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Health and Safety Workshop Report (2022)

During the

1st Symposium on Ammonia Energy

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Summary

This report summarises the discussions that took place around the topic of "Ammonia as an Energy Vector – Health and Safety" during the Health and Safety Workshop of the 1st Symposium on Ammonia Energy hosted at Cardiff University from the 1st to the 3rd of September 2022. Several presenters from various companies and organizations participated in the discussions, and all provided some insight into the most concerning issues when using ammonia as an energy vector. The workshop, hosted by the Health and Safety Executive (HSE), promised to examine some important questions that need to be answered via R&D to tackle the unknowns of using ammonia in both the energy and transport sectors. The outcome of the workshop is this document, which will be put forward in the following H&S workshops scheduled to be taking place in future sessions of the Symposium, with the aim of coordinating research efforts undertaken by industries, governmental bodies and academic institutions that are targeted at solving the problems related to producing, carrying, distributing and employing ammonia as an energy source.

Disclaimer: The report does not represent HSE's views. The report summarises the discussions addressed during the 1st Symposium on Ammonia Energy

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Introduction

Ammonia is both toxic and flammable and it is therefore important to carefully manage risks to health, safety and the environment related to potential loss of containment scenarios. Ammonia is usually stored and transported in liquid form at pressures above about 8 bar (at atmospheric temperature) or at temperatures below -33°C (at ambient pressure). Leaks of pressure-liquefied ammonia produce cold two-phase jets composed of ammonia aerosols and vapour. The resulting ammonia clouds are often heavier than air, due to the low temperatures and the presence of the aerosols. Releases of temperature-liquefied ammonia have also been observed to produce heavier-than-air clouds in some incidents. The dispersion of these dense toxic clouds can lead to significant hazard ranges.

Handling of ammonia presents some materials-related issues that need to be considered carefully, such as stress corrosion cracking. Appropriate materials should be selected and mitigations measures implemented, e.g., use of inert gas and the addition of a small quantity of water to anhydrous ammonia in cryogenic liquid ammonia storage tanks. It is also important to have appropriate inspection regimes.

These issues are recognized by the ammonia industry, who have a long track-record of operating ammonia production and distribution sites safely. However, the coming years are likely to see a significant growth the use of ammonia as an energy vector and marine fuel. It is important to ensure that new entrants to the market are aware of the health, safety and environmental risks of ammonia, and that they manage these risks appropriately. Novel risks may also emerge due to the use of ammonia in new environments and/or for new applications. It is important that research is undertaken to ensure that these novel risks are identified and appropriately managed.

This compilation of discussion-outcomes from the *1st Symposium on Ammonia Energy* has been divided into four sections: production, storage, distribution and use of ammonia. Each contains the comments raised by the participants. Additional comments have been added in some cases to highlight the progress made on each point and the requirements for R&D.

Production

A recurrent comment during the workshop was that production, although not necessarily linked to ammonia for energy, needs to be made inherently safe, especially considering new methods of production using decentralized systems (i.e., renewable energy). The need for designs and developments that can be made safer for the final consumer could make the market on this application, a new niche for energy generation and storage.

Storage

It was noted that several field-scale experimental test series have been undertaken to understand the behaviour of pressure-liquefied ammonia (e.g., Desert Tortoise, FLADIS) but

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there is little or no data on releases of cold, refrigerated ammonia. Releases of refrigerated ammonia should in principle present a lower risk than pressure-liquefied ammonia, but incidents such as the tank overfill at Blair, Nebraska in 1970 demonstrated that temperature-liquefied releases could still give rise to large, heavier-than-air clouds. Comments raised in the discussions included: "Has this been a coincidence across those reports documenting H&S events? Or is it that refrigerated ammonia has never caused major issues?". It was noted that there are documented cases where people have been exposed to ammonia, sometimes where transfer connections to tanks were not properly made, leading to leaks and exposure, e.g., the Beach Park, Illinois incident in 2019.

An important issue that concerned potential users (including those participating in the workshop) was related to transfer operations and filling of cylinders. Future applications include the replacement of LPG/propane with ammonia for fuel at sites that are not connected to the natural gas distribution network (or, in the future, the hydrogen distribution network). The level of training of operatives involved in filling ammonia tanks near occupied sites, and the use of appropriate risk assessment were raised in the discussions. New systems need to be developed to completely reduce the risk of leaks. It is foreseen that the designs will be found but with an additional cost: however, the cost of safety should not be the main concern.

Regarding good practice guidance and standards, some good precedents can be seen in the fossil fuels industry. Standards have been under development for several decades for LPG, LNG etc. Sites currently handling ammonia have also developed standards and procedures, although these are often internal to the company and not widely shared. It was agreed that it would be useful for current ammonia producers/users to work with new entrants to the market, to share their expertise and develop new standards to ensure that new ammonia infrastructure is designed and operated safely. For the fossil fuel industry, trade organisations such as the Energy Institute and IGEM have helped to produce publications on good practice guidance. For the ammonia industry, it is less clear who is helping to coordinate similar efforts. The American Institute of Chemical Engineers has an annual meeting on ammonia safety, which currently seems to be the main focal point. There are also organisations like the US-based Ammonia Safety Training Institute. For other toxic industrial chemicals, such as chlorine, there is more comprehensive guidance available than is the case for ammonia, e.g., Chlorine Institute publications. In the UK, the HSE and Environment Agencies have discussions with sites handling chlorine in bulk (through the Chlorine Covenant Steering Group), but there is no parallel currently for ammonia.

There have been some initial indications that in engines operating on ammonia, lubricating oils have been contaminated with ammonia. The potential risks to health from exposure to contaminated oil, e.g., during engine maintenance, requires further R&D.

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Finally, the potential uses of ammonia for aerospace applications was brought to the attention of the panel. Currently, the aerospace industry is focusing on hydrogen, but ammonia is a potential future option. A question was asked: “Would it be possible to design a system capable of controlling this evaporation in case of a catastrophic event?” A point for future discussions perhaps.

Distribution

Points raised regarding distribution were around the precedent of companies that have been already approached by ammonia producers, with Northern Germany and other countries already running yachts on ammonia. Ammonia is currently widely used in the fertiliser and chemical industries, and it would be useful to benefit from the long experience of use in these industries. However, some new problems could arise with the use of ammonia as a fuel. Some of the challenges that need to be addressed, as distinct from the current use where specialists tend to handle ammonia, come when inexperienced people are handling the chemical. This is an important issue, since ammonia has now been seriously considered as a transportation fuel. Risk assessments followed by test and demonstration campaigns in marine transport are required for these and other points, for what seems to be the most promising new market for the utilization of ammonia.

Utilization

Anhydrous ammonia (NH3) has been identified as a potential long-term fuel that could enter the market relatively quickly and offer a zero, or a near-zero, carbon solution (on a tank-to-wake basis and in some cases on a well-to-wake basis) irrespective of the origin of the fuel.

While there is little recent marine experience when using ammonia as a fuel – and some of the key machinery technologies (such as engines) are under development – extensive land-based experience with the production and use of ammonia for the petrochemical and fertiliser industries forms a sound basis for increasing its use as a marine fuel. Experience with the carriage of ammonia in liquefied-gas carriers – and the specific requirements for storage, distribution, personal protective equipment (PPE), etc. in the International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) – provide some of the statutory requirements to guide its application on ammonia-fuelled ships.

However, toxicity challenges and related risks are significant and, while manageable, they will add complexity to ship designs (compared to those for conventional and other low-flashpoint fuels and gases) and will potentially limit the ships for which it is a suitable fuel. Ammonia ultimately may prove to be a more appropriate solution for deep-sea cargo ships rather than short-sea, passenger or inland waterway craft. It is also envisaged that long distance or heavy cargo will benefit from ammonia utilisation.

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Some key considerations that need to be contemplated for ammonia to be commercially used as a global commodity include:

- Ammonia bunkering and supply - From a technological and operational perspective, loading and unloading ammonia as a commodity at the terminal is similar to bunkering ammonia as a fuel. However, the option of bunkering ammonia from cargo terminals presents immense challenges as a solution.
- Safety considerations in ship and heavy duty transport designs- One of the primary drivers of vessel design is the need to figure out how to reduce the risk of exposure to crew in case of a leak. Design and layout must be treated with a high level of safety, from concept to material selection (protecting the structures from corrosive exposure of ammonia) and finally operational measures. Relevant risk assessments are needed to prevent accidents. This would take into consideration the probability of leakage, gas detection systems, and certification along the supply chain. Also, new regulations and rules development are needed and could be extended and fortified from existing rules.
- Handling ammonia onboard ships will require a complete new set of skills and safety procedures. Ammonia is highly toxic – more so than traditional fuels. At ambient temperature and pressure, it is a corrosive and flammable gas and there is a high risk for human exposure through inhalation and skin contact with long-lasting effects. It can have similar impacts on aquatic life.

The UK framework COMAH 2015 came into force on the 1st June 2015 and revoked the COMAH regulations of 1999. Schedule 1 Part 2 of the Regulations lists named dangerous substances. Anhydrous Ammonia is number 35 on the list and the qualifying quantity in tonnes for the application of lower tier requirements is 50 tonnes. The qualifying quantity for upper tier is 200 tonnes. Under the new regulations all COMAH premises will be required to have major accident prevention policies in place. The COMAH regulations provide an example of a proven framework that controls the ammonia risks. This enabled some UK based industries to develop their own best practices guidance to enables the relevant duty holders to manage properly the ammonia risks and it can provide the basis for managing ammonia fuel risks.

There are other considerations related to the use of ammonia close to populated centres. Site operators will need training courses and better information about handling ammonia as a fuel. Similarly, questions such as the potential risk associated with the use of ammonia in dry (land) and wet (marine) locations will need to be addressed.

Important issues raised during previous workshops were also related to the heterogenous landscape of ammonia as a fertilizer, chemical, and now as a fuel. The lack of regulations in the final case shows that there is still a long way before full commercialization of ammonia fuel is achieved. Some safety considerations and international gas codes prevent the

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utilization of toxic substances as fuels, an issue that needs to be addressed in more detail across engine associations (which need to be also involved in these discussions).

Aspects that are related to the specific applications of ammonia are also important. It is likely that ammonia will have to be blended for use in combustion engines and a different pilot fuel will be needed to initiate stable combustion. Research in this area is taking place. There are also still challenges ahead with the production of NOx and affordable cracking methods to crack ammonia into hydrogen (which is then used to achieve moderated hydrogen contents in these ammonia blends). Other points such as corrosion in high temperature components are also critical, with seals, bearings, blades, etc., potentially being exposed to corrosive atmospheres. Research in this area is needed. Oils and ammonia can also react, hence the right lubricant needs to be employed to reduce risks. Safety concerns of using ammonia have delayed some of these progresses, thus requiring further analyses and interaction between interested parties to progress with this technology. Long-term impact of these interactions are still unknown, hence prompting to the need of more demonstrators worldwide.

Similarly, fuel cells require high cleanliness in the fuel so materials and membranes are not corroded and/or poisoned. Although hydrogen fuel cells have existed for many years, using fuel cells with ammonia can pose a challenge for the direct use of the molecule, which needs to avoid contaminants at very high limits.

Finally, public perception needs to be considered, since it will play a critical role in the development of an ammonia-fuelled economy. Although ammonia leaks can provide a recognisable smell (different to CO "silent" killer), it is essential that further training and understanding of the molecule is achieved at community level, especially in case of catastrophic events – which have not been looked at yet. Although ammonia's history is generally good in the refrigeration and agriculture sectors, its use as a fuel will bring other challenges. These need to be managed and technical solutions may be needed to be developed to mitigate risks.

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