SUSTAINABLE MOBILITY AND ITS CONSEQUENCES FOR OCCUPATIONAL SAFETY AND HEALTH

Introduction

This discussion paper presents developments related to the introduction **of renewable or sustainable energy in the European mobility domain and the potential risks to occupational safety and health (OSH).**

The European Union aims to reduce carbon emissions to slow down climate change. One of the main areas for carbon emission reduction is in the mobility domain: road, rail, marine and air transport. A reduction can be achieved by replacing fossil fuels for zero-emission fuels. This requires all kinds of new technologies to produce, store and transport zero-emission fuels. But new technological developments bring “new” safety risks. Look for example at the coal-to-gas transition for heating and cooking in houses in the 1960’s, where many civilians and emergency responders were experiencing more gas leakages and explosions which hampered its introduction.

The focus of this article will be on the current growth of zero-emission transport using zero-/low-emission energy carriers, such as the use of **electric batteries, hydrogen and liquid organic hydrogen carriers (LOHCs).** In this paper, transport is defined as the activity of carrying people or goods from one place to another (over a substantial distance) by means of road, rail, air or ship. Micro-mobility activities through vehicles such as e-steps/paddles, e-bikes, e-scooters or scoot mobiles are not included as these are used for small distances and contribute marginally to carbon emission reduction. New OSH risks also emerge in the *production* of sustainable fuels, but they are out of scope for this paper as well.

This paper focuses on the safety and health implications of the **vehicle, ship, and train operators, technicians, and emergency responders** as a result of sustainable developments, especially as their role is sometimes overlooked in existing legislation and guidelines.

A preliminary exploration of the use of **sustainable fuels, also called new energy carriers**, will be carried out on OSH risks for employees (vehicle operators, maintenance workers and technicians), as well as for first responders (private and public fire brigades). In light of the assessment of OSH risks due to sustainable, zero-emission transport developments this paper will result in a summary of actions meant to improve health and safety.

It is important to be aware that this paper has been written mainly from a Dutch perspective. This means that some of the examples and identified (regulatory) gaps originate from a Dutch context. They might, however, be applicable to (OR ‘relevant for’) other Member States as well.

Sustainable fuels: developments

The growing awareness that the climate is changing as a result of rising temperatures in the planet’s atmosphere has led to a strong European focus on limiting the temperature rise and the related reduction of CO_2 and methane emissions[1], as seen in the Paris Agreement, for example. This reduction can be achieved not only by reducing energy consumption but also by using renewable or sustainable energy sources. The COP28 UN Climate Change Conference in Dubai[2] has reinforced this development by announcing – even more ambitiously – the beginning of the end of the fossil fuel era.

The use of sustainable fuels or new energy carriers in mobility reduces emissions of carbon dioxide. An energy carrier can be a substance (fuel), but it can also be a system that contains or stores one form

[1] Methane (CH_4) is 34 times as strong as CO_2, and methane is responsible for about 20% of the greenhouse effect. See: https://www.wur.nl/nl/onderzoek-resultaten/dossiers/dossier/methaan-1.htm in particular, an issue in cattle breeding and less apparent in transportation.

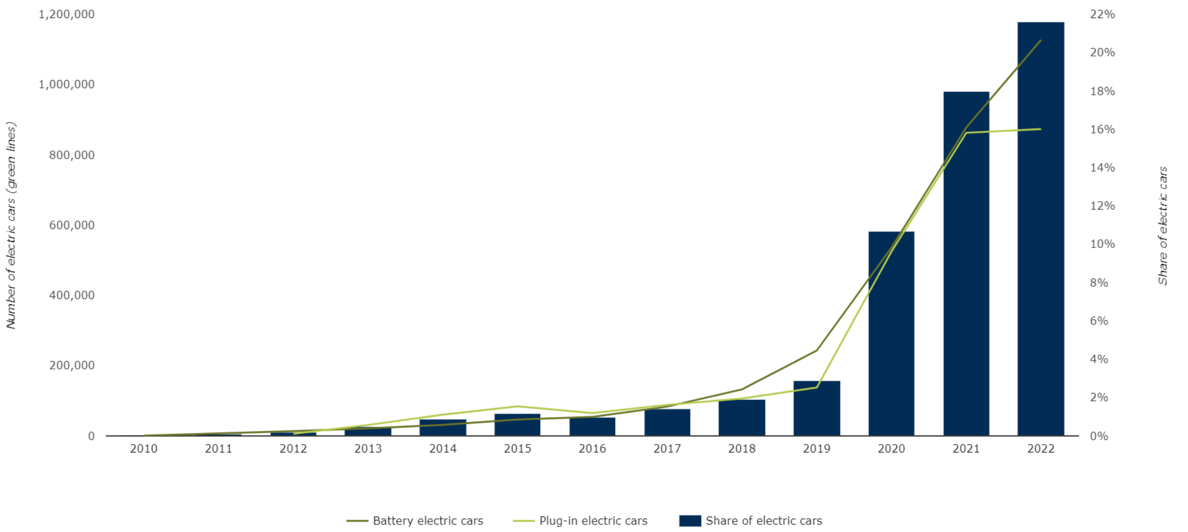
[2] See: https://unfccc.int/cop28

of energy (electrical, mechanical, potential) that can be later converted into another form, such as a propulsion system, propelling vehicles or heat or operating chemical processes.

For the transport domain in particular, the EU[3] prescribed the following sustainable goal: **all new cars and vans registered in Europe will be zero emission by 2035**. As an intermediary step towards zero emissions, the average emissions of new cars will have to come down by 55% and new vans by 50% by 2030. This will put road transport on a firm path to zero-emission mobility in 2050.

For electric cars, for example, we see a substantial increase in the EU[4] during the last four years:

Figure 1: Share of electric cars in the EU in recent years:



Source: Public bus-transportation[5] follows a similar trend.

Table 1: Trend of battery electric bus registrations (year-over-year) and share in city bus market:

Year	Battery-electric bus registrations	Trend yoy	Share on city bus market
2020	2,062	+22	15%
2021	3,282	+48	20%
2022	4,152	+26	30%
2023	6,354	+53	42%

Source: www.sustainable-bus[5]

Compared to electric cars, we see a considerable volume of newly registered alternative fuelled buses on the roads in Europe. in addition to the already mentioned 4,152 battery-electric buses (trolleybuses excluded) that use alternative drive technology in 2022, also 2,018 hybrid buses, 3,274 CNG buses and 99 hydrogen buses have been registered. Inn 2022, a total of 9,543 alternative fuelled buses are on the roads in Europe. It means that 62.5% of newly registered city buses in Europe are now powered through alternative fuels.

[3] See: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en

[4] See: https://www.eea.europa.eu/en/analysis/indicators/new-registrations-of-electric-vehicles#:~:text=Considerable%20progress%20in%20the%20uptake,1%2C74%20million%20in%202021

[5] See: https://www.sustainable-bus.com/electric-bus/electric-bus-public-transport-main-fleets-projects-around-world/#:~:text=Zero%2Demission%20bus%20registrations%20in,H1%20figures%2C%20is%2037.5%25

The mobility market (both private and public) is moving fast to become more sustainable/zero emission. The above-presented figures indicate the number of vehicles that use electric batteries, compressed natural gas or hydrogen. However, there is a broader variety of **applications of sustainable fuels** that are expected to grow in use in Europe, including:

- battery electric vehicles (BEV) in air transportation, construction sites and logistics,
- light electric vehicles (LEV) / micro-mobility with charging at home and the public domain,
- liquified natural gas (LNG) in heavy road transport and inland navigation, and for truck and vessel propulsion,
- compressed natural gas (CNG[6]) in road transport,
- e-fuels / synthetic fuels[7] in many transport modes,
- ammonia (NH_3), in particular as a fuel for seagoing vessels,
- hydrogen (H2) as a fuel for heavy goods road transport and inland navigation[8].

However, a chain of activities (production, storage, mass-fuel transportation and fuelling) needs to be constructed in order to fuel vehicles with zero-emission fuels. This chain could be structured as follows.

1. It all starts with the **production** of sustainable/renewable energy, using wind, solar, geothermal, hydro or even bio-based energy production, for example. These renewable energy sources could then be used to power electrolysers that produce hydrogen. The hydrogen can be used to fuel vehicles. In the vehicles, the hydrogen is either used to generate electricity (to propel the vehicle) and water or directly be used as fuel in a modified internal combustion engine powering the vehicle.

2. Next, sustainable fuels and electricity must be transported to fuel stations through pipelines or high voltage wires. The transportation of the large energy volumes (mass transport flows) such as electricity, ammonia[9], hydrogen, LOHCs and e-fuels is essential. To achieve this, new **mass energy transport** flows (liquids and gasses) are being developed[10] from production facilities to depots, storage facilities and fuel stations. These include:

   - hydrogen pipeline infrastructures, tube trailers and rail cars;
   - mass ammonia transportation using pipelines, rail cars, vessels; and
   - mass volumes of LOHC's transported by road, rail and waterways.

3. Fuel infrastructures, such as multi-fuel stations, need to be developed to accommodate vehicles that use sustainable fuel. To fuel the vehicles, advancements in the charging/fuelling **infrastructure** are necessary. These developments include:

   - mobility hubs: stations where all kinds of transport modes are concentrated, such as bus, train, cars, subways;
   - multi-fuel stations: stations where numerous fuels, such as electricity, hydrogen, petrol and diesel are present for fuelling vehicles;
   - battery swap stations: stations where empty (li-ion) batteries are replaced by a fully charged battery;
   - Energy storage systems for batteries, hydrogen and ammonia storage deport/tanks and so on;
   - Electricity charging infrastructure, electrified road/trains using overhead lines; and
   - LNG transhipment stations.

[6] LNG and CNG are not inherently zero emission, but because both emit less CO_2, both LNG and CNG own a position in sustainable transportation developments.

[7] E-fuels / synthetic fuels are produced using electrolysers to split water (H_2O) into hydrogen (H_2) and oxygen (O_2). After combining the hydrogen (H_2) with carbon dioxide (CO_2), the resulting mixture is transformed into e-fuels. Combusting of e-fuels produces CO_2. However, this is the same CO_2 that is captured in the air, hence it is 'sustainable'.

[8] Hydrogen

[9] LOHCs are used to transport energy in the form of hydrogen. Hydrogen is bonded to another carbon molecule allowing the same amount of energy to be transported under more favourable circumstances, such as atmospheric pressure or room temperatures rather than requiring high-pressure or extreme cooling. Examples include toluene ($C_6H_5CH_3$), ammonia (NH_3) and methanol (CH_4O).

[10] As for the Netherlands, there is a significant shift occurring in energy transportation. Before the war in the Ukraine, mass fossil energy transportation flows crossed the country from east to west. Nowadays, mass renewable transport flows are being developed from west (the harbours) to east and in the European hinterlands.

Looking at risks and regarding accidents, these fuels introduce different safety risks compared to those associated with diesel and petrol. They shape the occupational risks for vehicle operators, maintenance personnel and emergency responders. Unfortunately, there is only little attention given to these risks and the way they affect the safety of such professionals. These risks could be considered new occupational risks as until more recently workers in mobility-related occupations have mainly been dealing with the risks of fossil fuels.

Safety risks of new energy carriers / sustainable fuels

Box 1: Health effects of CO_2 emission reductions

Before focussing on the OSH risks of the new energy carriers, note that sustainable fuels also provide opportunities to reduce or even prevent enduring OSH risks that come with the use of fossil fuels, specifically related to health. A big advantage is the risk reduction in public health related to emissions from traffic (particulate matter due to fossil fuels like petroleum). Based on a report from the Health Council[11], the Dutch National Institute for Public Health and the Environment (RIVM) estimates the number of annual casualties due to particulate matter in the Netherlands to be between 7,000–12,000[12]. Pulmonologists estimate that particulate matter shortens the human lifespan by about 13 months. In several countries, more and more municipalities specify environmental zones in which only 'clean' vehicles are allowed (vehicles that do not emit particulate matter), which will be beneficial for many, though not for professional drivers.

Health benefits for professionals in transport

Reducing the use of diesel and petrol, in general, leads to significant health improvements not only for the citizens living near transport axes, but also for those at work. Maintenance workers, vehicle service engineers and airport platform workers are often exposed to high concentrations of particulate matter caused by the burning of fossil fuels. Drivers of busses, cars, and trains along with pilots and ship captains are also exposed to these hazards but to a lesser extent.

Health benefits for professionals in emergency management

Professional and voluntary emergency responders as well as company and private fire brigades are tasked with mitigating the consequences of accidents. They may be directly exposed to hazards such as flames, explosions or toxic substances. Additionally, during many emergency response actions, they also exposed to indirect consequences such as particulate matter. Although their personal protective equipment (PPE) and special gear limit this exposure, the frequency of such incidents can still lead to serious adverse health effects. Therefore, eliminating fuels that emit particulate matter is beneficial to the health of emergency responders.

Source: Intermezzo:

Safety risks of sustainable fuels / new energy carriers

The replacement of fossil fuels by sustainable fuels may cause adverse consequences for the safety of workers and emergency responders. The risks from sustainable fuels can be different from those produced by fossil fuels.

The following fuels will be elaborated on below: electric batteries, hydrogen, CNG, LNG, ammonia and LOHCs. The corresponding material safety data sheet (MSDS) of the sustainable fuel is used as the basis for assessing OSH risks. An MSDS provides basic information on a material or chemical product. It describes the properties and potential hazards of the material, how to use it safely and what to do in an emergency. To this end, the international chemical safety cards and the corresponding ILO web-based database search engine[13] have been used. In addition, the NIPV (2023) report in which the safety risks of the energy transition are listed has also been used.

In the beginning of each section below, the search term in the ILO database (which refers to the MSDS and the relevant OSH risks) will be presented. Next, the risks will be described briefly, a real-life accident

[11] See: https://www.gezondheidsraad.nl/documenten/adviezen/2018/01/23/gezondheidswinst-door-schonere-lucht
[12] See: https://www.rivm.nl/ggd-richtlijn-medische-milieukunde-luchtkwaliteit-en-gezondheid/andere-bronnen-van luchtverontreiniging/luchtverontreiniging-ander-verkeer#:~:text=Uitgaande%20van%2012000%20doden%20door,de%20uitstoot%20van%20de%20zeescheepvaart
[13] See: https://www.ilo.org/dyn/icsc/showcard.listCards3

(intermezzo) will be presented and finally, a brief description of the safety risks for workers and emergency responders in typical working conditions will conclude each section.

Electric battery safety risks[14]

Search term: lithium→ UN number 1415[15]

In order to store the sustainable energy produced, there are currently different kinds of battery technology/chemistries being developed. The key parameter in this development is energy density (the combination of maximising energy capacity (kWh), minimising weight (kg) and maximising charge/load cycles (runs)). Lithium-ion commercial applications are used mainly in road transport and inland navigation. For now, Lithium-Ion battery technology[16] is the leading technology. But this technology is inherently unsafe: the electrolyte (lithium) is flammable and may initiate a thermal runaway. The thermal runaway is hard to stop because the cooling agent hardly reaches the battery cells, and the battery cells ignite each other. The thermal runway results in a fierce fire which produces flammable and toxic gases including loads of particulate matter. If these gases are not vented properly, a vapour cloud explosion could follow. The health and safety effects for workers and emergency responders regarding electric batteries include:

- Heat stress
- Burns: thermal, chemical, electrical
- Explosions: blast waves and debris
- Electrocution
- Poisoning

Box 2: Fire on the car carrier, Freemantle Highway (25 July 2023, Wadden Sea, The Netherlands)

On the night of 25 July 2023 in the Dutch Wadden Sea, the car carrier Freemantle Highway caught fire. The cause of the fire is still unknown. The Freemantle Highway was transporting almost 4,000 cars, of which about 500 were electric. The fire lasted for days and was difficult to extinguish, mostly because of the electric cars on board. The carrier was transported to the Eemshaven port where the salvage activities took place. During the offloading of the cars, one of the electric batteries caught fire (thermal runaway)[17]. This again caused safety risks (fire, intoxication) for the fire fighters and the salvage workers.

Source: Intermezzo

Maintenance and service engineers for electric batteries are likely aware of these risks or although some may be encountering them for the first time. Take for example the battery energy storage systems (BESS) used by electricity network providers. Such systems may well have a capacity of over 1mWh. These BESS have skilled operators (workers) generally, who are aware of electricity and battery risks. Electricity is their core competence and in case of an incident, the network operator may very well assist the emergency responders with his/her knowledge.

On the contrary, electric bus and truck drivers, ship captains or the maintenance and service workers may not have been trained specifically in battery safety issues, despite the fact that these vehicles may also have quite large capacity batteries (a few hundred kWh) or ships with several mWh battery pack/containers. Similarly, emergency responders of road transport vehicles and barges may not have been trained in the use of these batteries and could be (unexpectedly) confronted with risks. Their PPE has been developed for fossil fuels, and their education is focused on traditional fire suppression, including tactics to extinguish the vehicle fires.

Table 1 lists the consequences of the use of electric batteries in vehicles for various types of workers (mostly in the left column). The incident situation (middle column) to a large extent influences the type and extent of the risk. The range of different situations could be extensive. Again, the way workers could be exposed to risks are unlimited, and the examples used here are only meant to understand the

[14] Electrification of road and train transport is getting more attention as well. See: https://www.euronews.com/next/2023/05/09/sweden-is-building-the-worlds-first-permanent-electrified-road-for-evs-to-charge-while-dri. However, the safety risks for the electric road and rail transport are mostly known and comparable to ordinary electricity risks. On the other hand, Li-ion battery packs do cause new risks.

[15] See: https://www.ilo.org/dyn/icsc/showcard.display?p_lang=en&p_card_id=0710&p_version=2

[16] Within Li-ion batteries there are many different chemistry varieties, each with its own specific safety risks.

[17] See: https://nos.nl/artikel/2488608-auto-vat-vlam-na-lossen-van-vrachtschip-fremantle-highway

occupational novelty of the risk and the way it may affect the worker. Hence, not all risks are described in detail.

Table 1: Electric battery safety risks

Workers	Situation	Impact
Drivers / On-board personnel Maintenance workers / Technicians	On route	The driver/shipper may not be aware of a fault in the battery, underestimating the safety risks or even attempting to extinguish the fire which is nearly impossible and highly dangerous.
	In the workplace	An electric battery fire can fully engulf the workplace/shipyard with toxic fumes in just a matter of seconds posing significant risks including the potential for a vapor cloud explosion.
Emergency responders	In the workplace	Company emergency responders may initiate fire suppression actions. However, this is difficult due to thermal runaway and dangerous because of toxic fumes and explosion hazards.
	On route	Professional first responders might not be aware of the typical safety risks. Cooling the battery is often ineffective. Getting too close to the battery may lead to toxic and explosion risks as well as the danger of being hit by parts of the battery and its casing.

Hydrogen safety risks

Search term: hydrogen→ UN number 1049[18]

There are different ways to produce gaseous hydrogen[19], such as electrolysis and steam-methane reforming. We see commercial hydrogen applications mainly in road transport and inland navigation (and a few projects in rail transportation). Hydrogen is the smallest molecule in the universe and is not naturally present in our atmosphere: it needs to be produced by humans. It is very light, highly flammable and easy to ignite. Because hydrogen is such a small molecule, it may affect metals, causing embrittlement which leads to leakages. Hydrogen and hydrogen fires are almost invisible (they do not produce soot and therefore have low heat radiation). In open spaces, hydrogen volatilises in the air, causing its density, flammability, and explosive range to decrease rapidly. This makes it less of a safety concern compared to confined spaces. But in confined spaces the hydrogen concentration increases as result of the leakage. With a low explosion limit, the risk of fires and explosions increase very rapidly. The safety and health risks of workers and emergency responders regarding hydrogen vehicles include:

- explosion/blast risks,
- fire risks.

Box 3: H_2 fuel station explosion (10 June 2019, Kjørbo, Norway)

On 10 June 2019, a hydrogen fuel (and small production) station exploded due to a hydrogen leakage. The fuel station opened in 2016. The hydrogen leaked was caused by an assembly error in the high-pressure storage unit. As a result, the hydrogen exploded, causing severe damage to the environment (broken windows at a distance of 70 metres from the station) but no fatalities[20].

Source: Intermezzo:

For the maintenance and service engineers of hydrogen trucks, cars, buses and construction equipment, knowing how to deal with (discharged) hydrogen in a (confined) space is very important. A hydrogen explosion is a big safety risk in the open but even bigger in confined spaces. For emergency responders, the low visibility of the hydrogen flames is another important safety risk alongside explosion hazards. They must recognise that a fire might be present even if it is not visible.

[18] See: https://www.ilo.org/dyn/icsc/showcard.display?p_lang=en&p_card_id=0001&p_version=2
[19] Hydrogen could be transported in gas and liquid (and even in solid phase). Transporting hydrogen in the gas-phase is the most common way, hence my focus in this paper on hydrogen-gas.
[20] See: https://www.sciencedirect.com/science/article/abs/pii/S1464285919302809

Table 2: Hydrogen safety risks

Workers	Situation	Impact
Car/train drivers / on-board personnel Maintenance workers / technicians	On route	The car/captain/train driver may not know the hydrogen risks (in particular when hydrogen accumulates in a contained space).
	In the workplace	A hydrogen release may result from: 1) an immediate ignition of a torch (flame from containment overpressure) exposing them directly; or 2) delayed ignition in an explosion.
Emergency responders	In the workplace	A fire suppression action will probably not be initiated with evacuation being prioritised instead. However, H_2 explosion risks may be seriously underestimated (no smell, no visible exposure levels, very combustible). The fire brigade can use an explosion meter and/or a CO meter to determine whether hydrogen is present. The CO meter must then be cross-sensitive to hydrogen.
	On route	First responders might not be aware of the typical safety risks (e.g. a torch: flame from containment overpressure) that may appear by surprise (see the Wassenaar bus incident below) and approach incident vehicles facing the risk of an explosion.

Compressed natural gas safety risks

Search term: Methane → UN number 1971[21]

Compressed natural gas (CNG) is mainly composed of methane (about 80%). The remaining 20% are ethane, propane, nitrogen and carbon dioxide. In order to store it or transport it, it is compressed to about 200 bars and compared to liquid natural gas, it remains gaseous. CNG commercial applications are primarily found in road transport and inland navigation. CNG leakages may lead to:

- torch fires, and
- gas cloud explosions.

Box 4: CNG public transport buses burnt down in France and Germany (Ineris report[22]**)**

Ineris (2014) published a brief report dealing with three CNG bus fires in France and Germany. In addition to several design measures, authors concluded that emergency responders' procedures were 'not appropriate for an efficient action'. Hence, they advise taking additional safety measures in bus design such as automated or manually activated fire suppression systems in the engine room where fires are most likely to start and the design of a pressure relief device (PRD) outlet so that the fire jet can only point upward and cannot under any circumstances affect a nearby tank.

Before these additional safety measures were recommended, a CNG bus fire occurred in 2012 in the Netherlands which posed substantial risks for the emergency responders. The safety risks for the emergency responders became clear when a public transport bus operated by Veolia caught fire during operation. The bus was powered by CNG. The fire originated in the motor compartment of the bus and heated the CNG storage tanks on the roof of the bus.

The thermal pressure relief devices (PRD) were, for the emergency responders, 'unexpectedly' activated. Although this safety mechanism prevents an explosion of the storage tanks, in this incident it caused a horizontally directed column of natural gas flames from 15 to 20 metres[23]. The emergency responders where not aware of the possibility of this danger and were lucky they were not engulfed by the flames.

Source: Intermezzo:

[21] See: https://www.ilo.org/dyn/icsc/showcard.display?p_lang=en&p_card_id=0291&p_version=2
[22] See: https://ineris.hal.science/ineris-00976180/document
[23] See: https://onderzoeksraad.nl/onderzoek/brand-in-een-aardgasbus-29-oktober-2012/

The CNG safety risks are comparable with the hydrogen safety risks (Table 2). Therefore, the same table can be referred to for CNG safety risks.

Liquid natural gas safety risks

Search term: LNG→ UN-number 1972

Liquid natural gas (LNG) is also composed mainly of methane, like CNG. However, instead of remaining gaseous it is liquified through extreme cooling (-162 degree C). This low temperature may cause embrittlement of metals (such as the case of hydrogen LNG commercial applications are mainly found in road transport, seagoing vessels and inland navigation. LNG is a liquid, heavier than air, and to some extent comparable to liquid petroleum gas. However, the extreme low temperature makes it, from a safety perspective, completely different from LPG. The typical LNG risks include:

- explosion (vapour cloud) → pressure impacts and heat radiation impacts;
- torch fire → heat radiation impacts;
- pool fire (though hardly visible) → heat radiation impacts;
- leakages → cold burn impacts; and
- leakages → suffocation by air displacement.

Box 5: LNG fuel tank leakage of truck on motorway A15 (5 July 2019, Hardinxveld, The Netherlands)

During the night of the 5 July 2019, on motorway A15 in the Netherlands, an LNG-propelled truck was transporting 23 tons of LNG. The tank, experienced a blowout, causing a leak in one of the LNG fuel tanks. Because there was no fire, the fire fighters considered the LNG leakage as an ordinary gas leakage[24]. However, the standard operating procedures for the fire brigade in case of fire are completely different from an ordinary fire: water is not advised because of the possibility of freezing the pressure relief device on the tank.

Source: Intermezzo

Table 3: LNG safety risks

Workers	Situation	Impact
Drivers / On-board personnel Maintenance workers / technicians	On route	The driver/captain may not know the LNG risks and may experience frostbite or even worse, suffocation (particularly when the LNG accumulates in a contained space).
	In the workplace	An LNG release may result from: 1) an immediate ignition in a pool fire, exposing workers directly, or 2) delayed ignition in an explosion.
Emergency responders	In the workplace	A fire suppression action will probably not be initiated with evacuation being prioritised instead. However, the LNG explosion risks may be seriously underestimated (no smell and harmless smoke visible, but very combustible and flammable).
	On route	Emergency responders might not be aware of the extremely low temperatures, putting water on the fire, freezing safety devices. Additionally, they may not see the flames of burning LNG and could inadvertently walk into them.

[24] See: https://nipv.nl/wp-content/uploads/2022/09/20220621-NIPV-Infoblad-Energietransitie-voor-incidentbestrijders.pdf

Safety risks of ammonia and liquid organic hydrogen carriers

Replacing fossil fuels with renewable alternatives introduces massive transport issues[25],[26]. Clearly this is the case of electricity: batteries flood the market and not without their particular risks. While alternative molecules as energy carriers present their own challenges, such as flammability and the need for pressurisation or cooling, they also present specific risks to various users. Two promising ways for transporting mass quantities of energy include converting hydrogen into ammonia by combining it with nitrogen or into LOHCs by combining it with liquid carbons. These methods are advantageous for mass transportation because they do not require extreme pressure or cooling. However, they also come with their own set of drawbacks.

Search term: Ammonia→ UN-number 1005[27]

Ammonia is a toxic gas with a strong smell. Inhaling ammonia will affect the lungs and mucous membranes. Ammonia storage and transport (as a liquid) are relatively easy and cheap because they require minor cooling (-33 degrees C) or increased pressure at ambient temperature (8-10 bar). Ammonia incidents and leaks may lead to fires; at high temperatures (above 650 °C), ammonia may decompose into the flammable gases, hydrogen and nitrogen dioxide (which is toxic). As a result, the following risks arise:

- toxicity,
- fire,
- irritation of the respiratory system,
- chemical burns,
- explosion.

Box 6: Serbia leaking ammonia rail tanker (26 December 2022, Serbia)

In Serbia, on 26 December 2022, a freight train derailed. From the total of 21 rail cars, 4 rail cars derailed, one of them containing and leaking ammonia. Fifty-one people needed to be hospitalised due to intoxication. They suffered burns, respiratory damage and skin and eye irritation[28].

Source: Intermezzo:

LOHC safety risks

LOHCs are hydrocarbon molecules that chemically bond with hydrogen (to form a new hydrogen-rich compound). The carbon molecule transports hydrogen, but it is not itself burnt, instead the hydrogen is stripped from the carbon molecule after which the hydrogen is used to generate energy. Thus, the hydrocarbon molecule serves as a carrier, akin to a vessel. It is filled with hydrogen on the way out and returns depleted. Examples include toluene (C_7H_8), UN-number 1294[29] or methanol (CH_4O) UN-number 1230[30,31]. In transit, LOHCs have petrol-like characteristics (flammable fluids). Compared to hydrogen, LOHCs can be transported more easily because they can be moved under ambient conditions and environmental temperatures. LOHCs are therefore cheaper to handle, while still having a good energy/mass-volume ratio (efficient).

The type of LOHC-molecule determines the safety risks. Both toluene and methanol have several risks including:

- flammability,
- explosivity, and
- toxicity.

[25] Ammonia can be used to propel vehicles or to transport mass amounts of energy. We see commercial ammonia application in seagoing vessels.

[26] See: https://www.berenschot.nl/media/0cxgltrg/eindrapport-volumes_-modaliteiten-en-veiligheid-waterstofrijke-energiedragers.pdf

[27] See: https://www.ilo.org/dyn/icsc/showcard.display?p_lang=en&p_card_id=0414&p_version=2

[28] See: https://nos.nl/artikel/2457747-ontspoorde-wagon-servie-lekt-nog-ammoniak-noodtoestand-blijft-van-kracht

[29] See: https://www.ilo.org/dyn/icsc/showcard.display?p_lang=en&p_card_id=0078&p_version=2

[30] See: https://www.ilo.org/dyn/icsc/showcard.display?p_lang=en&p_card_id=0057&p_version=2

[31] Methanol is very toxic (it should not be confused with ethanol, which is used in spirits).

Box 7: Methanol loaded rail tanker fire on marshalling yard (14 January 2011, Kijfhoek, The Netherlands)

On the evening of January 14 2011, on one of Europe's biggest marshalling yards, Kijfhoek (The Netherlands) a methane loaded rail tank was damaged during shunting activities. As a result, methanol leaked from the rail tanker and caught fire. An enormous fire lasted for several hours and required complex fire suppression tactics (mainly because of the difficulties of getting water on the rail tanker)[32].

Source: Intermezzo:

Table 4: Ammonia and LOHC safety risks

Workers	Situation	Impact
Drivers / on-board personnel	On route	The driver may not know the risks of inhaling ammonia or LOHC's and may face serious breathing problems.
Maintenance workers / technicians	In the workplace	Ammonia releases may result in a toxic cloud, hence poisoning the technicians. LOHC's may lead to fires and explosions.
Emergency responders	In the workplace	The company emergency responders will most probably initiate an evacuation rather than a hazardous materials containment action in case of an ammonia or LOHC release. However, the NH_3 and LOHC explosion risks may be serious.
	On route	Emergency responders might not be aware of the typical safety risks (intoxication, explosion) because both NH_3 and the LOHC are not widespread in society so far.

Dealing with new energy carrier safety risks

Quick safety benefits for the workers dealing with sustainable fuels / new energy carriers

To summarise, sustainable fuels / new energy carriers in transport introduce several new health and safety risks for workers and professional emergency responders. For the health and safety of the workers, some quick safety benefits are possible.

For operators and drivers, being aware of the specific safety features of the sustainable fuel is important. If the risks are known, the correct actions could be undertaken (evacuating rather than suppressing). This means they need to be educated in these risks. Additionally, standard operating procedures (SoPs) should be established to guide actions during an incident emphasising what to avoid for the safety of operators, passengers and crew. Quick and easy-to-use PPEs might be advisable for the early (evacuation) stage.

For technicians and maintenance workers, the main OSH risks due to sustainable fuels will be the result of a toxic release/fire/explosion. Energy related processes involving batteries, hydrogen, ammonia and LOHCs differ from those related to fossil fuels. In the workplace environment, it is crucial to apply the hierarchy of controls as outlined in OSH legislation[33].

[32] See: https://www.datocms-assets.com/37731/1607342970-4-leerarena-kijfhoekrapportage-opdrachtgevers.pdf
[33] See: https://www.osha.gov/sites/default/files/Hierarchy_of_Controls_02.01.23_form_508_2.pdf

Box 8: The hierarchy of controls

The hierarchy of controls

1. Elimination of the cause of the safety and health risk
2. Substitution of material or processes to reduce the hazard
3. Engineering controls to prevent hazards coming in contact with employees
4. Administrative controls such as procedures, training, and warnings
5. PPEs to protect employees against the hazards

Regarding sustainable fuels, the first two levels of hierarchy controls are impractical. The sustainable fuel itself is central to the energy transition. Eliminating or replacing it contradicts the very goal of transitioning to sustainable energy sources. There are still viable options within this framework. For example, in electric battery chemistry, using a more stable electrolyte or chemistry than the lithium-ion could improve safety. This would make the battery less vulnerable to mechanical, electrical and thermal abuse.

All the same, it is important that existing workplaces are redesigned taking into account the hazard features of batteries, hydrogen or LNG (third level of hierarchy). Engineering controls including monitoring systems or sensors that detect dangers such as heat, gas, and toxins in an early phase need to be installed, as well as ventilation/smoke control. Furthermore, it is crucial to develop comprehensive working procedures and conduct regular inspections. This should include educating, training and warning workers to ensure their safety and preparedness.

Although emergency responders have a minor exemption from OSH legislation, allowing them to accept some additional risks compared to ordinary workers, employers must still make substantial efforts to minimise these operational safety risks. It is crucial to create risk awareness and understand the different hazard mechanisms. Their SoPs must be tailored to address new risks, and responders need to be thoroughly trained and drilled to handle these risks. Additionally, their gear (including PPEs) should be compatible with the specific risks to ensure their protection.

3.2 Systemic OSH issues in sustainable fuels / new energy carriers

In addition to the fire, toxic (health) and explosion risks of renewable energy incidents, there are different systemic OSH challenges to be addressed. These are:

- regulatory gaps,
- complexity in granting permits,
- fragmented knowledge,
- competing goals, and
- emergency response challenges.

Firstly, it can be noted that new technologies such as sustainable fuels often have been introduced without proper or updated regulations. For example, energy storage systems are still allowed to be located anywhere. Multi-fuel stations have no limitation regarding the location of hydrogen fuel apparatuses or charge points. The new electron energy carriers largely fall outside existing environmental regulations, while the new molecule energy carriers lack appropriate safety requirements and design guidelines.

Secondly, because of the absence of existing safety guidelines for designing new energy carriers[34], for licensing authorities the process of granting permits has become complex. They face the following:

- What sort of analysis should be used to prove the technology is safe?
- How can reliable data be generated?

Thirdly, the stakeholder landscape of today's new energy carriers is fragmented. This means that many (sub-)developers of technologies are involved, but also policymakers, inspectors and researchers. This means that knowledge is fragmented and leading to limited perspectives on the safety and promoting

[34] In the Netherlands, a couple of new energy safety design guidelines have been developed recently, e.g. those for LNG (PGS 33-1 en 33-2: https://publicatiereeksgevaarlijkestoffen.nl/publicaties/pgs33-1/); energy storage systems (PGS 37-1 en 37-2: https://publicatiereeksgevaarlijkestoffen.nl/publicaties/online/pgs-37-1/2023/1-0-december-2023#top); hydrogen (PGS 35: https://publicatiereeksgevaarlijkestoffen.nl/publicaties/pgs35/) and multi-energy stations (PGS 38: https://publicatiereeksgevaarlijkestoffen.nl/publicaties/pgs38/. Currently, existing guidelines for NH_3 are being revised (PGS 12 https://publicatiereeksgevaarlijkestoffen.nl/publicaties/pgs12/).

silo mentality instead of comprehensive safety assessments. Moreover, coordination requires extensive communication and fine-tuning which can lead to errors and misunderstandings.

Fourthly, the people behind the new energy carrier industry are not primarily driven by health and safety. OSH competes with other goals, such as profit and sustainability. In addition, in-depth safety measures can cause significant doubt and delays, potentially result in a lag in the market. As a result, operational workers and maintenance workers may be confronted with unforeseen situations and previously unrecognised mechanisms such as material ageing issues.

Fifthly, emergency responders are largely unaware of all the new developments. Often, they are made aware of them the moment they face an incident. Clearly, this leads to acute safety risks. In the long term, this could also pose health risks due to frequent exposure to potentially unknown or unrecognised dangers.

Systemic difficulties in managing the new OSH risks and tentative solution directions

Ultimately, it is about identifying and understanding the new risks that alternative fuels introduce. This requires a thorough analysis of the alternative fuel system: technology, organisation and human behaviour. However, this is only the start of reducing OSH-risks.

Other aspects that need to be organised, on a macro (or systemic) level in order to tackle the safety risks of new energy carriers are listed below:

1. lagging laws and regulations,
2. understanding and analysing new risks,
3. securing the best safety experts,
4. addressing the shortage of (technical) human capital,
5. developing the emergency response.

Firstly, it is important to understand that generally laws and regulations, like Seveso, lag behind regarding innovations in private industries. Concerning the accidental safety risks of operators and emergency responders this is even more pronounced. Particularly with the energy transition and new energy carriers, the number, scale and variety of sustainable developments is enormous. The greatest challenge is to clarify what technologies will access the market. This is difficult, because for economic reasons, entrepreneurs might not be willing to share their ideas in early development stages.

In order to recognise renewable energy developments early on, proper intelligence by policymakers is needed as well as an open and flexible attitude. This means that policymakers should be in close contact with universities, chambers of commerce and industry bodies to learn about new developments.

Secondly, the next challenge for companies and authorities is to understand what these new technologies mean for OSH. Often, new processes, chemical compounds and combinations of apparatuses are developed, with which people have no experience. The safety assessment of the new developments often starts with a qualitative assessment. However, quantifying the problem is essential: what is the probability of something going wrong, and what are the potential consequences?

This requires a multidisciplinary approach including testing and analogy analysis.

Thirdly, once the risks have been identified and understood, guidelines and regulations must be put in place to protect workers. The hierarchy of controls set out in OSH legislation needs to be applied. This requires a lot of experience and knowledge not always available in the public domain. The greatest safety experts may be working in industries. Another challenge is that the proposed OSH legislation by authorities may complicate industrial processes and activities, resulting in objections and lawsuits. Additionally, developing guidelines is time-consuming and may even result in the disclosure of confidential information.

This requires proper network management and industry representation rather than relying on individual entrepreneurs.

Fourthly, educational material needs to be developed, and teachers have to be educated to train the workers (human capital building). However, there are several labour-related difficulties. First of all, the (technical) work force is small, complicating the recruitment of skilled people capable of development, as well as finding workers to produce, construct, install, and maintain the infrastructures for new energy carriers.

This requires a national programme to promote technical education in fields such as chemistry, electrical engineering, civil engineering and physics.

Fifthly, for emergency responders, new educational and training materials need to be developed, as well as understanding the sustainable objects and projects in their area. Site visits and communication with OSH personnel from the companies are crucial.

This requires investment in the organisation of emergency response to ensure they have the human capacity to study and anticipate safety risks through plans, education, equipment and training.

Conclusion

As already mentioned, the number of developments and entities in the new energy carrier transport domain is vast. What is certain though, is that new energy carriers introduce new risks which employers must address. Moreover, the workers facing these new risks (such as installers, technicians, maintenance workers and firefighters) are rarely involved in the development of the new technologies. Often, they become aware of the risks only by chance. This causes great danger to their safety and health. Involving them in the early design phases can add value by identifying safety risks and understanding how workers will interact with the new technologies.

Ideally, the complete project life cycle (construction, operation, maintenance, incident response and demolition) should become part of the design process of new energy carrier activities. Including workers from various life cycle phases in the design team is key for understanding and anticipating the risks.

However, in general, regulations and guidelines lag behind rapid market innovations. Design guidelines for parking garages and tunnel workplaces are still based on traditional, fossil fuel incidents. The same applies to OSH and first responders in companies. For example, they may not be aware of the risks associated with solar panels on vehicle roofs or how to handle a lithium-ion truck fire or thermal runaway. The assessments of OSH risks need to be developed, considering the risks of new energy carriers.

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