Guidance

Emergency service operations at hydrogen service tank facilities

December 2012

Fire exercise with hydrogen cars in California

Photograph: PNNL - Pacific Northwest National Laboratory

Picture on front cover: Mercedes-Benz B-Class F-CELL – Electric vehicle with fuel cell

Guidance: Emergency service operations at hydrogen service tank facilities

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Contents

Hydrogen for transport

It is expected that hydrogen cars will be launched on the market in 2015. In addition, work is in progress on using hydrogen and fuel cells for instance in buses and industrial vehicles such as fork-lift trucks.

Hydrogen cars are electric cars in which a fuel cell converts hydrogen and oxygen to water in an electrochemical process at the same time as electricity is generated. Efficiency is approximately 50-60%. At present there are around six hydrogen service tank facilities in Denmark and a number of hydrogen cars, trucks, etc.

For further information on hydrogen for transport in Denmark, see www.hydrogenlink.net and the report 'Brint til Transport i Danmark frem mod 2050' ('Hydrogen for transport in Denmark towards 2050') which can be downloaded at: www.hydrogenlink.net/brint2050.asp.

Examples are shown below of hydrogen-powered vehicles, as well as an overview map of planned hydrogen service tank facilities in Denmark by 2050.

Hydrogen car

FCEV: Fuel Cell Electric Vehicle

Tank pressure: 700 bar

Tank capacity: 3-7 kg hydrogen

Range: 400-700 km

Refuelling time: 3-4 min.

Conversion: Fuel cell

Consumption: 0.8-1.2 kg/100 km

(approx. 20-35 km/litre petrol equivalent)

Hydrogen bus

Tank pressure: 350 bar

Tank capacity: 30-40 kg hydrogen

Range: 300-400 km

Refuelling time: <10 min.

Conversion: Fuel cell

Consumption: 8-12 kg/100 km

(approx. 2.5-3.8 km/litre diesel)

Hydrogen fork-lift truck

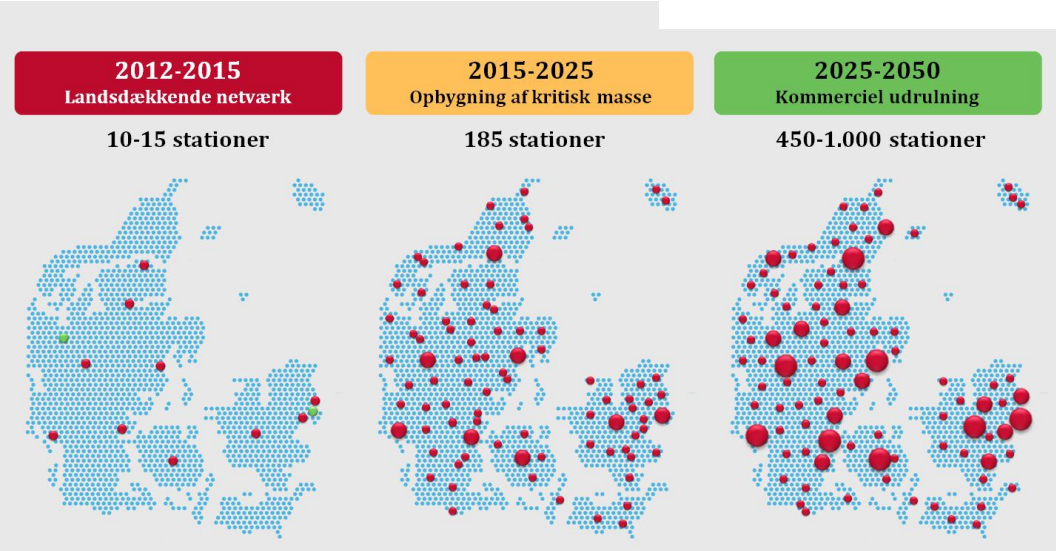
Tank pressure: 350 bar

Tank capacity: 0.5-2 kg hydrogen

Operating time: 5-8 hours

Refuelling time: <3-4 min.

Conversion: Fuel cell

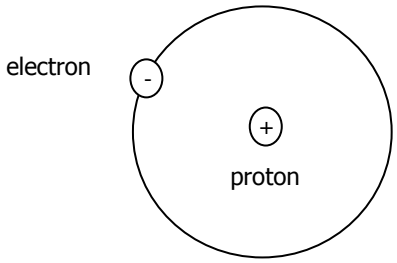


Expected trend in the number of hydrogen service tank facilities in Denmark up to 2050.

2012-2015 Landsdækkende netværk	2012-2015 Nationwide network
2015-2025 Opbygning af kristisk masse	2015-2025 Build-up of critical mass
2025-2050 Kommerciel udruining	2025-2050 Commercial roll-out
stationer	stations

Properties of hydrogen

Hydrogen is a gas which is substantially lighter than atmospheric air. Hydrogen can be compressed and/or cooled so that it changes to liquid form. This takes place at very low temperatures or at very high pressure. Hydrogen is invisible and has no odour or taste.



A drawing of a hydrogen atom

The flammability limits of hydrogen are from 4 to 74% in a mixture with atmospheric air. The ignition energy for hydrogen is very low.

The flames from burning hydrogen are very weakly bluish and in daylight will generally only be perceivable as flickering. If a fire occurs in the vicinity of other combustible material, for example painted surfaces on vehicles, the fire will generate smoke.

The flames are only visible with a thermal imager.

A hydrogen flame from vehicles/facilities will immediately be a jet flame due to the pressurisation. There will be turbulence and a very clearly audible sound.

The thermal radiation from a hydrogen fire is substantially lower than for a natural gas fire and around half as powerful as for a petrol fire.

Hydrogen service tank facilities – structure and technology

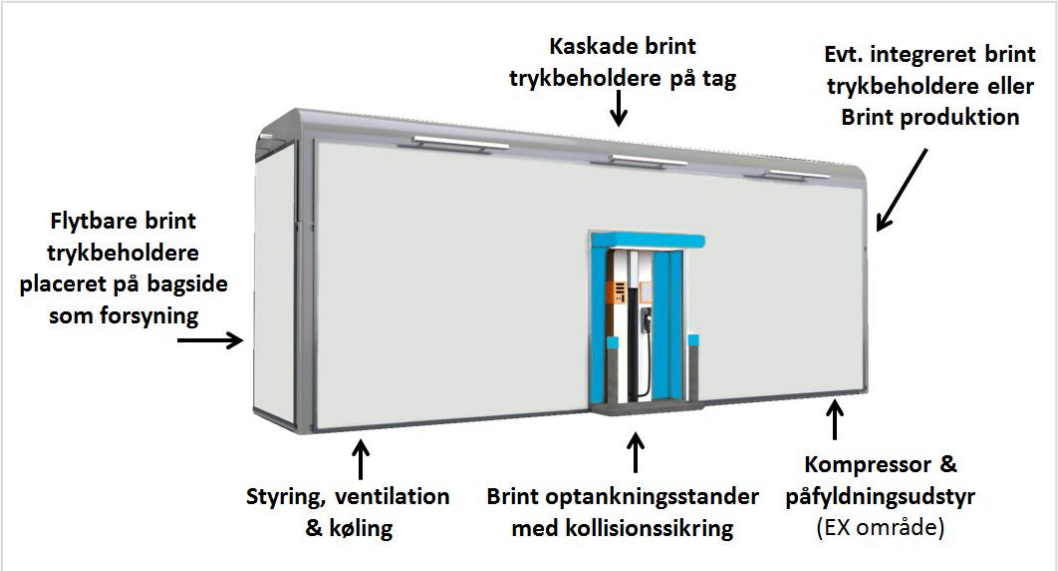
Structure of hydrogen service tank facilities

A hydrogen service tank facility consists of a number of principal components, which can either be integrated into a combined module or divided, depending on location:

- Hydrogen supply
- Mobile pressure cylinders supplied from gas company (or back-up)
- Hydrogen production on the spot with electrolysis of water (using electricity)
- Hydrogen compression and storage at refuelling pressure
- Integrated compressor either with storage on the roof or separate
- Control, ventilation and cooling
- Refuelling equipment and pump
- Integrated or separate pump

Hydrogen is either supplied to the tank facility in traditional cylinder batteries or is produced on the spot by using electricity to split water, with pressure cylinders acting solely as back-up. The hydrogen is then compressed to refuelling pressure and stored in high-pressure containers located either on the roof or outside the tank facility itself. The actual refuelling takes place at a pump, which is either built into the station module or located separately, for example alongside existing petrol filling stations.

An example of a possible structure of a hydrogen service tank facility is shown below.



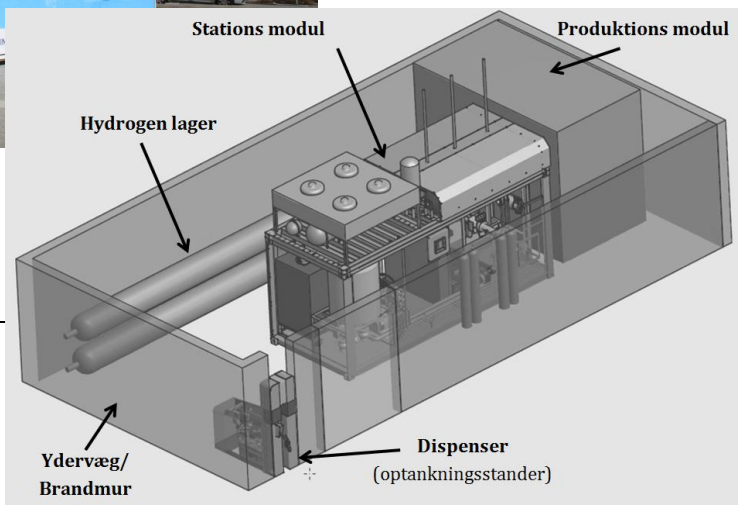
Flytbare brint trykbeholdere placeret på bagside som forsyning	Mobile hydrogen pressurised containers located at rear for supply
Kaskade brint trykbeholdere på tag	Cascade hydrogen pressurised containers on roof
Evt. integreret brint trykbeholdere eller Brint produktion	Integrated hydrogen pressurised containers or hydrogen production also possible
Styring, ventilation & køling	Control, ventilation and cooling
Brint optankningsstander med kollisionssikring	Hydrogen refuelling pump with collision guard
Kompressor & påfyldningsudstyr (Ex område)	Compressor and refuelling equipment (EX area)

The structure and in particular the location of the various principal components can vary according to the manufacturer and the geographical location of the facility.

Examples are shown below of hydrogen tank facilities established in Denmark and Norway in recent years, together with the capacity of the tank facility in question.

Holstebro | 700 bar with cylinder supply and separate refuelling pump | volumes of under 50 kg a day | max. 65 kg hydrogen stored at the site | 2010.

Oslo | 700 bar with hydrogen production and integrated refuelling pump | volumes of under 200 kg a day | max. 156 kg hydrogen stored at the site | 2011.



Stations modul	Station module
Produktions modul	Production module
Hydrogen lager	Hydrogen store
Ydervæg/Brandmur	Outer wall/Fire wall
Dispenser (optankningsstander)	Dispenser (refuelling pump)

The size of hydrogen storage tank facilities in terms of daily refuelling capacity varies.

Over the next few years, the refuelling capacity of tank facilities is expected to be around 50-200 kg hydrogen a day, and in the longer term it is expected to be between 400 and 1000 kg or more. A hydrogen car on average refuels 3-5 kg hydrogen at a time, equivalent to around 300-500 kilometres of driving. On an annual basis, a hydrogen car uses around 150-180 kg hydrogen.

Storage of gases and hazardous liquids at hydrogen service tank facilities

Pressurised hydrogen containers

Hydrogen is stored at hydrogen service tank facilities in stationary pressurised containers located either on the roof, at the side of the station or in the tank facility itself.

Different types of pressurised containers are used for different pressure levels:

Type 1: Steel containers up to approx. 500 bar

Type 2: Steel containers reinforced with carbon fibre up to approx. 500 bar

Type 3: Composite containers with aluminium liner from approx. 500-1 000 bar.

Type 4: Composite containers with plastic liner from approx. 500-1 000 bar.

Pressurised containers for other gases

In addition, hydrogen storage tank facilities can contain a large number of different types of pressurised cylinders used in the operation of the station, for example:

- Nitrogen for operation of valves and pneumatics
- Gases in cooler systems

Liquids

Hydrogen storage tank facilities may contain a number of liquids that may be combustible, toxic or hazardous, for example:

- Combustible oils in mechanical systems
- Combustible or toxic coolants down to minus -40°C (frostbite)

Safety installations at hydrogen service tank facilities

Distribution and service tank facilities for hydrogen are not covered by Danish Emergency Management Agency Executive Order No 1444 on *technical regulations for gas.* Municipal councils (emergency services) may lay down requirements for the service tank facility, cf. Section 34(2) of the Emergency Management Act. The conditions set for individual facilities may therefore vary from one municipality to another.

Hydrogen service tank facilities are built with a number of safety installations with a view to:

- Minimising the risk of emissions of hydrogen
- Minimising the risk of sparks in areas where there may be a risk of hydrogen
- Having a set up that limits any leakage, fire or explosion

Typical safety installations for hydrogen service tank facilities	
Hydrogen refuelling pumps	Refuelling pumps are protected against collision and are equipped with a tilt sensor. The hose is equipped with a break-away coupling and is electrically conductive so that potential differences are equalised (static electricity). Pipe strings from storage containers out to refuelling pumps are constructed with a sufficient number of shut-off values to ensure that the hydrogen supply is cut off in the event of an accident.
Main on/off switch.	The facility has a main on/off switch for power supply. Main on/off switches may be located in various places, for example a transformer station or nearby building. The operator must inform the emergency services of the location of the main on-off switch before first use. The municipal council (emergency services) generally requires an emergency stop button to be located approximately 10 m from the facility – as in distribution and service tank facilities for petrol. Signposted.
Hydrogen chimney	Installed so that hydrogen is discharged from the station up through the chimney in the event of overpressure, leaks and

and valves	fire. The chimney also acts as a discharger in the emptying of hoses in connection with refuelling of vehicles. There is therefore zone classification around the chimney. Overpressure valves are mounted on storage containers and set to the design pressure of the facility.
Security lock and key	The facility is constructed with a security lock, so that all important areas of the facility can be accessed using a single key in the event of emergency operations (key box). Key location is determined in connection with the approval by the municipal council, cf. Section 34(2) of the Emergency Management Act. It must be noted that not all municipalities require a key to the facility because some facilities can be shut down using the facility's emergency stop button.
Hydrogen detectors	A number of hydrogen detectors will be installed that shut the installation down if the hydrogen concentration in the compartments exceeds 1% hydrogen (25% of the lower explosion limit (LEL)). In some municipalities detection of an emission triggers a visual signal (flash) displayed as 'Hydrogen alarm'.
Ventilation	There is sufficient built-in ventilation in the facility (either passively or actively) so that a high hydrogen concentration can be managed and discharged.
Hydrogen piping	All piping for hydrogen is made of stainless steel, with as few joints as possible. The piping is pressure-tested and tested for leaks after being installed and before use.
Earthing	Piping, storage tank and all available steel structures generally have to be potential-equalised and earthed.
Lighting	Adequate outdoor lighting is installed to make use after dark possible and reduce the risk of collisions.
Signposting	The following signs are installed as a minimum: 'Stop engine before refuelling' (at refuelling pump)

	'No smoking or naked flames' (at refuelling pump) 'Emergency stop – Hydrogen facility' 'Emergency stop button located on, for example, building' 'Pressurised cylinders should be removed in the event of fire' 'EX zone' 'No admission for unauthorised persons' (at entrance to station) 'HYDROGEN ALARM' (incl. visual signal at service area entrance) 'GAS STORAGE – Hydrogen' An agreement on signposting and location is generally made with the municipal council (emergency services) in connection with approval of the facility.
Visual signal	The facility has a visual signal to reveal a detected escape of more than 50% LEL at the service area entrance.
Fire-extinguishing equipment	Minimum installation: CO2 extinguisher of min. 5 kg of type 70 B, located close to the technical area of the facility. Powder extinguisher of min. 6 kg of type 183 B located outdoors close to station. Equipment and location are decided by the emergency services.
Emergency stop button.	Number and location are decided by the emergency services. The minimum recommendation is to site in an easily accessible position an emergency stop button close to refuelling pump and if appropriate at shop if the facility is located at an existing

	petrol filling station. The municipal council (emergency services) generally requires an emergency stop button to be located approximately 10 m from the facility – as is customary in distribution and service tank facilities for petrol.
Monitoring	The facility is constructed with a monitoring system with remote access, which can detect fractures and pressure drops in piping, as well as temperature fluctuations which may indicate fire.

Emergency services operation – hydrogen service tank facilities

The municipal emergency services must be able to make a reasonable effort to prevent harm to persons, property and the environment in the event of accidents and disasters, cf. Section 12(1) of the Emergency Management Act.

Reasonable effort in terms of safety

Efforts are always made to ensure that work at the scene is planned, organised and carried out in a way that is fully acceptable in terms of health and safety.

The commander of the technical operation at the scene is responsible throughout the operation for all personnel deployed.

This means that prior to the operation an overall risk assessment has to be made based on the knowledge and experience that exist concerning the type of operation concerned. In addition, a specific assessment has to be made of the conditions on site.

The commander of the technical operation will, moreover, make a continuous assessment of risk, which includes the particular dangers to the emergency services crew, and the operation must be arranged and carried out in accordance with this assessment.

Procedure to follow when emergency service intervention is required

Assessment of situation

When the commander of the technical operation arrives at the scene, a rapid assessment of the situation is made to obtain a provisional impression of the damage caused. Based on this assessment of the situation, the commander considers and decides on what initial action should be taken.

Initial action

The purpose of initial action is to provide assistance to casualties and persons in immediate danger and to prevent the damage that has occurred from spreading. While the initial action is being carried out, the commander of the technical operation has time time to carry out closer reconnaissance of the situation as a whole.

In connection with the initial action, priority is given to tasks normally in the following sequence:

- Rescue of people
- Rescue of animals
- Rescue of valuable assets, including the environment
- Removal of particular dangers
- Stopping of spread
- Considerations regarding final control of the damage

If people or animals are in danger, the emphasis in the initial action must be on life-saving efforts. If there are particular dangers that make a life-saving effort difficult, it may be necessary first to remove the particular dangers that pose a direct threat to the emergency personnel and/or any casualties.

Facilities in which people or animals are in danger are prioritised ahead of accomplishing the overall task.

Special points concerning escapes of or fire in hydrogen

Hydrogen has some special properties of which the emergency services should be aware:

1. Hydrogen is a highly combustible, explosive gas, which is invisible, odourless and tasteless, and is far lighter than atmospheric air.
2. Hydrogen is not toxic, and there are no environmental consequences if there are emissions from a tank.
3. Hydrogen has a very wide flammability interval and can be ignited at concentrations in air of between 4 and 74 per cent by volume (vol. %).
4. The flames in a hydrogen fire are difficult to see in daylight – use a thermal imager. In the event of a fire in a jet flame from a pressurised tank, it is important to establish the spread of the fire.
5. A hydrogen fire can be extinguished like any other gas fire, i.e. with a water mist jet, CO_2 or a powder extinguisher. Powder has the best extinguishing effect but also causes the greatest material damage.
6. If there is a fire in escaping hydrogen, the flame should **only** be extinguished if it is possible to halt the escape. If the jet flame threatens other objects, these can be cooled. If the jet flame affects other pressurised tanks/containers of gas, these must be cooled with at least 10 litres/m^2 per minute.

Concerning hydrogen service tank facilities

Hydrogen service tank facilities have overpressure valves. If there is too much pressure in the facility, the valves will open and release excess hydrogen into the open air. **There is a loud noise** when the gas escapes through the valves. Pay attention to the escaping gas with regard to remote ignition and wind conditions. There are often requirements that overhead power lines must not be located above hydrogen service tank facilities.

At most hydrogen service tank facilities there is a compressor room and a technical room next to the facility. In the event of a leak there will be a danger of explosion in both these rooms. There will also be a danger of explosion in other rooms or areas where the hydrogen is trapped and the concentration rises.

Concerning pressurised cylinders

The table below describes safety measures and the approach to follow in connection with a rescue action where the various types of pressurised hydrogen containers are present.

Emergency management of pressurised hydrogen cylinders at service tank facilities	
Type 1-2: Steel containers	
Location and safety	May be located on the roof of the tank facility, at the side or indoors. Must be protected by a safety valve that automatically shuts off gas from the containers in the event of overpressure in the event of a fire in the chimney of the tank facility.
In the event of suspected leakage	The emergency services must contact the station operator, who must be able to check the status of the station and leaks by remote monitoring.
In the event of fire	Cool the containers with water to keep the temperature down. If containers are located to the side of the station, they can be disconnected and moved a safe distance away from the fire.
 	

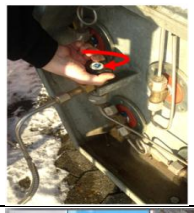
Type 3-4: Composite containers	
Location and safety	May be located on the roof of the tank facility, at the side or indoors. The containers must be equipped with a temperature-activated safety valve which opens in the event of an excessively high temperature. May be protected by plastic nitrogen piping which in the event of fire breaks and activates a safety valve so that the hydrogen is discharged through the station's chimney. The discharge of hydrogen may take up to 30 minutes.
In the event of suspected leakage	The emergency services must contact the facility operator, who can check the status of the facility and any leaks by remote monitoring.
In the event of fire	Cool the containers with water to keep the temperature down. If containers are located to the side of the station, they can be disconnected and moved a safe distance away from the fire.
	

If an external hydrogen container is connected to the station, this must be disconnected in the event of fire. This applies, for example, to trailers that are moved to safety and kept cooled by spraying water, or a hydrogen production facility which is fire-extinguished and disconnected.

Safe removal of hydrogen batteries

1. Close the 'main tap' where the battery is connected with an armoured hose.
2. Close the tap(s) on the battery (batteries) (Turn clockwise)
3. Open the 'venting tap' so that remaining hydrogen from the hose escapes and then close it
4. Unscrew armoured hose from the batteries (Turn clockwise)
5. Remove empty battery (batteries)

Hovedhanen	Main tap
Udluftningshanen	Venting tap
Metalen flexibele slange	Metal flexible hose

A guide for the emergency services – hydrogen service tank facilities	
Activate emergency stop, which shuts off the power supply to the hydrogen tank facility When the power supply is switched off, the various valves in the system are closed automatically and the risk of sparks is removed. An emergency stop button is generally required by the municipal council (emergency services)	
Assessment of situation Rescue of people Rescue of animals Rescue of assets, including the environment Removal of particular dangers Stopping of spread Considerations on final control of the damage	
Turn off the supply Turn off the supply of hydrogen from the battery of hydrogen cylinders	
Remove the battery of cylinders The battery of cylinders supplying the tank facility should be removed a safe distance away from the facility	
Contact The owner of the hydrogen storage tank facility - Contact information can typically be found on the **'safety instructions'** at the door/gate to the technical area at the rear/side of the hydrogen storage facility.	

Own notes

Sources

Cooperation

This guidance has been prepared in cooperation with:

Danish Association of Municipal Emergency Management Officers

KL

H2 Logic A/S

BAR Transport og Engros – fire and rescue

Images

The images in the guide have been kindly provided by:

H2 Logic A/S

Daimler AG

Further information

Guidance: Indsats ved uheld med elkøretøjer (Action in the event of accidents involving electric vehicles)

Danish Emergency Management Agency 2011

http://brs.dk/viden/publikationer/uddannelsesmateriale/Documents/Vejledning%20om%20indsats%20ved%20uheld%20med%20elk%C3%B8ret%C3%B8jer.pdf

US links for hydrogen safety and accidents

http://h2bestpractices.org

http://h2incidents.org

http://www.hydrogenandfuelcellsafety.info

Video: Comparison of natural gas and hydrogen flame

http://h2bestpractices.org/media/short_prop_V3.mov

Video: Fire exercise with hydrogen cars in California

http://www.fdnntv.com/Hydrogen-Fuel-Cell-Training

Video: Driving a hydrogen car across Denmark

http://www.youtube.com/watch?v=lbO4PInKCAA

Hydrogen for transport in Denmark

The association Hydrogen Link Danmark www.hydrogenlink.net

The Hydrogen and Fuel Cell Partnership in Denmark

Industry association: www.hydrogennet.dk