impacts, hazards, risks of their activities, and tasks and instructions necessary for correct behaviour

Hydro should be well prepared for sharing knowledge and experience as the society is moving into new applications for hydrogen. The use of hydrogen as fuel for vehicles faces new safety related challenges, mainly related to the more public locations for production and handling of hydrogen. Up to now, large quantities of hydrogen has mainly been produced and handled inside industrial areas.

2.2 The CEP-Berlin fuelling station in particular

The aim in the CEP-Berlin project was to follow the guidelines from the European Integrated Hydrogen Project, phase 2, (EIHP2) [1] when planning and designing a new hydrogen fuelling station. These guidelines focus on installation and operation of hydrogen refuelling stations, and were based upon best practice and knowledge from the industrial partners in EIHP

The infrastructure partners made an agreement at en early stage (Leistungsbeschreibung CEP-Infrastrukturgruppe [2]). Important parts of this agreement were the chapters about HSE and safety activities:

- All the infrastructure partners are conscious of the importance of taking account of safety, environmental and health aspects in the planning, erection and operation of the hydrogen refuelling point.

- Use Risk-based safety management

- Perform HAZOP studies. A “Hazard and Operability” (HAZOP) study shall be undertaken as soon as a general description of the process with process plans, pipeline and instrumentation diagrams are available to disclose any weak points in the system.

- Perform a Quantitative Risk Analyses. A Quantitative Risk Analysis (QRA) of the hydrogen refuelling point is recommended because the system represents a significant potential for safety risk:
    - Storage of flammable gases at very high pressure
    - Limited experience of refuelling vehicles at high pressures
    - Location of the hydrogen refuelling point in a densely populated area
- The results of the QRA will show whether the safety risk generated by the hydrogen system lies within previously defined limits and can therefore be accepted. If the safety risk is exceeded, risk reduction measures must be initiated. In addition to the latter, the results of the QRA form a basis for communications with the authorities and the local population about the risk posed by the system.
- Be in line with
    - Central EU-directives
    - Important guidelines and standards
    - CE-certification

During erection and operation of the hydrogen system, the internal HSE operational guidelines of Deutsche BP shall apply to the entire petrol station site.

The objective of the agreement above is to make sure that the owners and operators, the authorities and the society accept the risk level and that the design is consistent to make sure accidents are strongly prevented.

The public must understand and experience that the facility is safe.

Based on the above, the Infrastructure partners agreed: **"Safety is CEP number one priority"**. [3]

3. CEP-BERLIN SAFETY AND RISK ASSESSMENTS

3.1 General

As agreed in the infrastructure agreement [2], definite safety related activities were to be carried out. During the spring of 2004 Aral/BP carried out a Hazid (hazard identification) of the facility and based upon the present design at that time, This Hazid, lead up to several safety related assessments and analyses:

- Hydro has carried out HAZOP analysis of the electrolyser and ancillary systems delivered by Hydro Electrolysers.
- Hydro arranged with support from the partners a HAZOP analysis of the interface between the electrolyser and the compressor, an interface with two different suppliers on each side.
- A QRA (Quantitative Risk Analysis) of the entire fuelling station has been carried out.
- Hydro has carried out a quantitative explosion risk analysis of the electrolyser container supplied by Hydro, Electrolysers.

3.2 Explosion risk analysis for the Hydro, Electrolyser water electrolysis container. [4]

Generic failure frequencies from Norsk Hydro's Handbook of Safety Risk Assessment [5] were used to determine leakage frequencies. A simplified ignition model was established in order to predict the frequencies of explosions. The ignition model assumed a hydrogen ignition probability of 1. It furthermore assumed that 50 % of the leakages ignited immediately, resulting in a jet fire, while 50 % of the leakages had a delayed ignition, resulting in an explosion. If a delayed ignition occurred, the model used a leakage duration of 60 s before ignition.

Hydrogen dispersion and explosion simulations were carried out using the computational fluid dynamics (CFD) software FLACS [6]. A visualisation of the hydrogen dispersion is showed in figure 4. The calculations showed that explosion events with the annual frequencies of 10^{-4}, 10^{-5} and 10^{-6} all were capable of disengaging the wall panels from the container steel structure. A fatal probability of 1 for a person hit by the panels was used in order to produce individual risk contours.

A qualitative assessment was done for evaluation of missile risk. With the given design of the wall panels and their failure mode, missile risk was assessed as low. Small impulses from the calculated explosions indicate that fragments and small process equipment will have limited possibilities for producing hazardous missiles.

For the proposed CEP Berlin location, several safety issues were discussed. It was recommended to direct the ventilation outlet upwards. Walls in the fuelling facility shop and the fence surrounding the production area should be able to resist the impact of a disengaged wall panel. The use of window glass facing the production and storage area should be limited. If glass is desirable, glass strength specification should be applied. Access to the production and storage area should be restricted.

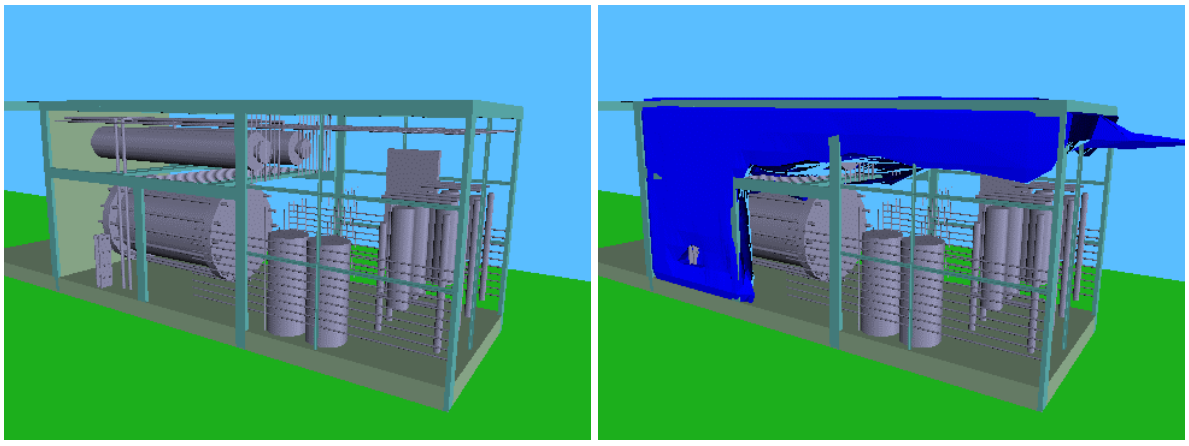

Figure 4. Visualisation of the gas dispersion model of the hydrogen production container (without cladding). Left: Before leakage. Right: Extents of lower flammability limit for hydrogen/air mixture inside container after 60 seconds.

3.3 Quantified risk assessment of hydrogen fuelling station

MMI Engineering was engaged by the infrastructure partners to give a Quantified Risk Assessment of the complete CEP-Berlin site. [8] The QRA was based upon a Hazid workshop, from which the output gave a number of site level hazards. The QRA was intended to supplement the detailed safety assessments conducted by each partner on their respective systems. The QRA also attempted to give a formal demonstration of their associated risk being either tolerable, or tolerable following implementation of appropriate risk reduction measures. The latter required a process that included the

ALARP principle (i.e. As Low As Reasonably Practical – principle for assessing implementation of practical risk reduction measures) to demonstrate that the risk was tolerable.

The assessment focused on the site layout and the local environment influence of the site's risk level. The assessment came up with several findings and recommendations. The findings were mainly related to activity and operation of the five matters:

- The forecourt liquid hydrogen storage tank. Crash protection and a plinth was implemented as risk reduction measures.

- The offloading of liquid hydrogen from tanker. Changed location for tanker during offloading was suggested.

- The forecourt dispensers.

- The rear courtyard electrolyser container. This was evaluated in a separate study, and several measures and modifications were done.

- The rear courtyard high pressure hydrogen store. A wall was made to resist impacts from vehicles, and it was decided to bury pipe work serving the storage.

3.3. Hazop of the interfaces

The individual owners and manufacturers of the equipment did individual HAZOPs for their units. In addition, a HAZOP was carried out with focus on the interfaces between the units. [7] This was done to make sure responsibilities and co-operation of the different unites and the interfaces were operated without any dangerous moments, operating errors or malfunctions.

The interface HAZOP was conducted by Hydro Research Centre, but with assistance and contributions from all infrastructure partners.

4. SUMMARIES AND RECOMENTADTIONS

The CEP-Berlin fuelling station is a demonstration project, and the objective for the different partners' participation may vary, still there is a common goal to enable mobility with hydrogen and thus have a common contribution to all necessities to enable this vision. It has been of advantage that, common partnership objectives and individual partner's objectives were made clear from the very beginning.

The safety acceptance criteria should be agreed upon as early as possible.

From a safety point of view, the site level hazards should be defined from the start. The individual systems and the site layout should be tailored to address these possible hazards. It has proven beneficial that safety assessments were carried out in a right order, for example, not to determine the final layout before relevant safety and risk assessments were done.

All HSE related activities and work needed is to be part of the general project schedule. A safety management system in accordance with relevant industrial experiences should be adopted.

It has proven beneficial to involve authorities at an early stage of the project in order to inform and discuss solutions for design and construction of the fuelling station.

The focus on the operating phase and the customer needs when designing the facilities is a key success criterion. One should seek safe and practical ways to carry out everyday inspections, routine activity and maintenance.

In the CEP-Berlin Partnership there are different owners of the fuelling station units. Aral is the owner of the site and the compressor, gaseous storage and dispenser. Linde is the owner of the liquid hydrogen equipment. Hydro is the owner of the electrolyser. As a result of the divided ownership, the owners are individually responsible for operation and maintenance of their equipment. For safety purposes a mutual agreement fulfilling the public requirements has been set up, to bridge the partly sub-optimal way to organize these responsibilities in a demonstration project with somehow divergent goals of the different owners and operators.

For this particular project Aral/BP was responsible for contact and information with the authorities and TÜV as far as the overall approvals were concerned. The individual partners were responsible for their own properties and obligated to give sufficient information and documentation for the approvals.

The ability to move forward from the office desk and realize and demonstrate hydrogen solutions based upon the best technology available is needed if the Hydrogen society shall move closer in time. German federal authorities and the CEP-Berlin partners see this and have all contributed in Berlin.

Some have the opinion of Hydrogen as hazardous, which is true for hydrogen as for any other vehicle fuel, if not handled properly. The opinion of hydrogen as hazardous might work as a barrier against the use of hydrogen as an energy carrier. Real projects in public areas and everyday use are probably the best way to learn how to handle, assess the risks, to demonstrate safe operations and to break down this barrier.

The CEP-Berlin partnership will hopefully be a source for solutions, experiences, approval processes and safety activities for the coming hydrogen fuelling stations. [9]

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