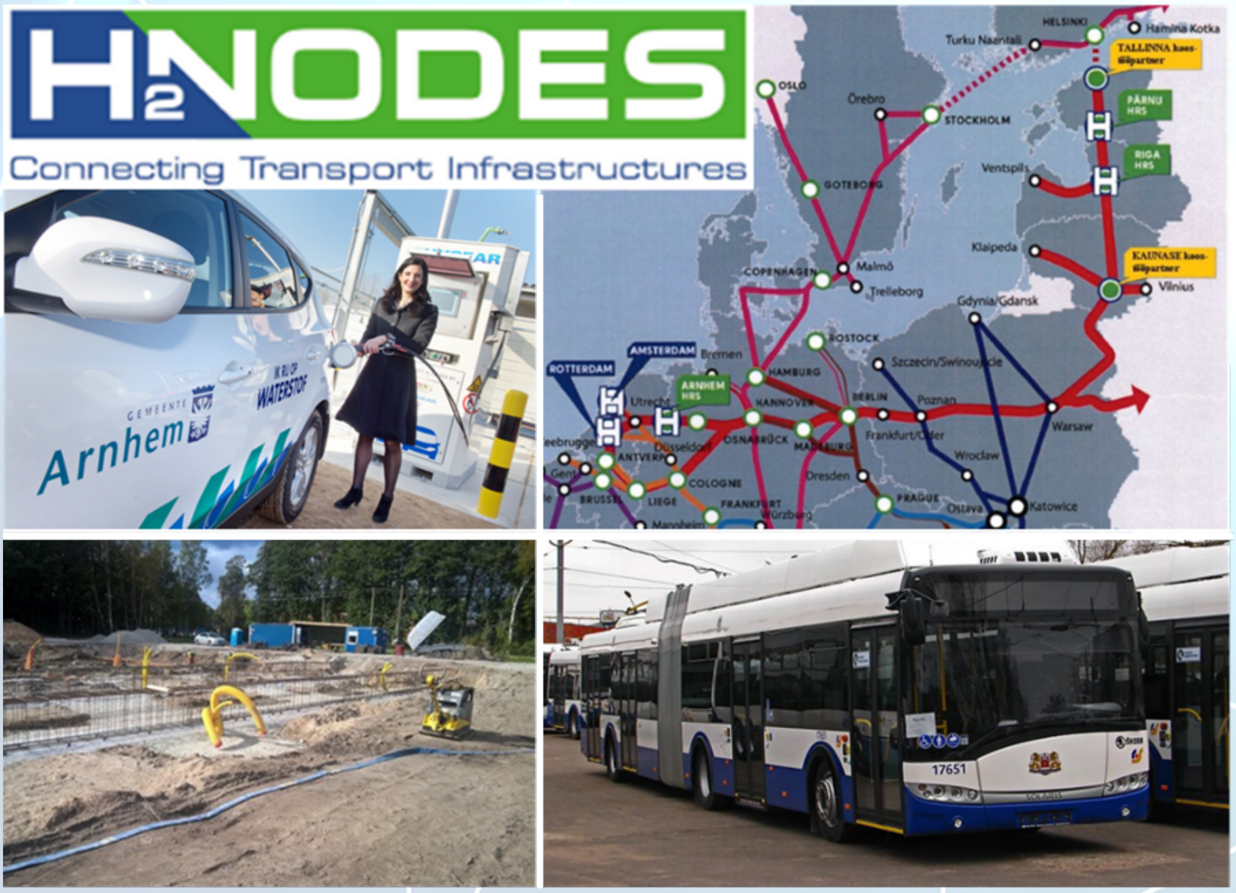
Milestones H2NODES

Milestone 10

Riga HRS Upscaling



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Milestone 10 Report

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Table of Contents

1. Introduction

This report describes the upscaling potential for the Riga HRS (Hydrogen refuelling station) gradual expansion and potential for additional HRS deployment in Region (Latvia). The starting point for regional upscaling is the reference for hydrogen refuelling demand based on Sub-Activities 3.1 and 3.2. of the Action as described in the H2Nodes Grant Agreement.

Sub-Activity 3.1. includes 10 HyTrolleybuses that serve the objective of real-life trials, making it possible to monitor and evaluate the use of units.

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

The upscaling of Riga HRS and additional HRS deployment in region is related to hydrogen refuelling demand in the near-term and is described within this report. The additional demand originates from Milestone 16 “Mobilising and engaging local and regional stakeholders in Riga” report whereas stakeholder initiatives and actions to substitute the fossil fuelled vehicles and to deploy fuel cell electric vehicle (FCEV) units such as additional FCE-buses, Heavy-duty vehicles and even trains (shunting locomotives) is described.

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

Milestone 10 “Riga HRS Upscaling” report consists of specific HRS upscaling plans for stations in Latvia. Within this report each HRS is described in separate chapter. In total the Report includes descriptions about 7 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. Evaluation of HRS deployment land plot (if applicable);
8. Assessment of air quality (nitrogen dioxide, carbon monoxide);
9. Noise pollution in day, evening and night scenarios;
10. Risk scenarios and probabilities for specific HRS components;
11. Overall risk level of intended activity.

The annex of the Milestone 10 “Riga HRS Upscaling” includes specific insight of legal, environmental aspects as well as the description of performed risk assessment methodology.

Note that for not all HRS include hydrogen production. The report includes also description about potential movable HRS. The evaluation of HRS deployment land plot is made for HRSs that are already dedicated to a specific land-plot.

2. Existing Riga HRS

RM LLC deployed Hydrogen refuelling and production station is located in Riga on Vienības Gatve 6. The hydrogen production is made using steam-methane reforming equipment with total capacity of 300kg/H_2/24h. The overall hydrogen storage capacity reaches 600kg/H_2. In order to refuel the FCE-vehicles 350bar and 700 bar dispensers are deployed. Mainly the RM LLC Rigas Satiksme own Trolleybuses with fuel cell genset (HyTrolleybuses) are refuelled in the existing hydrogen refuelling station. The overall scheme of existing Riga HRS is included in the Figure 1.

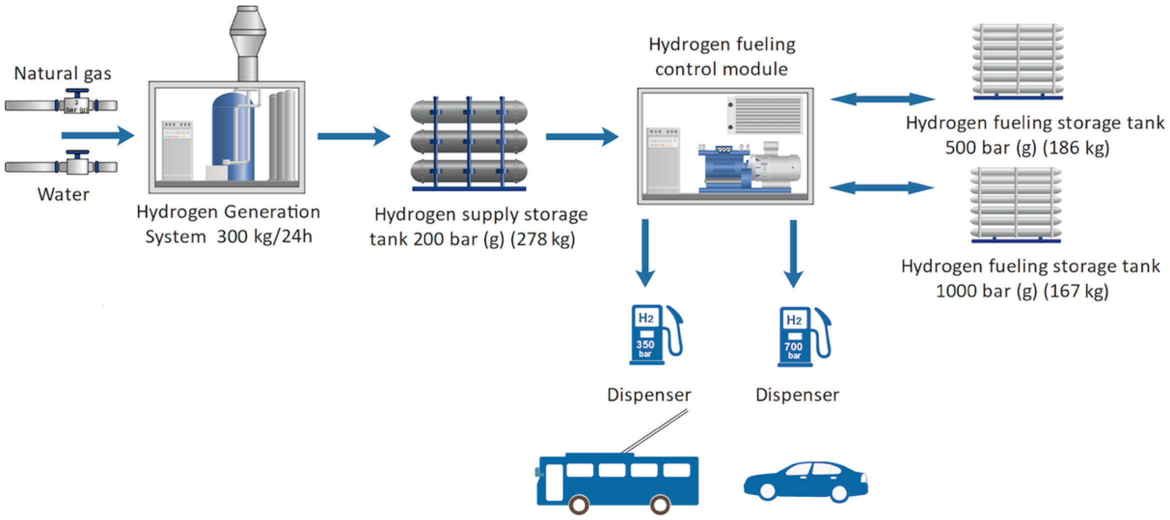


Figure 1. Scheme of existing Riga HRS

2.1 Technological solutions

Currently in Riga HRS there are two natural gas compressors deployed with total capacity of 60Nm^3/h. The modularity principles that are used in the Riga HRS foreseen that a total number of 3 hydrogen generation systems were deployed. Each hydrogen generation system capacity is 90kg/24h. 3 hydrogen generation systems were deployed in order to achieve the hydrogen availability in cases of maintenance or malfunction. This allows the Riga HRS to produce hydrogen with reduced capacity if one or more hydrogen generation systems are not operating. Additionally, two hydrogen compressors are mounted that increases the produced hydrogen pressure in order to store it in the hydrogen supply storage. The overall capacity of hydrogen supply storage is 278kg/H_2 at 200bar. The hydrogen fuelling control module is connected between the hydrogen supply storage, hydrogen fuelling storage units and both dispensers. Equipment and modularity is showed in Figure 2.

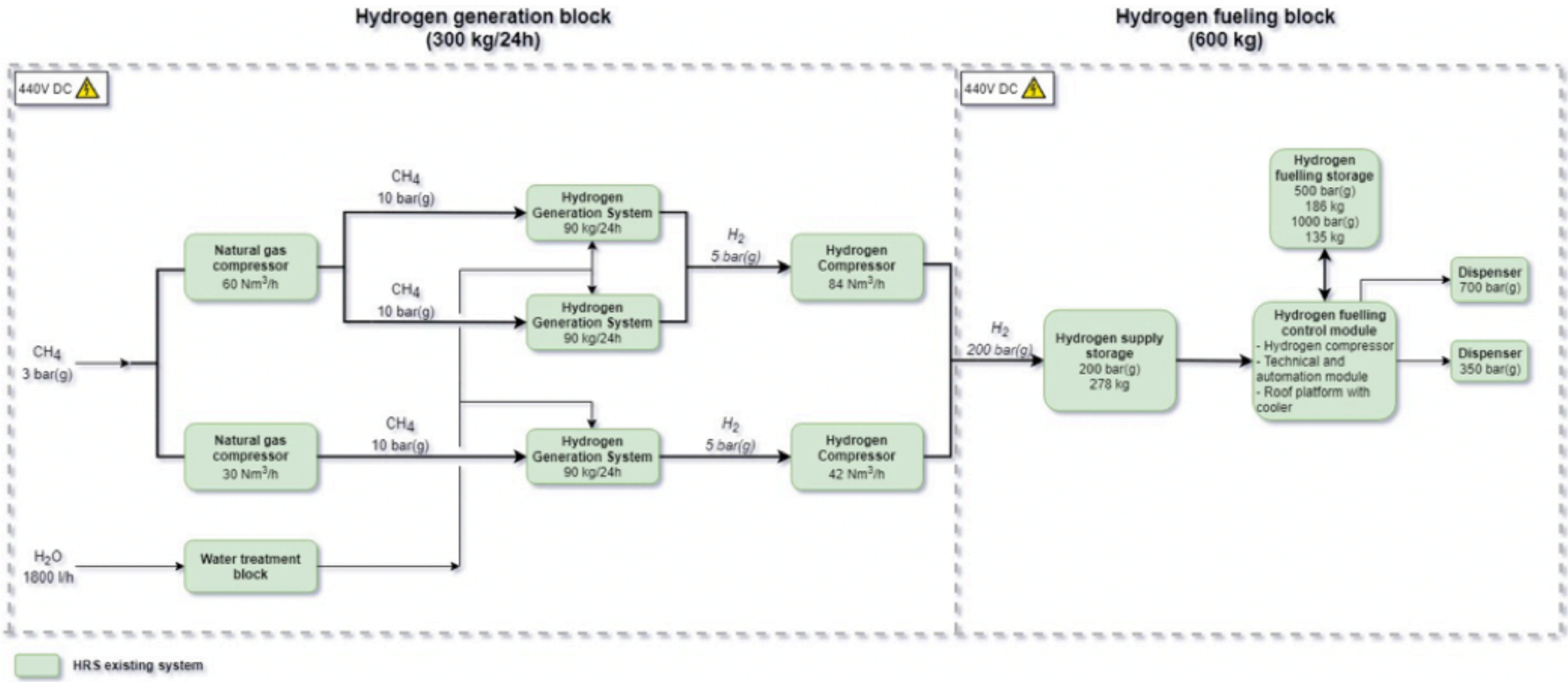


Figure 2 Equipment of existing Riga HRS.

3. Riga HRS upscaling first step

The Riga HRS upscaling first step is based on already existing equipment in the HRS. If additional 15 FCE-buses are deployed by RM LLC Rigas Satiksme the hydrogen production capacity must be increased to reach around 453kg/H_2 per day (99.999%). Concept wise the suggestion would be to increase the hydrogen production up to 540kg/H_2 per day. This would allow to look forward for deployment of additional 15 FCE-buses that would be used for RM LLC Rigas Satiksme and for any other identified units (see Table 1).

Table 1 Potential H2 demand per day[1]

Vehicle	Units	H2(kg)
HyTrolleybus	10	110
18m FCE-bus	15	337,5
FCE-passenger	5	5
Total		**452,5**

By developing the first upscaling and combining the necessary technical equipment it was noted that the potential hydrogen demand of the Rigas Satiksme for 350bar dispenser would reach 448kg/H2. As Rigas Satiksmes usual practice is for buses and trolleybuses to refuel during a 6-hour window during night time, the same approach is considered for determination the necessary equipment. The refuelling during night time results as increased amount of fuelling storage capacity in order to secure the fuelling for the FCEVs in 6-hour window. The overall scheme of the First step upscaling is included in Figure 3.

[1] More insight on the hydrogen demand can be found in H2NODES M16 "Mobilising and engaging local and regional stakeholders in Riga".

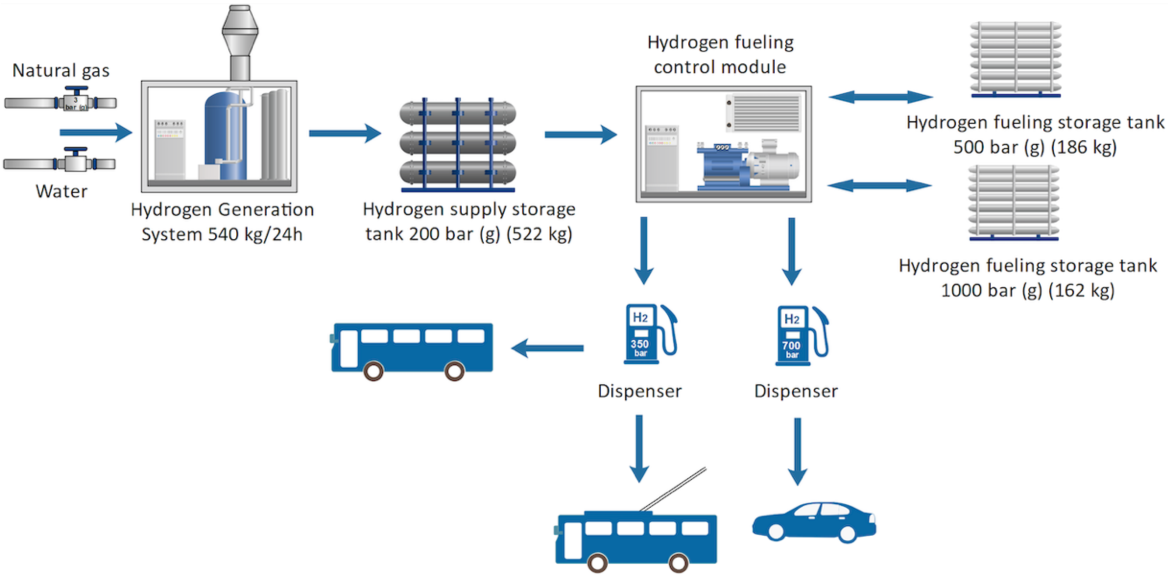


Figure 3 Scheme of Riga HRS first step upscaling.

3.1 Technological solutions

In order to reach the set targets for the HRS expansion it is necessary to increase the hydrogen production capacity and to increase the Natural gas compressor capacity in order to achieve higher flow of natural gas. Therefore, the total number of natural gas compressors would still be 2. But the capacity of one natural gas compressor should be increased to 100Nm3/h.

The higher flow of natural gas would allow to increase the capacity of hydrogen production and to deploy higher capacity hydrogen production units. The current HRS has 3 hydrogen generation systems with 90kg/H_2/24h capacity each. In order to reach the 540kg/H_2/24h the capacity of at least one hydrogen generation system should be increased to 270kg/H_2/24h. Additionally the new hydrogen compressor capacity should reach 170Nm3/h.

For the existing equipment the hydrogen supply storage that is installed on site between Hydrogen production equipment and Hydrogen fuelling control module to make the H2 station more flexible should be increased by 244kg/H_2. Therefore, the total capacity of hydrogen storage would reach 870kg/H_2. Considering that additional heavy-duty vehicles such as FCE-buses would refuel at the HRS additional 350bar dispenser should be deployed. Note that the already existing dispenser is located 52m away from the HRS and placed at the Rigas Satiksme Trolleybus depot. It is not clear whether the additional dispenser could be placed even further away from the HRS. The additional 350 bar dispenser would allow to secure faster FCE-bus fleet refuelling. Such aspects as additional cooling equipment would be necessary, thus further investigations on this aspect should be made. As currently the dispenser is not located further than 60 meters, this aspect is considered for evaluation of additional dispenser deployment. The overall consensus is that the dispenser should not be placed further than 60m from the HRS. The specification of the preferred units is summarised in Figure 4.

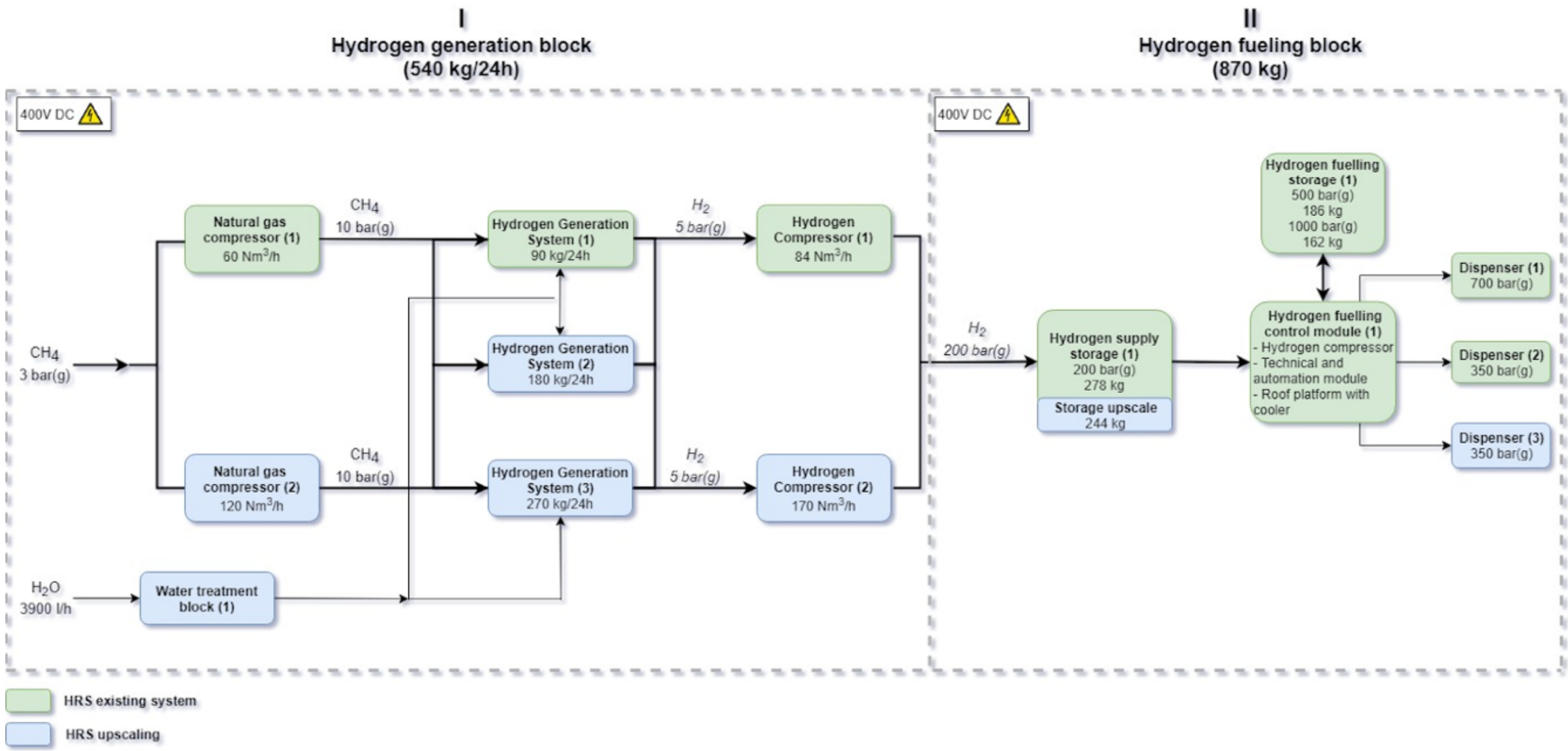


Figure 4 Equipment of Riga HRS first step upscaling.

The initial technical specification of the upscaling is summarized in Table 2. 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 2 technical specification of Riga HRS first step upscaling.

System description	Technical parameters	Quantity
Natural gas compressor unit	Qmax = 60 Nm3/h	1
Natural gas compressor unit	Qmax = 120 Nm3/h	1
Hydrogen generation system	Qmax = 90 kg/24h	1
Hydrogen generation system	Qmax = 180 kg/24h	1
Hydrogen generation system	Qmax = 270 kg/24h	1
Hydrogen compressor unit	Qmax= 84 Nm3/h	1
Hydrogen compressor unit	Qmax= 170 Nm3/h	1
Hydrogen supply storage	P = 200 bar V = 522 kg	1
Hydrogen fuelling storage	P = 500 bar V = 186 kg	1
Hydrogen fuelling storage	P = 1000 bar V = 162 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= 3900l/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 3.

Table 3 Utility connections for Riga HRS first step upscaling.

Utility	Measure	Technical requirements
Natural gas connection	Nm3/h	180 @ 10 bar(g)
Water connection	l/h	3900
Waste water connection	l/h	3900
Electricity 400V	kW	600

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 5).

1kg H2 cost breakdown

Cost per 1kg H2, in € (24m after launch)		2025
Cost position	Ref	EUR
Producde H2 kg cost		1,76
Employees		0,31
Services		1,25
Depreciation		2,34
Financing costs		0,07
Total cost per 1kg H2 produced (Yr Avg)		5,73
Applied premium		9,0%
Proposed sell price before taxes, EUR		6,24

Figure 5 1kg H2 cost breakdown of Riga HRS first step upscaling

The total price of HRS reaches around 8’500’000 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. Note that the costs are specified for new HRS deployment and not only the costs for additional equipment to increase the existing HRS capacity.

Space requirements

For the space requirements it is set that the current HRS land plot can be used and only the equipment modules should be changed that are described in prior. The overall HRS deployment land plot currently occupies 453 sq.m and no additional expansion is required (see Figure 6). The placement of additional 350bar dispenser should be identified as the already existing one is placed in the trolleybus depo next to the HRS.

Figure 6 Space requirements for Riga first step upscaling.

By combining the previous information, the first visualisation of the Riga HRS first step upscaling is made (Figure 7) whereas hydrogen production of the current Riga HRS is increased to 540kg/H_2/24h and the overall hydrogen storage capacity is increased to 870kg.

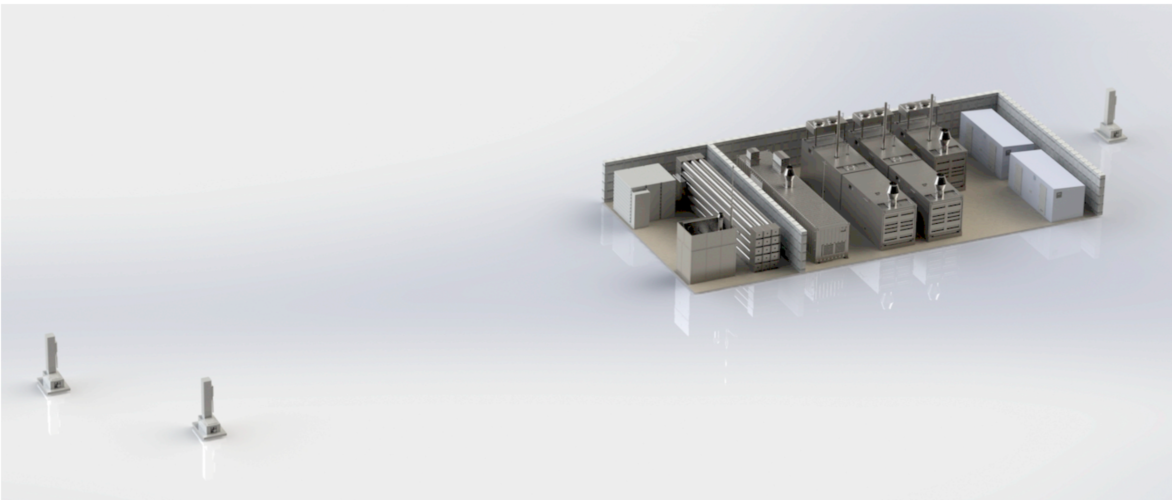


Figure 7 Riga HRS first step upscaling visualisation.

3.2 Evaluation of HRS deployment land plot.

Riga HRS first step upscaling is planned on a plot of land where the HRS is already located. According to Riga city territorial plan 2006-2018, intended activity planned in technical building territory (T) (see Figure 8), in which such action (hydrogen refuelling station deployment) is allowed, in accordance with the regulations for the use and construction of the territory of Riga (No.34 from 20.12.2005).

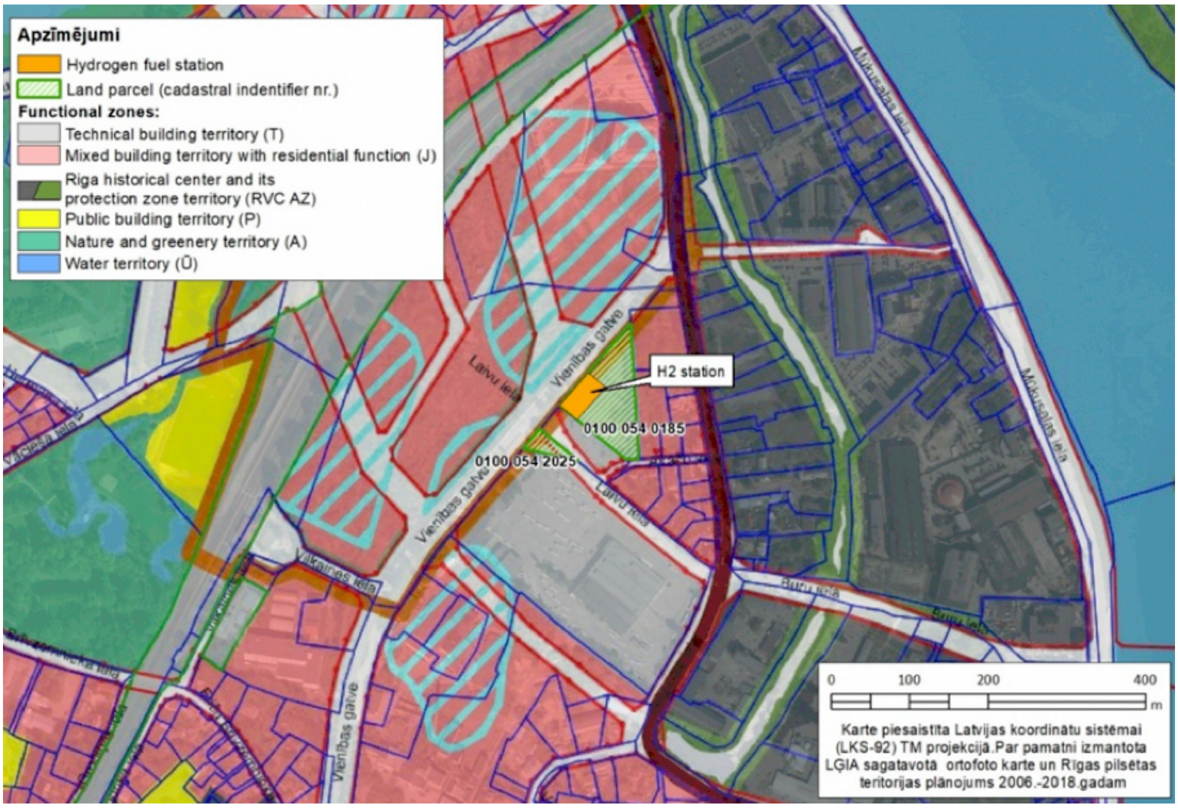


Figure 8 Location of First step Riga HRS upscaling.

In assessing the potential impact of the station, its planned location in relation to other areas in its surroundings has been considered (see Table 4).

Table 4 Description of the surroundings of the intended activity.

The type of areas/objects that could be affected by the intended activity	Distance (m) from intended activity
Functional zone	Intended activity planned in technical building territory (T)
Nearest residential house	95 (Akaču iela 4)
Nearest multi-storey residential house	100 (Jelgavas iela 19)
Nearest public building	220 (canteen) 220 (university)
Nearest enterprise	160 (2nd trolley depot)
Transport infrastructure objects	20 (Vienības gatve) 50 (Buru iela) 90 (Akaču iela) 120 (Jelgavas iela)

Existing Riga HRS refuelling part location corresponds to the spatial plan and in accordance with the plan in this territory the further development of its technical construction is also allowed.

3.3 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 the three combustion equipment units. Emissions of pollutants from natural gas combustion in a HRS are summarized in Table 5. The calculations take into account the maximum fuel consumption for each combustion equipment unit and the operating time - 8760 hours per year.

Table 5 Emissions of pollutants from the combustion of natural gas.

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	-
Nitrogen dioxide	180kg/24h	46 Nm3/h	0,387	0,012	71,79
Carbon monoxide			0,581	0,018	107,69
Carbon dioxide			766,58	24,308	-
Nitrogen dioxide	270kg/24h	69 Nm3/h	0,581	0,018	71,79
Carbon monoxide			0,871	0,028	111,68
Carbon dioxide			1149,86	36,5	-

The following total emissions are projected at the hydrogen gas combustion equipment:

- Nitrogen dioxide– 1,162 t/year;
- Carbon monoxide – 1,742 t/year;
- Carbon dioxide– 2299,73 t/year.

The concentration of emissions generated by any of the planned Hydrogen generation systems does not exceed the Cabinet of Ministers Regulation No. 17 “Regulations on the limitation of air pollution from combustion plants” Annex 7 emission limit values that are set at:

- Emission limit values for new combustion equipment:
  - NO_x = 100 mg/m^3,
  - CO = 150 mg/m^3.

In the pollutant dispersion model, three emission sources are defined:

- Hydrogen generation system 90kg/24h chimney;
- Hydrogen generation system 180kg/24h chimney;
- Hydrogen generation system 270kg/24h chimney.

Calculations of pollutant dispersion were performed using a software ADMS 5.2 (developer CERC – Cambridge Environmental Research Consultants, perpetual license P05-0399-C-AD520-LV). In the pollutant dispersion model, combustion plants are defined as point sources.

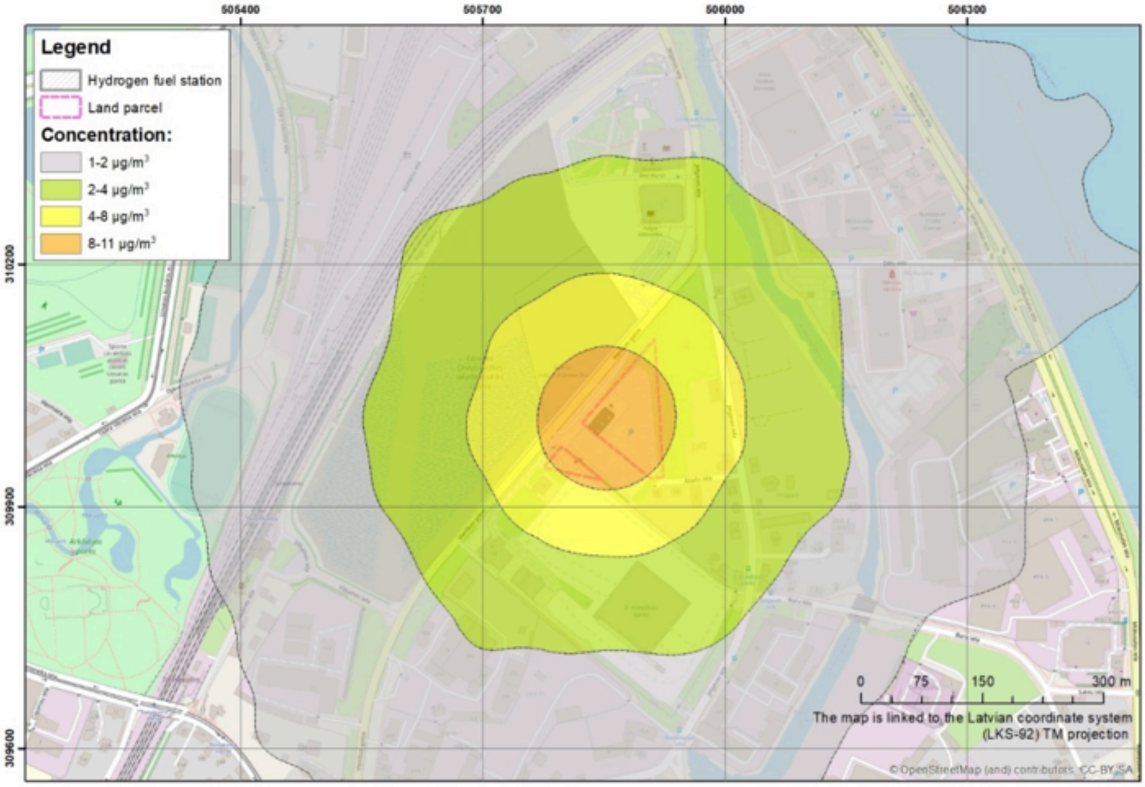


Figure 9 Nitrogen dioxide 99,79 percentile concentration.

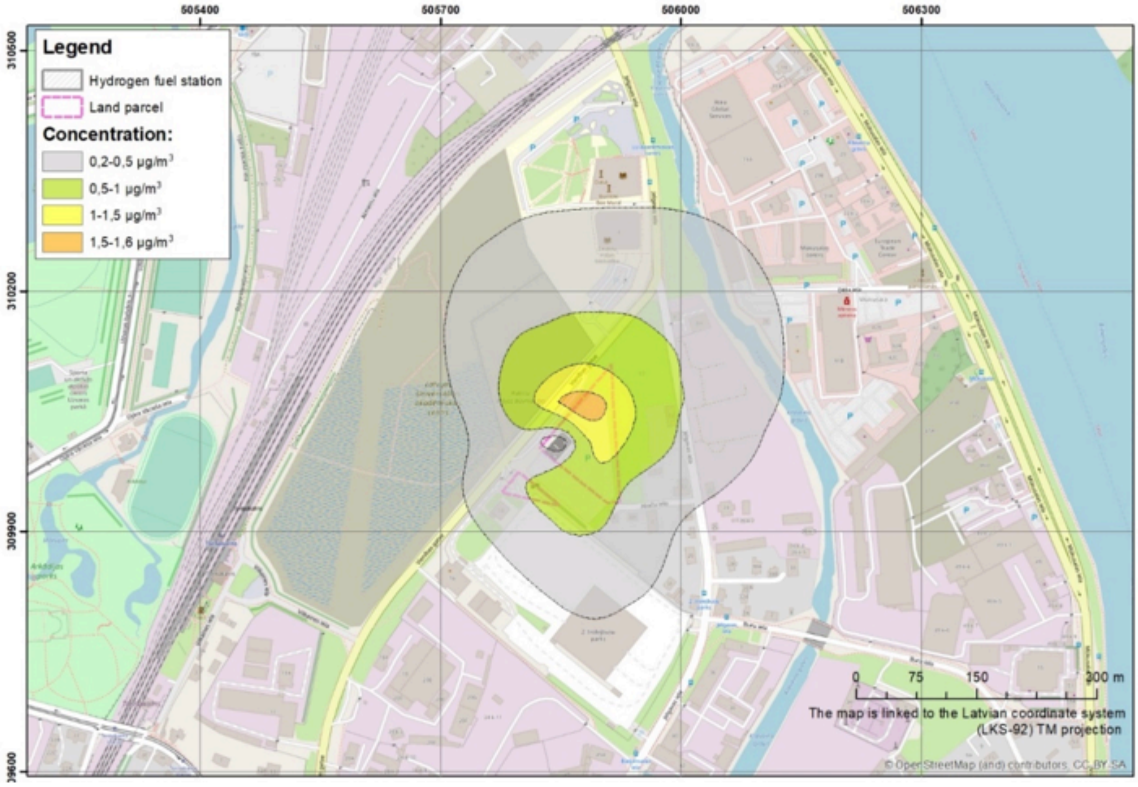


Figure 10 Nitrogen dioxide annual average concentration.

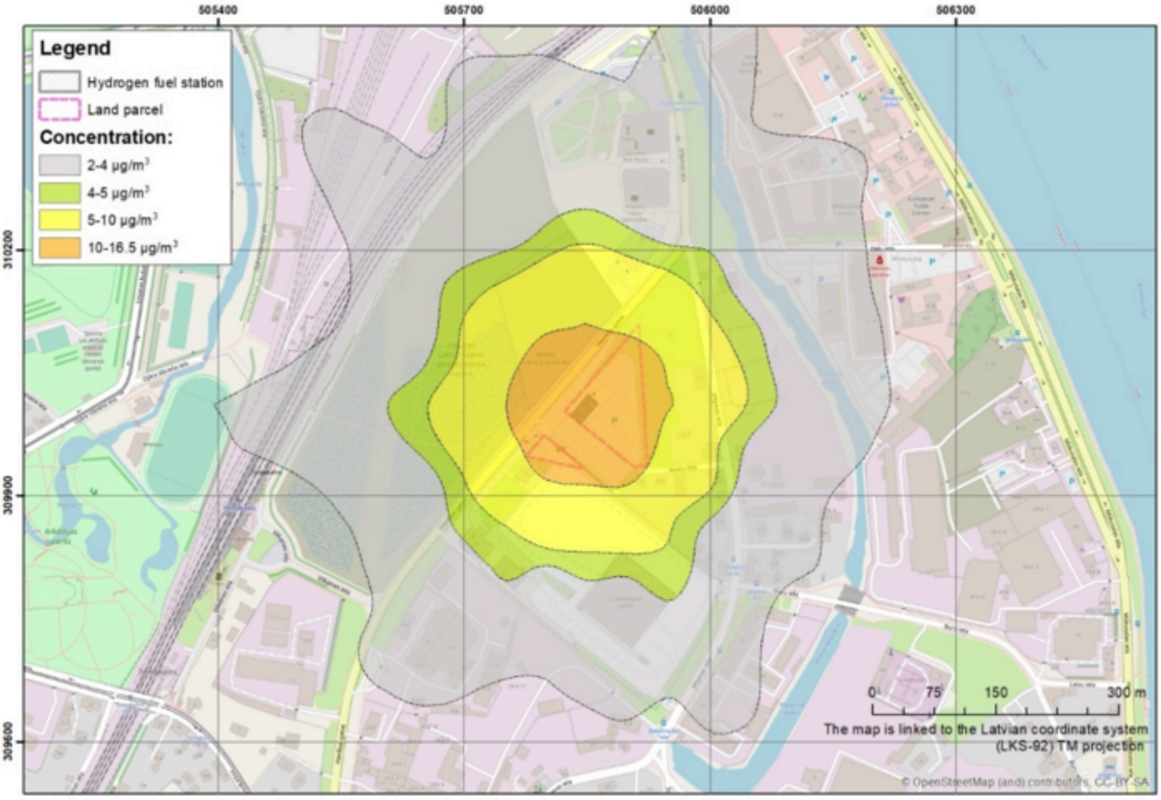


Figure 11 Carbon monoxide maximum daily 8 hour mean concentration.

Assessing the results of the air pollution dispersion calculations, it is concluded that both carbon monoxide and nitrogen dioxide emissions from the combustion of natural gas are not significant as the emissions of carbon monoxide do not reach even 1% of the limit value, and the concentration of nitrogen dioxide is 6% (99,79 percentile concentration) and 4% (annual average concentration) of the limit value. As well, pollution does not exceed the limit values set by the Cabinet of Ministers Regulations No. 1290 "Regulations on air quality".

3.4 Noise pollution

The noise forecasting and mapping software IMMI 2020-1 (License number S72/317), developed by Wölfel Meβsystem Software GmbH+Co K.G, was used to evaluate the noise indicators and to model the noise.

As part of the noise assessment, the individual noise level generated by the Riga HRS first step upscaling was calculated. The calculations do not consider the background noise caused by road traffic on Vienibas gatve and Jelgavas Street, as well as the impact of nearby railway.

Considering that the operation of the hydrogen station is continuous around the clock, the noise level was calculated for the noise indicators L_{day}, $L_{evening}$ and L_{night}.

Information on the noise level and operating time of the equipment used in the noise assessment is summarized in Table 6, but the location of the noise sources is shown in Figure 12.

Table 6 Operating time of noise sources involved in the hydrogen production and filling process and the resulting sound pressure level at the receiving point.

Name of noise source (container)	Relative height of the plane, m	Working hours, h/year			Distance of the receiving point from the source plane	Sound pressure level at the receiving point, L_{Aeq}, T dB(A)
		Day-time (07:00-19:00)	Evening (19:00-23:00)	Night (23:00-07:00)		
Natural gas compressor (1) Natural gas compressor (2)	2,8	4380	1460	2920	1 m	85
Hydrogen Generation System (1)	2,8	4380	1460	2920	1 m	80
Hydrogen Generation System (2)	2,8	4380	1460	2920	1 m	80
Hydrogen Generation System (3)	2,8	4380	1460	2920	1 m	80
Hydrogen compressor (1) Hydrogen compressor (2)	2,8	4380	1460	2920	1 m	80
Hydrogen fueling control module (1)	2,8	4380	1460	2920	5 m	60 (day and evening) 50 (at night)

Noise sources are placed in the acoustic model as three-dimensional objects (containers), where each of the source planes (regardless of the surface area) creates the same sound pressure level at the receiving point. The calculations include a 3,5 m high concrete wall located along the northern and north-western perimeter of the station (see Figure 6).

For the development of the noise map, the data provided by the Latvian Environment, Geology and Meteorology Center on meteorological conditions from the Riga observation station in 2019 were used.

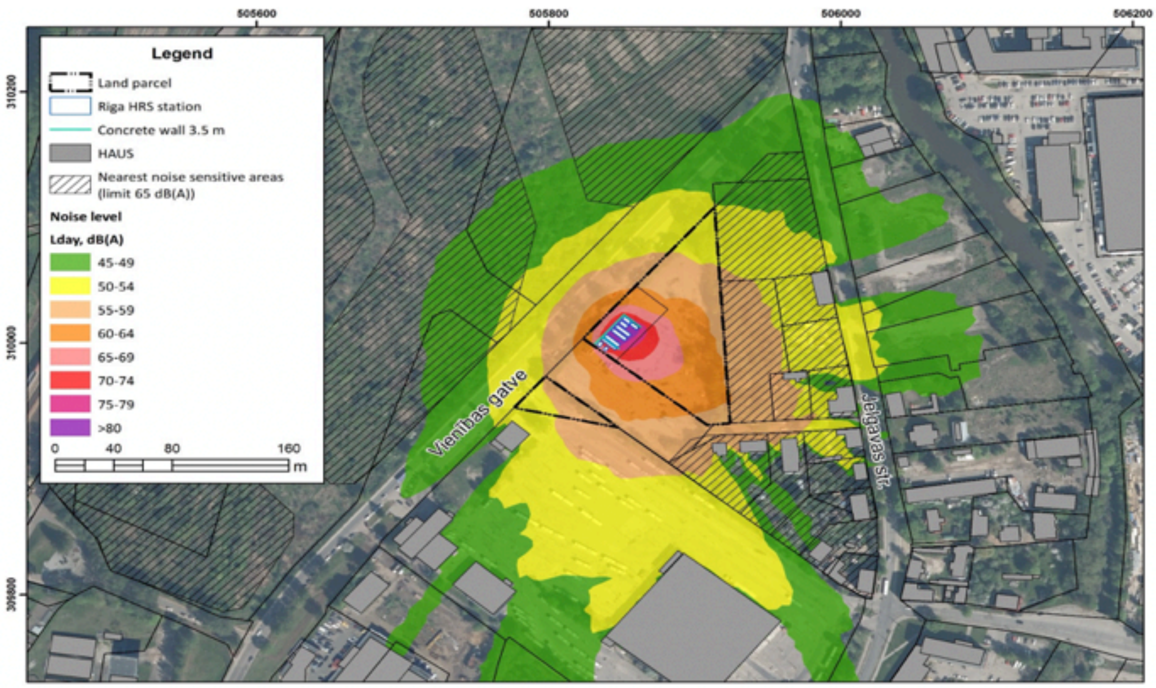


Figure 12 Noise exposure scenario in day-time.

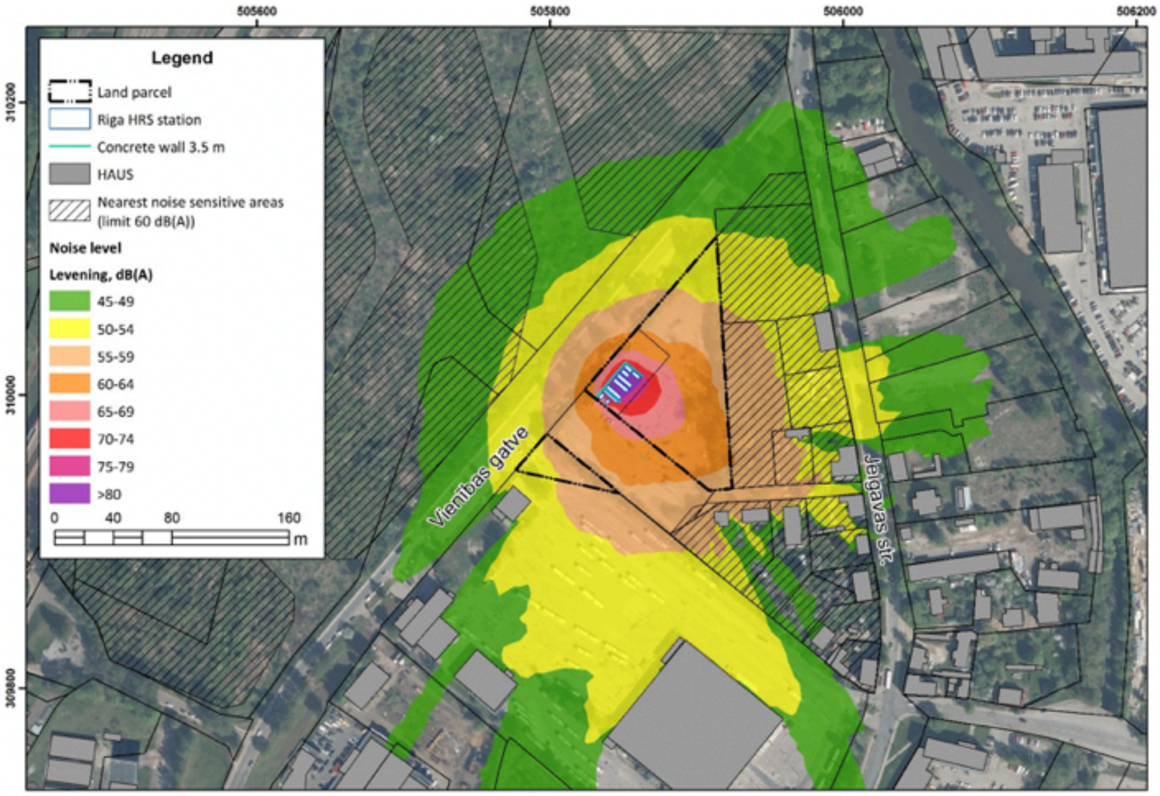


Figure 13 Noise exposure in evening.

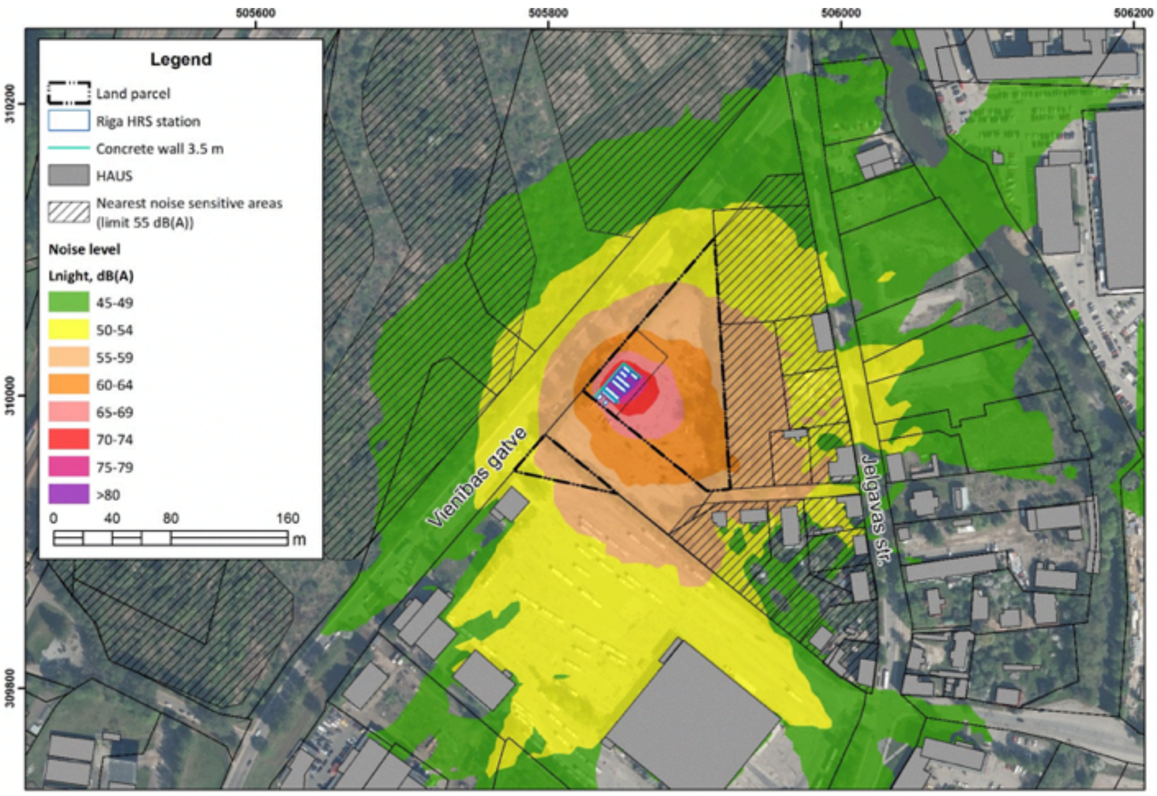


Figure 14 Noise exposure in night.

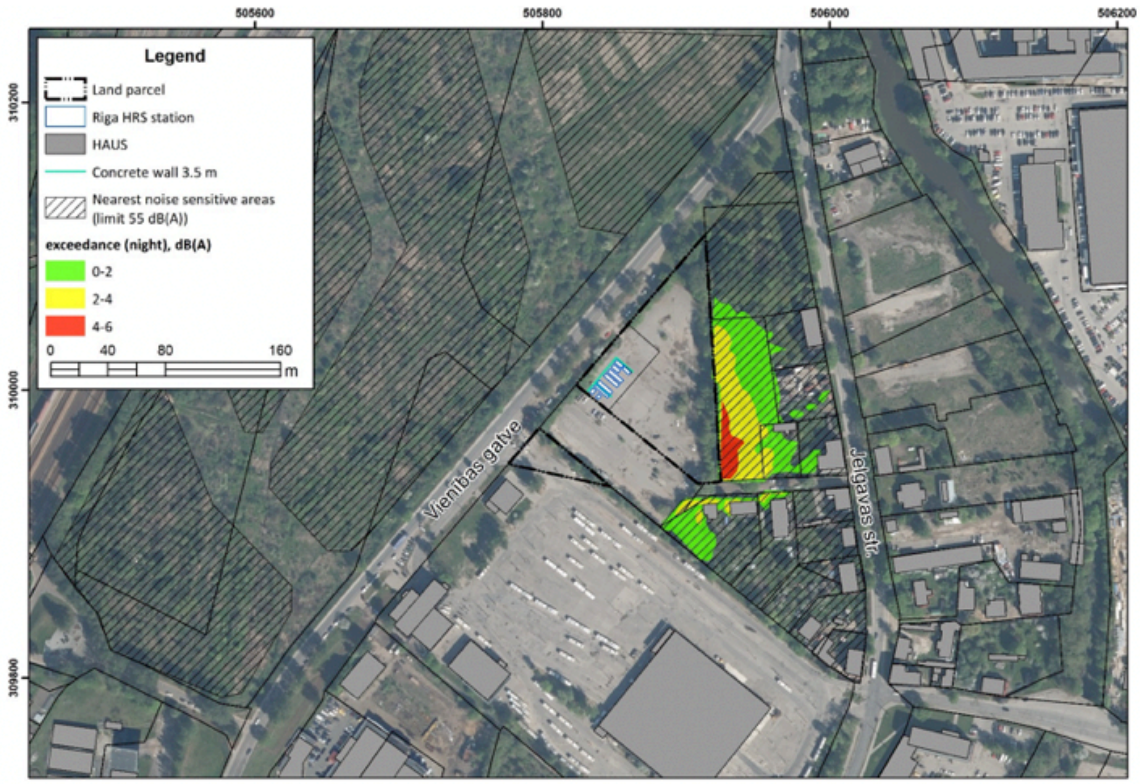


Figure 15 Areas with noise limit value exceedances.

Calculation results regarding First step Riga HRS upscaling noise pollution levels for the noise indicators L_{day}, $L_{evening}$, L_{night} are shown from

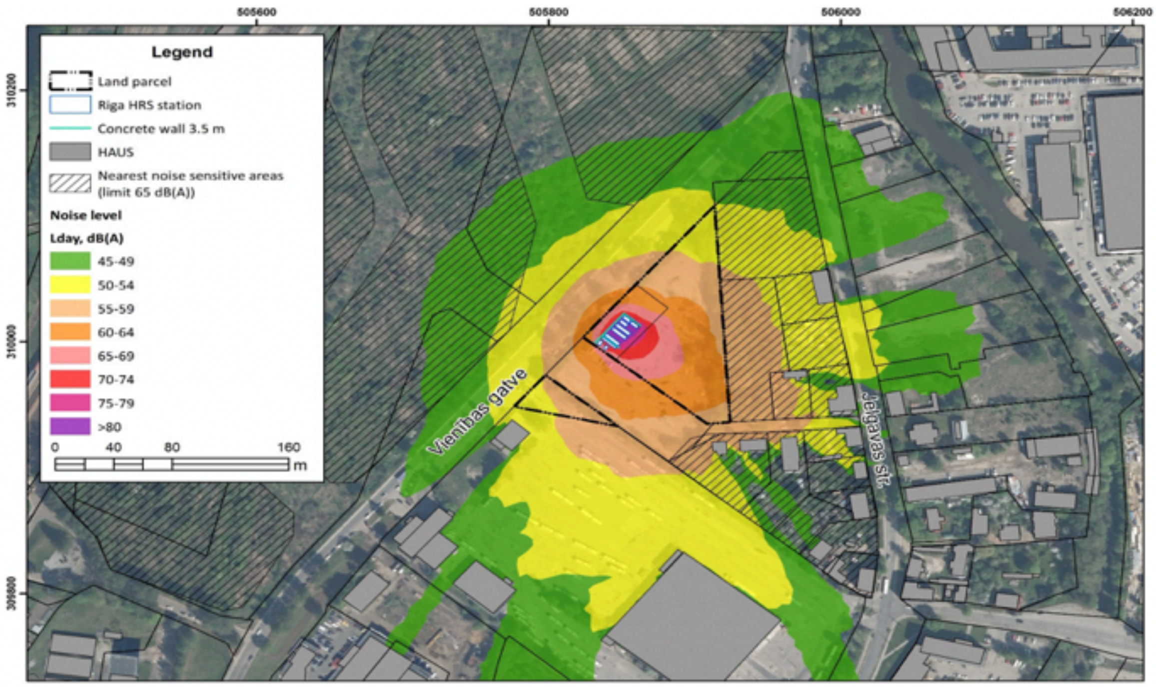


Figure 12 to Figure 14, but the areas where the noise limit value is exceeded - Figure 15.

According to the calculation results, Riga HRS first step upscaling generated individual noise level exceeds the Cabinet Regulation No. 16 (07.01.2014) environmental noise limit values for the night period (55 dB (A)) in a mixed building territory with a residential function, located to the east and south-east of the production area, it would therefore be necessary to provide for noise abatement measures.

The total area of exceedances during the night is 0.67 ha and, regardless of the time of day, the highest calculated noise level in the residential area reaches 60 dB (A).

Although there are not a large number of residential houses in the area of influence of the station, which are subject to the noise level limit value exceedance, however, it should be taken into account that the noise limit values are applicable in accordance with the use function of the territory, as a result of which it must be ensured that noise limits are not exceeded not only near residential houses, but in the entire area of use of the territory.

Given that the noise sources located in the hydrogen station operate continuously around the clock and it is not possible to significantly limit the operating time of the sources during the night, then as the most effective measure to reduce the noise generated by the station would be to build a noise-reducing wall along the entire south-eastern boundary of the facility, shielding the noise sources in the direction facing the residential area. The exact location and technical characteristics of the noise reduction barrier must be determined in the technical design on the basis of calculations of the predicted noise level.

3.5 Risk scenarios and probability

In assessing the risk of Riga HRS first step upscaling 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 7 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 Riga HRS first step upscaling the total number of cylinders that are used in hydrogen storage are 129 units. As the hydrogen is stored in different pressures the storage units break-down is:

- Supply storage (200 bar): 15 gas cylinders;
- Storage (500 bar): 48 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 unit gets damaged. This option prevents the gaseous hydrogen that is stored in other cylinders to escape through the damaged cylinder.

Table 8 H_2 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	7.50E-06	1.73E-06	9.00E-07
Continuous release from a hole with an effective diameter of 10 mm	1.00E-05/year	1.50E-04	1.20E-06	6.00E-07
Storage (500 bar)				
Instantaneous release of the entire contents of the gas cylinder	5.00E-07/year	2.40E-05	1.27E-06	6.48E-07
Continuous release from a hole with an effective diameter of 3,3 mm	1.00E-07/year	4.80E-06	3.84E-08	1.92E-08
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 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:

- 350 bar dispenser – 1342 hours /year;
- 700 bar dispenser – 14 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 9 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	5.37E-05	2.84E-06	1.45E-06
Leak of the hose	4.00E-05/hour	5.37E-04	4.29E-06	2.15E-06
700 bar dispenser				
Full bore rupture of the hose	4.00E-06/hour	5.50E-07	1.27E-07	1.49E-08
Leak of the hose	4.00E-05/hour	5.50E-06	4.40E-08	2.20E-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 10. 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 10 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	-	-
Leak of the hose – gas cloud explosion	-	-
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	-	-

The summary 1% lethal exposure zone was obtained by connecting furthest 1% lethal exposure distances around all technological equipment, see Figure 16.

Figure 16 1% lethal exposure map.

Risk level of intended activity

In this and the following examples Software Riskcurves (version 11.2.2) of the Norwegian company Gexcon is used for modelling contours of individual risk. For the development of the individual risk model, the data available at the Latvian Environment, Geology and Meteorology Center on meteorological conditions at the Riga meteorological observation station for the period 2008-2017 were used. The results of individual risk modelling with Riskcurves are shown in the Figure 17.

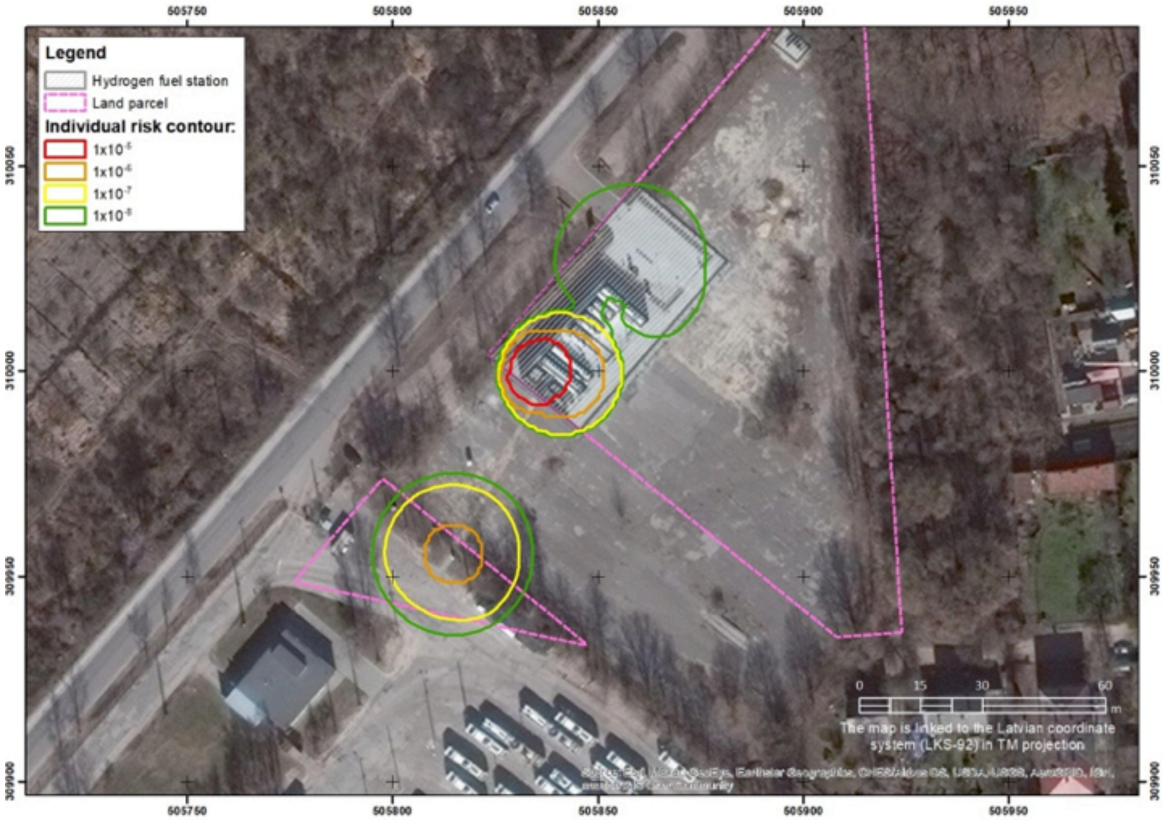


Figure 17 Contour of the individual risk around a hydrogen filling station.

3.6 Conclusion of the Riga HRS first step upscaling.

By deploying more FCE-vehicles the hydrogen availability in Riga HRS must be increased. The foreseen option to increase the hydrogen production to 540kg per day would allow to refuel 30 FCEVs (see Table 1). As for the price of deployment the costs would reach around 8’500’000 EUR. The increased hydrogen demand would allow to decrease the price of hydrogen to 6,24 EUR per kg (see Figure 5).

From risk perspective, the results of modelling the consequences of accidents show that after first step upscaling there are possible accident scenarios at the station, the consequences of which may endanger human life outside the station area. However, this level of threat is expected only within the boundaries of the technical construction area and does not reach residential areas.

The results of the individual risk assessment show that the internationally accepted individual risk level of 1×10^{-6} is achieved around H_2 storage and 350 bar dispenser. However, there are no other objects of economic activity or residential areas in the high-risk area. According to the criteria using in this risk assessment First step Riga HRS upscaling is acceptable.

Planned amount of hydrogen in the object - 870 kg which is < 1000 kg. Consequently, this object is not subject to the requirements applicable to Objects of Increased Danger.

As for location, the existing Riga HRS refuelling part location corresponds to the spatial plan and in accordance with the plan in this territory the further development of its technical construction is also allowed as the same land plot could be used.

4. Riga HRS second step upscaling

The Riga HRS second step upscaling foresees to refuel even more FCEVs (see Table 11). The modulation of upscaling is based on the original equipment that is already deployed in the Vienības Gatve 6 and considering the Riga HRS first step upscaling equipment.

Table 11 Potential Hydrogen demand[2]

Vehicle	Units	H2 (kg)
HyTrolleybus	10	110
18m FCE-bus	15	337,5
FCE-passenger	5	5
FCE-heavy duty	8	480
Shunting locomotive*	1	150
Total		**1083**

*The hydrogen for shunting locomotive would be delivered using MEGC to Movable HRS.

The MEGC (multiple element gas container) technology would enable hydrogen availability in places where it is not economically viable to deploy hydrogen production equipment. The modulation of upscaling is based on the original equipment that is already deployed in the Vienības Gatve 6 and considering the Riga HRS first step upscaling equipment. The significant change of the first Riga HRS upscaling step is that within this modulation the overall production capacity is increased to reach around 1200kg/H_2 per day. Additionally, an option to use road vehicles for hydrogen supply MEGC (multiple element gas container) to other HRS is included.

[2] More insight on the hydrogen demand can be found in H2NODES M16 "Mobilising and engaging local and regional stakeholders in Riga".

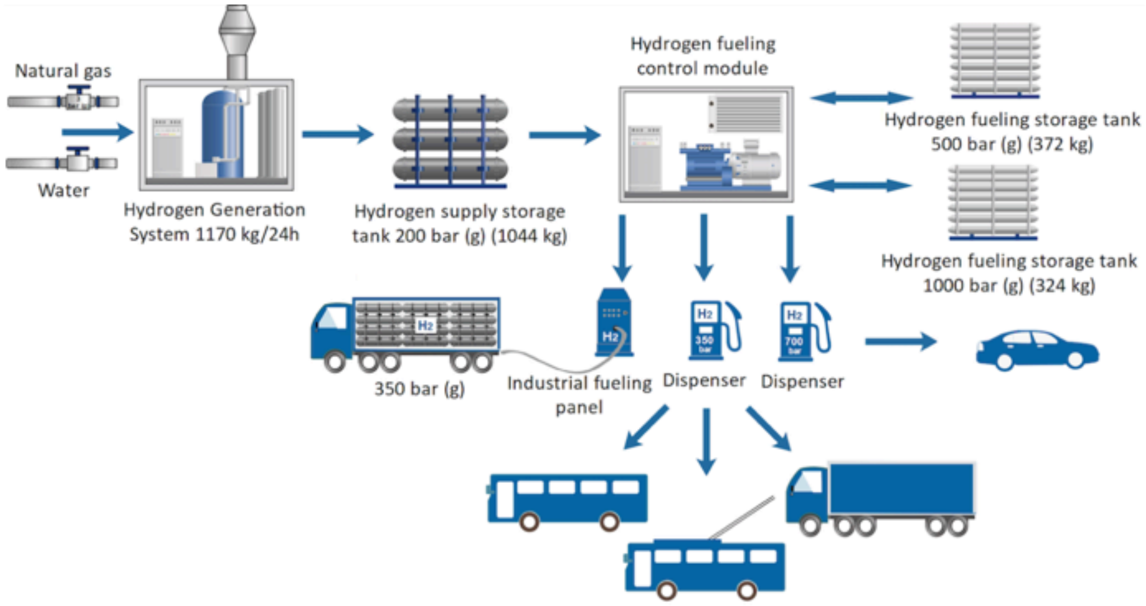


Figure 18 Scheme of Riga HRS second step upscaling.

4.1 Technological solutions

In order to reach the set targets for the HRS expansion it is necessary to increase the hydrogen production capacity and to increase the Natural gas compressor capacity in order to achieve higher flow of natural gas. The overall approach would be to deploy a symmetrical infrastructure next to the already existing one (see Figure 19).

The total number of natural gas compressors would be 4. The total combined natural gas compressor capacity would reach 420 Nm3/h. The higher flow of natural gas would allow to increase the capacity of hydrogen production and to deploy higher capacity hydrogen production units. The total number of 6 hydrogen generation systems would be required. Current HRS has 3 hydrogen generation systems with 90kg/H_2/24h capacity each. In order to reach the 1200kg/H_2/24h additional 3 hydrogen generation systems from whom two would need to reach the capacity of 270kg/H2/24h and one additional 90kg/H2/24h should be deployed. Additionally, to that two additional hydrogen compressors must be deployed with each capacity of 150Nm^3/h.

In the second Riga HRS upscaling step the hydrogen supply storage must be expanded by 522kg of hydrogen and additional hydrogen fuelling control module that operates with 3rd 350bar dispenser and the industrial filing panel that would be able to fill MEGC (multiple element gas container). 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). The MEGC refuelling would secure ability to deliver the produced hydrogen to HRS with no hydrogen production units.

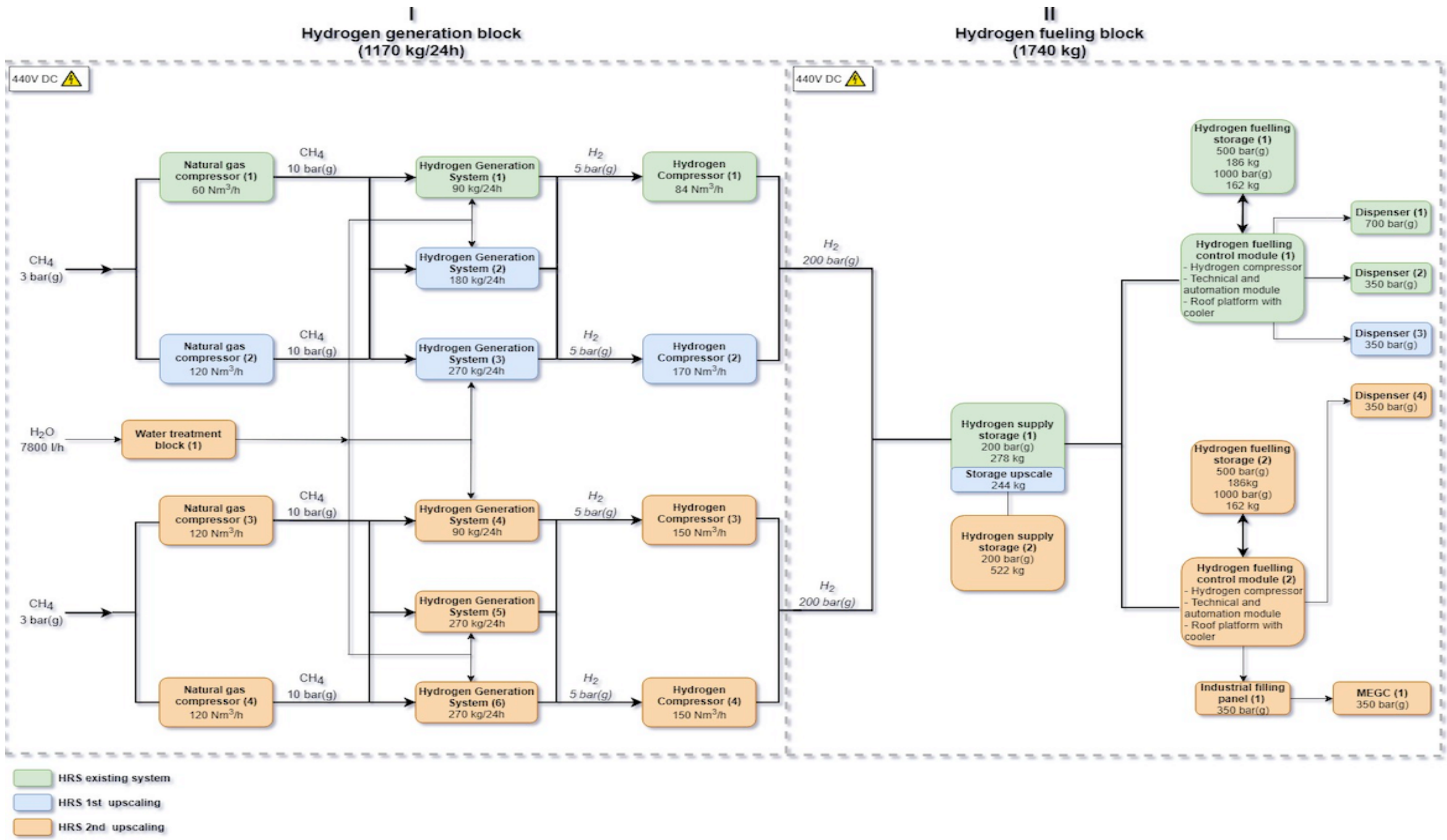


Figure 19 Equipment of Riga HRS second step upscaling

The initial technical specification of the Riga HRS second step upscaling is summarized in Table 12. By developing the technical specification, the modularity principles were considered 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 12 Technical specification of Riga HRS second step upscaling.

System description	Technical parameters	Quantity
Natural gas compressor unit	Qmax = 60 Nm3/h	1
Natural gas compressor unit	Qmax = 120 Nm3/h	3
Hydrogen generation system	Qmax = 90 kg/24h	2
Hydrogen generation system	Qmax = 180 kg/24h	1
Hydrogen generation system	Qmax = 270 kg/24h	3
Hydrogen compressor unit	Qmax= 84 Nm3/h	1
Hydrogen compressor unit	Qmax= 150 Nm3/h	2
Hydrogen compressor unit	Qmax= 170 Nm3/h	1
Hydrogen supply storage	P = 200 bar V = 522 kg	2
Hydrogen fuelling storage	P = 500 bar V = 186 kg	2
Hydrogen fuelling storage	P = 1000 bar V = 162 kg	2
Hydrogen fuelling control module	Qmax: 48.5 kg/h Maximum design pressure: 1000 bar(g)	2
Dispenser	P = 350 bar	3
Dispenser	P = 700 bar	1
Industrial filling panel	P = 350 bar	1
Water treatment block	Qmax= 7 800l/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 13.

Table 13 Utility connections for Riga HRS second step upscaling.

System description	Measure	Technical requirements
Natural gas connection	Nm3/h	420 @ 10 bar(g)
Water connection	l/h	7 800
Waste water connection	l/h	7 800
Electricity 400V	kW	1 200

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 20).

1kg H2 cost breakdown

Cost per 1kg H2, in € (24m after launch)		2025
Cost position	Ref	EUR
Producde H2 kg cost		1,76
Employees		0,13
Services		0,96
Depreciation		1,87
Financing costs		0,06
Total cost per 1kg H2 produced (Yr Avg)		4,77
Applied premium		9,0%
Proposed sell price before taxes, EUR		5,20

Figure 20 1kg H2 cost breakdown for Riga HRS second step upscaling

The total price of HRS estimates reaches around 15’000’000 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. The main decrease of hydrogen price compared to the Riga HRS first step upscaling can be seen in Services and Depreciation, this is due to the fact that the service costs are divided for more produced and filled kg of hydrogen. Note, that the land acquisition is not included in the price estimates and the total price does not exclude already deployed equipment.

Space requirements

For the space requirements it is set that the current HRS land plot must be extended and second similar fundament must be deployed in order to install the additional equipment. The overall HRS deployment land plot would occupy 1338 sq.m (see Figure 21).

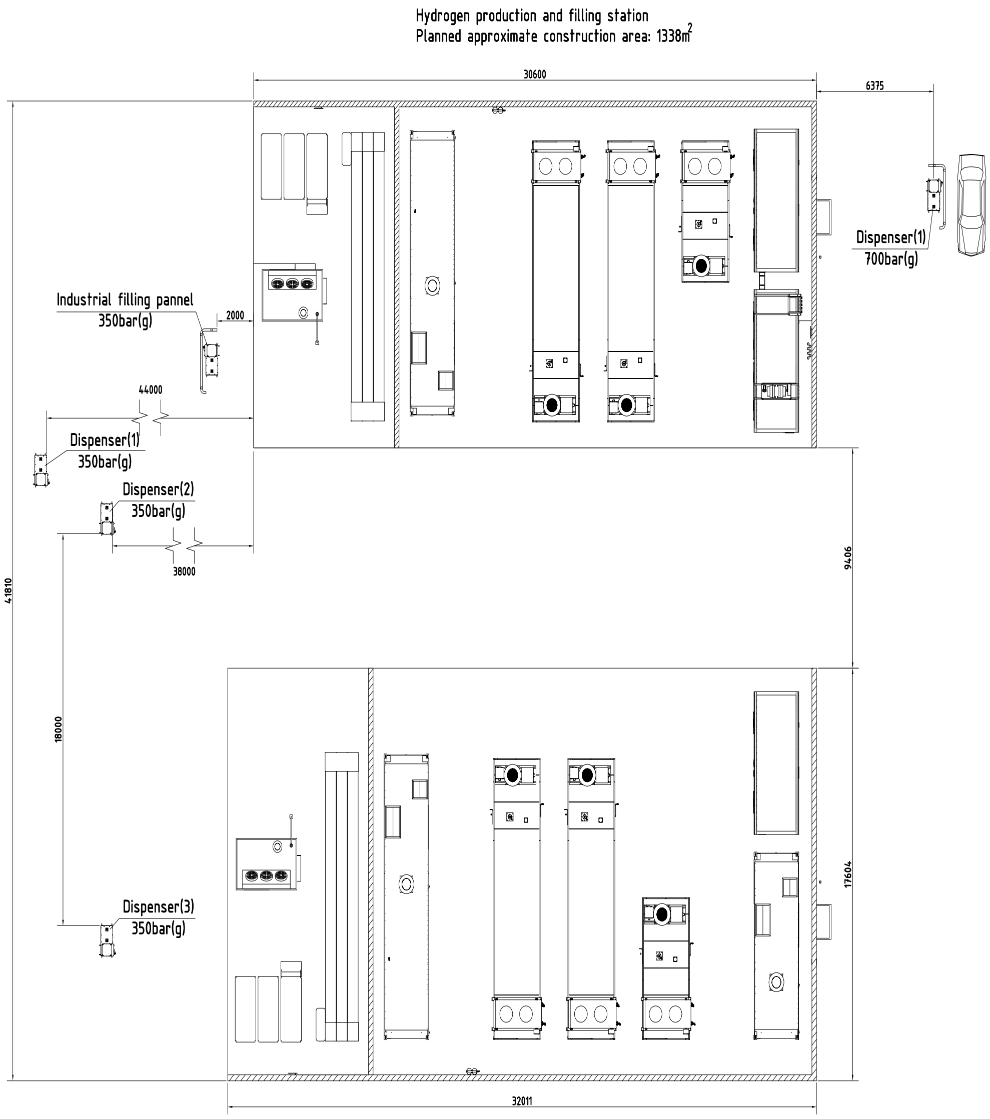


Figure 21 Space requirements for Riga HRS second step upscaling.

By combining the previous information, the first visualisation of the Riga HRS second step upscaling is made (Figure 22) whereas hydrogen production of the current Riga HRS is increased to 1170kg/H_2/24h and the overall hydrogen storage capacity is increased to 1740kg.

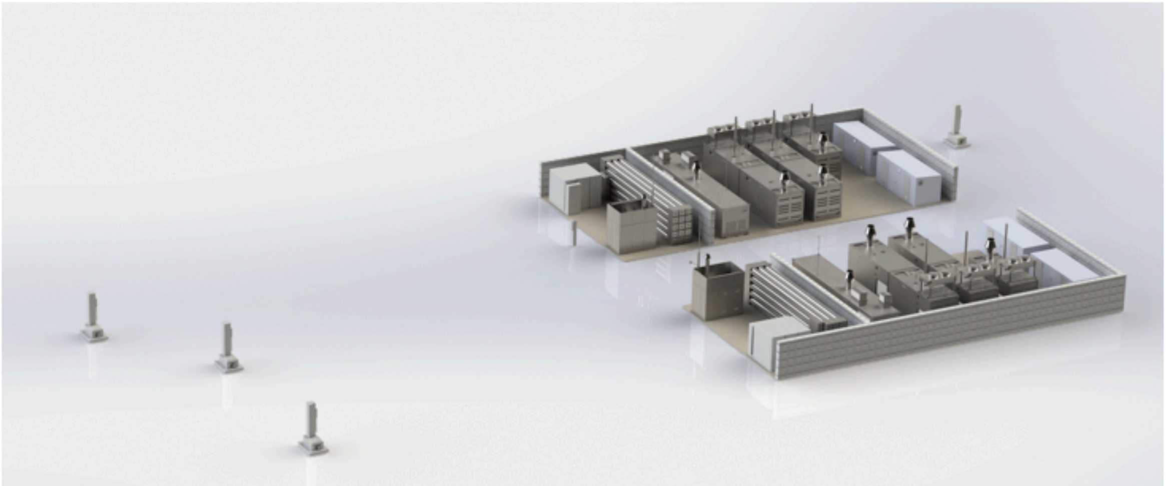


Figure 22 First visualization of Riga HRS second step upscaling.

4.2 Evaluation of HRS deployment land plot.

The location of Riga HRS second step upscaling is intended on the same plot of land as First step Riga HRS upscaling. It is planned that the Riga HRS second step upscaling equipment will be located in larger area, but it will still be located in an area that according to Riga city territorial plan 2006-2018 is technical building territory (T), in which deployment of refuelling station is allowed, in accordance with the regulations for the use and construction of the territory of Riga (No. 34 from 20.12.2005).

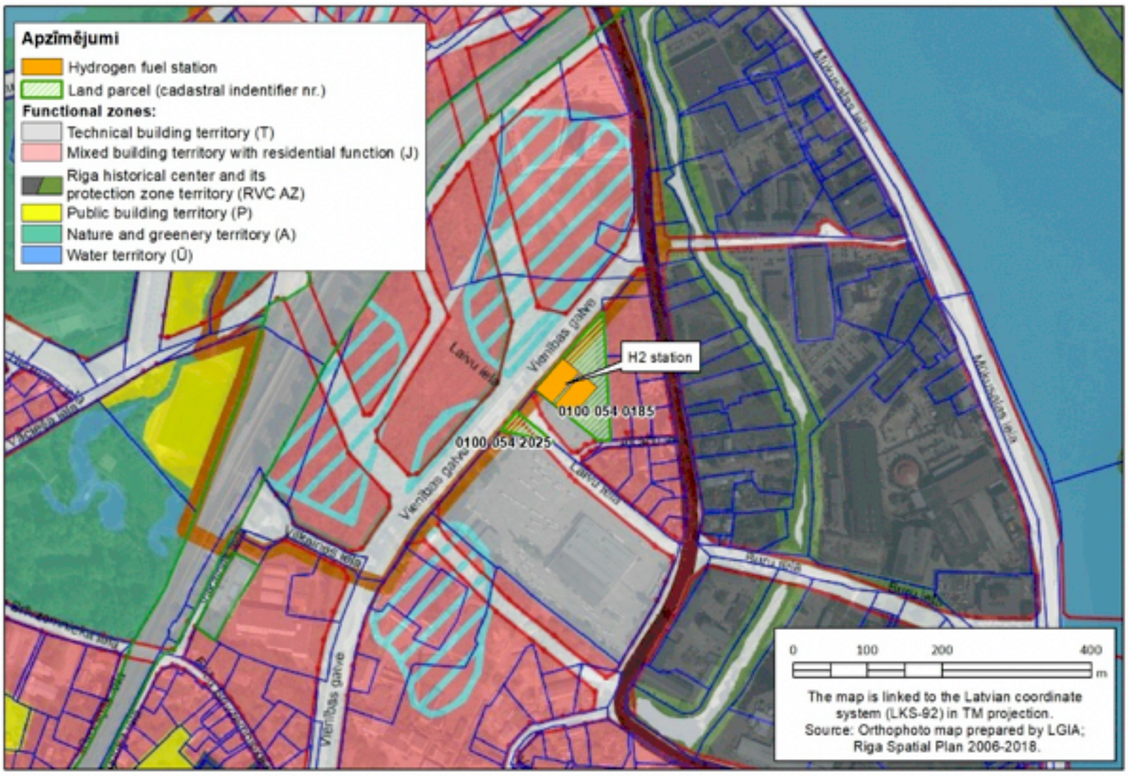


Figure 23 Location of Riga HRS second step upscaling.

In assessing the potential impact of the station, its planned location in relation to other areas in its surroundings has been considered (see Table 14). The expansion of the station is planned in the south-eastern direction from the existing object, thus the object will be located closer to the residential building on Akaču Street.

Table 14 Description of the surroundings of the intended activity.

The type of areas/objects that could be affected by the intended activity	Distance (m) from intended activity
Nearest residential house	75 (Akaču iela 4)
Nearest multi-story residential house	100 (Jelgavas iela 19)
Nearest public building	220 (canteen) 220 (university)
Nearest enterprise	160 (2nd trolley depot)
Transport infrastructure objects	20 (Vienības gatve) 50 (Buru iela) 90 (Akaču iela) 120 (Jelgavas iela)

4.3 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 six combustion plants. Emissions of pollutants from natural gas combustion in a hydrogen station are summarized in Table 15. The calculations take into account the maximum fuel consumption for each combustion equipment and the operating time - 8760 hours per year.

Table 15 Emissions of pollutants from the combustion of natural gas.

Pollutant	Hydrogen generation system capacity	Fuel consumption	t/year	g/s	mg/m^3
Nitrogen dioxide	90kg/24h (two units)[1]	23 Nm^3/h	0,194	0,006	71,79
Carbon monoxide			0,290	0,009	107,69
Carbon dioxide			383,29	12,2	-
Nitrogen dioxide	180kg/24h	46 Nm^3/h	0,387	0,012	71,79
Carbon monoxide			0,581	0,018	107,69
Carbon dioxide			766,58	24,308	-
Nitrogen dioxide	270kg/24h (three units)[1]	69 Nm^3/h	0,581	0,018	71,79
Carbon monoxide			0,871	0,028	111,68
Carbon dioxide			1149,86	36,5	-

Notes: 1-Fuel consumption and emissions per unit.

The following total emissions are projected at the hydrogen gas combustion equipment:

- Nitrogen dioxide– 2,518 t/year;
- Carbon monoxide – 3,774 t/year;
- Carbon dioxide – 4982,74 t/year.

The concentration of emissions generated by any of the planned Hydrogen generation systems does not exceed the Cabinet of Ministers Regulation No. 17 “Regulations on the limitation of air pollution from combustion plants” Annex 7 emission limit values. In the pollutant dispersion model, six emission sources are defined:

- Two Hydrogen generation system 90kg/24h chimneys;
- One Hydrogen generation system 180kg/24h chimney;
- Three Hydrogen generation system 270kg/24h chimneys.

Calculations of pollutant dispersion were performed using a software ADMS 5.2 (developer CERC – Cambridge Environmental Research Consultants, perpetual license P05-0399-C-AD520-LV). In the pollutant dispersion model, combustion equipment is defined as point sources.

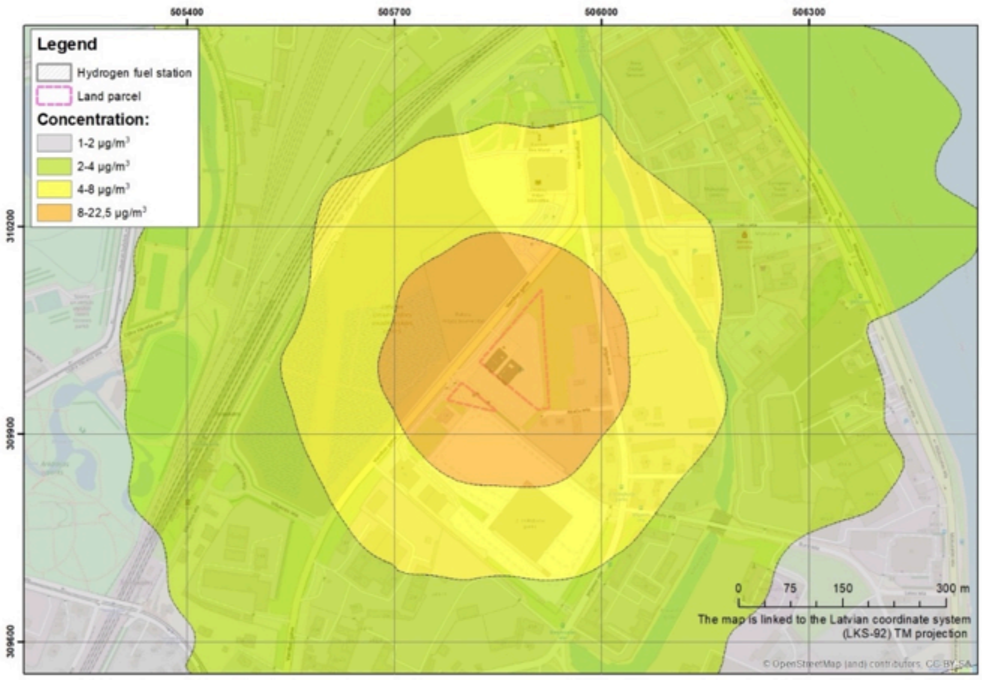


Figure 24 Nitrogen dioxide 99,79. percentile concentration.

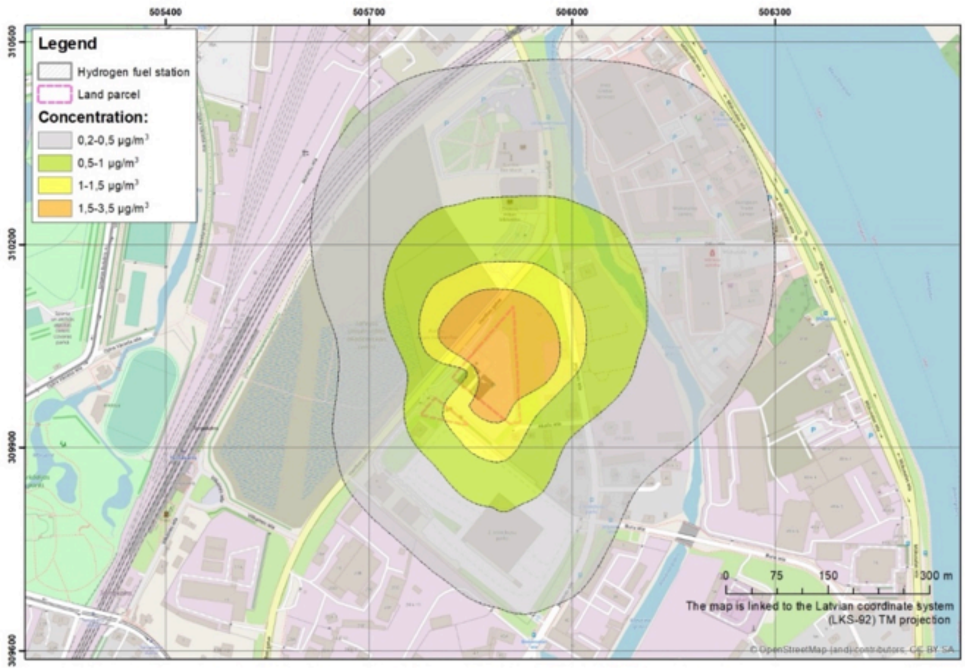


Figure 25 Nitrogen dioxide annual average concentration.

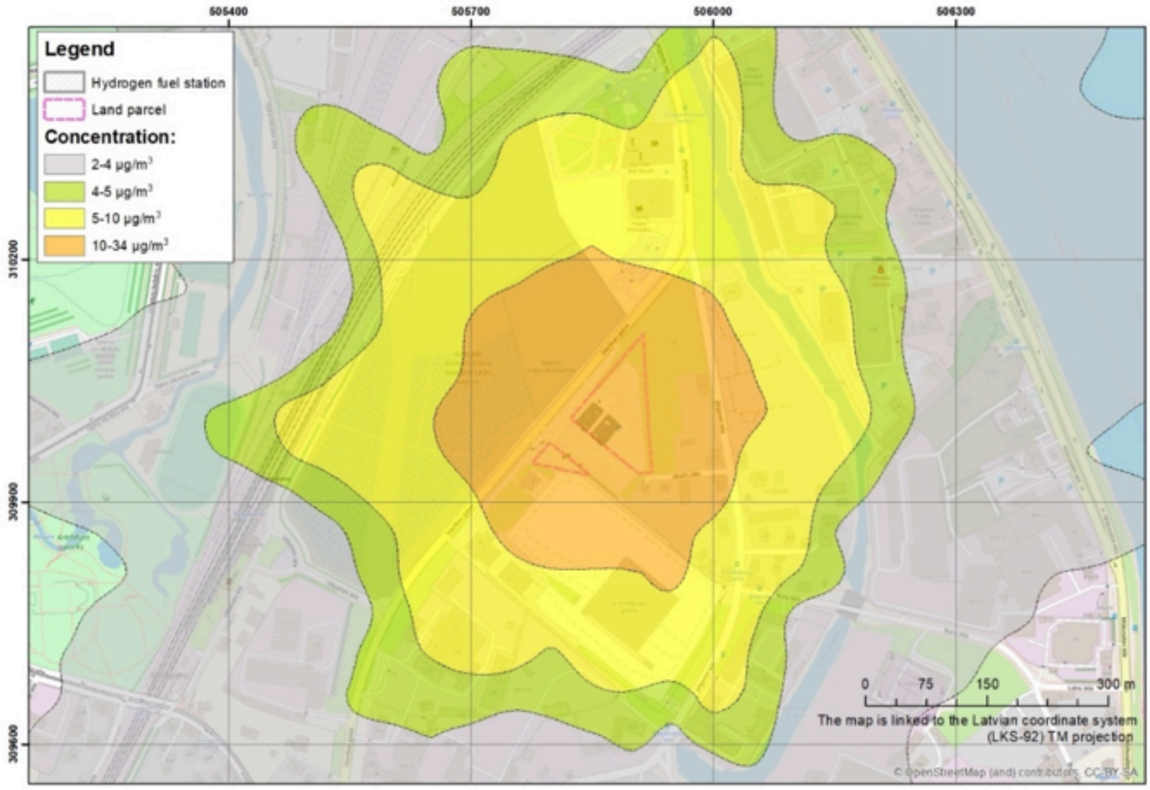


Figure 26 Carbon monoxide maximum daily 8 hour mean concentration.

In case of the implementation of the second step Riga HRS upscaling scenario, the amount of emissions from natural gas combustion will significantly increase compared to the first step Riga HRS upscaling scenario, but will not exceed the limit values set by the Cabinet of Ministers Regulations No. 1290 "Regulations on air quality" its -pollution does not exceed the regulatory limit values. When evaluating the results of air pollution dispersion calculations, the second step Riga HRS upscaling pollution concentration can be considered significant. Even though emissions of carbon monoxide do not reach even 1% of the limit value, the concentration of nitrogen dioxide fluctuates around 10% of the limit value - the 99.79 percentile concentration reaches 11% and the annual average concentration - 9% of the limit value.

4.4 Noise pollution

As part of the noise assessment, the individual noise level generated by the Riga HRS second step upscaling was calculated. The calculations do not consider the background noise caused by road traffic on Vienibas gatve and Jelgavas Street, as well as the impact of nearby railway.

Considering that the operation of the Riga HRS second step upscaling station is also planned around the clock, the noise level was calculated for each period of the day.

Information on the noise level and duration of the equipment included in the noise assessment is shown in Table 16 but location of noise sources - Figure 21. Noise sources are placed in the acoustic model as three-dimensional objects, where each of the source planes (regardless of the surface area) creates the same sound pressure level at the receiving point. The calculations include two 3,5 m high concrete walls located as shown in Figure 21.

For the development of the noise map, the data provided by the Latvian Environment, Geology and Meteorology Center on meteorological conditions from the Riga observation station in 2019 were used.

Table 16 Operating time of noise sources involved in the hydrogen production and filling process and the resulting sound pressure level at the receiving point.

Name of noise source (container)	Relative height of the plane, m	Working hours, h/year			Distance of the receiving point from the source plane	Sound pressure level at the receiving point, $L_{Aeq,\,T}$ dB(A)
		Day-time (07:00-19:00)	*Evening (19:00-23:00)*	*Night (23:00-07:00)*		
Natural gas compressor (1) Natural gas compressor (2)	2,8	4380	1460	2920	1 m	85
Natural gas compressor (3) Natural gas compressor (4)	2,8	4380	1460	2920	1 m	85
Hydrogen Generation System (1)	2,8	4380	1460	2920	1 m	80
Hydrogen Generation System (2)	2,8	4380	1460	2920	1 m	80
Hydrogen Generation System (3)	2,8	4380	1460	2920	1 m	80
Hydrogen Generation System (4)	2,8	4380	1460	2920	1 m	80
Hydrogen Generation System (5)	2,8	4380	1460	2920	1 m	80
Hydrogen Generation System (6)	2,8	4380	1460	2920	1 m	80
Hydrogen compressor (1) Hydrogen compressor (2)	2,8	4380	1460	2920	1 m	80
Hydrogen compressor (3) Hydrogen compressor (4)	2,8	4380	1460	2920	1 m	80
Hydrogen fueling control module (1)	2,8	4380	1460	2920	5 m	60 (day and evening) 50 (at night)
Hydrogen fueling control module (1)	2,8	4380	1460	2920	5 m	60 (day and evening) 50 (at night)
Water treatment block (1)	2,8	4380	1460	2920	1 m	75
Water preparation, compressed air preparation and automation module	2,8	4380	1460	2920	1 m	75

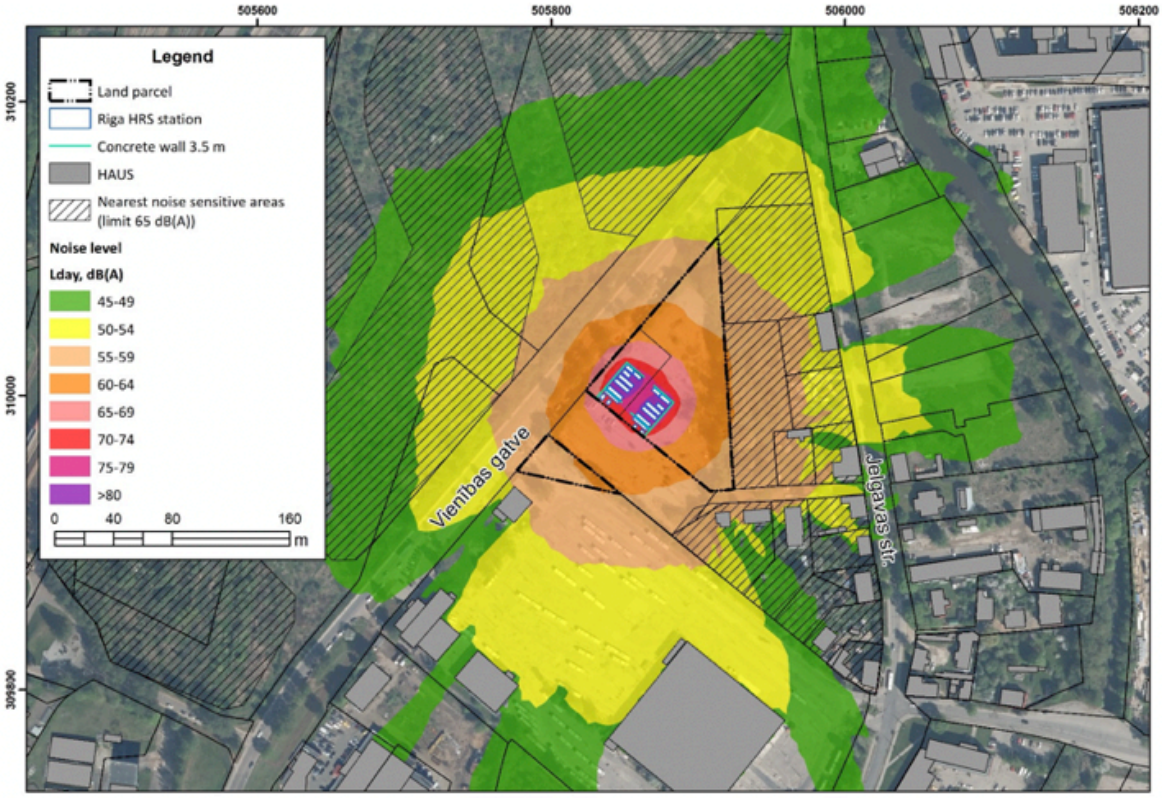


Figure 27 Noise exposure, day scenario.

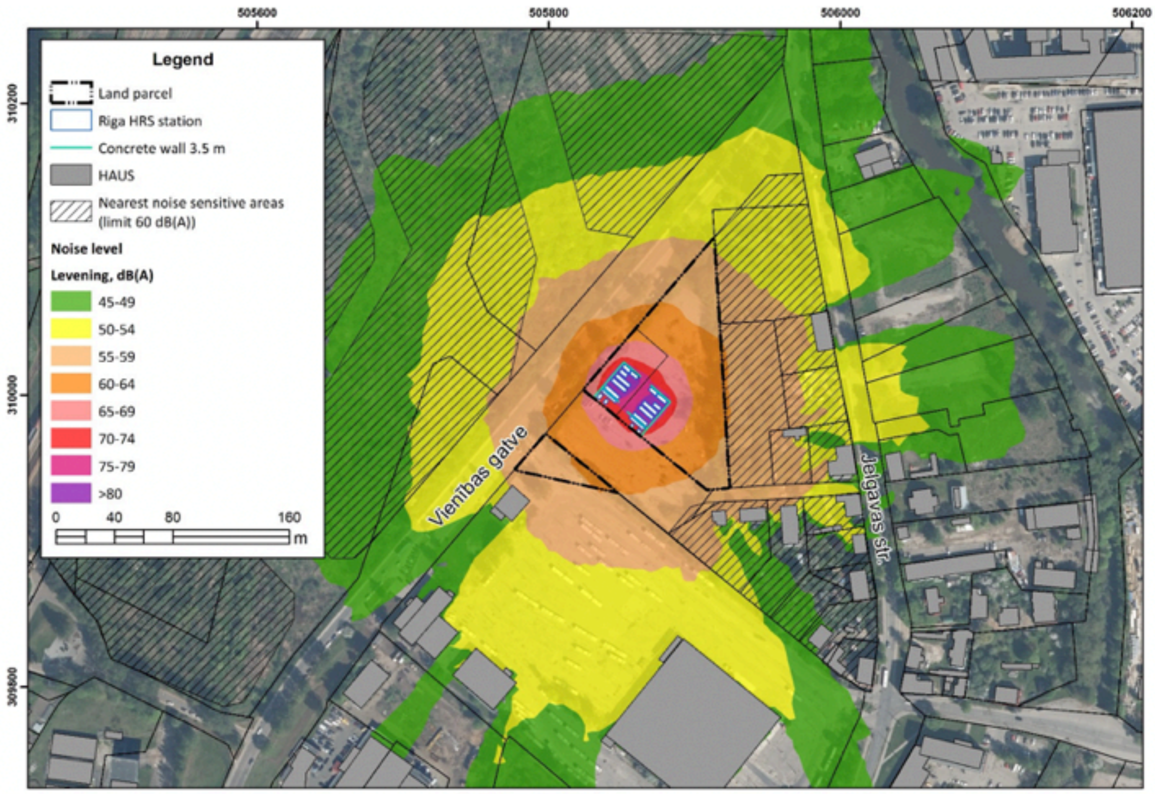


Figure 28 Noise exposure, evening scenario.

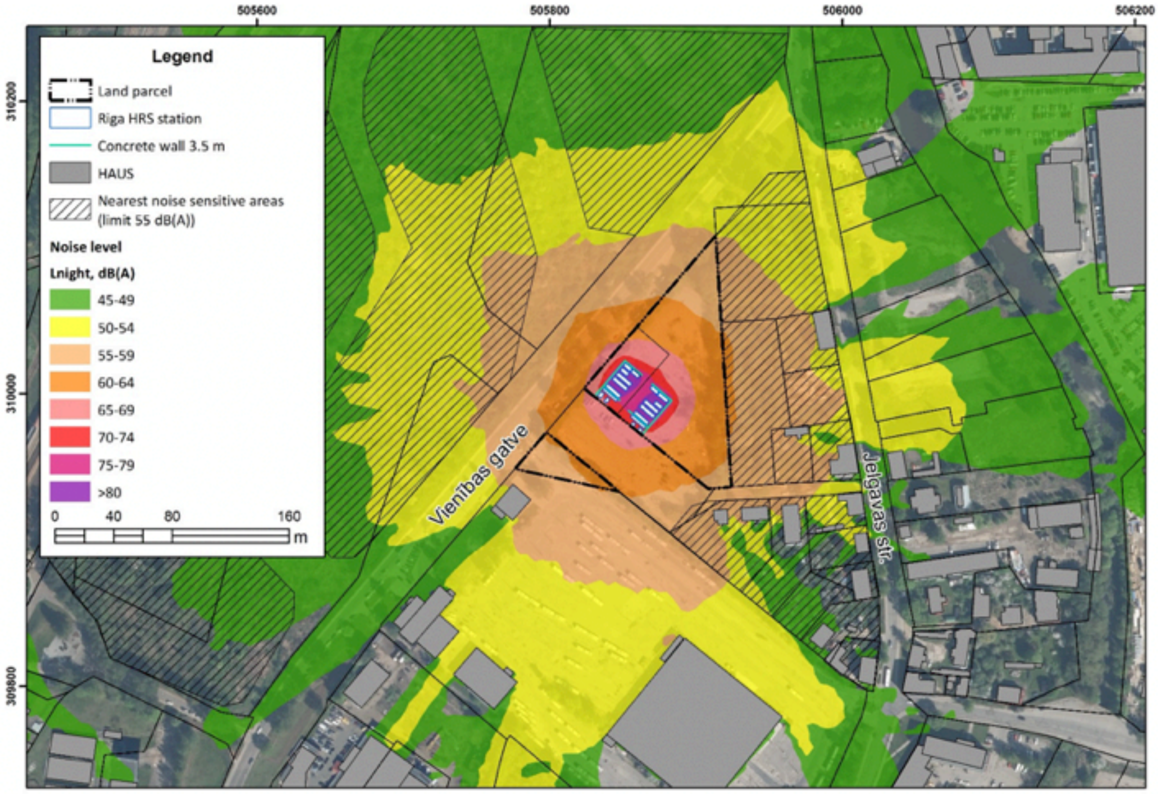


Figure 29 Noise exposure, night scenario.

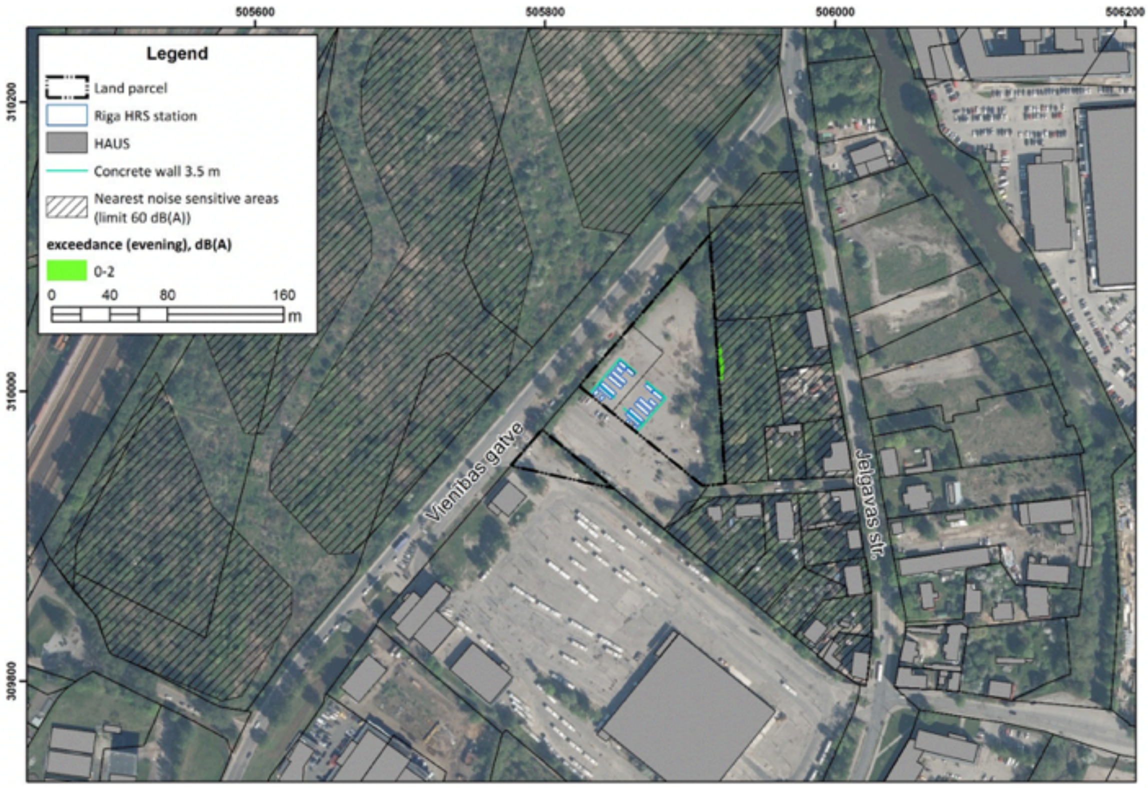


Figure 30 Areas with noise limit value exceedance evening scenario.

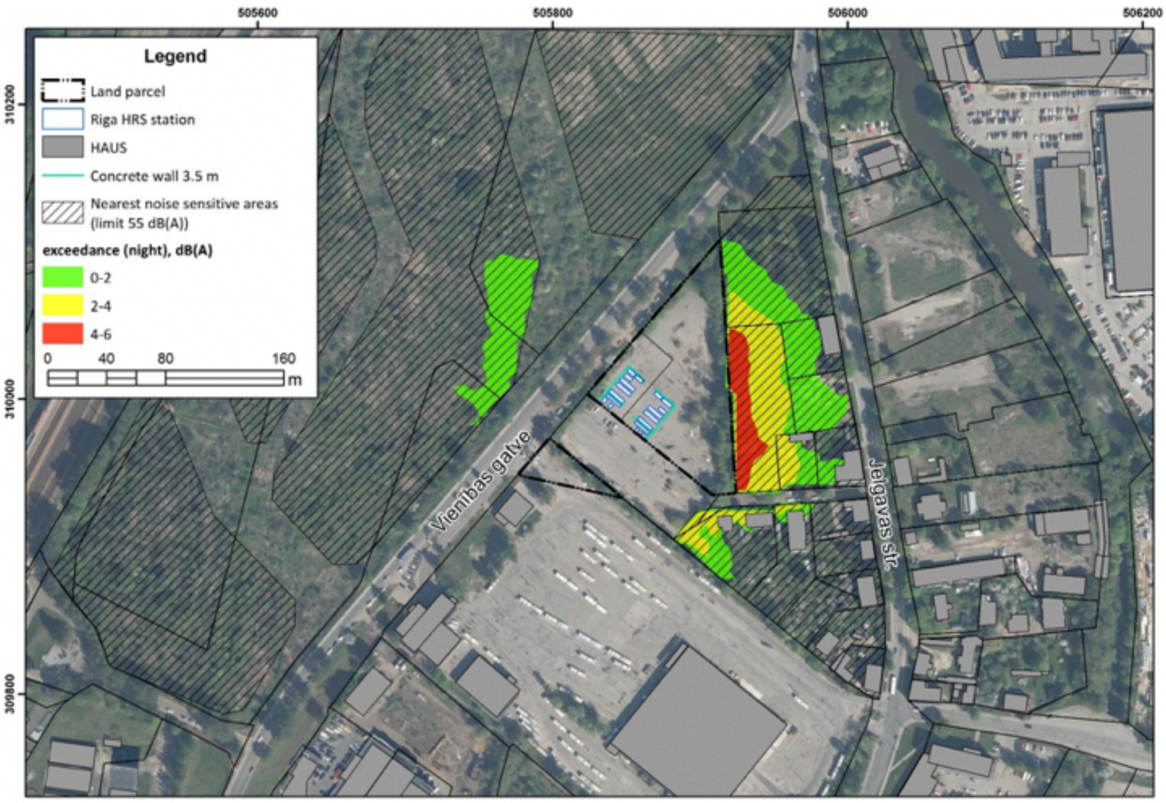


Figure 31 Areas with noise limit value exceedance night scenario.

Calculation results regarding second step Riga HRS upscaling station noise pollution level are shown from Figure 27 to Figure 29, but the areas where the noise limit value is exceeded - Figure 30 and Figure 31.

According to the calculation results, second step Riga HRS upscaling station generated individual noise level exceeds the Cabinet Regulation No. 16 (07.01.2014) environmental noise limit values for the evening and night period in a mixed building territory with a residential function. Regardless of the time of day, the highest calculated noise level in the residential area will reach 61 dB (A).

Although there are not a large number of residential houses in the area of influence of the station, which are subject to the noise level limit value exceedance, however, it should be taken into account that the noise limit values are applicable in accordance with the use function of the territory, as a result of which it must be ensured that noise limits are not exceeded not only near residential houses, but in the entire area of use of the territory.

Comparing HRS stations first step Riga HRS upscaling and second step Riga HRS upscaling variants, it was found that in the case of second step Riga HRS construction the noise limit value is expected to be exceeded also in the evening period – in the area of 69 m^2, as well as the noise level of the area at night will increase by almost 102% reaching 1,35 ha.

Given that the noise level generated by the second step Riga HRS upscaling station will cause environmental noise exceedances, the implementation of the planned activity should be carried out together with noise abatement measures.

4.5 Risk assessment

In assessing the risk of Riga HRS second step upscaling the following sources of risk were considered:

- Natural gas pipeline;
- Hydrogen storages;
- Dispensers;
- Industrial filling panel.

Natural gas pipeline

When 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.

The assessment considers that Riga HRS second step upscaling requires two gas input connections. The total probability of gas pipeline accidents shows in Table 17.

Table 17 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	2.00E-08	4.00E-09	1.20E-9
Leak	5.00E-06 / m/ year	1.00E-07	2.00E-08	6.00E-9

Hydrogen storages

The calculations consider the number of cylinders in hydrogen storage:

- Supply storage (200 bar): 30 gas cylinders;
- Storage (500 bar): 96 gas cylinders;
- Storage (1000 bar): 132 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 18 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-05	3.45E-06	1.80E-06

Continuous release from a hole with an effective diameter of 10 mm	1.00E-05/year	3.00E-04	2.40E-06	1.20E-06
Storage (500 bar)				
Instantaneous release of the entire contents of the gas cylinder	5.00E-07/year	2.40E-05	2.54E-06	1.30E-06
Continuous release from a hole with an effective diameter of 3,3 mm	1.00E-07/year	4.80E-06	7.68E-08	3.84E-08
Storage (1000 bar)				
Instantaneous release of the entire contents of the gas cylinder	5.00E-07/year	3.30E-05	3.50E-06	1.78E-06
Continuous release from a hole with an effective diameter of 3,3 mm	1.00E-07/year	6.60E-06	1.06E-07	5.28E-08

Dispenser

The probability calculations consider dispenser operating time due to the potential hydrogen demand:

- 350 bar dispenser – 1342 hours /year;
- 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 19 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	5.37E-05	2.84E-06	1.45E-06
Leak of the hose	4.00E-05/hour	5.37E-04	4.29E-06	2.15E-06
700 bar dispenser				
Full bore rupture of the hose	4.00E-06/hour	1.10E-06	2.53E-07	2.97E-08
Leak of the hose	4.00E-05/hour	1.10E-05	8.81E-08	4.40E-08

Industrial filling panel (MEGC)

The calculations consider the following H2 characteristics in order to refuel the MEGC system:

- 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 20 H2 MEGC loading 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	7.66E-08	4.06E-09	2.07E-09
Continuous release from a hole the size of the largest connection of MEGC	5.00E-07/year	7.66E-08	6.13E-10	3.06E-10
Full bore rupture of the hose	4.00E-06/hour	4.83E-03	3.86E-05	1.93E-05
Leak of the hose	4.00E-05/hour	4.83E-02	3.86E-04	1.93E-04

The following data is considered for determining H2 MEGC loading time in the fuelling station:

- Loading quantity – 160965 kg/a;
- Loading rate – 120 kg/h.

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.

Table 21 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	-	-
Leak of the hose – gas cloud explosion	-	-
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	-	-

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 and all three 350 bar dispenser are located in one place. Opening with diameter 30 mm assumed as the largest connection of transport module.

The summary 1% lethal exposure zone was obtained by connecting furthest 1% lethal exposure distances around all technological equipment, see Figure 32.

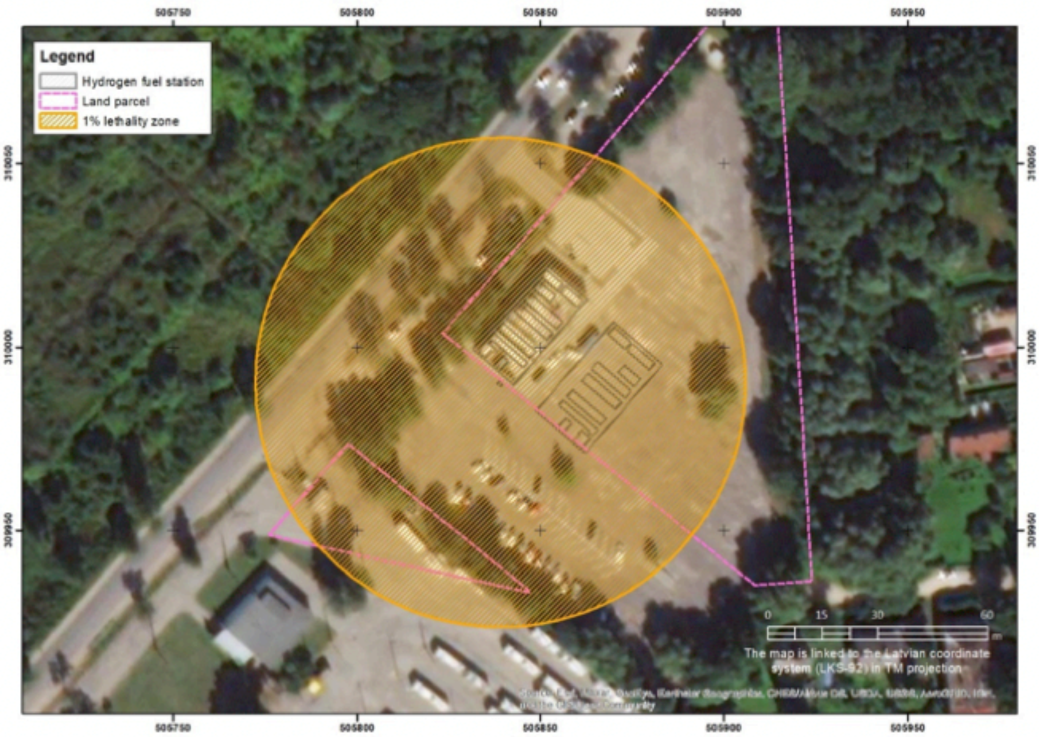


Figure 32 1 % lethal exposure map.

Risk level of intended activity

For the development of the individual risk model, the data available at the Latvian Environment, Geology and Meteorology Centre on meteorological conditions at the Riga meteorological observation station for the period 2008-2017 were used. The results of individual risk modelling with Riskcurves are shown in the Figure 33.

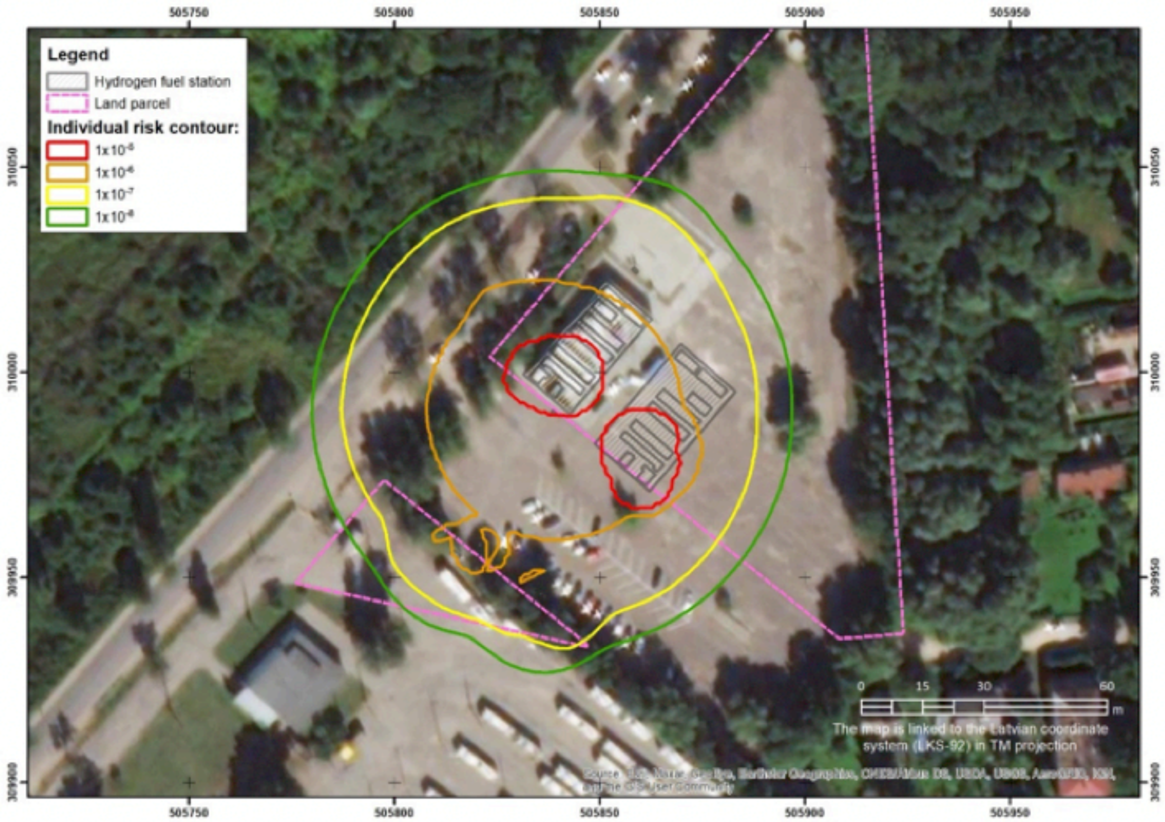


Figure 33 Contour of the individual risk around a hydrogen filling station.

4.6 Conclusion of Riga HRS second step upscaling.

By deploying more FCE-vehicles the hydrogen availability in Riga HRS must be increased. The foreseen option to increase the hydrogen production to 1200kg per day would allow to refuel at least 39 FCE-vehicles (see Table 11). As for the price of deployment the costs to deploy such HRS would reach around 15’000’000 EUR. The increased hydrogen demand would allow to decrease the price of hydrogen and even achieve 5,2 EUR per kg (see Figure 20). Compared to the first step upscaling the price per hydrogen is decreased by 1,04 EUR but the costs to deploy HRS increases by 6’500’000 EUR. Additionally the HRS would occupy larger land plot and in general a second HRS is built next to the already existing one.

From Risk perspective, the results of accident consequences modelling show that there are possible accident scenarios at the station, the consequences of which may endanger human life outside the station area. The highest hydrogen release has been considered in the case of an H2 MEGC accident, when in the event of an unfavourable condition, all the gas in the container can be released. In the event of hydrogen spillage and combustion, the endangered area can reach up to 63 m from the scene of the accident, and in the case of Second step Riga HRS upscaling, this hazard can be expected on the adjacent street and beyond in mixed building territory with residential function.

The results of the individual risk assessment show that the internationally accepted individual risk level of degree 1×10^{-6} is also achieved outside the boundary of the object, but there are no other objects of economic activity or populated areas in the high-risk area.

According to the actual use currently in the vicinity of the station, the second step Riga HRS upscaling does not pose an increased risk to the surrounding population or economic activity compared to already located HRS. Note that the responsible entities will evaluate the further development of the surrounding area in conjunction with the intension to deploy HRS.

Planned amount of hydrogen in the object – 1740 kg which is > 1000 kg but < 5000 kg. Consequently, this object is Object of Increased Danger of Category C and Civil protection plan must be prepared.

5. Additional HRS in Region – Jelgava

AS one of the options to deploy additional HRS in region is to deploy a station in Jelgava. For Jelgava the public transport operator LLC "Jelgavas autobusu parks" is looking forward to deploy FCE-vehicles for public transportation. Unfortunately, the city of Jelgava is not located on the North-sea-Baltic Sea core network corridor.

Figure 34 The city of Jelgava location in Latvia

The intension would e to deploy the hydrogen filling and production station SIA "Jelgavas Autobusu parks" bus depot Meiju ceļš 64. The hydrogen production would be performed using water-electrolysis process with total production capacity of 1290 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 30 FCE-buses that are used for public transport operations within city boundaries. Additional demand would be secured by novel FCE-coach that would be used by two bus operators. Overall projected demand is included in Table 22. Considering that the buses must be refuelled in 6 hours, the equipment is modulated to ensure this aspect.

Table 22 Potential Hydrogen demand per day[3]

Vehicle	Units	H2(kg)
12m FCE-bus	30	426
Intercity (FCE-coach)*	51	699
FCE-passenger	3	3

[3] More insight on the hydrogen demand can be found in H2NODES M16 "Mobilising and engaging local and regional stakeholders in Riga".

FCE-waste treatment	4	48
Total		**1176**

*Intercity (FCE-coach) includes various types of buses i.e. Class II; III; Class A buses.

If needed, The Jelgava HRS would serve also as a hydrogen supply for Movable HRS and would allow to deploy a number of small scale hydrogen filling stations in the Region. The overall scheme of Jelgava HRS is included in Figure 35.

5.1 Technological solutions

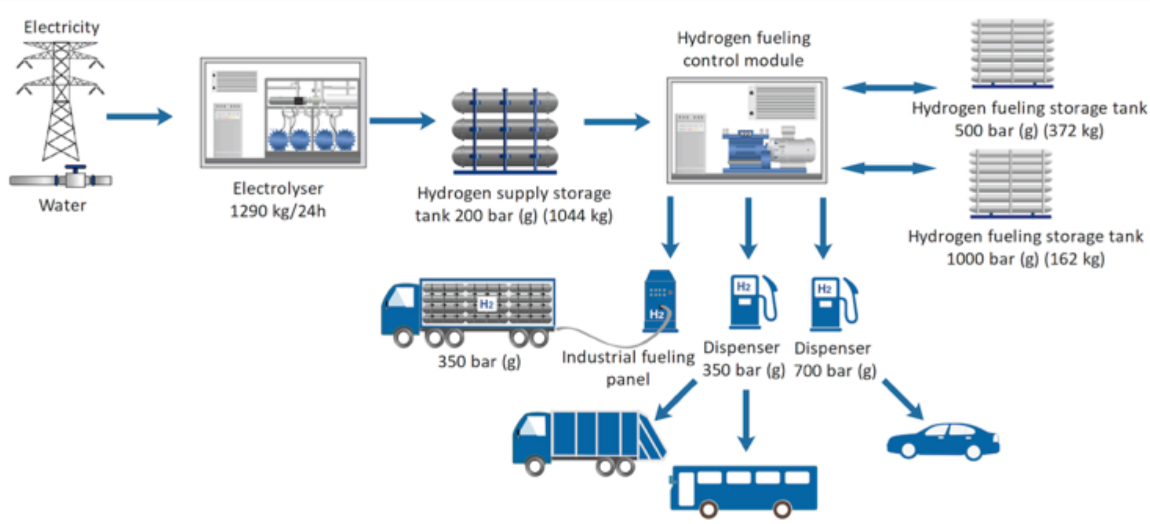


Figure 35 Scheme of Jelgava HRS.

For Jelgava HRS the hydrogen production will be made using water-electrolysis process. Therefore, green hydrogen production can be achieved. 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 full operating.

A total number of 3 electrolysers with production capacity of 430kg/H_2/24h would be installed. For the means to increase the hydrogen pressure two separate hydrogen compressors with capacity of 300NM^3/h are required.

For the storage and refuelling part, the equipment is similar to the ones that are used in the Riga HRS upscaling first and second steps. The characteristics can be seen in Figure 36.

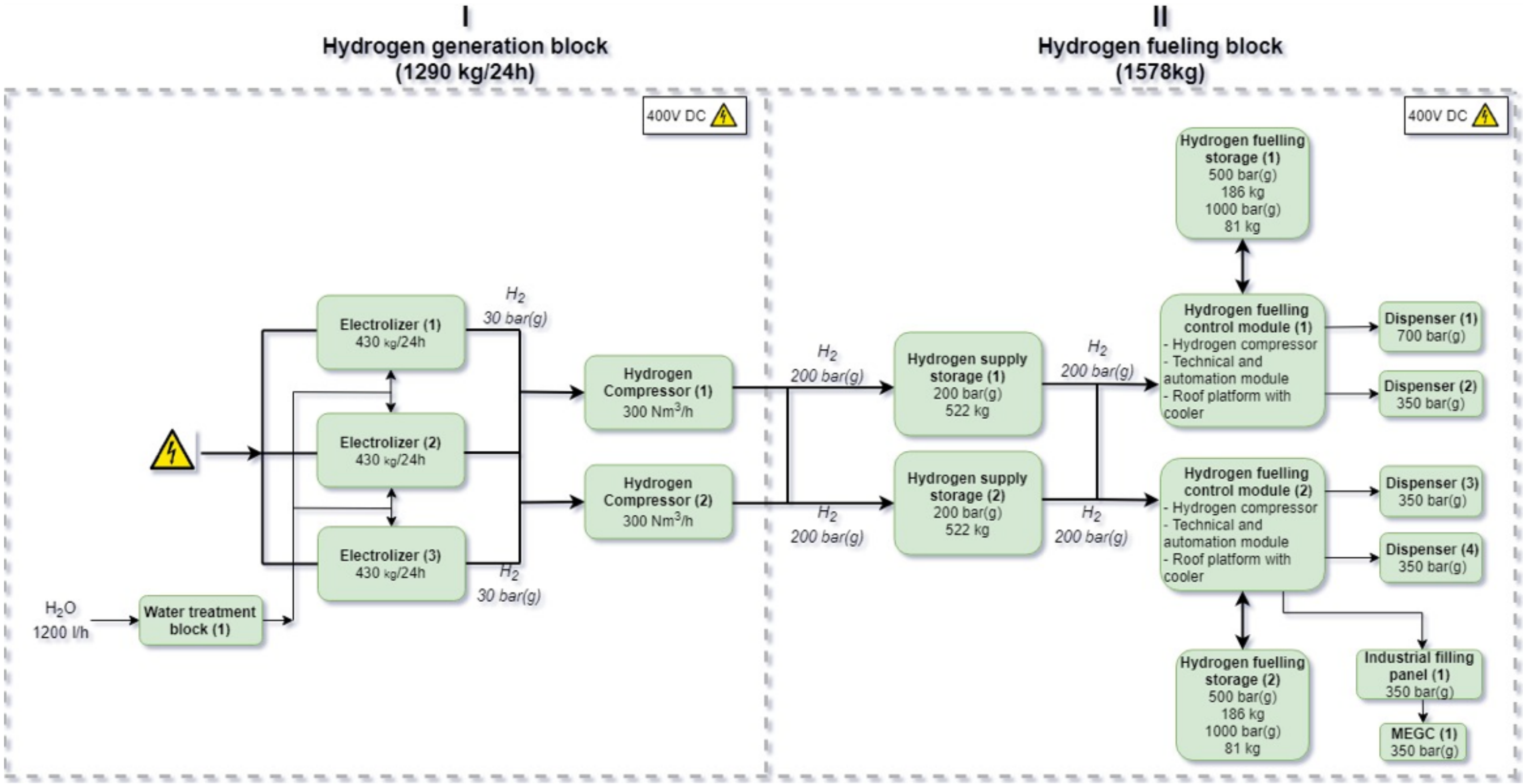


Figure 36 Equipment of Jelgava HRS

The initial technical specification of the Jelgava HRS is summarized in Table 23.By developing the technical specification, the modularity principles were considered 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 23 technical specification of Jelgava HRS.

System description	Technical parameters	Quantity
Electrolyser	Qmax = 430 kg/24h	3
Hydrogen compressor unit	Qmax = 300 Nm3/h	2
Hydrogen supply storage	P = 200 bar V = 522 kg	2
Hydrogen fuelling storage	P = 500 bar V = 186 kg	2
Hydrogen fuelling storage	P = 1000 bar V = 162 kg	2
Hydrogen fuelling control module	Qmax: 48.5 kg/h Maximum design pressure: 1000 bar(g)	2
Dispenser	P = 350 bar	3
Dispenser	P = 700 bar	1
Industrial filling panel	P = 350 bar	1
Water treatment block	Qmax = 1200 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 24.

Table 24 Utility connections for Jelgava HRS.

System description	Measure	Technical requirements
Water connection	l/h	1200
Waste water connection	l/h	1200
Electricity 400V	kW	5 500

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 37)

1kg H2 cost breakdown

Cost per 1kg H2, in € (24m after launch)		2025
Cost position	Ref	EUR
Producde H2 kg cost		1,94
Employees		0,12
Services		0,45
Depreciation		1,38
Financing costs		0,04
Total cost per 1kg H2 produced (Yr Avg)		3,93
Applied premium		9,0%
Proposed sell price before taxes, EUR		4,28

Figure 37 1kg H2 cost breakdown of Jelgava HRS

The total price estimates of HRS according to suitable technologies in market reaches around 13’000’000 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 price that could be achieved in Jelgavas HRS is lower than compared to Riga HRS upscaling both steps. This is due to the aspect that different technologies are used (Steam-methane reforming for Riga HRS and Water-electrolysis for Jelgava HRS). The total price does not include land acquisition costs. The price per electricity is calculated according to NordPool prices and therefore the transmission fees are excluded from calculations.

Space requirements

The overall HRS deployment land plot would occupy 1000 sq.m (see Figure 38).

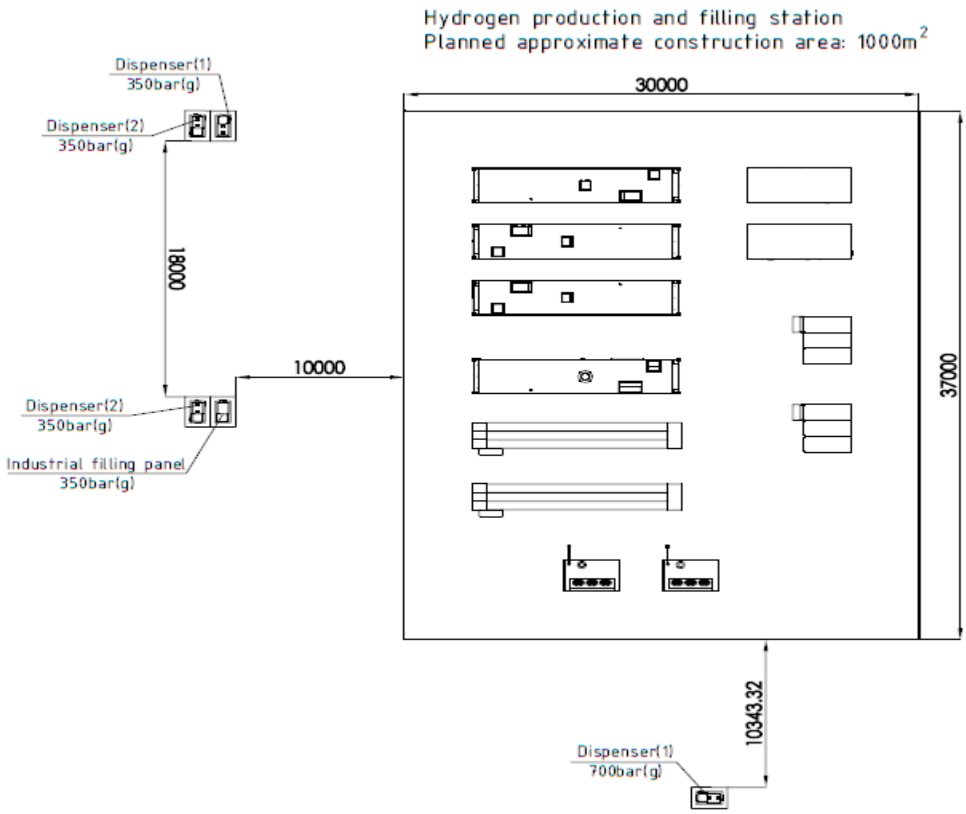


Figure 38 Space requirements of Jelgava HRS.

By combining the previous information, the first visualisation of the Jelgava HRS is made (Figure 39).

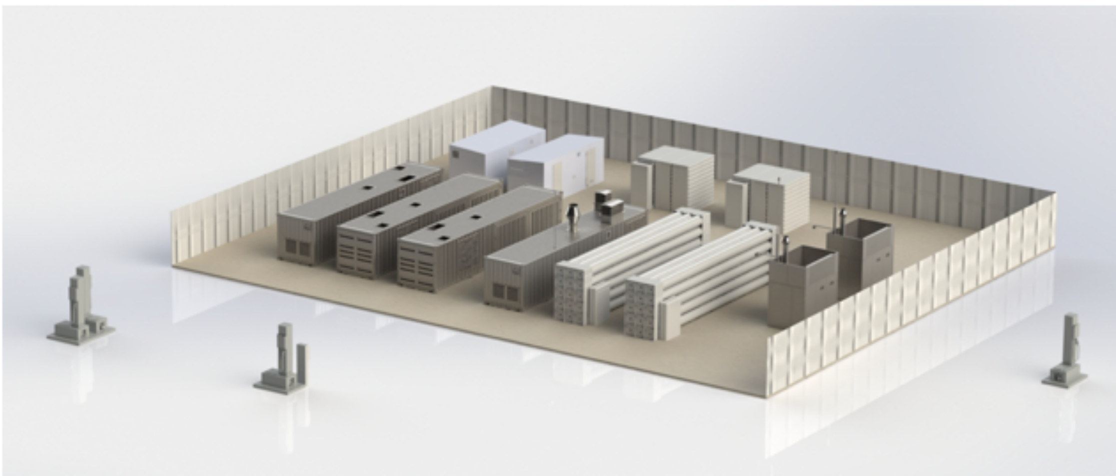


Figure 39 First visualization of Jelgava HRS

5.2 Evaluation of HRS deployment land plot.

HRS Jelgava location is planned in the area, the type of use of which according to the Jelgava city spatial plan 2009-2021 is an industrial construction territory. According to the Jelgava City Council binding regulations No. 17-23 of 23 November 2017 “Regulations on the use and construction of the territory”, the main types of use of the industrial construction territory are light and heavy industry, as well as construction of primary processing enterprises. As result the hydrogen refuelling station could be deployed in the intended location.

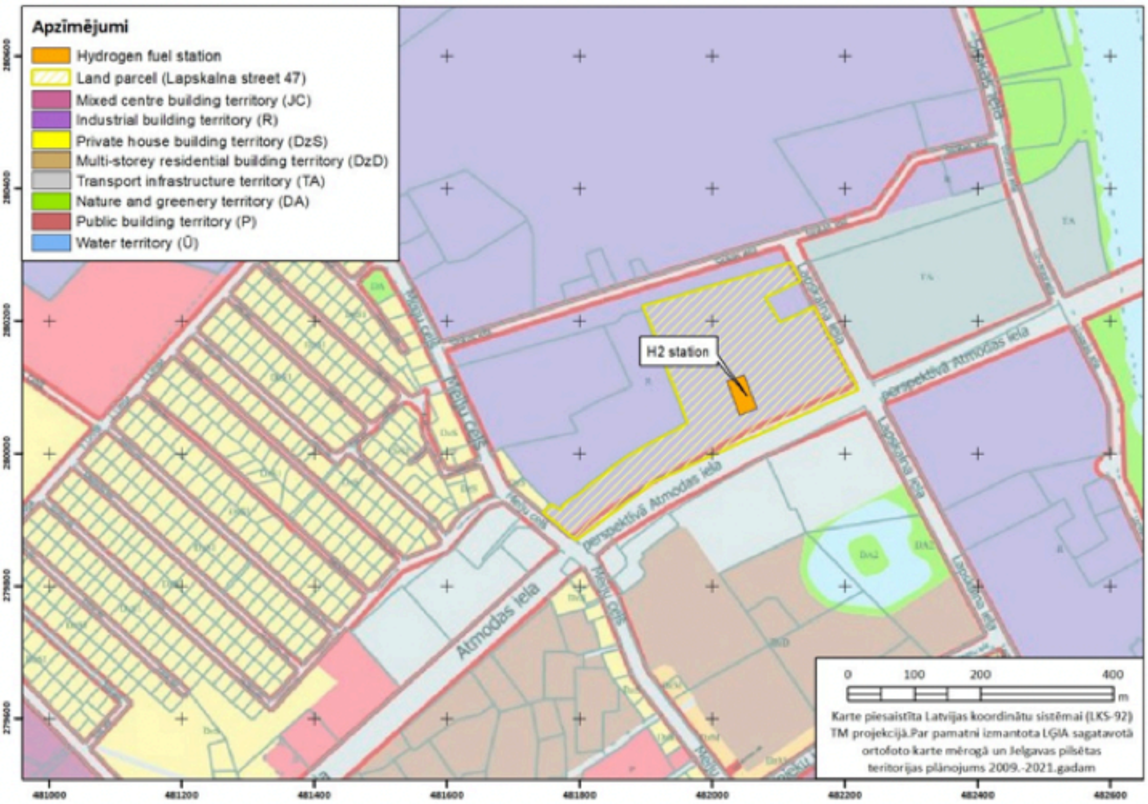


Figure 40 Location of HRS Jelgava.

Information on the distances of the location of the planned station to other objects of economic activity or populated areas is shown in the Table 25.

Table 25 Description of the surroundings of the intended activity.

The type of areas/objects that could be affected by the intended activity	**Distance (m) from intended activity**
Nearest residential house	200
Nearest multi-storey residential house	230 (five-storey apartment house)
Nearest public building	535 (kindergarten) 620 (store)
Nearest enterprise	70 (gas station) 315 (administration building of Jelgava Bus Park)
Transport infrastructure objects	180 (Slokas street) 230 (Lapskalna street) 300 (Meiju road)

The location of Jelgava HRS corresponds to the spatial plan.

5.3 Assessment of air quality

It is planned to use electricity and water for hydrogen production, separating hydrogen from water in the electrolysis process. Electrolysis equipment does not require constant maintenance and has no moving parts. These facilities are considered modular, making them suitable for decentralized use close to residential, commercial and industrial areas. During the electrolysis process only, hydrogen and oxygen are released, as well as heat loss may occur, but in this process there are no emissions of pollutants into the air [4].

In the process of water electrolysis, oxygen is produced as a by-product of hydrogen production. If the electrolysis process requires the production of a large amount of hydrogen, its by-products will also be produced in large quantities. In such a situation, it is advisable to completely utilize (use) the by-product - oxygen, as oxygen is an important industrial gas used in many processes, such as incineration, semiconductor production, wastewater treatment, etc. Efficient use of oxygen can improve the energy efficiency of certain industrial processes. Although oxygen can be safely released into the atmosphere during the hydrogen production process without harming the environment, the literature suggests that its possible economic use should be considered[5]. Hydrogen production by electrolysis is not associated with air pollution.

5.4 Noise pollution

Electrolysis equipment is considered to be non-noise and does not emit sound during the electrolysis process itself[6]. Auxiliary equipment, such as compressors, which generate noise emissions are used to ensure the operation of the station. Information on the planned noise sources at Jelgava HRS station, their location, capacity and noise level were provided by the Customer.

Considering that the operation of the hydrogen station is continuous around the clock, the noise level for the noise indicators L_{day}, $L_{evening}$ and L_{night} was calculated.

Information on the noise level and duration of the equipment included in the noise assessment is summarized in Table 26. Noise sources are placed in the acoustic model as three-dimensional objects, where each of the source planes (regardless of the surface area) creates the same sound pressure level at the receiving point.

For the development of the noise map, the data provided by the Latvian Environment, Geology and Meteorology Center on meteorological conditions from the Riga observation station in 2019 were used.

[4] https://www.eia.gov/energyexplained/hydrogen/production-of-hydrogen.php

[5] https://www.researchgate.net/publication/222650677_Effective_utilization_of_by-product_oxygen_from_electrolysis_hydrogen_production

[6] https://www.sciencedirect.com/topics/engineering/electrolytic-hydrogen-production

Table 26 Operating time of noise sources involved in the hydrogen production and filling process and the resulting sound pressure level at the receiving point.

Name of noise source (container)	Relative height of the plane, m	Working hours, h/year			Distance of the receiving point from the source plane	Sound pressure level at the receiving point, $L_{Aeq,T}$ dB(A)
		Day-time (07:00-19:00)	Evening (19:00-23:00)	Night (23:00-07:00)		
Electrolyzer (1)	2,8	4380	1460	2920	1 m	40
Electrolyzer (2)	2,8	4380	1460	2920	1 m	40
Electrolyzer (2)	2,8	4380	1460	2920	1 m	40
Hydrogen compressor (1) Hydrogen compressor (2)	2,8	4380	1460	2920	1 m	80
Hydrogen fueling control module (1)	2,8	4380	1460	2920	5 m	60 (day and evening) 50 (at night)
Hydrogen fueling control module (2)	2,8	4380	1460	2920	5 m	60 (day and evening) 50 (at night)
Automation and operator module	2,8	4380	1460	2920	1 m	75

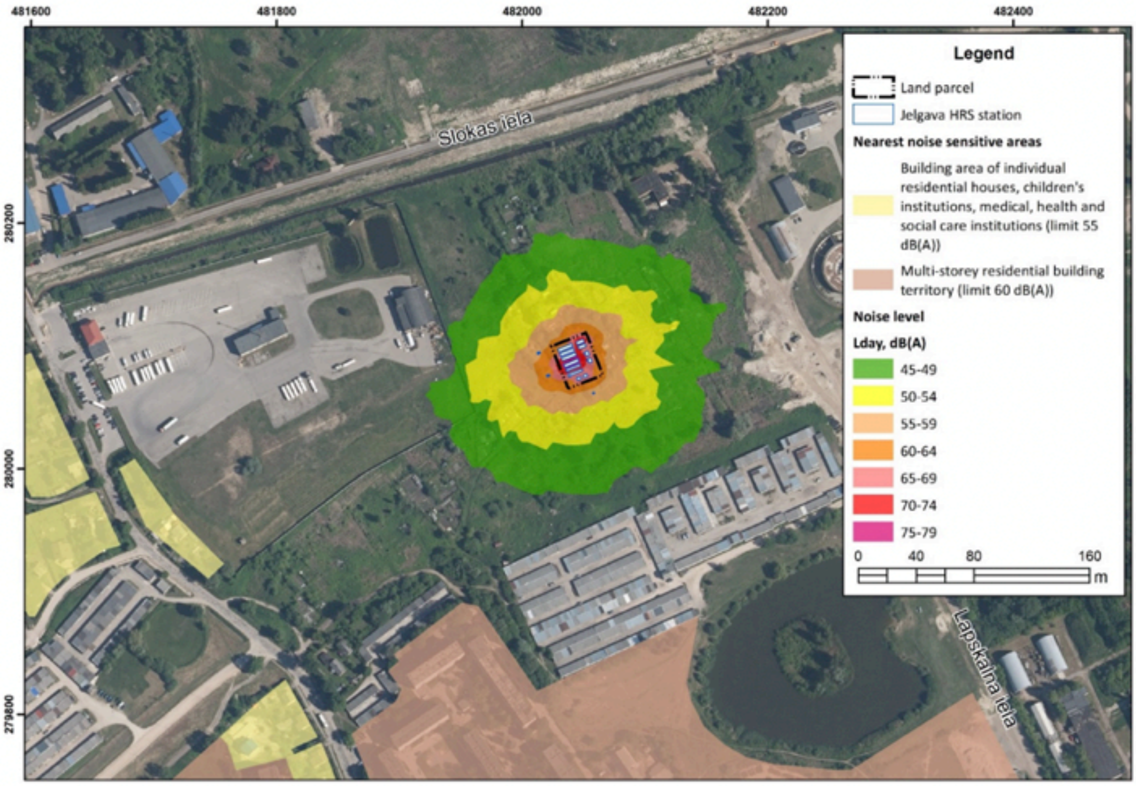


Figure 41 Noise exposure, day scenario.

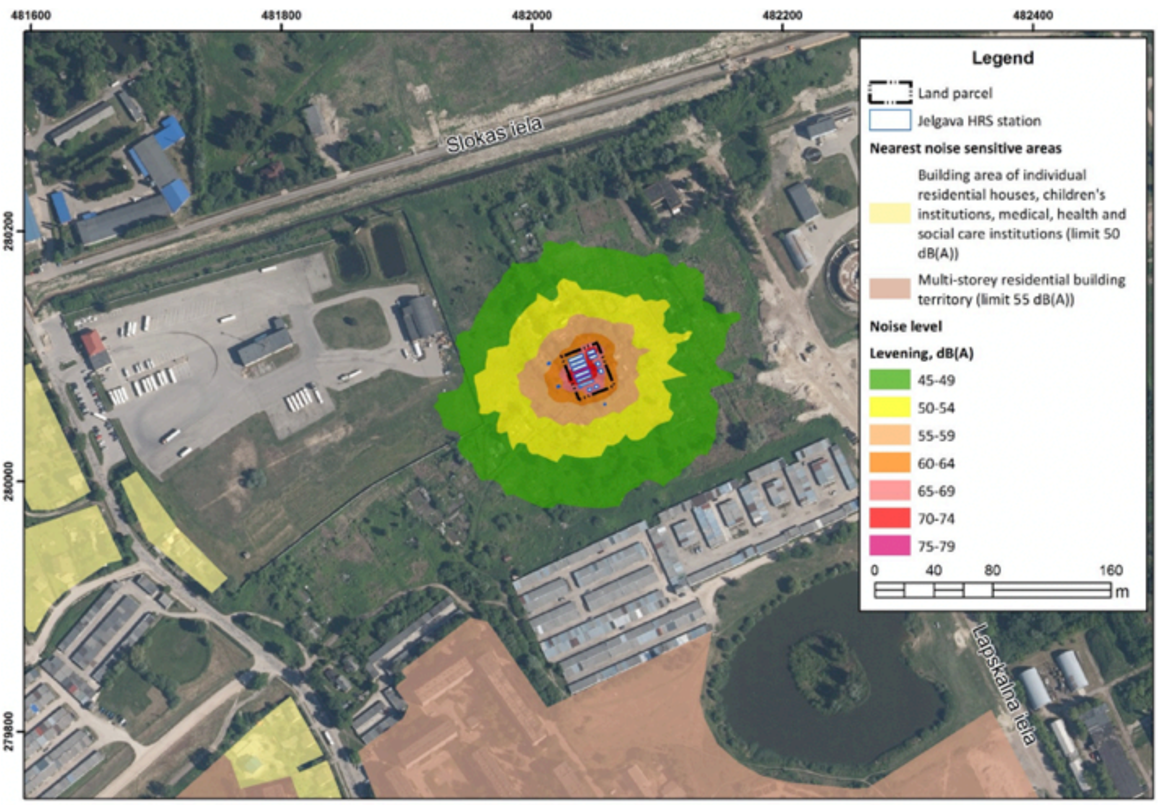


Figure 42 Noise exposure, evening scenario.

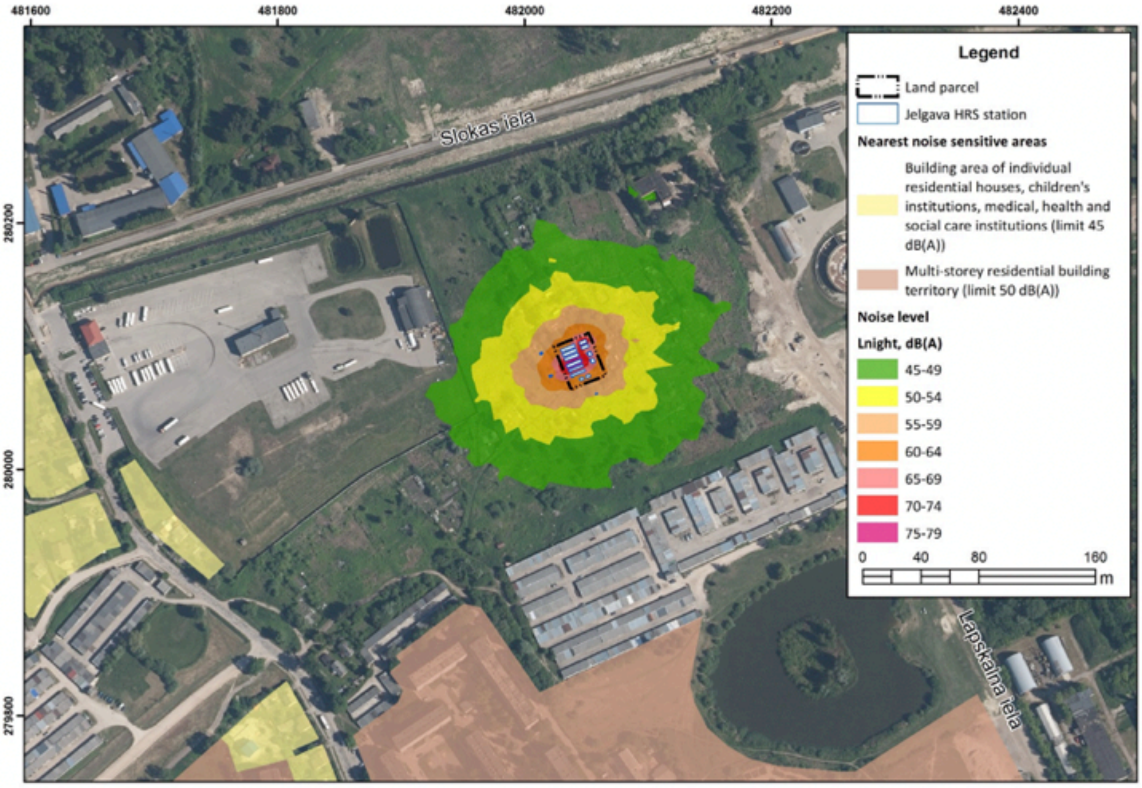


Figure 43 Noise exposure, night scenario.

The results of noise level dispersion, which characterize the individual noise level generated by Jelgava HRS station during day, evening and night periods, are shown from Figure 41 to

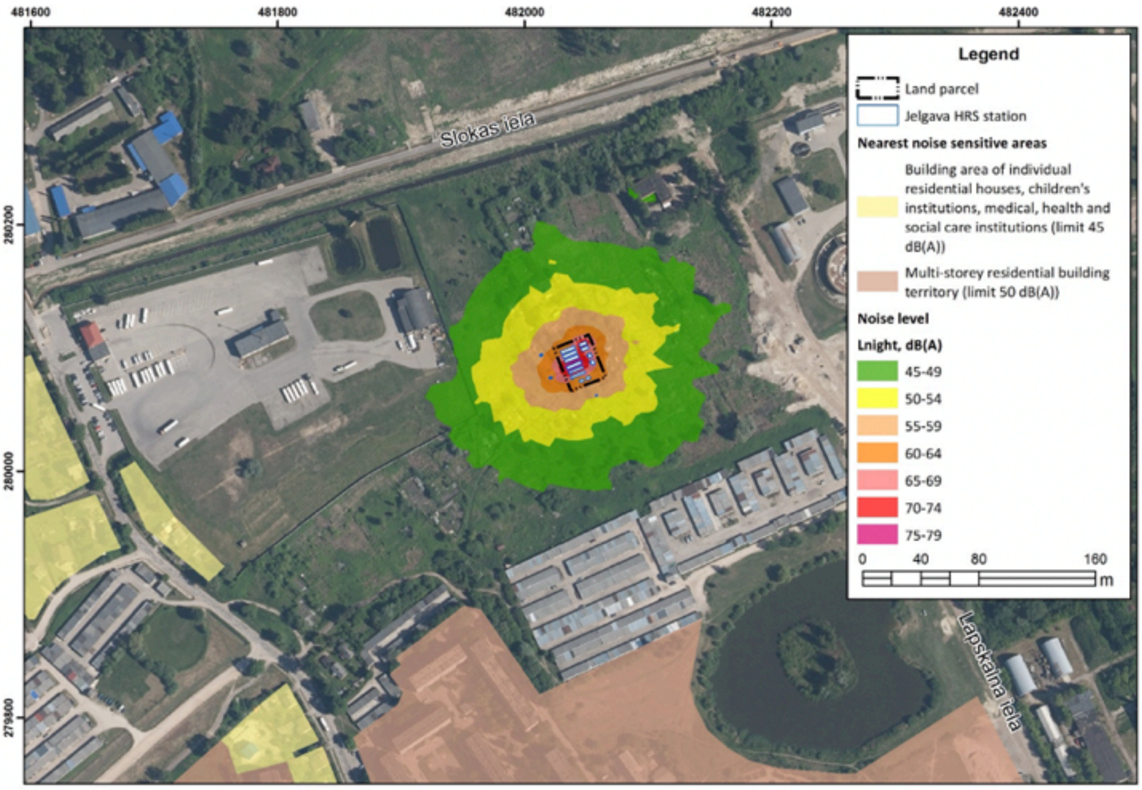


Figure 43.

Evaluating the results of the calculations, it was established that the noise generated by Jelgava station will not exceed the Cabinet of Ministers Regulation no. 16 (07.01.2014.) Specified environmental noise limits in nearby residential construction territories, if during the operation of the station equipment with a significantly higher noise level will not be used as assumed in the calculations.

5.5 Risk assessment

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

- Hydrogen storages;
- Dispensers;
- Industrial filling panel.

Hydrogen storage

The calculations consider the number of cylinders in hydrogen storage:

- Supply storage (200 bar): 30 gas cylinders;
- Storage (500 bar): 96 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 27 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-05	3.45E-06	1.80E-06
Continuous release from a hole with an effective diameter of 10 mm	1.00E-05/year	3.00E-04	2.40E-06	1.20E-06
Storage (500 bar)				
Instantaneous release of the entire contents of the gas cylinder	5.00E-07/year	4.80E-05	2.54E-06	1.30E-06
Continuous release from a hole with an effective diameter of 3,3 mm	1.00E-07/year	9.60E-06	7.68E-08	3.84E-08

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 consider dispenser operating time:

- 350 bar dispenser – 2707 hours /year
- 700 bar dispenser – 17 hours / year

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

Table 28 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	1.08E-04	5.74E-06	2.92E-06
Leak of the hose	4.00E-05/hour	1.08E-03	8.66E-06	4.33E-06
700 bar dispenser				
Full bore rupture of the hose	4.00E-06/hour	6.60E-07	1.52E-07	1.78E-08
Leak of the hose	4.00E-05/hour	6.60E-06	5.28E-08	2.64E-08

Industrial filling panel (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 29 H2 MEGC loading 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	1.54E-07	8.19E-09	4.17E-09
Continuous release from a hole the size of the largest connection of MEGC	5.00E-07/year	1.54E-07	1.24E-09	6.18E-10
Full bore rupture of the hose	4.00E-06/hour	9.74E-03	7.79E-05	3.90E-05
Leak of the hose	4.00E-05/hour	9.74E-02	7.79E-04	3.90E-04

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

- Loading quantity – 324791,6 kg/a;
- 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. 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.

Table 30 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	-	-
Leak of the hose – gas cloud explosion	-	-
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	-	-
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	-	-

The summary 1% lethal exposure zone was obtained by connecting furthest 1% lethal exposure distances around all technological equipment, see Figure 44. Hydrogen discharge and jet fire have been considered in the accident scenarios for filling pipes in the dispensers.

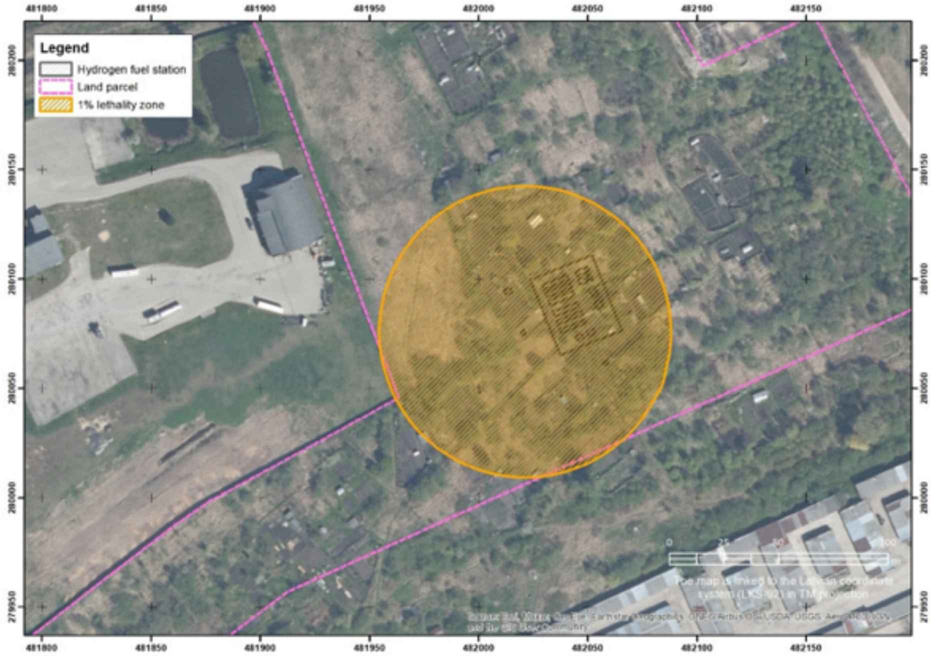


Figure 44 1 % lethal exposure map of Jelgava HRS.

Risk level of intended activity

For the development of the individual risk model, the data available at the Latvian Environment, Geology and Meteorology Center for the period 2008-2017 were used. The results of individual risk modelling with Riskcurves are shown in the Figure 45.

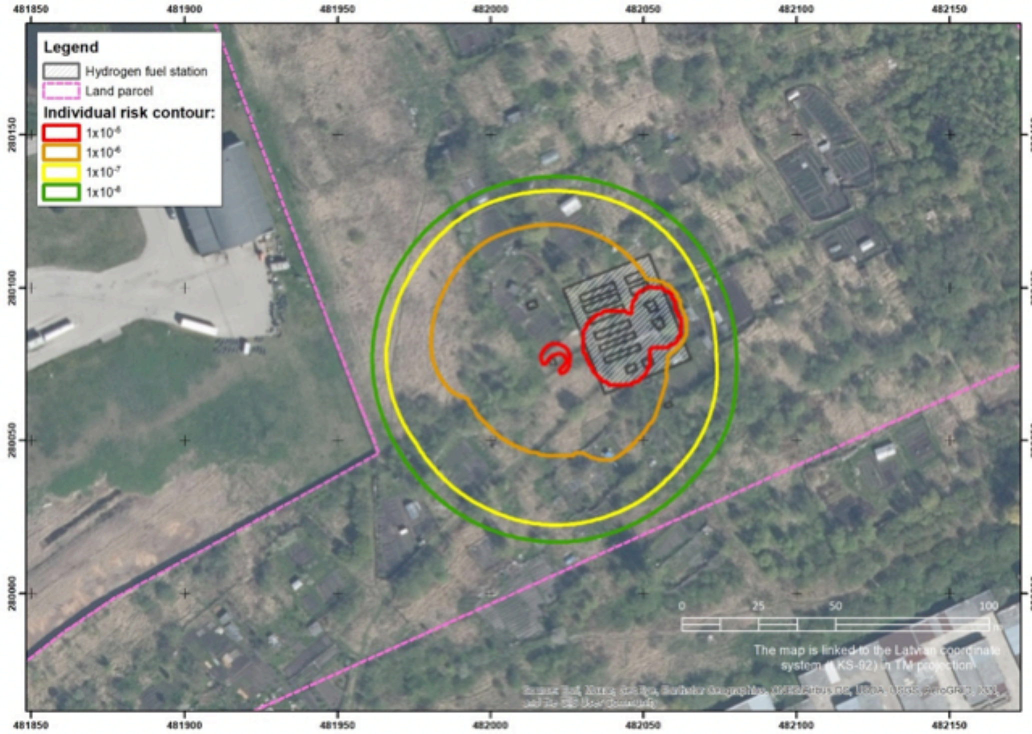


Figure 45 Contour of the individual risk around a hydrogen filling station.

5.6 Conclusion of Jelgava HRS

The Jelgava HRS would achieve green hydrogen availability in Latvia. The foreseen hydrogen production capacity would be increased to 1290kg per day that would allow to refuel at least 88 FCE-vehicles (see Table 22). As for the price of deployment the costs to deploy such HRS would reach around 13’000’000 EUR. The significant hydrogen demand would allow to decrease the price of hydrogen and even achieve 4,28 EUR per kg (see Figure 37). Compared to the Riga second step upscaling the intension to deploy Jelgava HRS is cheaper and better price per kg is achievable due to the fact that that different technologies are used (Steam-methane reforming for Riga HRS and Water-electrolysis for Jelgava HRS). The total price does not include land acquisition costs. Additionally, the price per electricity is calculated according to NordPool prices and therefore the transmission fees are excluded from calculations.

From Risk perspective the results of accident consequences modelling show that there are possible accident scenarios at the station, the consequences of which may endanger human life outside the station area. However, this level of threat is expected only within the boundaries of the industrial construction area and does not reach populated areas.

The results of the individual risk assessment show that the internationally accepted individual risk level of 1×10^{-6} is achieved around the equipment of the hydrogen filling station, but there are no other objects of economic activity or populated areas in the high-risk area.

Planned amount of hydrogen in the Jelgava HRS – 1578 kg which is > 1000 kg but < 5000 kg. Consequently, this object is Object of Increased Danger of Category C and Civil protection plan must be prepared.

6. Large scale hydrogen production and refuelling station in Riga

As the near-term strategy foresees to deploy zero-emission buses in Riga, to perform the public transport operations, a large-scale HRS for Riga Satiksme is evaluated. The hydrogen production would be performed using water-electrolysis process with total production capacity of 4940 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 231 FCE-buses that are used for public transport operations. Taking into account the Rigas Satiksme practice, the buses must be refuelled during night time in 6 hours, therefore the equipment is modulated to ensure this aspect. The potential hydrogen demand is estimated in Table 31.

Table 31 Potential Hydrogen demand per day[7]

Vehicle	Units	H2(kg)
FCE-passenger	5	5
12m FCE-bus	68	1039,5
15m FCE-bus	58	1028,5
18m FCE-bus	105	2237,5
FCE-heavy duty	8	480
Shunting locomotive*	1	150
Total		**4940,5**

*The hydrogen for shunting locomotive would be delivered using MEGC to Movable HRS.

The additional hydrogen demand would be secured by 8 heavy duty vehicles and one shunting locomotive the projected volume for these vehicles reaches around 630kg/H2 and would be refuelled outside the 6-hour window that is dedicated only for FCE-buses therefore additional dispensers are necessary and higher capacity of fuelling storage must be achieved. 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. Note that for calculations the 700bar dispenser is foreseen only to achieve the availability to refuel passenger vehicles. The overall scheme of Large-Scale Riga HRS is included in Figure 46.

[7] More insight on the hydrogen demand can be found in H2NODES M16 "Mobilising and engaging local and regional stakeholders in Riga".

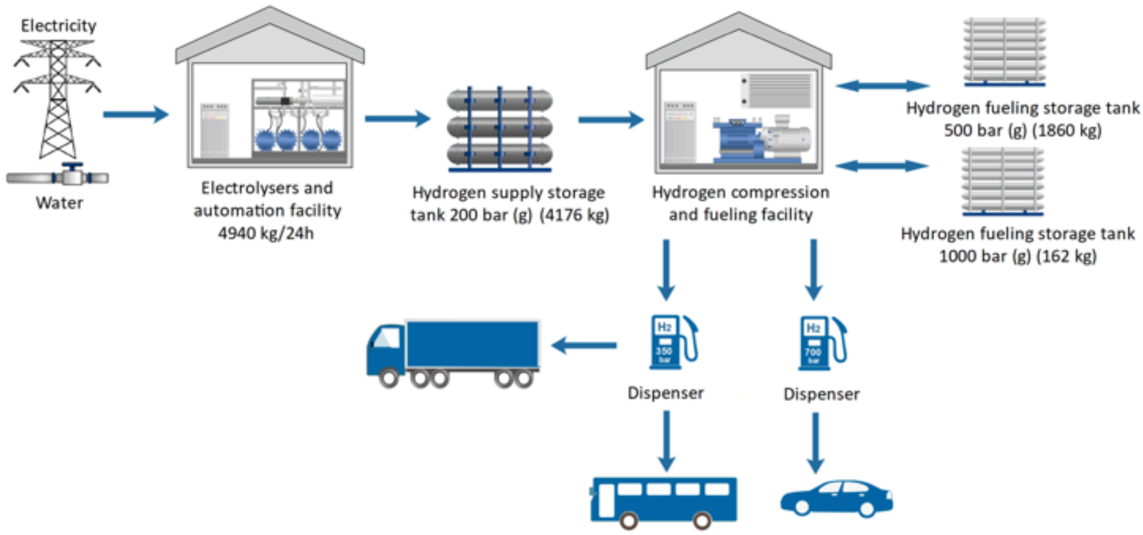


Figure 46 Scheme of Large scale Riga HRS.

6.1 Technological solutions

For Large scale Riga 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 full operating.

A total number of 5 electrolysers with each production capacity of 1000kg/H_2/24h would be installed. For the means to increase the hydrogen pressure four separate hydrogen compressors with capacity of 580NM^3/h are required.

For the storage it would be necessary to deploy 8 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 3 separate compressor modules that would increase the pressure of hydrogen for different levels. The Hydrogen fuelling storage consist of 10 units with various pressures and capacities (see Figure 47). In total to secure the 6-hour refuelling window for FCE-buses it is necessary to deploy eleven 350 bar dispensers. In general, this is a hydrogen production and refuelling facility.

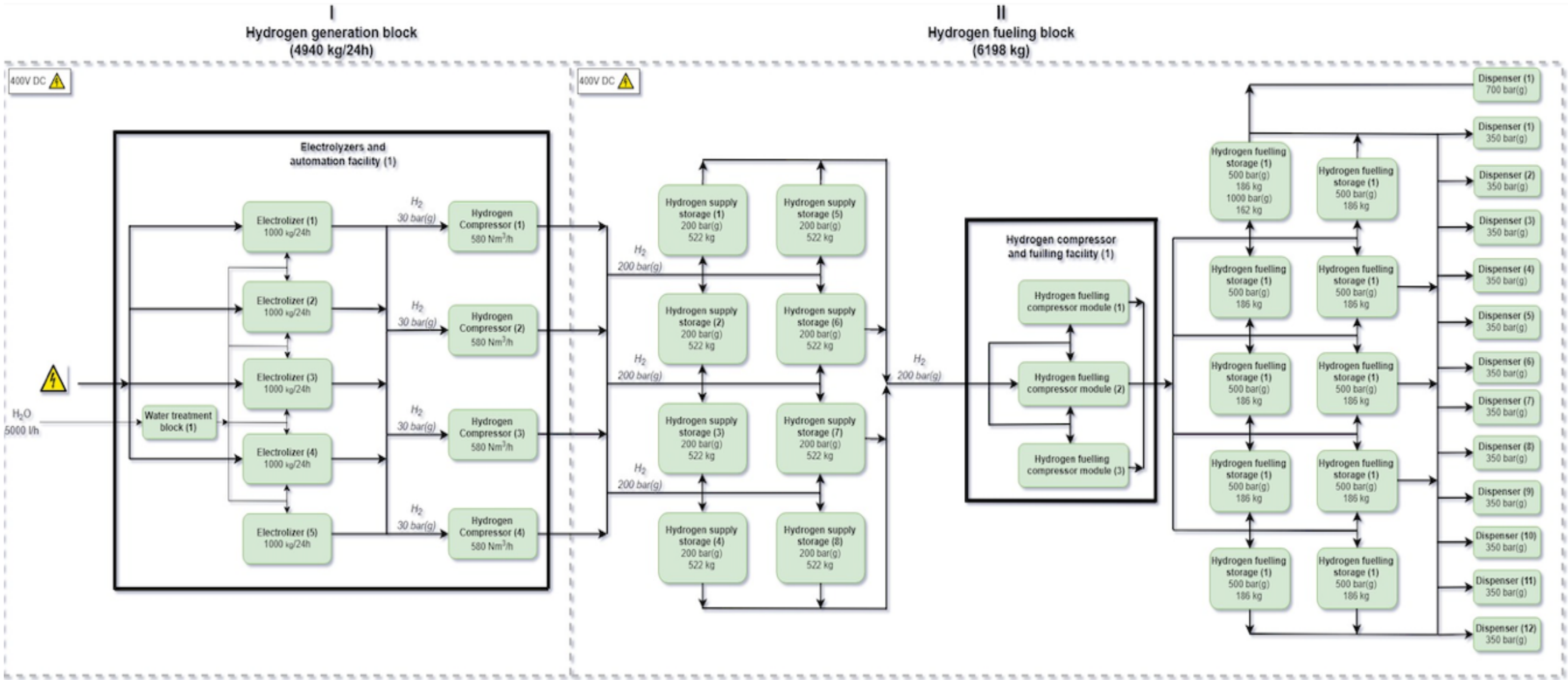


Figure 47 Technological solution of Large-Scale Riga HRS

The initial technical specification of the Large-Scale Riga HRS is summarized in Table 32. By developing the technical specification, the modularity principles were considered 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 32 Technical specification of Large-scale Riga HRS facility.

System description	Technical parameters	Quantity
Electrolyzers and automation facility	Qmax = 4940 kg/24h H2 outlet pressure=200bar	1
Hydrogen supply storage	P = 200 bar V = 522 kg	8
Hydrogen fuelling storage	P = 500 bar V = 186 kg	10
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	11
Dispenser	P = 700 bar	1
Water treatment block	Qmax = 7000 l/h	1

Utility connections

In order to deploy the facility, it is necessary that the utility connections could secure the figures listed in Table 33.

Table 33 Utility connections of Large-scale Riga HRS.

System description	Measure.	Technical requirements
Water connection	l/h	7000
Waste water connection	l/h	7000
Electricity 400V	MW	27.5

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 48).

1kg H2 cost breakdown

Cost per 1kg H2, in € (24m after launch)		2025
Cost position	Ref	EUR
Producde H2 kg cost		2,31
Employees		0,03
Services		0,27
Depreciation		0,79
Financing costs		0,02
Total cost per 1kg H2 produced (Yr Avg)		3,43
Applied premium		9,0%
Proposed sell price before taxes, EUR		3,74

Figure 48 1kg H2 cost breakdown of Large-scale Riga HRS.

The total price of HRS reaches around 30’000’000 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 cost per kg of hydrogen is much cheaper than in Riga HRS upscaling steps due to the fact that that different technologies are used (Steam-methane reforming for Riga HRS and Water-electrolysis for Jelgava HRS and Large-scale Riga HRS). The total price does not include land acquisition costs. Additionally, the price per electricity is calculated according to NordPool prices and therefore the transmission fees are excluded from calculations. Calculations are based on estimations that the Large-scale Riga HRS is working in full capacity.

Space requirements

The overall HRS deployment would occupy 3360 sq.m of possible land plot (see Figure 49).

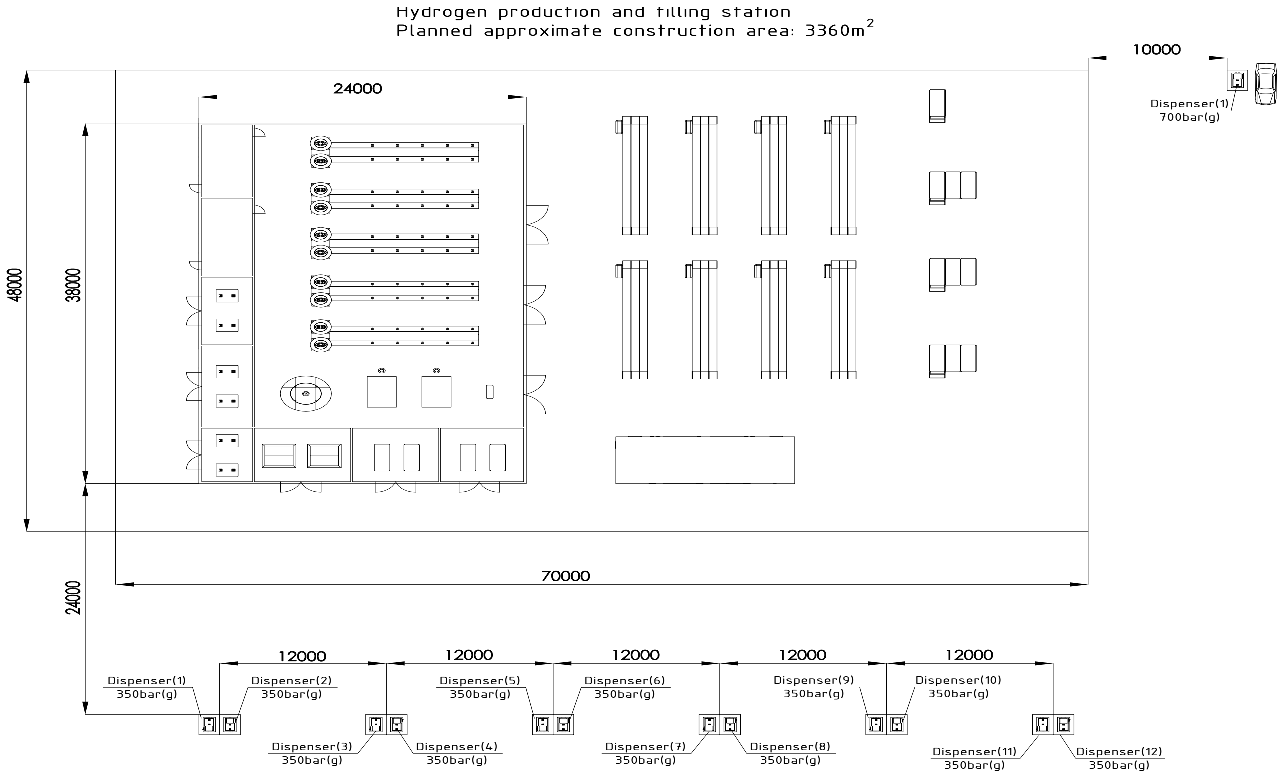


Figure 49 Space requirements of Large-scale Riga HRS

By combining the previous information, the first visualization of the Large-Scale Riga HRS is made (Figure 50)

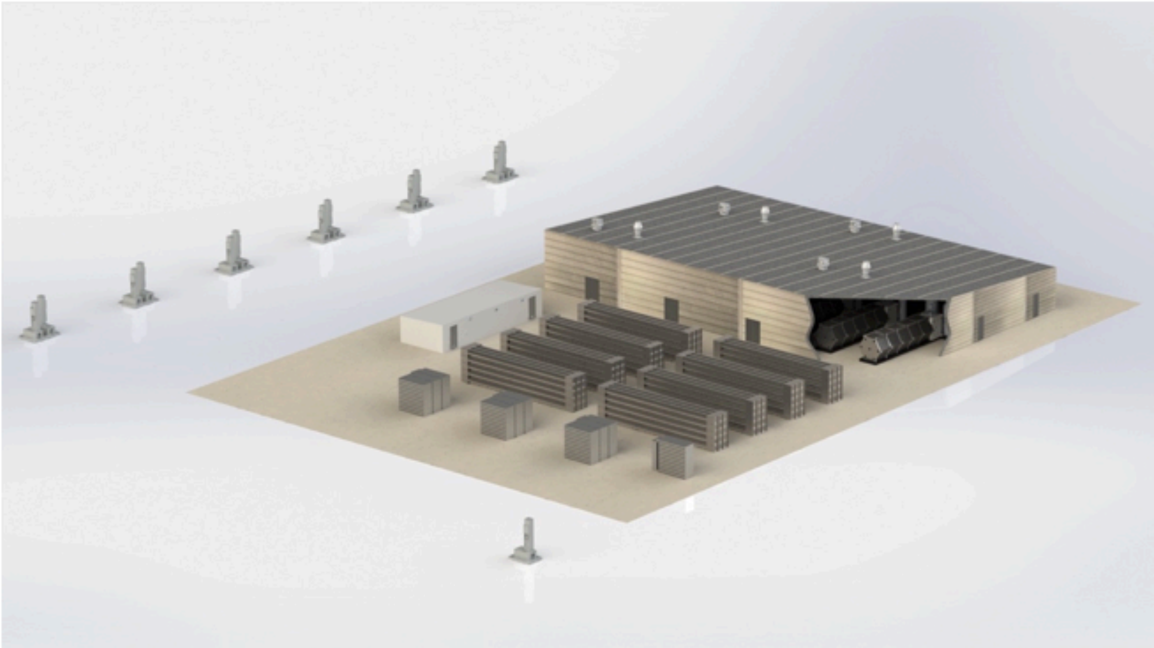


Figure 50 Visualization of large-scale Riga HRS facility.

6.2 Requirements for placement of large-scale Riga HRS facility.

When choosing the location of a large-scale HRS in Riga, similarly to other 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.

Currently a exact location for the potential Large scale Riga HRS is not known, therefore evaluation according to spatial plan cannot be made. Hydrogen production is planned by electrolysis which is not associated with air pollution.

6.3 Noise 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.

6.4 Risk assessment

In assessing the risk of Large-scale hydrogen production and refuelling station in Riga 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): 120 gas cylinders;
- Storage (500 bar): 480 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 34 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	6.00E-05	1.38E-05	7.20E-06
Continuous release from a hole with an effective diameter of 10 mm	1.00E-05/year	1.20E-03	9.60E-06	4.80E-06
Storage (500 bar)				
Instantaneous release of the entire contents of the gas cylinder	5.00E-07/year	2.40E-04	1.27E-05	6.48E-06
Continuous release from a hole with an effective diameter of 3,3 mm	1.00E-07/year	4.80E-05	3.84E-07	1.92E-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

Dispensers

The probability calculations consider 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. The failure probability of dispensers has been assumed to be 0,01.

Table 35 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	5.88E-04	3.12E-05	1.59E-05
Leak of the hose	4.00E-05/hour	5.88E-03	4.71E-05	2.35E-05
700 bar dispenser				
Full bore rupture of the hose	4.00E-06/hour	1.08E-06	2.48E-07	2.92E-08
Leak of the hose	4.00E-05/hour	1.08E-05	8.64E-08	4.32E-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 36 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	-	-
Leak of the hose – gas cloud explosion	-	-
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	-	-

Risk level of intended activity

Given that this Large-scale Riga HRS is a facility, 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 37 Consequences and risk distances from object

Type of distance	Distance [m]
Risk value 10^{-6} per year	17
Risk value 10^{-8} per year	22
Largest effect-distance (1% lethality)	28

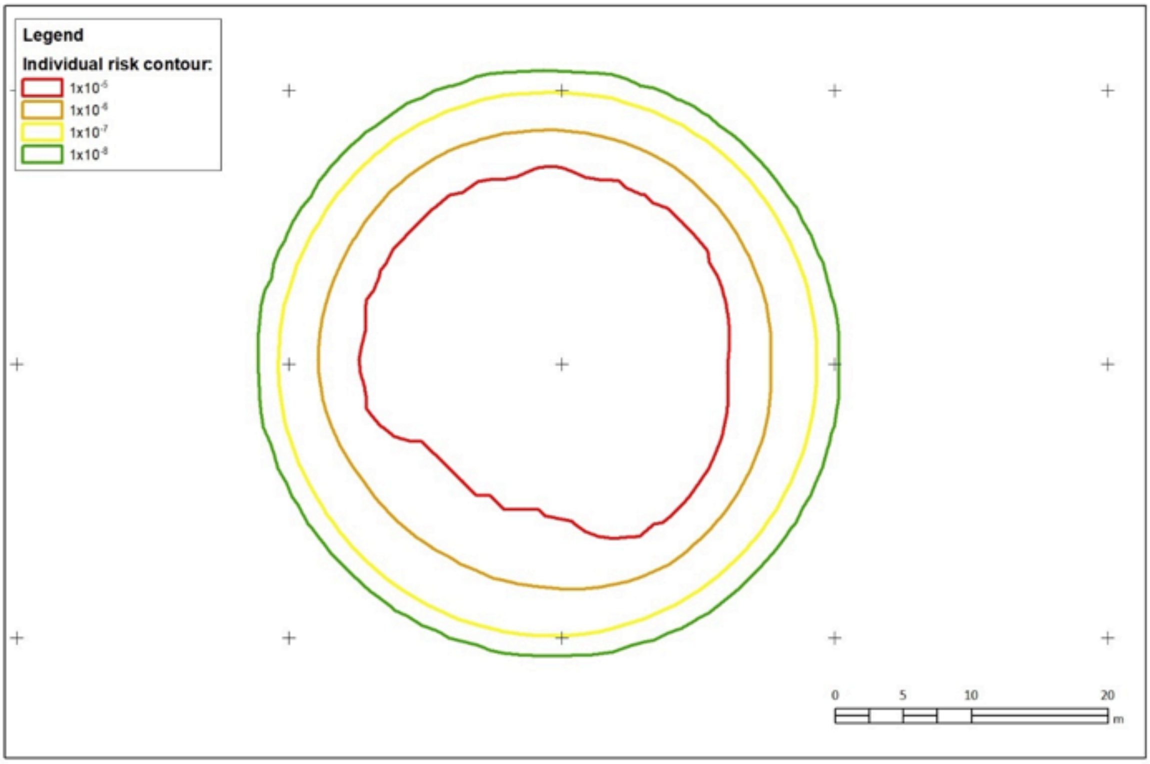


Figure 51 Contour of the individual risk around a example of large scale hydrogen production and refuelling station in Riga.

Note that the location of Large-scale HRS is not set, therefore the contour of the individual risk around a example of large scale HRS should be evaluated under set land-plot for further evaluations.

6.5 Conclusion on Large scale HRS in Riga.

The Large-scale Riga HRS would enable significant amounts of green hydrogen availability in Latvia. The foreseen hydrogen production capacity would 4940kg per day would allow to refuel at least 245 FCE-vehicles (see Table 31) per day. As for the price of deployment the costs to deploy such HRS would reach around 30’000’000 EUR. The significant hydrogen demand would allow to decrease the price of hydrogen and even achieve 3,74 EUR per kg (see Figure 48). This type of hydrogen production facility would allow to achieve cheap hydrogen for mobility purposes.

From risk perspective, the site could pose a threat to the population in the area of about 30 m around it. However, it should be noted that the total amount of hydrogen stored in the station is up to 6198 kg, which means that it is classified as Object of Increased Danger of Category B and Civil protection plan and Industrial risk prevention program must be prepared. With the implemented safety management system, it will be necessary to confirm that everything necessary is being done at the station to prevent large-scale accidents.

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

7. 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. 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 or 10 FCE-buses that are used for public transport operations. Considering that the buses must be refuelled in 6 hours, the equipment is modulated to ensure this aspect. As other option for the movable HRS would be to refuel a H2-locomotive (see Figure 52).[8]

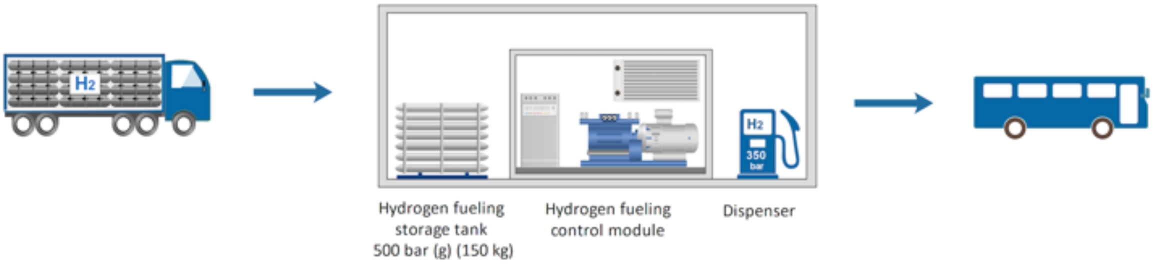


Figure 52 Scheme of movable HRS.

7.1 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 53).

[8] More insight on the hydrogen demand can be found in H2NODES M16 "Mobilising and engaging local and regional stakeholders in Riga".

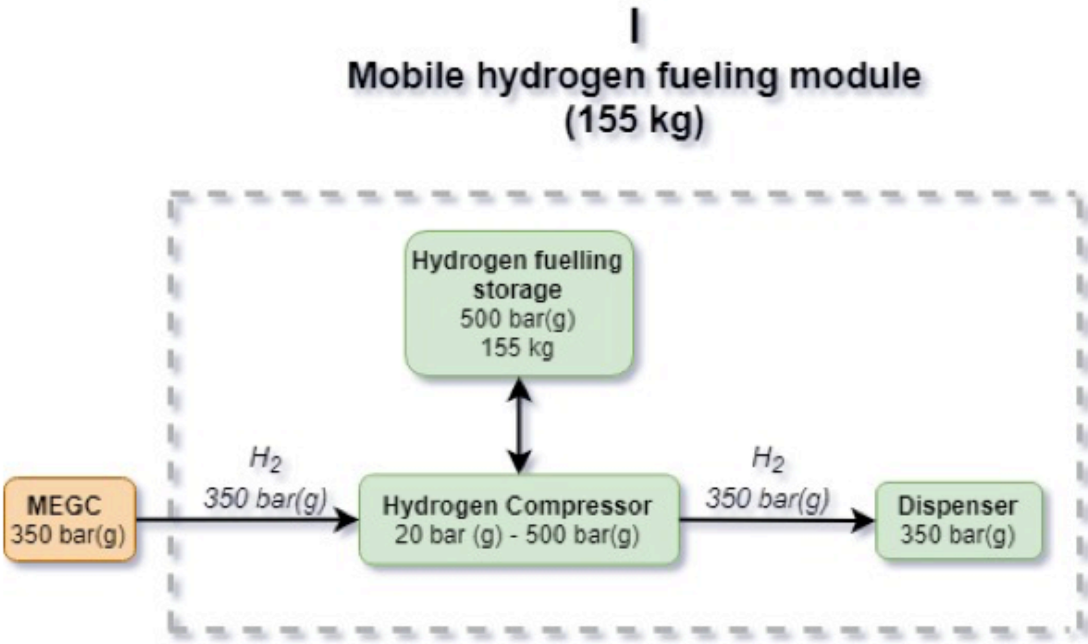


Figure 53 Equipment of Movable HRS.

The initial technical specification of the Movable HRS is summarized in Table 38. Note that the HRS is container type therefore all equipment is mounted inside.

Table 38 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

In order to operate the Movable HRS, it is necessary that only the electricity is provided (see Table 39)

Table 39 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 are equipped with MEGC system i.e. Riga HRS second step upscaling or Jelgava HRS. In the calculations only the Jelgav HRS is taken into account due to the fact that the expanses to operate Movable HRS and to deliver the hydrogen in range of 50km does not change. 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.

Figure 54 Distribution and refilling costs if hydrogen is delivered from Jelgava HRS

Distribution, Cost per 1kg H2, in € (12m after launch)		2024
Cost position	Ref	EUR
Distributed to Refilling station 1		
H2 purchase cost	13	4,28
H2 delivery cost	16	0,65
H2 kg distributed (% from total)	2,5	100%
Proportional lease payments	25,26	0,40
Proportional employee cost	28,29	0,00
Proportional depreciation	35,36	0,45
Proportional financing cost	39-43	0,12
Total cost per 1kg H2 distributed		5,90
Applied premium		0,0%
Proposed sell price before taxes, EUR		5,90

Refilling, Cost per 1kg H2, in € (12m after launch)		2024
Cost position	Ref	EUR
Refilling station 1		
H2 purchase cost	13	5,90
H2 Storage maintenance	16	0,00
Service	27	0,43
Depreciation	35,38	0,44
H2 kg refilled (% from total)	*2,5*	*100%*
Employee cost 1	23-25	0,45
Financing cost 1	43-45	0,003
Total cost per 1kg H2 refilled		7,22
Applied premium		9,0%
Proposed sell price before taxes, EUR		7,87

If the hydrogen is delivered to Movable HRS that is located 50km away from the Jelgava HRS, the delivery costs of hydrogen (incl. equipment, service and employee costs) would add 1,62 EUR per kg of hydrogen. Additionally to that 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.

Space requirements

The overall HRS deployment land plot would occupy 180 sq.m (see Figure 55).

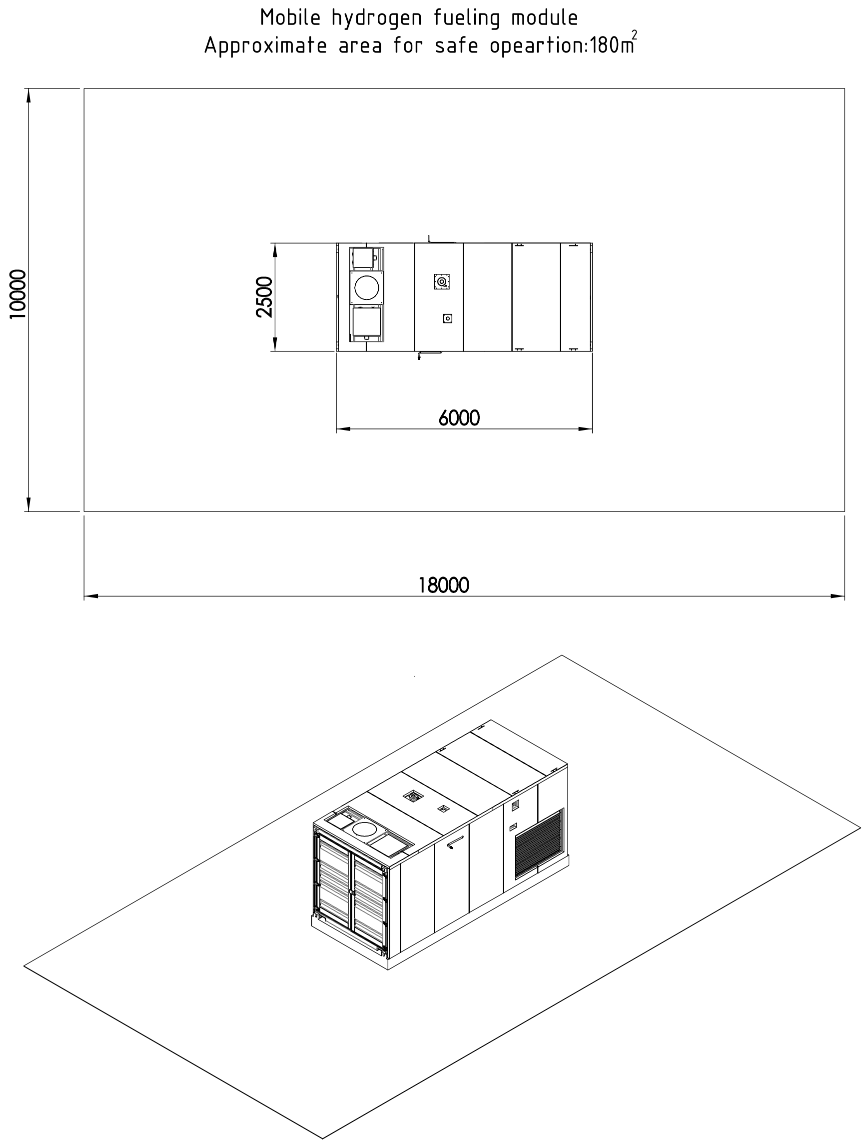


Figure 55 Movable HRS space requirements.

By combining the previous information, the first visualization of the Movable HRS is made (Figure 56)

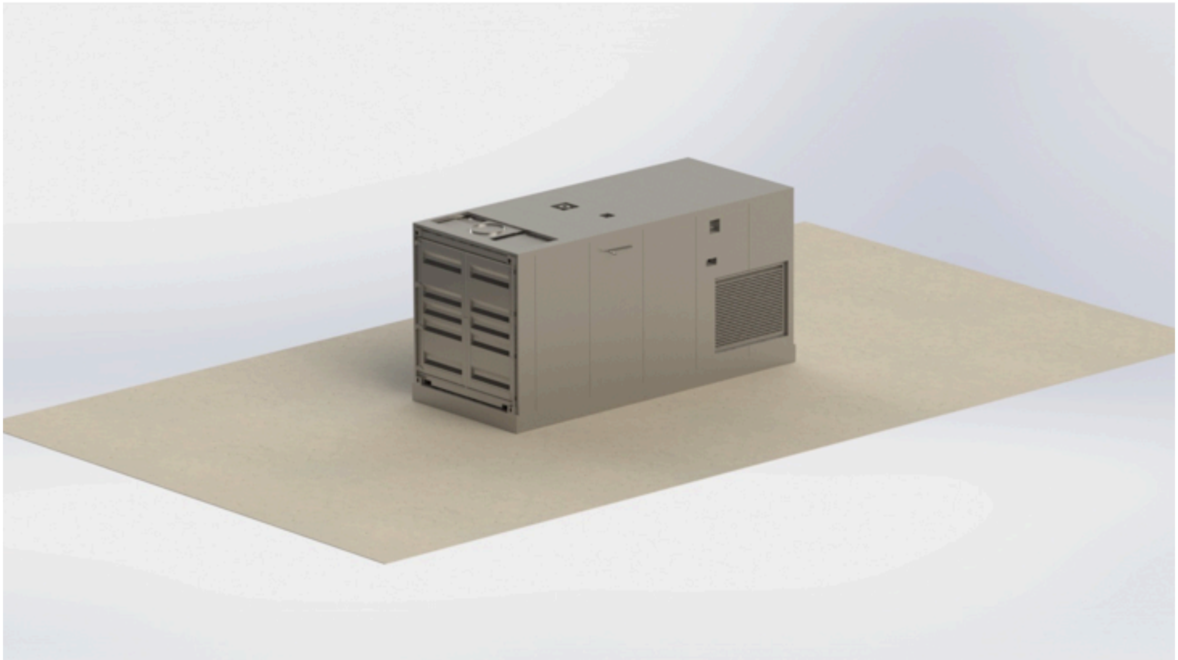


Figure 56 Visualisation of movable HRS.

7.2 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.

7.3 Noise pollution

When calculating the noise level of a Movable HRS, it was assumed that:

- the sound pressure level at a distance of 5 m from any plane of the container is 60 dB(A);
- source dimensions (length 6,06 m, width 2,43 m and height 2,59 m);
- the noise source operates continuously;
- solid ground cover;
- the terrain is flat and there are no obstacles nearby;
- meteorological conditions favourable for sound propagation.

Indicative calculation results characterizing the noise generated by the Movable HRS are shown in Figure 57. When planning the location of a Movable HRS in nature, it is necessary to abide the minimum distances to noise sensitive areas so that the noise limit values are not exceeded as a result of the operation of the station.

For each Movable HRS object, the 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. At the same time, it should be noted that the noise generated by the planned activity must be assessed combined with the already existing background noise level at the specific site.

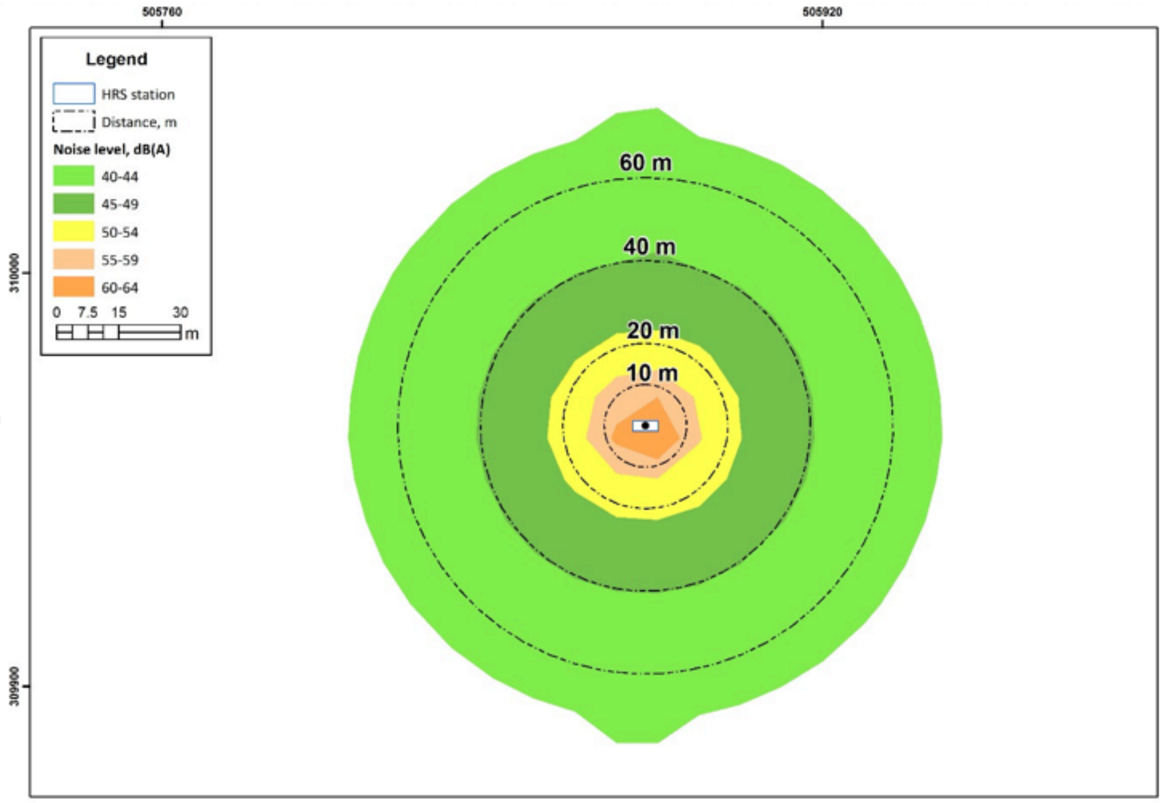


Figure 57 Noise exposure and distance.

7.4 Risk assessment

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

- Hydrogen storages;
- Dispensers;
- Delivery with MEGC.

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 someone of all gets damaged, preventing the gas in other cylinders from escaping through the damaged cylinder.

Table 40 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 41 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 42 H2 MEGC unloading process accident scenarios and their probabilities.

Scenario		Probability per year

	Generic LOCs	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/a;
- 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 43 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 44 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

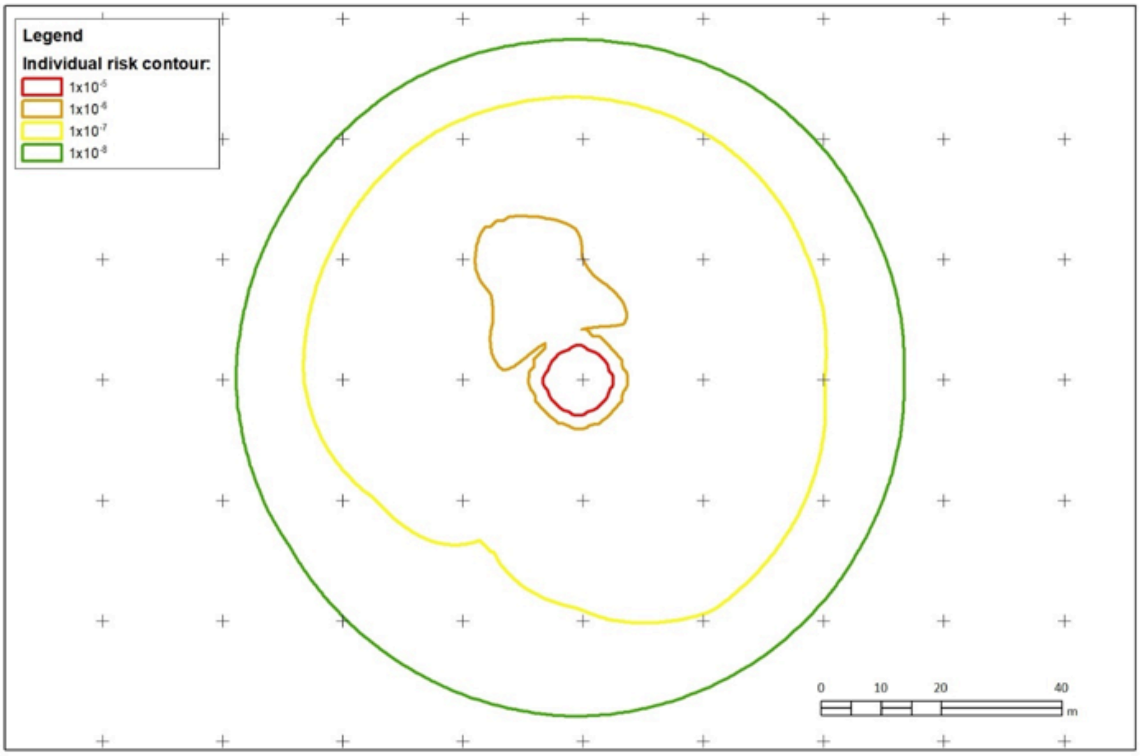


Figure 58 Contour of the individual risk around a example of movable hydrogen refuelling station.

7.5 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 Jelgava 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 (4,28 EUR per kg). 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 resulting the price at the movable HRS dispenser at 7,87 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.

8. Conclusion

In order to increase the hydrogen availability different options are possible. There is potential to increase the hydrogen production and refuelling capacity in existing Riga HRS (see Riga HRS first step upscaling, Riga HRS second step upscaling) or to deploy another HRS in the Region (see Jelgava HRS). 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. With a forecasted regional refuelling capacity of about 6225 kg/per day, it is necessary to deploy additional HRS in the Region in the upcoming years. The total estimated FCEV deployment reaches:

Table 45 Potential Hydrogen demand per day in near term[9]

Vehicle	Units	H2 (kg)
HyTrolleybus	10	110
12m FCE-bus	98	1466
15m FCE-bus	58	1028,5
18m FCE-bus	105	2237,5
Intercity (FCE-Coach)	51	700
Heavy-duty	8	480
FCE-passenger	8	5
FCE-waste treatment	4	48
Shunting locomotive	1	150
Total	**343**	**6225**

Note that the necessary hydrogen (kg) reflects to potential mileage and in some cases does not foreseen to refuel the vehicle unit at full capacity. The previous table indicates that from the potential FCEV units deployed, 94% would be used to perform public transport services by different operators.

As the potential hydrogen demand would slowly grow, the need for available hydrogen would occur and gradual expansion of Riga HRS that would have to be done. Note that the existing HRS deployment site does not allow to deploy large scale HRS, therefore eventually a hydrogen production and refuelling facility should be deployed to secure the potential demand.

[9] More insight on the hydrogen demand can be found in H2NODES M16 "Mobilising and engaging local and regional stakeholders in Riga".

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.

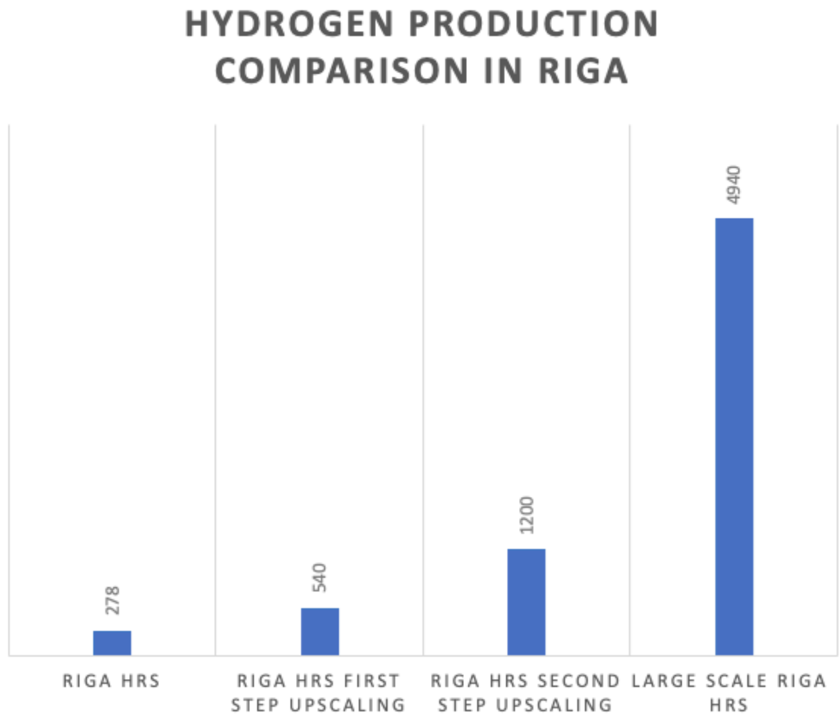


Figure 59 Hydrogen production in Riga

The affordable hydrogen can be achieved if more FCEVs are deployed. According to calculations the price per kg drops significantly if additional 15 buses and 5 FCE-passenger vehicles are refuelled at Riga HRS. Further price reduction can be achieved by deploying large number of FCE-fleets.

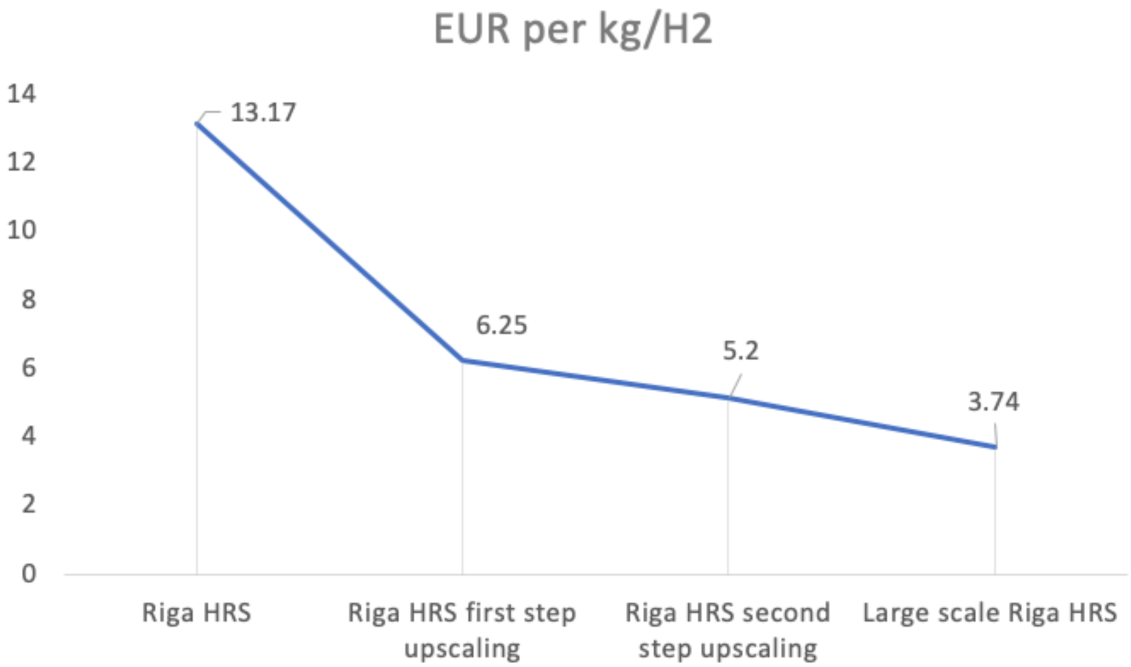


Figure 60 Price per kg/H2

Currently the price at Rigas Satiksme HRS is 13,17 EUR per kg. The high price may be due to the low usability of the HRS and high service costs per filled kilogram as the HyTrolleybuses are the only FCEVs that are using the HRS on daily basis.

As the first movers are generally public transport operators, a option is that there will be a deployment of small amount HRSs with on-site hydrogen production. The modularity of such HRSs allows to gradually expand the hydrogen production and refuelling by installing additional equipment to achieve the rump-up if hydrogen demand is secured.

As opposite possibility would be 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.

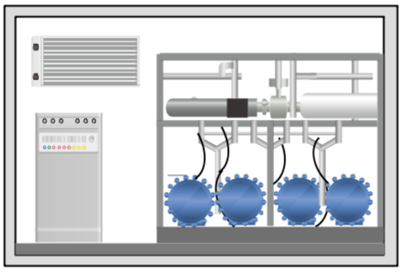
The current identified locations of HRS (Riga HRS upscaling first/second step and Jelgava HRS). shows that the first deployment would happen right next to the public transport operator owned fleet depots as the main amount of hydrogen would be used for public transport operations.

The demand for intercity (FCE-coach) is rapidly growing thus there are no information about available units in the market. Additionally, the demand was expressed for Heavy-duty vehicles and FCE-waste treatment vehicles that are yet to be demonstrated in Europe.

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 as there is no significant support mechanisms available. 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:

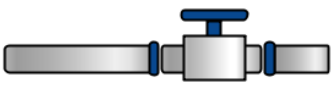
1. Alkaline electrolyser: usually potassium hydroxide or sodium hydroxide solutions are used as an electrolyte.
2. Proton exchange membrane (PEM) Electrolyser: solid polymer is used as an electrolyte.

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/24h), 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.

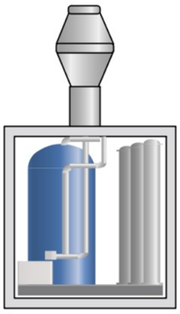
One of the advantages of produced hydrogen by electrolysing method is its purity. There is no need for additional filtration and separation of produce hydrogen, and the purity can vary from 99.995 to 99.999%



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



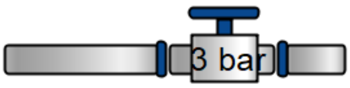
Hydrogen Generation System is an equipment that produces hydrogen using uses steam-methane reforming process. For the proper operation of generation system, it is required to have following utility connections: water, electricity, compressed air and natural gas.

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.

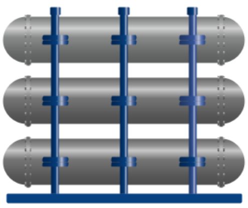
Hydrogen storage and refuelling

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.

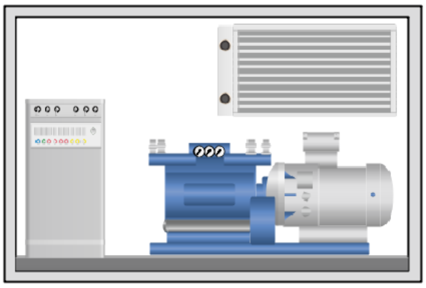


Hydrogen Supply Storage

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:

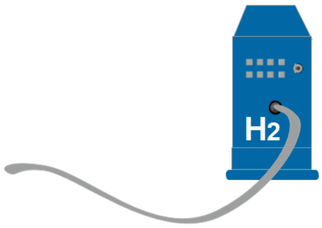
1. Interface indicating fuelling quantities
2. Valve and instrumentation unit module who is led from Hydrogen fuelling control module
3. Fuelling hose with nozzle

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 Laws, standards, codes

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 62).

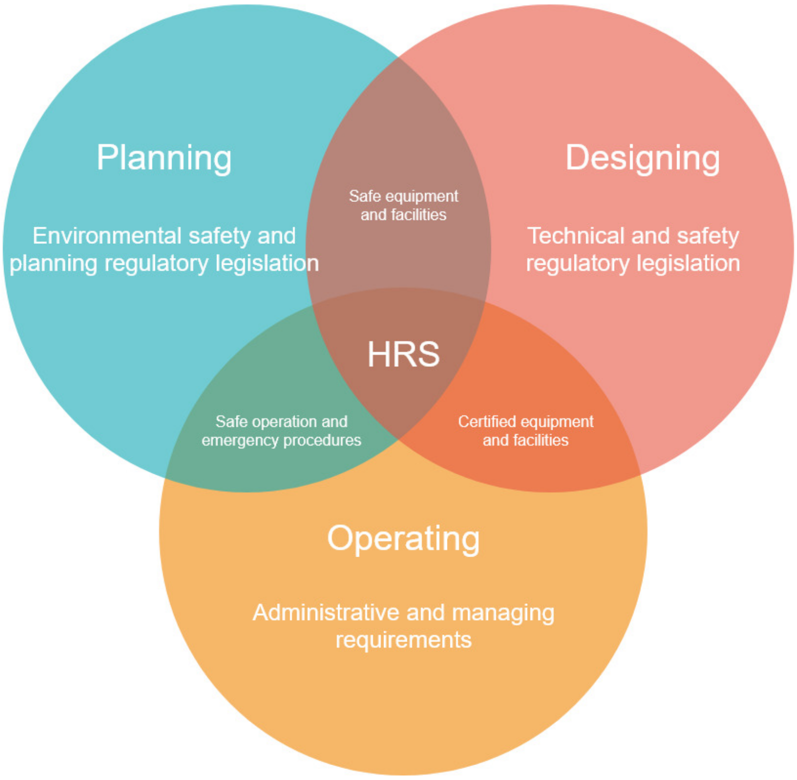


Figure 61 Diagram of legislative framework

Planning

Environmental safety and planning regulatory legislation that are binding on HRS deployment in Latvia:

Act	Link
Law On Environmental Impact Assessment.	https://likumi.lv/ta/id/51522
Law on Pollution	https://likumi.lv/ta/id/6075
Cabinet Regulation No.1082 Procedure by Which Polluting Activities of Category A, B and C Shall Be Declared and Permits	https://likumi.lv/ta/id/222147

for the Performance of Category A and B Polluting Activities Shall Be Issued	
Cabinet Regulation No.240 General Regulations for the Planning, Use and Building of the Territory	https://likumi.lv/ta/id/256866

Designing

Technical and safety regulatory legislation for technical compliance on HRS equipment in designing phase:

Act	Link
Cabinet Regulation No. 78 Requirements for Electric Vehicle Charging, Natural Gas Filling, Hydrogen Filling and Shore-side Electricity Supply Equipment transposing the requirements of the EU Directive 2014/94/ES on the introduction of alternative fuel infrastructure	https://likumi.lv/ta/id/297090
Cabinet Regulation No.348 Regulations for Pressure Equipment and Their Complexes transposing the requirements of the Directive 2014/68/EU of pressure equipment	https://likumi.lv/ta/id/282674
Cabinet Regulation No.231 Rules for Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres transposing the requirements of the Directive 2014/34/EU on equipment and protective systems intended for use in potentially explosive atmospheres	https://likumi.lv/ta/id/281628
Cabinet Regulation No.195 Regulations Regarding the Safety of Machinery	https://likumi.lv/ta/id/173016
Cabinet Regulation No.209 Electrical Safety Regulations for Equipment within certain voltage	https://likumi.lv/ta/id/281514
Cabinet Regulation No.500 Regulations Regarding Transportable Pressure Equipment	https://likumi.lv/ta/id/232428
Law On Environmental Impact Assessment	https://likumi.lv/ta/id/51522
Chemical Substances Law	https://likumi.lv/ta/id/47839
Protection Zone Law	https://likumi.lv/ta/id/42348
Law On Pollution	https://likumi.lv/ta/id/6075

Operating

Administrative and safety management requirements that are binding to HRS operator on operational phase:

Act	Link

Labour Protection Law	https://likumi.lv/ta/id/26020
Cabinet regulation No.300 Labour Protection Requirements at Work in Explosive Atmospheres	https://likumi.lv/ta/id/76254
Cabinet Regulation No.660 Procedures for the Performance of Internal Supervision of the Work Environment	https://likumi.lv/ta/id/164271
Fire Safety and Fire-fighting Law	https://likumi.lv/ta/id/68293
Cabinet Regulation No.238 Fire safety regulations	https://likumi.lv/ta/id/281646
Law on Technical Supervision of Dangerous Equipment	https://likumi.lv/ta/id/50117
Protection Zone Law	https://likumi.lv/ta/id/42348
Civil Protection and Disaster Management Law	https://likumi.lv/ta/id/282333
Cabinet of Ministers Regulation No. 563 (19.09.2017) "Procedures for Identifying and Determining Objects of Increased Danger, as well as for the Planning and Implementation of Civil Protection and Disaster Management"	https://likumi.lv/ta/id/293660
Cabinet of Ministers Regulation No. 131 (01.03.2016) "Industrial Accident Risk Assessment Procedures and Risk Reduction Measures"	https://likumi.lv/ta/id/280652

Note. The above list of legislative acts is not exhaustive.

As this report deals specifically with hydrogen filling stations, focusing on the safety aspects related to the HRS operation, the requirements discussed below mainly concern the design, construction and operation phases.

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, taking into account 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 63 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.

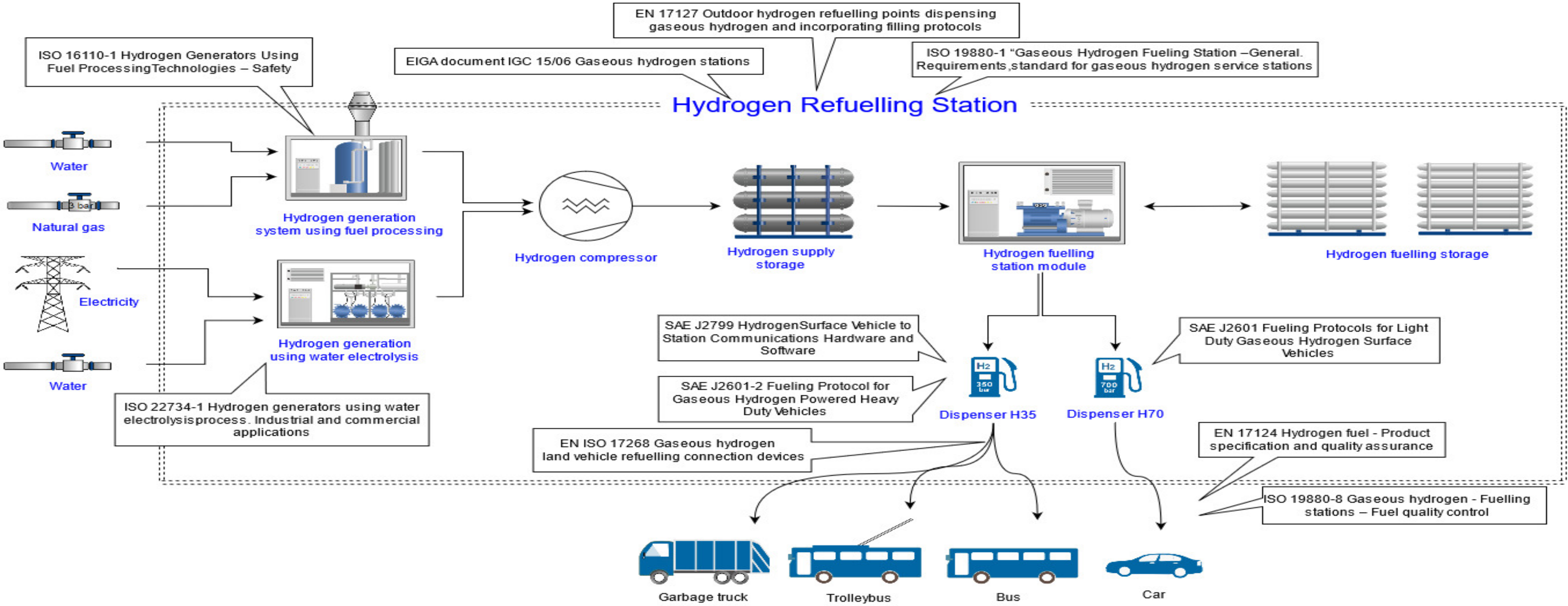


Figure 62 Standards for specific HRS equipment

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 required amount of documentation follows from the regulatory enactments binding on 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 a hydrogen fuelling station placement, the environmental impacts, including the risk of those stations have to be considered.

Based on the Latvian national law "On Environmental Impact Assessment", an environmental assessment can be applied to chemical production objects/operations if the operation is included in Annex 1 of the law or an initial assessment can be applied if the activity is listed in Annex 2 of the same law. In these cases, the decision about the necessity of an environmental impact assessment is made by the State Environmental Service based on an application prepared by the initiator in line with the Cabinet of Ministers Regulation No. 18 "Procedures for assessing the environmental impact of the proposed activity and approving the proposed activity" and considering proposed activity's environmental impact according to requirements outlined in Section 11 of the law "On Environmental Impact Assessment". If as a result of the initial assessment, the State environmental Service decides that planned activity does not require an environmental impact assessment, then the institution provides technical rules for the specific planned activity. If the State Environmental Service decides that an environmental impact assessment is necessary, the initiator has to conduct a full environmental impact assessment.

As stipulated in the law "On Environmental Impact Assessment" the developer of specified activities has to receive a pollution permit before the start of operations. According to Annex 1 of the law "On Pollution", hydrogen production is a polluting activity, that requires a category A polluting activity permit if production occurs on an industrial scale (Annex 1, Section 7). If these conditions are met, then the planned activity corresponds to the above-mentioned law's subparagraph (a) "for the production of gases, such as ammonia, chlorine or hydrogen chloride, fluorine or hydrogen fluoride, carbon oxides, sulphur compounds, nitrogen oxides, **hydrogen**, sulphur dioxide, carbonyl chloride" of the Paragraph 2 "installations for the production of inorganic chemicals" of the Annex 1 Section 4 "Chemical Industry". Regulations do not provide criteria for defining industrial production; therefore, this question will be evaluated during individual processes.

Hydrogen is a hazardous chemical and is subject to the requirements of the "Chemical Substances Law" and the "Civil Protection and Disaster Management Law". "Chemical Substances Law" and Cabinet of Ministers Regulation No. 131 (01.03.2016) "Industrial Accident Risk Assessment Procedures and Risk Reduction Measures" incorporates legal norms arising from Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC.

The Category of Objects of Increased Danger object and the requirements for them shall be determined according to Cabinet of Ministers Regulation No. 563 (19.09.2017) "Procedures for Identifying and Determining Objects of Increased Danger, as well as for the Planning and Implementation of Civil Protection and Disaster Management".

The basic criteria for determining the category of object and bonding requirements are summarized in Table 46.

Table 46 Basic criteria for identification Category of Objects of Increased Danger

Required risk management and safety document	Amount of simultaneous hydrogen storage at the object			
	< 1000 kg	≥1000 < 5000 kg	≥ 5000 kg < 50000 kg	≥ 50 000kg
Category of Objects of Increased Danger	-	C	B	A
Civil protection plan	-	✓	✓	✓
Industrial risk prevention programme	-	-	✓	-
Safety report	-	-	-	✓

The hydrogen production, storage, and refilling process have multiple potential environmental impacts. The most important which should at least be assessed are as follows:

- Air pollution
- Noise nuisance
- Risk of accidents

8.1 Air pollution

Air pollution occurs if hydrogen is produced using the steam-methane reforming method. This technology requires natural gas combustion, which results in nitrogen oxides, carbon monoxide, and carbon dioxide emissions. The amount of resulting pollution is mostly dependent on fuel consumption. The hydrogen production using the electrolysis method on the other hand does not result in any pollutant emissions.

Air quality limit values for nitrogen oxide and carbon monoxide are regulated by the Cabinet of Ministers Regulation No. 1290 (03.11.2009.) “Air quality regulation” (Table 47).

Table 47 Emission limit values

Pollutant	Type of limit value	Determination period	Limit value
Nitrogen Dioxide	Hourly limit value for the protection of human health (R_h)	1 hour	200 µg/m3, not to be exceeded more than 18 times a calendar year (99,79. percentile)
Nitrogen Dioxide	Annual limit value for the protection of human health (R_h)	calendar year	40 µg/m^3
Carbon Monoxide	Eight-hour limit value for the protection of human health (R_{8h})	maximum daily eight hour mean concentration	10 mg/m^3 (100. percentile)

To estimate the amount of pollutant emissions produced from natural gas combustion, the methodology and emission factors from Annex 1 of Cabinet of Ministers Regulation No. 17 (07.01.2021.) "Regulation on the limitation of air pollution from combustion plants" was used (Table 47), assuming that the nominal power of supplied heat for each equipment unit is in the range from 0,2 to 1 MW. To estimate CO_2 emissions LVGMS methodology "Methodology for calculating CO_2 emissions from stationary fuel combustion"[10] was used. Pollutant emission factors from fuel combustion are summarised in Table 48.

Table 48 Pollutant emission factors for low power combustion equipment

Combustion equipment type	Emission factors (mg/MJ)		CO_2 emission factor, t/TJ
	NO_x[1]	CO	
New combustion equipment	28	42	55,45851

Notes:

1-expressed as NO_2

The amount of pollutant emissions can be calculated using the following equation:

$$E_{t/g} = EF \times B \times 10^{-9},$$

where:

E – emissions, t/g;

EF – emission factor (mg/MJ);

B – fuel consumption (MJ).

The lowest heat of combustion for natural gas is 34,30242 GJ/1000 m^3.

It is important to note, that the assessment of the impact of a hydrogen station on the air quality at the initial research stage is performed without taking into account the existing level of air pollution, thus it is not possible to determine whether the total pollution concentration of the planned activity is going to fall within the limits set in regulations. In order to comprehensively assess the changes in air quality from natural gas combustion at the location of the planned activity, information on the current level of air pollution in the area affected by the planned activity is necessary.

Emissions from low power combustion equipment cannot exceed the emission limit values for low power combustion equipment outlined in Annex 7 of the Cabinet of Ministers Regulation No. 17 (07.01.2021.) "Regulation on the limitation of air pollution from combustion plants" if the combustion equipment uses natural gas:

- Emission limit values for new combustion equipment:
  - NO_x = 100 mg/m^3,
  - CO = 150 mg/m^3.

[10] [10] https://videscentrs.lvgmc.lv/lapas/gaisa-piesarnojums

The operator has to ensure the purchase and installation of combustion equipment that guarantees that these emission limit values are met. The concentration of a pollutant in flue gases can be determined through calculations. A theoretical air consumption (m^3/kg fuel) was calculated using the following equation:

$$V^0 = \frac{0,267 \times Q_z^d}{1000},$$

where:

V^0 – theoretical air consumption (m^3/m^3);
Q_z^d –lowest heat of combustion for fuel (kJ/m^3).

The actual volume of flue gases (under normal conditions) can be calculated using the following equation:

$$V_d = V_d^0 + 1,0161 \times (\alpha - 1) \times V^0,$$

where:
V_d – actual volume of flue gas (nm^3/m^3);
V_d^0 - theoretical volume of flue gas (m^3/m^3);
α – air consumption coefficient;
V^0 – theoretical air consumption (m^3/m^3).

The air consumption coefficient can be calculated using the following equation:

$$\alpha = \frac{21}{21 - O_2},$$

where:
α – air consumption coefficient;
O_2 – oxygen concentration in flue gases.

Flue gas flow can be calculated using the following equation:

$$V = B \times V_d,$$

where:
V –flow of flue gas (m^3/h);
B – fuel consumption (m^3/h);
V_d – actual volume of flue gas (m^3/m^3).

Pollutant concentration in flue gas can be calculated using the following equation[11]:

[11] Methodological Guidelines for the Development of a Draft of the Maximum Permissible Emission Limits for Enterprises and Institutions, Ministry of Environment and Regional Development of the Republic of Latvia, 2000

$$C_i = \frac{M_i}{B_{sek.\,max} \times V_d \times \left(1 - \frac{q_4}{100}\right)} \times 10^3,$$

where:
C_i – pollutant concentration (mg/m^3);
M_i – maximum emission of the pollutant (g/s);
$B_{sek.\,max}$ – maximum fuel consumption per second (m^3/s);
V_d – actual flue gas volume (m^3/m^3);
q_4 – losses from mechanically incomplete combustion, %

8.2 Noise

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.

The order in which environmental noise should be assessed is stipulated in the Republic of Latvia Cabinet of Ministers Regulation No. 16 of January 7, 2014 “The procedure of noise assessment and management” (hereinafter – Regulation No. 16 (07.01.2014.)). The limit values for environmental noise are set for annual average noise levels.

For the purposes of the noise assessment carried out for the current research, only individual noise levels of objects have been evaluated- excluding background noise from other sources unrelated to the planned activity, such as motor vehicle movements, railway operation, or industrial activity nearby.

According to regulations, construction and operation of new objects are deemed acceptable, if their individual noise level does not exceed the limit values stipulated in Regulation No. 16 (07.01.2014) and if the existing noise level (background) exceedances of residential areas nearby are not increased.

To comply with these requirements, it is necessary to perform a detailed environmental noise assessment when designing new objects, during which the total background noise level from motor vehicles, railway movements, and other industrial objects is calculated and the contribution towards this noise level by the planned activity is assessed. 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.

Software and noise indicators. For the assessments included in the practical section of this paper the noise forecasting and mapping software IMMI 2020-1 (License number S72/317), developed by Wölfel Meβsystem Software GMbH+Co K.G, was used to evaluate the noise indicators and to model the noise. The IMMI 2020-1 software enables the possibility to calculate the noise indicators in accordance with the noise evaluation methods provided in Regulation No. 16 (07.01.2014.).

The noise from sources in hydrogen filling station was assessed using methodology from Subsections 2.4 “Industrial noise” and 2.5 “Calculation: propagation of noise from road traffic, rail traffic, and industrial sources” from Annex 5 to Regulation No. 16 (07.01.2014).

Information on the location of the buildings as well as the surface of the land was obtained from a topographic map prepared by the Latvian Geospatial Information Agency (*Latvijas Ģeotelpiskās informācijas aģentūra*) at a scale of 1:10 000, but terrain data – from a digital elevation model. Technical information on HRS (including the location of the noise source, load and noise level) was provided by Client.

For the assessment and mapping of the environmental noise, the following noise indicators were applied:

- Day noise indicator – L_{day}, which characterizes the discomfort during the day. This is the A-weighted long-term average sound level (dB (A)) as defined in LVS ISO 1996-2: 2008 "Acoustics - Description, measurement and assessment of environmental noise - Part 2: Determination of environmental noise levels" which describes the annual average noise level during the daytime. Determined by considering all days during the year.
- Evening noise indicator – $L_{evening}$, which characterizes the discomfort during the evening. This is the A-weighted long-term average sound level (dB (A)) as defined in LVS ISO 1996-2: 2008 "Acoustics - Description, measurement and assessment of environmental noise - Part 2: Determination of environmental noise levels" which describes the annual average noise level during the evening. Determined by considering all evenings during the year.
- Night noise indicator – L_{night}, which characterizes the discomfort during the night. This is the A-weighted long-term average sound level (dB (A)) as defined in LVS ISO 1996-2: 2008 "Acoustics - Description, measurement and assessment of environmental noise - Part 2: Determination of environmental noise levels" which describes the annual average noise level during the night time. Determined by considering all nights during the year.

Pursuant to Appendix 2 to the Regulation No. 16 (07.01.2014), these noise indicators are subject to limit values applicable according to the function of use of the site . The function of use of building areas is determined in accordance with building zoning and primary use stipulated in the Riga and Jelgava spatial plans. The both cities are mentioned as in Riga already a HRS is deployed and potential upscaling will be evaluated. As for Jelgava, there are intensions to deploy the HRS. 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 building use zone.

Table 49 The noise limit values applied (Riga).

Function of use of the territory	Noise limit values		
	L_{day} (dB(A))	$L_{evening}$ (dB(A))	L_{night} (dB(A))
Mixed building territory, including commercial and service buildings (with residential buildings)	65	60	55

Table 50 The noise limit values applied (Jelgava).

Function of use of the territory	Noise limit values		
	L_{day} (dB(A))	$L_{evening}$ (dB(A))	L_{night} (dB(A))
Building area of individual residential houses (low-rise), children's institutions, medical, health and social care institutions	55	50	45
Multi-storey residential building territory	60	55	50

According to Annex 1, Subsection 1.2. to the Regulation No. 16 (07.01.2014.), in assessing and modelling the noise indicators, it was assumed that the day period lasts for 12 hours – from 7am to 7pm, the evening period lasts for 4 hours – from 7pm to 11pm, but the night period lasts for 8 hours – from 11pm to 7am.

Noise indicators were evaluated at a height of 4 m above the ground. Noise dispersion maps are prepared with a grid step of 5 x 5 m.

In accordance with Section 5 of Annex 1 to the Regulation No. 16 (07.01.2014.), the input data for the calculation models prepared by the software used in noise calculations are attached as an appendix to the noise assessment (in electronic format).

8.3 ATEX zoning

ATEX for Hazardous areas (potentially flammable mixtures). Based on hydrogen characteristics, an explosive atmosphere can form when hydrogen concentration in the air reaches 4%-75%. Therefore, explosion hazard zone assessment and choice of suitable equipment for those zones are very important.

In case of deviations, a potentially explosive atmosphere can form during the technological process both of natural gas processing as well as hydrogen production, storage, and filling.

ATEX for Natural gas supply. The hazardous area also has to be established around natural gas equipment, where hydrogen is produced using the steam-methane reforming method.

The natural gas supply hazardous area is determined according to LVS EN 60079-10-1:2016 "Explosive atmospheres. Part 10-1: Classification of zones. Explosive gas environments" and other available standards.

In case of deviations, potential leak sources inside the technological room of natural gas compressors are:

- Pipeline connections;
- Compressor seals;
- Measuring equipment connection points;
- Safety valve outlet;
- Gas drain vent opening.

When installing equipment in the technological room, technological measures including an automatic process control system for accidental leaks (for example, gas leak detector, that is connected to the electromagnetic valve) and appropriate ventilation conditions, which reduce the risk that an explosive atmosphere may form in case of a natural gas leak, should be applied.

ATEX for Hydrogen production, storage and filling.

Similarly, to other flammable gases, hazardous area zoning for hydrogen production and filling stations is determined according to EN 60079-10-1: Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres (IEC 60079-10-1:2015 + COR1:2015), as well as considering other appropriate standards.

IEC 60079-10-1 is concerned with the classification of areas where flammable gas or vapour hazards may arise and may then be used as a basis to support the proper design, construction, operation and maintenance of equipment for use in hazardous areas.

Technological nodes related to hydrogen production and circulation where an explosive atmosphere can potentially form are as follows:

- Hydrogen production module;
- Hydrogen compression module;
- Hydrogen storage module;
- Hydrogen station;
- Hydrogen filling locations for motor vehicles.

Typical gas leak locations in case of deviations are:

- Pipeline connections;
- Compressor seals;
- Safety valves;
- Seals for gas cylinders valves;
- Dispenser, local pipeline connection.

Explosive atmosphere zoning can differ depending on the technologies that are being used, their working parameters (working pressure, temperature), materials used and their physical characteristics, technological solutions (the type of pipeline connections, gaskets, packaging), safety system, typical solutions, and the surrounding environmental conditions, that have to be evaluated when designing a project for any specific hydrogen fuelling station.

An example of explosive atmosphere zoning that was established for technological equipment for a hydrogen station, is summarised in the table below.

Table 51 Hazardous zones – hydrogen technology

Source description	Location of the leak source	Substance	Zoning	Size of the zone (m)	
				Vertical	Horizontal
Hydrogen production module HyGEN 50	Indoors	Methane, hydrogen	Zone 1 and Zone 2	1m	1m
	Outdoors		Zone 1	9m	6m
Hydrogen compressor module;	Indoors	Hydrogen	Zone 1	For the whole volume	For whole volume
safety valve vent	Outdoors	Hydrogen	Zone 1	4,5 m From outlet	4m From outlet
			Zone 2	7 m	6 m
Ventilation outlet	Outdoors	Hydrogen	Zone 1	1 m From outlet	1m From outlet
			Zone 2	2 m From outlet	2m From outlet
Hydrogen storage module (200 bar) 400 kg	Outdoors	Hydrogen	Zone 2	2m	1m

Hydrogen storage module (450 bar/ 200kg, 900bar /25kg)	Outdoors	Hydrogen	Zone 2	2m	1m
Hydrogen station	Indoors	Hydrogen	Zone 1 and Zone 2	Limited equipment volume	Limited equipment volume
Outlet	Outdoors	Hydrogen	Zone 1	2m	2m
Outlet	Outdoors	Hydrogen	Zone 2	2,5m	2,5m
Hydrogen dispensers (filling islands)	Indoors	Hydrogen	Zone 1	Equipment volume	Equipment volume
	Outdoors	Hydrogen	Zone 2	2m	1m

Protection from ignition due to accumulation of static charge

To avoid presence of ignition sources in hazardous area, all equipment should be grounded. When implementing protection measures against generation of static electricity guidelines provided in CENELEC Report R044 - 001 “Safety of machinery Guidance and recommendations for avoidance of hazard due static electricity” should be followed.

Protection requirements for electrical equipment within hazardous areas

The equipment used in hydrogen production have to comply with the requirements outlined in Directive 2014/34/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres (recast).

The equipment for working zones with a risk of explosive atmosphere is chosen according to requirements provided in the EN 60079-14:2014 Explosive atmospheres – Part 14: Electrical installations design, selection end erection (IEC 60079-14:2013) standard.

To choose the appropriate electronic protection class the following factors should be considered:

- Classification of the hazardous area including the equipment protection level requirements were applicable;
- Gas classification in relation to the group or subgroup of the electrical equipment;
- Temperature class or ignition temperature of the gas or vapour involved;
- Intended application of the equipment;
- external influences and ambient temperature.

Electrical equipment class is chosen according to a gas group and temperature class of raw materials present at the object:

- natural gas- IIAT1;
- work areas with possibility of hydrogen leaks - IICT1;

The acceptable level of protection for equipment temperature classes for hydrogen technology T1-T6. The relationship between equipment protection levels and zones is shown in Table 52.

Table 52 Hazardous zones – hydrogen technology[12]

Zoning	Equipment protection level (EPLs)
Zone 0	„Ga”
Zone 1	„Ga” or „Gb”
Zone 2	„Ga”, „Gb” or „Gc”

8.4 Hazards and risks

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

- Hydrogen is a flammable gas;
- Hydrogen production with steam methane reforming method natural gas is used, which is also 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 the typically hydrogen filling stations are equipped with modern safety systems, to determine safety distances, especially to various sensitive objects or areas they also should be considered. 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.

[12] EN 60079-14:2014 Explosive atmospheres – Part 14: Electrical installations design, selection end erection (IEC 60079-14:2013)

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 53. The table shows the radius of risk zones around respective technological objects with the individual risk level of 1×10^{-6}/year.

Table 53 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[13] (see Table 54).

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

Table 54 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
Liquid oxygen storage (not greater than 125 000L tank capacity) (* *)	8 (*)
Nonflammable 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

In Latvia, protection zones are regulated by the Protection Zone Law. The Protection Zone Law does not provide requirements and conditions for safety and operational protection zones around hydrogen fuelling stations. Considering that hydrogen is a hazardous chemical substance, a hydrogen fuelling station can be classified as hazardous chemical storage, and therefore a safety distance provided in Section 30 of the Protection Zone Law of 100 m, measured from buildings where chemical substances are stored, can be applied.

Considering that the establishment of protection zones restricts the permitted activities in the surrounding territories and their further development, during the project development the construction (installation) has to be coordinated with the landowner or legal possessor or- in cases specified in regulatory acts- have to inform the landowner or legal possessor whose property is within the protection zone, as well as municipality about the protection zone or its changes.

Existing safety zones and restrictions have to be considered when developing a new object.

The risk assessment of hydrogen refuelling station included in this report is based on principles of the Dutch Guidelines for Quantitative Risk Assessment[14]. The typical accident scenarios and probabilities given in these guidelines have been used. For initial characterization of the risk situation, are included only accident scenarios typically for this technology and with the greatest impact on the level of risk.

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

- Natural gas pipeline;
- Hydrogen supply storage;
- Hydrogen storage;
- Dispenser;
- Industrial filling panel – place for filling H2 MEGC (Multiple Elements Gas Container).

Defects are also possible in other technological equipment – reformers, 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 natural gas pipelines:

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

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

- 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 litres) 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.

For loading activities in an establishment (dispensers and places for loading module for H2 transport):

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

- 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.

For H2 transport module:

- Instantaneous release of the entire contents of the one gas cylinder of transport module;
- Continuous release from a hole the size of the largest connection of transport module.

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

In case of adverse conditions, hydrogen or natural gas 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 55 summarises information on the ignition probabilities of natural gases used in risk assessments of this study.

Table 55 Probability of immediate and delayed ignition in case of a natural gas leak.

Outflow [kg/s]	Probability of immediate ignition	Probability of delayed ignition
< 10	0,2	0,06
10 - 100	0,5	0,2
>100	0,7	0,3

The probabilities of ignition in case of hydrogen leakage have been specified according to the International Energy Agency recommendations.[15]

Table 56 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

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

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 ^{o}C.

Considering that natural gas and hydrogen are highly flammable gases, 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;
- Overpressure from explosion of gas – air mixture;
- Heat radiation from Jet fire.

Recommendations for using results from quantitative risk assessment

The following principles can be applied when determining a safety distance around hydrogen fuelling stations:

- Individual risk ≥ 10^{-6}/ year- zona where individual building and prolonged presence of people who are not involved in the operation of the facility is prohibited;
- Individual risk < 10^{-6} ≥ 10^{-8}/ year – zone where multi-storey buildings and sensitive objects (schools, hospitals etc.) is prohibited;

Maximum 1% lethal exposure distance - measure for civil protection planning purposes, evacuation zone.