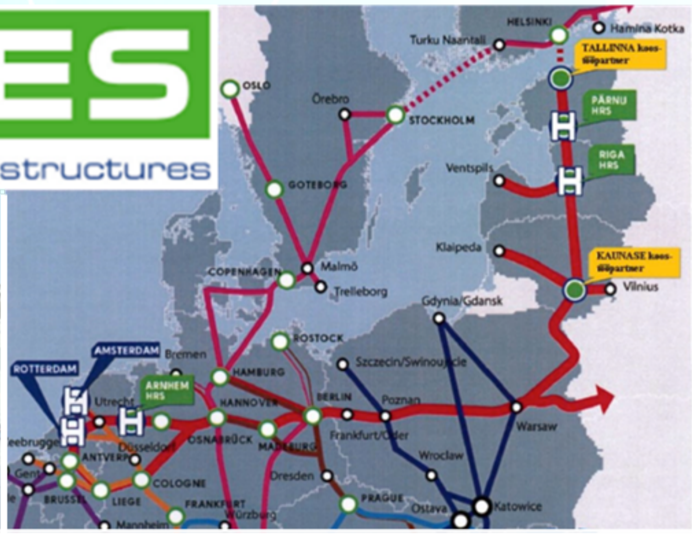
Milestones H2NODES

Milestone 12

Pärnu HRS Upscaling

H2NODES
Connecting Transport Infrastructures



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Milestone 12 Report

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Author(s): Dainis Bošs (Trezors); Aivars Starikovs (Trezors); Ilvars Sirmais (Trezors); Jānis Fricsons (Trezors).

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1. Introduction

This report describes the upscaling potential for the Pärnu HRS (Hydrogen refuelling station) gradual expansion and potential for additional HRS deployment in Region (Estonia). The starting point for regional upscaling is the reference for hydrogen refuelling demand based on Sub-Activity 3.2. of the Action as described in the H2Nodes Grant Agreement.

Sub-Activity 3.2. includes the mobilisation of local actors and users. In the case of Pärnu HRS and potential other HRS deployment in region based on the location of the potential stakeholders.

The upscaling of Pärnu HRS and additional HRS deployment in region is related to hydrogen refuelling demand that is indicated within this report.

This report provides more insight of how to technologically secure the hydrogen availability and what equipment is necessary to be deployed.

Milestone 12 “Pärnu HRS Upscaling” report consists of specific HRS upscaling plans for stations in Estonia. Within this report each HRS is described in separate chapter. In total the Report includes descriptions about 3 HRS. The overall content for each HRS includes description of:

1. Hydrogen demand and HRS concept;
2. Technological solutions;
3. List of equipment;
4. Utility connections;
5. Budget estimates;
6. Space requirements;
7. Risk scenarios and probabilities for specific HRS components;
8. Overall risk level of intended activity.

The annex of the Milestone 12 “Pärnu HRS Upscaling” includes description of specific equipment, recommended standards and specific insight of legal, environmental aspects as well as the description of performed risk assessment methodology.

2. Pärnu HRS

The Pärnu HRS is foreseen to be deployed within the Action H2NODES. The initial capacity that must be provided is to refuel 15 FCE-buses per day. Note that the potential hydrogen demand to refuel 15 FCE-buses is only stipulated in H2NODES Grant Agreement. Due to lack of determination by potential FCE-bus deployers in Pärnu, it is unlikely that FCE-vehicles and HRS will be deployed in Pärnu in the near term. As historically it was indicated that a HRS would be deployed in Pärnu within the Action H2NODES, a theoretical evaluation of potential HRS is made. In order to achieve the necessary capacity, the Pärnu HRS must ensure 180kg/H2 availability per day. The overall scheme of intended Pärnu HRS is made in Figure 1.

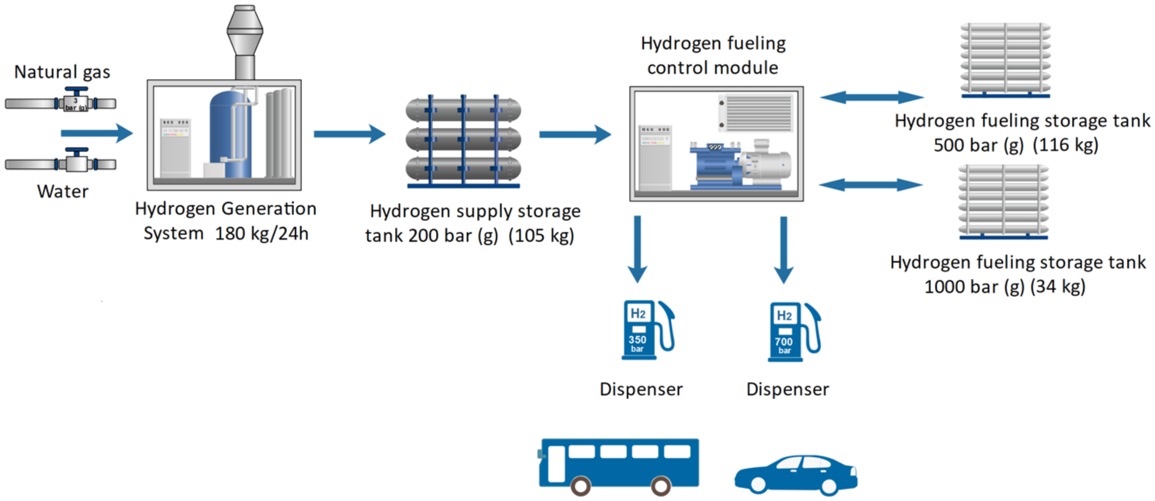


Figure 1 Scheme of intended Pärnu HRS

2.1 Technological solutions

The hydrogen will be produced using Steam-methane reforming process. In order to achieve the necessary hydrogen availability and to secure the modularity principle, two separate hydrogen production lines should be installed. For each line, the reformers capacity must be 90kg/H_2 per day.

For Pärnu HRS the hydrogen production will be made using steam-methane reforming process. As the produced hydrogen would mainly be used by FCE-buses that perform public transportation, the hydrogen availability must be secured. The usual principle is to deploy a modular HRS with separate hydrogen production lines. This enables the option to perform maintenance services for one line while the other ones are fully operational. Two separate hydrogen production lines should be installed. For each line, the reformers capacity must be 90kg/H_2 per day. For the means to increase the hydrogen pressure two separate hydrogen compressors with capacity of 42NM^3/h are required.

For the storage it would be necessary to deploy one hydrogen supply storage unit with capacity of 105 kg/H_2. One hydrogen fuelling control module would be required in order to operate the both 350bar and 700bar dispensers (see Figure 2)

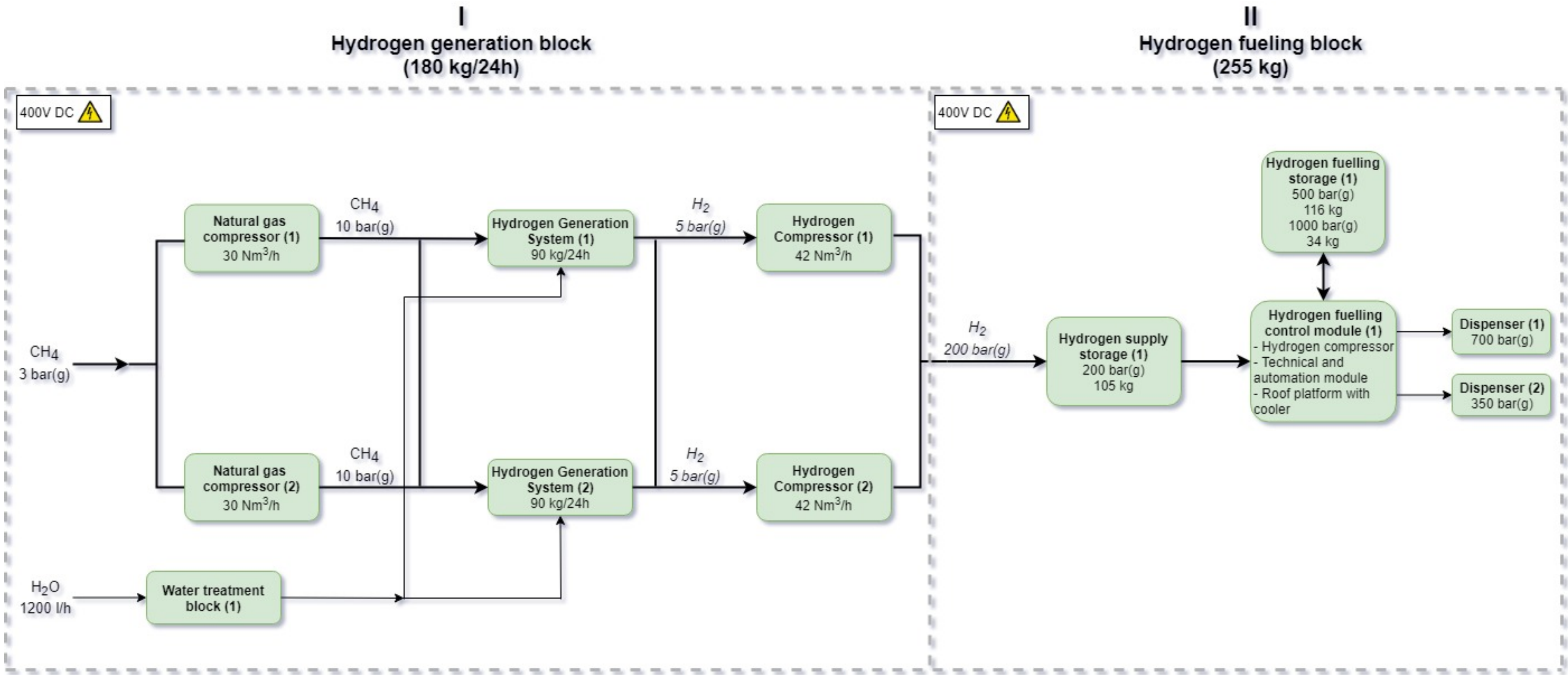


Figure 2 Technological solutions for Pärnu HRS

The initial technical specification of the Parnu HRS is summarised in Table 1. By developing the technical specification, the modularity principles were considered in order to continue the practice of separate hydrogen production lines, whereas one could be used if maintenance or any other aspects affect the other hydrogen production lines operations.

Table 1 Technical specification of Pärnu HRS

System description	Technical parameters	Quantity
Natural gas compressor unit	Qmax = 30 Nm3/h	2
Hydrogen generation system	Qmax = 90 kg/24h	2
Hydrogen compressor unit	Qmax= 42 Nm3/h	2
Hydrogen supply storage	P = 200 bar V = 105 kg	1
Hydrogen fuelling storage	P = 500 bar V = 116 kg	1
Hydrogen fuelling storage	P = 1000 bar V = 34 kg	1
Hydrogen fuelling control module	Qmax: 48.5 kg/h Maximum design pressure: 1000 bar(g)	1
Dispenser	P = 350 bar	2
Dispenser	P = 700 bar	1
Water treatment block	Qmax= 1200l/h	1

Utility connections

In order to secure the Pärnu HRS operations, it is necessary that the utility connections could secure the figures listed in Table 2.

Table 2 Utility connections for Pärnu HRS

Utility	Measure	Technical requirements
Natural gas connection	Nm3/h	60 @ 10 bar(g)
Water connection	l/h	1200

Waste water connection	l/h	1200
Electricity 400V	kW	380

Budget estimates.

By evaluating the indicative price of the HRS equipment and deployment an assumption of price per kg of hydrogen is made and 8,8 EUR per kg of hydrogen could be achieved. (see Figure 3).

1kg H2 cost breakdown

Cost per 1kg H2, in € (24m after launch)		2025
Cost position	Ref	EUR
Producde H2 kg cost		2,36
Employees		0,78
Services		1,73
Depreciation		3,13
Financing costs		0,08
Total cost per 1kg H2 produced (Yr Avg)		8,07
Applied premium		9,0%
Proposed sell price before taxes, EUR		8,80

Figure 3 1kg H2 cost breakdown of Pärnu HRS

The total price of HRS reaches around 5’500’000 EUR. The budget estimates include price of equipment depreciation, price of utility connection establishment, price of resources (utilities) to produce hydrogen, construction costs, reconditioning costs and administrative costs. The section “services” includes maintenance costs and staff costs that perform the maintenance.

Space requirements

Due to the intended equipment the Pärnu HRS would occupy up to 634 sq.m Figure 4.

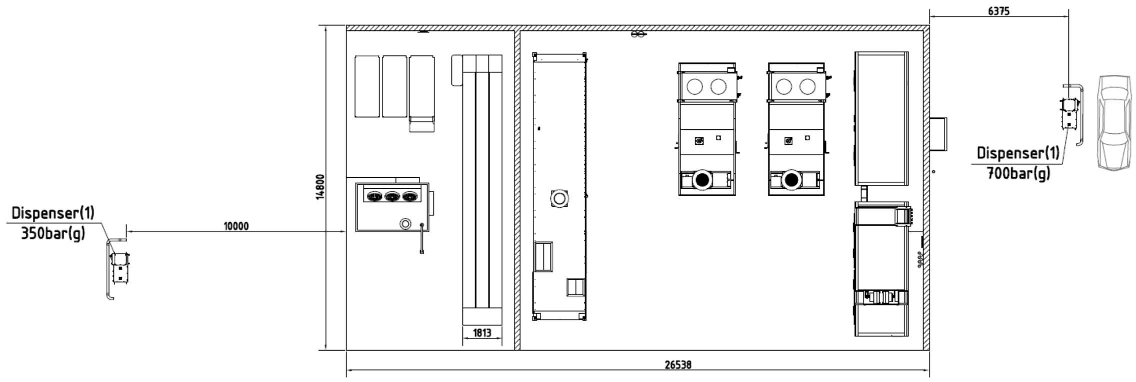


Figure 4 Space requirements for Pärnu HRS.

By combining the previous information, the first visualisation of the Pärnu HRS first step upscaling is made (Figure 5).

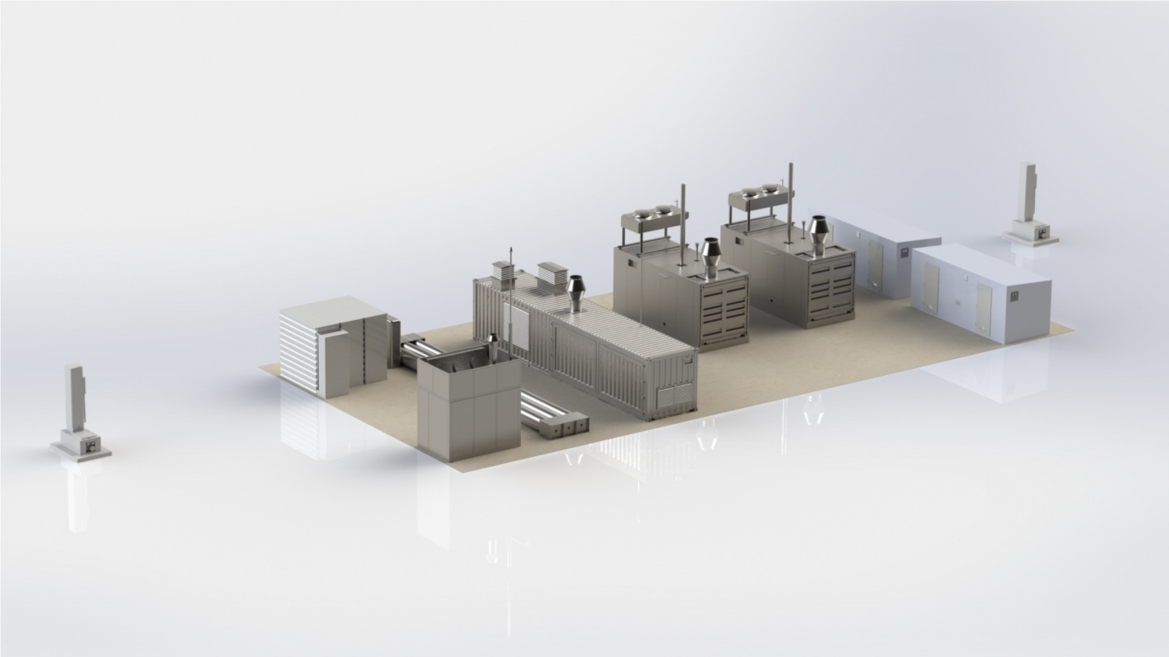


Figure 5 Visualization of Pärnu HRS

2.2 Requirements for placement of hydrogen refuelling station

When choosing the location of Pärnu HRS type hydrogen filling station, similarly to other objects, the following must be taken into account:

- correspondence to the spatial plan of the territory to the needs of the location of the hydrogen filling station - technical construction, industrial construction territory or other suitable type of use;
- Noise level generated by the equipment;
- Emissions of pollutants from natural gas combustion in a steam-methane reforming process;
- Risk of accidents related to the operation of the equipment.

2.3 Assessment of the air quality

To assess the impact of the hydrogen fuelling station operation on air quality, an emission calculation has been performed for two identical combustion equipment. Emissions of pollutants from natural gas combustion in one hydrogen station are shown in Table 3. The calculations consider the maximum fuel consumption for one combustion equipment and the operating time - 8760 hours per year.

Table 3 Emissions of pollutants from the combustion of natural gas from one reformer.

Pollutant	Hydrogen generation system capacity	Fuel consumption	t/year	g/s	mg/m³
Nitrogen dioxide	90kg/24h	23 Nm3/h	0,194	0,006	71,79
Carbon monoxide			0,290	0,009	107,69
Carbon dioxide			383,29	12,2	-

The following total emissions are projected at the hydrogen gas combustion equipment. Note that the previous table indiciates the emissions of one hydrogen production unit (reformer), thus in the potential Pärnu HRS upscaling to produce 180kg/H_2 per day two separate units must be deployed, therefore the total emissions are projected as:

- Nitrogen dioxide– 0,388 t/year;
- Carbon monoxide – 0,58 t/year;
- Carbon dioxide– 766,58 t/year.

The hydrogen production capacity and natural gas consumption of the Pärnu HRS are lower than existing Riga HRS. Based on the above, without additional modeling, it can be assumed that the impact of Pärnu HRS on air quality is insignificant, as the results of Riga HRS upscaling first step dispersion modeling already indicate that predicted carbon monoxide and nitrogen dioxide emissions from the combustion of natural gas are not significant. For more information, please see the H2NODES Milestone Report 10 “Riga HRS Upscaling” Chapter Riga HRS first step upscalling.

2.4 Risk scenarios and probability

In assessing the risk of Pärnu HRS the following sources of risk were considered:

- Natural gas pipeline;
- Hydrogen storage units;
- Dispensers.

Natural gas pipeline

For determining the probability of an event, it has been assumed that the diameter of a natural gas pipeline is 25,4 mm and that the length of the pipeline above the ground within the object territory is 1 m. The safety system is automatic and its probability of failure is set at 0,01.

Table 4 Natural gas pipeline accident scenarios and their probabilities.

Scenario	Generic LOCs	Probability per year		
		Leak	Leak with immediate ignition	Leak with delayed ignition
Full bore rupture	1.00E-06 / m/ year	1.00E-08	2.00E-09	6.00E-10

Leak	5.00E-06 / m/ year	5.00E-08	1.00E-08	3.00E-9

Hydrogen storage units

The calculations consider the number of cylinders that are used for hydrogen storage. In the Pärnu HRS the total number of cylinders that are used in hydrogen storage are 33 units. As the hydrogen is stored in different pressures the storage units break-down is:

- Supply storage (200 bar): 3 gas cylinders;
- Storage (500 bar): 30 gas cylinders;
- Storage (1000 bar): 10 gas cylinders.

The cylinders in the hydrogen storage are equipped with a safety system, which disconnects each cylinder from the common system in case someone of unit gets damaged. This option prevents the gaseous hydrogen that is stored in other cylinders to escape through the damaged cylinder.

Table 5 H2 storage accident scenarios and their probabilities.

Scenario	**Generic LOCs**	**Probability per year**		
		Leak	Leak with immediate ignition	Leak with delayed ignition
Supply storage (200 bar)				
Instantaneous release of the complete inventory	5.00E-07/year	1.50E-06	3.45E-07	1.80E-07
Continuous release from a hole with an effective diameter of 10 mm	1.00E-05/year	3.00E-05	2.40E-07	1.20E-07
Storage (500 bar)				
Instantaneous release of the entire contents of the gas cylinder	5.00E-07/year	1.50E-05	7.95E-07	4.05E-07
Continuous release from a hole with an effective diameter of 3,3 mm	1.00E-07/year	3.00E-06	2.40E-08	1.20E-08
Storage (1000 bar)				
Instantaneous release of the entire contents of the gas cylinder	5.00E-07/year	5.00E-06	2.65E-07	1.35E-07
Continuous release from a hole with an effective diameter of 3,3 mm	1.00E-07/year	1.00E-06	8.00E-09	4.00E-09

Dispenser

The probability calculations consider dispenser operating time due to the potential hydrogen demand are assumed for each dispenser. Note that the actual operating hours can change due to real-life HRS usability. Within the calculations the operation hours are assumed as:

- 350 bar dispenser – 514 hours /year;
- 700 bar dispenser – 41 hours / year.

Dispensers are equipped with automatic safety system with probability of failure chance is assumed as 0,01 probability within the risk assessment.

Table 6 H2 dispenser accident scenarios and their probabilities.

Scenario	Generic LOCs	Probability per year		
		Leak	Leak with immediate ignition	Leak with delayed ignition
350 bar dispenser				
Full bore rupture of the hose	4.00E-06/hour	2.06E-05	1.09E-06	5.55E-07
Leak of the hose	4.00E-05/hour	2.06E-04	1.65E-06	8.23E-07
700 bar dispenser				
Full bore rupture of the hose	4.00E-06/hour	1.65E-06	3.80E-07	4.46E-08
Leak of the hose	4.00E-05/hour	1.65E-05	1.32E-07	6.60E-08

In this and the following examples Software Riskcurves (version 11.2.2) and software Effects (version 11.2.2) of the Norwegian company Gexcon are used for modelling consequences of accident. For scenarios of natural gas supply pipeline accidents, gas discharge and jet fire have been considered. Hydrogen discharge with gas cloud explosion, gas cylinder rupture, and jet fire have been analysed as consequences in the accident scenarios for H2 accidents. The results of the consequence modelling summarized in the Table 7. In the calculations, it is assumed that the diameter of the dispenser hose is 15 mm. Note that the higher the distance, the larger the lethality zone around the station.

Table 7 Distances of Possible consequences in the considered accident scenarios.

Scenario	1% lethality distance [m]	
	F 1,5	D 5

Gas pipeline		
Full bore rupture – jet fire	14	12
Leak – jet fire	1	1
Supply storage (200 bar)		
Instantaneous release of the complete inventory – gas cylinder rupture	10	10
Instantaneous release of the complete inventory – gas cloud explosion	15	15
Continuous release from a hole with an effective diameter of 10 mm – jet fire	21	18
Storage (500 bar)		
Instantaneous release of the entire contents of the gas cylinder – gas cylinder rupture	6	6
Instantaneous release of the entire contents of the gas cylinder – gas cloud explosion	8	8
Continuous release from a hole with an effective diameter of 3,3 mm – jet fire	10	9
Storage (1000 bar)		
Instantaneous release of the entire contents of the gas cylinder – gas cylinder rupture	7	7
Instantaneous release of the entire contents of the gas cylinder – gas cloud explosion	9	9
Continuous release from a hole with an effective diameter of 3,3 mm – jet fire	14	12
350 bar dispenser		
Full bore rupture of the hose – jet fire	22	18
Full bore rupture of the hose – gas cloud explosion	7	7
Leak of the hose – jet fire	1<	1<
Leak of the hose – gas cloud explosion	1<	1<
700 bar dispenser		
Full bore rupture of the hose – jet fire	28	23
Full bore rupture of the hose – gas cloud explosion	9	9

Leak of the hose – jet fire	5	4
Leak of the hose – gas cloud explosion	1<	1<

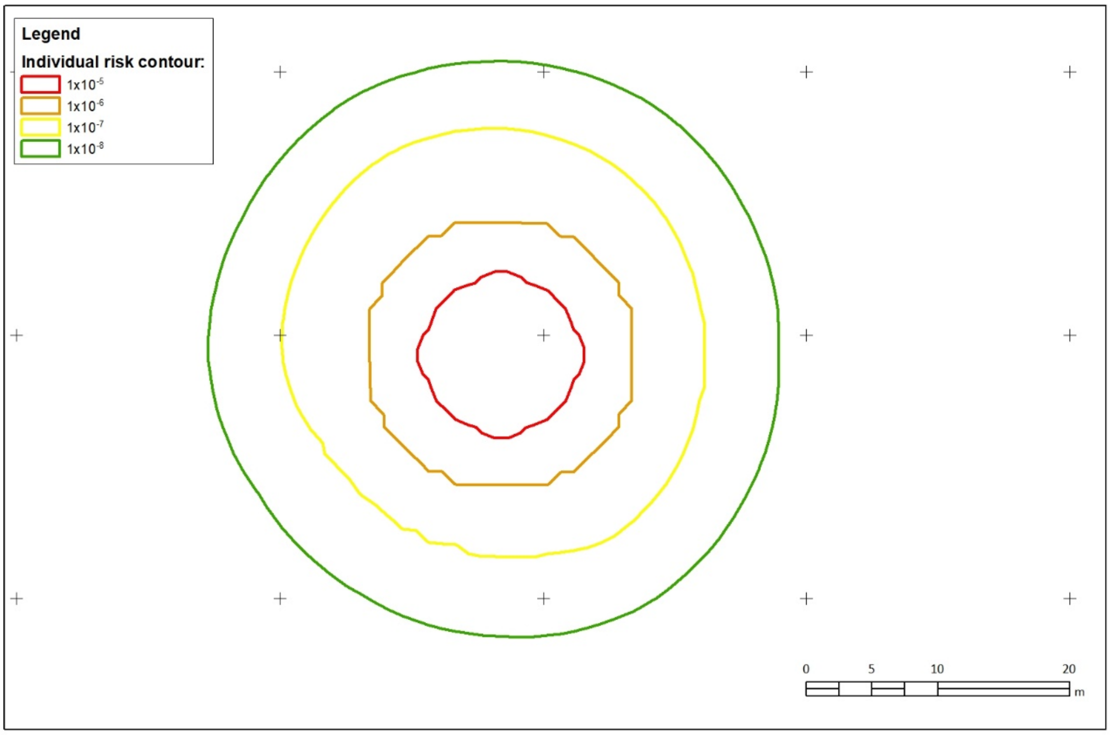
Risk level of intended activity

Given that this applicable Pärnu HRS type hydrogen filling station location is not approved the risk modelling with the software Riskcurves was performed assuming that all sources of risk are located at one point. As a result of modelling, the following maximum consequences and risk distances have been determined:

Table 8 Consequences and risk distances from object.

Type of distance	Distance [m]
Risk value 10^{-6} per year	10
Risk value 10^{-8} per year	22
Largest effect-distance (1% lethality)	28

Figure 6 Contour of the individual risk around a hydrogen filling station.



The previous Figure indicates the risk zones around the potential Pärnu HRS.

2.5 Conclusion of the Pärnu HRS.

The foreseen hydrogen production capacity for Pärnu HRS is 180kg. Due to the lack of FCE-vehicle deployment it is foreseen that the HRS won't be deployed in Pärnu. By calculations the cost of this type of HRS would reach around 5'500'000 EUR and the foreseen price per kg would reach 8,8 EUR.

The operation of the Pärnu HRS does not involve a large amount of hazardous substances; therefore the operation of the installation may pose a threat up to approximately 30 m around it. Which can be accepted as a minimum safety distance to sensitive objects. This does not cancel the need to apply safety zones specified in regulatory enactments. The spatial plan of the territory must be considered when choosing the location of the hydrogen filling station.

When planning the outdoor location of the Pärnu HRS station, the minimum distances to noise-sensitive areas must be considered so that the noise limits are not exceeded as a result of the station's operation. The noise generated by the planned activity must be assessed combined with the existing background noise level at the specific location

3. Large scale hydrogen production and refuelling station in Estonia

As the near-term strategy foresees a possibility to deploy zero-emission buses in Tallinn Estonia, to perform the public transport operations, a large scale HRS for Tallinna Linnatranspordi is evaluated. The hydrogen production would be performed using water-electrolysis process with total production capacity of 3000 kg/H_2 per day. The refuelling capacity must be ensured in the same amount.

It is projected that the HRS would be used to refuel 196 FCE-buses that would be used for Tallinna Linnatranspordi for public transport operations. The 196 FCE-bus units are taken from evaluation of entire Tallinna Linnatranspordi fleet and is not set as a commitment from transport operator side.

Considering that the buses must be refuelled in night-time the refuelling window is set the same as for Riga (Latvia) PTO Rigas Satiksme - 6 hours. In order to ensure the availability for passenger vehicles also the 700bar dispenser would be deployed thus the total capacity would not exceed 5 kg/H2 per day therefore the 700bar dispenser is added as a possibility to achieve availability to refuel passenger vehicles. The overall scheme of Tallinn HRS is included in Figure 4.

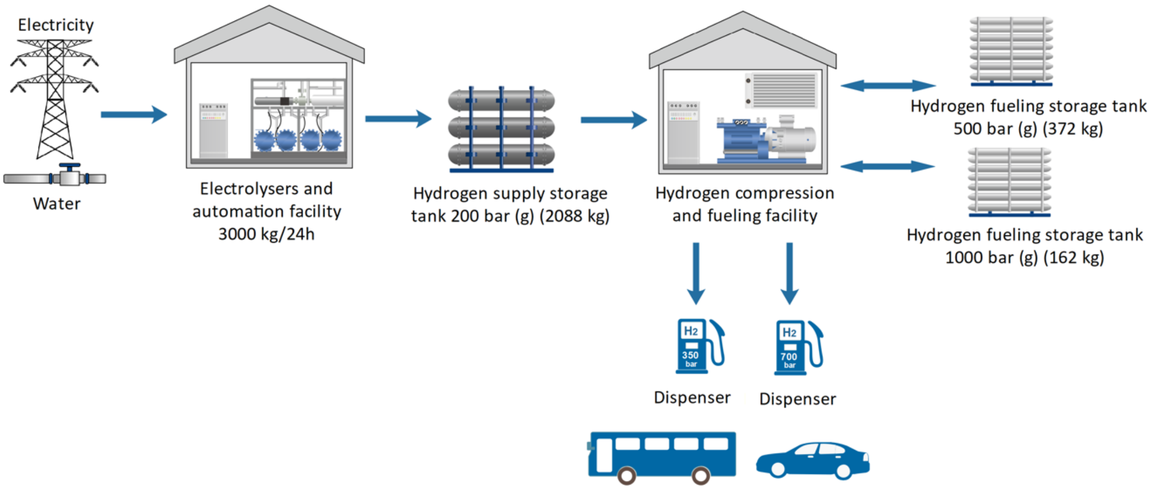


Figure 7 Scheme of Tallinn HRS facility

3.1 Technological solutions

For Large scale Tallinn HRS the hydrogen production will be made using water-electrolysis process. As the produced hydrogen would mainly be used by FCE-buses that perform public transportation, the hydrogen availability must be secured. The usual principle is to deploy a modular HRS with separate hydrogen production lines. This enables the option to perform maintenance services for one line while the other ones are in fully operational.

A total number of 3 electrolysers with each production capacity of 1000kg/H_2 per day would be installed. For the means to increase the hydrogen pressure two separate hydrogen compressors with capacity of 540NM^3/h are required.

For the storage it would be necessary to deploy 4 separate hydrogen supply storage units with 522kg each. In order to provide the significant amount of hydrogen for refuelling the Hydrogen compressor and fuelling facility would consist of 2 separate compressor modules that would increase the pressure of hydrogen for different levels. The Hydrogen fuelling storage consist of 6 units with various pressures and capacities (see Figure 8). In total to secure the 6-hour refuelling window for FCE-buses it is necessary to deploy six 350bar dispensers. In general, this is a hydrogen production and refuelling facility.

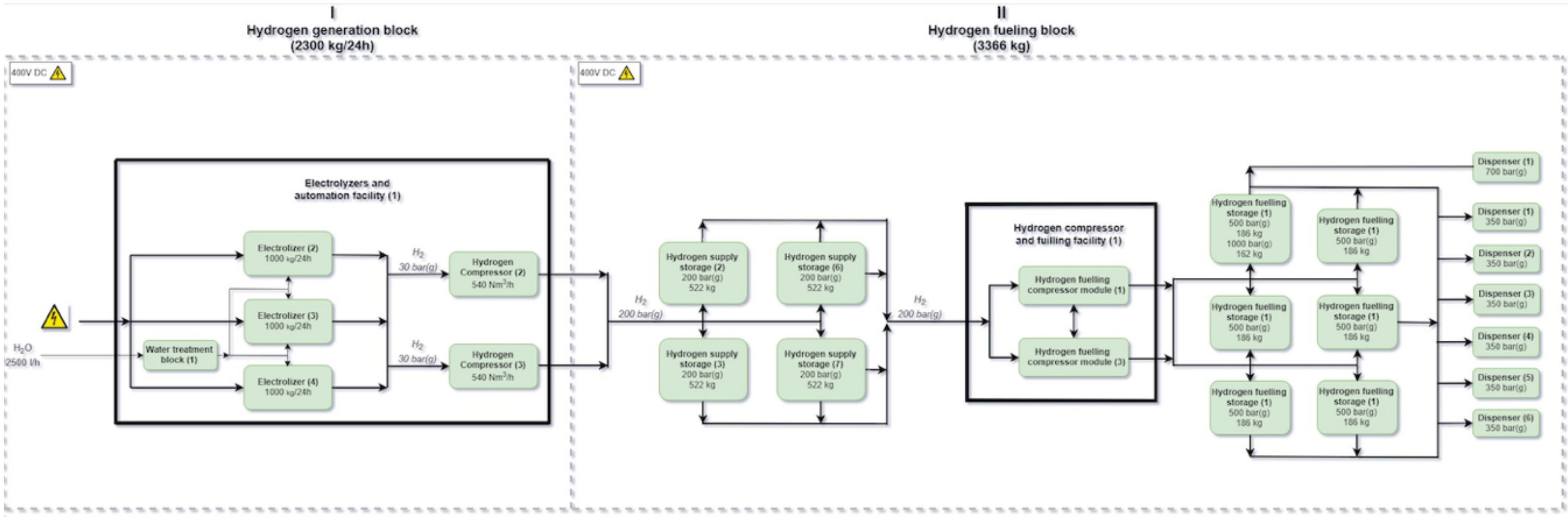


Figure 8 Equipment of Tallinn HRS

The initial technical specification of the Tallinn HRS is summarized in Technical specification of Tallinn HRS second step upscaling.Table 9 Technical specification of Tallinn HRS second step upscaling. By developing the technical specification, the modularity principles were taken into account in order to continue the operation of separate hydrogen production lines, whereas one could be used if maintenance or any other aspects affect the other hydrogen production lines operations.

Table 9 Technical specification of Tallinn HRS second step upscaling.

System description	Technical parameters	Quantity
Electrolizers and automation facility	Qmax = 2300 kg/24h H2 outlet pressure=200bar	1
Hydrogen supply storage	P = 200 bar V = 522 kg	4
Hydrogen fuelling storage	P = 500 bar V = 186 kg	6
Hydrogen fuelling storage	P = 1000 bar V = 162 kg	1
Hydrogen compressor and fuelling control module	Maximum design pressure: 1000 bar(g)	1
Dispenser	P = 350 bar	6
Dispenser	P = 700 bar	1
Water treatment block	Qmax = 2500 l/h	1

Utility connections

In order to deploy the additional equipment, it is necessary that the utility connections could secure the figures listed in Table 10.

Table 10 Utility connections for Tallinn HRS second step upscaling.

System description	Measure.	Technical requirements
Water connection	l/h	2500
Waste water connection	l/h	2500
Electricity 400V	MW	10.5 MW

Budget estimates

By evaluating the indicative price of the HRS equipment and deployment an assumption of price per kg of hydrogen is made. (see Figure 9).

1kg H2 cost breakdown

Cost per 1kg H2, in € (24m after launch)		2025
Cost position	Ref	EUR
Producde H2 kg cost		2,11
Employees		0,06
Services		0,36
Depreciation		1,10
Financing costs		0,03
Total cost per 1kg H2 produced (Yr Avg)		3,66
Applied premium		9,0%
Proposed sell price before taxes, EUR		4,00

Figure 9 1kg H2 cost breakdown for Tallinn HRS second step upscaling

The total price of HRS estimates reaches around 22'000'000 EUR according to suitable technologies provided in the market. The budget estimates include price of equipment depreciation, price of utility connection establishment, price of resources (utilities) to produce hydrogen, construction costs, reconditioning costs and administrative costs. In general, by achieving more FCE-vehicles the potential hydrogen price per kg decreases as the equipment operates in higher efficiency and the price at dispenser could be as low as 4 EUR per kg of hydrogen. Note, that the land acquisition is not included in the price estimates and the used price of electricity is taken from NordPool therefore excluding the transmission fees.

Space requirements

The overall HRS deployment land plot would occupy 2520 sq.m (see Figure 10). The 350bar dispensers would be located approx. 24 meters away from the Tallinn HRS facility. The space between the dispensers and the facility is used for the buses to access the dispensers.

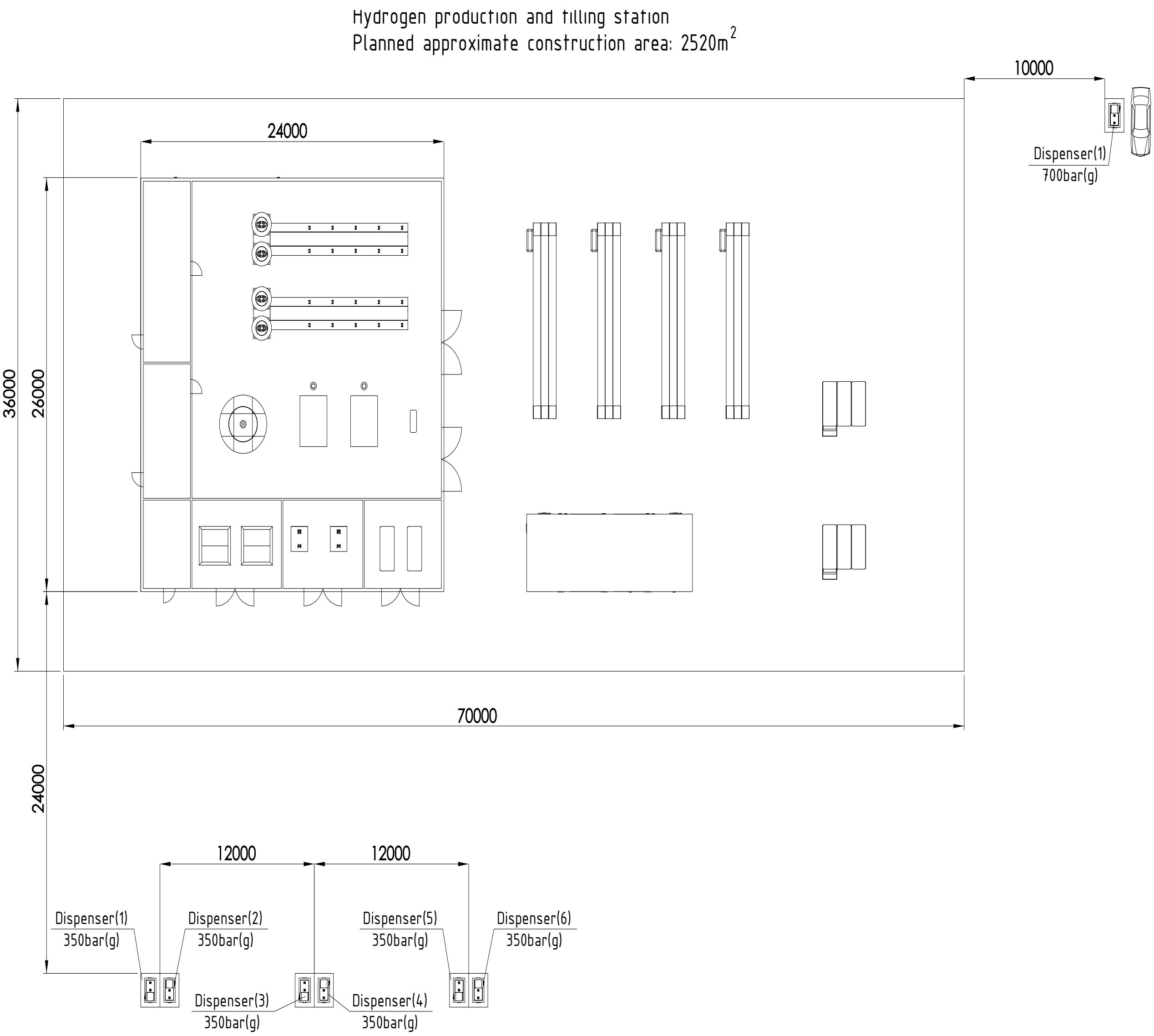


Figure 10 Space requirements for Tallinn HRS second step upscaling.

By combining the previous information, the first visualization of the Large Scale Tallinn HRS is made (Figure 11)

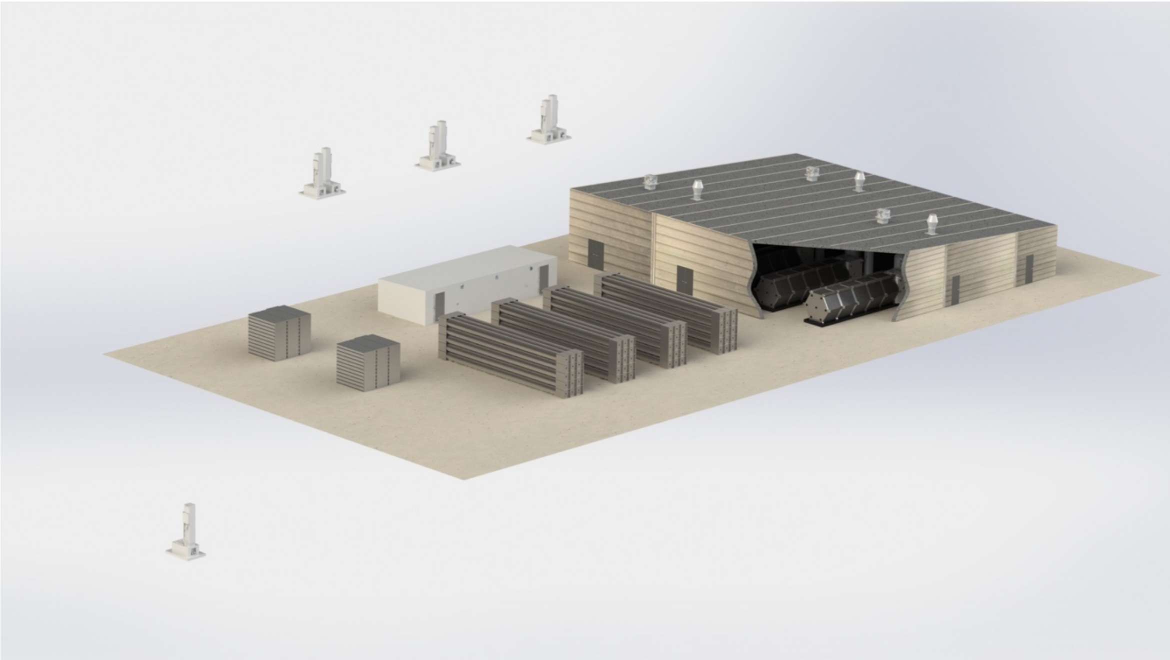


Figure 11 First visualization of Tallinn HRS second step upscaling.

3.1 Requirements for placement of large-scale hydrogen production and refuelling station in Estonia

When choosing the location of a large scale hydrogen production and refuelling station in Estonia, similarly to other objects, the following must be taken into account:

- correspondence to the spatial plan of the territory to the needs of the location of the hydrogen filling station;
- Noise level generated by the equipment;
- Risk of accidents related to the operation of the equipment.

Hydrogen production in large scale hydrogen production and refuelling station in Estonia planned by electrolysis which is not associated with air pollution.

Given that all noise sources will be located inside the building and at the current stage no high detail information is available on the sound insulation levels of the building structures, the exact location of the noise sources and sound power, the noise level through the building structures is not assessed.

3.2 Risk assessment

In assessing the risk of Large scale hydrogen production and refuelling station in Tallinn the following sources of risk were considered:

- Hydrogen storages;
- Dispensers.

Hydrogen storage

The calculations consider the number of cylinders in hydrogen storage:

- Supply storage (200 bar): 60 gas cylinders;

- Storage (500 bar): 288 gas cylinders;
- Storage (1000 bar): 66 gas cylinders.

The cylinders in the hydrogen storage are equipped with a safety system, which disconnects each cylinder from the common system in case someone of all gets damaged, preventing the gas in other cylinders from escaping through the damaged cylinder.

Table 11 H2 storage accident scenarios and their probabilities.

Scenario	**Generic LOCs**	**Probability per year**		
		Leak	Leak with immediate ignition	Leak with delayed ignition
Supply storage (200 bar)				
Instantaneous release of the complete inventory	5.00E-07/year	3.00E-05	6.90E-06	3.60E-06
Continuous release from a hole with an effective diameter of 10 mm	1.00E-05/year	6.00E-04	4.80E-06	2.40E-06
Storage (500 bar)				
Instantaneous release of the entire contents of the gas cylinder	5.00E-07/year	1.44E-04	7.63E-06	3.89E-06
Continuous release from a hole with an effective diameter of 3,3 mm	1.00E-07/year	2.88E-05	2.30E-07	1.15E-07
Storage (1000 bar)				
Instantaneous release of the entire contents of the gas cylinder	5.00E-07/year	3.30E-05	1.75E-06	8.91E-07
Continuous release from a hole with an effective diameter of 3,3 mm	1.00E-07/year	6.60E-06	5.28E-08	2.64E-08

Dispenser

The probability calculations take into account dispenser operating time:

- 350 bar dispensers – 14710 hours /year (total operating time);
- 700 bar dispenser – 28 hours / year.

Dispensers are equipped with automatic safety system with probability of failure, in risk assessment has been assumed 0,01.

Table 12 H2 dispenser accident scenarios and their probabilities.

Scenario	Generic LOCs	Probability per year		
		Leak	Leak with immediate ignition	Leak with delayed ignition
350 bar dispenser				
Full bore rupture of the hose	4.00E-06/hour	2.74E-04	1.45E-05	7.39E-06
Leak of the hose	4.00E-05/hour	2.74E-03	2.19E-05	1.10E-05
700 bar dispenser				
Full bore rupture of the hose	4.00E-06/hour	6.50E-07	1.50E-07	1.76E-08
Leak of the hose	4.00E-05/hour	6.50E-06	5.20E-08	2.60E-08

Consequences of accident

Hydrogen discharge with gas cloud explosion, gas cylinder rupture, and jet fire have been analysed as consequences in the accident scenarios for H2 accidents. In the calculations, it is assumed that the diameter of the dispensers hose is 15 mm.

Table 13 Distances of possible consequences in the considered accident scenarios.

Scenario	1% lethality distance [m]	
	F 1,5	D 5
Supply storage (200 bar)		
Instantaneous release of the complete inventory – gas cylinder rupture	10	10
Instantaneous release of the complete inventory – gas cloud explosion	15	15
Continuous release from a hole with an effective diameter of 10 mm – jet fire	21	18
Storage (500 bar)		
Instantaneous release of the entire contents of the gas cylinder – gas cylinder rupture	6	6
Instantaneous release of the entire contents of the gas cylinder – gas cloud explosion	8	8

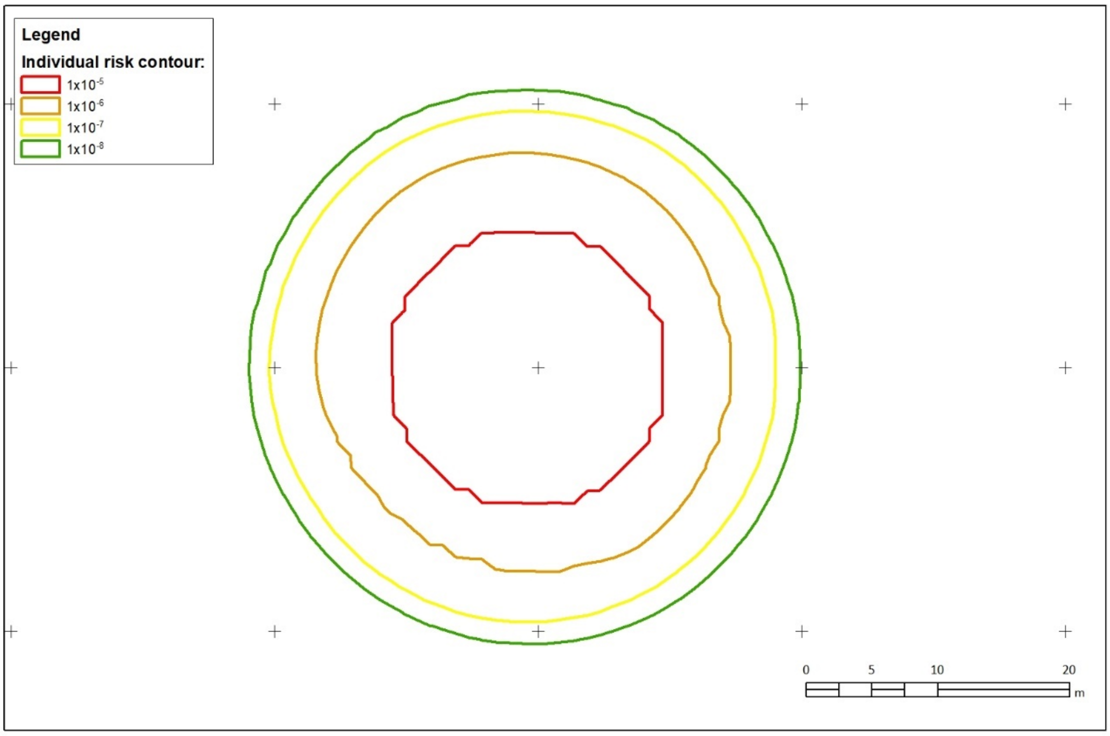
Continuous release from a hole with an effective diameter of 3,3 mm – jet fire	10	9
Storage (1000 bar)		
Instantaneous release of the entire contents of the gas cylinder – gas cylinder rupture	7	7
Instantaneous release of the entire contents of the gas cylinder – gas cloud explosion	9	9
Continuous release from a hole with an effective diameter of 3,3 mm – jet fire	14	12
350 bar dispenser		
Full bore rupture of the hose – jet fire	22	18
Full bore rupture of the hose – gas cloud explosion	7	7
Leak of the hose – jet fire	1<	1<
Leak of the hose – gas cloud explosion	1<	1<
700 bar dispenser		
Full bore rupture of the hose – jet fire	28	23
Full bore rupture of the hose – gas cloud explosion	9	9
Leak of the hose – jet fire	5	4
Leak of the hose – gas cloud explosion	1<	1<

Risk level of intended activity

Given that this applicable transportable hydrogen filling station is considered without connection to the territory, risk modelling with the Riskcurves software was performed assuming that all sources of risk are located at one point. As a result of modelling, the following maximum exposure and risk distances have been determined:

Table 14 Consequences and risk distances from object.

Type of distance	Distance [m]
Risk value 10^{-6} per year	16
Risk value 10^{-8} per year	21
Largest effect-distance (1% lethality)	28



3.3 Conclusion of Tallinn HRS.

The large-scale Tallinn HRS would enable significant amounts of green hydrogen availability in Estonia. The foreseen hydrogen production capacity would reach 3000kg per day and would allow to deploy and fully use 196 FCE-buses. As for the price of deployment the costs to deploy such HRS would reach around 22’000’000 EUR. The significant hydrogen demand would allow to decrease the price of hydrogen and even achieve 4 EUR per kg. This type of hydrogen production facility would allow to achieve cheap hydrogen for mobility purposes.

From risk perspective, in the case of the considered solution the site could pose a threat to the population in the area of about 30 m around it. However, when planning the location of the facility, the requirements of national legislation in Estonia must be taken into account. The location of technological equipment in the territory of the object and their distance from potentially endangered nearby objects is also important.

In case the noise level is expected from the operation of the station, which may affect the nearby noise sensitive areas, it is necessary to develop a detailed noise assessment, which must be assessed combined with the already existing background noise level in a specific area.

4. Movable hydrogen refuelling station

the large-scale hydrogen production and refuelling facility deployment would allow to deploy a number of movable hydrogen refuelling stations whereas hydrogen is delivered. In order to proceed with this type of action, it would be necessary to equip the large-Scale Tallinn HRS with specific equipment, that would allow to fill the hydrogen in the delivery vehicles.

As for the Movable HRS, the container type refuelling station would allow to place it in smaller areas to achieve the hydrogen availability. Considering that environmental aspects are related to hydrogen production and storage, the movable HRS would be excluded from EIA etc. as the stored hydrogen amounts are only around 150kg/H_2.

It is projected that the HRS would be used to refuel one shunting locomotive for AS Operail. AS Operail is a railway operator, who has expressed an interest to deploy a fuel cell and hydrogen shunting locomotive in order to secure zero emission operations in railway routes whereas the electrification is not economically viable. The movable HRS stored hydrogen would allow to refuel 10 FCE-buses. The figure of 10 FCE-buses is provided as an alternative due to potential usage of movable HRSs in Estonia.

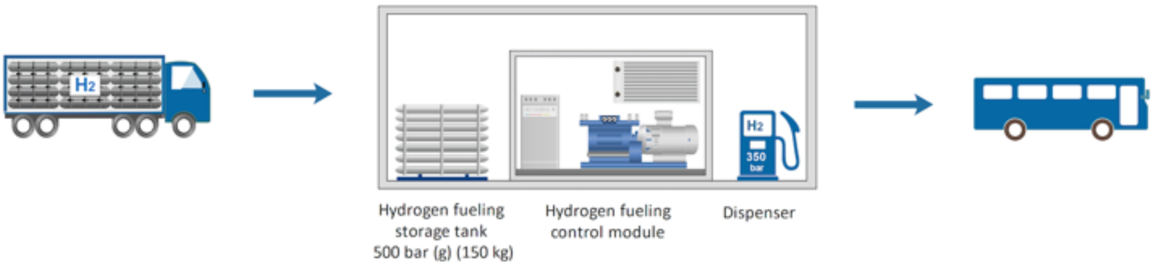


Figure 12 Scheme of movable HRS.

4.1 Technological solutions

For Movable HRS the hydrogen would be delivered with heavy truck, that is equipped with hydrogen suitable storage tank. The hydrogen afterwards would be fuelled to Movable HRS storage tanks (Hydrogen fuelling storage). As the it was identified that only heavy-duty vehicles would refuel in the Movable HRS, only the 350bar dispenser is equipped (see Figure 13).

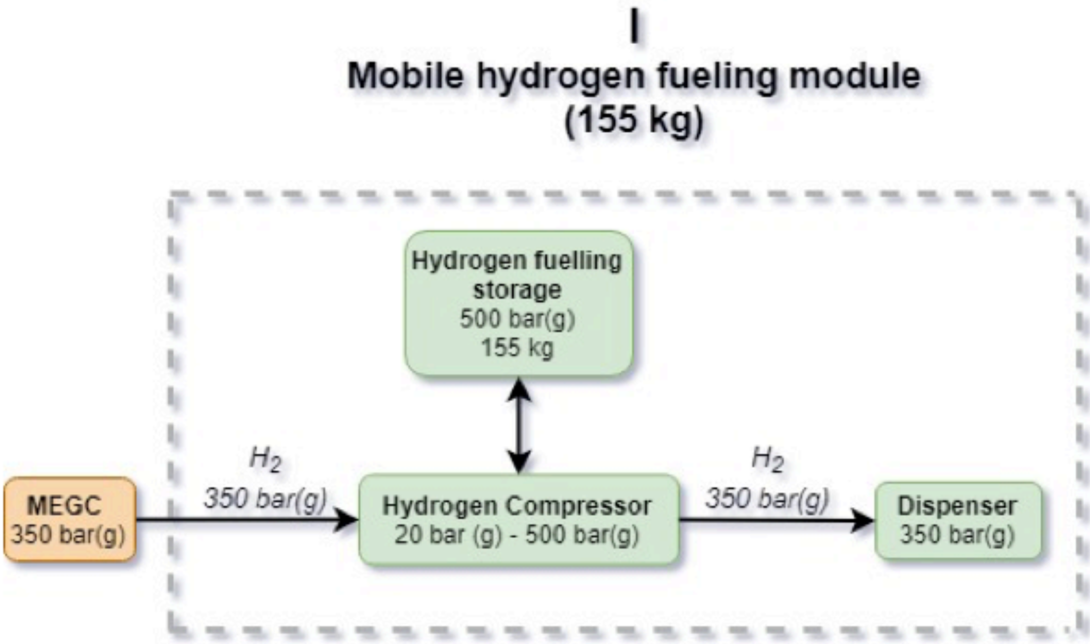


Figure 13 Equipment of Movable HRS.

The initial technical specification of the Movable HRS is summarized in Table 15. Note that the HRS is container type therefore all equipment is mounted inside.

Table 15 Technical specification of Movable HRS.

System description	System technical parameters
Mobile hydrogen fueling module	**Hydrogen compressor:** Hydrogen inlet pressure: 20-500 bar(g) Maximum design pressure: 1000 bar(g) **Hydrogen storage 500 bar(g):** Total capacity of H2: 155kg Quantity of tanks: 40 pcs **Dispenser for light vehicle refilling:** Nominal working pressure: 350 bar(g) Maximum working pressure: 435 bar(g) Maximum flow rate: 120 g/s Filling hose length: 2.5 meters Refueling time and protocol: SAE J2601-1:2016 Nozzle: WEH TK16 HF - with Infrared transmit Calculated total weight: <12000 kg Ambient temperature range: -30 °C to +40 °C Electrical connection: 400V DC CE marking

Utility connections

As the Movable HRS may be delivered to desired location in order to perform operations it still is necessary to establish Utility connections. Note that only electricity connection would be required (see Table 16).

Table 16 Utility connections.

System description	Measure.	Technical requirements
Hydrogen supply	-	Pressure: 20-500 bar(g) Quality: 99.999%
Electricity 400V	kW	50 kW

Budget estimates

Note that this HRS does not have hydrogen production equipment and therefore the base price can be taken from one of the previous HRSs that i.e. large-scale Tallinn HRS. If the hydrogen is delivered to Movable HRS that is located 50km away from the Tallinn HRS, the delivery costs of hydrogen (incl. equipment, service and employee costs) would add 1,62 EUR per kg of hydrogen. Additionally the movable HRS must be services and operated and therefore additional 1,97 EUR per kg of hydrogen is added to refuel the FCEVs at the movable HRS.
The total costs per kg would include also the distribution costs (delivery of hydrogen) and filling the movable HRS storage units. The total price estimates of Movable HRS according to suitable technologies in market reaches around 550’000 EUR. The budget estimates include price of equipment depreciation, price of utility connection establishment, construction costs, reconditioning costs and administrative costs. The total price does not include land acquisition costs.

Space requirements

In order to deploy the Movable HRS, it would be necessary to secure atleast 180sq.m. landplot. (see Figure 14).

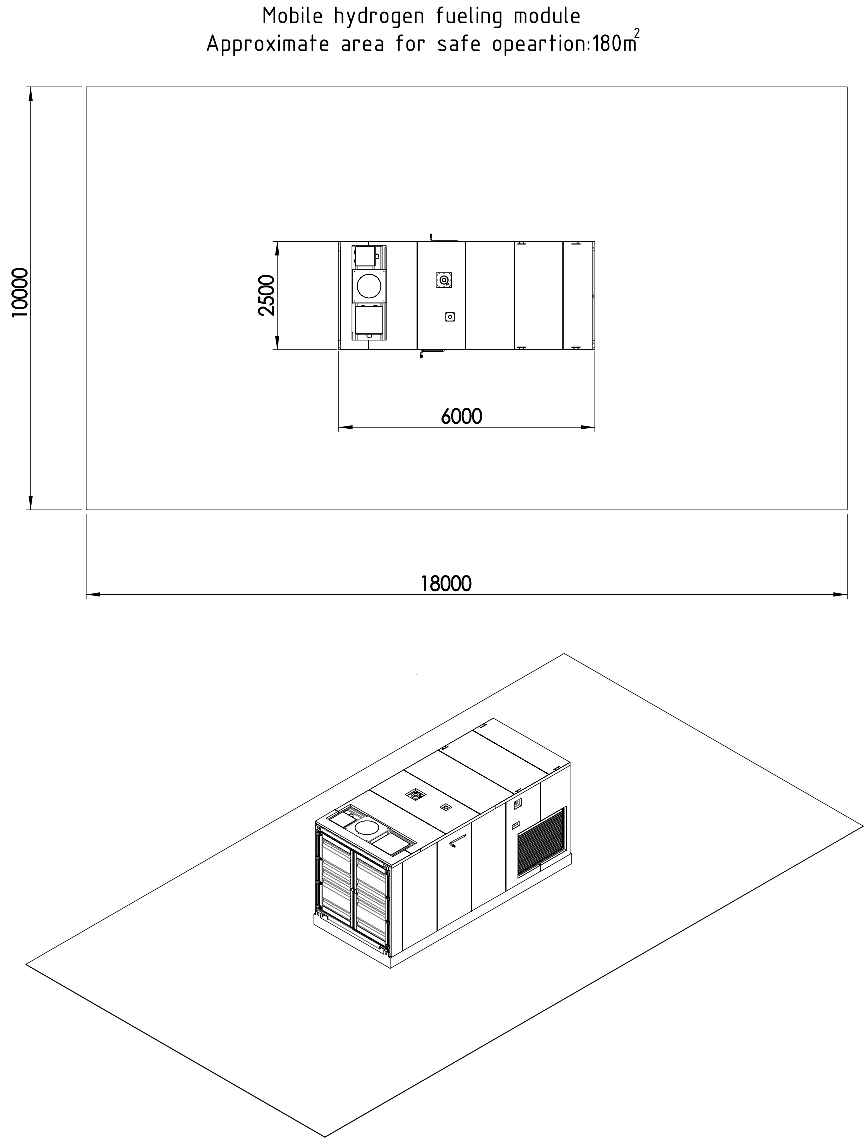


Figure 14 Movable HRS space requirements.

By combining the previous information, the first visualization of the Movable HRS is made (Figure 15)

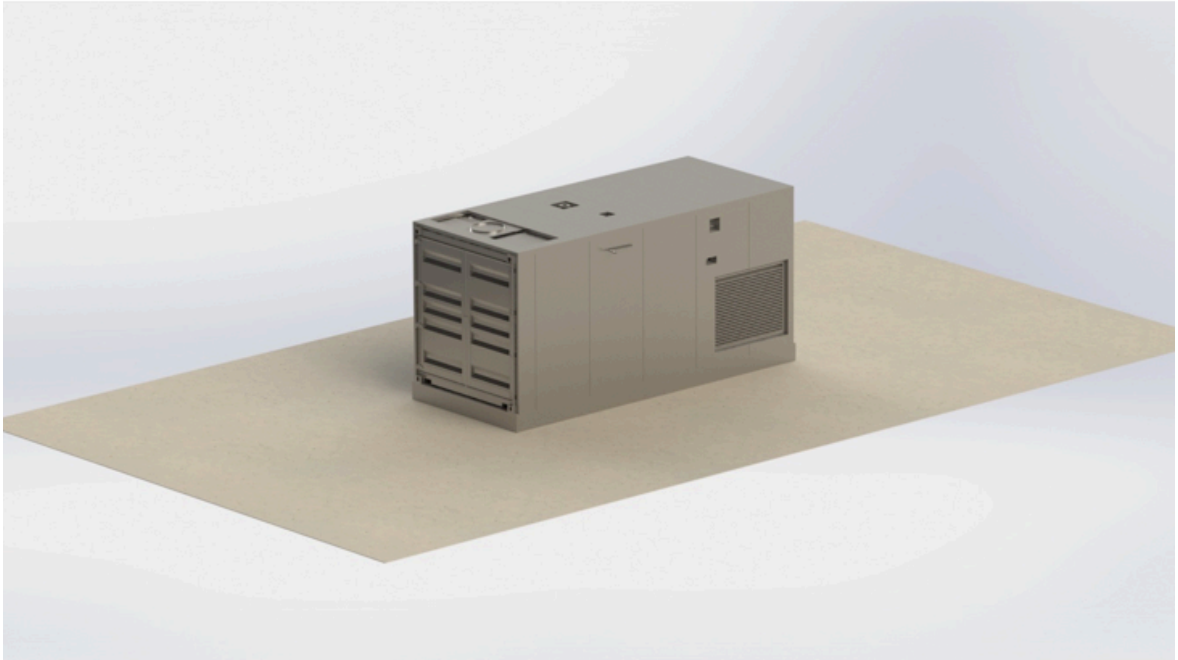


Figure 15 Visualisation of movable HRS.

4.2 Requirements for placement of movable hydrogen refuelling station

When choosing the location of a Movable HRS, similarly to stationary objects, the following must be considered:

- correspondence to the spatial plan of the territory to the needs of the location of the hydrogen filling station - technical construction, industrial construction territory or other suitable type of use;
- Noise level generated by the equipment;
- Risk of accidents related to the operation of the equipment.

The Movable HRS will not produce hydrogen, so its operation is not related to atmospheric emissions and it is not necessary to assess the air pollution it causes.

4.3 Risk assessment

In assessing the risk of movable HRS the following sources of risk were considered:

- Hydrogen storages;
- Dispensers;
- Delivery with MEGC (multiple element gas container).

Hydrogen storage

The calculations consider the number of cylinders in hydrogen storage (500 bar) are 40. The cylinders in the hydrogen storage are equipped with a safety system, which disconnects each cylinder from the common system in case these get damaged, preventing the gas in other cylinders from escaping through the damaged cylinder.

Table 17 H2 storage accident scenarios and their probabilities.

Scenario	Generic LOCs	Probability per year		
		Leak	Leak with immediate ignition	Leak with delayed ignition
Instantaneous release of the entire contents of the gas cylinder	5.00E-07/year	2.00E-05	1.06E-06	5.40E-07
Continuous release from a hole with an effective diameter of 3,3 mm	1.00E-07/year	4.00E-06	3.20E-08	1.60E-08

Dispenser

The probability calculations consider 350 bar dispenser operating time is 411 hours /year. Dispensers are equipped with automatic safety system with probability of failure, in risk assessment has been assumed 0,01.

Table 18 H2 dispenser accident scenarios and their probabilities.

Scenario	Generic LOCs	Probability per year		
		Leak	Leak with immediate ignition	Leak with delayed ignition
Full bore rupture of the hose	4.00E-06/hour	1.64E-05	8.71E-07	4.44E-07
Leak of the hose	4.00E-05/hour	1.64E-04	1.32E-06	6.58E-07

Delivery with MEGC

The calculations consider the following H2 MEGC:

- Capacity 4410 Nm^3
- Number of cylinders in the unit 40;
- Unit volume (water capacity) 450 litres nominal;
- Hydraulic test pressure 375 bar;
- Max allowable working pressure 250 bar;
- Unit cylinder weight (empty weight): ~165 kg;
- Total cylinders weight (40×): ~6600 kg;

It is assumed that the process control and management is manual, and the probability of human error is assumed to be 0,9.

Table 19 H2 MEGC unloading process accident scenarios and their probabilities.

Scenario	Generic LOCs	Probability per year		
		Leak	Leak with immediate ignition	Leak with delayed ignition
Instantaneous release of the entire contents of the gas cylinder	5.00E-07/year	7.73E-09	4.10E-10	2.09E-10
Continuous release from a hole the size of the largest connection of transport module	5.00E-07/year	2.34E-08	1.88E-10	9.38E-11
Full bore rupture of the hose	4.00E-06/hour	1.64E-04	1.31E-06	6.57E-07
Leak of the hose	4.00E-05/hour	1.64E-03	1.31E-05	6.57E-06

The following data is considered for determining H2 transport module's unloading time in the fuelling station:

- Loading quantity – 49275 kg/annum;
- Loading rate – 120 kg/h.

Consequences of accident

Hydrogen discharge with gas cloud explosion, gas cylinder rupture, and jet fire have been analysed as consequences in the accident scenarios for H2 accidents.

Table 20 Distances of possible consequences in the considered accident scenarios.

Scenario	1% lethality distance [m]	
	F 1,5	D 5
Storage (500 bar)		
Instantaneous release of the entire contents of the gas cylinder – gas cylinder rupture	6	6
Instantaneous release of the entire contents of the gas cylinder – gas cloud explosion	8	8
Continuous release from a hole with an effective diameter of 3,3 mm – jet fire	10	9
350 bar dispenser		
Full bore rupture of the hose – jet fire	22	18
Full bore rupture of the hose – gas cloud explosion	7	7
Leak of the hose – jet fire	-	-

Leak of the hose – gas cloud explosion	-	-
Industrial filling panel		
Instantaneous release of the entire contents of the gas cylinder – gas cylinder rupture	7	7
Instantaneous release of the entire contents of the gas cylinder – gas cloud explosion	10	10
Continuous release from a hole the size of the largest connection of transport module – jet fire	8	6
Continuous release from a hole the size of the largest connection of transport module – gas cloud explosion	3	3
Full bore rupture of the hose – jet fire	63	53
Full bore rupture of the hose – gas cloud explosion	30	30
Leak of the hose – jet fire	7	6
Leak of the hose – gas cloud explosion	-	-

In the calculations, it is assumed that the diameter of the dispenser hose is 15 mm. Opening with diameter 30 mm assumed as the largest connection of transport module.

Risk level of intended activity

Given that this applicable movable hydrogen filling station is considered without connection to the territory, risk modelling with the software Riskcurves was performed assuming that all sources of risk are located at one point. As a result of modelling, the following maximum consequences and risk distances have been determined:

Table 21 Consequences and risk distances from object.

Type of distance	Distance [m]
Risk value 10^{-6} per year	30
Risk value 10^{-8} per year	57
Largest effect-distance (1% lethality)	63

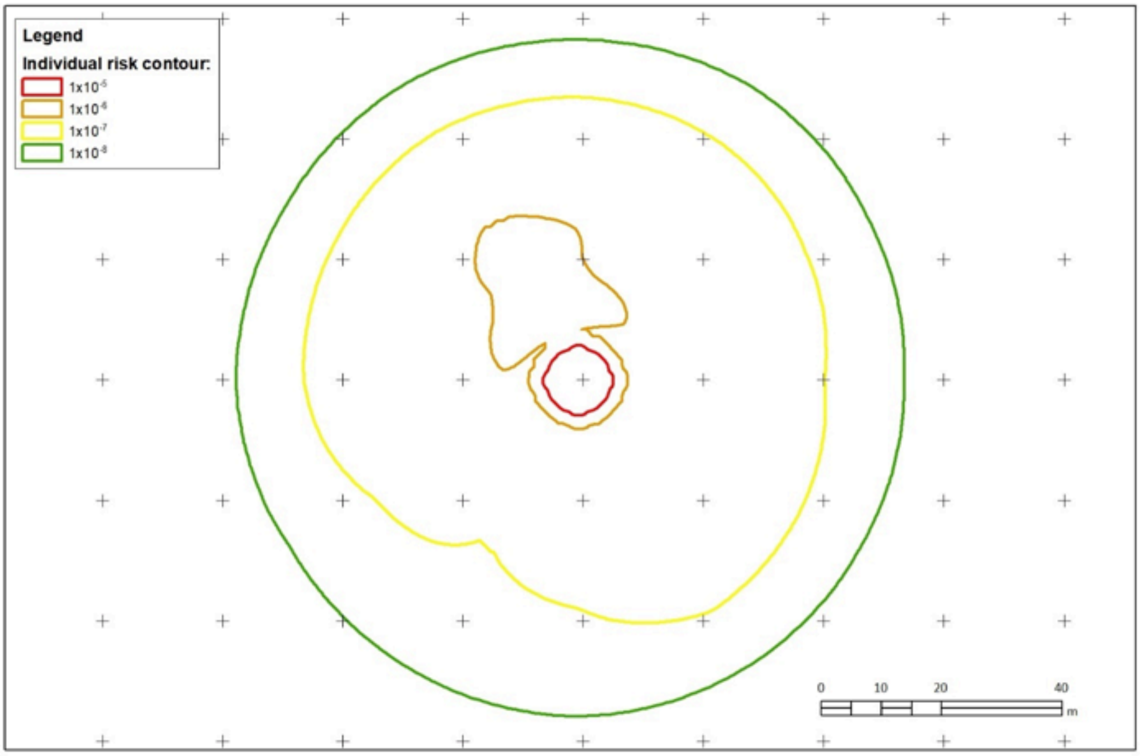


Figure 16 Contour of the individual risk around a example of movable hydrogen refuelling station.

4.4 Conclusion on movable HRS

A number of movable HRS deployment would achieve the hydrogen availability in different regions whereas it would not be suitable to deploy a hydrogen production and refuelling station due to lack of hydrogen demand.

If the hydrogen is delivered to Movable HRS that is located 50km away from the Tallinn HRS, the delivery costs of hydrogen (incl. equipment, service and employee costs) would add 1,62 EUR per kg of hydrogen from the base price (4 EUR per kg). Additionally the movable HRS must be serviced and operated and therefore additional 1,97 EUR per kg of hydrogen is added to refuel the FCEVs at the movable HRS therefore the final price at Movable HRS dispenser would reach up to 7,59 EUR kg/H_2 .

From risk perspective, the operation of the intended Movable HRS does not involve a large amount of hazardous substances, therefore the operation of the installation itself may pose a threat up to approximately 25 m around it. However, hydrogen supplies are provided by MEGC with a capacity greater than the capacity of the storage tanks. Consequently, there is a possibility that there is more hydrogen in the facility than in the storage tanks, and in the event of a major accident, the consequences of the accident may spread a little more than 60 m from the MEGC admission site.

For each Movable HRS object, the minimal distances to the residential area shall be determined individually based on the nearby function of the use of the area and the applicable limit value.

5. Conclusion

In order to achieve the hydrogen availability a hydrogen refuelling and production station must be deployed in Estonia. The original plan to deploy a HRS Pärnu was withheld by the actor in the field Parox Energy OU due to the lack of potential hydrogen demand in Pärnu.

As the overall characteristics of the Pärnu HRS was already set, its evaluation is included in this report. Additionally an option for Tallinn public transport operator Tallinna Linnatranspordi was made in order to seek for potential to deploy 196 FCE-buses.

If the potential demand would increase rapidly it would establish the grounds to deploy a large-scale HRS production facility that would be able to secure the hydrogen demand also in Regions if a number of movable HRS would be deployed. Currently only the AS Operail (railway operator in Estonia) has expressed the interest to deploy a Fuel cell and hydrogen shunting locomotive, and therefore the option for movable hydrogen refuelling station was made.

It can be seen that by increasing the hydrogen demand it is possible to secure cheaper hydrogen production. This is due to the fact that the HRSs would perform at full capacity on daily basis.

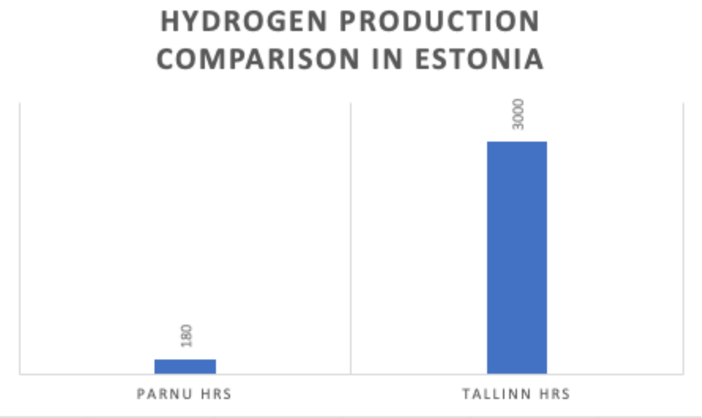


Figure 17 Potential hydrogen production in Estonia kg/H_2

The affordable hydrogen can be achieved if more FCEVs are deployed and the grounds for larger hydrogen production and refuelling station are made.

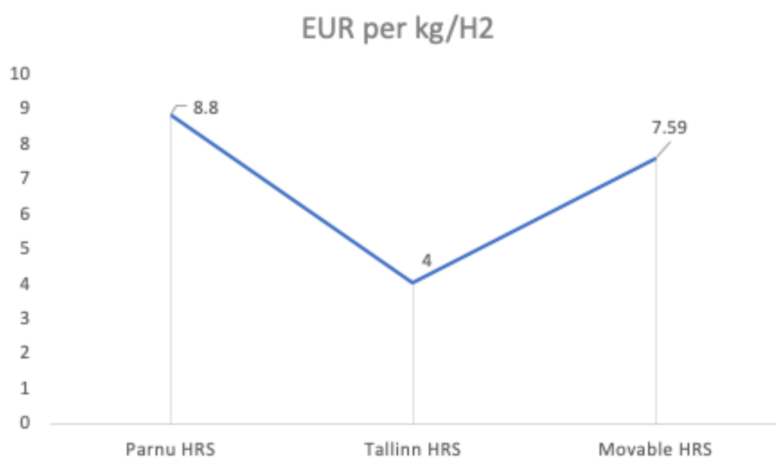


Figure 18 Price per kg/H2

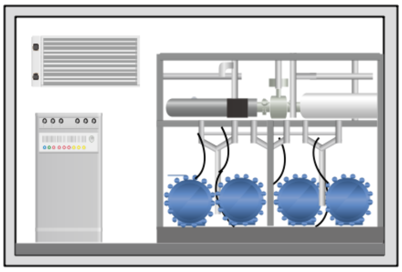
The price estimations for the Pärnu HRS per kg/H2 reaches around 8,8 EUR. The relative high price is based on the small demand of hydrogen. If the large-scale Tallinn HRS would be deployed, whereas the hydrogen production would be based on water-electrolysis process, the price of 4 EUR kg/H2 could be reached. Within the estimations the electricity price is estimated from the NordPool, therefore no transmission fees are considered. The price will increase if the need to deploy movable HRS would occur and it will be necessary to solve the delivery aspects of hydrogen.

For Estonia, the hydrogen demand must be achieved in order to deploy HRSs. The possibility to deploy a large-scale HRS that could serve as a huge distribution centre to a number of movable or smaller HRSs without on-site production to secure the hydrogen availability. The option to use MEGC to deliver the hydrogen to refuelling site is not widely identified and additional research should be done.

The demand for passenger vehicle refuelling and interest to deploy such type of vehicles is still relatively small. Currently it can be assumed that these vehicles would be deployed for demonstration purposes. The 750bar dispensers were included in the HRSs in order to secure the availability and probability to refuel the passenger vehicles.

Annex 1 HRS equipment

Hydrogen production using water-electrolysis



Water electrolysis with electricity: water electrolysis is a process where electrical current decomposes water molecule into oxygen and hydrogen gases. Electrical power (DC power supply) is connected through two electrodes – anode and cathode. At the negatively charged cathode reduction reactions will appear, hydrogen cations taking additional electrons forms hydrogen gas. At positively charged anode, oxidation reaction takes place, oxygen gas is generated and electrons transported to an anode to complete the circuit. If renewable energy is used as a source of electrical power supply, then produced hydrogen becomes transportable clean energy source, which has numerus emission benefits comparing with fossil energy sources.

Depending on the electrolyte material involved there are two main types of electrolysers:

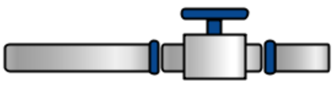
1. Alkaline electrolyser: usually potassium hydroxide or sodium hydroxide solutions are used as an electrolyte.
2. Proton exchange membrane (PEM) Electrolyser: solid polymer is used as an electrolyte.

Electrolyser models can have different parameters and different hydrogen generation capacities depending on the manufacturer.

Hydrogen production modules can vary from small footprint (about 1 m^2) to large scale electrolyser facilities with the area of hundreds of square meters. For small hydrogen capacity production (up to 100 kg/H_2 per day), usually, PEM electrolysers are used. If there is a necessity of higher production capacities both PEM and alkaline electrolysers can be found on the market.

There are two types for the hydrogen production modules to be made – containerized or indoor types. Speaking about containerized type, more often, for the production consumption from 200 to about 500 kg/24h electrolysers are built in 6-meter sea containers. Electrolysers with bigger consumption, from 500 up to 1000 kg/24h, are manufactured in 12-meter containers. Indoor type electrolysers dimensions will depend on the production capacities and type of electrolysis. For this study, we assumed that our generation system can consist of 3 containerized modules with approximate generation capacity of 430 kg/24h each.

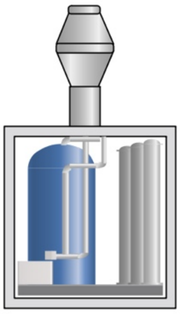
One of the advantages of produced hydrogen by electrolysing method is its purity. There is no need for additional filtration and separation of produce hydrogen, and the purity can vary from 99.995 to 99.999%



Due to physical process of electrolysis both water and electricity are very important parameters for the system. Power consumption of the generation system will be different for different manufacturers, it could be in the range from 3.8 kWh/Nm^3 of hydrogen to 7 kWh/Nm^3 of hydrogen. Water consumption can be about 1 – 2 liters for the production of 1 kg of hydrogen.

As was mentioned before, for this study a system of three modules with average production capacity of 430 kg/24h each were chosen. Taking into account, that usually such kind of modules can be manufacture in 6-meter or 12-meter containers, we can say that summery footprint of three electrolyser modules could reach up to 500 m^2.

Hydrogen production using steam-methane reforming



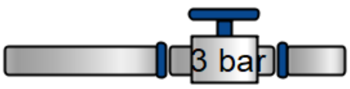
Hydrogen Generation System is an equipment that produces hydrogen using uses steam-methane reforming process. For the proper operation of generation system, it is required to have following utility connections: water, electricity, compressed air and natural gas.

Steam-methane reforming: by chemical reaction of hydrocarbons (mostly methane) with water (high-temperature steam), a syngas (mixture of hydrogen, carbon monoxide and carbon dioxide) is created. This reaction is strongly endothermic, that is why it requires a lot of heat ΔH_r= 206 kJ/mol. The carbon monoxide is reacted with steam which produces additional hydrogen. Further, the mixture can be separated to a pure hydrogen and carbon dioxide.

Hydrogen generation system for at least 300 kg/24h capacity theoretically can consist 3 steam-methane reforming modules. One module with hydrogen generation capacity of 50 – 100 kg/24h, one module with 100 – 200 kg/24h hydrogen generation capacity and one steam-methane reforming hydrogen generation module with 200 – 300 kg/24h generation capacity.

Purity of generated hydrogen can vary from 99.5 % to 99.9999 %. Maximum generation capacity depends on the required purity if higher purity is required, lower maximum capacity can be achieved.

Water consumption for steam-methane reforming hydrogen generators varies from manufacture to manufacturer, but in average, if water treatment (osmosis filter for example) is used then approximately up to 200 l/h of water can be used for small hydrogen generation consumption, and up to 400 l/h for 200 – 300 kg/24h hydrogen generation consumption.



Natural gas consumption depends on several factors – generated hydrogen purity, water purity, stem-methane reforming module manufacturer etc. For hydrogen production capacity of at least 300 kg/24h steam-methane reforming hydrogen generation modules that were theoretically calculated in this study, natural gas consumption can be approximately 300 Nm^3/h.

Usually, steam-methane reforming hydrogen generation systems are manufactured in 6-meter sea containers (for generation capacities up to 100 kg/24h) and 12-meter sea containers (for bigger hydrogen generation capacities).

Specific equipment related to steam-methane reforming include:

1. Natural gas compressor. Natural gas compressor module has the purpose to compress low-pressure natural gas to required pressure for hydrogen generation units. This module is not necessary if natural gas is available at required pressure. The compressor module consists of two compressors, cooling unit and automation unit.

2. Water treatment block. The purpose of a water treatment and compressed air block is to purify water within required level for hydrogen generators while also ensuring that there

is a sufficient supply of water to meet the hydrogen production needs. This module also has air compressors with dyer for supply or required quantity of compressed air to hydrogen generation system and natural gas compressor control actuators.

3. Hydrogen compressor. The compressor module has the purpose to compress the produced hydrogen by hydrogen generation units from 4.5 till 200 bar(g). The compressor module consists of two compressors, cooling unit and automation unit.

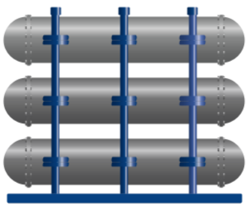
Hydrogen storage and refuelling

There are two types how hydrogen physically can be stored, as either a gas or a liquid. Storing of hydrogen as a gas usually requires high pressure tanks (200 – 1000 bar(g)). If hydrogen needs to be stored as a liquid, it requires cryogenic temperatures due to boiling point of the hydrogen at one atmosphere pressure. In this study, cylinders for a gas hydrogen storage were chosen.

Hydrogen supply storage is a group of cylinders installed on site between hydrogen production equipment and Hydrogen fuelling control module to make the hydrogen generation and fuelling station more flexible, even when production is not in operation. Today on the market, there are four standard types of cylinders:

- Type I - all-metal cylinders;
- Type II - all-metal hoop-wrapped composite cylinders;
- Type III - fully wrapped composite cylinders with metallic liners;
- Type IV - fully wrapped composite cylinders with no-load bearing non-metallic liners.

These types of cylinders can be stored in cascades, number of maximum cylinders as well as overall dimension of the cylinder and cascade depends on the manufacturer. In this study we chose Type I-cylinder cascade of maximum 15 cylinders for 200 bar(g). The Type-I cylinders are used due to the lower costs compared to other types of cylinders. With the dimensions of 12-meter sea container and capacity of hydrogen in one cylinder about 35 kg.

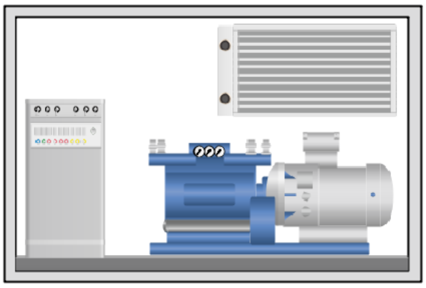


Hydrogen Supply Storage

Supply Storage is a group of cylinders with pressure up to 200 bar(g) installed on site between Hydrogen production equipment and Hydrogen fuelling control module to make the H2 station more flexible, even when production is not in operation. Supply storage also gives an opportunity to directly connection it to mobile Hydrogen tanks or trailers for storage filling from outsource.

Hydrogen Fuelling Storage.

It is a group of tanks assembled in flexible racks with two different pressure levels - 500bar(g) and 1000 bar(g). Fuelling Storage consist of hydrogen storage and control valve block through which the storages are connected with Hydrogen fuelling control module and Dispensers.



Hydrogen fuelling control module.

Hydrogen fuelling control module is the "brain" of a hydrogen production and refuelling station. All main automatization, such as refuelling parameters, connections between hydrogen storages, pressure in hydrogen storages etc. is controlled by this module. For each manufacturer, this module will be different with know-how systems inside. Often hydrogen fuelling control modules have separate non-contaminating compressors inside. Those compressors compress hydrogen to fuelling storages. When hydrogen is compressed, the heat is generated, that is why before compressing hydrogen is pre-cooled in pre-cooling system inside the control module. Hydrogen fuelling control module is connected to supply storage for hydrogen intake and to fuelling storage and dispensers for controlling the hydrogen fuelling process.

Dispenser

Dispenser is a standalone module for vehicle fuelling. Function of the dispenser is to be the contact point for vehicle refuelling. The connecting item is the refuelling nozzle, which must be connected to the vehicle in order to perform a refuelling.

Dispenser consist of:

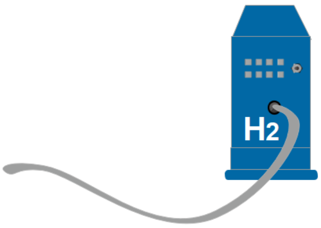
1. Interface indicating fuelling quantities
2. Valve and instrumentation unit module who is led from Hydrogen fuelling control module
3. Fuelling hose with nozzle

Each type of vehicle has a dedicated dispenser:

Heavy duty vehicle dispenser also called a 350bar dispenser is dedicated to Heavy duty vehicles where the filling amounts are more than 10 kg/H_2. This dispenser is controlled as per SAE J2601-2. The usual refuelling capacity is from 30-60g/sec if the communication connection between the FCEV and the HRS is established. If the communication connection is not available the refuelling speed would not exceed 5g/sec.

Car dispenser also called a 700bar dispenser is dedicated to Light Duty vehicles here the filling mass is from 2 to 10 kg/H_2. This dispenser is controlled as per SAE J2601-1. The refuelling speed for 700bar dispenser is usually around 120g/sec.

Industrial filing panel for MEGC (Multiple element gas container).



Industrial filing panel is a specific refuelling equipment that is used to fill the hydrogen in MEGC (multiple element gas container. MEGC can be used in order to deliver hydrogen to other HRS where no hydrogen production equipment is mounted.

It is a unit with flexible connection interface that can be applied to any hydrogen delivery type storage (trailers, cylinders etc.). Systems software allows to optimize fuelling parameters for fast and full hydrogen transfer. Same as for dispensers, industrial fuelling panel has safety interlock to ensure correct connection with delivered hydrogen storage. Maximum operating pressure usually for this type of systems is 240 bar(g).

Usually this module can be placed within 200 – 300 meters from the hydrogen supply storage.

Annex 2 Standards and documentation

Legal requirements are intended to ensure that a product / system / infrastructure or activity, in this particular case hydrogen refueling station (HRS) will not impact on the human safety / health, property or on the environment. As the HRS consists of infrastructure, technological equipment, process management, and a processes to manage the HRS, it is bounds by legislation that covers these aspects and sets minimum requirements for such operation. Generally, the legislation does not specify the direct, constructive or operational means to achieve the statutory safety objective, so such specific requirements are set out in standards and industry guidelines or specifications. In turn, regulatory enactments either directly or indirectly refer to these standards. The regulatory framework associated with the establishment of the station is shown in the diagram (Figure 19).

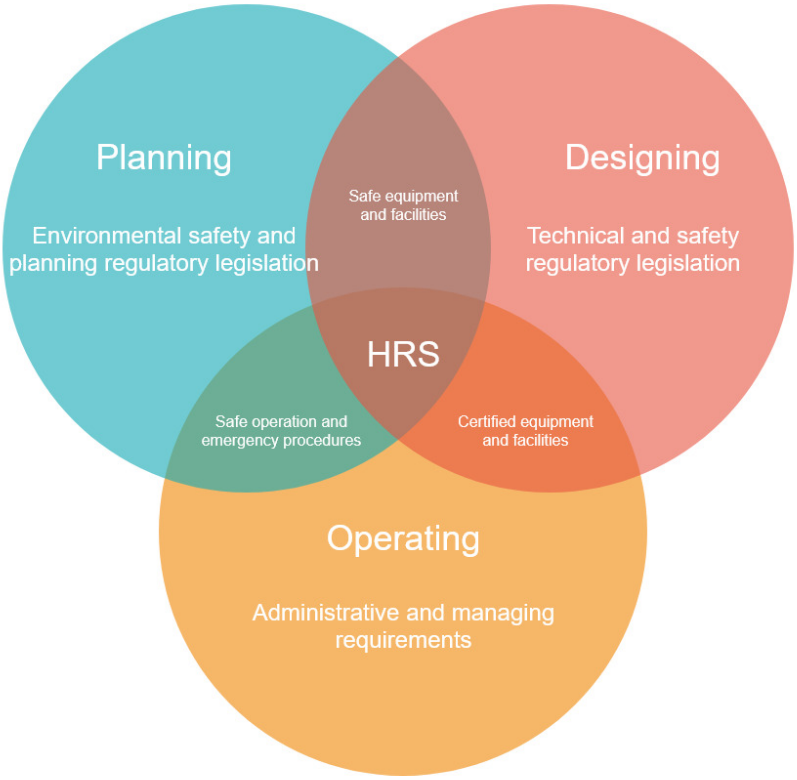


Figure 19 Diagram of legislative framework

Particular requirements for hydrogen refuelling stations are laid down in EU Directive 2014/94/ES on the introduction of alternative fuel infrastructure. It lays down minimum requirements for the construction of hydrogen refilling points as well as technical specifications for such hydrogen refilling points. Annex II sets out the technical specification for the filling points, where the following standards are mentioned, their scope are described in tables.

Many other specifications may be used if the equipment is covered by one of the product harmonized directives listed above. These Directives lays down the essential requirements for the product, while the harmonized standards provide indications how to satisfy the essential requirements of the Directive and verification methods as well.

Document	**EN 17127 Outdoor hydrogen refuelling points dispensing gaseous hydrogen and incorporating filling protocols**

Scope

Standard defines the minimum requirements to ensure the interoperability of public hydrogen refuelling points including refuelling protocols that dispense gaseous hydrogen to road vehicles (e.g. Fuel Cell Electric Vehicles) comply with applicable regulations.

The safety and performance requirements for the entire hydrogen refuelling station (HRS), addressed in accordance with existing relevant European and national legislation, are not included in this document.

References & guidelines

The standard describes the general requirements for filling points, fuel quality, control of dispensing equipment for critical parameters of the filling process and general safety requirements for the filling point. According to the standard, public filling stations must ensure the filling of vehicles of categories M and N that comply with the requirements of Regulation 79/2009 or UNECE R134.

During the fulling process dispenser shall meet following protocol limits:

- Ambient temperature between -40C and +50 C;
- Pressure less than maximum operating pressure;
- Gas temperature greater than -40C;
- Fuel flow rate less 60 g/s for light duty vehicles and 120 g/s for trucks and buses;
- When communication is used, the CHSS temperature not exceeding 85 C.
- Dispenser terminate refuelling within 5 sec when:
  - Through communication receiving an abort or halt signal from vehicle;
  - Any deviations from fuelling protocol.
- Able to determine the start pressure prior to the start of refuelling. Dispenser shall not start fuelling the vehicle which pressure are lower 0,5 MPa or greater than the appropriate vehicle NWP.

As well standard lays down inspection before commissioning, periodical inspection and minimum SAT to ensure interoperability consist of:

- Ambient, fuelling pressure and temperature sensor calibration;
- Compressed Hydrogen Storing System (on vehicle) starting pressure;
- Communications break;

- Communications abort signal;
- Non-communication refuelling validation for each pressure level;
- Communication refuelling validation;

Standard for communication protocols recommends to use SAE J2799 standard or protocols that have been approved by manufacturer of vehicle.

Document	EN ISO 17268 Gaseous hydrogen land vehicle refuelling connection devices
Scope	
Standard applies to design, safety and operation characteristics of gaseous hydrogen land vehicles refuelling connectors. GHLV refuelling connectors consist of the following components, as applicable: • receptacle and protective cap (mounted on vehicle); • nozzle; • communication hardware. This document is applicable to refuelling connectors which have nominal working pressures or hydrogen service levels up to 70 MPa.	
Notes & references	
Standard lays down construction requirements for nozzles and receptacles, connector pressure ratings, define nozzle types, design verification test procedures and marking requirements. For the communication hardware Infrared data association are used and design shall meet SAE J2799. The standard provides that to ensure filling within certain limits hydrogen dispenser shall either: • use communication protocol such as SAE J2601 or • use that have been approved by the manufacturer of each vehicle to fuel at that station using that protocol. The HRS operator shall take measures to prevent to refuelling of vehicles where protocols not approved by the manufacturer of the vehicles using that refuelling point. Fuelling protocol shall ensure if the communication fail during fuelling, the station shall either terminate fuelling within 5sec or the fuelling may continue without communication if allowed by the fuelling protocol.	

Document	**EN 17124 Hydrogen fuel - Product specification and quality assurance - Proton exchange membrane (PEM) fuel cell applications for road vehicles.**
Scope	
This document specifies the quality characteristics of hydrogen fuel and the corresponding quality assurance in order to ensure uniformity of the hydrogen product as dispensed for utilization in proton exchange membrane (PEM) fuel cell road vehicle systems. Its sets out quality control measures such as sampling and monitoring.	
Notes & references	
Standard describes hydrogen quality criteria for the use of PEM and hydrogen quality control activities such as sampling, monitoring, identification of sources of impurities and a risk approach and a prescription approach to hydrogen quality assurance. The HRS must provide activities of preventing oil, graphite entry or any other impurity into the gas stream in the event of any process equipment defect or malfunction. In the standard annexes includes a description of the effects of specific impurities and an example for determining the origin of potential sources of impurities in the supply chain.	

Standards, codes of practice and guidelines

As the standards referred in EU Directive 2014/94/EU don't cover all aspects of hydrogen application, so following documents can be used to other hydrogen operational phases.

In this sub-chapter are listed those standards, codes of practice and industry guidelines which may be used as recommendations additionally to above mentioned directly applicable standards. The specifications considered below are developed by following bodies. SAE International are international association of engineers that are recognized for their role in helping ensure the safety, quality, and effectiveness of products and services across the mobility engineering industry. In this report SAE developed standards cover the safety aspects of fuelling of vehicles and its fuelling protocols and communication protocols.

The European Industrial Gases Association (EIGA) is Non-Profit on a safety and technically oriented organisation representing the vast majority of European and a number of non-European companies producing and distributing industrial, medical and food gases. The EIGA recommendations for hydrogen pipeline systems and filling stations, considering the properties of hydrogen. This document can be used as a general guide in addition to, but does not replace, published standards and existing regulations.

The PGS are Netherlands government supported expert team which draw up publications Series provides guidance for companies who produce, transport, store or use hazardous substances and for authorities responsible for granting license's and monitoring these companies. The content of the publications is determined in mutual consultation between the business community and the authorities involved.

General standards

Document	Standard ISO 19880-1 "Gaseous Hydrogen Fueling Station – General. Requirements, standard for gaseous hydrogen service stations"

Scope

Standard defines a general requirement and defines the minimum design, installation, commissioning, operation, inspection and maintenance requirements, for the safety, and, where appropriate, for the performance of public and non-public fuelling stations.

The standard set out the minimum requirement for fuelling stations, manufacturers can take additional safety precautions as determined by risk management methodology to address potential safety risks of specific design and application.

This document is targeted for the fuelling of light duty hydrogen road vehicles, requirements and guidance for fuelling medium and heavy-duty road vehicles (e.g. buses, trucks) are also covered.

It provides requirements for and guidance on on following elements of fuelling station:

- hydrogen production/delivery system;
- compression;
- gaseous hydrogen buffer storage;
- pre-cooling devices;
- gaseous hydrogen dispensing systems.

Notes & references

This standard widely used at global level that recommends the minimum design characteristics for safety and where appropriate, for performance of public and non-public fuelling stations that dispense gaseous hydrogen to light duty land vehicles.

This document places great emphasis on a risk management approach to the installation of HRS stations and what aspects and sources of hazard should be taken into account in the risk assessment, covering not only hydrogen activities but also risks not directly related to hydrogen hazards. It refers to risk assessment methods and technics described in ISO 31000 IEC 31010 and ISO 12100 standards. According to risk assessment methodology, it is determined what risk mitigation measures should be taken to improve the safety and security system. The ISO 19880-1 standard also covered general principles of safety distance requirements and other protection measures related to HRS operation based on risk assessment.

The standard includes general recommendations on equipment, components and system, as well as considerations to be taken into account in their design. For on-site hydrogen production at the HRS should comply with ISO 16110-1 fuel processing technologies and ISO 22734 using water electrolysis. Due to the handling of flammable gas at the HRS, the requirements is lay down for the definition of hazardous areas, electrical safety and operational monitoring. For the functional safety requirements of technological process referred to the functional safety standards IEC 61508, IEC 61511, IEC 62061 and ISO 13849-1 and ISO 13849-2.

The standard specifies hydrogen quality requirements and tasks to be performed for quality control with reference to ISO 14687.

The standard clearly defines the scope of inspections required before commissioning, including references to the test method which must be done as Factory Acceptance Tests (FAT) or Site Acceptance Test (SAT) which are:

- pressure test for pressure equipment;
- leak test, electrical testing;
- fueling safety and performance functional testing;
- hydrogen quality tests.

Document	**EIGA document IGC 15/06 Gaseous hydrogen stations**
Scope	
This Code of Practice has been prepared for the guidance of designers and operators of gaseous hydrogen stations. It is considered that it reflects the best practices currently available. Its application will achieve the primary objective of improving the safety of gaseous hydrogen station operation. The Code covers gaseous hydrogen, compression, purification, filling into containers and storage installations at consumer sites. It does not include production, transport or distribution of hydrogen.	

Document	**PGS35 Hydrogen: Installations for delivery of hydrogen to road vehicles**
Scope	
This PGS applies to hydrogen delivery installations on land, including the associated and/or necessary auxiliary equipment, with a maximum delivery pressure of 350 bar or 700 bar of hydrogen gaseous for road vehicles with European type approval. This document does not apply to: • local production of hydrogen; • the delivery of liquid hydrogen as a fuel to road vehicles; • the delivery of hydrogen to ships; • delivery to separate refillable cylinders or intermediate storage.	
Notes & references	

The majority of the requirements or regulations that apply to the use of hazardous substances are laid down in legislation. These requirements may be based on European Directives or follow directly from European regulations. The PGS publications aim to give as complete a description as possible of the way in which companies can comply with the requirements arising from legislation and regulations.

Standards for hydrogen production

Document	**Standard ISO 16110-1:2007 Hydrogen Generators Using Fuel Processing Technologies – Safety.**
Scope	
This standard applies to packaged, self-contained or factory matched hydrogen generation systems with a capacity less than 400 Nm3/hr (normal cubic meters per hour) and 101,325 kPa (1,01 Bar) that convert a fuel to a hydrogen rich stream of composition and condition suitable for the type of device using hydrogen (e.g. a fuel cell power system or a hydrogen compression, storage and delivery system). It applies to hydrogen generators using a input fuels as natural gas and other methane-rich gases derived from renewable (biomass) or fossil fuel sources. It is applicable to stationary hydrogen generators intended for indoor and outdoor commercial, industrial, light industrial and residential use.	
Notes & references	
In this standard are listed and dealt with significant hazards and hazardous situations which can occur from hydrogen generators. This standard is a product safety standard suitable for conformity assessment procedures.	

Document	**Standard ISO 22734-1:2008 Hydrogen generators using water electrolysis process. Industrial and commercial applications.**
Scope	
Standard defines the construction, safety and performance requirements of packaged or factory matched hydrogen gas generation appliances, herein referred to as hydrogen generators, using electrochemical reactions to electrolyze water to produce hydrogen and oxygen gas. This International Standard is applicable to hydrogen generators that use the following types of ion transport medium: • – Group of aqueous bases; • – Solid polymeric materials with acidic function group additions such as acid proton exchange membrane (PEM).	

Notes & references
The authors of the document precaution that this document is not a complete design guide and does not deny the need for competent engineering judgment and interpretation. It is recommended that the designer shall review any specific problems based on risk assessment and related legislation.

Requirements for hydrogen storage and piping

In general, vessels and assemblies with a maximum allowable pressure of more than 0.5 bar are covered by the Pressure Equipment Directive 2014/68/EU (PED) setting out the requirements for the design, manufacture and conformity assessment of pressure equipment. And as hydrogen is a highly flammable gas, there are binding specific regulations on equipment and protective systems intended for use in potentially explosive atmospheres. ATEX Directive (2014/34/EU) for that reason are applicable. The harmonized standards published in the European Official Journal are available for both directives. Their list is available on the website of the European Commission.

The following document can be used as an supplement guideline for the construction of hydrogen pipelines, but it does not replace the requirements of current regulations.

Document	**EIGA document IGC 121/14 Hydrogen pipeline systems**
Scope	
The scope of this document is for metallic transmission and distribution piping systems carrying pure hydrogen and hydrogen mixtures. It is limited to gaseous products: • with a temperature range between –40°C (-40°F) and 175°C (347°F); • total pressures from 1MPa (150 psig) up to 21 MPa (3000 psig) or for stainless steels only partial H2 pressure higher than 0,2 MPa; • concentration criteria defined in Appendix G. This document does not apply to the following processes: • cylinder filling plants; • producing plants; • compressor units; • Bulk facilities (liquid or high pressure gas) at the customer's site up to the point where gas enters the distribution systems; • Piping on specialized equipment and machines. The purpose of this publication is to further the understanding of those engaged in the safe design operation and maintenance of transmission and distribution systems. It is not intended to be a mandatory standard or code. It contains a summary of the current industrial practices. It	

is based upon the combined knowledge, experience, and practices of the major producers in Europe and North America as represented by their members on the IHC Ad-Hoc group on pipeline transportation systems.
Notes & references
The authors of the document precaution that this document is not a complete design guide and does not deny the need for competent engineering judgment and interpretation. It is recommended that the designer shall review any specific problems based on risk assessment and related legislation.

Standards for hydrogen refuelling

The standard EN 17127 is set out general requirements for fuelling protocols with reference on following SAE international standards which specify fuelling protocol and communication protocol requirements between vehicle and dispenser.

Document	**Standard SAE J2601 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles**
Scope	
Standard establishes the protocol and process limits for hydrogen fuelling of vehicles with total volume capacities greater than or equal to 49.7 L. These process limits (including the fuel delivery temperature, the maximum fuel flow rate, the rate of pressure increase, and the ending pressure) are affected by factors such as ambient temperature, fuel delivery temperature, and initial pressure in the vehicle's compressed hydrogen storage system. SAE J2601 establishes standard fuelling protocols based on either a look-up table approach utilizing a fixed pressure ramp rate, or a formula-based approach utilizing a dynamic pressure ramp rate continuously calculated throughout the fill. Both protocols allow for fuelling with communications or without communications. The table-based protocol provides a fixed end-of-fill pressure target, whereas the formula-based protocol calculates the end-of-fill pressure target continuously.	
Notes & references	
An important factor in the performance of hydrogen fuelling is the station's dispensing equipment cooling capability and the resultant fuel delivery temperature. There are three fuel delivery temperature categories denoted by a "T" rating: T40, T30, and T20, where T40 is the coldest. Under reference conditions, SAE J2601 has a performance target of a fuelling time of 3 minutes and a state of charge (SOC) of 95 to 100% (with communications), which can be achieved with a T40-rated dispenser. However, with higher fuel delivery temperature dispenser ratings (T30 or T20) and/or at high ambient temperatures, fuelling times may be longer. SAE J2601 includes protocols which are applicable for two pressure classes (35 MPa and 70 MPa), three fuel delivery temperatures categories (-40 °C, -30 °C, -20 °C) and compressed hydrogen storage system sizes (total volume classification) from 49.7 to 248.6 L (35 MPa ➔ H35, and 70 MPa ➔ H70), and from 248.6 L and above (H70 only) For fuelling with communications, this standard is to be used in conjunction with SAE J2799.	

Document	Standard SAE J2601/2 Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles
Scope	
The purpose of this document is to provide performance requirements for hydrogen dispensing systems used for fuelling 35 MPa heavy duty hydrogen transit buses and vehicles (other pressures are optional). This document establishes the boundary conditions for safe heavy-duty hydrogen surface vehicle fuelling, such as safety limits and performance requirements for gaseous hydrogen fuel dispensers used to fuel hydrogen transit buses. For fuelling light-duty vehicles SAE J2601 should be used. SAE J2601-2 is a performance-based protocol document that also provides guidance to fuelling system builders, manufacturers of gaseous hydrogen powered heavy duty transit buses, and operators of the hydrogen powered vehicle fleet(s).	
Notes & references	
This fuelling protocol is suitable for heavy duty vehicles with a combined vehicle CHSS capacity larger than 10 kilograms aiming to support all practical capacities of transit buses. It is non-prescriptive in how to achieve a full fill or 100% state of charge (SOC) in the vehicle tank storage system. For fuelling with communications, this standard is to be used in conjunction with SAE J2799.	

Document	Standard SAE J2799 Hydrogen Surface Vehicle to Station Communications Hardware and Software
Scope	
This standard specifies the communications hardware and software requirements for fuelling hydrogen surface vehicles (HSV), such as fuel cell vehicles, but may also be used where appropriate, with heavy-duty vehicles (e.g., busses) and industrial trucks (e.g., forklifts) with compressed hydrogen storage. It contains a description of the communications hardware and communications protocol that may be used to refuel the HSV. The intent of this standard is to enable harmonized development and implementation of the hydrogen fuelling interfaces.	
Notes & references	
This standard is intended to be used in conjunction with the hydrogen fuelling protocols in SAE J2601 and nozzles and receptacles conforming with SAE J2600.	

Standards for Hydrogen quality

The quality of hydrogen delivered at the HRS is critical to ensure the length of life of FCEV. As previously mentioned, there is a directly applicable standard EN 17124 for hydrogen quality referred in Directive 2014/94 /EU. However, the quality assurance requirements are also described in the above-mentioned ISO 19880-1 standard, which specifies the degree of hydrogen quality and hydrogen quality verification, as part of the station acceptance test and thereafter, as a continuous operation according to the quality assurance plan as defined in ISO 19880-8 standard.

Document	Standard ISO 19880-8:2019 Gaseous hydrogen — Fuelling stations — Part 8: Fuel quality control
Scope	
This document specifies the protocol for ensuring the quality of the gaseous hydrogen at hydrogen distribution facilities and hydrogen fuelling stations for proton exchange membrane (PEM) fuel cells for road vehicles.	
Notes & references	
Standard describes hydrogen quality criteria for the use of PEM and hydrogen quality control activities such as sampling, monitoring, identification of sources of impurities and a risk approach and a prescription approach to hydrogen quality assurance. The standard annexes include a description of the impact of specific impurities on powertrains, example for risk assessment, example of Japanese hydrogen quality guidelines, example typical hydrogen supply chain and routine hydrogen quality analysis.	

Requirements for hydrogen supply using road vehicles.

Gaseous hydrogen can be delivered to the HRS by compressed gas cylinders, tube trailers or multiple element gas containers using land transport. When hydrogen is transported within or between Member States the Directive 2008/68/EC of the European Parliament and of the Council of 24 September 2008 on the inland transport of dangerous goods shall apply. Directive refers to the international rules for the transport of hazardous substances, which come from the ADR convention. ADR Directive lay down uniform rules for the safe international transport of dangerous goods, including the activities of loading and unloading, the transfer to or from another mode of transport and the stops necessitated by the circumstances of the transport.

In addition to the above, Directive 2010/35/EU on transportable pressure equipment lays down rules which affect the particularities of hydrogen transportation, as they refer to the assessment of transportable cylinders, tubes, vessels and tanks for transporting gases.

An important stage in the supply of hydrogen is its safe unloading at HRS. Guidelines of safety precautions to be observed when unloading hydrogen at an HRS station and the requirements to be observed during the delivery process are described in Dutch Hazardous Substances Publication Series 35 (PGS35). It covers not only the delivery process, but also the broader requirements for the establishment and operation of HRS stations. Annex F of PFS 35 contains instructions for unloading hydrogen in accordance with safety requirements. PGS 35 is neither a standard nor a Dutch law and can be used as a guide, if applicable.

In this chapter are listed those standards, codes of practice and industry guidelines which can be considered for use, but we recommend for each specific project and case to evaluate the framework of requirements individually. In addition to the specifications in this diagram, the requirements of EU harmonized legislation and harmonized standards related to other processes and risks should be considered, without prejudice to hydrogen technology.

Finally, the Figure 20 together shows the specifications described above to better understand their scope. Documents for several HRS activities or the display of general requirements are displayed next to the station name, while the standards applicable to a specific technological activity or process are displayed close to them.

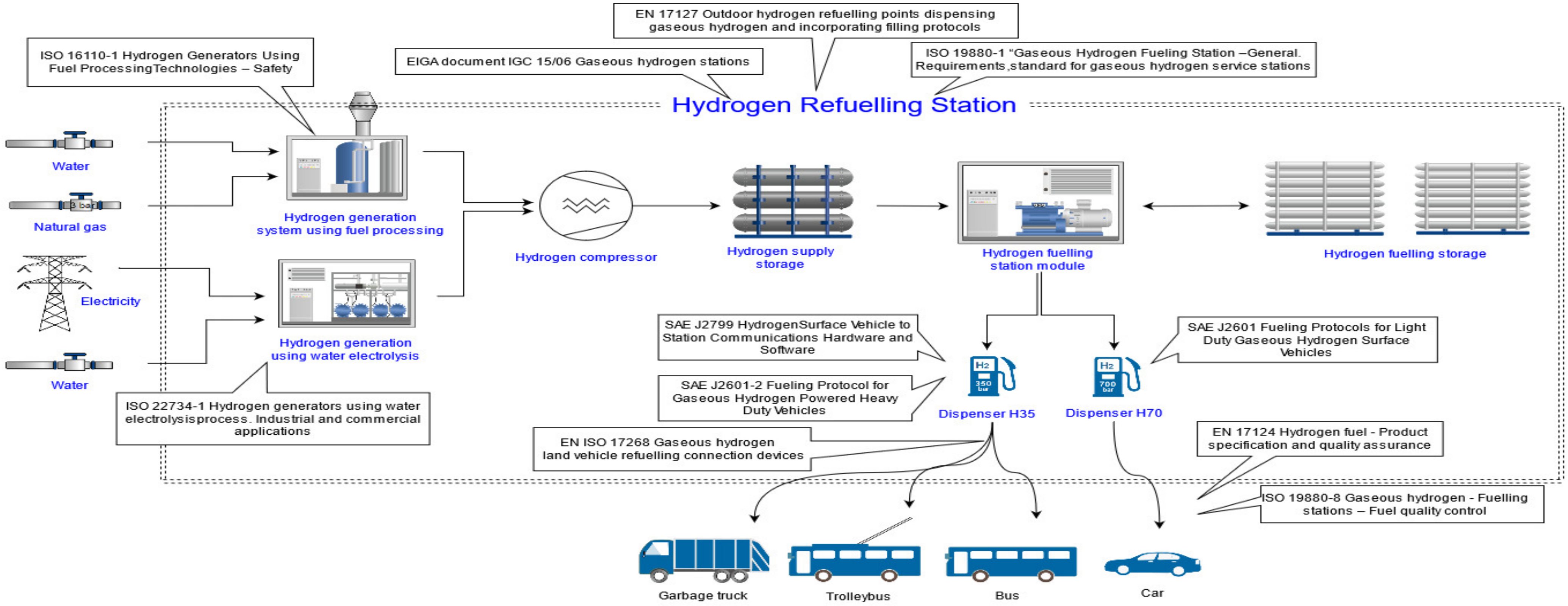


Figure 20 Standards for specific HRS equipment

HRS documentation:

It is the responsibility of the HRS station owner to provide and maintain appropriate documentation for the safe operation of the station.

The HRS owner must receive the following documentation form HRS equipment manufacturer and/or installer:

- The declaration of conformity and certificate, if applicable;
- User operational manual for equipment and/or installation with detailed description on operation, maintenance and safety precautions;
- Description of safeguards, interlocking functions and guards (with diagrams);
- Technical specification of each equipment and device;
- Assembly and layout drawings;
- Schematics and diagrams (electric circuit, piping and flow diagrams, emergency system, etc.);
- Setpoints for alarms;
- HAZOP or underlying risk assessment and ATEX area classification (Zones);
- FAT and SAT protocols from supplier tests;
- Technical documentation about installation.

The following documentation is required to start the operation of HRS:

- A permit for polluting activities issued by the State Environmental Service;
- Technical passport of dangerous equipment (for pressure equipment and complexes); which certifies that the equipment is registered in the Register of dangerous equipment and issued by an accredited inspection body;
- Fire safety inspection report.

The following operational documentation must be in place:

- Work safety instructions;
- Emergency response plan;
- HRS risk assessment;
- Environmental protection plan;
- Fire safety instructions;
- Identification of explosive areas in working environment;
- Identification and assessment of work environment risks;
- Occupational safety requirements during repair of electrical equipment;
- List of workplaces at the HRS;
- Hydrogen delivery procedure by MEGC/tube trailer;
- Hydrogen sampling procedure;
- Public instruction for use of the hydrogen dispenser;
- Hydrogen quality assurance plan.

The list of listed documents is indicative and its purpose is to indicate the type of documents required for the operation of the station. In practice, the purpose of these documents can be achieved through other types of documentation and other titles while maintaining the purpose.

Annex 3 Environmental and safety aspects, risk assessment methodology

When deciding on hydrogen fuelling station placement, the environmental impacts, including the risk of those stations have to be considered. Within this annex the overall legislative aspects of HRS deployment in Estonia is made. Additionally, the risk assessment methodology is explained.

Environmental impact assessment

Regards the need for Environmental Impact Assessment (EIA), there is no specific regulations about hydrogen production, storage or handling. EIA is mandatory when development potentially results in significant environmental impact. According to the law "Environmental Impact Assessment and Environmental Management System Act" [1], § 6 section (1) list of activities with significant environmental impact include pt. 11: manufacture on an industrial scale of substances using chemical conversion processes, in which several units are juxtaposed and are functionally linked to one another and which are for the production of basic organic chemicals, basic inorganic chemicals, phosphorous-, nitrogen- or potassium-based fertilizers (simple or compound fertilizers), plant protection products and biocidal products, basic pharmaceutical products using a chemical or biological process, or explosives. Hydrogen could probably be considered as "basic inorganic chemical".

The list also includes construction of an establishment that handles hazardous chemicals, provided that it is a category A enterprise with a major hazard under the Chemicals Act. The areas of activity in which a preliminary assessment of the necessity of an environmental impact assessment must be provided are specified in a regulation of the Government of the Republic[2]. This list includes also B-category enterprises with a major hazard. There is threshold set for hydrogen in the regulation established under the Chemicals Act. (Table 22)

Table 22. Hazard categories for hazardous chemicals and minimum and threshold levels for determining the hazard category of a hazardous plant. Extract from the Annex to the Regulation[3]

Hazardous chemical	**Minimum level for designation of hazardous establishment (tonnes)**		
	Dangerous establishment (C-category)	Category B enterprise with a major hazard	Category A enterprise with a major hazard
Hydrogen	0,5	5	50

[1] Keskkonnamõju hindamise ja keskkonnajuhtimissüsteemi seadus (RT I 2005, 15, 87)

[2] "Tegevusvaldkondade, mille korral tuleb anda keskkonnamõju hindamise vajalikkuse eelhinnang, täpsustatud loetelu" Regulation of the Government no 224 of 29.08.2005 (RT I 2005, 46, 383)

[3] "Kemikaali ohtlikkuse alammäär ja ohtliku kemikaali künniskoguse ning ettevõtte ohtlikkuse kategooria määramise kord" Regulation of the Ministry of Economy and Infrastructure no 10 of 02.02.2016 (RT I, 11.02.2016, 22)

Also according to § 6 section 2, where the proposed activity is not included among the activities specified in subsection 1, the decision-maker makes a preliminary estimate as to whether the activities of the following areas have significant environmental impact:

2) energy industry;

10) construction or use of infrastructure;

16) storage of hazardous chemicals, including fuel;

22) another activity which may result in significant environmental impact.

Handling of chemicals (Chemicals act[4])

Chemicals Act regulates the handling of chemicals and the restriction of economic activities relating to the handling of chemicals for the purpose of protecting human life and health, property and the environment, and ensuring the free movement of goods. Among other things it defines the obligations of dangerous enterprises and enterprises with major hazard including authorization. Chemical Act is available in official translated version in English[5].

Based on the hazardousness of the enterprise (see Table 22), the operator must draw up the following documents (subsection (2) of § 22 of the Chemicals act):

- a data sheet, risk analysis and emergency plan if the enterprise is a category C enterprise (dangerous enterprise);
- a data sheet, risk analysis, description of the safety management system and emergency plan if the enterprise is a category B enterprise with a major hazard;
- a data sheet, safety report and emergency plan if the enterprise is a category A enterprise with a major hazard. The safety report also contains a risk analysis and a description of the safety management system.

To test the emergency plan, the operator of an enterprise with a major hazard organises a training exercise at least once every three years. The Rescue Board[6] is informed of the training exercise at least 20 working days before the exercise. In the event of the permanent closure or decommissioning of a dangerous enterprise or enterprise with a major hazard, the operator of the enterprise will inform the Consumer Protection and Technical Regulatory Authority[7] at least five working days before the permanent closure or decommissioning of the enterprise.

The above mentioned mandatory documents must be kept up-to-date, revised and, where necessary, renewed in following frequency (subsection (1) of § 23 of the Chemicals act):

- at least once every five years, thereby the emergency plan of the enterprise must be renewed at least once every three years;
- when the contact details or other circumstances are changed, including the modification of the nature or physical form or quantity of a hazardous chemical as well as modification of

[4] Kemikaaliseadus (RT I, 10.11.2015,2)

[5] https://www.riigiteataja.ee/en/eli/ee/513042021005/consolide/current

[6] Päästeamet https://www.rescue.ee/

[7] Tarbijakaitse ja Tehnilise Järelevalve Amet https://ttja.ee/

an establishment or installation, which could have significant consequences for accident hazards or could result in a change of the hazardousness category of the enterprise;
- when new technological knowledge about safety matters arises, including knowledge from analysis of accidents or, as far as possible, 'near misses', and by developments in knowledge concerning the assessment of hazards; or
- following a major accident in an establishment.

The mandatory documents must be approved by the competent authority. The competent authority is:

- the Consumer Protection and Technical Regulatory Authority[8] in the event of a data sheet and safety management system;
- the Rescue Board[9] in the event of an emergency plan of an enterprise;
- the Consumer Protection and Technical Regulatory Authority in cooperation with the Rescue Board in the event of a risk analysis and safety report.

Exact requirements for the aforementioned mandatory documents can be found in a sub–Act No.18 (not available in English), that has been adopted on 01.03.2016. on the basis of the Chemicals act.[10]

In § 24 of the Chemical Act there are requirements for informing of public. The operator of an enterprise with a major hazard must preventively inform the public and the persons who may be located in the accident impact zone about the major-accident risk arising from the enterprise, safety precautions and advisable conduct in the event of an accident. At request, the operator of a dangerous enterprise will publish additional information, including a summary of the risk analysis. The summary of the risk analysis will also be submitted to the Consumer Protection and Technical Regulatory Authority[11].

The operator of an enterprise with a major hazard must have liability insurance for indemnifying non-contractual and unlawful damage that may be caused to a third party upon handling a chemical in the enterprise. Requirements for liability insurance are set in subsection (2) of §25 of Chemical Act:

- the insurance contract has been made with the insurer who has the right to insure an insurable risk located in Estonia;
- the insurance contract covers at least direct material damage and, in the event of damage to health, physical injury or the causing of death, also the loss of profit, unless otherwise provided by law;
- the insured event is an unexpected occurrence relating to the handling of a chemical that the operator is in charge of, which arises from the properties of the handled chemical and as a result of which the damage specified in subsection (2) of this section has been caused to the injured party.

In an establishment, a hazardous chemical may be handled in a quantity above the minimum level or the threshold level only on the basis of an operation authorisation. An authorisation is not

[8] Tarbijakaitse ja Tehnilise Järelevalve Amet https://ttja.ee/

[9] Päästeamet https://www.rescue.ee/

[10] Nõuded ohtliku ja suurõnnetuse ohuga ettevõtte kohustuslikele dokumentidele ja nende koostamisele ning avalikkusele edastatavale teabele ja õnnetusest teavitamisele (RT I, 02.03.2016,3)

[11] Tarbijakaitse ja Tehnilise Järelevalve Amet https://ttja.ee/

required if a hazardous chemical is handled on the basis of an integrated environmental permit issued under the Industrial Emissions Act[12] or on the basis of an authorisation granted under the Explosive Substances Act or the Weapons Act the proceedings of which also cover the requirements contained in the object of inspection of the operation authorisation in accordance with Chemicals Act. To obtain an operation authorisation, an application must be submitted to the Consumer Protection and Technical Regulatory Authority[13]. The mandatory documents mentioned above are annexed to the application.

Special requirements for planning land use and designing construction works

Upon planning land use and granting design specifications and building permits, circumstances arising from the establishment must be taken into account. Thereby:

- establishments with domino effects must be identified;
- buildings and facilities, such as highways, public places and residential areas located in the vicinity of the existing establishment must be taken into account if the location of the buildings and facilities may increase the risk of a major accident or the severity of the consequences of a major accident;
- for the purpose of ensuring safety, preserve the required distance between the establishment and residential districts, public buildings and areas, recreational areas and, where possible, between the main transport lines;
- protect areas in the vicinity of the establishment that are of special interest in terms of nature or that are especially sensitive, ensuring a safe distance to that end or by taking other relevant measures;
- where necessary, take additional measures in the existing establishment;
- in the event of an increase of the risk of a major accident or severity of the consequences thereof, ensure the notification of the public and persons who may be located in the impact zone of an accident arising from the establishment.

The comprehensive, special or detailed spatial plans and building design documentation must be submitted to the Rescue Board[14] for approval in the following events:

- upon selection of the location of a new establishment;
- upon expansion of the operations of an existing establishment or increasing production, provided that a plan needs to be initiated or amended or a building permit needs to be granted for such an activity;
- upon planning an area located in the danger zone of a dangerous enterprise and of an enterprise with a major hazard or upon planning construction works there.

[12] Tööstusheite seadus (RT I, 16.05.2013, 1)

[13] Tarbijakaitse ja Tehnilise Järelevalve Amet https://ttja.ee/

[14] Päästeamet https://www.rescue.ee/

Using gas installations (Equipment safety act[15])

The purpose of Equipment Safety Act is to ensure the safety of equipment and equipment-related processes. The act regulates the putting of equipment into service, the use of equipment, and equipment work. The Act is available in official translated version in English[16]

The requirements arising from the Act for the competence of a person and for proving it, for equipment work and for audits apply to the following equipment:

- pressure equipment with an inner operating pressure of over 0.5 bar or pressure equipment used for handling a dangerous chemical regardless of the inner operating pressure;
- gas equipment;
- a machine used for lifting a human, animal or property (lifting equipment), including amusement park equipment;
- electrical equipment.

According to §5 of the Equipment Safety act the equipment can be put into service where:

- it complies with the requirements, is in a good mechanical condition and safe for using for the designated purpose and in the designated manner, including equipped with control and safety devices that are reliable and operational;
- it is installed at the place of use and configured in such a manner that the threat originating from the equipment is minimal and the use, maintenance and inspection of the equipment is not impeded;
- in a prescribed event an audit has been carried out and, according to the auditor's opinion, the equipment is in a mechanically good condition and it is safe to use the equipment for the designated purpose and in the designated manner.

The equipment is deemed as put into service as of the moment when the use of the equipment is commenced for the designated purpose and in the designated manner (§5 section 2). Specified requirements for gas installations equipment are established by a regulation established on the bases of the Act[17] ("Requirements for Gas Installations Using Heating Gas, Their Construction and Installation of Gas Appliances, and Storage of a Gas Cylinder and Filling of a Gas Tank", English version is not available.). The requirements apply to all gas equipment. According to the Chemicals Act gas is all types of chemicals, which have an absolute steam pressure at 20C degrees of at least 101,3 kPa.

Gas installations are divided into categories according to their work pressure:

- A-category – gas installations with work pressure up to 0,1 bar (including);
- B- category – gas installations with work pressure over 0,1 bar up to 5 bar (including);
- C- category – gas installations with work pressure over 5 bar up to 16 bar (including);
- D- category – gas installations with work pressure over 16 bar.

[15] Seadme ohutuse seadus (RT I, 28.03.2015,4)

[16] https://www.riigiteataja.ee/en/eli/ee/505062015001/consolide/current

[17] Küttegaasi kasutavale gaasipaigaldisele, selle ehitamisele ja gaasiseadme paigaldamisele ning gaasiballooni ladustamisele ja gaasianuma täitmisele esitatavad nõuded (RT I, 07.07.2015,32)

According to the sub-Act[18] the gas equipment must be marked according to the requirements (§10 of the regulation):

- Piping in gas terminal must be marked with yellow colour.
- gas storage site must be marked with at least one safety sign, with white background, red edge and letters with the height of at least 5 cm with words "VEDELGAAS" (liquid gas).
- also additional sign for fire hazard must me added.

The distance of storage tanks from other objects is regulated in §16 and §17 of the sub-act [19] as seen in Table 23 and Table 24.

Table 23. Aboveground storage tanks

Object	Max amount of gas in tank	
	up to 5t	**>5t but <50t**
Residential single house	3m	35m
Neighbouring objects (land area, street, other neighbouring buildings)	5m	10m
Paired house, traffic junction	15m	50m
Apartment building, school, hotel, mall, restaurant/catering establishment, cinema, market	50m	100m
health- or care institution (hospital, nursing home, sanatorium)	300m	300m

Table 24. Underground storage tanks

Object	Max amount of gas in tank		
	up to 5t	**>5t but <50t**	**50t, >50t but <200t**
Residential single house	2m	5m	not allowed
Neighbouring objects (land area, street, other neighbouring general buildings)	3m	5m	10m
Paired house, traffic junction	10m	15m	30m

[18] Küttegaasi kasutavale gaasipaigaldisele, selle ehitamisele ja gaasiseadme paigaldamisele ning gaasiballooni ladustamisele ja gaasianuma täitmisele esitatavad nõuded (RT I, 07.07.2015,32)

[19] Küttegaasi kasutavale gaasipaigaldisele, selle ehitamisele ja gaasiseadme paigaldamisele ning gaasiballooni ladustamisele ja gaasianuma täitmisele esitatavad nõuded (RT I, 07.07.2015,32)

Apartment building, school, hotel, mall, restaurant/catering establishment, cinema, market	20m	30m	50m
health- or care institution (hospital, nursing home, sanatorium)	50m	100m	100m

Distance of Storage tanks from other storage tanks:

- if the storage tanks are not one installation - at least 1m from each other.
- aboveground tanks, from oxygen and burning liquid tanks- at least 10m, if the burning liquid tank is surrounded by protective wall - 5m.

3m area around and under the storage tank must be built, so no gas can collect/concentrate into holes in the ground. 1,5m around the tank, all vegetation and fire hazard object must be removed. In order to ensure fire safety the storage tanks capacity >7,5t, must be isolated in case of fire, that remains isolated for 90min or equipped with liquid fire extinguishing system (at least 10L/m^2/minute for minimum of 90min).

Audit requirements

An audit must be carried out upon putting into service of the equipment corresponding to the Act or more detailed criteria listed in sub-act[20] (Equipment and requirements for the audit and presentation of audit results) of the Equipment Safety Act as well as after a certain period of time upon using the equipment and in other events provided by law. 'Audit' means technical inspection aimed at identifying the good mechanical condition of the equipment and the safety of use for the designated purpose and manner as well as possible substantial deficiencies. The audit body must be independent, competent and ensure the unanimity and reliability of the audit.

In legislation established on the basis of the Equipment Safety Act, it may be provided that audit steps may be replaced with self-inspection when following requirements are met:

- Self-inspection must ensure a result equal to that of an audit and cover steps required for the maintenance of the equipment.
- Self-inspection steps must be included in a relevant management system that has been certified by an accredited management system certification authority and be indicated in the management system certificate.
- Installations with audit obligation, but where self-inspection is carried out must be reported to the Consumer Protection and Technical Regulatory Authority.21

The Sub-Act [22] **"**Equipment and requirements for the audit and presentation of audit results" (not available in English) defines the equipment subject to the audit obligation, sets out the requirements for its audit, including audit methods and self-monitoring, sets out the requirements for pre-commissioning, periodic and extraordinary audits and the presentation of audit results.

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[20] Auditi kohustusega seadmed ja nõuded auditile ning auditi tulemuste esitamisele (RT I, 18.07.2015,2)

[21] Tarbijakaitse ja Tehnilise Järelevalve Amet https://ttja.ee/

[22] Auditi kohustusega seadmed ja nõuded auditile ning auditi tulemuste esitamisele (RT I, 18.07.2015,2)

§ 6. Pressurized devices with inspection (audit) obligation:

(1) A device having an inspection obligation (audit) is a pressure device whose technical parameters meet or exceed the following parameters:

- *a vessel with a safe gas or hot water (over 110 ºC) having a work pressure (in bar) and a volume (in litres) of more than 10 000;*
- *a container containing dangerous gas or liquid, in which the product (in bar) and volume (in litres) is more than 500;*
- *safe gas pipelines with a maximum working pressure (in bars) and a nominal cross-sectional area (in square meters) of more than 106;*
- *dangerous gas pipelines with a maximum value of 104 in the maximum working pressure (in bars) and a nominal section (in square meters) and a dangerous liquid pipeline with an inside diameter of 150 millimetres;*

Gas installation is a device with audit obligation.

The frequency of mandatory audit is set in chapter 3 of the regulation[23]. Audit is mandatory before first use. Regular audit frequency:

- A-category gas installation, that is over 15 years old and in public building- after 4 years.
- A-category gas installation, that has a connected usage device of more than 120Kw and the sum of all connected devices of more than 300KW- after 4 years.
- B, C, D gas installations- after 2 years.

Noise assessment

The operation of hydrogen devices produces noise. The main sources of noise during the hydrogen production process are various compressors and cooling systems, including ventilators.

Environmental noise in Estonia, is regulated mainly by the following acts:

- Atmospheric Air Protection act (RT I, 05.07.2016,1)
- 16. dec 2016 act nr 71 of the minister of the environment “Välisõhus leviva müra normtasemed ja mürataseme mõõtmise, määramise ja hindamise meetodid“ (RT I, 21.12.2016, 27

The 2016 act No. 71 regulates normative levels for noise. The regulations are based on the time period, noise source type, noise characteristics and the categories of the land areas. The possessor of a noise source shall ensure that the noise from the territory of the noise source of the possessor does not exceed the normative level. If there is a possibility of this exceedance or it is required by competent local authorities (local municipality, Estonian Health Board etc), to comply with these normative levels, it is necessary to perform a detailed environmental noise assessment when designing new objects. In case it is found that the planned object would result in noise level limit value exceedances or worsen already existing ones, it is necessary to plan for noise mitigation measures based on calculations.

[23] Auditi kohustusega seadmed ja nõuded auditile ning auditi tulemuste esitamisele (RT I, 18.07.2015,2)

Noise indicator is the physical scale to describe the environmental noise with negative impact. Noise indicators are separated as day and night time indicators.

- Day time noise indicator Ld is the A-weighted long-term average sound level (dB (A) for all the days of the year, that indicates the disturbing noise effect for the whole day time of 07.00-23.00
- Whole day time noise level is calculated with the formula:

$$L_d = 10 \lg\left[\frac{1}{16}\left(12 \cdot 10^{0,1L_{r,T1}} + 4 \cdot 10^{0,1\left(L_{r,T2}+5\right)}\right)\right],$$

- Where $L_{r,T1}$ is the assessed noise level during day time (7.00-19.00) and $L_{r,T2}$ is the assessed noise level for evening (19.00-23.00). From the formula, its visible that from the whole day time (07-23), a correction of 5 dB is added for evening period, to take into account the bigger impact of noise during resting hours for people.
- Night time indicator Ln is the A-weighted long-term average sound level (dB (A) for all the nights of the year, that indicates the disturbing noise effect for night time of 23.00-07.00

The normative levels are the highest allowed noise indicator numerical levels, that are dependant on the type of noise source (road traffic, industrial sources) and the characteristics of the impacted land area. The hydrogen devices can be taken into account as industrial sources. The function of use of land areas is determined in accordance with building zoning and primary use stipulated in the local municipality general plans. It should be noted that the noise limit values have to be met not only near the residential buildings but for the whole territory of the residential area (property).

The noise limit values are dependant on the land area type, the noise is impacting. According to the local municipality effected, the land areas are divided according to the general plans accordingly:

- Category 1- land areas for recreational activities or planned quiet areas;
- Category 2- educational-, healthcare- and social welfare establishments; residential areas and green areas
- Category 3- city center area;
- Category 4- public establishment area;
- Category 5- industrial areas;
- Category 6- road traffic areas.

The limit values for categories 1-4 for industrial noise is in the following table (Table 25). For categories 5 and 6, limit values from other noise sources according to environmental noise acts do not apply.

Table 25 The noise limit values applied in Estonia (industrial noise)

Land use category	Noise limit values	
	L_{day} (dB(A))	L_{night} (dB(A))
1	55	40
2	60	45
3 and 4	65	50

Noise assessment, compliance with the spatial plan and other assessments shall be performed at the actual technical solution and at the actual location.

Characterization of potential hazards and risks of HRS

There are several factors that indicate that the production and use of hydrogen is associated with hazards:

- Hydrogen is a flammable gas;
- Operations are performed at elevated pressures.

Hydrogen filling stations may be located in the neighbourhood of other objects or populated areas, therefore, accidents in them may endanger the safety of adjacent areas. This is the reason in the process of planning such objects include identification of their hazards and assessment of the risks.

Risk identification and assessment can be performed for two purposes, which are also interdependent:

- For determining and increasing the level of safety of hydrogen technologies;
- For spatial planning and determination of safety distances.

For initial identification and prioritization of risk reduction measures it is recommended to start with qualitative or a semi-quantitative risk assessment method, such as Risk matrix, Fault tree (FTA), the Event tree (ETA), the hazard and operability study (HAZOP), "What-If" analysis, layers of protection analysis (LOPA), etc. We recommend that this process be performed by equipment designers to ensure appropriate selection and compatibility of equipment and safety equipment.

Although typically the hydrogen refuelling stations are equipped with modern safety systems to determine safety distances, especially to various sensitive objects or areas, they should also be considered. This is considered to be an important aspect in the context of spatial planning and the location of hazardous objects. There are multiple methods and assumptions for establishing safety distances that are based on:

- standards and industry guidelines;
- accident consequence modelling results;
- risk assessment results.

For example, recommendations for fire safety, work safety, and environmental safety regarding hydrogen fuelling stations have been published in Dutch good practice guidelines NPR 8099:2010 "Hydrogen fuelling stations - a guide for safe application of installations for delivery of hydrogen to vehicles and boats with respect to fire, workplace, and environment". Typical risk zones around technological objects in hydrogen fuelling stations according to these recommendations are compiled in Table 26. The table shows the radius of risk zones around respective technological objects with the individual risk level of 1×10^{-6}/year.

Table 26. Recommendations for estimating risk zones for hydrogen refuelling stations

Equipment	Object operational parameters	Outer safety distance, based on individual risk of 10^{-6}/ year [m]
H_2 container	Small fuelling stations, storage up to 25 kg (350 bar)	10
	Medium fuelling stations, storage from 25 to 100 kg (350 bar)	11

	Medium fuelling stations, storage up to 100 kg (700 bar)	15
	Large fuelling stations, storage from 100 to 500 kg (350 bar)	13,5
H_2 pipeline	Pressure in pipeline 350 bar	4,5
	Pressure in pipeline 700 bar	5,5
H_2 dispenser	Small fuelling stations, storage up to 25 kg (350 bar)	5
	Medium fuelling stations, storage from 25 to 100 kg (350 bar)	6,5
	Medium fuelling stations, storage up to 100 kg (700 bar)	8,5
	Large fuelling stations, storage from 100 to 500 kg (350 bar)	11

The European industrial gases association also has provided recommendations for safety distances between hydrogen fuelling stations and objects nearby[24] (see Table 27).

Table 27. Minimum recommended horizontal safety-distances for hydrogen stations

Typical type of outdoor exposure	Distance of hydrogen from
Open flames and other ignition sources (incl. electrical)	5
Site boundary and areas where people are likely to congregate such as car parks, canteens, etc.	8
Wooden building or structure	8
Wall opening in offices, workshops, etc.	5
Bulk flammable liquids and LPG storage above ground in accordance with NATIONAL CODES, where they exist, for the particular substance. Otherwise	8
Bulk flammable liquid and LPG below ground 6.1 Tank (horizontal distance from shell) 6.2 Vent or connections	 3 5
Flammable gas cylinder storage, other than hydrogen	5
Gaseous oxygen storage (cylinders)	5

[24] GASEOUS HYDROGEN STATIONS, IGC Doc 15/06/E, Revision of Doc 15/96 and Doc 15/05, EUROPEAN INDUSTRIAL GASES ASSOCIATION AISBL, 2006

Liquid oxygen storage (not greater than 125 000L tank capacity) (* *)	8 (*)
Non flammable cryogenic liquid storage, other than oxygen, e.g. argon, nitrogen (*)	5 (*)
Stocks of combustible material, e.g. timber	8
Air compressor, ventilator intakes, etc.	

(*) Where satisfactory arrangements are made to divert liquid spillage away from the hydrogen system, these distances may be reduced.

(**) For tank capacities greater than 125 000 litres see IGC Document 3/75

The aforementioned recommendations provide sufficient information to make an initial assessment of the situation and to decide on the probable location of the facilities. However, in order to perform a more accurate and comprehensive analysis of the situation, we offer to perform a quantitative risk assessment, which would include the assessment of the consequences of potential accidents, the determination of probabilities of accidents, as well as the modelling of individual risks. The risk assessment of hydrogen refuelling station included in this report is based on principles of the Dutch Guidelines for Quantitative Risk Assessment[25]. The typical accident scenarios and probabilities given in these guidelines have been used. Within this initial characterization of the risk situations, only accident scenarios that are typical for this technology and have the greatest impact on the level of risk, have been included.

The following installation or equipment have been identified as main potential sources of risk for hydrogen refuelling station:

- Hydrogen storage;
- Dispenser.

Defects are also possible in other technological equipment – electrolizer, compressors, internal pipelines their connections, vales, etc. However, the consequences potential for such equipment accidents is lower than in those technological elements indicated above. For the initial assessment, only the most important technological objects were considered, the accidents of which could potentially endanger people outside the object territory.

Based on Dutch Guidelines for Quantitative Risk Assessment, the follows Loss of Containment (LOCs) events are included in QRA for hydrogen refuelling station:

For storage tanks (tanks with volume > 150 litters):

- Instantaneous release of the complete inventory
- Continuous release of the complete inventory in 10 min at a constant rate of release
- Continuous release from a hole with an effective diameter of 10 mm

Given that the discharge time of one cylinder from a 10 mm rupture will be less than 10 minutes, a separate 10 - minute discharge scenario has not been included in risk assessments of this report.

For gas cylinders (cylinders with volume < 150 litters) the follows scenarios should be included:

- Instantaneous release of the entire contents of the gas cylinder;
- Continuous release from a hole with an effective diameter of 3,3 mm.

[25] "Guidelines for quantitative risk assessment", "Purple Book" CPR 18E, Committee for the Prevention of Disasters, Hague 1999

For loading activities in an establishment (dispensers):

- Full bore rupture of the loading hose - The outflow is from both sides of the full bore rupture;
- Leak of the loading hose - The outflow is from a leak with an effective diameter of 10% of the nominal diameter, with a maximum of 50 mm.

When determining the distribution of fallout from an accident and modelling individual risk, the possibility of ignition of leaked hydrogen has to be considered.

In case of adverse conditions, hydrogen leak may develop as a leak with ignition of the leaked substance. In case of release of chemical substances, immediate and delayed ignition possibilities have to be considered.

The probability that dangerous substances will ignite is affected by the flash point of that substance. The likelihood of immediate and delayed ignition of highly flammable gases is dependant of the volume of the substance that has been released. Table 28 summarises information on the probabilities of ignition in case of hydrogen leakage have been specified according to the International Energy Agency recommendations.[26]

Table 28. Probability of immediate and delayed ignition in case of a hydrogen leak.

Outflow [kg/s]	Probability of immediate ignition	Probability of delayed ignition
< 0,125	0,008	0,004
0,125 – 6,25	0,053	0,027
>6,25	0,230	0,120

For assess the consequences of an accident, a 1% lethal human exposure assessment has been conducted, which according to the Dutch Guidelines for Quantitative Risk Assessment can be described by the following exposure characteristics:

- 0,3 bar overpressure effect;
- 10 kW/m^2 exposure to heat radiation.

In this study the results from accident consequence modelling are presented under the following meteorological conditions:

- Wind speed and atmospheric stability class:
    - F 1,5,
    - D 5,
- Air humidity: 82 %,
- Air temperature: + 10 ^oC.

Considering hydrogen is highly flammable gas, that during a technological process are stored and transported under elevated pressure, the following types of accident consequences have been included in assessments of this study:

- Overpressure from rupture of the pressure tank;

[26] GASEOUS HYDROGEN STATIONS, IGC Doc 15/06/E, Revision of Doc 15/96 and Doc 15/05, EUROPEAN INDUSTRIAL GASES ASSOCIATION AISBL, 2006

- Overpressure from explosion of gas – air mixture;
- Heat radiation from Jet fire.