SAFETY & TRANSPORT
RISE FIRE RESEARCH

From petrol station to multifuel energy station: Changes in fire and explosion safety

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RISE-report 2021:26

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Abstract

From petrol station to multifuel energy station: Changes in fire and explosion safety

A multifuel energy station is a publicly available station which offers refueling of traditional fossil fuels in combination with one or more alternative energy carriers, such as hydrogen or electric power to electric vehicles. The goal of this study is to survey how the transition from traditional petrol stations to multifuel energy stations affects the fire and explosion risk.

Relevant research publications, regulations and guidelines have been studied. Four interviews with relevant stakeholders have been conducted, in addition to correspondence with other stakeholders. The collected information has been used to evaluate and provide a general overview of fire and explosion risk at multifuel energy stations. The scope of the project is limited, and some types of fueling facilities (in conjunction with supermarkets, bus- and industrial facilities), some types of safety challenges (intended acts of sabotage and/or terror), as well as transport of fuel to and from the station, are not included.

Availability of different types of fuel in Norway was investigated and three types were selected to be in focus: power for electric vehicles, gaseous hydrogen, as well as hydrogen and methane in liquid form. The selection was based on expected future use, as well as compatibility with the goal of the National Transport Plan that all new vehicles sold from 2025 should be zero emission vehicles. Currently, the category zero emission vehicle includes only electric- and hydrogen vehicles.

In facilities that handle flammable, self-reactive, pressurized and explosive substances there is a risk of unwanted incidents. When facilities with hazardous substances comply with current regulations, the risk associated with handling hazardous substances is considered not to be significant compared to other risks in society. When new energy carriers are added, it is central to understand how the transition from a traditional petrol station to a multifuel energy station will change the fire and explosion risk. Factors that will have an impact include: number and type of ignition sources, number of passenger vehicles and heavy transport vehicles at the station, amount of flammable substances, duration of stay for visitors, complexity of the facility, size of the safety distances, fire service's extinguishing efforts, environmental impact, maintenance need etc. In addition, each energy carrier entails unique scenarios.

By introducing charging stations at multifuel energy stations, additional ignition sources are introduced compared to a traditional petrol station, since the charger itself can be considered as a potential ignition source. The charger and connected car must be placed outside the Ex-zone in accordance with NEK400 (processed Norwegian edition of IEC 60364 series, the CENELEC HD 60364 series and some complementary national standards), in such a way that ignition of potential leaks from fossil fuels or other fuels under normal operation conditions is considered unlikely to occur. A potential danger in the use of rapid charging is electric arcing, which can arise due to poor connections and high electric effect. Electric arcs produce local hot spots, which in turn can contribute to fire ignition. The danger of electric arcs is reduced by, among others, communication between the vehicle and charger, which assures that no charging is taking place before establishing good contact between the two. The communication also assures that it is not possible to drive off with the charger still connected. There are requirements for weekly inspections of the charger and the charging cable, which will contribute to quick discovery and subsequent repair of

faults and mechanical wear. Other safety measures to reduce risk include collision protection of the charger, and emergency stop switches that cut the power delivery to all chargers. There is a potential danger of personal injury by electric shock, but this is considered most relevant during installation of the charger and can be reduced to an acceptable level by utilizing certified personnel and limited access for unauthorized personnel. For risk assessments and risk evaluations of each individual facility with *charging stations*, it is important to take into account the added ignition sources, as well as the other mentioned factors, in addition to facility specific factors.

Gaseous hydrogen has different characteristics than conventional fuels at a petrol station, which affect the risk (frequency and consequence). Gaseous hydrogen is flammable, burns quickly and may explode given the right conditions. Furthermore, the gas is stored in high pressure tanks, producing high mechanical rupture energy, and the transport capacity of gaseous hydrogen leads to an increased number of trucks delivering hydrogen, compared with fossil fuels. On the other hand, gaseous hydrogen is light weight and easily rises upwards and dilute. In the case of a fire the flame has low radiant heat and heating outside the flame itself is limited. Important safety measures are open facilities, safe connections for high pressure fueling, and facilitate for pressure relief in a safe direction by the use of valves and sectioning, so that the gas is led upwards in a safe direction in case of a leakage. For risk assessments and risk evaluations of each individual facility with *gaseous hydrogen*, it is important to take into account the explosion hazard, as well as the other mentioned factors, in addition to facility specific factors.

Liquid hydrogen (LH2) and liquid methane (LNG, LBG) are stored at very low temperatures and at a relatively low pressure. Leakages may result in cryogenic (very cold) leakages which may lead to personal injuries and embrittlement of materials such as steels. Critical installations which may be exposed to cryogenic leakages must be able to withstand these temperatures. In addition, physical boundaries to limit uncontrolled spreading of leakages should be established. Evaporation from tanks must be ventilated through safety valves. During a fire, the safety valves must not be drenched in extinguishing water, as they may freeze and seal. Leakages of liquid methane and liquid hydrogen will evaporate and form flammable and explosive gas clouds. Liquid hydrogen is kept at such a low temperature that uninsulated surfaces may cause air to condense and form liquid oxygen, which may give an intense fire or explosion when reacting with organic material. For risk assessments and risk evaluations of each individual facility with *liquid hydrogen and liquid methane*, it is important to take into account the cryogenic temperatures during storage and that it must be possible to ventilate off any gas formed by evaporation from a liquid leakage, as well as the other mentioned factors, in addition to facility specific factors.

For the combination of more than one alternative energy carrier combined with fuels of a conventional petrol station, two areas of challenges have been identified: area challenges and cascading effects. *Area challenges* are due to the fact that risks to the surroundings must be evaluated based on all activity in the facility. When increasing the number of fueling systems within an area, the frequency of unwanted incidents at a given point in the facility is summarized (simply put). If two energy carriers are placed in too close proximity to each other, the risk can be disproportionately high. During construction, the fueling systems must be placed with sufficient space between them. In densely populated areas, shortage of space may limit the development. *Cascading effects* is a chain of events which starts small and grows larger, here due to an incident involving one energy carrier spreading to another. This may occur due to ignited liquid leakages which may flow to below a gas tank, or by explosion- or fire related damages to nearby installations due to shock waves, flying debris or flames. Good technical and organizational measures are important, such as sufficient training of personnel, follow-up and facility inspections, especially during start-up after installing a new energy carrier. The transition from a traditional petrol station to a multifuel energy station could not only give negative cascading effects, since sectionalizing of energy carriers, with lower storage volume per energy carrier, as well as physical separation between these, may give a reduction in the potential extent of damage of each facility. Apart from *area challenges* and *cascading effects* no other combination challenges, such a *chemical interaction challenges*, have been identified to potentially affect the fire and explosion risk.

For future work it will be important to keep an eye on the development, nationally and internationally, since it is still too early to predict which energy carriers that will be most utilized in the future. If electric heavy transport (larger batteries and the need for fast charging with higher effect) become more common, it will be necessary to develop a plan and evaluate the risks of charging these at multifuel energy stations. For hydrogen there is a need for more knowledge on how the heat of a jet fire (ignited, pressurized leakage) affects impinged objects. There is also a general need for experimental and numerical research on liquid hydrogen and methane due to many knowledge gaps on the topic. During operation of the facilities and through potential unwanted incidents, new knowledge will be gained, and this knowledge must be utilized in order to update recommendations linked to the risk of fire and explosion in multifuel energy stations.

Key words:
Multi fuel energy station, energy station, safety, fuel, DC fast charging, quick charging, rapid charging, hydrogen, new energy carriers.

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Front page photo: Example of a multifuel energy station. Photo: Eight Inc (contacted for permission to use)
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Content

Foreword

RISE Fire Research has since 2015 studied fire safety challenges related to alternative energy carriers in vehicles. This project is funded by the Norwegian Directorate for Civil Protection (DSB) as part of the project portfolio under the research agreement between DSB and RISE Fire Research.

We would like to thank representatives from the industry, fire service, research institutes and authorities who have participated in interviews and provided input for the project.

Cristina Sanfeliu Meliá has been working on her master's thesis *Study and Analysis of Fire Safety in Energy Stations in comparison with Traditional Petrol Stations* at NTNU (http://hdl.handle.net/11250/2621262) in parallel with the project. We would like to thank Cristina for important input and background information.

This report is a translation of the Norwegian version of the report (RISE report 2020:11). If there are conflicting phrasing or uncertainties, the phrasing in the Norwegian version has priority. The scientific content of the report is updated per early 2020, as the majority of the report is prepared in 2019 and early 2020.

Trondheim, July 2021

Dr. Ragni Fjellgaard Mikalsen
Researcher and Project Manager

1 Introduction

1.1 Background

In connection with an increasing share of the car fleet being operated by energy carriers other than fossil fuels, a restructuring of the traditional petrol stations to become multifuel energy stations is expected. Here, other energy carriers than petrol are also offered, such as electricity, hydrogen in gaseous and liquid form (LH2), liquefied and compressed natural gas (LNG and CNG). The EU Directive 2014/94/EU [1] on the establishment of infrastructure for alternative energy carriers is helping to drive this development. In the long term, fossil fuels are expected to be phased out.

The Norwegian Directorate for Civil Protection (DSB) has asked RISE Fire Research to study how petrol stations need to be changed to meet future fuel demand, as well as the risks this represents with regard to fire and explosion.

1.2 Objectives and research questions

The objective of this study is to highlight the risks that a change from petrol stations to multifuel energy stations entails with regard to fire and explosion hazards, and which risks must be taken into account when establishing energy stations.

1.3 Limitations

The project does not include standalone stations (not connected to petrol stations), stations that are not publicly available (e.g. stations for fuel supply for buses or inside industrial facilities), stations connected to facilities other than petrol stations (such as supermarkets, restaurants or the like), or offshore/maritime facilities. However, some learning points from such facilities are included, in cases where risk factors relevant to energy stations have been found.

Facilities with potential for major accidents[1] are not the focus of this study.

Will-created hazards (by individuals or terror) is beyond the scope of the study.

Transport of energy carriers to and from energy stations is beyond the scope of the study.

The assessment of the explosion hazard is limited to evaluating the possibility of build-up and late ignition of a gas cloud. The explosion pressure and the consequences of an explosion have not been assessed in detail.

[1] These facilities are as defined in the Regulation on major accidents, *Storulykkeforskriften* [2]

Due to the number of energy carriers studied and the following large scope of relevant standards and guidelines, content in each standard is not presented in detail, but an overview of relevant standards is provided.

1.4 Method description

Literature review:

Relevant research in the field was identified through searches for publications in scientific databases. It has also been searched for reports and other publications in other databases and search engines on the internet that may contain relevant information.

Relevant, Norwegian regulations have been studied to provide a summary of regulations that govern energy stations. Guidelines and standards that can be used for the design of energy stations have also been studied.

Requests were sent out to the industry to provide access to risk assessments, either for standalone facilities or for integrated multifuel energy stations. A total of four risk assessments were received and reviewed, of which one was of a standalone hydrogen filling stations, and three were existing petrol stations that were expanded to also include fast charging, or filling of hydrogen or propane.

Contact with stakeholders

The following interviews were-conducted (see Appendix A for details on the information that was sent in advance of the interviews):

- Lloyds Register Norway: Chief Engineer, Risk Analysis of Hydrogen Stations, Interview 07.11. 2019.
- Asker and Bærum fire and rescue service: On-site chief (*beredskapssjef og innsatsleder*) at the Kjørbo incident, interview 15. 11,2019.
- Drivkraft Norway: Head of Trade (*fagsjef*), interview 28.11. 2019.
- Circle K, senior manager for fast charging, senior specialist HSE and senior engineer, interview 13.01. 2020

In addition, the following have provided input:

- Oslo Municipality: Mobility Advisor
- Trondheim Municipality: Advisor department climate and society
- Bergen Municipality: Advisor mobility
- ASKO Midt-Norway AS: Technical responsible, vehicles
- RISE Research Institutes of Sweden: researchers in the Scandria®2Act project
- DSB: contact persons in the project
- Trøndelag Fire and Rescue Service (TBRT)
- Norwegian Electrical Engineering Committee: Head of Trade (*fagsjef*).
- NELFO: Director, technical section.

Risk overview:

Based on information obtained above, the project team conducted a brainstorming around which aspects are changed when changing from the base case of a petrol station and adding energy carriers one at the time. This laid the foundation for a what-if analysis of risk, where it was looked at what could go wrong in various scenarios, possible causes and possible consequences were identified, and a qualitative assessment of the risk picture was made, where also possible risk-reducing measures were identified. During this work, knowledge gaps were continuously identified, where additional expertise was needed, which laid the foundation for detailed questions in the interviews. These again gave input to the overall assessment of the risk picture.

1.5 Ethical reviews

Interviews have been conducted where different professional stakeholders have participated. The informants are anonymized in the report, but the job title or position in the relevant organization is stated.

1.6 Funding

The project is funded by the DSB.

1.7 Dictionary

An overview of the terms and definitions used in this report is provided in Table 1-1.

Table 1-1 Concepts and definitions used in the report

Idea	**Definition**
Alternative energy carriers	Energy sources to partially replace fossil fuels and contribute to improved environmental impact in the transport sector. Examples of alternative energy carriers: Electricity, hydrogen, natural gas (including CNG and LNG) and Liquid Petroleum Gas (LPG).
BLEVE	Boiling Liquid Expanding Vapor Explosion. A sudden release of a large mass of pressurized superheated liquid to the atmosphere. [3]
Charging station	One or more charging points with installation for charging chargeable cars. A charging point is a parking space or place with a connection to a charging installation (charging post or charging box). [4] *(direct translation from Norwegian)*
Combustible	Capable of being ignited and burned [5]
Deflagration	Combustion (exothermic reaction of a substance with an oxidizing agent) wave propagating at subsonic velocity [5]

Detonation	Reaction characterized by a shock wave propagating at a velocity greater than the local speed of sound [5]
Explosion	Here used about deflagration.
Ex-range/ Ex-zone	Area where explosive atmosphere may form in normal operation, as defined in ATEX User Regulation §3.
Fast charge	Charging a chargeable car using a type of fast charge connector (power over 22 kW). Fast charge connector is a collective term for various connectors specifically designed for fast charging (Charging mode 4), e.g. Tesla Supercharger, CHAdeMO and Combo. [4] *(direct translation from Norwegian)*
Flammable substance (*Brannfarlig stoff*)	A solid, liquid or gaseous substance, mixture of substances and a substance that occurs in combinations of such states, which, due to its flash point, contact with other substances, pressure, temperature or other chemical properties, represent a fire hazard. (*from DSB's unofficial translation of the Regulation on handling of flammable, reactive and pressurized substances* [6] *per 16th March 2017*)
Multifuel energy station/ energy station	Publicly available station where filling of traditional fossil fuels is offered in combination with one or more alternative energy carriers.
Risk contour	A calculated line around a facility where a defined risk is constant. This term is used in this report about the points around a facility where the frequency is constant for a person standing in the same place, around the clock for one year, to perish as a result of an unwanted incident at the facility. [7,8] *(direct translation from Norwegian)*
Safety distance	Distance from a facility that presents a given risk based on a defined acceptance criterion. General safety distances do not take into account factors in the environment that could affect the consequences of an event [7]. *(direct translation from Norwegian)* The term is used for distances on and around small and medium-sized facilities.
Third-party	Person who does not visit the energy station, but who is staying nearby and may be indirectly affected by the activity. Differs from the first person (directly involved in activity by working at the station) and the second person (using the station). [9] *(direct translation from Norwegian)*
Zone	The term is used for explosive atmosphere at facilities in normal operation.
Zones requiring special consideration (*Hensynssone*)	There are many different types of zones requiring special consideration (cf. §11-8 in [10]), the one relevant here are safety, noise and hazard zones (cf. §11-8a in [10]). The term is used for area restrictions around facilities with potential for major accidents.

Table 1-1 Abbreviations for different types of fuel mentioned in the report, based on [4].

Abbreviation	**Importance**
ATEX	"ATmosphere EXplosible". EU directives regulating the hazards associated with explosive atmosphere.
CBG	Compressed BioGas. Methane produced from the decomposition of organic waste.
CNG	Compressed Natural Gas. Methane produced from fossil gas.
LBG	Liquified BioGas. Methane produced from the decomposition of organic waste.
LH2 -	Liquid Hydrogen (H_2).
LNG	Liquified Natural Gas.
LPG	Liquid Petroleum Gas. Either pure propane or pure butane or a mixture of these. In Norway, LPG is essentially propane, since it has properties that are well suited for the climate.

2 System description

2.1 Definition energy station

In this project, the term *multifuel energy station* is defined as follows:

Multifuel energy station: Publicly available station where filling of traditional fossil fuels is offered in combination with one or more alternative energy carriers.

In this report, the terms *multifuel energy station*, and *energy station* (in Norwegian - “Energistasjon”) is used interchangeably. There is no consensus on an unambiguous definition of this term in Northern-Europa, according to Wiberg and Bremer [11]. This is because this type of station is relatively new. In Norway there are currently few or no examples of stations with more than one alternative energy carrier in addition to fossil fuels. In this context alternative energy carriers are defined as energy sources or fuels to partially replace fossil fuels and contribute to improved environmental impact in the transport sector - such as electricity, hydrogen, natural gas (CNG and LNG) and liquid petroleum gas (LPG).

This project studies the change from a traditional petrol station (in Figure 2-1 illustrated with a station that has a kiosk and three filling pumps) to an energy station (in Figure 2-1 one of the filling pumps is replaced with an alternative energy carrier). There are also other areas where alternative energy carriers are offered, such as outside restaurants and shopping centers, but this is not in focus in this project.

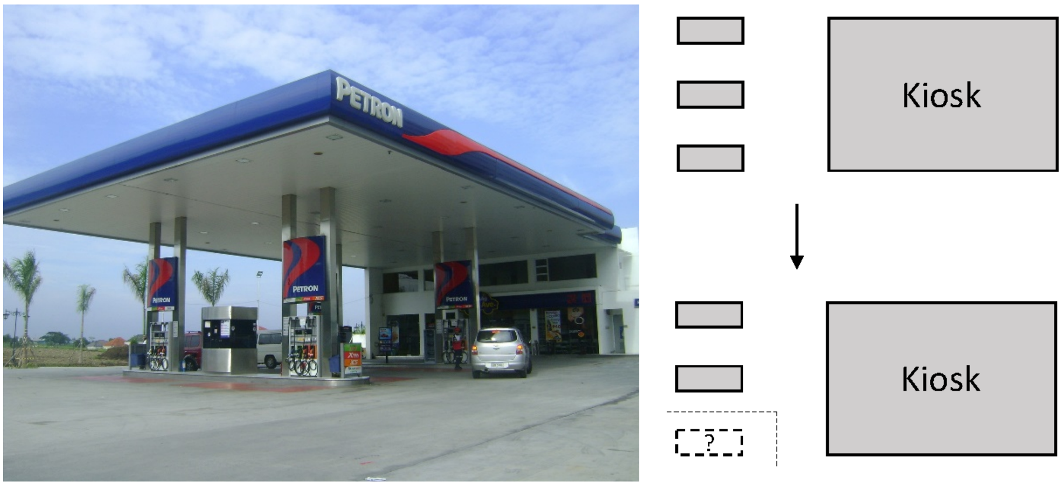

Figure 2-1 Example of a petrol station, with a kiosk and some pumps for petrol or diesel. When a petrol station is changed to be an energy station, one or more alternative energy carriers are offered, such as fast chargers, hydrogen in gas or liquid form, liquefied natural gas, liquefied propane or other form for energy carrier. Photo: Nora Tamba via Pixabay, used with permission.

Here the term public available refers to publicly available stations that anyone can use. These are typical stations along public roads or in a city center. It is not focused on areas inside industrial areas or other restricted areas, such as bus stations or individual filling points for heavy goods transport.

2.2 Market participants today

The different stakeholders in the market involved in various parts of the value chain of an energy carrier is illustrated in Figure 2-2.

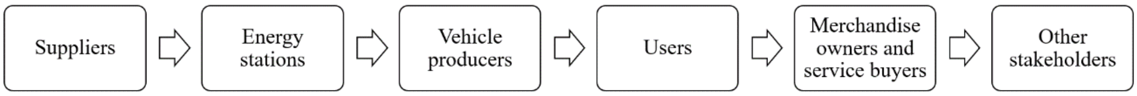

Figure 2-2 Stakeholders in the supply chain of energy carriers. Based on the city of Oslo's declarations of intent for biogas and hydrogen, made available for the project.

Examples of stakeholders within the different parts of the market for a given energy carrier:

- Suppliers/ Manufacturers: Statkraft, Uno X, VEAS, municipalities
- Energy stations: Circle K, Uno X, HyNiOn, AirLiquide, AGA
- Vehicle producers: Toyota, Hyundai, Tesla,
- Users: General population, goods transport, taxis, municipalities, municipalities, car hire companies
- Merchandise owners and service buyers: Municipalities, VEAS, shopping centers
- Other stakeholders: Authorities, municipalities, trade organizations such as Nelfo, Energigass Norway and Drivkraft Norway, Elbilforeningen, The Norwegian Automobile Industry Association.

2.3 Development and energy stations of the future

This section presents the distribution of different types of fuel today and how this may develop in the future, as well as national and regional guidance that influence this. Based on this, some energy carriers are selected as the focus in chapters 4 and 5.

Today, petrol and diesel still make up the vast majority of fuel used for road transport, according to Statistics Norway [12]. Figure 2-3 shows the development in consumption of conventional fuel and alternative fuel for road transport until 2018. The increase in biodiesel use represents the largest change in the use of alternative fuels. Biogas accounted for about 2% of the energy used for land transport in 2018 and natural gas amounted to less than 1%. Electricity accounted for just over 1% of the energy consumption of road transport, but it must be seen in the context of an electric car being over three times more energy efficient than a diesel car. The use of Hydrogen as fuel is still so low that it is not included in these statistics. [12]

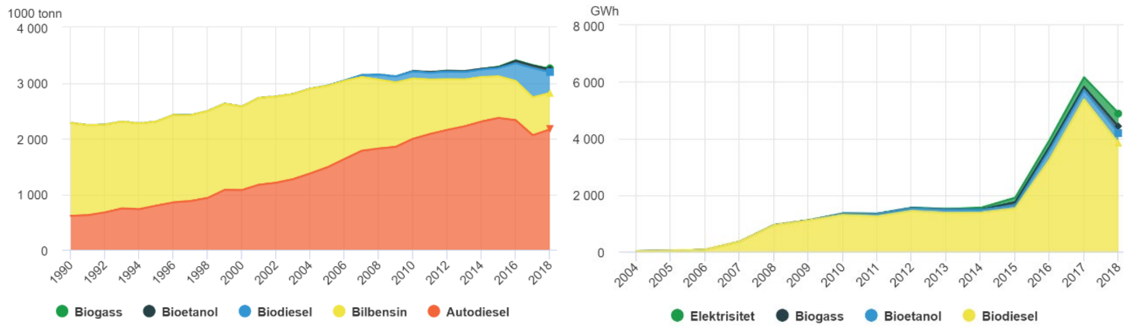

Figure 2-3 Consumption of fuel for road transport from 1990 to 2018, specified in 1000 tons (left graph, *English legends: Bio gas, bio ethanol, bio diesel, bio gasoline, auto diesel*). Consumption of alternative fuels for road transport from 2004 to 2018, specified in GWh (right graph, *English legends: electricity, bio gas, bio ethanol, bio diesel*). Notice different y-axis on the two graphs. The figures are taken from Statistics Norway [12].

According to the National Transport Plan 2018 - 2029, there is a goal that all new vehicles from 2025 will be zero emission vehicles [13]. This will help to change the transport sector to ensure that a larger share in the future will be zero emission vehicles. This will in turn affect the operation of energy stations, for example will a lower petrol/diesel consumption mean less frequent refilling of on-site fuel storage tanks. At the same time, will the filling of zero emission vehicles increase. Currently, only electric cars and hydrogen vehicles are defined as zero emission vehicles, while according to the trade organization Drivkraft Norge [14] also other energy carriers will be relevant in the future, such as LPG extracted from biomass.

The Norwegian government's action plan for alternative fuel infrastructure in the transport sector from July 2019 [4] presents the current status of alternative energy carriers in Norway, and the Government's planned future investments in the area. It is focused on electricity, hydrogen, biogas and liquid biofuels. It is pointed out that the developments should be market driven, that the state should not contribute to solutions that undermine the market, but that Enova[2] can provide support for the establishment of projects that would not otherwise have been realized. This is consistent with the desire of Drivkraft Norge, that political guidelines should be technology-neutral[3]

In municipalities across Norway, work is also being conducted to understand how the development of alternative energy carriers in each region will be, so that the municipality can facilitate increased use of renewable energy. Oslo municipality is working on declarations of intent for biogas and for hydrogen, with the goal of facilitating "simultaneousness in the value chain"[4]. In this way, the municipality will be able to facilitate the different players in the value chain to move to a given energy carrier at the same time, and this will ease the transition and introduction of new technologies. In Trondheim, the engineering, design and consultancy company Rambøll has mapped out the types of fuel, filling technology and business models that will be relevant in the municipality in the future, based on the status as of 2018 [15]. They have

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[2] Enova shall contribute to the restructuring of energy use and energy production and is owned by the Ministry of Climate and Environment (www.enova.no).
[3] According to an interview with the Head of Trade (*fagsjef*) at Drivkraft Norge, 28 November 2019.
[4] Email correspondence with m1999: Oslo Municipality

looked at electricity/ fast chargers, compressed and liquid biogas, hydrogen, biodiesel, bioethanol and a fossil reference. Their forecast shows that a strong growth in the share of electric cars can be expected and that charging capacity should therefore be developed. Biogas and hydrogen are the most widely used in the private sector as of 2018, such as bus companies and the grocery wholesale company ASKO. From the consumer's perspective (emissions, noise, fuel prices and energy use), electricity and hydrogen come out best. From the owner of the energy station's perspective (investment and operating costs, market risk and expected vehicles) biodiesel and fast chargers for light vehicles come out well, while hydrogen comes out worse due to market risk compared to electric vehicles, as well as high investment and operating costs and market risk. Bergen municipality has received a similar survey conducted by the consultancy company Flowchange, focusing on fossil-free freight transport and fossil-free construction operation [16].

The trade organization Drivkraft Norge organizes companies that sell liquid fuel and energy, and they point out that it is difficult to predict the future, but believes that a variety of fuels will be relevant for different parts of the market[5]. There is a clear trend towards the renewables, which is, for example, reflected in the fact that Drivkraft Norge changed its name from the Norwegian Petroleum Institute in 2017 and the fact that it is now being considered to permanently move from using the phrase *petrol station* to using the phrase *energy station* instead. Today, the industry in Norway supplies biofuels, hydrogen, gas, charging electric cars in addition to petrol and diesel. The use of biofuel in petrol and diesel accounted for 12% of the total amount sold in 2018 [17]. Hydrogen technology is in development and the industry believes that similar conditions are needed as electric cars have had in an introductory phase and support schemes to establish filling stations. Electric car charging stations is one of the areas where the industry sees a large and growing need, and it is desirable that energy stations can offer charging also in the future. LPG consists of propane and butane and can be used as fuel for vehicles. This is relatively little widespread in Norway, but is the third most widely used fuel in the world. The industry believes that this is a fuel that is important in the transition to low emission society and which in the long term can be mixed in biocomponents. [18]

In neighboring countries to Norway, the forecasts are similar, according to a report from the project Scandria®2Act, where different aspects of energy stations with several different fuel types are reviewed [19]. The main focus is on the situation in Sweden, but information is also collected from Norway, Denmark, Finland and Germany. The report deals with hydrogen, methane, ethanol, diesel, petrol and charging of electric vehicles. According to the report, different types of vehicles will use different types of fuel, and energy stations will be divided into three different categories with different types of fuel:

- Cars and small trucks will use compressed hydrogen, compressed methane or fast charging.
- Buses will use compressed hydrogen, compressed methane, fast charging or overnight charging.
- Heavy transport vehicles will use liquid hydrogen or methane.

[5] According to interview with the Head of Trade (*fagsjef*) at Drivkraft Norge, 28 November 2019, and https://www.drivkraftnorge.no/

Since these three types of vehicles will not normally refuel at the same energy station, it will not be necessary to combine all these energy carriers in the same place. Buses have available space on the roof for storing the volume required for fuel such as compressed gas, and it is therefore expected that buses will be able to use fuel in gaseous form. Trucks need a large amount of energy placed in a small volume to avoid reducing load capacity. As hydrogen in liquid form has a greater energy density per volume than hydrogen in gaseous form, heavy transport is expected to use more liquid hydrogen than hydrogen in gaseous form, according to the study. Thus, fuel in the form of liquid hydrogen or methane is applicable despite the fact that this probably has a higher cost than compressed gas. [19]

Much research is now underway on the use of hydrogen in liquefied and gaseous form, for example in the projects SH2IFT [20] and PRESLHY [21], where the aim is to study and find documentation that could be used for safety assessments of hydrogen in liquefied and gaseous form. Based on experience through these and other projects, our assessment is that there is still quite some work that remains before liquid hydrogen is distributed as fuel at energy stations, but that this is necessary in order to use hydrogen as an energy carrier with sufficient energy density for use in heavy vehicles heavy transport.

What energy carriers will be used in the future will depend on technical and safety aspects, such as energy density, local emissions when used, the possibility of storage under pressure, etc. It will also largely depend on policy changes, which in turn may be guided by preferences on, for example, CO_2 emissions from fossil fuels. An example of policy changes is the reduction of taxes and tolls, which resulted in a strong market growth for electric vehicles in Norway. Similarly, political policies and economic incentives could influence the introduction of the distribution of other energy carriers.

2.4 Risk acceptance criteria at facilities handling hazardous substances

In facilities that handle flammable, self-reactive, pressurized and explosive substances there is a risk of unwanted incidents. DSB has prepared a theme guide on acceptable risk at these types of facilities [7]. This explains how to define what is an acceptable risk for an energy station. As a general rule, persons should not be exposed to a significant risk from energy stations compared with the general risk of perishing in an accident in a person's everyday life. For all accidents in total, the number of fatalities per year is 3.72×10^{-4} and for fire this is 1.23×10^{-5}, in the period 1992 – 2008 compared with the population of Norway. This gives a picture of what is the background risk of perishing in an accident within a year and means that one person statistically will die in an accident within 2688 years or in a fire within 81301 years.

When handling hazardous substances, there will always be a certain risk that people in the area may perish. For this type of facility, three different zones requiring special consideration (*hensynssone*) are defined. These zones are calculated from a risk contour at the outer edge of each zone where the frequency at which someone perishes as a result of an accident at the energy station is constant. Figure 2-4 illustrates the different zones requiring special consideration and what may be located within each zone. The inner zone (*indre hensynssone*) is the facility's area, in which short term passing-by may occur. In the middle zone (*midtre hensynssone*), public roads and permanent work locations may be located. There should be no accommodation or housing in this zone. In the outer zone (*ytre hensynssone*), dwellings, shops, small-scale accomodations may be located. Schools, kindergartens, nursing homes, hospitals, shopping centers, hotels and large public venues shall be located outside the outer zone. The figure also indicates the risk contours around each zone requiring special consideration (*hensynssone*) [7].

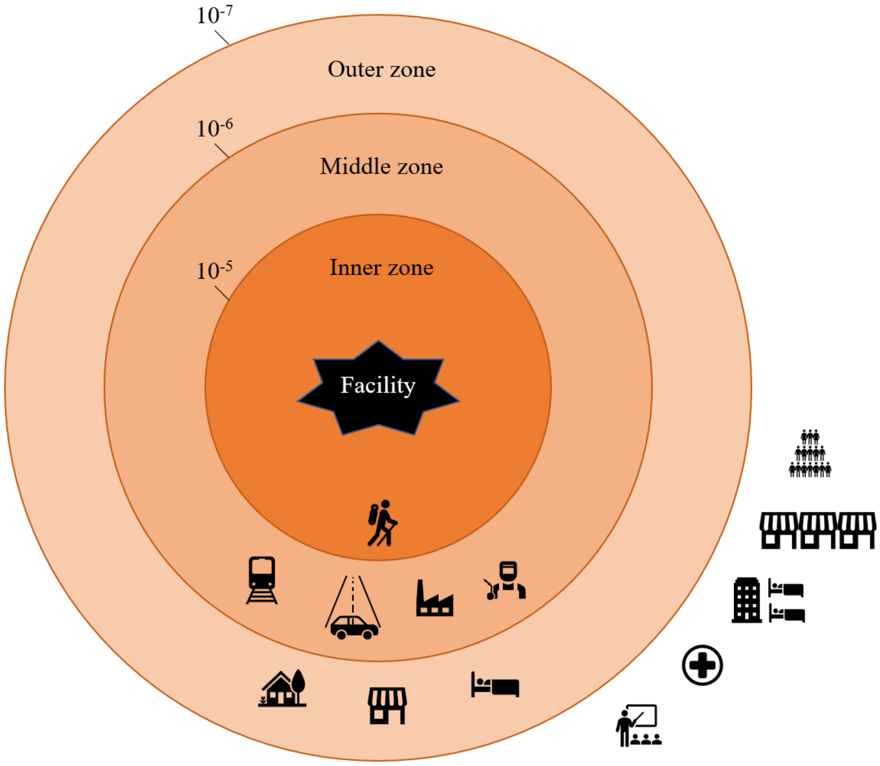

Figure 2-4 Illustration of the zones requiring special consideration (*hensynssone*) around an energy station and what may be located within each zones. Risk contours surround each zone. The figure is based on Fig 1 in DSB's theme guide [7].

In other words, these zones mean that for persons staying around the clock, all year round, on the boundary between the inner and middle zone at the outer edge of the energy station (the risk contour in Figure 2-4 marked as 10^{-5}) statistically, one person will die as a result of an accident at the station within 100 000 years.

As a starting point for quantitative risk analysis, an identification of hazards, often called HAZID, must be carried out. This should identify the events that may occur at the facility. The various events will be determined by the types of hazardous substances that are at the facility, the quantities of the hazardous substances, the size of the potential emission rate that can occur and the emission point locations at the facility. These events are further analyzed in terms of probability and consequence to identify the overall risk to the facility. [8]

Calculation of risk contours requires detailed knowledge of the facility and error rates as well as software for modeling the consequences of accidental incidents. The risk contours are up to the above acceptance criteria. Calculating risk contours for energy stations is not part of the work in this report. Furthermore, the focus will be on *qualitative* assessments of the risks that a change from petrol stations to energy stations represents.

3 Regulations and guidelines

The regulations and guidelines in this chapter are given in Norwegian, if there are conflicting phrasing or uncertainties, the phrasing in the Norwegian version of this report has priority.

3.1 Regulations

Different parts of the regulations regulate various processes and systems related to energy stations, and only what is found to be most relevant to this report is presented here.

Hazardous substance:

In the area of hazardous substances, these regulations are relevant for energy stations:

- Regulation on handling of flammable, reactive and pressurized substances including requisite equipment and installations hazardous substances [6]
    - Equipment, facilities and expertise shall comply with recognized norms (see details for each energy carrier in chapter 4 of this report).
    - Theme guide on re-filling of hazardous substances
- Internal Control Regulation [22]
    - Responsibility distribution risk-reducing measures
- Regulation on health and safety in explosive atmospheres[6] [23]
- Regulation on pressurized equipment[6] [24]

The Regulation on major accidents[6] [2] is not relevant to these facilities, as the energy carrier quantities relevant for multifuel energy stations are normally lower than the point of entry for this regulation.

For the transporters who supply fuel, the regulation for land transport of dangerous goods [25] apply, including directive for road transport (ADR- Accord Dangereux Routier) and transport by train (RID - International Carriage of Dangerous Goods by Rail), but this is beyond the scope of this report.

Inspection:

The fire service is responsible for inspections according to the Regulation on handling of flammable, reactive and pressurized substances [6] and inspection in cases where the energy station is defined as a specific type of fire object (*særskilt brannobjekt*)[7] according to § 13 of the Fire and Explosion Protection Act [26]. According to DSB[8] there is a large variation in whether or not this type of facility is registered as a "særskilt brannobjekt". Registration may depend, among other things, on whether the facility is connected with other objects, for example if they are located near other facilities. In addition, DSB can perform inspections at energy stations, under the Fire and Explosion Protection Act, but for this type of facility this does not occur as often as the fire service's inspections.

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[6] Direct translation from Norwegian
[7] *Særskilt brannobjekt*: Buildings, storages, areas, tunnels, facilities etc. where a fire can result in the loss of many lives or major damage to health, the environment or valuables.
[8] E-mail with contact person in DSB, 05.12.2019.

Electrical installations

The Regulation on electrical companies [27] require that persons who install and maintain electrical equipment have the right expertise. In the Regulation on low-voltage electrical systems [28] it is described how electrical installations should be carried out. Here it is also referred to the norms:

- NEK 400 Electric low-voltage installations[9] [29] – which describe how to install the electrical system.
- NEK 420 Electrical installations in explosive areas[9] [30] – which has detailed requirements for the selection of equipment and installation in Ex-areas.

Explosive atmosphere

The EU has two directives regulating the hazards associated with explosive atmosphere ("ATmosphere EXplosible", ATEX): ATEX User Directive (Workplace Directive) and ATEX Equipment Directive [31]. These deal with requirements for equipment and protection systems to be used in potentially explosive areas. The directives have been implemented in Norwegian law, by the Regulation on health and safety in explosive atmospheres[9] [23] (which include area classification), and the Regulation on equipment and safety system for use in explosive areas[9] [32] (which is, among other things, relevant for requirements for equipment in Ex areas).

3.2 Theme guides

3.2.1 Theme guide on re-filling of hazardous substance

The theme guide on re-filling of hazardous substance[9] [33] elaborates and explains regulations on the handling of hazardous substances, and deals with, among other things, preventive safety measures and installation requirements.

The purpose of the theme guide is: "*First and foremost to provide instructions on how regulations on handling hazardous substances can be met when it comes to requirements for engineering, construction, production, installation, modification, repair and control of fuel facilities, refrigeration facilities for propane bottles and bunkering of LNG."* [9] [33]

The theme guide points out that controls should be carried out to ensure that the facility is suitable for the purpose and safe. Controls should be carried out both during and after installation. The risk at the facility shall be reduced to a level that can reasonably be achieved, and a risk assessment shall include internal and external risks as well as unwanted intended actions. Based on the assessment, plans shall be drawn up and measures shall be taken to reduce the risk to an acceptable level. In addition to preparing a risk assessment, the owner is responsible for the performance of an area classification, where explosive areas are divided into zones depending on the likelihood of the presence of explosive atmosphere and duration. Electrical low voltage installations must be carried out in accordance with the regulation on electric low voltage systems. By following the

[9] Direct translation from Norwegian

norm NEK 400, this is fulfilled. For electrical installations in explosive areas, the norm NEK 420 must be used. Building or rooms where hazardous substances are handled shall have sufficient natural or mechanical ventilation, and rooms classified as explosive areas shall have pressure relief surfaces. For more detailed information, please refer to the theme guide.

3.2.2 Draft theme guide on safety distances

There is now a hearing on the proposed theme guidance on safety distances for small and medium-sized facilities where hazardous substances are handled [34]. It is based on a report by DNV GL that has calculated risk contours for some selected types of small and medium-sized facilities [35]. The background for the theme guidance is that it can be resource-intensive for small and medium-sized facilities to perform quantitative risk assessments (QRA) for each facility. The purpose of the theme guide is to establish pre-accepted distances for the inner, middle and outer zones requiring special consideration (*hensynssone*) that may be used. The use of pre-accepted distances will typically be applicable where there is a relatively long distance to surrounding buildings and other relevant objects. If a facility can not fit the pre-acceptance distances, detailed analyses will have to be carried out for the facility in question and possibly put in place measures that adequately reduce the risk and distances.

3.2.3 Theme guide for the use of hazardous substances part 1 – Consumer facility for liquid and gaseous fuels

Part 1 of the Theme guide on the use of hazardous substance [36] aims to "*elaborate on the requirements of the regulation and propose technical solutions when designing consumer facilities for liquid and gaseous fuels (...)*" [10].

This will be relevant for both new installations, operation, modifications and maintenance, so that one may *"maintain a safe workmanship to protect life, health, the environment and material values from incidents and accidents"*.

The parts of the theme guide relevant to this project overlap somewhat with the already mentioned theme guides.

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[10] Direct translation from Norwegian

4 Energy carriers one-by-one

In this chapter, various energy carriers will be presented, a brief overview is given of their properties relevant to fire and explosion safety, of risks associated with the energy carrier, and relevant, existing recommendations for measures and barriers. It is focused on the changed risk when changing from a traditional petrol station to an energy station with *one* additional energy carrier.

4.1 Diesel and petrol

4.1.1 Background information and existing facilities

Ever since the arrival of cars in Norway petrol stations has been where fuel is distributed -and petrol stations have been built evenly across the country so that you don't have to risk running out of petrol or diesel when you're out driving. According to statistics from the trade organization Drivkraft Norge, there are about 1,800 petrol stations in Norway [37].

The consumption of fuel for road transport in Norway is mainly petrol and diesel. Biodiesel and bioethanol are mixed into diesel and gasoline and accounted for 12% of total volume in 2018, most of the meddling is biodiesel (89%) [12]. Liquid biofuels are considered climate neutral [4].

4.1.2 Properties and risks associated with the energy carrier

According to Circle K, there is extensive experience in handling petrol and diesel over the years, and there are now good routines and procedures for operating a petrol station. This includes all processes taking place at a petrol station, including refueling for ordinary vehicles and re-fueling tanks underground. The good procedures have contributed to the fact that there have only been minor incidents at petrol stations in Norway (see chapter 4.1.3).

Risks associated with gasoline and diesel are linked to their properties as flammable liquids. Petrol has a lower flash point than diesel, and is thus both easier to ignite and evaporates more easily. Under normal outdoor temperatures, petrol may evaporate and the vapor may form a flammable cloud, while this will not be the case for diesel. The petrol vapor is heavier than air and will be able to spread along the ground and accumulate in recesses in the terrain [19].

Another danger of petrol and diesel is related to spills, which allows a fire to initiate some distance away from the leak point. In 2012, 3,000 liters of petrol were spilled from a tanker vehicle in connection with filling [38], without the petrol being ignited. Such a scenario, of course, has a huge damage potential. Here it is worth noting that whether a station or an area is Ex-safe says nothing about the possibility that fuel could flow away and end up outside the zone classified area.

According to Circle K, the greatest risk is associated with soil contamination due to minor spills that occur in connection with filling.

4.1.3 Incidents

Through news searches in Norway, as well as conversation with a fire service employee, we have not come across examples of serious fire incidents at petrol stations. Most of the news stories about a fire at a petrol station are less serious incidents that have been dealt with quickly by the fire service. There are examples of small [39] and large [38] loss of containment of petrol and diesel but without fire ignition, and examples where a fire is deliberately started [40], a fire in a car wash [41] and a fire in a residential home above a petrol station [42].

It has also occurred that cars have driven off with the filling hose connected, but without this leading to serious incidents.[11]

4.1.4 Existing recommendations

Regulations and guidelines presented in Chapter 3, including the Health and Safety Regulation in explosive atmospheres [23] apply.

An example of area classification for a petrol station with gas return, and sizes of different zones are given in Figure 4-1. A more detailed description of the different zones is given in Table 4-1. A similar figure is shown in appendix to theme guidance on re-filling of hazardous substances [33]. More information on existing recommendations for petrol stations based on relevant laws and regulations is detailed in themed guides from DSB, as described in chapter 3.

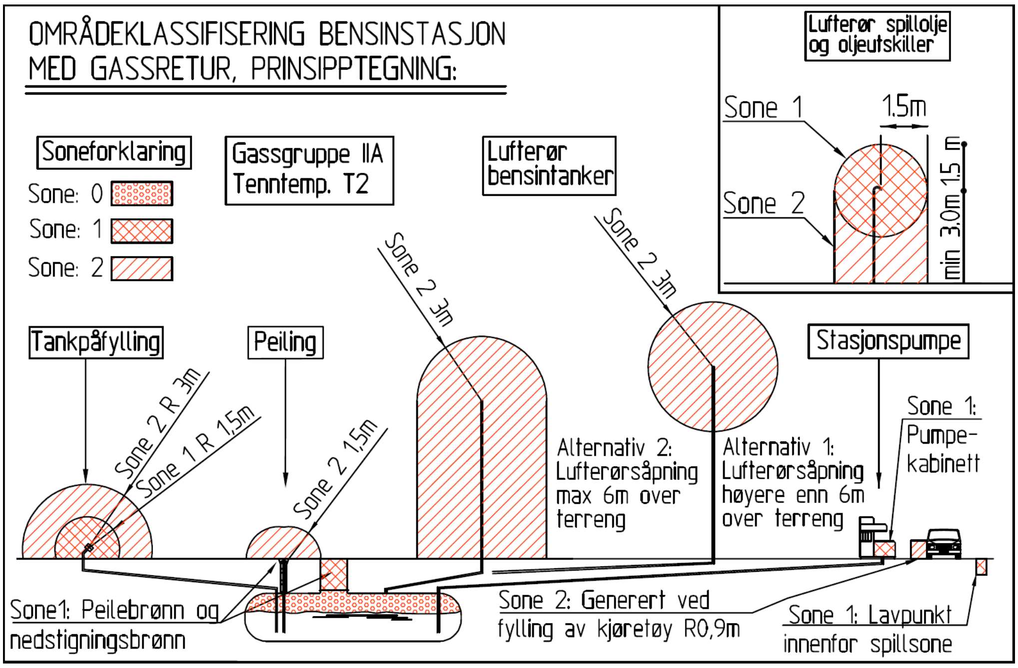

Figure 4-1 The principle of area classification for a petrol station with gas return. Key terms translated from Norwegian: zone explanation (*soneforklaring*), gas group (*gassgruppe*), ignition temperature (*tenntemp*), vent duct gasoline tanks (*lufterør bensintanker*), tank

[11] Interview with the on-site chief (*beredskapssjef og innsatsleder*) at the incident from Asker and Bærum fire and rescue service, 15.11.2019

refill (*tankpåfylling*), alternative 2: vent duct opening (*alternativ 2: lufterøråpning*). Made available by the DSB [43].

Table 4-1 Zone description for zones specified in Figure 4-1, translated from Norwegian. Made available by the DSB [43].

	Description
Zone 0	Area where explosive atmosphere occurs continuously or for long periods of time.
Zone 1	Areas where there occasionally must be presumed to be an explosive atmosphere during normal operating conditions.
Zone 2	Areas where explosive atmosphere may occur under normal operating conditions, but then only exceptionally and short-lived.
Safety zone[12]: Min. distance to neighboring border, public transport line, ignition source, combustible building/storage, opening in walls as window/door etc..	

4.1.5 Measures and barriers

One of the most important measures to reduce the risk of fire and explosion in the storage of petrol and diesel is that the storage tanks are place underground, and the risk of damage to the tank and large leaks is thus significantly reduced.

Any electric low voltage installations on the site should be carried out in accordance with the Regulation on low-voltage electrical systems [28]. To meet the safety requirements, the regulation refer to recognized norms. In general, this is the norm NEK 400 Electric low-voltage installations [29], and for facilities in zone-classified areas: the norm NEK 420 - Electrical installations in explosive areas [30]. Electrical equipment must meet the requirements of the Regulation on electrical equipment [44].

The Regulation on handling of flammable, reactive and pressurized substances [6] is elaborated in theme guide about the re-filling of hazardous substances [33] and sets a number of premises to safeguard values and personal safety at existing petrol stations. Among other things, area restrictions and safety of third-parties shall be determined through a risk assessment. Examples of area restrictions is that property development nearby the facility, such as dwellings, communal halls, hospitals, schools etc., may be forbidden. All tanks and piping systems at the facility should be tested and checked through pressure and leakage testing after they are installed and before they are covered/buried. Such a functional test shall take place in normal operating conditions and verify that the facility is satisfactory for all relevant conditions. Functional testing will also ensure that the facility has no leaks, and that all associated components such as valves, regulators etc. work.

[12] The term safety zone (*sikkerhetssone*) is a term that the DSB has stopped using today. The term "zone requiring special consideration" (*hensynssone*) is used on area restrictions around facilities with potential of major accidents; "safety distances" (*sikkerhetsavstander*) are used for distances at and around small and medium-sized facilities; "zones" (*soner*) are used for explosive atmospheres at facilities in normal operation. This is according to email correspondence with the contact person in the DSB.

Another safety measure is the emergency stop switch [13] which closes the power supply to all fuel pumps. This measure is designed to stop a leak from a fuel pump.

Measures such as detection, alarms, automatic shutdown due to alarm or error message, closing valves with short closing time and thorough testing of safety mechanisms are all relevant for petrol stations with diesel and gasoline, and also for energy stations with one or more additional energy carriers. These measures are described in the following sections.

4.2 Power for electric vehicles

4.2.1 Background information and existing facilities

At the end of June 2019, 231 000 electric passenger cars and 6 500 electric vans were registered in Norway [45], and the number is expected to increase in the years to come. This is due to a number of favorable incentives and broad political consensus to facilitate an increased share of electric cars. In the National Transport Plan 2018-2029 [13] the following aims are established:

- New passenger cars and light vans should be zero-emission vehicles in 2025.
- New city buses should be zero-emission vehicles or use biogas in 2025.
- By 2030, new heavier vans, 75% of new long-haul buses and 50% of new trucks should be zero-emission vehicles.

With an increased share of electric cars, there is also an increased need for fast chargers along the road network.

The Norwegian electric car association (*Elbilforeningen*) estimates a need for 1200 new fast chargers each year until 2025. To date, a charging power of 50 kW has been the standard for DC fast charging, but more and more fast charge operators are establishing even faster chargers (charging power of 150 kW or more). The mean power at fast charging in 2017 was 30.5 kW. Of the fast charging stations registered in the NOBIL charging station database, approximately 35% are located at shops/shopping centers, 30% located along the street, 20% at the petrol station and 15% other [45]. Fast charging differs from normal charging [14] (typically used for home charging) which has a maximum power of 22 kW [4].

4.2.2 Properties and risk associated with the energy carrier:

The greatest risk of high-power charging is the risk of electric arcs. An arc occurs when the electrical voltage between two points is higher than the breakdown voltage of the intermediate material (normally air) [46]. An arc will create a local very hot point and can lead to fire. In

[13] Interview with senior head of fast charging, senior specialist HSE and senior engineer from Circle K, 13.01.2020

[14] Normal charging: Charging a chargeable car using an electric car socket (power up to 22 kW). Electric car connector (type 2 connector) is a standard connector for charging a chargeable car (charging mode 3/English: Mode-3). [4]

general, the risk increases with higher charging current and power[15]. By introducing fast charging, a new arc source is simultaneously introduced. The probability of an arc occurring is therefore considered to be higher relative to if the fast charger was not present. At the same time, it can be argued that the probability of emissions of petrol and diesel is reduced by fewer people filling up their cars, and there will be fewer deliveries of petrol/diesel to the station.

Improper installation, poor maintenance or improper use may cause a fire in connection with a charging station. As there is communication between the charger and the electric car, charging will not be initiated until the charging plug is properly inserted into the socket, or if it detects faults on either the car or charger. In addition, it should not be possible to drive off with the charging cable connected. These measures help to reduce the risk of an arc occurring, wear and tear of cable, and prevent improper charging.

In another project for DSB [47] the risk of charging electric cars has been investigated, and the conclusion is that as long as the electrical system attached to the charger is dimensioned and installed correctly, there is no basis for claiming that the fire hazard increases during charging.

An important element that distinguishes the risk of fast charging from the other energy carriers is their role in the fire triangle. In the case of liquid or gas, an incident is caused by a leakage or a spill of flammable liquid or gas, and an ignition source is required. For a fast charger, it is not flammable substances that is astray, but on the other hand the ignition source (arc). Whether a fire occurs, and how large the fire becomes, will then depend on whether there is combustible materials or flammable substances near where the arc occurs, and the amount of it. The development of a fire that occurs as a result of an arc will vary depending on what combustible materials that are present nearby. However, it is likely that such a fire will not develop as quickly as if it starts to burn in a flammable liquid such as petrol and diesel.

If an arc occurs that causes a fire in the electric car that is charging, this does not mean that the battery in the car has started to burn. If the battery is not involved in the fire, the fire can be extinguished in the same way as a petrol or diesel car. If the battery starts to burn, it must be expected to take longer time and more water before the fire is completely extinguished, and there may be a need to monitor battery temperatures a while after the fire is considered extinguished.

The most serious incident is considered to be a fire in a large stationary lithium-ion battery (if there is such a devise associated with the fast charger), as this battery will contain much more energy than one single electrical vehicle, and it can be challenging to put out a fire in lithium-ion batteries [48]. It will likely require large amounts of extinguishing water, and firefighters will potentially be exposed to hydrofluoric acid gas. It is uncertain to what extent a sprinkler extinguishing system will be able to put out such a fire. When testing at FM Global [49] the sprinkler system dampened the fire, but as the water did not enter where it was needed the most, the fire was not extinguished.

Table 4-2 shows a selection of events that may occur in connection with the establishment of a fast charging station at the existing petrol station as well as the probability and consequence of these events. The information is based on input from Circle K[16]

[15] E-mail correspondence with contact person in DSB, 25.10.2019

[16] Interview with senior manager for fast charging, senior specialist HSE and senior engineer at Circle K, 13.01.2020.

Table 4-2 A selection of potential incidents related to the establishment of a fast charger at the existing petrol station. The probability is: 1 (imaginable), 2 (has happened), 3 (has occurred several times). The consequence is: 1 (transient injury), 2 (permanent injury), 3 (death). [17]

Event	Probability (P) and consequence (C)	Risk-reducing measure [18]
Personal injury to the user or electrician in connection with installation	P:1 C:3	The installer shall be certified and the area shall be limited to certified personnel
Personal injury or damage to a car due to other traffic	P:2 C:2	Secure position of charger in relation to entrance of cars
Fire in electric car during charging, or when it is parked	P:2 C:1	The fire service will deal with such an incident
Damage to charger as a result of car driving off with the charging cable connected	P:1 C:1	Should in principle not happen due to communication between car and charger
Damage to charger due to collision	P:2 C:2	Collision protection in front of chargers. Chargers are equipped with fuses that cut the power when a short circuit occur.
Fire or explosion in charger due to technical fault or use of not authorized components and spare parts.	P: 1 S:3	Good contract on the service of the chargers as well as spare parts.

Circle K [19] also believes that there is less risk at their stations because they are used to assessing and managing risk, as opposed to the situation at, for example, charging stations adjacent to shopping centers etc.

4.2.3 Incidents

Despite the fact that a large proportion of all vehicles in Norway are electric cars, there have not been many fires in electric cars, and only one fire is recorded where an electric car was rapidly charged [47]. Among a review of fires in electric cars internationally, only 2 incidents have been reported where they were connected to a fast charger [50].

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[17] The information in the table is based on input from Circle K.
[18] RISE has made the text more general. For more detailed information please refer to Circle K.
[19] Interview with senior manager for fast charging, senior specialist HSE and senior engineer at Circle K, 13.01.2020.

One case where a fire started while charging was in 2016 when a Tesla started burning while it was connected to a 120 kW fast charger. During charging, a component of the charging circuit in the car broke down, causing an arc (~3000 °C) to cut into the battery, initiating an uncontrolled heat development, a so-called thermal runaway, in the battery. In the aftermath of this fire, Tesla has made improvements to avoid similar failures in the future.[20]

According to Tesla [51], a Tesla vehicle has burned for every 274 million drove km, while regular vehicles burn for every 31 million drove km. This comparison does not take into account that the average age of a Tesla is significantly lower than the average age of ordinary vehicles. Nevertheless, it gives an indication that it is not to expect that a fire will occur more frequently than in another vehicle.

4.2.4 Existing recommendations

DSB has issued a guide on safe charging of an electric vehicle [52], accompanied by a technical guide on planning and engineering of charging installations for charging of electric cars [53]. The technical guide was made jointly by the DSB, *Elbilforeningen*, NELFO and the Norwegian Electrical Committee.

In the latest release (4th edition 2015) the following reads: "A charging station must be at least 10 meters from all Ex zones". According to the editor.[21] this distance was chosen so that the car + charging cable should not be able to be within an Ex zone. The guide has not been updated after the new edition of NEK 400 (2018) [29], but the next edition will be in agreement with NEK 400, which sets the following premises for distance between the charging station and the Ex zone:

NEK 400 (2018)

722.55.305.2 «Charging stations must be located at a distance from any Ex zone so that vehicles being charged are not in *an Ex zone.» (direct translation from Norwegian)*

4.2.5 Factors that change when changing from petrol station to energy station with power for electric vehicles

Ignition sources: The charger with its electrical equipment will in itself constitute a potential source of ignition. The charging station should be located outside the Ex zone, according to NEK 400 [29]. The Ex zones deal with any leaks that are part of normal operation. If an emission result in a large cloud of or flammable gas, this will extend outside the defined Ex zone, thus the charging station will be a potential source of ignition.

Number of passenger vehicles: The number of cars visiting the station depends mainly on two things; the range of the car, and what other options for charging there are. For an electric car, the

[20] E-mail correspondence with contact person in DSB, 25.10.2019
[21] Email correspondence with editor of NEK 400 – 16.09.2019.

range per charging is generally less than for a fully refueled petrol/diesel car. At the same time, there are many electric vehicles being charged at home, and there are many separate fast-charging stations. Given that a petrol/diesel car is replaced by an electric car, it is therefore expected that the number of passenger vehicles visiting a station is most likely to decrease. If the need for charging is greater than the capacity of the station, a charging queue may occur, which could lead to an increase in the number of vehicles and people present at the station.

The number of heavy goods vehicles for the delivery of the energy carrier: A fast charging station does not depend on refills from a tanker, unlike a petrol/diesel pump. It is therefore estimated that there will be fewer tankers stopping at the station.

The number of heavy goods vehicles for the purchase of the energy carrier: If electric trucks become common, these will probably have very large batteries. These will likely have their own fast chargers with greater effect than today's fast chargers for passenger cars. In addition, todays charging stations are adapted to the physical size of private cars. An electric truck will require greater physical space, and parts of the truck may then appear within the defined Ex zone (see ignition sources above). This means that today's charging stations for fast chargers are not necessarily adapted to the electric trucks of the future.

Quantity of flammable substance: The amount of flammable substance present is likely to be unchanged, as the fast charging station itself does not provide much extra fuel load. The stock of petrol/diesel is likely to be the same at any given time, but the filling interval of the tanks is likely to be increased. The battery in the electric car itself can burn, but the amount of energy is no greater than the amount of energy contained in a petrol/diesel tank.

However, if there is a large buffer battery in connection with the fast charging station, this may increase the amount of fuel load.

Retention period of visitors: Charging an electric car takes longer time than filling a petrol/diesel car, and a queue formation at the chargers is more likely. These two effects contribute to that visitors will tend to stay longer at the station.

Unique scenarios for the energy carrier: With high power fast chargers, an arc may potentially occur. This is a scenario not expected by the other energy carriers. In the case of diesel/petrol etc., there is a risk that the fire will move many meters away from its original position e.g. in case of leakage. This will not happen with electricity as an energy carrier. An explosion is also not expected as the fast charger is located outdoors, and any non-ignited or flammable gases will have little possibility of accumulating.

Complexity of the facility (joints, couplings etc.): The electrical power system must be dimensioned according to the power of the fast chargers. Beyond this, there are no changes.

Number of third-parties/ size of safety distances: The number of third parties or the size of safety distances is not expected to change.

Other additional installations that may affect safety: Adding a buffer battery may alter the risk image somewhat, as a fire in it may take a long time to extinguish, but also produce large amounts of smoke. It may also be appropriate to install a solar system that charges the buffer battery. In this case, fire risk associated with the solar installations, and any interactions with extinguishing systems, must be considered in addition.

Fire department's extinguishing effort: A battery fire can be challenging to extinguish, and in the past, it has been questions[22] about whether conventional fire clothing is sufficient to protect against all types of gases that may occur in the event of a battery fire.

External fire – possibility of escalation: It is not expected that an external fire will be heavily escalated due to the presence of a fast charging station. This is partly due to the fact that there is no liquid or gas that has the ability to move. If a buffer battery has been established in connection with the facility, this should have sufficient distance from flammable substances, such as vehicles, to prevent an external fire from spreading to the buffer battery.

Environmental impact: A battery fire may require large amounts of water. Having a plan for where this water will end up makes sense. However, this is something that is recommended for all types of fires and is therefore considered no change.

Increased maintenance (risk of installation errors): There will be a need for weekly inspection of the connection line etc. Unlike with a diesel/petrol hose, it should not be possible to drive off with a charging cable still connected to the electric car. This can help reduce wear and maintenance at the charging station.

Other (not fire related, economy, health etc.) that is affected: Need for increased power capacity, this may require an infrastructure upgrade. Electricity does not cause evaporation during filling as opposed to petrol/diesel, and fewer cars will idle in the area. This can provide marginally better conditions regarding health/working environment.

4.2.6 Measures and barriers

The standards under which the facilities are built provide details of measures and barriers found at the facilities, see section 4.2.4.

For fast chargers, weekly visual inspection of the charging station and plug should be carried out, and an annually expert inspection[23]. This should reveal wear, weaknesses and the need for replacements. In addition, there are safety features built into the charging station that should check that everything is in order. The DSB [24] is aware of some incidents where motorists have attempted to pull the charging cable over the roof to reach the charging socket of the car. Such behavior naturally creates wear and tear on wire and should be avoided.

Fast chargers follow a communication protocol with the car, and if faults are registered in either the car's system to receive charging, or the fast charger system to give up power, charging will not be initiated or stopped. This is a barrier that helps protect the battery from improper charging, reduces the risk of arc, and helps reduce fire risk. In addition, it is not possible to drive off with the car as long as the charging cable is connected. This eliminates the risk of running off with the cable.

In normal operation, there should be no risk that a fast charger may act as a source of ignition to flammable liquid or gas, as there is a requirement that *"Charging stations should be located at a*

[22] Dialogue with the employee in Trøndelag Fire and Rescue Service (TBRT) – 28.11.2019
[23] E-mail correspondence with contact person in DSB, 25.10.2019
[24] E-mail correspondence with contact person in DSB, 25.10.2019

distance from any Ex zone so that *vehicles charging are not in an Ex zone.»*[25] [29]. In the event of an accident (leak), however, there may be a risk of this.

Below are measures and barriers that Circle K [26] has established in connection with its charging stations:

- Circle K has, on its own initiative, established a manual emergency stop switch that shuts down the power on all the charging stations. Such a switch will create predictability for firefighters in the event of a fire of an electric vehicle being charged. Such a switch is not currently available at all stations but will be in the future.
- A physical collision protection has also been installed around their charging stations to make them less vulnerable to direct collision. There has also been established a snow clearing instructions that provides instructions on how to drive near charging stations, to reduce the risk of the charger being hit by the plow truck, and to avoid splashing water, gravel and snow on the chargers.
- Employees have been trained to use fire extinguishers, but in case of fire in a charger or an electric car, the employees are instructed to call the fire brigade without attempting to put out the fire themselves.
- Circle K has routines for visual checking, cleaning chargers, logging and reporting error messages.

If a large stationary buffer battery is established in connection with the fast charger, our assessment is that this should be at a distance from flammable substances so that an external fire (fire in a vehicle) cannot spread to the buffer battery. The battery should have been checked in a variety of safety tests, and have a design that prevents the escalation of a fire occurring in a battery cell. Automatic extinguishing systems that both reduce the risk of spread from the inner and outer sources of fire should be considered.

4.3 Hydrogen in gaseous form

4.3.1 Background information and existing facilities

A station with gaseous hydrogen can either have deliveries of hydrogen transported to the site, or have on-site hydrogen production. The cars use the hydrogen gas to produce electricity in a fuel-cell. The power is stored in a battery and operates an electric motor in the same way as an electric battery car. The battery in a hydrogen car is only used for intermediate storage of power from the fuel-cell and from regenerative braking.

Publicly available filling stations shall be built and checked in accordance with the requirements of the Regulation on handling of flammable, reactive and pressurized substances [6] and the Regulation on pressurized equipment [24]. In cases where this has not been documented, the DSB may issue closures.

[25] Direct translation from Norwegian
[26] Interview with senior head of fast charging, senior specialist HSE and senior head of Circle K,13.01.2020.

There are a few publicly available filling stations for hydrogen, see an overview in Table 4-3. Not all are open, publicly available filling stations. In addition, there is a filling station in operation for the transport company Ruter's hydrogen buses in Oslo.

Table 4-3 Overview of hydrogen filling stations in Norway as of February 2020 [54–57].

Place	Company	Available for*
Høvik, Oslo	Hynion	The public
Herøya, Porsgrunn	Hynion	The public
Hvam, Skjetten	Uno-X	The public
Gardermoen	Hynion	The public
Kjørbo, Bærum	Uno-X	The public
Rosenholm, Oslo	Air Liquide	The transport company Ruter's 5 hydrogen buses
Rosten, Trondheim	ASKO -	The grocery wholesale company ASKO's forklifts and trucks, as well as passenger cars. Not publicly available.
Åråsen, Lillestrøm	Ife	Test station
Public, norway	Uno-X	The public

* Not all are open as of 2020

4.3.2 Properties and risks associated with the energy carrier

Hydrogen has some unique properties compared with other flammable gases. One of the most important properties in terms of fire and explosion hazard is the ignition energy of 0.017 mJ and the wide flammability range[27], with the lower flammability limit[28] of 4 volume% and the upper flammability limit of 75 volume%, making hydrogen easy[29] to ignite. Flammability limits will also affect the proportion of a gas cloud that can burn and thereby also affect the overpressure of an explosion. The pressure and intensity of a hydrogen explosion or -fire will also be affected by hydrogen's high energy density (heat of combustion 119.9 MJ/kg) and flame speed (laminar flame

[27] Flammability range: The range between the lower and upper flammability limit.
[28] Lower/ upper flammability limit: lowest/highest concentration of fuel vapor in air above and below which propagation of a flame will not occur in the presence of an ignition source [5].
[29] After ISO/TR 15916 at 20°C and under atmospheric pressure.

spread rate of 2.91 m/s [58]) leading to a more intense combustion process and thus also greater hazard of a so-called *deflagration detonation transition* (DDT).

Both thermal and mass diffusion of hydrogen is much higher than that of other gases. Hydrogen is also the lightest of all gases, with a density of 0.08 kg/m^3, which causes hydrogen to rise rapidly upwards. Indoors, the gas will therefore be collected under the roof. Outdoor leaks will quickly dilute, due to high diffusivity, and for small leaks this can reduce the risk of ignition.

A pure hydrogen-air flame burns without forming soot, which leads to low thermal radiation and thus reduced risk of radiation damage, compared with other flames. Since, among other things, the energy is not "drained" via radiation, the flame temperature is higher than for other gas flames. A pure hydrogen-air flame can additionally be difficult to detect visually. However, in a realistic scenario, other materials will most likely also contribute to the flame and likely increase the radiation and make the flame visible.

In a report that DNV GL has prepared for DSB, leak rates for different types of fuel systems are estimated [35]. The total leak rate depends, among other things, on facility design, such as the number of connectors and components. Figure 4-2 shows leakage frequencies for a gaseous hydrogen facility compared to leakage frequencies for an over-ground filling facility for gasoline and diesel, as well as a liquefied natural gas (LNG) facility, to provide a rough overview of the difference in the order of magnitude for leakage frequencies. Please note that this is based on a selection of representative facilities and that underground facilities for petrol and diesel are not presented. We expect overground facilities to have at least as high leakage frequencies as a typical underground system. In other words, there is a significantly higher leak rate for hydrogen in gaseous form, compared to petrol and diesel.

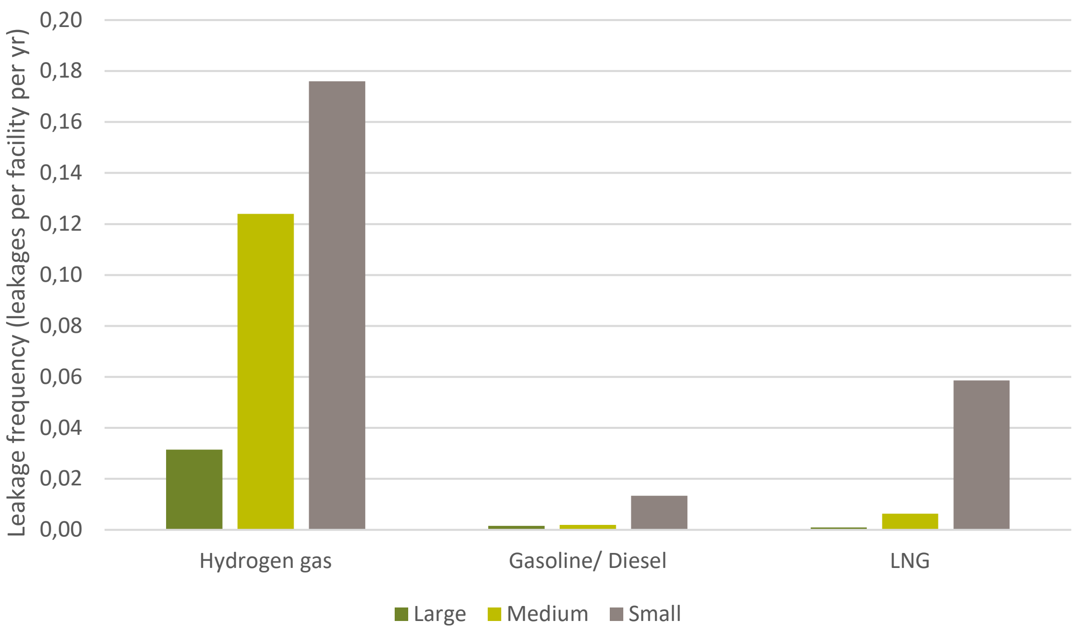

Figure 4-2 Leakage frequencies for filling facilities with hydrogen in gaseous form, liquefied natural gas (LNG) compared with an overground filling facility for gasoline and diesel. The leakage frequencies is set to Large, Medium, and Small. Data is taken from DNV GL's report; data for hydrogen from table 3-1 in their Appendix 6, data for petrol and diesel from Table 3-1 in their Appendix 7 and data for LNG from Table 3-1 in their Appendix 4 [35].

A risk analysis done for one of Circle K's filling stations with both petrol/diesel, hydrogen and fast charging has been made available for the project [59]. Please note that this is from 2012, so specific distances and assessments are for information and not for use in new risk assessments. It is also noted that the use of hydrogen at the station is currently discontinued due to market economic considerations. Some points from the risk assessment will still be presented here, as this is one of the few stations where a risk assessment has been made based on petrol/diesel in combination with more than one alternative energy carrier. The risk assessment concludes that the risk to the facility is acceptable with a distance of 6 meters between the fast charger and the hydrogen facility. The fast charger must be considered a potential ignition source of hydrogen gas in the event of a leak, but it has been considered that the leak scenarios for this hydrogen facility cannot reach the fast charger. Other ignition sources, such as passing cars and road lighting, are considered to be more likely than the fast charger. An ignited large leak of 1 kg/s from the hydrogen facility has been stipulated to provide over 13 kW/m^2 heat radiation at the fast charger and give 23 meters as the distance of danger for outdoor personnel. However, the risk of this incident is considered to be low. If an electric car is to catch fire while charging or another car outside the hydrogen facility, it is not considered realistic that this should cause the hydrogen pressure bottles to heat up sufficiently to burst. All in all, the risk analysis concludes that there is little interaction between the fast charger and the hydrogen facility when there is 6 meters distance between these. None of the unwanted incidents from the fast charger are considered to be able to escalate into the hydrogen facility. The potential for unwanted events at the hydrogen facility can give hazardous pressure waves and high heat radiation in the area where the fast charger is located. The fast charger will increase the retention period of visitors in this area, but the overall risk is not considered to be significantly affected by this.

4.3.3 Incidents

Hydrogen explosion at Uno-X station in Sandvika

On June 10th 2019, a hydrogen leak from a high-pressure hydrogen tank at a hydrogen station belonging to Uno-X in Sandvika (Kjørboveien 1) occurred, which led to an explosion and a subsequent fire (Figure 4-3). An evaluation after the incident concluded that two bolts had been tightened to too loosely, which led to hydrogen leak [30]. However, the source of the ignition is not yet publicly known. The explosion led, among other things, to parts of the wall around the facility being thrown over a walk- and cycle way and into a roundabout, according to drone images from NRK [60].

An interview has been conducted[31] with the on-site chief (*beredskapssjef og innsatsleder*) from Asker and Bærum fire and rescue service on the fire service's experiences from the incident. When the fire service arrived at the scene, after a while it became clear that this was not caused by an intentional act and that there were no injured people in the area. After this was established, an exclusion area of 200 meters from the explosion was established for emergency personnel and a safety distance of 500 meters for others. A 100 meters recommended safety distance was listed

[30] Based on the press conference from Nel, 28.06.2019, Oslo and https://nelhydrogen.com/status-and-qa-regarding-the-kjorbo-incident/ (04.10.2019).
[31] Interview with the on-site chief (*beredskapssjef og innsatsleder*) from Asker and Bærum fire and rescue service, 15.11.2019

in the database for hazardous substances, but due to several unsolved conditions this was increased to 500 meters. This distance meant that the E18 road had to be closed. The hydrogen gas was allowed to burn out, and an extinguishing robot and water cannon were used from a ladder truck to cool surrounding objects. The fire service received good support from both the owners and the contractor of the station during the extinguishing effort which lasted about 3 hours. After it was verified that the tanks had been emptied of hydrogen, the safety distance was lifted, and traffic resumed. Two people were sent to check at the emergency room, but the incident did not result in any injury.

In a report on safety distances at facilities with hazardous substances [35], a given prerequisite is that hydrogen filling stations are encircled by a 4 m high fence intended to limit the extent of a horizontal jet fire (ignited leakage of pressurized, flammable liquid or gas [61]) from the facility. Another prerequisite is that the wall remains intact and does not form projectiles in the event of an explosion. The incident at Kjørbo shows that it is important that such a wall around the facility is built in a way that it can withstand the stresses it can be exposed to in the event of an explosion and that no loose parts of the wall can be blown away and hit people outside the facility.

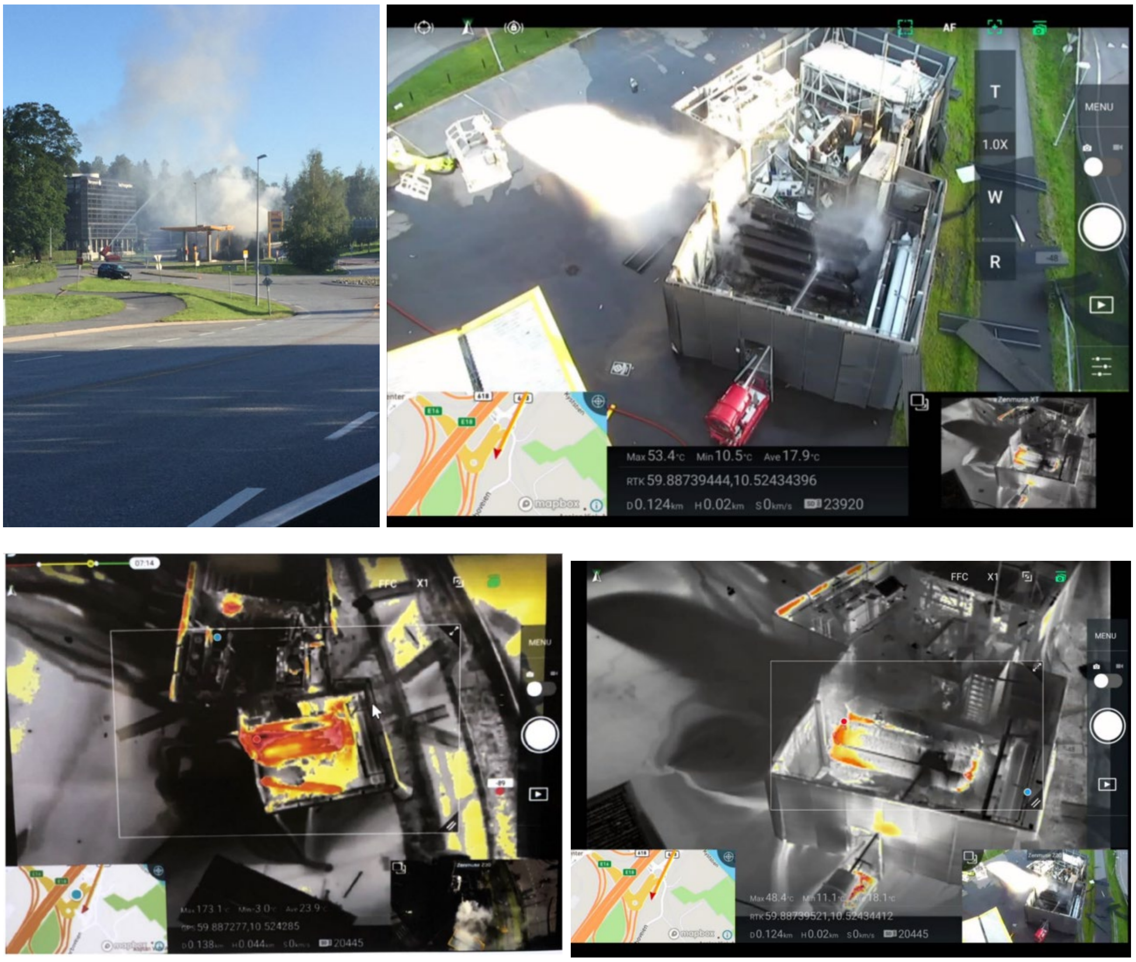

Figure 4-3 Uno-X hydrogen filling facility after the explosion on June 10th 2019. The fire department's drone images show temperature profiles inside the facility during extinguishing efforts. Photos: Asker and Bærum fire and rescue service, with permission.

4.3.4 Existing recommendations

Regulations and guidelines presented in chapter 3 apply, and there are some special factors that need to be taken into account when using hydrogen at an energy station.

Some standards that apply to hydrogen stations specifically are:

- ISO/TS 19880 Gaseous hydrogen – Fueling stations [62] (a series of standards)
- SAE J2601_201612 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles [62]
- ISO/TR 15916:2015, Basic considerations for the safety of hydrogen systems [63]

According to the Regulation on handling of flammable, reactive and pressurized substances [6], facilities shall be built according to a recognized norm. For facilities built in Norway the recognized norm is in practice ISO/TS 19880, according to DSB[32].

As an example of the fact that there are many different regulations that can come into play for hydrogen (and other types of gas facilities for fuel sale), hydrogen stations from Nel[33] are third-party certified and meet the requirements of the following international standards and EU Directives[34] (most of which are implemented in Norwegian law via Norwegian regulations):

- Mechanical and Safety Instrumented System IEC61511
- DIRECTIVE 2014/68/EU Safety of pressure vessel equipment and material
- DIRECTIVE 2014/34/EU Equipment used in potentially explosive atmospheres (ATEX)
- DIRECTIVE 2014/30/EU Electromagnetic compatibility
- DIRECTIVE 2014/35/EU Low-voltage electrical equipment
- DIRECTIVE 2006/42/EC Machinery Directive

Several of the directives may also be relevant to a facility with conventional fuel.

4.3.5 Factors that change when changing from petrol station to energy station with hydrogen in gaseous form

Ignition sources: Due to the fact that hydrogen ignites much easier than petrol/diesel, weaker energy sources will be able to act as ignition sources if exposed to a flammable cloud of hydrogen.

Number of passenger vehicles: No significant change.

The number of heavy goods vehicles for the delivery of the energy carrier: More transports to the station will be required to deliver hydrogen in gaseous form compared to petrol and diesel in order to deliver fuel for a given total mileage for the station's customers. The capacity of a truck with hydrogen in gaseous form is between 5 and 17 times[35] lower than that of a truck with liquid

[32] E-mail correspondence with contact person in DSB, 10.02.2020
[33] Based on press conference from Nel, 28.06.2019, Oslo, in connection with the Kjørbo incident.
[34] Detailed information about each of these can be found in «Official Journal of the European Communities» available on https://eur-lex.europa.eu/
[35] Hydrogen gaseous form: 250 kg (steel tanks, 190 bar) or 800 kg (composite tanks, 350 bar). Liquid hydrogen: 4300 kg per truck. [65]

hydrogen [65]. In section 4.4.5, it is shown that the capacity of petrol and diesel approximately equals the capacity of liquid hydrogen. That is, each truck with petrol or diesel correspond to approximately 5 to 17 trucks when delivering hydrogen in gaseous form.

The number of heavy goods vehicles for the purchase of the energy carrier: Hydrogen in gaseous form is not thought to be very relevant as fuel for heavier trucks due to the large volume required to store a sufficient amount of energy. Today, there are some examples of heavy goods vehicles using hydrogen in gaseous form, such as ASKO in Trondheim. Nevertheless, our assessment is that due to volume constraints, a significant increase is not expected in the number of trucks coming to refuel hydrogen in gaseous form.

Quantity of flammable substance: No significant change. Here it is chosen to compare the amount of energy required to drive a given number of kilometers with different types of fuel. This can be calculated as MJ/100km based on estimated consumption of comparable vehicles and the calorific value of the fuel. Although a fire in hydrogen gas differs from a fire in gasoline or diesel, this provides a comparable size for the fire energy that must be stored and distributed to deliver a given mileage to the energy station's customers. How much needs to be stored at the energy station will depend on how fuel tanks are filled and how many vehicles are stopped to fill in a certain amount of time.

The calorific value of the amount of hydrogen needed to drive a passenger car at a given distance is similar to the calorific value of petrol/diesel needed to drive the same distance. With a consumption of 1,1 kg/100 km [65–67] and a calorific value of hydrogen of 158.9 MJ/kg [69], the total amount of flammable fuel is 184 MJ/100 km. In comparison, this corresponds to a consumption of about 5 l/100 km for petrol and diesel which is considered to be roughly realistic for comparable modern cars.

Retention period of visitors: For passenger cars it is assumed that it will take about the same time to fill hydrogen as it currently takes to refuel petrol/diesel. At the same time, a hydrogen car will have to fill a little more frequent than a petrol/diesel car because they are assumed to have slightly shorter range than a petrol or diesel car.

Unique scenarios for the energy carrier: Low ignition energy, wide flammability range, rapid combustion and storage under high pressure mean that the probability of explosion or detonation is significantly greater than that of other relevant energy carriers.

Complexity of the facility (joints, couplings etc.): For facilities producing hydrogen with electrolysis, the complexity of the facility will be significantly higher than a petrol/diesel facility. If the hydrogen gas is delivered, the complexity will be less than when producing hydrogen at the facility. Either way, the facility will operate under very high pressure in order to deliver to vehicles that can be filled with up to 700 bar.

Number of third-parties/ size of safety distances: The size of safety distance and the number of third-parties who will be located in different zones will be necessary to consider for each facility. In some cases, larger safety distances may be required for gaseous hydrogen facilities than for petrol and diesel facilities.

Other additional installations that may affect safety: If it is appropriate to install, for example, solar cells to produce electricity for electrolysis of hydrogen, this must be placed so that it does not increase the risk of collecting or enclosing any hydrogen gas leakage.

Fire department's extinguishing effort: One of our contacts in the fire service[36] believes that the work tasks of future energy stations will not be too different from the risks and challenges they already have to deal with, such as transportation of hazardous substances (hydrogen, oxygen, propane etc.) on roads and railways. Fire services in larger cities are well prepared for the challenges the future energy stations can entail. In rural areas, it can be somewhat worse as a large part of the fire service is based on part-time employees.

External fire – possibility of escalation: The hydrogen facility is placed above the ground. Thus, it will be more prone to heat stress from an external fire than a buried tank with gasoline or diesel.

Environmental impact: An emissions of hydrogen gas is not considered to have any significant negative environmental impact if it is spread and thinned out without igniting.

Increased maintenance (risk of installation errors): The facility will be relatively complex and must be maintained and inspected by qualified professionals. This is especially true for facilities with self-production of hydrogen by electrolysis.

Other (not fire related, economy, health etc.) that is affected: Establishment and maintenance may affect facility economy.

4.3.6 Measures and barriers

The facilities are built based on relevant standards, and these standards provide details on measures and barriers at the facilities, see sections 4.4.4 and 4.3.4.

The density and diffusivity of hydrogen gives an efficient ventilation of hydrogen gas upwards for dilution of the gas. This can be exploited in the design of hydrogen energy stations so that any leak is quickly directed away from the rest of the facility. In order for this to work optimally, there should be no roof over the parts of the hydrogen facility where large leaks may occur.

Since the direction from leakage points is difficult to predict, installation of vertical plates around accumulations of leak points will enable sending gas from a horizontal leakage point efficiently upwards to prevent the gas from spreading laterally and thus exposing it to ignition sources. A vertical emission direction without too many obstacles, like a half-roof and the like will also provide faster dilution of the gas. In total, this will limit the risk of explosion. Tight, robust fences around the installations are also important to reduce the impact of an incident for people nearby.

Smaller leaks will rise and quickly dilute, as opposed to leaks of heavier substances that can accumulate in recesses in the terrain. It is therefore important to reduce the potential for large leaks rates that can create larger clouds of flammable gas before they are diluted to a safe concentration. This is important in those segments of the facility that contain large amounts of hydrogen. Where the leak occurs through thin supply pipes, the potential leakage rate will be limited by this.[37]

[36] Interview with the on-site chief (*beredskapssjef og innsatsleder*) from Asker and Bærum fire and rescue service, 15.11.2019
[37] Interview and email correspondence with chief engineer at Lloyds Register Norway

4.4 Liquid hydrogen, liquid methane (LNG, LBG)

4.4.1 Background information and existing facilities

Liquid methane is produced by fossil gas or by the degradation of organic matter. If the gas originates from fossil sources it is called Liquified Natural Gas (LNG), and if it originates from organic matter it is called Liquified BioGas, LBG. Liquid methane is purified to varying degrees and made liquid by cooling it to below -160°C which is the boiling point for methane. Hydrogen can also be made liquid by cooling below the boiling point at about -250 °C. The main advantage of making the gas liquid is to increase the energy density without having to compress the gas to a very high pressures. [70–72].

There are no facilities for the filling or production of liquid hydrogen in Norway today (per 2020).

There are 2 filling stations for LNG/LBG in Norway as of December 2019, according to the Natural & Bio Gas Vehicle Association (NGVA Europe). One is located in Stokke outside Tønsberg and the other is located at Furuset in Oslo. They are operated by Air Liquide and AGA.

4.4.2 Properties and risks associated with the energy carrier:

Since liquid hydrogen and methane are stored under very low temperatures, the potential for severe cooling will occur if a leak occurs. This may pose a hazard for people being exposed, or other materials that change their properties at low temperatures. For example, steel becomes brittle and lose some of its ductile properties by heavy cooling. [73]

Liquid methane keeps a temperature of -161°C, and liquid hydrogen keeps a temperature of -250°C. The boiling point of oxygen is -183 °C [74]. This results in that if air comes into contact with temperatures lower than -183 °C, the oxygen in the air can condense. This can also occur if air comes into contact with surfaces that hold temperatures down towards the boiling point of hydrogen. Liquid oxygen can react strongly with organic matter and might cause a very large fire or explosion.

The leakage frequency for an LNG filling facility is estimated to be between about 1 to 4 times greater than the leakage frequency of a petrol and diesel filling facility for small, medium and large leaks as shown in Figure 4-2 on page 32 [35]. This analysis is based on frequency analyses of a representative filling facility for LNG for heavy vehicles and a representative overground fuel facility for gasoline and diesel. This gives a picture of the magnitude of leakage frequencies, while the total leakage frequency depends, among other things, on the facility design, such as the number of joints, components etc.

Since liquid hydrogen is stored at similar facilities, it is also believed that the leakage frequency of liquid hydrogen are in the same order of magnitude. However, it is important to note that the properties of liquid hydrogen today are not fully understood, and several projects are underway for the purpose of improving the knowledge in the field, such as the projects SH2IFT [20] and PRESLHY [21].

Although hydrogen is a very light gas that quickly rises if a leak occurs, both liquid hydrogen and the cold hydrogen gas that evaporates will be heavier than air. This means that the flammable gas will stay close to the ground and may form larger flammable clouds than it would if the leak occurred from the gas phase at ambient temperature. Both liquid and cold methane are also heavier than air so the same risk is also relevant here.

RPT, or Rapid Phase Transition, is a phenomenon that can occur when liquefied natural gas suddenly transitions to gas phase as an explosion. This can typically happen if LNG is released onto a water surface. [75] The theory says that RPT is unlikely for hydrogen, but there are no known experiments that show this phenomenon of liquid hydrogen. [76]

4.4.3 Incidents

An example of materials being affected by the low temperature associated with LNG is an event at Esso Langford LNG-terminal Australia 1998. A heating circuit that was supposed to keep important components warm, failed and caused a heat exchanger for LNG to cool to around -48°C, which made the metal brittle. When the heat circuit was restarted, a rupture occurred which led to a large discharge that ignited and eventually led to an explosion. Two people were killed and several were injured in the incident. [77]

4.4.4 Existing recommendations

In addition to regulations and guidelines presented in Chapter 3, the following standards are among the standards relevant for filling stations with liquid hydrogen or liquid methane:

- NS-EN ISO 16924:2016 Natural gas filling stations - LNG stations for filling vehicles [78]
- EN 13645:2001 Liquefied natural gas facility and equipment - Construction of onshore facilities with storage capacity between 5 h and 200 h [79]
- NFPA 55 Compressed Gases and Cryogenic Fluids Code. [80]

For liquid hydrogen, the following standards are among the standards that are relevant:

- ISO 13984:1999 Liquid hydrogen - Land vehicle fueling system interface [81]
- ISO 13985:2006, Liquid hydrogen - Land vehicle fuel tanks [82]

4.4.5 Factors that change when changing from petrol station to energy station with liquid hydrogen or liquefied natural gas

Ignition sources: The number of ignition sources is not expected to increase significantly. In terms of ignition, the same applies here as is described for hydrogen in gaseous form in section 4.3.5 - it can be ignited by smaller ignition sources than other types of fuel, since hydrogen ignites much easier. Methane has about the same ignition energy as gasoline. Liquid hydrogen and methane are heavier than air so that the gas cloud from a leak could to a greater extent spread outward along the ground than a leak from compressed gas. As a result, the gas cloud is more likely to find a source of ignition than compressed gas.

Number of passenger vehicles: Liquid methane and hydrogen are probably most applicable for heavier vehicles. A larger number of passenger cars are therefore not expected.

The number of heavy goods vehicles for the delivery of the energy carrier: A tanker with LNG can load almost 18 000 kg in a tank of 48 m^3 [83]. Diesel has about twice the density of LNG so that an equally large tanker can get about twice as many kg of diesel. In a comparison test of trucks with diesel and LNG, consumption measured in kg/100 km was approximately the same [84]. This means that the number of tankers needed to supply LNG is about double of that needed for the delivery of diesel to cover the same mileage for customers at the energy station.

Tankers for the transport of liquid hydrogen have a capacity of up to 4300 kg according to Air Liquide [65]. For a passenger car, consumption is approximately 1.1 kg hydrogen per 100 km [65–67]. This is admittedly consumption for cars running on compressed hydrogen gas, but it is assumed that the consumption of a similar car with liquid hydrogen on the tank will be similar. This gives a total mileage of 390 000 km for a passenger car per tanker with liquid hydrogen. In order to drive the same distance with a petrol or diesel car, 27 000 liters of fuel are needed if you assume a consumption of 7 l diesel per 100 km. This amount of diesel is thought to fit on a relatively large tanker. In other words, there will be no significant change in the number of tankers needed to deliver fuel in the form of liquid hydrogen compared to diesel or gasoline.

The number of heavy goods vehicles for the purchase of the energy carrier: It is expected that it is mainly large trucks that will fill liquid methane or hydrogen. Where this type of fuel is available, it will therefore most likely be a predominance of heavier vehicles.

Quantity of flammable substance: As shown in section 4.3.5, the calorific value of the amount of hydrogen in gaseous form needed to drive a car a given distance measured in MJ/100km is similar to that of a petrol or diesel car. It is assumed that the consumption of a car running on liquid hydrogen is equivalent to the consumption of a car that runs on hydrogen in gaseous form. Thus, liquid hydrogen will also not require a significantly greater amount of flammable substance in order to be able to drive a given distance, compared with petrol or diesel.

A test of an LNG truck and a diesel truck that was driven through Europe three times showed that the average consumption was 23,6 kg/100 km for LNG and 27.1 liters/100 km for diesel [84]. If converted, this will be approximately 1147 MJ/100 km for LNG and 984 MJ/100 km for diesel. Thus, the total amount of flammable substance needed to drive these trucks a given distance is about 17% higher for LNG than for diesel.[38]

Retention period of visitors: The filling time for liquid hydrogen and methane will not be significantly different compared with filling time for other liquid fuels such as gasoline and diesel. Thus, the retention time of visitors will not increase.

Unique scenarios for the energy carrier: Liquid hydrogen and liquid methane are stored at very low temperatures. Severe cooling in the event of a spill is unique to this type of fuel. This can cause frost damages for people exposed to the leak or for construction materials, such as steel, that become brittle and crack.

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[38] The specific weight of diesel is estimated to approximately 0.83 kg/L. Lower calorific fuel value for LNG is set to 48.6 MJ/kg and 42.8 MJ/kg for diesel (https://h2tools.org/hyarc/calculator-tools/lower-and-higher-heating-values-fuels).

Complexity of the facility (joints, couplings etc.): Liquid hydrogen and methane are stored at relatively low pressures in insulated tanks. The design of the facility is relatively simple, but it requires the right safety equipment and staff. Evaporation from storage tanks must be regularly ventilated to avoid pressure build-up. The need for ventilation depends on the consumption and temperature of the gas supplied. Liquid hydrogen and methane facilities must also be designed so that there are no enclosed areas without the possibility of ventilating gas.

Number of third-parties/ size of safety distances: Size of safety distances, and the number of third-parties who will be staying in different zones will required facility-specific considerations. In some cases, greater safety distances may be required for facilities with liquid hydrogen and liquid methane than facilities with gasoline and diesel.

Fire department's extinguishing effort: In the event of a fire, it will be important for the fire service to ensure that storage tanks are not exposed to excessive heat from the fire without reducing the pressure through the safety valves. There may also be a risk when using water on the tank to cool it that the safety valve will be sealed by ice formation.

For liquid hydrogen, the risk of very large fires or explosions comes as a result of reactions between liquid oxygen and organic matter. This phenomenon occurs due to the fact that liquid hydrogen has a boiling point that is lower than air. If air comes into contact with the surfaces of liquid hydrogen or equipment that is not insulated and that keeps temperatures down to the boiling point of hydrogen, then the oxygen in the air can condense into liquid oxygen.

External fire – possibility of escalation: Heat exposure to insulated tanks with liquid hydrogen or methane can as a worst case lead to BLEVE (Boiling Liquid Expanding Vapor Explosion). However, the fact that these tanks are insulated, protects against a BLEVE. This is unlike, for example, LPG, which is stored on uninsulated tanks.

Environmental impact: Tanks with liquid hydrogen or LNG will release the gas as it is formed if there is too little consumption from the tank. The evaporation rate depends on how well the tank is insulated and how large the surface area is. Methane from LNG is a powerful greenhouse gas. It is therefore important to minimize the amount of methane gas emitted throughout the chain of LNG distribution and use. [85]

Increased maintenance (risk of installation errors): As for hydrogen in gaseous form, the facility will be relatively complex and must be maintained and inspected by qualified professionals.

Other (not fire related, economy, health etc.) that is affected: Establishment and maintenance may affect the facility's economy.

4.4.6 Measures and barriers

The facilities are built based on relevant standards, and these standards provide details on measures and barriers at the facilities, see section 4.4.4.

For the storage of liquid hydrogen and methane, it is important that the tanks are well insulated to reduce the evaporation in the tank in case of low consumption. Insulation will also protect the tank in case of external heat exposure in case of a fire. Despite good insulation, gas will always evaporate from these cryogenic liquids (cryogenic gases), this must be ventilated safely to avoid pressure increase. It is also important to use materials and steel qualities that can withstand the low temperatures to which they are exposed during normal operation and possibly during an accidental leak.

Important barriers to prevent external heat from causing an escalation to BLEVE include that the tank is well insulated from external heat impact and that the safety valves work and release gas to prevent the pressure from getting too high inside the tank. However, it is worth mentioning that a safety valve function to prevent BLEVE is disputed, as there are many factors that effects this. It does not have to be one-sided positive with a safety valve in this context. There is little documented knowledge of BLEVE in tanks with liquid hydrogen. This is one thing that, among other things, the SH2IFT research project is currently studying [20]

A collection pool under liquid methane or hydrogen storage tanks will prevent the liquid phase from spreading outward in the event of a leak. The size of this collection pool will determine how large leaks can be prevented from flowing outwards. As shown in Figure 4-2 on page 32, small leaks are thought to have significantly greater frequency for LNG filling facilities compared with petrol/diesel [35]. In addition, detectors that respond to gas concentrations and low temperatures can be installed. These detectors can activate shut-off valves that may isolate the different parts of the facility and reduce the potential amount that leaks as much as possible. [35]

4.5 Other energy carriers: ethanol, CNG, CBG, LPG

In addition to fast chargers, hydrogen in gaseous and liquid form and liquid methane, there are several other energy carriers that may be applicable to a greater extent than what is the case today. This includes ethanol, compressed natural gas (Compressed Natural Gas, CNG), compressed biogas (Compressed BioGas, CBG) and liquid propane or butane (Liquid Petroleum Gas, LPG).

Liquid propane and liquid methane have beneficial properties as fuel, with high energy density, low local emissions and low pressure storage. In comparison, compressed methane and hydrogen have lower energy density and must be stored under significantly higher pressure. Such aspects may affect the risk picture for these energy carriers, but this has not been reviewed in detail here, since these currently has a very low market share in Norway, and it is considered that in the near future they will not be widespread in the private market in Norway.

In Norway there was one energy station with a combination of traditional fossil fuels and LPG, but for market reasons, the LPG-part of this was discontinued a few years ago[39]. In addition, there are stations that offer LPG only. Ethanol as fuel is more common in Sweden than in Norway, and it will be possible to learn lessons from there if the use of ethanol is increased. Similarly, one should look to other countries in Europa and internationally when introducing other energy carriers.

[39] Interview with senior head of fast charging, senior specialist HSE and senior head of Circle K, 13.01.2020.

5 Risks of change from traditional petrol station to energy station

In this chapter, an overview will be given of the risks involved when changing from a traditional petrol station to an energy station with *one* additional energy carrier. This is based on the presentation of each energy carrier given in chapter 4.

Scenarios used to study the change in risk from traditional petrol station to energy station are illustrated in Figure 5-1. In general, an increase in the total energy content in one place will lead to an increased risk, regardless of whether it is petrol, hydrogen or other energy carriers. In order to study the contribution of new types of energy carriers, it is therefore based on the assumption that the energy content of the total amount of energy carriers is unchanged.

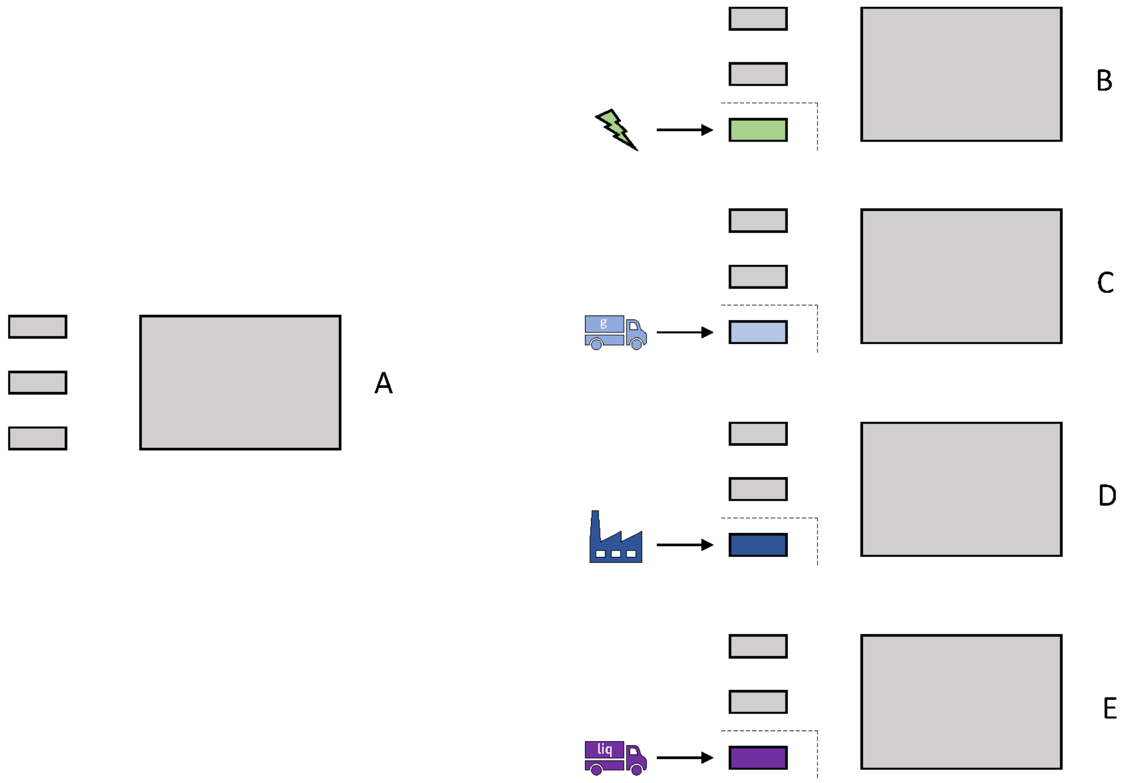

Figure 5-1 Five different scenarios: Traditional petrol station with kiosk and filling pumps (scenario A), fast charger energy station (scenario B), energy station with gaseous hydrogen transported to the site (scenario C), energy station with hydrogen produced on-site (scenario D), energy station with liquefied hydrogen or liquefied natural gas transported to the site (scenario E). Distances and sizes are only illustrative.

A simplified overview of possible event chains and outcomes that can lead to injury or unwanted events at an energy station is shown in Figure 5-2. For energy carriers in gaseous or liquid form, loss of containment means gas release or fuel spills to the surrounding area. For electricity as an energy carrier, this means that the electrical energy goes somewhere it should not (e.g. arc or creep current).

There are many different factors that can affect fire and explosion safety when a traditional petrol station changes to an energy station. An assessment of these is summarized in Table 5-1, detailed information can be found in paragraphs 4.2.5, 4.3.5 and 4.4.5.

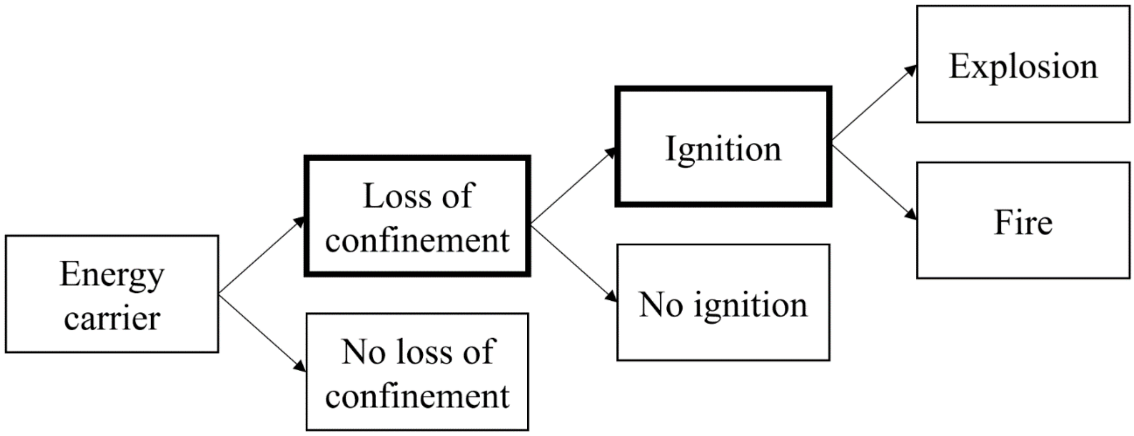

Figure 5-2 Event tree showing what may happen and which consequences it may have. The highlighted fields are reviewed in detail in Table 5-2 and Table 5-3.

In Table 5-2 and Table 5-3, a *what-if*-analysis is presented for two events: loss of containment and ignition of emissions. Note that content in the table is a qualitative simplification, intended to give the reader a general overview of the topic as presented in paragraphs 4.2, 4.3 and 4.4. The measures highlighted are those highlighted through interviews and input from stakeholders, as well as by reviewed literature, which are particularly relevant to that scenario (beyond measures already in place at the petrol station). For a more detailed approach, a more comprehensive quantitative risk assessment is needed for each facility type and energy carrier.

Responsible for the various measures is usually the facility itself, normally the owner of the energy station. The fire service is responsible for supervision for some facilities with hazardous substances and for a specific type of fire object (*særskilt brannobjekt*, see section 3.1). There is a general need to increase the knowledge and expertise at fire services with regard to new energy carriers. According to Drivkraft Norge[40] the fire services requests knowledge and training, especially on hydrogen and other gases. Competence raising is highlighted in Table 5-3 as a risk-reducing measure that could reduce the impact of a fire. Here, follow-up studies/ education and courses held at Norges Brannskole is relevant, both for fire service's emergency preparedness and preventive departments. Topics that will be particularly relevant to address are knowledge of fire and explosion properties for flammable gas in general and especially for hydrogen, difference between the behavior of LPG and natural gas, safety distances with regard to evacuation/wind direction, how fires in lithium batteries behave etc. Fear and uncertainty concerning unknown factors may be on obstacle, while knowledge will facilitate proper handling, early and effective extinguishing efforts.

Another general risk-reducing measure that applies to all energy carriers is correct installation in accordance with regulations and installation instructions, as well as regular and good maintenance and inspection of the facility. This should go without saying , as this is required by the Regulation

[40] Interview with Head of Trade (*fagsjef*) at Drivkraft Norge, 28.11.2019.

on handling of flammable, reactive and pressurized substances [6], but it is pointed out nonetheless, since human failure can make a difference between theory and practice, if the system is not simple, unambiguous and robust.

Table 5-1 Assessment of factors that may be affected by change from traditional petrol station (scenario A) to energy station with various energy carriers (scenario B-E) see Figure 5-1. More detailed information about each anergy carrier is provided in sections 4.2.5 4.3.5and 4.4.4.

Factor	**Scenario B: Fast Charger**	**Scenario C: H_2 (g) delivered**	**Scenario D: H_2 (g) produced on-site**	**Scenario E: H_2 (L), LNG (L) delivered**
Ignition sources:	Charger and associated electrical equipment are ignition sources	Small ignition sources can ignite hydrogen.	Small ignition sources can ignite hydrogen.	Small ignition sources can ignite hydrogen. LNG no change.
Number of passenger vehicles:	Increases when charging queue. Decreases due to home charging.	Unchanged	Unchanged	Unchanged
The number of heavy goods vehicles for the delivery of the energy carrier:	Reduced	5 – 17 times increase	Reduced	LH2: Unchanged. LNG: Doubled
The number of heavy goods vehicles for the purchase of the energy carrier:	Currently not very relevant	Not very relevant	Not very relevant	Yes, relevant
Quantity of flammable substance	If battery bank: increases	Unchanged	Unchanged	Unchanged to slightly higher
Retention period of visitors:	Increases	Unchanged	Unchanged	Unchanged
Unique scenarios for the energy carrier:	Electric car fire, battery fire, arc, transformer	Low ignition energy, wide flammability range	Low ignition energy, wide flammability range	Cryogenic temperatures
Complexity of the facility (joints, couplings etc.):	Unchanged	Increases	Increases	Increases
Number of third-parties/ size of safety distances:	Unchanged	May increase	May increase	May increase
Other additional installations that may affect safety:	Solar cells and buffer battery		Solar cells in connection with power supply	
Fire department's extinguishing effort:	If battery fire: increased effort time, possible more toxic fire smoke	Flame with low radiation and not easy to see	Flame with low radiation and not easy to see	BLEVE, icing of safety valves. LH2: risk of liquid oxygen, large fire
External fire – possibility of escalation:	Unchanged	Several pressurized pipes, tanks exposed to heat	Several pressurized pipes, tanks exposed to heat	BLEVE
Environmental impact:	Unchanged	Unchanged	Unchanged	Evaporation of methane should be limited
Increased maintenance (risk of installation errors):	General maintenance of charging cable etc.	Maintenance by external: Competence important. Some local support in case of connection errors etc.	Maintenance by external: Competence important. Some local support in case of connection errors etc.	Maintenance by external: Competence important. Some local support in case of connection errors etc.
Other (not fire related, economy, health etc.) that is affected:	Economy: Establishing power-supply. Can utilize residual current. Health/ working environment: less fumes/odor	Economy: establishment and maintenance	Economy: establishment and maintenance	Economy: establishment and maintenance

Table 5-2 What-if analysis of the event *loss of containment* of an energy carrier. Description of the cause of the incident, with a change in probability of the incident compared with a traditional petrol station. Description of consequences of the event, with the change of severity to consequences compared to a traditional petrol station. Scenarios are described in Figure 5-1 . The table is qualitative and intended to provide a quick overview of the more detailed information on the characteristics and risks associated with each energy carrier, as well as on possible risk-reducing measures, which are provided in sections 4.2, 4.3 and 4.4.

Incident	**Scenario**	Description of possible cause	Change in probability*	Description of consequence (Health and safety, environment, economy)	Change of consequence*	Possible risk-reducing measures (cause and consequence)	Responsible for measures
Loss of contain-ment	**All**	User error, sloppiness, car crash into equipment, component failure, installation error, error/failure of maintenance				Avoid user errors: info about equipment, simple, unambiguous and robust system. Avoid equipment failures: follow acknowledged standards for facilities, inspection, maintenance, third-party control	The facility
	B: Fast Charger	Loss of containment is here power astray: arc, creep current and ground faults. An arc may occur in case of fault or wear on the facility, improper installation/ maintenance.	1	An arc can give locally very high temperatures, and lead to fire. Power astray: electric shock/personal injury	Given in Table 5-3	Properly dimensioned electrical equipment, and regular inspection of equipment. Communication between car and charger helps reduce incorrect charging and prevent the car from driving with charging cable connected.	The facility

Incident	**Scenario**	Description of possible cause	Change in probability*	Description of consequence (Health and safety, environment, economy)	Change of consequence*	Possible risk-reducing measures (cause and consequence)	Responsible for measures
	C: H_2 (g) delivered	Compared with Petrol/Diesel, these are pressurized and filled in a closed system. This reduces the possibility of activating filling without the hose being properly connected to the vehicle.	2	Overpressure- anything that doesn't shut down will leak out. Rises and dilutes quickly.	1	Sectioning for vertical dispersion and dilution. Limit potential leakage rate.	The facility
	D: H_2 (g) prod.		2		1	Sectioning for vertical dispersion and dilution. Limit potential leakage rate.	The facility
	E: H_2 (l), LNG delivered		1	Overpressure- anything that doesn't shut down will leak out. Cold: personal injury, material failure. Liquid and cold gas will spread along the ground	2	Physical separation and thermal insulation: avoid that fire nearby gives BLEVE.	The facility

* Probability of event *loss of containment,* compared to scenario A (traditional petrol station):
Much smaller (-2), less (-1), equal (0), increased (1), much increased (2).

Table 5-3 What-if analysis of the event *ignition*. Description of the cause of the incident, with a change in probability of the event compared to a traditional petrol station. Description of the consequences of the event, with a change of severity to the consequence compared to a traditional petrol station. What-if analysis of what can happen if there is ignition. Scenarios are described in Figure 5-1. The table is qualitative, and intended to provide a quick overview of the more detailed information about the characteristics and risks associated with each energy carrier, as well as about possible risk-reducing measures, which are given in sections 4.2, 4.3 and 4.4.

Incident	**Scenario**	Description of the reason for the cause/ probability	Change of probability*	Description of consequence (health, environment, economy)	Change in consequence *	Possible risk-reducing measures (cause and consequence)	Responsible for measures
Igniting	**All**			If uncertainty about handling/ extinguishing the energy carrier: prolonged time to extinguishing: increased consequences.	1	Facilitate for effective extinguishing efforts: competence and training of fire service: early and proper handling	Fire service, authority
	All			Escalation due to systems over ground, more exposed to external fire	1	Physical distance, physical barrier to potential external fire exposures	The facility
	B: Fast Charger	The arc leads to locally very high temperatures and can start a fire if there is combustible materials or flammable substances nearby.	1 Increased probability of ignition given an arc	Most of the materials are less reactive than petrol and diesel and a fire is expected to develop slower Fire can be spread to electric cars that are charging, battery not included in fire. *(cont. next page)*	-1 0	Cause: Equipment maintenance and proper installation Consequence: Good design of stationary battery to prevent escalation. Good distance from combustibles.	The facility

Incident	**Scenario**	Description of the reason for the cause/ probability	Change of probability*	Description of consequence (health, environment, economy)	Change in consequence *	Possible risk-reducing measures (cause and consequence)	Responsible for measures
				Fire can be spread to electric cars that are charging, battery included in fire. Fire can spread to a large, stationary battery.	1 2		
	C: H_2 (g) delivered **D: H_2 (g) prod.**	Very low ignition energy. This provides many potential sources of ignition.	2	Very high ignition probability. Late ignition can cause a powerful explosion/ detonation. Heat radiation from the flame is less than from petrol/diesel.	1	Solid walls can stop exposure from a jet fire	The facility
	E: H_2 (L), LNG **delivered**	Cold, heavy methane and hydrogen gas, and liquids can be spread along the ground. Methane has about the same ignition energy as gasoline vapor, hydrogen gas much lower.	LNG: 0 LH2: 2	The gas cloud that forms can catch fire. This can cause an explosion or a flash fire.	0	Limit the potential leakage rate.	The facility

* Probability of event *ignition*, compared to scenario A (traditional petrol station):
Much smaller (-2), less (-1), equal (0), increased (1), much increased (2)

6 Energy carriers in combination

It may be of interest to have many energy carriers located in the same physical area, in cases where the company wants to collect everything in one place for a complete offer. It is currently difficult to predict which energy carriers this will apply to, and to what extent this will be applicable.

It has not been possible to finding industry guidelines or standards that address energy carriers in combination at energy stations, and which are available in Scandinavian or English language.

The following is therefore based on research literature found on the topic, as well as input from interviews.

6.1 Existing research literature on energy carriers in combination at energy stations

Scandria®2Act is an Interreg Baltic Sea Region project that has studied the possibilities of transport based on several renewable types of fuel in the region around the Baltic Sea. The report concludes that there are no significant safety barriers in establishing energy stations with different types of renewable and conventional fuels. Charging stations for electric vehicles should be considered a potential source of ignition and must be kept away from the surroundings where explosive atmospheres are expected. In addition all equipment that are to be used for the different types of fuels must be dimensioned for the most conservative type of fuel. Gases and vapors from different substances are classified into three different groups, based on how low ignition energy is needed to ignite a mixture with air. Equipment to be used where it may be an explosive atmosphere from these substances must take into account the substance that has the lowest ignition energy. If equipment is to be used in an area with both methane and hydrogen must satisfy the equipment class IIC (hydrogen), while methane, gasoline and LPG comes under equipment class IIA, and ethanol under IIB. The temperature class is classified in the same manner as the equipment class but according to the auto ignition temperature (AIT) of the substance. Hydrogen and methane belong to the lowest temperature class (T1), then comes ethanol and LPG (T3) and then gasoline and diesel (T3).

In a 2017 study, the national renewable energy laboratory in the United States, NREL, has compiled an overview of regulations and standards covering filling stations for different types of fuel [86]. According to the overview, the U.S. Department of Energy has defined six types of fuel as alternatives to gasoline and diesel:

- Biodiesel
- Electricity
- Ethanol
- Hydrogen
- Natural gas
- Propane

Of these, electricity is by far the most prevalent, followed by ethanol, LPG and CNG [87]. The study from NREL summarizes that there is a set of standards and regulations that make it possible to build and operate an energy station with all these types of fuels (note that these are probably not as relevant in Norway, as we mainly use ISO and EN standards) There are specific requirements for safety distances for different types of fuel installations. For example, NFPA requires that the venting point for hydrogen storage shall be placed at least 32 feet (approx. 10 m) from the property border. Natural gas storage tanks must be placed at least 10 feet (approx. 3 m) from the property border and from buildings according to NFPA 52. The various regulations and standards covering these fuel types are not coordinated. The systems for the different types of fuel are therefore not fully coordinated, so that an emergency stop switch of, for example, hydrogen does not necessarily stop the filling of diesel from another pump. Old petrol stations that are not built according to today's requirements must be upgraded to the current requirements if a new type of fuel is to be installed. It is also pointed out that maintenance requiring a shutdown on one of the fuel systems must also take into account the other fuel systems at the facility. [86]

6.2 Interactions between several energy carriers: assessment of total risk

Change from traditional petrol station to energy station with many energy carriers collected is illustrated in Figure 6-1.

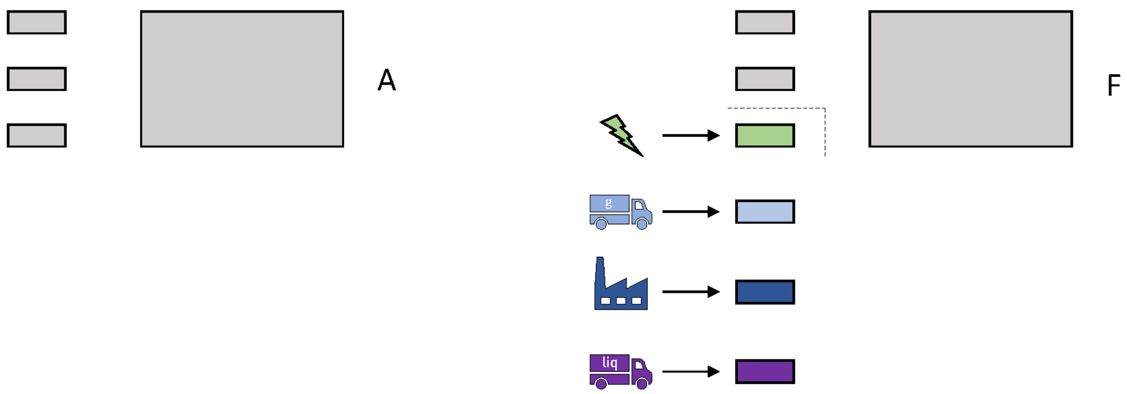

Figure 6-1 Traditional petrol station (scenario A), energy station with a combination of scenarios from Figure 5-1: fast charger, gaseous hydrogen transported to the site, hydrogen produced on site, liquefied hydrogen or liquefied natural gas transported to the site, and/or other energy carriers (scenario F). Distances and sizes are only illustrative.

Challenges have been identified concerning interactions between the different energy carriers that can contribute to the risk of fire and explosion within two areas:

- Areal challenges
- Cascading effects

No chemical interactions between the energy carriers that could provide challenges have been identified, beyond that which apply to the energy carriers individually.

Areal challenge: Risks for the surroundings should be assessed based on the overall activity at the facility [8]. When increasing the number of filling systems within a given area, the frequency of unwanted events at a given location will be summarized (put simply), as illustrated in Figure 6-2. As shown in the figure, the close proximity of several risk objects will affect risk contours, and consequently the size of the zones requiring special consideration (or, when it comes to small and medium-sized facilities, safety distances) will change. An example of changed risk is that by an increase in the number of filling systems for different types of fuels within an area, the frequency of leaks from each system will be summed up, and the total leak rate is expected to increase. In some cases, the implementation of one energy carrier will affect the use of other energy carriers at the energy station (as described in chapters 4 and 5), and in this case, the frequency of incidents in one facility cannot simply be summarized directly with the frequency of incidents at the other facility.

In the event of business or property development, however, there must be sufficiently available space in order for two energy carriers to be physically closer together than what is specified in their risk assessments separately, and a joint risk assessment must be made that addresses this issue. Unless risk-reducing measures are taken, the total risk from the facility will increase. In densely populated areas, lack of land could prevent a development.

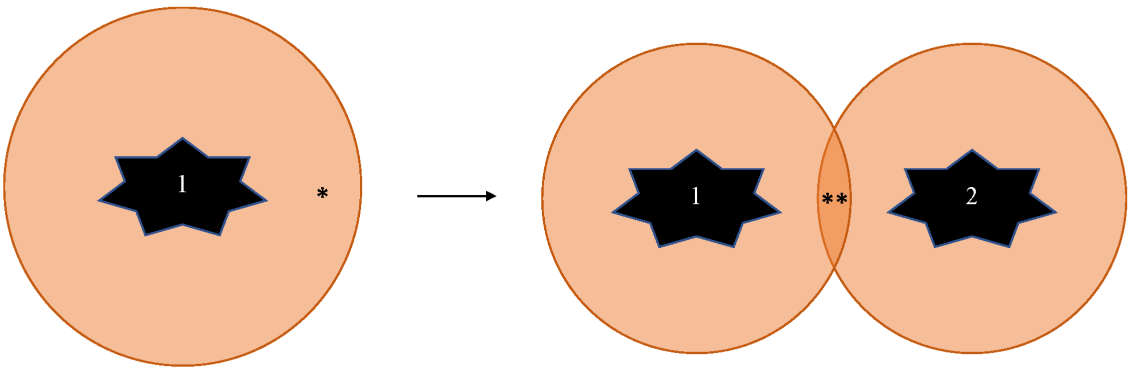

Figure 6-2 Illustration of interactions that effect the risk: The risk for a person (*) located in one area of an energy station with one type of energy carrier (1) and how this risk increases by the sum when adding more energy carriers (1+2).

Cascading effects: This is defined as "An event chain that starts as a minor event and grows into a larger event» [61], illustrated in Figure 6-3.

Some examples of relevant chains of events that have been identified:

- Pool fires that spread outwards, or flow downwards and end up under a gas tank
- Explosion or fire that damages surrounding installations (pressure wave that is spreading, flying fragments, flames, etc.).
- Fire in a small amount of fuel that ignites more fuel which in turn ignites more fuel.

For the latter, the risk will not necessarily be greater for an energy station compared to a traditional petrol station. The consequences in the event of an internal escalation in one energy carrier may be as large as in the event of a spread to other energy carriers, but the changed properties between the energy carriers may give a change in the expected sequence of events.

On the other hand, division into several energy carriers and physical separation between these could have a positive interaction, in that the separate facilities individually may have less extent of damage in the event of an incident. For energy carriers in liquid and gaseous form, facilities with many smaller tanks with energy carriers will have less potential total emissions than at a facility with fewer, larger tanks.

In addition, cascading effects due to willful action (individual or terror) can initiate a chain of events and/or destroy barriers, but this is beyond the scope of this project.

The risk (frequency and consequence) of negative cascading effects can be reduced by good technical and organizational measures and barriers. When an energy carrier is new and relatively unknown, good training and follow-up will be central to avoiding increased frequency of errors. Events that are normally considered highly unlikely may be more likely in an introductory period if this is not taken care of.

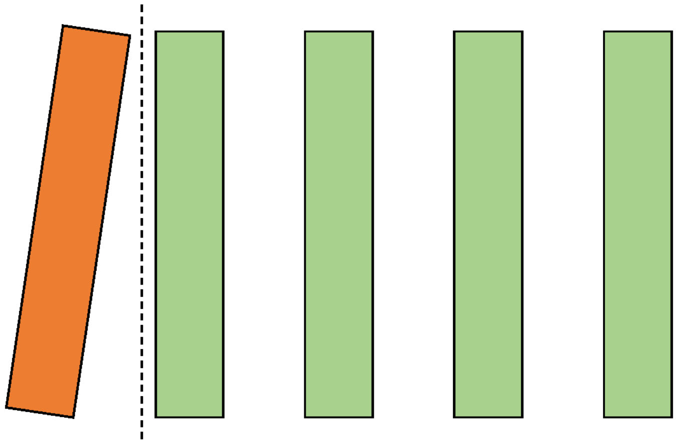

Figure 6-3 Illustration of interactions that affect the risk: An event in one area of an energy station may affect other areas, if there are no barriers in place (illustrated by dotted line) to deal with cascading effects.

7 Summary and recommended further work

In facilities that handle flammable, self-reactive, pressurized and explosive substances there is a risk of unwanted incidents. When facilities with hazardous substances comply with current regulations, the risk associated with handling hazardous substances is considered not to be significant compared to other risks in society.

In the transition from a petrol station to a multifuel energy station with one or more alternative energy carriers, the risk of fire and explosion may be affected, in a positive or negative direction. For example, when introducing fast chargers for electric vehicles, there will be an additional potential source of ignition, but there will also be fewer fuel deliveries from heavy goods vehicles. When introducing gaseous energy carriers, the complexity of the facility will increase due to higher pressure, compared to simpler facilities (without or with low pressure). In risk assessments of each facility, a number of general factors for each energy carrier will be important to take into account, in addition to facility specific factors. Good, technical and organizational measures adapted to each facility and each type of energy carrier are important.

For the combination of more than one alternative energy carrier combined with fuels of a conventional petrol station, two challenges have been identified that could affect the fire and explosion risk: Area challenges and Cascading effects. When changing or developing the facility, area challenges will need to be taken into account and be included in the assessment of the station area's overall suitability for combination of energy carriers. When increasing the number of filling systems within an area, the frequency of unwanted incidents at a given location will often be summed up, and physical distance or barriers between systems must be prioritized to reduce the risk. Cascading effects are event chains that start as a minor event and grow into a larger event, such as a pool fire or pressure wave from an explosion that damage surrounding installations. No chemical interactions have been found that could affect the risk of fire and explosion.

A specific recommendation from the industry to the authorities is that if new recommendations or guidelines are needed, it is beneficial that this is coordinated with or included in existing theme guides, rather than preparing new ones.

Recommended for further work:

If there are to be many electrical trucks in the future, a plan and a separate risk assessment of how charging of these at an energy station will have to be developed, as these are physically larger, and they are likely to have larger batteries and need for their own fast chargers with greater power compared to today's fast chargers for passenger cars. For pressurized hydrogen in gaseous form, tank breakage is an important scenario to avoid, and thus important focus area for further studies. There is a lack of information about the heat impact on an object that is exposed to a hydrogen jet fire when this occurs in the direction of this object. When it comes to liquid hydrogen there is little research and experiments. A relevant question is whether BLEVE (Boiling Liquid Expanding Vapor Explosion) is a relevant scenario for liquid hydrogen, and how a hydrogen tank may behave compared to a methane tank. In general, as this is an ever-evolving market, it is still too early to determine which energy carrier is going to be most used in the future, and it is important that governments and other associated stakeholders keep up to date on what is happening internationally, and that recommendations are continuously updated as new knowledge is acquired through operations and potential unwanted incidents.

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Appendix A: Information sent out in advance of interviews

The following information was sent to all interviewees prior to the interview. The information was sent in Norwegian and is here translated to English.

Background

The Norwegian Directorate for Civil Protection (DSB) has asked RISE Fire Research (RISE) to map how petrol stations need to be changed to meet future fuel demand, as well as the risks this represents with regard to fire and explosion.

The objective of the project is to highlight the risks of a change from petrol stations to energy stations with regard to fire and explosion hazards, and what risks must be taken into account when establishing energy stations. By energy stations we mean stations where there are different energy carriers such as traditional petrol/diesel, hydrogen, fast charge etc.

Interview information:

One of the methods for commencement of knowledge in the project is to conduct in-depth interviews with stakeholders who are connected to this issue in some way, for example through engineering, operation, maintenance, safety etc.

Interview is conducted via Skype/phone, and we want to take notes from what is being discussed, as well as take audio recordings of the call. Audio recordings will only be saved temporarily and will be deleted at the project's conclusion. If you don't want audio recordings, let us know. The notes will be stored, and you will have the opportunity to read through these after the interview. You will not be directly quoted in the report without consent.

We have set up some topics and questions/keywords below that we would like you to think through in advance of the interview. We take these into account, and if other things appear in the conversation that are of interest, or if you thinks that there are other aspects that are important to include, then we would like to hear your views.

Theme 1: Energy Stations of the Future:

Thoughts on the energy stations of the future: what will these look like, what will the future energy demand be like, what political policies will be able to influence this, how will various community functions have to adapt, thoughts on fire safety and the role of the fire service for the future energy stations.

Topic 2: Events that have occurred (if applicable)

Summarize the course of events, possible causes of the incident, consequences, severity of the consequences, how likely this particular incident was to occur, measures that were put in place, measures that should have been taken/ what should have been done differently, who is responsible for action.

Fire brigade's efforts: How did the actual effort take place, what assessments were made along the way, what do you have from experience with these types of incidents?

Learning points: What have you learned from the incident? Would you do anything differently in a similar accident in the future? How could the station, and the stations of the future, be designed differently for better fire and explosion safety, even in terms of facilitating the fire department's efforts?

Preparation/training: How to prepare for such events?

Theme 3: What can happen if...

What could go wrong in the future? Possible causes, consequences, severity of the consequences, how likely are it that various events occur (preferably a number here, but thoughts are most important), measures that can be put in place, measures that should be put in place (recommended measures), what can/should be done differently than today, who is responsible for measures?

- What could happen if... there will be a leak of an energy carrier?

- What could happen if... this leak ignites?

- What could happen if...

For example, the energy carrier can be hydrogen, LNG, LPG, i.e. liquid or gaseous fuel, or it can be arc, creep current, short circuit in conjunction with fast charging.

Do routines/training/exercises or other changes in relation to current practice when establishing energy stations?

Theme 4: Other aspect

New energy stations will be able to have both petrol/diesels, as well as hydrogen and fast charging. What do you think about this? How can the combination of many energy carriers in one place affect the risk (enhanced or worsened), compared to individually? Is there any other aspect than what we've been talking about so far that could affect fire and explosion safety?

What should the government focus on in guidance to the energy stations of the future?

Through our international collaboration programmes with academia, industry, and the public sector, we ensure the competitiveness of the Swedish business community on an international level and contribute to a sustainable society. Our 2,200 employees support and promote all manner of innovative processes, and our roughly 100 testbeds and demonstration facilities are instrumental in developing the future-proofing of products, technologies, and services. RISE Research Institutes of Sweden is fully owned by the Swedish state.

Gjennom internasjonalt samarbeid med akademi, næringsliv og offentlig sektor bidrar vi til et konkurransekraftig næringsliv og bærekraftig samfunn. RISEs 2 200 medarbeidere driver og støtter alle typer innovasjonsprosesser. Vi tilbyr et hundretalls test- og demonstrasjonsmiljø for framtidssikre produkter, teknikker og tjenester. RISE Research Institutes of Sweden eies av den svenske staten.

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