Avinor

Feasibility study - Hydrogen infrastructure at airport

Norconsult

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Summary

This feasibility study evaluates the potential for establishing compressed hydrogen infrastructure at an airport in Norway. Bergen Airport, Flesland, was used as the study case scenario for the feasibility study. The study is carried out by Norconsult in collaboration with THEMA Consulting (who performed the market and logistics study) and forms part of the international test arena for zero and low emission aviation. The feasibility study assesses technical, logistical, regulatory, operational and safety-related considerations for a pilot-scale deployment involving a hydrogen-powered snow sweeper and a small aircraft. Based on a weekly pilot demand of 2,000 kg, two supply concepts were evaluated:

- Option A – Stationary solution: Permanently installed H2 storage tanks with stationary infrastructure
- Option B – Mobile solution: H2 battery swap with modular storage unit and mobile dispenser unit

Both concepts use off-site hydrogen production and weekly truck deliveries. Refueling is based on 350 bar, with flexibility for 350–700 bar depending on the selected supplier solution.

An assessment of the regulatory framework has been performed in this feasibility study, which includes all authority approvals and permits needed for storage and use of hydrogen at the airport. Aviation regulations for hydrogen-powered aircraft remain immature. Hydrogen facilities require a building permit, notification to DSB, and consent under the Major Accident Regulations, including risk and emergency preparedness assessments. Environmental requirements may apply to groundwork, Avinor must update its HSE system, and approval from the Labour Inspection Authority is expected to ensure safe working conditions. An estimated regulatory timeline was developed with a total duration of approx. 24 months.

The technical safety evaluation assessed hazards from compressed hydrogen releases. Simulations of a credible worst-case 1,000 kg release defined hazard zones and informed equipment placement and separation distances. Key safeguards include leak prevention, ignition control, ATEX zoning, gas and flame detection, emergency shutdown and controlled venting.

An AACE class 5 (highest uncertainty) CAPEX estimate both for Option A and Option B was developed. Option A (stationary solution) shows a higher CAPEX with a range of 59–93 mil. NOK. The cost drivers are mainly the permanent storage and dedicated compression infrastructure. The wide range is linked to the dependency of compressor and refueling selection. Option B (mobile solution) shows a lower CAPEX with a range of 50–60mil NOK. The range is narrower for Option B because the cost estimate is based on the technology provided by Hexagon Purus, who supply both the storage and dispenser technology in container solutions. An OPEX estimate was also established which in the feasibility study is assumed to be equal for both concepts (Option A and Option B). OPEX includes hydrogen supply, transport and logistics, electricity consumption, service and maintenance and operations & handling. The OPEX is estimated to be in the range of 12–48 mil NOK pr. year including hydrogen supply and 2-6 mil NOK excluding hydrogen supply.

This feasibility study does not offer a definitive conclusion about the details on a hydrogen infrastructure. However, it can be stated that no technical, practical and regulatory showstoppers have been identified for the establishment of the hydrogen infrastructure at Flesland airport (study case). The feasibility study shows that a mobile solution (e.g. Option B – mobile solutions) has advantages over a stationary solution (e.g. option A – stationary solution) in the pilot case (storage and weekly usage of approx. 2000kg compressed H2). The main advantages of a mobile solution are an estimated lower CAPEX and flexibility of installation and operation. In addition, a mobile solution for hydrogen storage will probably contain multiple smaller storage tanks which could reduce the safety risk, compared to a few larger storage tanks.

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1 Introduction

Background: Avinor is undertaking this study to support the aviation sector's transition towards net-zero emissions and contribute to the long-term ambition of a fossil-free aviation industry by 2050. As part of its strategy to enable new energy carriers in aviation, Avinor is evaluating how hydrogen infrastructure for storage, distribution, and refueling can be safely and efficiently established at airports

Avinor: Avinor is a state-owned operator of 43 airports and the ANSP (Air Navigation Service Provider) in Norway. Avinor supports Norway's ambition for fossil-free aviation by 2050. As the aviation sector faces increasing pressure to reduce emissions, new energy carriers such as hydrogen will be essential—both for airport operations and future flight.

CAA Norway (Civil Aviation Authority Norway): The CAA has an overall mission to contribute to safe, societally beneficial, and sustainable aviation. Safe integration of new technologies, including hydrogen-based solutions, is at the core of the work on innovation and research, as well as ensuring the involvement of all relevant areas of the highly regulated aviation eco-system.

International Test Arena: Avinor and the Civil Aviation Authority Norway (CAA) have entered into a cooperation agreement to establish Norway as an International Test Arena, hereafter referred to as "Test Arena", for zero and low emissions aircrafts. Avinor provides infrastructure, airspace, and access to energy, while the CAA ensures regulatory facilitation. The purpose of the agreement is to facilitate the accelerated introduction of zero- and low-emission aircraft by reducing barriers to testing and demonstration. Among the work packages under the Test Arena agreement is the supply of hydrogen (H2).

Feasibility study: This document presents a feasibility study conducted by Norconsult and THEMA Consulting on establishing hydrogen infrastructure at a Norwegian airport. Bergen Airport, Flesland, is selected as the case study scenario for the feasibility study. The infrastructure covers hydrogen distribution, storage and refueling.

1.1 Abbreviations

Table 1: Table of Abbreviations

Abbreviation	Definition
AACE	Association for the Advancement of Cost Engineering
ADR	Accord Dangereux Routier (regelverk for farlig gods)
API	Application Programming Interface
ATEX	Atmosphères Explosibles
AWT	Acceptance With Test
BFD	Block Flow Diagram
BoD	Basis of Design
CAA	Civil Aviation Authority Norway
CAPEX	Capital Expenditure
CGH_2	Compressed Gaseous Hydrogen
CLP	Classification, Labelling and Packaging
CO_2	Carbon dioxide
CSNE	Conditional Signed Network Embedding
DMZ	Demilitarized Zone
DSB	Direktoratet for samfunnssikkerhet og beredskap
EASA	European Union Aviation Safety Agency
EEA	European Industrial Gases Association

EIA	Environmental Impact Assessment
EIS	Entry Into Service
ESD	Emergency Shut Down
FAT	Factory Acceptance Test
GPU	Ground Power Unit
HAZID	Hazard Identification
HAZOP	Hazard and Operability Study
HMI	Human–Machine Interface
HSE	Health, Safety and Environment
H_2	Hydrogen
IACS / ICS	Industrial Automation and Control Systems
IT	Information Technology
LEL	Lower Explosive Limit
LH_2	Liquid Hydrogen
LOPA	Layer of Protection Analysis
MITRE ATT&CK	Cyber-security framework
NEA	Norwegian Environment Agency
NVE	Norwegian Water Resource and Energy Dirctorate
NSO	Norwegian Industrial Safety Organisation
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
OT	Operational Technology
PFAS	Per- and polyfluoroalkyl substances
PFD	Process Flow Diagram
PLC	Programmable Logic Controller
PRD	Pressure Relief Device
QRA	Quantitative Risk Assessment
REACH	Registration, Evaluation, Authorisation of Chemicals
ROM	Rough Order of Magnitude
SAF	Sustainable Aviation Fuel
SAK10	Regulations relating to building applications (*Byggesaksforskriften*)
SAT	Site Acceptance Test
SIL	Safety Integrity Level
SMR	Steam Methane Reforming
TEK17	Building Technical Regulations
TRL	Technology Readiness Level
UEL	Upper Explosive Limit

2 Market and logistics

2.1 The Norwegian hydrogen market

Hydrogen is a highly versatile energy carrier and input factor, capable of serving multiple end-user segments. It can be used as a feedstock in chemical and refining industries, as fuel for heavy-duty transport such as shipping and aviation, and as an energy storage medium to balance intermittent renewable generation.

Hydrogen can be produced through different pathways, primarily via electrolysis or steam methane reforming (SMR). Electrolysis uses electricity to split water into hydrogen and oxygen, while SMR converts natural gas into hydrogen and CO_2. The carbon footprint of hydrogen depends on the production method and associated energy sources. Hydrogen produced from renewable electricity[1] through electrolysis is considered renewable, whereas SMR combined with carbon capture and storage can deliver low-carbon hydrogen. In Norway, SMR-based hydrogen production often includes CO_2 utilization in industrial applications (food, greenhouses, process industries), meaning that emissions are not simply released. However, as the carbon is not permanently stored, such hydrogen is not traditionally considered to be low-carbon.

When produced through low-emission pathways hydrogen becomes a critical tool for decarbonizing processes and operations where direct electrification is challenging. This can happen either by replacing SMR-based hydrogen without CO_2 handling to a low-emission hydrogen alternative e.g. in refining or ammonia production or by switching from fossil fuels to hydrogen, e.g. in transport (including aviation) or the production of green steel.

The European Union (EU) has positioned hydrogen as a cornerstone of its climate strategy. Under the EU Hydrogen Strategy and the REPowerEU Plan, the Union targets the production of 10 million tons of renewable hydrogen domestically by 2030. However, the current pipeline of hydrogen projects falls significantly short of this target, even if taking announced projects without final investment decisions into account. If the ambitious targets of using low-emission hydrogen as a tool for decarbonization are to be realized, the EU will depend on imports at least in the medium term.

Norway currently produces approximately 153 kilotons of hydrogen annually, primarily from natural gas for industrial applications (European Hydrogen Observatory, 2024). Only 3 percent of the total production was low-emission hydrogen, though several projects have emerged over the past few years. As of mid-2025, Norway has more than 200 hydrogen-related projects in planning or development, with 66 focused on low-emission production (The Norwegian Hydrogen Forum, 2025). Among these projects, less than 20 have reached a final investment decision, are under construction or are in operation.

A key challenge for the low-emission hydrogen market is cost competitiveness. Producing low-emission hydrogen remains significantly more expensive than conventional alternatives, creating a barrier for widespread adoption. While costs are expected to decline with scale, the cost gap persists, making policy support essential for competitiveness. The hydrogen market faces the classic chicken-and-egg dilemma: producers hesitate to invest without guaranteed offtake, while consumers delay adoption due to limited supply and uncertain cost development. This mutual dependency has significantly delayed the scaling of the hydrogen market, both in Norway and in Europe. As in Figure 1, which illustrates the development of hydrogen supply cost by production pathways towards 2050, fossil-based hydrogen and fossil-based aviation fuel are currently significantly cheaper than low-emission hydrogen alternatives.

[1] RFNBO-compliant

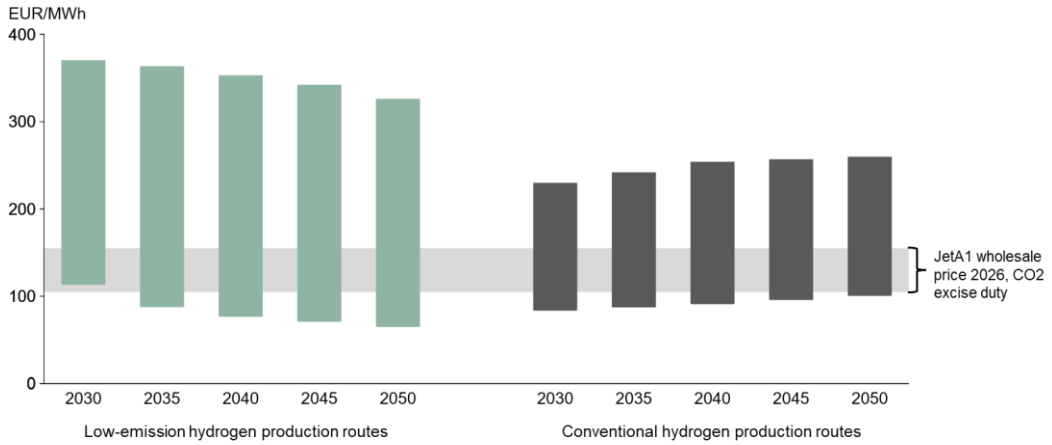


Figure 1: Supply cost development for hydrogen compared to current supply cost of conventional JetA1 fuel in Norway. Sources: Hydrogen production cost development extracted from the THEMA Hydrogen Outlook October 2025 with a 50-100% distribution cost add-on. JetA1 wholesale price from AFSN (February 2026). EU-ETS costs 2026 from the THEMA Green Values October 2025.

2.2 Hydrogen in airport operations

Together with electricity, biofuel and Sustainable Aviation Fuel (SAF), clean hydrogen is expected to be a key component for the decarbonization of future aviation and airport operations.

Avinor aims to reduce its greenhouse gas emissions by 42% by 2030 compared to 2022 levels and by 90% by 2050. In addition, Avinor targets that 71% of airlines associated with its value chain have science-based climate targets by 2028. Through these efforts, Avinor supports the transition towards fossil-free aviation in Norway by 2050.

While Avinor has already made significant progress in electrifying light vehicles at their airports and has initiated piloting of electric aircraft, other means, such as hydrogen, are necessary to decarbonize heavy-duty vehicles and larger aircraft.

Hydrogen can power vehicles and machinery at airports through two main technologies: fuel cell technology and hydrogen combustion engines. Fuel cells convert the chemical energy in hydrogen into electricity through an electrochemical reaction, with high conversion efficiency and water and heat as the only by-products at the point of use. Hydrogen combustion engines burn hydrogen in a conventional internal combustion engine (ICE) architecture and can produce NO_x emissions, depending on combustion strategy and after-treatment. While fuel cells have higher efficiency, combustion engines benefit from lower upfront costs and easier integration into existing engine platforms. This makes hydrogen engines attractive for certain heavy-duty and transitional applications where familiarity, robustness, and cost are key considerations. In the longer term, fuel cells are expected to play a central role in deep decarbonization due to their higher efficiency and zero-carbon operation at the point of use.

Hydrogen can be stored and used in several physical states. At ambient conditions, hydrogen exists as a gas with very low volumetric energy density, which necessitates either compression (typically to 350 or 700 bar) or liquefaction at -253℃ for efficient storage and transport. For applications where storage volume is highly constrained-such as aviation or long-range heavy-duty transport-liquefaction can be advantageous

due to its higher volumetric energy density, despite the significant energy penalty associated with the liquefaction process.

2.2.1 User segments

Hydrogen can be used in many parts of the aviation sector, offering opportunities both on the ground and in the air. At airports, hydrogen can be used to power **ground vehicles**, such as baggage tractors, pushbacks, belt loaders, forklifts, buses and snow sweepers. It can also supply energy for **support equipment** like ground power units (GPUs), mobile charging stations and heating systems. Lastly, hydrogen can be used for **aircraft propulsion**, enabling low-emission flight. While ground vehicles are expected to suffice with compressed hydrogen (CGH2), larger hydrogen-driven aircraft are expected to require liquid hydrogen (LH2).

2.2.1.1 Pilots

A mapping of hydrogen pilots at airports shows that there are at least three hydrogen pilot initiatives, BSR HyAirport, TULIPS and GOLIAT, that involve a series of European airports. In addition, there are examples of stand-alone hydrogen projects, where specific vehicles and infrastructure components have been tested in an airport environment. Common for the initiatives are that they are demonstration projects, where the main focus has been technology and operations validation, and not permanent implementation.



Figure 2: Hydrogen turnaround operation at Exeter Airport in 2024, involving a baggage truck (left), GPU (middle) and towing tractor (right). Picture source: Airsideint.com

Multiple initiatives involve towing tractors, GPUs and baggage tugs. **Exeter** Airport (UK) demonstrated all three types of equipment during a single turnaround operation in 2024, as shown in Figure 2. The pilot suggests that hydrogen vehicles can maintain turnaround efficiency, comply with safety procedures for airside operations and replace high-emission diesel equipment without operational disruption. Within the EU-funded TULIPS program, **Schiphol (NL)** also successfully tested hydrogen-powered GPUs and towing tractors in regular daily operations in 2024/25. While the results from the project have not yet been published, it demonstrates that it is possible to operate temporary refueling stations over an extended period in an airport environment.



Figure 3: As part of the BSR HyAirport, Finavia will replace one of the engines of a snow sweeper with a piston engine that burns gaseous hydrogen. The sweeper in the image is an illustration on Finavia's website. Source: Finavia.fi

For heavy-duty ground operations, such as trucks and snow-handling equipment, few hydrogen initiatives could be identified. At **Helsinki Airport**, as part of the BSR HyAirport initiative, Finavia announced in 2023 ambitions to test hydrogen-powered snow removal machines. As of November 2025, no information about the actual results of this work has been published. Discussions with known suppliers of heavy-duty airport machines indicate that purely hydrogen-driven machines do not exist in the market today or are in the very early stages of development. At **Edmunton International Airport**, however, a hydrogen/diesel dual-fuel runway snow sweeper will be piloted in 2026. The pilot marks the first time this type of hybrid machinery has been tested in the world.

Hydrogen-powered aircraft have undergone several test flights. In 2023, ZeroAvia flew a 19-seat Dornier 228 equipped with a hydrogen-electric fuel cell powertrain and subsequently completed an extensive flight test campaign. The same year, Universal Hydrogen conducted the first flight of a modified Dash 8 regional aircraft powered by a hydrogen fuel cell system, demonstrating hydrogen-powered operation on a commercial aircraft platform.

The necessary operational logistics and infrastructure for regular operations remain in an early development stage. The BSR HyAirport group plans a 2026 demonstration flight between **Rotterdam** and **Hamburg** to trial hydrogen operations between two commercial airports, and the GOLIAT consortium has scheduled a 2027 demonstration at **Lyon–Saint Exupéry** Airport focusing on LH_2 refueling and ground handling procedures. In November 2025, ZeroAvia received a grant from the EU Innovation Fund to introduce a series of retro-fitted hydrogen-electric aircraft in Norway from 2028.

2.2.1.2 Market status off-taker segments

- Despite several pilots and initiatives, only a limited number of hydrogen-powered vehicle types are currently commercially available. Early adopters include passenger cars, vans, and material handling equipment, while the first heavy-duty trucks are now entering the market with hydrogen drivetrains. For most vehicles, further development is required before wide-scale commercial deployment, as summarized in
- Table 2 and Table 3.
- **Towing tractors, GPUs, and baggage tugs** have been demonstrated through pilot testing, but are not yet available as standard commercial products.
- Suppliers indicate that hydrogen-powered **snow sweepers** can be delivered, although they would need to be specially manufactured and are significantly more expensive than fossil-based alternatives. Suppliers indicate that when put into production, it would take 2-3 years to develop and

deploy the machine, but they are dependent on up front financial risk-sharing with the user to make the investment. Due to engine limitations, particularly for the front-truck of towed sweepers, the first models are also expected to be somewhat smaller than the conventional snow sweeper models.

- Several companies are working to develop **hydrogen-powered aircraft**. Several tests have been performed but there is considerable uncertainty about the timeline for when various aircraft actually will be certified and when they can enter operations. Over the past few years, manufacturers like Airbus and ZeroAvia, have postponed their previously announced timelines.

Table 2: Hydrogen technology mapping for ground handling operation equipment

Category	Vehicle group	Pilots identified	Supply status	H2 propulsion technology
Ground operations	Baggage tractors / towing tractors	Yes	Custom-built on demand	Fuel cell
Ground operations	Snow sweepers / blowers	Yes, hybrids	Custom-built on demand	Combustion engine
Ground operation	Cars / Vans/ Buses	In operation	Commercial – available	Fuel cell
Energy supply	GPU	Yes	Custom-built on demand	Fuel cell

Table 3: Supplier mapping hydrogen-powered aviation. Information based on technical brochures downloaded from suppliers' websites, TØI report 2073/2025 and press releases from the respective suppliers.

Concept	Payload	Range	H2 type	H2 propulsion	Service entry	Comment
Airbus ZEROe	~ 100 pax	1000 nm	LH_2	Fuel cell	2040-2045	Airbus has officially stated that the target for EIS in 2035 has been delayed. Rumored to be ready between 2040 and 2045.
ZeroAvia ZA200	-	-	CGH_2	Fuel cell	~2028	Fuel cell system for light wing commercial aircraft, eVTOLs and Unmanned Air Vehicles. Technological focus for ZeroAvia per 2026.
ZeroAvia ZA600	10-20 pax	300 nm	CGH_2	Fuel cell	~2030	Powertrain, retrofit possibility.
ZeroAvia ZA2000	40-80 pax	500-1000 nm	LH_2	Fuel cell	After 2030	
Embraer Energia H2	19-50 pax	600 nm	LH_2	Both	2040	Three different hydrogen models (19, 30, 50 pax).
H2Fly HY4	3 pax	400 nm (CGH_2), 800 nm (LH_2)	LH_2 or CGH_2	Fuel cell	2030	Test flights conducted. Also planning a version with 40 pax.
Fokker Next Gen	120-150 pax	1350 nm	LH_2	Combustion engine	2035	Early-stage development. Aims to start testing in 2033, with earliest entry in 2035.

2.2.1.3 Relevance for Avinor

Avinor has already electrified a significant share of their passenger and utility vehicles, as well as buses and smaller equipment such as street sweepers. Electric wheel loaders and chemical spreaders are currently being tested, and there are plans to electrify ramp solutions, crew buses, trucks, wheel loaders, chemical applicators, deicing vehicles, and passenger stairs with lifts. GPUs, towing tractors, and baggage tractors have also been largely electrified. Given the progress already achieved on the electrification-side, the most relevant segments for further exploration in a future pilot are hydrogen-driven **snow sweepers and aircraft using gaseous hydrogen.**

2.3 Supply of hydrogen to and distribution within an airport

2.3.1 Supply and transport

Several low-carbon hydrogen production initiatives are under development in Norway today, however few have yet to come into operations. At present the distances from existing production sites to any Norwegian airport can be quite long, which adds complexity and cost to the logistics of securing hydrogen for airport operations.

In the long term, if hydrogen becomes widely used at airports, on-site or nearby production could be attractive to reduce transport costs and simplify logistics. However, setting up a production plant at an airport involves significant complexity and investment, which unlikely can be justified during a pilot phase with limited and uncertain demand. For this feasibility study, we therefore assume that hydrogen will be produced off-site and transported to the airport. Consequently, one of the main success factors for the pilot is securing supply from nearby production facilities.

Hydrogen can be transported to an airport in different ways. The feasibility of the different options depends on factors such as volume, distance and geography. The most common option for small volumes is truck transport, either as gas in pressurized cylinders or in liquid forms in cryogenic tanks. For large-scale transport, however, pipelines are the cheapest option. Ships can also move large volumes but are naturally limited by geographical conditions.

In a pilot, truck transport is the most viable option for most airports. Truck containers come in standard sizes of 300, 500 and 1000 kg, and the supply logistics to the airport will therefore consist of deliveries of these standard volumes. These delivery sizes will also define storage capacity needs at the airport. According to hydrogen suppliers interviewed for this study, the hydrogen tanks can either be used to store hydrogen (container swapping) or used to refill a more permanent storage solution at the airport. The supply cost quoted by the suppliers range from 100 – 400 NOK/kg, see Figure 4. Some suppliers state that transport costs are included in the quota, while others do not offer such services. Per transport an extra charge for container rental may be necessary. The exact supply cost will depend on distance, volume and scale of the production plant in question.

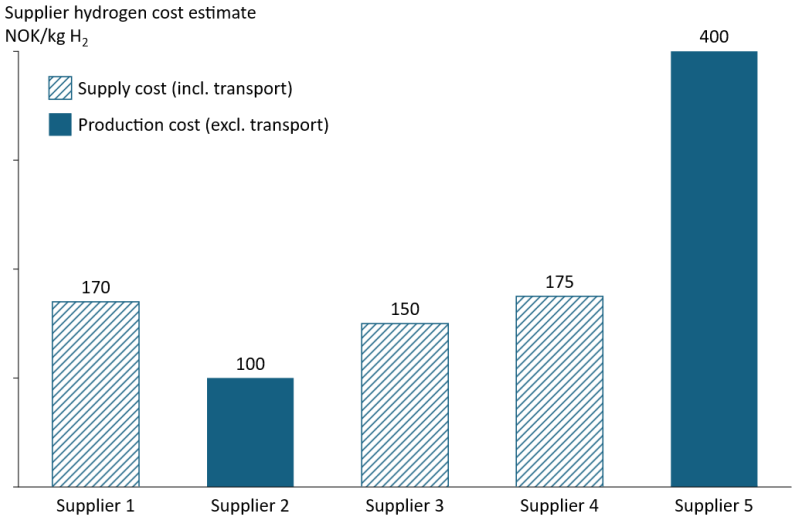


Figure 4: Hydrogen supply cost, with or without transport costs included, informally quoted by various hydrogen suppliers.

2.3.2 Handling at airport

Hydrogen operations within an airport require infrastructure for intake, storage, distribution and fueling of hydrogen. This hydrogen value chain can be quite simple, with few temporary components for a pilot, or quite complex with multiple off-taker segments and conversion between hydrogen states. In recent years, there have been multiple studies covering the potential hydrogen value chains compatible with airport operations.[2][3][4]The studies map different value chains emphasizing that the actual setup will be influenced by

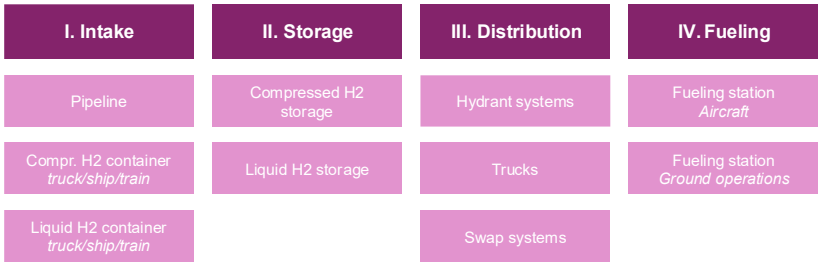


Figure 5: Hydrogen value chains in airport operations.

[2] *Feasibility study on the general use of gaseous hydrogen in airport machinery (BSR HyAirport, 2025)*
[3] *Hydrogen Infrastructure and Operations (FlyZero, 2022)*
[4] *Zero Emission Flight Infrastructure (Catapult, 2023)*

hydrogen volumes, the type of hydrogen supplied and required by different user segments, demand profiles, mix of user segments and safety considerations at the airport in question.

This study focuses on heavy snow sweepers and small aircraft (see Chapter 2.2.1.3). While the first hydrogen-electric aircraft are expected to suffice with 350 bar hydrogen, snow sweepers will require 700 bar compressed hydrogen. For larger aircraft, it is expected that also liquid hydrogen is required. Solutions containing different pressure levels, e.g. to minimize storage sizes or adapt to the supply solutions are also possible but require compressor systems.

To dimension the infrastructure for these test cases, the following considerations must be made:

- **Total demand:** The delivery volumes and on-site storage tanks need to be dimensioned according to hydrogen demand from these two user segments.
- **Seasonality:** While flight operations will need hydrogen volumes that are (almost) constant over the year, snow operations are highly seasonal and require large amounts of hydrogen only in a few days.
- **Short-term demand:** The storage tanks must be large enough to cover for a certain minimal period of continuous operation of the offtake machinery. The exact number will depend on the operation schemes at a specific airport and the possible delivery volumes and delivery frequency. Chapter 2.4 breaks the volumes down for a specific case.

2.4 Case study: Flesland

Bergen Airport, Flesland, has been selected as a case study scenario for this feasibility study. Flesland is located 12 km southwest of Bergen and is one of the largest regional airports in Norway.

The purpose of the feasibility study, and later pilot, is to investigate the feasibility of hydrogen as an energy carrier in an airport environment and assess its potential to decarbonize hard-to-abate vehicles. By focusing on Flesland, the study can provide more practical insights into how hydrogen can be integrated in daily operations and what implications it has for infrastructure and logistics.

2.4.1 Demand in a pilot phase

For the case study we assume that one hydrogen-driven airplane and one snow sweeper will be tested, starting operations from mid-2028. Some testing in 2027 may also be possible, depending on supplier timelines. The annual demand from a sweeper and a small aircraft is assessed to **42 tons**. Depending on the specific operations planning and uncertainties about actual hourly demand a range between 18 and 67 tons is estimated. Figure 7 shows the demand per segment, with different usage assumptions. In the text box below, the annual hydrogen demand and storage capacity needs for Flesland in a pilot are explained in more detail.

HYDROGEN DEMAND AT FLESLAND FROM SWEEPERS AND AVIATION IN PILOT PHASE

Snow sweepers have highly seasonal demand and variable operating patterns, with peak activity concentrated during winter months when snow removal is critical for maintaining runway safety. During these periods, machines may operate continuously for extended shifts, creating short-term spikes in fuel demand. In contrast, summer demand is minimal, with machines largely idle for occasional maintenance runs. This seasonal variability has implications for hydrogen deployment and storage capacity needs. At Flesland, the annual hours of operation for a snow sweeper are roughly 200-300 hours and the number of snow days vary from 20 to 90. When in operation, the sweepers are in constant operation - up to 18 hours per day.

Parameter	Value	Comment
Fossil fuel consumption (litres/hour)	35 - 40	*Avinor data*
Hourly demand converted to hydrogen (kg/hour)	12 - 14	*Combustion engine efficiency 37 %*
Annual hours of operation (hours/year)	200-300	*Avinor data*
Hydrogen storage leakage (%)	10	
On-site storage capacity requirement (hours)	72	*Avinor data*
Annual hydrogen demand (kg)	**2400 – 4100**	
Storage capacity requirements (kg)	**900 - 1100**	*e.g. weekly demand peak*

Aircraft naturally have more regular operating patterns than snow handling machines. In a pilot phase, however, the operational pattern is expected to vary somewhat due to technical validation exercises and demonstration runs. Over time, as testing expands to longer routes and more frequent operations, hydrogen demand will naturally increase. The hydrogen storage infrastructure should therefore be scalable to accommodate increasing demand as the pilot progress.

Parameter	Value	Comment
Hourly hydrogen demand (kg/hour)	25 - 30	*ZeroAvia ZA600 model*
Daily hours of operation	4-8	*Pilot phase, Avinor estimate*
Days in operation per week	3-5	*Pilot phase, Avinor estimate*
Hydrogen storage leakage (%)	10	
On-site storage capacity requirements (hours)	12-40	*to cover weekly demand*
Annual hydrogen demand (kg)	**15600- 62400**	
Storage capacity requirements (kg)	**300 - 1300**	*e.g. weekly demand*

Total storage capacity needs

Summing up the above estimates, the necessary storage capacity is 1200-2400 kg for Flesland. The seasonal variability of demand for snow sweepers, however, means that a somewhat smaller storage solutions are possible given reductions in aircraft testing in their peak demand periods. Therefore, we assume that the storage requirement is 2000 kg.

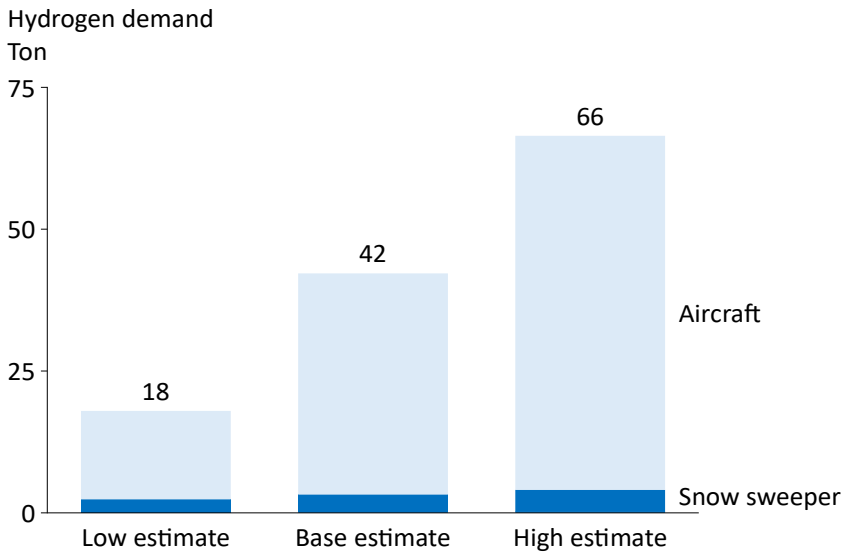


Figure 7: Annual hydrogen demand estimate to test one snow sweeper and a hydrogen-electric aircraft.

2.4.2 Hydrogen supply options

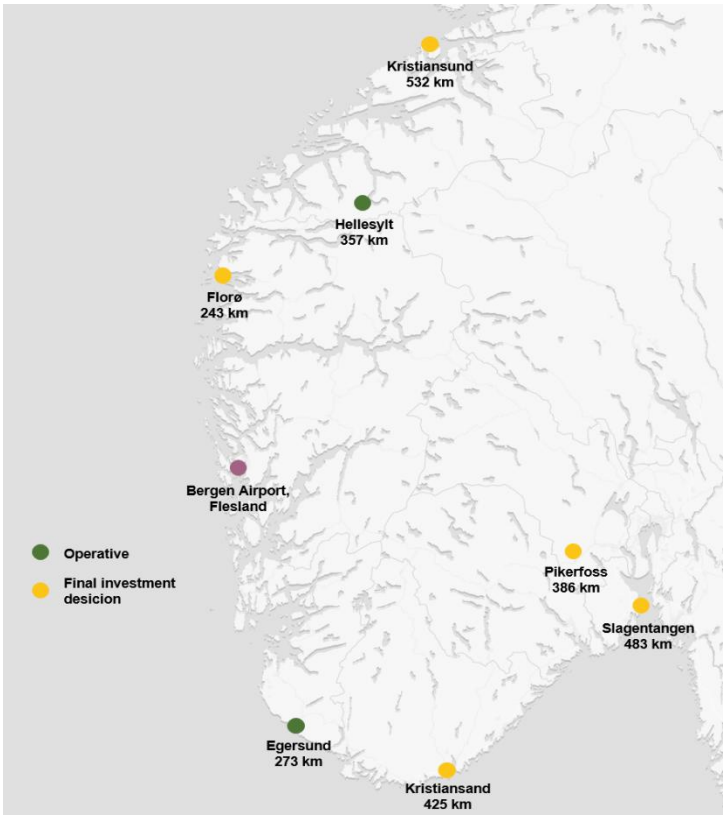


Figure 6: Hydrogen production facilities and their shortest driving distance to Bergen Airport, as calculated via Google Maps. The status of the hydrogen projects is based on publicly available information.

There are currently no low-carbon hydrogen production initiatives located near Flesland, see Figure 6. The closest facility with a FID in place, is in Florø, which is more than 200 km away from the airport. In Hellesylt and Egersund, 357 km and 273 km away respectively, there are hydrogen production plants in operation.

An important success criterion for a potential pilot is to establish supply arrangements with available suppliers. Despite significant distance, suppliers interviewed for this study raised few technical concerns of the feasibility of transporting hydrogen to Flesland in an early pilot phase by truck. While long-distance trucking of hydrogen can serve as a practical solution for a limited pilot, it should not be interpreted as a scalable supply model. The selected airport is indeed located far from existing and planned hydrogen production, and these logistical constraints are known and recognized. Therefore, trucking should be viewed as an interim measure that enables the pilot rather than a general success criterion for hydrogen deployment at airports.

In the long term, the feasibility of hydrogen at the airport will depend on aligning supply solutions with demand volumes. For small pilot-scale consumption, road transport may provide sufficient flexibility and reliability. However, as demand increases, the economic and environmental viability of long-distance trucking diminishes, and options such as on-site production, nearby production facilities, or pipeline delivery will need to be assessed to ensure scalability.

3 Basis of Design (BoD) - Summary

The Basis of Design (BoD) defines the key requirements, assumptions, and criteria upon which the entire design and analysis for the hydrogen infrastructure will be developed. The BoD is normally updated with more details for each consecutive engineering phase.

Below is a BoD summary, while the complete BoD is found in Appendix A – Basis of Design (BoD).

Bergen Airport, Flesland, was selected as the case-study location. The hydrogen infrastructure pilot assumes a weekly hydrogen demand of approximately 2,000 kg for a hydrogen-powered snow sweeper and small aircraft.

A simple block flow diagram of the hydrogen infrastructure is seen in Figure 8.

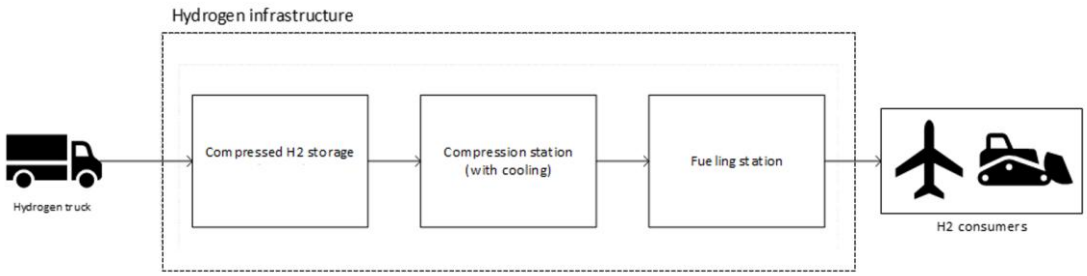


Figure 8: Hydrogen infrastructure simple block flow diagram

Two concepts for the hydrogen infrastructure are assessed:

- Option A – Stationary solution: Permanently installed H2 storage tanks with stationary infrastructure
- Option B – Mobile solution: H2 battery swap with modular storage unit and mobile dispenser unit

The BoD further defines the feasibility-level operating principles and design boundaries needed to develop the pilot infrastructure. It clarifies delivery and refueling sequences, pressure management, equipment interfaces, utility needs, monitoring, maintenance access, staffing assumptions, modular installation principles, and responses to abnormal conditions. It also identifies matters requiring development in later phases, including supplier-specific parameters, detailed procedures, equipment sizing, control logic, civil works, formal hazard studies, permitting, and emergency planning.

4 Regulatory framework

Norconsult has performed an assessment of the relevant legal framework, including all authority approvals and permits needed for storage and use of hydrogen. The assessment is primarily based on laws and regulations applicable to airports in general, with additional clarifications provided for Bergen Airport Flesland (used as the study case scenario in the feasibility study). In this chapter Norconsult presents:

- A list of the permits required for establishing the planned hydrogen infrastructure facility
- Identification of the regulatory authority responsible for each permit or approval
- A description of permitting processes and related activities, including expected timelines and identification of time-critical issues in relation to the overall project schedule.
- An overview of the supporting documentation and information required for permit applications.

Although this part of the study report aims to present all necessary permits and approvals, additional applications may be required. Regular revision and updates are therefore recommended throughout the project lifecycle.

4.1 Permitting overview

This subchapter provides an overview of the main permitting procedures for establishment of hydrogen infrastructure at an airport. The permitting procedures include several processes towards different authorities and legal framework, as listed in Table 4.

Table 4. Authorities and legal framework for permitting procedures.

Authority	Legal framework
Civil Aviation Authority Norway (CAA) (Luftfartstilsynet)	The Aviation Act (Luftfartsloven)
The Norwegian Directorate for Civil Protection (DSB)	Fire and Explosion Prevention Act
The Norwegian Environment Agency (NEA)/ The County Governor/Municipality	Pollution Control Act
Bergen municipality	Planning and Building Act
The Norwegian Industrial Safety Organisation (NSO)	Regulations relating to Systematic Health, Environmental and Safety Activities in Enterprises
Norwegian Labor Inspection Authority (Arbeidstilsynet)	Working Environment Act

The subsequent subchapters discusses the listed acts. In addition, relevant cyber security acts are presented.

4.2 The Aviation Act

In Norwegian the The Aviation Act is called *Luftfartsloven*. It is relevant because the hydrogen infrastructure will be located airside at the airport.

The Norwegian Aviation Act (Norwegian: Lov om luftfart, the Aviation Act)(Samferdelsdepartementet, 2022) as set out by the Ministry of Transport, *"establishes that aviation in Norway may only take place in accordance with this Act and regulations issued pursuant to the Act. For aviation activities covered by the provisions of the EEA Agreement, the rules on the supplementation and implementation of the EEA Agreement in the field of aviation, as incorporated into this Act, take precedence over the Act's other provisions." (§ 1-1.).*

The Regulation on the Certification of Aerodromes, etc. (FOR-2015-08-25-1000)(Samferdselsdepartementet, 2015) is governed by Commission Regulation (EU) No 139/2014, which includes, inter alia, design requirements for aerodromes and related facilities.

Approval and regulatory oversight pursuant to the applicable legislation are enforced in Norway by the Civil Aviation Authority Norway (Luftfartstilsynet), which holds regulatory authority within Norwegian civil aviation, but is directly subordinate to and reports to the Ministry of Transport

A prerequisite for an airport to be in operational service is that it holds a valid certificate. Pursuant to Section 1 of the Regulation on the Certification of Aerodromes, etc. dated 25 August 2015, cf. Article 6 of EU Regulation No 139/2014, the Civil Aviation Authority Norway has certified the aerodrome in question. For a specific establishment, Avinor will specify which certificate-related conditions must be assessed and fulfilled before the establishment of infrastructure can be considered feasible. These requirements will apply both to the construction phase and to the permanent operational situation, including any potential impacts on aviation safety.

For any potential establishment of hydrogen infrastructure, the feasibility of implementing such measures at the specific airport must be clarified with Avinor. Avinor must be notified, either through a neighbor notification pursuant to the Planning and Building Act or through a pre-application conference at an early project stage, in order to obtain conditions for implementation that do not conflict with the airport operator's certificate.

For permits and regulation of aviation safety in Norway, the Civil Aviation Authority Norway bases its work on European guidelines and regulations(European Union Aviation Safety Agency, 2026) (EASA).

Note! Aviation regulations do not apply to the use of hydrogen for ground vehicles, but they come into effect when hydrogen is used as fuel for aircraft.

At present, there are no global or national guidelines for the use of new alternative energy sources as aviation fuel. This applies, for example, to both electric batteries and hydrogen. The EASA has initiated work related to alternative fuels, but no decisions or clear guidelines have yet been established. Aviation regulations and relevant applications regarding the use of hydrogen for aircrafts must therefore be further investigated in later studies or project phases. The timeline for the establishment of regulations is still unknown.

4.3 The Fire and Explosion Prevention Act

In Norwegian the Fire and Explosion Prevention Act is called *Brann- og eksplosjonsvernloven.* This act is relevant because hydrogen is a potentially hazardous (explosive) fluid.

The Fire and Explosion Prevention Act(Lovdata, 2023) is set in place to protect life, health, the environment and material assets against fire and explosion, against accidents involving hazardous substances and dangerous goods and other acute accidents, as well as unwanted intentional incidents. Section 7 in Regulations on flammable, reactive and pressurized substances as well as equipment and facilities used for handling [3] states that there is a legal requirement that everyone who designs, manufactures, installs,

operates, modifies, repairs, maintains or controls equipment and facilities used in the handling of hazardous substances shall have the necessary competence.

Industrial Emergency preparedness (Industrivern) is required for all industries classified in accordance with an activity code regime. Regulations relating to industrial safety were Issued by the Norwegian Directorate for Civil Protection on 20 December 2011 pursuant to the Municipal Emergency Preparedness Act and the Civil Protection Act.

As hazardous substance will be handled at the facilities within the airport, the facility will be subject to the requirements of this act.

If a fire breaks out at the airport, the location of the incident will determine who is responsible for extinguishing it. If buildings or vehicles are burning, responsibility lies with the municipal fire service, whereas if the fire involves an aircraft, the airport's own fire and rescue service is responsible. In practice, the two parties will work together in a joint effort if a fire occurs.

The Directorate for Civil Protection (called DSB – *Direktoratet for Samfunnssikkerhet og Beredskap*), is the responsible authority for the Fire and Explosion Prevention Act.

The listed regulations have their legal basis in the Fire and Explosion Prevention Act:

- Major accident regulations [4] (Seveso III) (*storulykkeforskriften*)
- Regulations on flammable, reactive and pressurized substances as well as equipment and facilities used for handling (*forskrift om håndtering av brannfarlig, reaksjonsfarlig og trykksatt stoff samt utstyr og anlegg som benyttes ved håndteringen*) [3]

It is foreseen that a mandatory reporting according to attachment 2 in Regulations on flammable, reactive and pressurized substances as well as Equipment and facilities used for handling [3] shall be submitted for hydrogen. The threshold value for this is 0,4 m^3.

The threshold values for hydrogen are listed in attachment one, part two of the regulation [4] and presented in Table 5 below. Consent from DSB to build and put the facility into operation is required for facilities covered by the Major accident regulations due to handling materials covered by the regulation on handling hazardous substances.

Consent requirement shall be according to §6 or §9 in Storulykkeforskriften [4].

Table 5. Limit values for Hydrogen given in the Major Accident Regulations, attachment one, part two.

Hazardous Substance	Storage quantity – Notification (§6)	Storage quantity – Safety report (§9)
Hydrogen (CAS. 1333-74-0)	5 tons	50 tons

Generally, major accident facilities must be approved by DSB through a consent application based on stored quantities. Existing chemicals on site must also be included using a summarization rule to ensure correct total inventory. Consent Requirement shall be according to §6 or §9 in Storulykkeforskriften [4]. Airports already approved as Major Accident Facilities must update their existing consent and documentation.

Existing chemicals kept at Flesland are registered with different companies serving different purposes, such as fueling and deicing (Table 6).

Table 6. Existing chemicals in the vicinity of the planned hydrogen station.

Substance	m^3	tonnes
Jet A1	650	519,4
Jet A1 for helicopter	3	2,4
Petrol tank	60	46,5
Diesel tank (underground)	20	16,0
Diesel for emergency power	50	42,3
Diesel for vehicles	60	50,7
Formate	Unknown	
Glycol	Unknown	

Note! An important regulatory change that will be effectuated 01.01.2027 states that all hydrogen filling and dispensing stations must undergo approval and consent from DSB [17]. It is therefore highly likely that the hydrogen infrastructure proposed in this feasibility study will fall under this new regulatory change, regardless of the amount of chemicals stored.

For new facilities subject to the Major Accident Regulations, the consent process has two stages:

Step I: Consent to construct

Step II: Consent to commence operation

The application must follow DSB's guidelines, be submitted in Norwegian, and include early notification to DSB, typically via an initial information meeting. The surrounding area must be evaluated for potential domino effects from nearby establishments. None has been identified so far, but this will be reassessed during the risk evaluation.

It is currently unclear whether Flesland airport is registered as a major-accident establishment. The municipal land-use plan applies the planning zone code H350_1 for the adjacent areas to the planned station (Figure 9) [20], which designates an area as a fire and explosion hazard zone associated with major-accident type activities.



Figure 9. Excerpt from the municipal land-use plan (BERGEN LUFTHAVN FLESLAND. Nasjonal PlanID 1201_61710000).

4.3.1 Quantitative risk assessment (QRA) and consideration zones (*hensynssoner*)

A quantitative risk assessment (QRA) is a key part of the DSB consent application and is used to determine whether spatial restrictions (consideration zones) are needed to ensure acceptable public risk. Risk contours from the QRA guide the municipality in establishing these zones. The DSB theme report on safety about hazardous substance facilities [21] defines tolerable third-party risk levels and requires risks to be reduced to an ALARP (As Low As Reasonably Practicable) level.

Consideration zones, also illustrated in Figure 10:

- **Inner consideration zone (10^{-5} contour):**
  Mainly the company's own area. Agriculture, nature and outdoor areas may be included. Only brief third-party passage is allowed.

- **Middle consideration zone (10^{-6} contour):**
  It can include roads, railways, jetties, and permanent industrial/office workplaces. Accommodation is not permitted, though scattered housing may be accepted in some cases.

- **Outer consideration zone (10^{-7} contour):**
  May include residential areas, shops, and small accommodations.

- **Outside the outer consideration zone:**
  Sensitive uses—schools, kindergartens, nursing homes, hospitals, shopping malls, hotels, and areas with large crowds—must normally be located outside this zone.

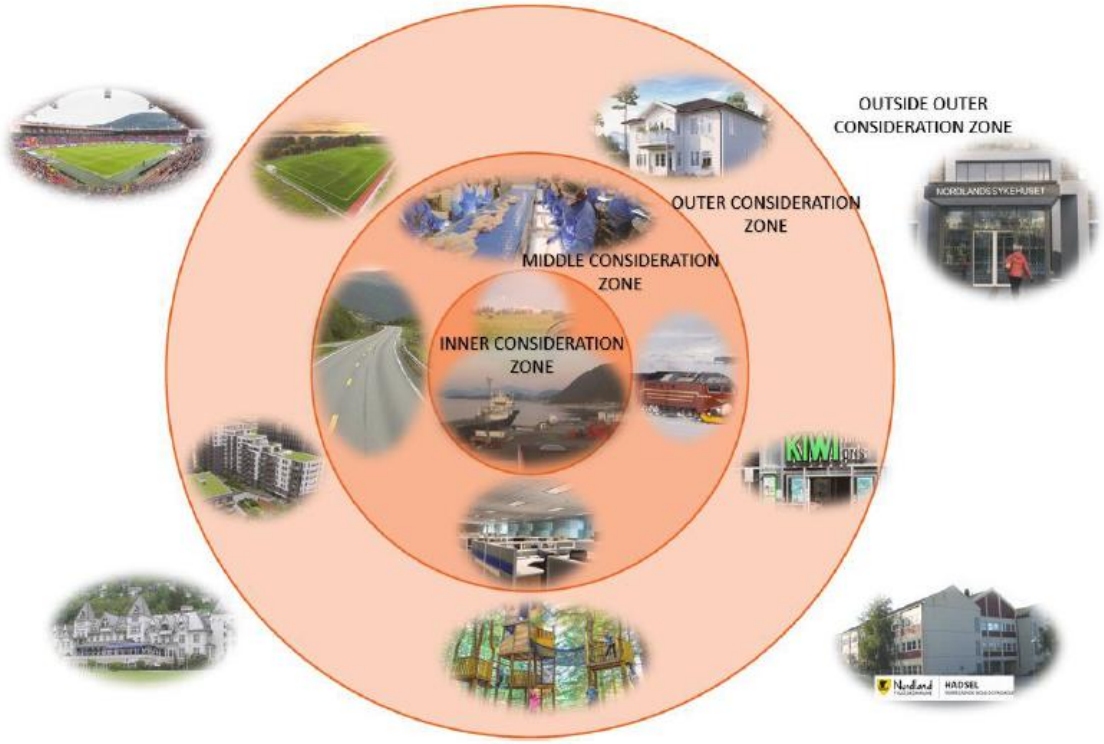


Figure 10 Illustration of consideration zones and activities/objects accepted in each zone

4.3.2 Dependencies

- Normally, DSB does not issue consent for construction before the zoning plan has been approved. However, Norconsult has previously experienced that consent was granted some time ahead of the final approval of the zoning plan. Before consent was given there was a close dialogue between DSB and the municipality and the probability that the zoning plan would be adopted was high.

- Some municipalities require that DSB has issued consent step 1, before the municipality issues a building permit.

4.3.3 Risks

- Consent must be obtained according to regulations on the handling of dangerous substances before construction can begin. Construction here means the construction of equipment and facilities for handling hazardous substances. The land arrangement, infrastructure such as electricity, underground pipes, etc. is not considered construction. However, foundation establishment or other preparatory work for equipment for hazardous substances cannot be carried out until consent has

been granted. Before consent is obtained, all possible preparatory work and financial expenses are at the developer's own risk.

- The facility design and layout must be determined before the application for consent is sent to DSB. Changes in facility design could mean that the QRA must be updated, and the application must be sent for another public hearing. Such iteration can be resource intensive and time consuming.

- To obtain consent from DSB to build the facility, the risk contours visualizing risk of fatality around the facility needs to be within established risk acceptance criteria. The criteria are given in the DSB theme report *Safety around facilities handling flammable, reactive, pressurized and explosive substances [21].* Short distances to public roads, houses, institutions and places where third persons may be present represent a risk that the risk contours will not be within the risk acceptance criteria, resulting in the application for consent being refused.

4.4 The Pollution Control Act and related regulations

The Pollution Control Act in Norwegian is called Forurensningsloven. The act is relevant as the hydrogen infrastructure might cause emissions to air, soil and noise.

The Pollution Control Act (Forurensningsloven)(Klima- og miljødepartementet, 2023) is established to protect the outdoor environment against pollution, including waste, and to reduce existing pollution. It has an overarching scope concerning environmental matters. Meanwhile, the Regulation on Pollution Control (Forurensningsforskriften)(Klima- og miljødepartementet, 2022) provides detailed rules governing pollution. Both the Pollution Control Act and the Regulation on Pollution Control are applicable to businesses with the potential to have impact on the environment.

The Norwegian Environment Agency (Miljødirektoratet) is responsible for managing cases and applications under the Pollution Control Act. Some subject areas may still be delegated to the County Governor (Statsforvalteren) or the Municipality (kommunen). At Bergen airport Flesland, the County Governor is the environmental authority and regulates the conditions in the environmental permit.

The environmental authority may require that the party planning a notifiable activity carry out an environmental impact assessment (EIA) (konsekvensutredning) to assess the environmental consequences of pollution. This is further described in the Handbook M-1941(Miljødirektoratet, 2026) with guidance on how to assess the mapping and investigation of impacts on the climate and environment.

An Emission Permit in accordance with the Pollution Control Act (Tillatelse til virksomhet etter forurensningsloven) is required before initiating industrial production activities that could potentially cause noise, emissions, or pollution to water, soil, or air. Airports are not included in the Industrial Emission Directive and do not automatically require an emission permit.

Activities in marine environments, such as filling, dredging, or installing intake or discharge pipes (e.g., for cooling water), also require a defined permit from the environmental authority before construction can commence.

4.4.1 Corrective action plan and permit for terrain intervention

In accordance with the Regulations Pollution Control, it is required to conduct an assessment for contaminated soil within development sites where terrain intervention is planned. The assessment must be executed at the outset of the construction phase. Since Avinor already has a general procedure prepared for

performing terrain intervention and sampling of the soil, including specification of the different pollutants, following this procedure should be sufficient to comply with regulations. Airport facilities have shown themselves to be susceptible to different pollutions in the soil due to activities as de-icing and the use of PFAS chemicals.

If evidence suggests possible soil contamination in the area designated for new installations or foundations, it is essential to conduct appropriate investigations to determine the extent and effects of the contamination. These investigations must, at a minimum, determine whether the soil contains levels of contamination exceeding established normative values. Any excavation and removal of contaminated soil must strictly adhere to a remedial action plan and be transported to a certified facility authorized to handle the specific category of waste material.

A detailed corrective action plan outlining the proposed management of contaminated soil must receive approval from the appropriate environmental authority prior to commencing work. This authority may operate at the local, district, or national level, encompassing the municipality, and at Bergen airport Flesland, the County Governor is the environmental authority.

It is important to note that the estimated processing time for reviewing and approving a corrective action plan and its associated application can extend up to 6-12 moths (with PFAS)in the worst-case scenario.

For Bergen Airport Flesland, the existing discharge permit includes terms for the procedure concerning contaminated soil and sediments. At Bergen Airport Flesland, large areas have already been mapped regarding contaminated soil. Nevertheless, supplementary sampling will likely be required during ground disturbance associated with the construction of foundations or underground infrastructure.

4.4.2 Application of Emission Permit or change in existing Permit

EU’s Industrial Emissions Directive does not apply to airports as such, because the directive regulates specific categories of industrial installations, and airports are not listed among them. The directive targets activities such as large combustion plants, waste treatment facilities, and various chemical and industrial processes. Individual installations on airport grounds may be covered if they fall within the directive’s defined industrial categories. A site-specific assessment is required to determine whether any such installations exist. Each Norwegian airport has an emission permit, and the main conditions in emission permits are related to the use of de-icing chemicals for runway and airplanes and for fire suppression agents.

All businesses subject to Chapter 36, Annex 1 of the Pollution Control Regulations must obtain an Emission Permit in accordance with the Pollution Control Act. This permit ensures that the company complies with environmental standards and mitigates any potential negative impacts on soil, water, and air quality.

For the Avinor airports both the County Governor and The Norwegian Environment Agency can serve as the environmental authority under the Pollution Control Act. An application for a revised Emission Permit for a new installation at a facility with existing emission permit must encompass a description of the production process, production-related concerns, regular emissions, and waste disposal procedures. For an activity including infrastructure and storage for hydrogen for use as fuel for ground transportation it is not expected to be any environmental issues of concern. It might still be necessary to issue an application for a revised emission permit. In some cases, it might be sufficient to report the change in activity to the environmental authorities. This must be further clarified with the relevant environmental authority, as early as possible.

The report should include a summary of the technical installation and any emissions and noise generated by the additional facility. If the hydrogen infrastructure does not cause emissions to air or additional noise this should be stated in the report.

For an airport with existing Emission Permit, it must be assured that the environmental authority is informed about the new activity of storing and handling hydrogen, although hydrogen storage and handling is not considered to be an activity that will cause pollution. This will ensure that any new terms are incorporated in the planning of the new facility and before operation and use starts.

4.4.3 Dependencies

- Environmental permits for terrain interventions must be approved before the municipality issues project start-up permits for the project or individual work packages. However, these permits are not required before submitting the application for a General Permit (rammetillatelse).

- The Emission Permit in accordance with the Pollution Control Act (Tillatelse til virksomhet etter forurensningsloven) must be in place or revised before any additional polluting activities or other new activities from production can start.

4.4.4 Risks

- The timeline for environmental authorities to process various permit applications is not clearly defined. It should be noted that the processing time may be longer than initially anticipated.

- Establishing installations on a site with potential soil pollution from previous activities increases the risk of high costs for handling contaminated soil during terrain interventions. Conducting preliminary investigations and sampling can mitigate this risk, potentially lowering costs and minimizing impacts on project progress.

4.5 The Planning and Building Act

The Planning and Building Act in Norwegian is called Plan- og bygningsloven.

The Planning and Building Act(Kommunal- og distriksdepartementet, 2025) has the intent to promote sustainable development in the best interests of individuals, society, and future generations.

The purpose of planning under this Act is to help different levels of government (national, regional, and local) work together. It also guides decisions about how resources are used and protected.

The processing of building applications according to this act ensures that projects are carried out in compliance with statutes, regulations and planning decisions. Individual projects shall be carried out in a proper manner.

Planning and administrative decisions ensure transparency, predictability and public participation for all affected interests and authorities. There shall be emphasis on long-term solutions, and environmental and social impacts shall be described.

The authority that enforces the Planning and Building Act is the municipality where the project property is located, in the case of the feasibility study is Bergen municipality.

The listed regulations have their legal basis in the Planning and Building Act:

- Regulations on impact assessments(Klima- og miljødpartemenet, Kommunal- og distriktsdepartemenet, 2026) (*Forskrift om konsekvensutredninger*)
- Regulation relating to building applications(Kommunal- og distriktsdepartementet, 2026) (*Byggesaksforskriften SAK10*)
- Regulation on technical requirements for construction works(Kommunal- og distriktsdepartemenet, 2017) (*Byggteknisk forskrift TEK17*)

All documentation issued to the municipality must be in a Scandinavian language.

4.5.1 Zoning plan (*reguleringsplan*)

Current zoning plan status

The area of the airport activity is included in the area zoning plan for Bergen Airport Flesland, PlanID 61710000.

Zoning plan

A zoning plan consists of a plan map with associated plan provisions and plan description. The zoning plan with associated provisions states the use, protection and design of areas and physical surroundings, see the Planning and Building Act § 12-1. We assume that in case of a new zoning here it will be an *alteration of existing plan*. The zoning plan determines how, and for what purposes, the areas within the plan can be utilized and any conditions related to the use. The plan will also list additional required documentation for the building application. Alongside a zoning plan a risk and vulnerability analysis is carried out.

The work related to zoning plan will address the need for physical areas, the detailed use of these areas, expected traffic, necessary technical infrastructure such as water supply and sewage capacity and more. The storage and use of hydrogen for fuel is regarded to follow the zoning regulations applicable for Bergen Airport Flesland. For other airports this is an issue to be addressed in an early phase to ensure that existing zoning plan includes the planned new activities.

4.5.2 Particular focus on risks of natural hazards

If an area does not already allow for hydrogen installations, it is important to carefully review the risks that come with setting up such a facility. This review will be required as part of the zoning or building permit process. An area prone to such risks can be limited with respect to which activities are allowed. These issues should be dealt with at an early stage because they can influence the design and utilization of the industrial area as well as the progression of the project.

According to the Norwegian water and energy directorate (NVE) adequate security against natural hazards (flooding/tidal water and landslides) must be ensured through consideration zones and planning provisions at the last zoning level, as it is not possible to push further clarification of such risks and hazards by requiring conditions in relation to building permits. H-5/18 Samfunnssikkerhet i planlegging og byggesaksbehandling - regjeringen.no

4.5.2.1 Dependencies

An important dependency in this plan is the topic concerning the Major Accident Regulations. This will set certain guidelines for the planning work, as the risk profile related to major accident events will influence the design of the plan. At Bergen Airport Flesland, the relevant volume of hydrogen included does not meet the threshold for classification as a major hazard establishment. However, DSB has stated that all hydrogen filling and dispensing stations must undergo approval and consent from DSB from 01.01.2027.

4.5.2.2 Risks

The risk related to major accidents is the most significant aspect related to risk in the planning process. Proximity to surrounding areas will impose important constraints on the planning proposal.

Another risk could be unpredictability in the public approval process, which may impact the timeline and when the zoning plan will receive official approval.

As long as the existing zoning plan does cover all aviation related activities, such as storage and use of fuel for land transportation use, the risk is insignificant.

4.5.3 Building permit (*byggetillatelse*)

According to the Planning and Building Act, the developer will need to apply for a building permit from the municipality. The developer needs to designate a responsible applicant («*ansvarlig søker*») for the application process. As per § 23-4 in the Planning and Building Act, the responsible applicant is the responsible party's representative towards the municipality and is responsible for ensuring that the building application contains the necessary information for the municipality to be able to decide whether the civil and building design of the plant is in accordance with regulations and permits accorded by or pursuant to this act.

The applications procedure normally includes general application (*rammesøknad*), application for project start-up permission (*søknad om igangsettingstillatelse*) and finally an application for certificate of completion (*ferdigattest*). Application for project start-up permission may be divided into more applications. It is also possible to combine the general application and application for start-up permission, but this process is not suited for larger and more complex projects.

In addition to a responsible applicant, the developer must designate responsible designers (*ansvarlig prosjekterende*) and responsible contractors (*ansvarlig utførende*) for relevant subject areas. This can be civil engineering, environmental topics, architecture, water and sewage systems, geotechnical engineering etc. Certain subject areas also must be verified by a third-party in projects of a certain complexity. In this project it

is anticipated that civil engineering/construction, geotechnical engineering, fire safety and building engineering physics (energy efficiency of the building) must be verified by a third party.

Project start-up permission can only be granted after all requirements for the general permission are fulfilled, responsibilities are properly assigned, and the scope of control is defined. Additionally, necessary permissions from other relevant authorities must be obtained, as stated in Section 21-5, first paragraph of the Planning and Building Act.

Relevant subject areas must have designed sufficiently for construction before application for project start-up permission can be sent.

The building project ends with a certificate of completion. It is possible to apply for a temporary permit for parts of the project or if the project is not completed, but safe to use.

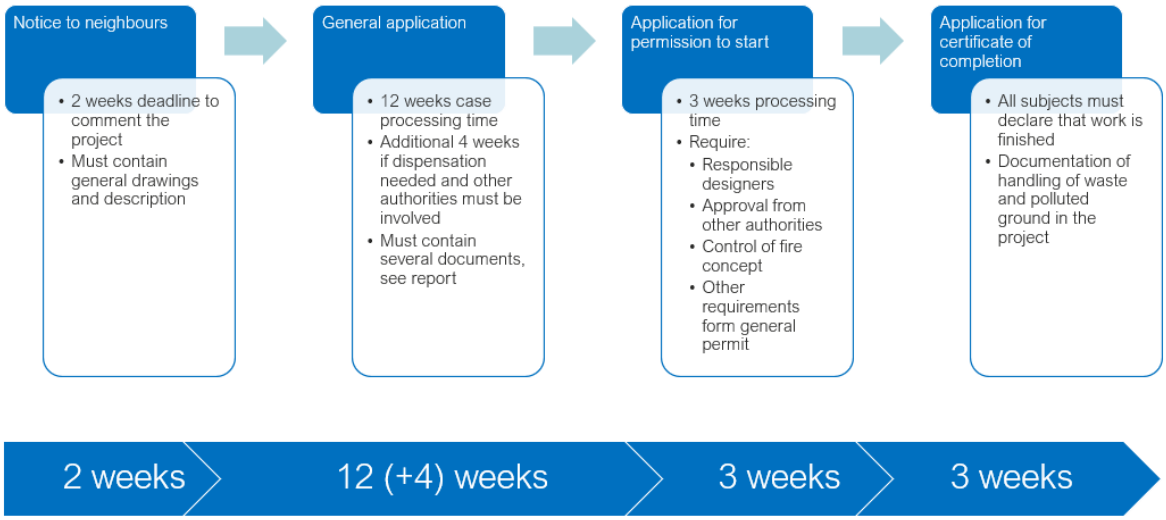


Figure 11: Building permit application process

Figure 11 above shows the processing times for different application stages. This timeline does not include time for engineering and construction. In practice, the overall duration of the building project will be much longer than expected.

Normally the application is processed by the administration in the municipality. For certain projects of interest, the application will be considered by the politicians. If the project fulfils all requirements in the Planning and Building Act and zoning plan, the administration or politicians cannot deny a permit. The authorities can express their views about how the building project looks and may require changes to the design or placement of buildings to improve appearance and site arrangement.

For process equipment and elements covered by the Fire and Explosion Prevention Act, an exception has been made in parts of the Planning and Building Act and in the regulations relating to building applications (*Byggesaksforskriften*). These projects are exempt from the rules on responsibility, quality assurance and control, and audit pursuant to the Planning and Building Act. However, they are still obligated to apply and follow the other procedural rules. This exception does not cover the buildings surrounding the process equipment.

Required documentation in the building permit application

The requirements for a building permit application are given in SAK10 § 5-4, but this must also be adjusted to the specific project. Standard documentation includes:

Notice to neighbors:

- Plan layout of site
- Facades/volumes
- Map
- Basic description of the project

General permit application:

- More detailed drawings
  - plans
  - facades
  - section drawings
  - map
  - landscape plan
- More detailed description
- Stability report/geotechnical engineering
- Description of surface water handling
- Description of sufficient capacity for extinguishing water
- Responsible designers

Project start-up application:

- Responsible contractors
- Responsible controlling actors
- Permits from other authorities
- Completed control of fire concept (if relevant)
- Sufficient technical maturity
- Plan for surface water handling
- Other topics the municipality has asked for in the general permit

Application for certificate of completion:

- Declaration of conformity from designer, contractors and controller functions.
- Declaration that documentation for management, operation and maintenance is complete and handed over to the developer.
- Other topics the municipality has set as terms in the permit

4.5.3.1 Dependencies

The measure must be in accordance with the valid zoning plan before application by the Plan and Building Act can be submitted.

We assume permit for framework can be given without permits/statements from other authorities and that these will be needed for the relevant applications for permits to start to work.

Before an application to start work can be submitted, the following permits/statements must be in place:

- Consent for construction (Step I) from DSB. This is likely to be relevant according to a regulatory change that will be effectuated on 01.01.2027 stating that all hydrogen filling and dispensing stations must undergo approval and consent from DSB.
- Approval of terrain intervention from Municipality/County Governor/NEA
- Approval of Emission Permit from NEA
- Approval from the Norwegian Labour Inspection Authority for relevant start up applications. It is possible to start early work before a consent from the Authority.

Before an application for certificate of completion (or temporary permit) can be submitted, the following permits/statements must be in place:

- Consent for operation (Step II) from DSB according to “Temaveiledning om innhenting av samtykke”.

4.5.3.2 Risks

It should be clarified whether the municipality is positive about processing the application for a framework permit before statements/decisions from other affected authorities have been obtained. This falls under the municipality’s coordination duty.

The application process depends on other authority clarifications. There are dependencies related to the application to start work. The various statements are related to the relevant commencement application. Since the applications to start to work can be split into several applications, this can be planned in more detail.

Furthermore, consents are also necessary before an application for the completion certificate related to safe use can be submitted.

4.6 Regulations relating to Systematic Health, Environmental and Safety Activities in Enterprises

In Norwegian Regulation relating to Systematic Health, Environmental and Safety Activities in Enterprises is called Forskrift om systematisk helse-, miljø- og sikkerhetsarbeid i virksomheter.

4.6.1 Internal Control Regulations

The Internal Control Regulations (Regulations relating to Systematic Health, Environment and Safety Activities in Enterprises)(Arbeids- og inkluderingsdepartementet, 2026) are central to the company's systematic follow-up of health, environment, and safety. The purpose of the health, environment and safety (HSE) management system is to ensure that hazards and problems are detected and addressed in time. The requirement for systematic procedures applies not only to the working environment but also, for example, to fire safety, electrical safety and environmental protection.

The Internal Control Regulations are based on a variety of laws, and the company's management system must therefore encompass the entire HSE concept. The Internal Control Regulations require that the party responsible for the company ensures systematic follow-up of the requirements set by the regulations for HSE in their business. This must be done in collaboration with the employees and their representatives. The regulations are also known as the 'HSE Regulations'. In addition to the Labor Inspection Authority, several other authorities as the Directorate for Civil Protection (DSB) and the Norwegian Environment Agency also supervise the Internal Control Regulations. The Internal Control Regulations describes this in more detail in § 7.

4.6.2 Requirements for Management Systems and Emergency Preparedness According to the Major Accident Regulations

Some of the key requirements for management systems and emergency preparedness in Annexes III and IV of the Major Accident Regulations are listed below.

Annex III: Requirements for Management Systems

1. Organization and Personnel: Overview of the organization, tasks, and responsibilities of personnel involved in preventing and limiting major accidents. Identification of training needs and implementation of necessary training.
2. Identification and Assessment of Risk: Procedure for identifying and assessing the likelihood and consequences of potential major accidents during normal and abnormal operations.
3. Operational Control: Procedures for safe operation, including condition monitoring and maintenance of facilities, processes, and equipment.
4. Management of Changes: Procedures for planning, implementing, and documenting all types of changes in the business.
5. Emergency Planning: Procedures to reduce the consequences of potential major accidents and to develop, maintain, practice, and test the emergency plan.

Annex IV: Contents of the Emergency Plan

1. Description of Measures: Description of measures to limit the consequences of major accidents for people, the environment, and material assets.
2. Notification Procedures: Procedures for notifying internal and external emergency resources.
3. Evacuation Plans: Plans for evacuating employees and other persons who may be affected by a major accident.

4. Cooperation with Emergency Services: Procedures for cooperation with emergency services and other relevant authorities.

4.6.3 Dependencies

The HSE management system must be updated before operation starts and when application to DSB, step II is undergoing. This means that it also must be ready before application to certificate of completion after the Plan and Building Act can be possessed.

4.6.4 Risks

There are no obvious risks regarding this application.

4.7 The Working Environment Act

In Norwegian the Working Environment Act is called arbeidsmiljøloven. This act is relevant because the hydrogen infrastructure must comply with HSE work requirements defined by law.

The administrative process of obtaining the necessary permits has been simplified in recent years when the construction project involves only pre-accepted solutions. In such cases, it is usually Norconsult's SØK (responsible applicant) who follows up. Pre-accepted solutions are rarely (if ever) the case for industrial facilities, and in those instances, more effort is required to demonstrate that the solution ensures worker safety.

According to section 18-9 in the «Working Environment Act» (*Arbeids- og inkluderingsdepartementet, 2022*), any company that wants to put up a building or carry out construction work must submit an application following the Planning and Building Act. The company must first obtain prior consent (*samtykke*) from the Norwegian Labour Inspection Authority (*Arbeidstilsynet*).

The application shall demonstrate that the working conditions regarding safety, health and welfare are within the law. Workplaces shall be facilitated and designed based on the work tasks planned, the employees and relevant risk factors. A risk assessment that shows the solutions are acceptable should be performed according to established working environment acts, Regulations concerning the performance of work, use of work equipment (Arbeids- og inkluderingsdepartementet, 2026) and related technical requirements and Construction Client Regulations (Arbeids- og inkluderingsdepartementet, 2022).

The application can be submitted digitally via e.g. www.ebyggesok.no or similar applications, alternatively by use of a dedicated building form given by the authorities. In both cases the application must have a self-declaration form and the necessary documentation required by the authorities.

The application must include the following required information:

- Copy of the application for building permit
- Description of type of work tasks / operations to be performed at the hydrogen infrastructure
- A self-declaration form with the Norwegian Labor Inspection Authority's pre-accepted solutions
- Documentation of employees' participation in the plans for establishing the hydrogen infrastructure
- Documentation of the employer's participation in the plans for establishing the hydrogen infrastructure
- Documentation that the occupational health service has assisted in planning and design of the hydrogen infrastructure
- Other relevant documentation regarding working environment factors and workplace design

If the digital application includes a self-declaration form and the hydrogen infrastructure design is according to the pre-accepted solutions from The Working Environment Act, the application will be automatic approved. In case the hydrogen infrastructure design differs from the pre-defined solutions, the applicant must explain and document how the alternative design meets requirements in laws and regulations.

If the application is not sent digitally and/or the hydrogen infrastructure design differs from the pre-defined solutions the application needs to be evaluated by a case handler. The authority typically processes applications within 8 to 12 weeks after receiving them, which is also the mostly likely scenario for this project. The municipality cannot grant a start-up permit until the Norwegian Labor Inspection Authority has given their consent to the plans.

To obtain the shortest possible case processing time, the following must be attended:

- Design the facility in accordance with the pre-accepted solutions in the self-declaration scheme.
- Send a digital application.
- Submit all necessary documentation. If the application is incomplete, the company will receive a letter with information about what is missing and a deadline for submitting new documentation.

4.7.1 Dependencies

This approval is required before application to start to work according to the Plan and Building Act can be possessed. The approval is necessary for the application relevant for the permanent workplace. This means that it is possible to send applications for groundwork before there is a consent from the Norwegian Labor Inspection Authority.

4.7.2 Risks

Applications are typically processed automatically. However, if selected options differ from the standard solutions, a case handler must manually review the application, which may introduce uncertainties about case processing time.

There is always a risk associated with assessments of solutions that deviate from predefined solutions as they are based on discretion.

4.8 The Digital Security Act and the Digital Security Regulations

The purpose of the act is to contribute to ensure that fundamental requirements for digital security in organizations delivering essential services in society by preventing, detecting, and counteracting unwanted incidents in network and information systems used to deliver essential services and digital services. It applies to providers of essential services in the sectors of energy, transport, health, water supply, banking, financial market infrastructure, and digital infrastructure, as well as providers of digital services.

The act and regulation are applicable, as Avinor falls under the essential services within transportation, e.g. air navigation services and as a provider of commercial airports.

In short, organizations subject to the Act and the Regulations are required to carry out the following activities:

1. Notify the authorities that you provide essential services.

2. Establish an appropriate level of security.

3. Map the services, delivery requirements, and systems.

4. Conduct a risk assessment.

5. Prepare a plan for managing risk.

6. Follow up with partners and subcontractors.

7. Prepare an emergency preparedness plan and practice it.

8. Report incidents.

The requirements in the Digital Security Act are minimum requirements.

4.9 Regulation 2023/203 EASA Part-IS

This EASA regulation is included in Norwegian laws via the regulation on informational security in Civil aviation.

The regulation requires organizations to establish and maintain an Information Security Management System (ISMS) covering governance, risk assessment, risk treatment, incident management, reporting, personnel competence, record keeping, and continuous improvement.

A key principle of Part-IS is that information security risks must be assessed based on their potential impact on aviation safety, rather than solely on financial or business consequences. Organizations remain accountable for security activities even when these are outsourced and must report significant information security incidents to the competent authority within 72 hours of becoming aware of them. The regulation promotes integration of cybersecurity into existing aviation management and safety processes, making information security a management responsibility rather than solely an IT function.

4.10 Regulatory summary

The regulatory review indicates that the following acts and associated regulations are the most relevant for the establishment and operation of a hydrogen infrastructure at Bergen Airport Flesland:

- **The Aviation Act**
  Due to the current lack of maturity in regulations governing the use of hydrogen in aviation, further regulatory development is required before the applicable requirements can be fully clarified. For hydrogen use in ground-based operations, aviation regulations do not apply.
- **The Planning and Building Act**
  A standard building permit is expected to be required for the construction of stationary facilities. The existing zoning plan for the area allows for activities associated with a hydrogen refueling station.
- **The Fire and Explosion Prevention Act**
  Handling of hazardous substances requires the operator to notify the Norwegian Directorate for Civil Protection (DSB) of the quantities involved prior to construction or commissioning of the facility. As the facility is expected to fall under the major accident regulations as of 01.01.2027, a formal consent application will be required. The facility's design, risk assessments, and emergency preparedness measures must comply with the detailed requirements for hazardous substances and major accident prevention.
- **The Pollution Control Act**
  Permits are generally required for terrain interventions related to foundations or underground infrastructure within the airport area. During the operational phase, a revised environmental permit may be required; however, it is considered likely that a notification to the County Governor will be sufficient.
- **Regulations relating to Systematic Health, Environment and Safety Activities in Enterprises (Internal Control Regulations)**
  Existing documentation and procedures within Avinor address many of the relevant requirements, but updates will be necessary to reflect new risks and conditions associated with hydrogen handling. This also applies to the Emergency Response Plan. Through its ISO 14001 certification, Avinor ensures this.

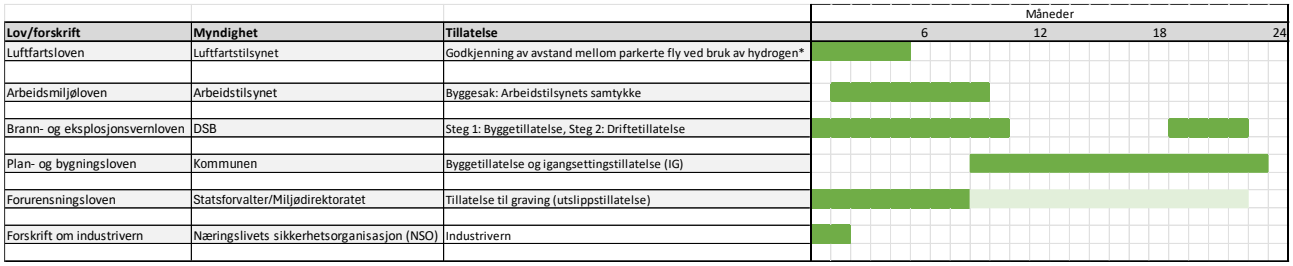
- **The Working Environment Act**
  It is expected that the establishment of the new facility will require consent from the Norwegian Labor Inspection Authority.

- **The Digital Security Act**
  Given its location within the airport environment and the fact that it forms part of Avinor's operational infrastructure, the technical systems of the new facility are expected to be subject to the same digital security requirements as those applicable to Avinor, to ensure compliance with the Norwegian Digital Security Act.

- **Regulation 2023/203 (Part-IS)**
  Given its location within the airport environment and the fact that it forms part of Avinor's operational infrastructure, the facility is expected to be subject to the requirements applicable to Avinor under EASA Part-IS, including the establishment and maintenance of an information security management system where information security risks are assessed in relation to their potential impact on aviation safety.

4.11 Estimated timeline regulatory frameworks and permits

Based on the identified relevant act and regulations (presented in subchapters 4.2-4.7), a completed estimated timeline for the regulatory framework and permits has been established and is found in Appendix F – Estimated Regulatory Timeline. A simplified version of the timeline is seen in in Figure 12.



Lov/forskrift	Myndighet	Tillatelse
Luftfartsloven	Luftfartstilsynet	Godkjenning av avstand mellom parkerte fly ved bruk av hydrogen*
Arbeidsmiljøloven	Arbeidstilsynet	Byggesak: Arbeidstilsynets samtykke
Brann- og eksplosjonsvernloven	DSB	Steg 1: Byggetillatelse, Steg 2: Driftetillatelse
Plan- og bygningsloven	Kommunen	Byggetillatelse og igangsettingstillatelse (IG)
Forurensningsloven	Statsforvalter/Miljødirektoratet	Tillatelse til graving (utslippstillatelse)
Forskrift om industrivern	Næringslivets sikkerhetsorganisasjon (NSO)	Industrivern

Figure 12: Estimated timeline regulatory frameworks and permits

5 Safety

This chapter presents safety and risk assessments carried out during this feasibility study. The assessed topics that are presented are:

- Technical safety
- Digital safety (cyber security)
- Intentional harmful actions

5.1 Technical Safety

5.1.1 General safety considerations

Hydrogen is a highly flammable gas with a Lower Explosive Limit at (LEL) at 4% and Upper Explosive Limit (UEL) at 75%. Thus, it can ignite across a wide range of concentrations and requires only 0.017 mJ ignition energy to be ignited. Ignition of hydrogen within flammable concentrations will result in a fire or explosion depending on the surroundings of the ignited gas. Hydrogen is defined as a hazardous substance due to its flammability.

Hydrogen is, however, highly buoyant and will disperse rapidly in open air conditions. As a part of a safe hydrogen fueling station design, the ventilation conditions are important to take into consideration.

A design that minimizes the likelihood of a release, prevents any leaked gas from accumulating, and eliminates or controls ignition sources is crucial to reduce the risk of fires and explosions.

5.1.2 Road and sea transport of hydrogen

Hydrogen production is outside the project scope and therefore hydrogen must be produced at a remote location and transported to the airport.

Hydrogen is defined as dangerous goods when transported. Road transport of dangerous goods is regulated by the “Regulation on the land transport of dangerous goods” [6]. The safety of the surroundings to where dangerous goods are transported, is regulated through zoning planning according to “The Planning and Building Act”. The zoning planning process will require that risk from transport of dangerous goods is evaluated.

Flesland Airport is located on the west coast of Norway. Based on data from the Norwegian Public Roads Administration (http://www.vegkart.no) there is one stretch of road with restrictions for transport of dangerous goods in Norway, and that is on National Road 658 outside Ålesund. Here, tunnel category D applies to the Aksla Tunnel, Ellingsøy Tunnel, and Valderøy Tunnel during the periods 07:00–09:00 and 14:00–18:00 every day. In addition, there is a special arrangement for the tunnel in Hvaler in Østfold municipality, where the tunnel is closed to other traffic by the road traffic control center when notification is given of the transport of dangerous goods. Hence, there should be no transport restrictions for hydrogen by truck apart from the ADR regulations specifically for the trucking company/handler.

For sea going transport, for example ferries connecting islands, there are specific requirements for transport of hazardous goods [7].

5.1.3 Safety design

5.1.3.1 Operational Risks and dependencies

For concept alternatives, please refer to BoD.

5.1.3.2 External safety distances and layout

The Norwegian inspection authority of hazardous substances, DSB, has not provided safety distances for facilities with hydrogen in regulations or guidelines. Land use limitations must be established around equipment and installations where this is necessary, according to a risk assessment, to safeguard the adjacent area in a satisfactory manner. The risk assessment must be adapted to the complexity, size, and location of the installation/equipment and should be used as a basis for decision making and as documentation of an adequate safety level.

For installations where risk contours are prepared in accordance with DSB's guidelines for quantitative risk assessments (QRA) for facilities handling hazardous substances, DSB's risk acceptance criteria may be used to determine whether the risk to the surroundings is acceptable [19].

The following types of fires are seen as relevant scenarios following a hydrogen leakage (Table 7) [19]:

Table 7: Scenarios and lethality threshold values.

Scenarios	Description of scenario	Lethality threshold values
Explosion	A flash fire in which the ignited gas cannot expand freely, causing turbulence in the gas and significant pressure buildup.	0,4 barg overpressure (50 % lethality)
Jet fire	A fire in an ongoing leak where pressure is present behind the leak point.	15 kW/m² for 28 seconds and down to heat radiation of 1,5 kW/m² for 610 seconds. (50% lethality)
Flash fire	A short-lived fire resulting from the ignition of a gas cloud.	100% LEL (100% lethality)

The lethality threshold values are treated as binary criteria and exposures below the threshold are assumed to result in no fatalities, while exposures above the threshold are assumed to result in 100% mortality. For comprehensive quantitative risk assessments, the threshold for thermal radiation is replaced with a probit function that calculates probability of death based on heat radiation level and exposure time.

A leakage scenario assessed to be a credible worst-case scenario has been simulated (using the software Phast 9.11) to estimate the possible extent of lethal consequences. This worst-case scenario can be described as emptying a whole hydrogen tank of 1000 kg hydrogen, through the tank's largest pipe connection. The input parameters to the simulation are summarized in Table 8.

Table 8: Input parameters for simulation for consequence.

Hydrogen (kg)	Pressure (barg)	Hole size (mm)	Temperature (°C)	Release direction
1000	350	25	20	Horizontal

Figure 13, Figure 14 and Figure 15 illustrate the estimated extents of an explosion, a jet fire, and a flash fire that are expected to result in fatalities.



Figure 13: Lethality radii following a large hydrogen leak which leads to a credible worst-case explosion. The radii shows 0,4 barg overpressure which corresponds to 50% lethality rate. Ignition times are reported in seconds in left hand upper corner at different atmospheric conditions. Dark blue circle: 1.5/F (stable atmosphere, typically night-time conditions) 0,4 bar (Effect Zone) at Time: 6,08756 s; Purple circle: Category 1.5/D (neutral atmosphere) 0,4 bar (Effect Zone) at Time: 8,6238 s; Light blue circle: Vind (D) 12 m/s 0,4 bar (Effect Zone) at Time: 5,47436 s; Pink circle: Category 5/D (neutral atmosphere with stronger wind) 0,4 bar (Effect Zone) at Time: 7,94798 s.

NOTE: Not all circles are visible because they converge.



Figure 14: Lethality radii for jet fire, following a large hydrogen leak which leads to a credible worst-case jet fire.

Dark blue circle: Category 1.5/F (Stable atmosphere, typically night-time conditions) 50% (Effect Zone); Light blue circle: Vind (D) 12 m/s 50% (Effect zone); Purple circle: 1.5 D (neutral atmosphere) 50% (Effect zone); Pink circle; Category 5/D (Neutral atmosphere with stronger wind) 50% (Effect zone).

Note: all radii are at the same distance, thus they all converge in the same blue radius.



Figure 15: Lethality radii for flash fire following a large hydrogen leak which leads to a credible worst-case flash fire. The radii shows 100% LEL which corresponds to 100% lethality rate. Pink circle: Wind (I) 12 m/s (0.04 fraction); Red circle: Category 1.5D (neutral atmosphere) (0.04 fraction); Dark red: Category 5D (neutral atmosphere with stronger wind) (0.04 fraction); Dark blue: Category 1.5E (slightly stable atmosphere) (0.04 fraction).

NOTE: Not all circles are visible because they converge.

The figures show simulations of a leakage scenario that is assessed to be a credible worst-case scenario for a permanent bulk storage installation containing 1000 kg of hydrogen. Note that if the tank is equipped with an outlet pipe larger than 25 mm, a release through a larger opening would also be considered credible, and the extent of the consequences would increase accordingly. For example, increasing the hole diameter to 50 mm is estimated to increase the consequence range by approximately 50%.

For the option B solution, the current information from Hexagon Purus shows that hydrogen is stored in multiple smaller tanks, thereby reducing the probability of a large release. Option B could therefore result in a shorter risk extent compared with a permanent storage tank as described in Option A.

The simulation tool used is Phast 9.11 which is developed by DNV. This is an empirical 2D-tool which does not take topography into account. This limitation should be taken into consideration when the results are evaluated. The results are collected from a height of interest 1 meter above ground. As the hydrogen storage is located at a raised area, one meter above ground for the simulation tool, corresponds to a higher level in real life for surrounding areas. Thus, the results may be conservative for ground level.

Note! The zones cannot be used as a basis for an application for approval to DSB but provide an initial illustration of the extent of possible fatal consequences following a large hydrogen leakage.

5.1.3.3 Equipment safety distances - plant layout

Hydrogen installations are not explicitly regulated in DSB's safety distance tables, however EIGA (European Industrial Gases Association) [18] offers some empirical guidelines regarding distances between different objects in the vicinity of the hydrogen station (Table 9). DSB has a recommendation of 60 meters distance from 400 kV power lines for LPG/LNG plants which is also relevant for hydrogen stations. There are no power lines within that distance based on chosen location [16] .

Table 9: EIGA (European Industrial Gases Association) empirical guidelines for separation distances.

Typical type of outdoor exposure	Distance in metres of hydrogen from
1. Open flames and other ignition sources (incl. electrical)	5
2. Site boundary and areas where people are likely to congregate such as car parks, canteens, etc.	8
3. Wooden buildings or structures	8
4. Wall opening in offices, workshops, etc.	5
5. Bulk flammable liquids and LPG storage above ground in accordance with national codes, where they exist, for the particular substance. Otherwise	8
6. Bulk flammable liquid and LPG below ground 6.1 Tank (horizontal distance from shell) 6.2 Vent or connections	 3 5
7. Flammable gas cylinder storage, other than hydrogen	5
8. Gaseous oxygen storage (cylinders)	5
9. Liquid oxygen storage (not greater than 125 000 litre tank capacity)[2)]	8[1)]
10. Non-flammable cryogenic liquid storage, other than oxygen, for example argon, nitrogen[1)]	5[1)]
11. Stocks of combustible material, for example timber	8
12. Air compressor, ventilator intakes, etc.	15

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

[2)] For tank capacities greater than 125 000 litres see EIGA Document 127, *Bulk Liquid Oxygen, Nitrogen and Argon Storage Systems at Production Sites* [21].

5.1.3.4 Risk assessment

A brief screening of the risk factors was performed with participation of key project members (Appendix C – Risk matrix). This preliminary risk assessment is to be considered a starting point for future more in-depth risk assessments. The primary focus has been safety for personnel and supply/operation.

5.1.3.5 Area classification (ATEX) and ignition sources

The ATEX 2014/34 [5] directive sets out rules for equipment and protective systems intended for use in potentially explosive atmospheres and for hydrogen it will be classification as temperature class T1 and equipment group IIC. The use of ATEX zones should be limited to release points that create explosive zones, typically around flanges, pressure relief valves and vents, compressors, dispenser hoses and the dispenser station. In these zones ignition sources should be mapped and equipment must be approved for use in explosive areas [8][14]. ATEX equipment increases the cost and puts constraints on the layout and design, so it must be planned carefully.

Area classification drawings should be developed for internal training of personnel and for documentation for authorities.

5.1.3.6 Fire & Gas detection

Fire detection:
Hydrogen flames are barely visible and can be very difficult to detect visually, especially in daylight. Multichannel infrared flame detectors are often used for detection of hydrogen fires. These can detect fires up to 40 meters away and provide a safe alternative to early detection from a distance.

Gas detection:
Hydrogen under pressure generates an ultrasonic sound at the leakage exit point and turbulent flow above a predefined sound pressure level can be detected efficiently. A single detector can respond to even small hydrogen leaks up to 20 meters from the leak and since ultrasonic detection does not rely on the presence or concentration of hydrogen gas it is ideal for monitoring pressurized pipes and vessels. The advantage of an ultrasonic detector is that it can cover a greater area without needing to be in direct visual sight of the leakage source. For specific release points in a Hydrogen facility a point gas detector is a good solution. It is specifically relevant for use in confined or less ventilated spaces.

Exact placement of fire & gas detectors should be further defined based on a risk assessment in the later project stages. In general, early detection of hydrogen leaks with automatic isolation of the leak point contributes significantly to reducing the risk for the surroundings.

5.1.3.7 Emergency shutdown

Fire and gas alarms shall trigger an automatic response by the control or safety system and initiate a shut-down sequence and alert the fueling station operator, and other users. Typically, a voting system is used with confirmation from several gas detectors in order not to have frequent untimely shutdowns. This is typically designed as a visual and auditive alarm at 15% LEL and another that initiates a shutdown if confirmed at 30% LEL. The emergency shutdown must override all other functions.

Most important actions are to:

1) Shut-off of the hydrogen supply to the equipment from an isolation point

2) Depressurization of the hydrogen to a safe location

3) Ignition source control by de-energizing electrical equipment

4) If any enclosed areas or buildings are a part of the design the ventilation should increase [1][2].

5.1.3.8 Fire protection

The most effective means of extinguishing a hydrogen fire is to terminate the gas supply. Extinguishing the flame without isolating the hydrogen flow can lead to the formation of an explosive mixture, creating a significantly greater hazard should reignition occur. Standard firefighting practice is to prevent the fire from spreading and allow it to burn until the hydrogen is consumed or the source can be isolated. An adequate water supply should be maintained to cool adjacent equipment during the incident normally by fire hydrants and connected hoses.

The local fire department at Flesland should be aware of the presence of hydrogen and instructed in appropriate firefighting techniques for hydrogen related incidents.

5.1.3.9 Fire and explosion barriers

Appropriate barriers should be determined based on simulations of the heat flux from jet fires and explosions of clouds of hydrogen. Barriers can take many forms and explosion-resistant structures, and earth embankments can be considered.

5.1.3.10 Working environment

Exposure to cold gas
Hydrogen expands during release, absorbs heat and produces very low temperatures — often far below freezing down to −100 °C or colder in some cases. During maintenance activities, this shall be taken into account, and appropriate PPE (Personal Protective Equipment) and safety measures shall be implemented.

Noise
During pressure relief compressed gas will produce high impact noise levels. This can occur from activation of safety devices such as relief valves or during offloading Hydrogen. Compressors can also produce high noise levels during operation.

5.1.4 Operations and Maintenance

Chapter 1 presents a high-level operational procedure for the hydrogen infrastructure, both for option A and option B. Safety aspects are further presented below.

Operations and maintenance activities constitute an integral part of the overall safety concept for the pilot-phase hydrogen installation. Although the installation is limited in scale and hydrogen inventory, safe operation depends on clear operational principles, controlled execution of routine tasks, and well-defined interfaces between involved parties.

Operational activities such as container connection and disconnection, start-up and shutdown of compression and dispensing equipment, and basic functional checks shall be carried out in accordance with documented procedures and by personnel with appropriate hydrogen competence. Attention shall be given to activities involving system opening, temporary connections, or potential introduction of ignition sources, regardless of whether these activities are performed by AVINOR, suppliers, or other parties.

Routine operation shall include visual inspections for leaks, abnormal noise, vibration, or mechanical damage, as well as periodic functional verification of gas detection, emergency shutdown, and other safety-critical functions where applicable. Access control and housekeeping measures shall be maintained to reduce the likelihood of unintended interaction with hydrogen-containing equipment and to preserve clear escape and intervention routes.

Maintenance activities during the pilot phase are expected to be limited and predominantly preventive. Maintenance planning shall be based on vendor recommendations and focus on components essential to hydrogen containment and safety, including valves, seals, hoses, pressure relief devices, and safety-related instrumentation. Any maintenance or corrective work requiring depressurization or physical intervention on hydrogen systems shall be treated as a controlled activity and executed under defined isolation, permit, and verification routines.

By establishing clear operational expectations and proportional operation and maintenance principles, without prescribing detailed organizational arrangements at this stage. AVINOR retains flexibility in how roles and responsibilities are allocated, while ensuring that the pilot installation is operated within a robust and well-understood safety framework.

5.2 Digital safety (cyber security)

5.2.1 System under consideration

During this project phase, the System Under Consideration is outlined at a high level and subject to preliminary assumptions, which will be further refined in subsequent phases. The system encompasses the OT (Operational Technology) domain for controlling and managing field assets across fueling stations, storage facilities, and the Operations Center. Specific components will be detailed as the project progresses.

The boundary of the System Under Consideration explicitly excludes enterprise IT and DMZ environments, which are classified as external networks or conduits for connectivity and data exchange. Two main access points have been identified: wireless data paths to the cloud monitoring service and a controlled DMZ/firewall interface to the enterprise network.

All defined boundaries, access points, and asset groupings are considered provisional and will undergo refinement during the detailed design phase, following IEC 62443 and best practices from NIST SP-800-82-3. The current topology, developed from limited available information, illustrates the initial network zoning and communication interfaces for the Hydrogen Fueling and Storage System. This conceptual boundary defines the relationships between the Operations Center, field zones, and external environments including the DMZ, enterprise IT network, and operational cloud.

Note: to be validated and changed during later project stages.

5.2.2 Digital risk assessment

A preliminary cybersecurity risk assessment has been prepared in accordance with IEC 62443-3-2 to identify potential worst-case, unmitigated cybersecurity events that could impact mission-critical operations within the defined System under Consideration, identified threat scenarios were informed by national and European threat-intelligence publications and mapped to the MITRE ATT&CK for ICS framework. The scenarios were evaluated against the SuC interfaces, conduits, and operational dependencies to determine potential impacts on operational continuity, safety, and the operational environment. See Appendix B *f*or the *Digital risk assessment matrix.*

Note: to be validated and changed during later project stages.

5.2.3 Applicable laws and regulations

Applicable laws and regulations to inform later phase CSNE (Conditional Signed Network Embedding) requirements are presented in chapter 9.

5.2.4 Applicable standards and references

Applicable standards to inform later phase CSNE (Conditional Signed Network Embedding) requirements are presented in chapter 9.

5.3 Intentional harmful actions

Hydrogen is not a precursor for explosives and is not included in the regulation for such substances [22].

It is still mandatory to include hydrogen in risk assessments to be secured against intentional unwanted acts through measures such as barrier requirements and physical protection, establishment of access control systems and development of procedures to prevent hydrogen from being misused for criminal purposes.

DSB explicitly states that hazardous substances – including hydrogen – must not be susceptible to criminal misuse. This requirement forms a fundamental element in the management of intentional security-related incidents.

This is to be further evaluated in the next project phase.

6 Cost estimation

This chapter provides a Rough Order of Magnitude (ROM) CAPEX cost estimate of class 5 (as defined by the AACE practice), which is the highest uncertainty. The cost estimates should be used for comparative and strategic decision-making only, not for budgeting or procurement. It also presents an OPEX estimate based on information obtained from the Market and logistics study (chapter 2) and Norconsult experience data.

6.1 Cost estimation introduction

The engineering maturity corresponds to early feasibility level; no concept selection, optimization, or detailed design has been performed. Two overall infrastructure pathways are still under consideration in the PFD (document 52506847-NO-PM-D-003) (Option A: Stationary solution; Option B: Mobile solution).

See BoD for definitions of different options.

At the ROM level used here, no preference is expressed between options. Both options are technically feasible; however, they differ significantly in operational characteristics and sensitivity to utilization.

Table 10 presents a high-level comparison of various aspects of the two options.

Table 10 Option A and Option B comparison

Aspect	Option A – Stationary solution	Option B – Mobile solution
Technical feasibility	High	High
Operational robustness	Medium	High
Refueling speed	Medium	High
Suitability for snow sweepers	Low	High
Suitability for aircraft (pilot)	Low	Medium
Hydrogen utilization	Medium	High
Logistics intensity	High	Medium
CAPEX attractiveness (ROM)	Low	High
Overall pilot suitability	Medium	High

Note: *For all assessed aspects, a higher rating indicates a more favorable outcome. For CAPEX attractiveness, a higher rating corresponds to a lower estimated CAPEX.*

While Option A -Stationary solution represents a technically simple configuration, its operational characteristics make it sensitive to refueling time requirements, and low utilization. Option B -– Mobile solution introduces additional equipment but provides a more stable and predictable operating envelope for pilot operation.

Early-phase hydrogen pilots are primarily intended to demonstrate safe, repeatable, and operationally reliable refueling rather than to minimize capital expenditure. For applications such as airport ground support

equipment and potential aircraft refueling, predictable refueling time, pressure control, and robustness under varying ambient conditions are critical.

Integrated, turnkey refueling stations, as Option B– Mobile solution, with buffering and pressure management reduce operational dependencies, and provide a controlled interface to vehicles and aircraft. While such solutions introduce moderately higher CAPEX when at scale, they reduce operational complexity and uncertainty during the pilot phase and enable learning under realistic operating conditions.

6.2 CAPEX

The CAPEX cost estimate has been prepared utilizing cost data obtained from technology vendors as well as Norconsult's internal cost database.

The listed technology vendors have provided cost data as indicative budgetary, non-binding, prices for this study:

- HOERBIGER: Compressor package
- Atlas Copco: Compressor package
- Sundyne (via Delta-P Pumpe- og Kompressor Systemer AS): Compressor package
- Hexagon Purus: Compressed hydrogen storage tanks (permanently installed)
- Hexagon Purus: Compressed hydrogen storage tanks (battery swap)
- Hexagon Purus: Complete hydrogen refueling station

These inputs have been consolidated to reflect the technical assumptions defined in the BoD.

At the ROM level used here, no preference is expressed between options, though it is noted that drop-and-swap-based concepts (Hexagon Purus) are inherently well-suited for <2 t/week consumption and minimal on-site footprint.

Detailed engineering, supplier clarification, and final user requirements (pressure levels, number of fills per day, redundancy needs) will materially change the values in later phases.

A concise ROM comparison of the principal technological options is presented in Table 11 summarizing the key characteristics, pressure levels, and indicative cost ranges.

Table 11: CAPEX ROM Overview for Option A and Option B[7]

Item	Unit	Option A – Stationary		Option B – Mobile solution		Comments/Source
		Low	High	Low	High	
Storage tanks	mil NOK/tank	6,7	7,8	6,7	7,8	Vendor costs
Number of containers / Storage tanks	-	2	2	1	2	Option A typically requires two units for availability. Option B may allow single-
Refueling hardware	mil NOK	2,3	4,4	16,7	16,7	Dispenser and basic equipment
Hydrogen compressor	mil NOK	5,0	21,2	*	*	Vendor costs
Integration & installation (FAT, Commissioning, SAT, AWT, ATEX)	mil NOK	2,2	4,4	Limited	Limited	Civil, electrical, safety integration
Nitrogen-/Instrument Air	mil NOK	0,3	0,3	0,2	0,2	Norconsult experience data
Fire protection system	mil NOK	2,0	2,0	2	2	Norconsult experience data
Cybersecurity engineering	mil NOK	4,2	4,2	4,2	4,2	Norconsult experience data
Control system	mil NOK	3,0	3,0	*	*	Norconsult experience data and vendor
Electric systems (transformer, switchgear)	mil NOK	1,0	1,0	*	*	Norconsult experience data and vendor
Control room	mil NOK	2,0	2,0	*	*	Norconsult experience data and vendor
Truck Staging Loading Area	mil NOK	1,5	1,5	1,5	1,5	Norconsult experience data
Civil Elements	mil NOK	2,5	2,5	2,5	2,5	Norconsult experience data
Total CAPEX (equipment)		**39,4**	**62,1**	**33,8**	**42,7**	
Engineering	mil NOK	4	6,2	3,3	3,4	Assumption: 10% of total CAPEX
Installation	mil NOK	4	6,2	3,3	3,4	Assumption: 10% of total CAPEX
Commissioning	mil NOK	4	6,2	3,3	3,4	Assumption: 10% of total CAPEX
Unexpected/Unforeseen	mil NOK	8	12,5	6,7	6,9	Assumption: 20% of total CAPEX
Total Cost	mil NOK	**59,4**	**93,2**	**50,4**	**59,8**	

*Option B: Cost item included in the refueling station cost of 16.7 mil NOK

In accordance with the BoD (chapter 3), compression requirements for this study have been normalized to 350 bar, which represents the technically appropriate and operationally proportionate design level for the expected pilot-phase application. This pressure is fully compatible with typical ground-handling equipment, and no aircraft concepts within the current scope require gaseous fueling systems above this level. Selecting 350 bar avoids the unnecessary cost, power demand, maintenance burden, and increased complexity associated with 500–700 bar systems, while still enabling safe and efficient operation. This ensures that the infrastructure remains aligned with the modest hydrogen throughput anticipated during early deployment, with flexibility to adjust in later phases should future operational requirements change.

The ROM values presented herein provide a practical basis for comparing feasible infrastructure pathways. They demonstrate that, at this scale, storage and dispensing are the dominant cost elements, while compression requirements — constrained to the justified 350 bar level — remain moderate.

For simplified refueling concepts relying on dedicated on-site compression (Option A), a limited selection of commercially available hydrogen compressors has been reviewed at feasibility level to establish indicative cost and performance ranges. The compressors listed in the table typically operate at discharge pressures significantly higher than the nominal vehicle refueling pressure of approximately 350 bar. This reflects the

[7] *Suppliers have provided their estimates in Euros, the conversion to NOK is as per 2026-03-09, 1 EUR = 11.14 NOK*

need for sufficient pressure margin to overcome pressure losses, enable controlled refueling, and compensate for declining container pressure during operation. The listed pressure levels should therefore be understood as compressor capability rather than required dispensing pressure.

Table 12: Compressor solutions (primarily relevant for Option A)

Supplier	Technology	Capacity	Pressure	Notes
Sundyne / Delta-P	PPI9000 diaphragm	50–70 kg/h	500 bar	Scalable
Atlas Copco	H2Y 5-1-900 booster	50–80 kg/h	950 bar	Two compression units
Hoerbiger	HCP-500 package	Up to 250 kg/h	500 bar	Heavy-duty, FAT, Commissioning, SAT, ATEX excluded.

Note that the budget costs presented in Table 12 are non-binding budgetary prices.

A CAPEX sensitivity analysis presented in Appendix D.

6.3 OPEX

OPEX estimates reflect the pilot configuration defined in the BoD (chapter 3) and PFD (document 52506847-NO-PM-D-003), with low, intermittent demand (one ground-handling vehicle and, potentially, a single pilot aircraft). OPEX is presented using cost drivers rather than fixed annual values, as actual costs depend on utilization, logistics strategy, and contractual arrangements.

Table 13: OPEX estimate structure

OPEX element	Unit	OPEX estimate		Comment
		Low	High	
Hydrogen Supply	mil NOK/year	10,6	42,4	Supply cost estimate set based on info from Figure 4 (Market and logistics study)
Transport & logistics	mil NOK/year	1,2	4,9	Container transport and exchange (Norconsult experience data)
Electricity consumption	mil NOK/year	0,3	0,7	Estimated electricity consumption of 159-212 MWh/year (Assumed cost for el. and grid)
Service and maintence	mil NOK/year	0,3	0,5	Preventive maintenance and inspection. (Norconsult experience data)
Operations and handling	mil NOK/year	0,2	0,4	Container exchange and supervision (Norconsult experience data)
TOTAL exl. Hydrogen supply	mil NOK/year	**2,0**	**6,5**	
TOTAL incl. Hydrogen supply	mil NOK/year	**12,6**	**48,9**	

Supplier indications for delivered hydrogen span ~NOK 100–400/kg, with the variation driven by production route, distance, and whether transport is included. For the pilot demand of ~106 t/yr, this corresponds to ~NOK 10.6–42.4 million/yr. The commodity cost is therefore the dominant OPEX component in the pilot.

For ~2 t/week, the container-based model is viable. For a mobile/passive setup, ~1 trip(s)/week were indicated as a planning basis; a complete station configuration improves utilization but still requires regular swaps. Supplier-specific container lease / swap / freight charges may apply and should be confirmed in the next phase.

Electricity consumption for hydrogen compression is highly dependent on compressor technology, pressure ratio, and operating conditions. Vendor information for heavy-duty high-pressure compressors indicates specific energy consumption in the order of 1.5–2.0 kWh/kg H_2. This range is considered indicative and supplier-specific and is used solely for feasibility-level sensitivity assessment, primarily for concepts relying on dedicated compression (Option A).

An OPEX sensitivity analysis is presented in Appendix D.

7 Further recommendations

This chapter presents topics recommended to be investigated in the next project phase and which knowledge gap should be closed.

General concept development

- Advance the selected concepts(s) (Option A and/or Option B) to the next design phase, including development of detailed PFDs, layout, and definition of system interfaces.
- Perform site-specific assessment, including constructability review, and integration with existing airport infrastructure and operations.
- Refine demand assumptions as pilot-phase operational concepts mature, particularly with respect to aircraft operations and dispensing solutions.
- Confirm hydrogen quality requirements in coordination with potential suppliers and end users once technology choice(s) are clarified.
- Develop a more robust AACE class 4 cost estimate based on defined concepts, layouts, and preliminary technical requirements.
- Asses long-term scalability beyond the pilot-phase, including alternative supply concepts (e.g., nearby production, on-site production, pipeline supply), to inform strategic planning.

Safety

- Prepare documentation for major accident application.
- Develop safety basis including zoning and qualitative HAZID, to support dialogue with authorities and emergency services.
- Perform a more detailed risk assessment based on Flesland acceptance criterias for flight operative risk assessments.
- Area classification according to ATEX zoning.

Technological development:

- Emerging hydrogen storage technologies: Planck-Technologies AS, based on adsorption-enhanced compressed hydrogen storage were identified during supplier engagement activities. These concepts aim to reduce operating pressure by integrating adsorbent materials within the storage vessel, potentially lowering compression energy requirements. The technology reviewed is currently assessed at approximately Technology Readiness Level (TRL) 5 and has not yet reached commercial deployment or industrial certification. Due to the early maturity level and the implementation timeline of the Avinor pilot project, such solutions were not considered as part of the reference concepts evaluated in this feasibility study. It is recommended that developments within adsorption-based hydrogen storage technologies are monitored in future project phases, as

increased maturity may provide opportunities for reduced operating pressure and improved system efficiency in subsequent hydrogen infrastructure deployments.

- Hydrogen compressor technology: HOERBIGER, one of the compressor vendors contacted during the feasibility study, has communicated that they are in the process of developing a down-sized and containerized 90 kg/h version of their compressor HCP-500 package. The compressor technology is estimated to be commercially available in 2028. This smaller compressor would be more suitable for the pilot case as it both has a more suitable capacity and is assumed to have a lower cost.

8 Discussion and conclusion

The Summary at the beginning of this report presents the key takeaways from this feasibility study for each of the assessed topic:

- Market and Logistics
- Basis of Design (BoD)
- Regulatory framework
- Technical safety
- Digital safety
- Intentional harmful actions
- Cost

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Appendix A – Basis of Design (BoD)

The Basis of Design (BoD) defines the key requirements, assumptions, and criteria upon which the entire design and analysis for the hydrogen infrastructure will be developed. The BoD is normally updated with more details for each consecutive engineering phase.

Background

The project is part of the test arena collaboration between Avinor and the Civil Aviation AuthorityNorway (CAA). The purpose of the test arena is to facilitate the accelerated introduction of zero- and low-emission aircraft by reducing barriers to testing and demonstration.

The objective of this feasibility study is to assess the possibility of establishing a hydrogen infrastructure at an airport in Norway. Flesland airport in Bergen is used as the study case scenario. The study assumes that hydrogen is produced off-site by a third-party supplier and delivered to the airport by road using compressed hydrogen trailers. On-site hydrogen production is outside the scope of this study. The proposed airport infrastructure includes facilities for receiving delivered hydrogen, intermediate storage, and distribution to hydrogen consumers operating at the airport.

Site Location

For the purpose of this feasibility study, Bergen Airport Flesland has been used as a case location for assessing potential hydrogen infrastructure. Flesland airport is the second-busiest airport in Norway, and it is located ca. 12 km southwest of Bergen city center in Vestland county. The GPS Coordinates are 60°17′37″N 5°13′05″E.

Figure 16 shows the location of Flesland airport, relative to Bergen city. Figure 17 shows the area identified at the airport where the hydrogen infrastructure could be established. The area was identified in collaboration with the Flesland airport management team.



Figure 16: Location of Flesland airport, relative to Bergen city (source: norgeskart.no)



Figure 17: Identified suitable area for the hydrogen infrastructure at Flesland (marked in red)

Hydrogen Fluid Properties

This subchapter presents hydrogen fluid properties.

Hydrogen handled within the scope of this BoD is compressed gaseous hydrogen used during pilot-phase operation. The fluid properties presented in this chapter are provided to support high-level process definition, system boundaries, and indicative hydraulic and safety considerations under representative operational conditions.

Hydrogen quality is assumed to be suitable for the intended pilot-phase end uses, including fuel-cell applications. Detailed purity specifications, contaminant limits, and certification requirements are not defined at this stage and are not used as design inputs beyond what is necessary to establish representative operating conditions. Specific hydrogen quality requirements may vary between equipment suppliers and end users; no supplier-specific or proprietary quality specifications are assumed or imposed at this stage. Table 14 presents indicative hydrogen values provided infeasibility-level assessment only; not intended to define hydrogen quality or supplier requirements.

Table 14: Hydrogen fluid properties

Property	Unit	Value/ Comment
Molecular weight	g/mol	2.016
Physical state (BoD basis)	-	Compressed gas
Density (gas) @ operational conditions	kg/m^3	~1 – 1.5 (indicative, depending on pressure)
Viscosity (gas) @ operational conditions	µPa·s	~8 – 9
Boiling point (1 atm)	℃	-252.9 (Informative only)
Melting/ triple point	℃	-252.6 (informative only)
Explosion limits in air	vol%	~4 – 75
Auto-ignition temperature	℃	~585
Flash point	-	Not applicable since this is only gas phase considered in this stage.
Temperature expansion coefficient (gas)	1/K	Not defined as constant; ideal-gas behavior assumed at BoD level
ATEX temperature class	-	1
Fluid category (NS-EN 13480	-	Group 1 (flammable gas)

Meteorological conditions

Table 15 shows the maximum and minimum daily air temperature measured at Flesland airport in the period December 2005 – December 2025.

Table 15: Air temperature for Flesland airport from Dec 2005 to Dec 2024. Source: met.no

Temperature	Unit	Value
Maximum ambient temperature	°C	31.3
Minimum ambient temperature	°C	-14.4

Table 16 shows the precipitation data at Flesland airport.

Table 16: Precipitation at Flesland airport (source: met.no)

Precipitation	Unit	Value
Maximum Daily Rainfall (2005-2025)	mm/day	70.0
Average Daily rainfall (2017-2025)	mm/day	5.7
Maximum rainfall one hour (2015-2025)	mm/h	16.7

Study concepts

This study is performed at feasibility level and is intended to support concept evaluation and strategic decision-making rather than detailed design or implementation. Two alternative infrastructure concepts (option A and option B) are therefore assessed at high level, as illustrated in the hydrogen infrastructure process flow diagram (PFD) document 52506847-NO-PM-D-003, also seen in Figure 18.

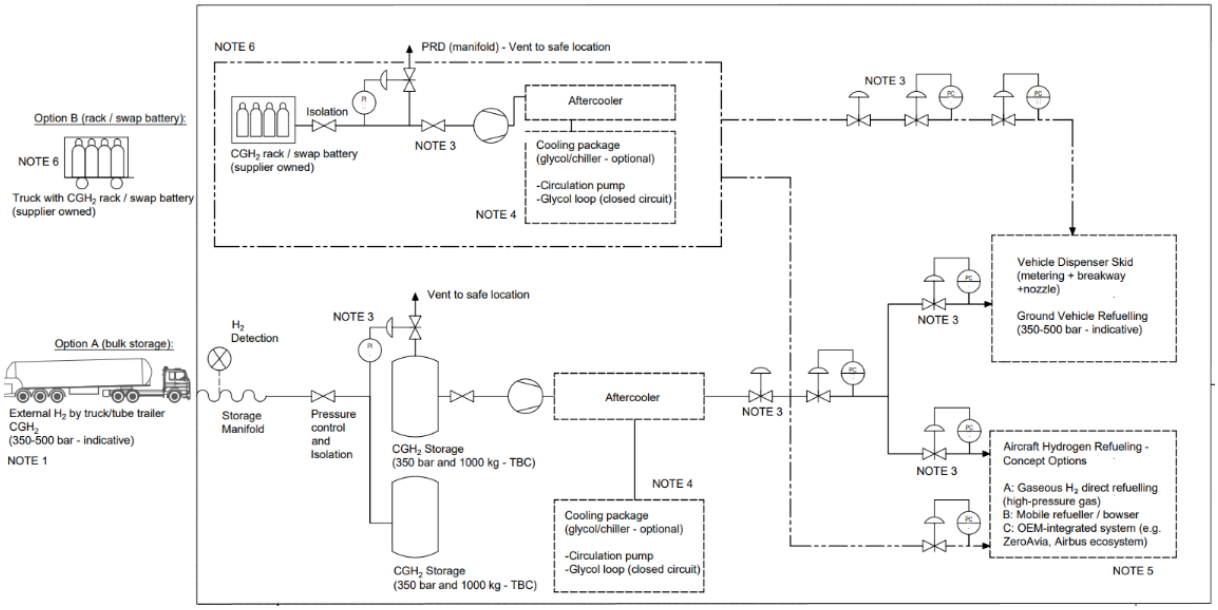


Figure 18: Hydrogen infrastructure Process Flow Diagram (PFD). Document number 52506847-NO-PM-D-003

The two evaluated concepts are:

- **Option A** is based on direct offloading of compressed hydrogen from transport trailers (truck/tube trailers) to on-site high-pressure storage tanks, followed by dispensing to hydrogen consumers.

- **Option B** introduces a battery swap supply concept, where hydrogen delivery and storage are based on transportable or modular storage units, with limited or no permanent on-site storage.

Note! During the development of the feasibility study and discussions with suppliers, it was determined that Option B can be effectively paired with a mobile dispenser unit. This combination—referred to as the “Option B - Mobile solution”—was identified as the most technically and economically appropriate approach for this pilot project, as detailed in chapter 8. For clarity, Option A will be referred to as the “Option A - Stationary solution” throughout the remainder of this document.

Both options are proposed using high level process definitions, indicative equipment blocks, and preliminary layout (see Figure 22) and footprint considerations sufficient to identify principal interfaces, operational boundaries, and potential scalability considerations.

The purpose of the study is not to select a preferred concept but to establish a common basis for the feasibility assessment of the concepts. Cost, capacity, and operational aspects are considered at so-called rough order of magnitude (ROM) level only, with typical uncertainties as defined for an AACE class 5 cost estimate. Limited supplier input may be used where explicitly stated to inform footprint assumptions, capacity ranges, or cost benchmarking; such input is used for indicative purposes only and does not constitute detailed engineering, vendor selection, or binding technical or commercial commitments.

Demand and high-level operational assumptions

Hydrogen demand used at the design basis for this BoD is defined in 2.4.1 of the feasibility study. This includes hydrogen demand associated with the pilot operation of aircraft and selected ground support equipment, such as snow sweepers. The present chapter does not re-derive or modify these demand estimates but applies them as input to establish the design basis for the level of detail of this study. Demand is treated as indicative and representative of pilot-phase operation only and is not intended to define long-term full-scale airport hydrogen demand.

Based on hydrogen demand defined in 2.4.1 the following high-level operational descriptions are provided to establish the operational assumptions underpinning the BoD. The procedures describe the intended operating principles for the assessed supply options at a conceptual level and are used solely to define boundary conditions, interfaces, and functional requirements for the feasibility study. They do not represent detailed operating procedures and are subject to further development in subsequent project phases.

Option A bulk storage

Operational concept:
Compressed hydrogen is delivered to the airport by tube trailer and offloaded to permanent on-site bulk storage. The fixed storage provides buffering between deliveries and operational demand for ground vehicles and pilot aircraft operations.

High-level operational procedure:
An operational procedure for Option A is presented below. Note that this is a preliminary procedure that should be re-evaluated in the next engineering phase and established together with the technology suppliers.

1. Hydrogen delivery and connection
   Compressed hydrogen is delivered by tube trailer (350–500 bar, indicative) and connected to the storage manifold. Isolation valves, pressure control, and hydrogen detection systems are activated prior to transfer.

2. Offloading to bulk storage
   Hydrogen is transferred from the tube trailer to the on-site CGH_2 storage vessels via the storage manifold. Pressure control and isolation ensure controlled filling. Pressure Release Devices (PRDs) are routed to a safe vent location. The storage manifold is assumed to include isolation functionality, allowing safe disconnection of the delivery truck and isolation of the on-site storage during normal operation, maintenance, and abnormal conditions.

3. Storage and pressure management
   Hydrogen is stored in fixed CGH_2 vessels (indicative 500 bar). Storage pressure, temperature, and

inventory are monitored via the control system. Nitrogen purge and inerting connections are available for commissioning and maintenance.

4. Conditioning and distribution
   Hydrogen is routed from storage through pressure control and optional aftercooling/cooling package prior to distribution. The system supplies hydrogen to the vehicle dispenser skid and to the aircraft refueling interface.

5. Refueling operations
   Hydrogen is dispensed to ground vehicles (indicative 350–700 bar) and to pilot aircraft refueling systems via defined refueling concepts (direct gaseous refueling, mobile refueller/bowser, or OEM-integrated solutions).

6. Standby and abnormal operation
   In case of delayed deliveries, operations continue until storage inventory is depleted. Safety systems allow isolation, controlled depressurization, and venting to safe location if required.

Option B battery swap

Operational concept:
Compressed hydrogen is delivered by truck-mounted rack or swap battery systems. The connected rack functions as temporary on-site storage and is replaced when depleted.

High-level operational procedure:
An operational procedure for Option B is presented below. Note that this is a preliminary procedure that should be re-evaluated in the next engineering phase and established together with the technology suppliers.

1. Hydrogen delivery and positioning
   A truck delivers a CGH_2 rack or swap battery system to the designated location. The rack is positioned and secured according to site procedures.

2. Connection and system check
   The rack is connected to the hydrogen supply line. Isolation valves, pressure control, and hydrogen detection are verified prior to operation. PRDs are vented to a safe location.

3. Hydrogen supply and conditioning
   Hydrogen is supplied directly from the connected rack through pressure control and optional aftercooling/cooling package before distribution to refueling systems.

4. Refueling operations
   Hydrogen is dispensed to ground vehicles and pilot aircraft systems as per defined refueling concepts. Operation continues until the rack reaches minimum allowable pressure.

5. Rack swap
   When depleted, the rack is isolated, disconnected, and replaced with a full unit. The empty rack is returned to the supplier for refilling.

6. Standby and abnormal operation
   Operational continuity depends on timely rack replacement. Systems allow isolation and safe shut-down during swap operations.

For both assessed supply options, hydrogen dispensing to end users is assumed at 350 bar. For Option A (bulk storage), on-site hydrogen storage is assumed at pressures up to 700 bar to ensure sufficient pressure head for refueling without the need for additional downstream compression. For Option B (rack / swap battery), storage pressure is governed by supplier-provided rack configurations and may range from approximately 350 to 700 bar. Where storage pressure is below dispensing requirements, booster compression is assumed as part of the refueling system. These assumptions are used solely to define the BoD for the feasibility study.

Design philosophy

This subchapter presents the design philosophy that is to be applied when designing the hydrogen infrastructure. It includes the standards that the system design must comply with. Also, functional requirements, reliability, maintainability and operability, operability and manning and constructability are presented at a high level.

All the topics presented below are to be further assessed in the next engineering phase.

Standards, Acts and Regulations

Relevant standards for the hydrogen infrastructure are found in chapter 9, while relevant acts and regulations are presented in chapter 4.

Hydrogen supply and infrastructure (PFD basis)

For the pilot phase, two alternative hydrogen supply and on-site infrastructure concepts (Option A and Option B) are established as the design basis, as illustrated in the PFD (document 52506847-NO-PM-D-003). The concepts represent different approaches to receiving, storing, and distributing compressed hydrogen delivered to the airport by road from off-site production facilities.

Option A is based on delivery of compressed hydrogen by truck/tube trailer(s), offloading to permanent on-site high-pressure storage, and subsequent distribution to hydrogen consumers via a fixed dispensing system. Option B is based on delivery of compressed hydrogen in transportable or modular storage units with limited permanent on-site storage. Both Concepts include the necessary interfaces for trailer arrival connection, disconnection, and safe operation within the airport environment.

Both Option A and Option B are treated as valid design bases for the pilot phase at feasibility level only. The BoD does not seek to compare, rank, or select between the two concepts. Instead, the PFD (document 52506847-NO-PM-D-003) is used to define system boundaries, principal process steps, interfaces, and functional requirements common to both options, forming the basis for footprint, operational assumptions, and rough ROM cost assessment(s).

Functional requirements

The hydrogen infrastructure shall provide the functional capability to safely receive compressed hydrogen delivered by road, manage on-site storage or storage-in-use as defined by Option A and Option B, and supply hydrogen to pilot-phase consumers in accordance with the proposed PFD (document 52506847-NO-PM-D-003). The system shall support routine delivery, connection, disconnection, and dispatch operations without disrupting airport activities.

The infrastructure shall enable controlled offloading or connection of hydrogen transport units, pressure management between delivery systems, storage, and dispensing systems, and regulated supply to end users. Functional requirements include isolation, depressurization, purging, and venting functions as

required to support normal operation, planned maintenance, and abnormal operating conditions as defined at principal level in the PFD (document 52506847-NO-PM-D-003).

The system shall be capable of operating within the defined pilot-phase demand envelope, including representative peak conditions, without reliance on continuous operation intervention. Instrumentation and control functions hall be sufficient to monitor pressures, flows, and system status and to enable safe shutdown in case of deviations from normal operating conditions, Functional requirements are common to both Option A and Option B unless explicitly stated otherwise in the PFD (document 52506847-NO-PM-D-003).

Reliability, maintainability and sparing

Reliability considerations for the hydrogen infrastructure are addressed at principal level and are based on supporting stable pilot-phase operation within airport environment. The design philosophy is to minimize operational disruption due to foreseeable equipment failures, without introducing unnecessary complexity that would be disproportionate for pilot scale operation. The design shall avoid single points of failure that would lead to loss of hydrogen supply during normal operation, to the extent predictable at feasibility level and within the constraints of pilot-scale deployment.

Maintainability is addressed through clear system segregation, isolation capabilities, and access for inspection, testing, and maintenance of critical components such as valves, pressure regulation equipment, instrumentation, and safety devices. The design shall allow routine maintenance activities to be performed without full system shutdown where reasonably achievable in accordance with the functional capabilities indicated in the PFD (document 52506847-NO-PM-D-003).

Sparing philosophy is addressed at principal level only. The BoD assumes that pilot-phase operation relies on pragmatic replacement strategies for critical components rather than extensive on-site spare part inventories. No detailed spare part lists, quantities, or procurement strategies are defined within the BoD. Detailed reliability analysis maintenance planning, and sparing definition are outside the scope of this BoD and would be developed in later project phases if required.

Operability and manning

Operability is addressed at principal level and assumes that the hydrogen infrastructure will be operated as part of normal airport activities during the pilot phase. The infrastructure concepts defined by Option A and Option B, as reflected in the PFD (document 52506847-NO-PM-D-003), are intended to support straightforward operation with clear operational states for delivery, normal supply, stand by, and shutdown.

The BoD assumes that routine operation can be performed by appropriately trained airport or contractor personnel without the need for continuous specialist assistance. Normal operating activities include connection and disconnection of hydrogen transport units, monitoring of system status, and basic operational checks. Control and monitoring functions are assumed to be sufficient to support safe operation and to clearly indicate abnormal conditions requiring intervention.

Manning requirements are not defined in detail in this stage. The BoD assumes limited additional manning compared to existing airport operations, with hydrogen related tasks integrated into existing operational roles where feasible. Detailed operating procedures, competence requirements, shift patterns, and training programs are outside the scope of this BoD and should be developed in later stage.

Constructability

Constructability is addressed at principal level and is based on the assumption that the hydrogen infrastructure will be implemented within an operational airport environment during the pilot phase. The design philosophy emphasizes solutions that can be installed with minimal disruption to ongoing airport operations and with limited requirements for complex construction activities.

The infrastructure concepts defined by Option A and Option B, as reflected in the PFD (document 52506847-NO-PM-D-003), are based on modular and largely prefabricated systems where practicable. This includes skid-mounted equipment, transportable storage units, and standardized interfaces, enabling phased installation and reducing on-site construction scope. Civil works are assumed to be limited, and site-specific ground conditions are not addressed in detail at this stage.

The BoD does not define construction methods, sequencing, temporary work, or detailed installation planning. These aspects are outside the scope of this BoD and would be addressed in later project phases once site-specific constraints, permitting requirements, and contractor input are available.

Safety

Safety is addressed at feasibility-level in 5.1.3 and forms a fundamental part of the design philosophy for hydrogen infrastructure. The BoD assumes that all infrastructure concepts shall be developed in accordance with applicable Norwegian, European, International regulations, standards, and recognized industry practices for hydrogen systems and operation within airport environment.

The infrastructure concept defined by Option A and Option B, as reflected in the PFD (document 52506847-NO-PM-D-003) incorporate fundamental safety functions such as isolation, controlled depressurization, venting, and emergency shut down capabilities. Safety considerations in this feasibility study, include separation distances, access control, and the management of ignition sources, addressed at a conceptual level sufficient to inform layout and functional requirement during the pilot phase.

The BoD does not include quantitative risk analysis, detailed ATEX classification, or formal hazard studies such as HAZID or HAZOP. These activities are outside the scope of this BoD and would be undertaken in later project phases as the design matures. Interfaces with airport emergency responses and fire and rescue services are recognized as critical.

Technical requirements and site infrastructure

This chapter defines the high-level technical requirements and site infrastructure interfaces for the hydrogen system based on the process configuration illustrated in the Block Flow Diagram (BFD) in Figure 19 and the Process Flow Diagram (PFD) in Figure 18. The requirements are defined at feasibility level and are intended to establish system boundaries, functional interfaces, and indicative capacities for pilot-phase operation. Detailed equipment specifications and final design parameters are outside the scope of this BoD.

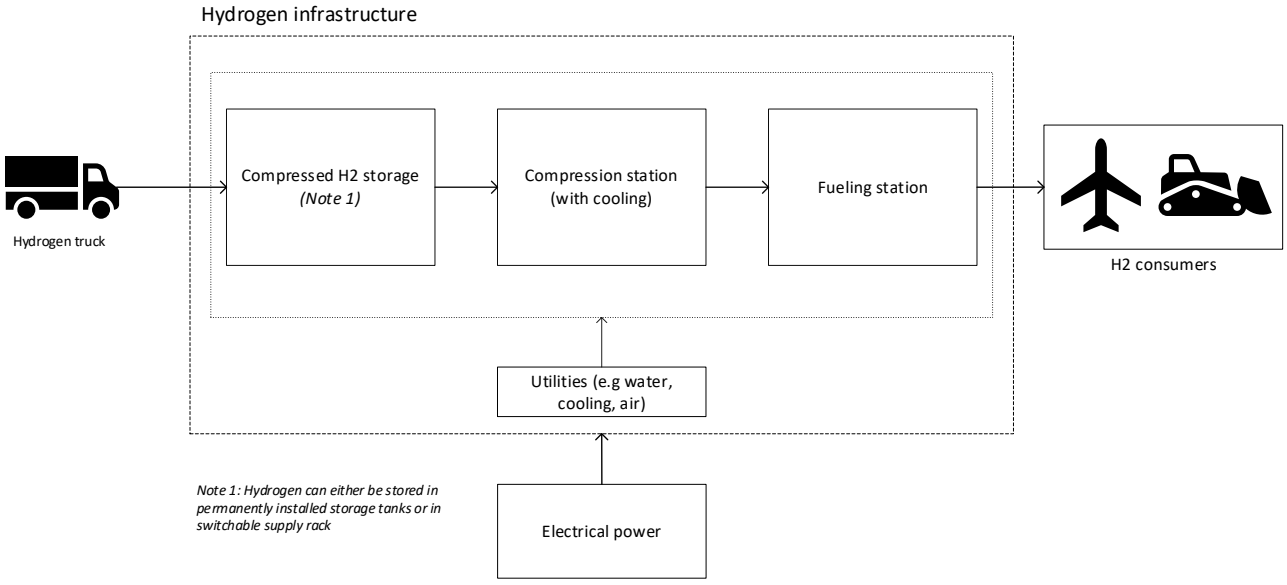


Figure 19: Hydrogen infrastructure - Block Flow Diagram (BFD). Document

The key study assumptions are presented in Table 17.

Table 17: Feasibility-level assumptions. [8]

Parameter	Unit	Value
H_2 storage capacity at pilot phase	kg	2 000
H_2 supply frequency at pilot phase	-	Once pr. week
H_2 storage pressure	bar	Assumed to be 350bar (not fixed at this stage)
H_2 storage temperature	℃	Supplier-dependent / to be defined in later stage
Power supply[9]	kW	Indicative electrical power for hydrogen compression: 120-726 kW, depending on selected compressor technology and configuration. Electrical power required for compression, control, and auxiliary systems; capacity and connection point to be defined in later phase

For feasibility-level layout development only, indicative footprints for the hydrogen infrastructure are established by benchmarking against representative modular compressed hydrogen refueling solutions. This benchmarking is used solely to define order-of-magnitude spatial requirements and site interfaces and shall not be interpreted as fixing storage pressure levels, operating conditions, or detailed system design. Storage pressure, temperature, and configuration remain supplier-dependent and are not fixed at this stage.

Estimated electricity consumption associated with hydrogen compression and auxiliary systems is discussed in Chapter 6.3. The estimate is based on supplier information indicating a specific energy consumption in the order of 1.5-2.0 kWh/kg H_2 for high-pressure hydrogen compression and the assumed hydrogen demand in

[8] The parameters presented in this table are indicative only and provided to support feasibility-level assessment. They shall not be interpreted as detailed design requirements or procurement specifications.
[9] Electrical power demand is highly dependent on the selected infrastructure concept and supplier specific equipment and is therefore not quantified at feasibility level.

the pilot phase. Electrical power demand is highly dependent on compressor selection and operating philosophy and should therefore be regarded as indicative only at this stage.

Process and system boundaries

The hydrogen infrastructure shall include facilities for receipt of compressed hydrogen delivered by road, on-site storage or storage-in-use as defined by Option A and Option B, compression where required, and dispensing to hydrogen consumers. The system boundary includes hydrogen storage systems, compression equipment, dispensing systems, piping, valves, and associated safety systems as reflected in the PFD (document 52506847-NO-PM-D-003). Hydrogen production facilities are outside the system boundary.

Hydrogen storage

The infrastructure shall provide sufficient storage capacity to support pilot-phase operation, with an indicative total storage capacity of approximately 2 000 kg of compressed hydrogen, assumed to be at 350bar. Storage may be provided either by permanently installed storage vessels or by transportable storage units, depending on the selected concept. Storage pressure levels are not fixed at this stage and are treated as indicative, subject to supplier solutions and later stage development. Examples of mobile and stationary storage solutions are seen in Figure 20 and Figure 21.



Figure 20: Example of mobile storage solution (source: Hexxagon Purus)



Figure 21: Example of stationary storage (source: Baglioni Pressure Solutions)

Compression and dispensing

Where required by the infrastructure concept, hydrogen compression shall be provided to enable transfer from storage to end users. Compression and cooling requirements are addressed at functional level only. Compression and cooling functions are required to enable transfer of hydrogen from deliver or stored pressure levels to the pressure and temperature conditions required for dispensing. Cooling is included to manage temperature rise during compression and filling, in accordance with applicable safety and operational constraints, as indicated in the PFD (document 52506847-NO-PM-D-003). Detailed performance requirements such as flow rates, ramp rates, and temperature control are not defined at this stage. At this stage it is assumed that the end used will require compressed hydrogen in the range of 350 – 700bar, but this must be confirmed in the next engineering phase.

Dispensing requirements differ depending on the type of hydrogen consumer. The BoD accounts for alternative dispensing concepts for aircraft and ground support equipment, including fixed dispensing points, mobile or skid-based dispensing units, and connection via transportable storage systems, as previously examined. The PFD (document 52506847-NO-PM-D-003) illustrates these alternatives at a functional level. Detailed interface definitions, flow rates, and operational sequences are not fixed at this stage and will depend on aircraft and vehicle technology.

Piping and valves

Hydrogen piping and valves shall be designed for gaseous hydrogen service. At this stage, piping and valve design is addressed at a conceptual level only to define system boundaries and functional interfaces as reflected in the PFD (document 52506847-NO-PM-D-003).

Material selection, wall thickness, insulation, and detailed stress analysis are outside the scope of this BoD. Isolation, depressurization, and venting functionality shall be provided in accordance with the safety philosophy (outlined in feasibility-study level in chapter 1) and as indicated in the PFD (document 52506847-NO-PM-D-003).

Utilities and auxiliary systems

The hydrogen infrastructure is assumed to require auxiliary utilities including electrical power, control and communication systems, and auxiliary utilities such as cooling media, instrument air, and/or nitrogen where applicable as indicated in the PFD (document 52506847-NO-PM-D-003). Instrument air is required to support operation of actuated valves and instrumentation while nitrogen is required for purging and inerting functions associated with maintenance, commissioning, and abnormal operating conditions.

Utility systems are addressed at interface and functional level only. Supply source, capacity, pressure levels, redundancy, and on-site versus off-site provision are not defined at this stage and will depend on site-specific infrastructure and supplier solutions. These utilities are included to establish system boundaries and site interface only.

Electrical control systems

Electrical supply and control systems are addressed at a conceptual level only. The BoD assumes that basic monitoring and control functionality will be required to support safe operation of the hydrogen infrastructure during pilot phase; however, specific control functions, alarm philosophies, and shutdown logic are not defined at this stage. These aspects are outside the scope of this BoD and will be developed in later project phases as the design matures.

Cybersecurity for feasibility study level is addressed in chapter 5.2.

Safety and site infrastructure

The infrastructure shall interface with the site safety systems including fire detection, fire water or deluge systems where required, drainage, and emergency response arrangements. The BoD at this level does not define detailed fire protection design, hazardous area classification, or emergency response procedures. Site infrastructure interfaces such as roads and access control are identified conceptually to support feasibility-level layout.

Exclusions

This subchapter presents the feasibility study exclusions.

This BoD is prepared at feasibility level and is limited to the development of high-level technical concepts supported by coarse PFD (document 52506847-NO-PM-D-003). No concept selection or optimization has been performed at this stage, and the BoD does not represent a basis for detailed design or procurement.

The following items are explicitly excluded from the scope of this BoD unless otherwise stated:

• Selection or confirmation of a preferred technical concept, including comparison or decision between alternative solutions (e.g. Option A vs Option B).

• Detailed process design, including mass and energy balances, line sizing, pressure drop calculations, and equipment sizing.

• Detailed operational procedures, work instructions, maintenance routines, and staffing concepts.

• Definition of organizational roles, responsibilities, or interfaces between Avinor, equipment suppliers, and third parties.

• Detailed safety studies and risk assessments, including HAZID, HAZOP, SIL allocation, and quantitative risk analysis. Only high-level safety principles are addressed.

• Detailed control, electrical, and automation design, including PLC logic, software architecture, alarm philosophy, and cybersecurity.

• Civil, structural, and architectural design beyond high-level layout considerations, including foundations, fire separation distances, drainage, and load-bearing structures.

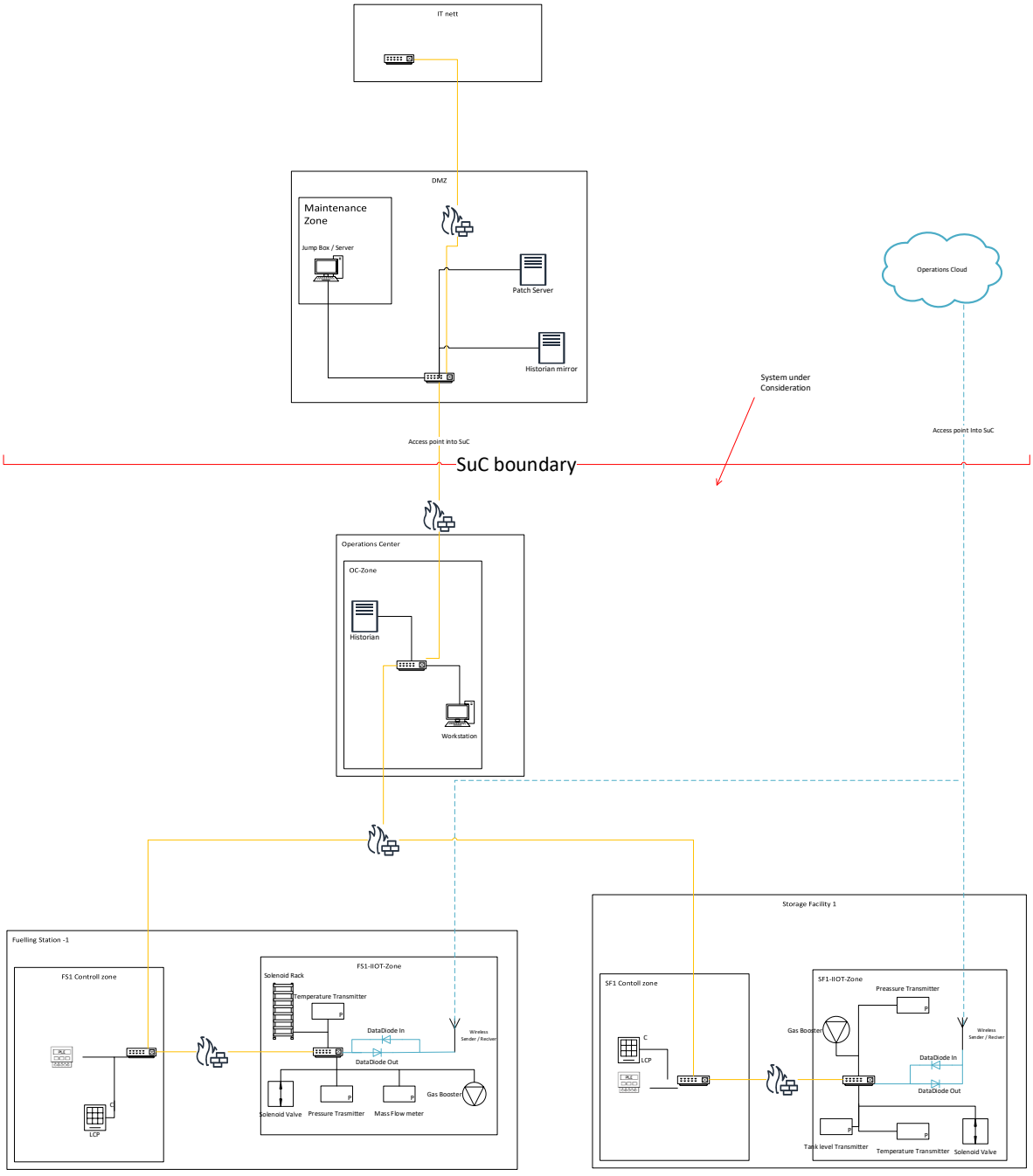
• Utility systems design, redundancy philosophies, and backup arrangements beyond what is required to illustrate the feasibility of the concepts.

• Emergency response planning, authority engagement, and regulatory approval processes.

• Commercial operation, scaling, or integration into permanent airport hydrogen infrastructure beyond the pilot and feasibility context.

This exclusion list reflects the early project maturity and is intended to clearly define the boundaries of the feasibility work, while maintaining maximum flexibility for AVINOR in subsequent concept selection and design phases.

Appendix B - System under consideration topology



Preliminary System under Consideration Topology.

Digital risk assessment matrix

Note: to be validated and changed during later project stages.

#	Threat Scenario	Interface	Consequence	MITRE ICS	Severity
1	Intrusion trough perimeter leading to destructive malware or ransomware	Perimeter / DMZ to Operations Center	Loss of visibility and control, unsafe shutdown, prolonged outage	Loss of Control (T0827)	High
2	Supply-chain or update channel installs compromised firmware or software	Vendor remote access or update path	Unauthorized logic execution, incorrect vale operation, safety or environmental impact	Manipulation of control (T0831)	High
3	Credential theft or misuse enabling unauthorized control actions	Engineering Workstation to PLC communication	Disablement of safety interlocks, uncontrolled process changes	Valid accounts (T0859)	High
4	Manipulation or spoofing of sensor data sent to monitoring system	Sensor or IIOT communication to monitoring system	Operators make incorrect decisions due to false readings, delayed safety response	Manipulation of view (T0832)	High
5	Network flooding or denial-of-service between controllers and HMIs	Internal control-network traffic	Loss of visibility and control, fail-safe activation	Denial of Control (T0813)	Medium
6	Tampering with historian data or records	Historian and data export interfaces	Misleading trends, unsafe operational scheduling	Manipulation of View (T0832)	Medium
7	Hybrid sabotage combining physical interference and cyber disruption	Combined perimeter and internal access paths	Multi-system outage, emergency shutdown, safety exposure	Loss of Safety (T0880)	High
8	Insider misuse or negligent configuration change	Internal accounts	Degradation of integrity or availability of IACS functions	Modify parameter (T0836)	Medium
9	Targeted data exfiltration or espionage activity	Remote access and historian export	Theft of process data enabling later sabotage	Theft of Operational Information (T0882)	Medium

10	Compromise of cloud services or cloud integrated OT interfaces	Cloud service connector / API to Operations Center	Unauthorized remote actions, manipulation of operational data, loss of visibility or override of command signals	Remote services (T0886)	High
11	Interference or compromise of wireless industrial communication	Wireless links (Wi-Fi, IIOT gateways)	Loss of telemetry, delayed commands, or spoofed signals, potential unsafe system behavior	Denial of Control (T0813)	High
12	Unauthorized device connected to network	Physical port or maintenance interface	Injection of unauthorized commands; lateral movement, loss of control of field equipment	Unauthorized Command Message (T0855)	High
13	Improperly hardened devices, default credentials, outdated firmware or insecure protocol configurations	Internal control network	Increased likelihood of compromise, unauthorized changes, exploitation of weak services	Exploitation of Remote Services (T0866)	Medium
14	Manipulation of OT specific protocols, using legitimate function codes	PLC and fieldbus communication pathways	Forced device state changes, incorrect actuation, disruption of normal process control	Manipulation of Control (T0831)	High

Appendix C – Risk matrix

Acceptance criteria

Unwanted evets are allocated to cells within a risk matrix based on probability and consequence. The risk matrix consists of three sones:

GREEN	Acceptable risk – Risk reducing measures are not necessary, but should be considered
YELLOW	Acceptable risk - Risk reducing measures must be considered
RED	Unacceptable risk - Risk reducing measures are necessary

To reduce risk, risk reducing measures are suggested. By risk reducing measures we mean probability reducing (preventive) or consequence reducing measures (preparedness) which contributes to reducing risk. For example, from red sone down to acceptable yellow or green sone in the risk matrix. The risk reducing measures lead to a shift in the matrix for an event.

Events in the red area of the matrix – risk reducing measures are necessary
Events in the red area of the matrix are events that cannot be accepted based on the criteria of consequence and frequency. These are events that must be followed up with measures. Preferably, this includes measures that target the causes of the incident, and thus reduce the likelihood that the incident will occur.

Events in the yellow area of the matrix – risk reducing measures must be considered
Events in the yellow area are incidents which are not directly an excess of requirements or acceptance criteria, but which require a continuous focus on risk management. In many cases, these are events that cannot be prevented, but where measures should be taken as far as this is appropriate based on a cost/benefit assessment.

Events in the green area of the matrix – acceptable risk
Events in the green area of the risk matrix have acceptable risk, meaning that risk reducing measure are not necessary. However, if the risk for the events can be further reduced without large resource use, the measures should be considered.

ID#	Applies for option	Area or activity	Hazardous event	Cause	Consequence	Barriers planned in design	Risk with planned barriers				Risk with implementation of additional mitigating measures			
							Risk people	Risk operation	Risk environment	Additional mitigating measures	Risk people	Risk operation	Risk environment	Comment
H01	Permanent station Mobile solution	Hydrogen transport by truck to the hydrogen station	Collision with hydrogen station	Human error	Explosion due to gas igniting from the tanker truck's hot surfaces, e.g. the exhaust system Physical damage to the installation	Gas detection with ignition source shutdown and pressure relief				Install safety barriers in steel or concrete blocks around the installation to prevent accidental collisions				
H02	Permanent station	Hydrogen transport by truck to the hydrogen station	leakage from tank truck to hydrogen station during hose-loading operations	Mechanical failure Brake failure. Car rolls forward or backward	Explosion due to gas igniting from the tanker truck's hot surfaces, e.g. the exhaust system Physical damage to the installation	Gas detection with ignition source shutdown and pressure relief.				Break-away coupling that automatically shuts off on the truck (should be requirement from the hydrogen supplier)				
H03	Permanent station	Hydrogen transport by truck to the hydrogen station (in case of solution "containerswap")	Leakage from connection point in the "swap" container	Leakage in the container itself (which consist of smaller hydrogen bottles connected by a manifold) Leakage in the connection to the permanent parts of the hydrogen system when swapping container	Explosion due to gas igniting from the tanker truck's hot surfaces, e.g. the exhaust system Physical damage to the installation	Gas detection with ignition source shutdown and pressure relief.				Regular inspection intervals for corrosion and wear must be established				
H04	Permanent station Mobile solution	Hydrogen station (storage tanks, piping, valves)	Ignition sources are introduced or created by equipment in the hydrogen station	Human error Static electricity	Explosion due to gas igniting from the ignition sources Physical damage to the installation	ATEX zones must be established in later design phases				Procedures for handling ignition sources near ATEX zones.				
H05	Permanent station	Hydrogen station (storage tanks, piping, valves)	Large leakage from tanks	Mechanical failure Corrosion	Explosion due to gas igniting from ignition sources Physical damage to the installation	Gas detection with ignition source shutdown and pressure relief.				Regular inspection intervals for corrosion and wear must be established				
H06	Permanent station Mobile solution	Hydrogen station (storage tanks, piping, valves)	Small leakage from tank	Mechanical failure Corrosion	Explosion due to gas igniting from ignition sources Physical damage to the installation	Gas detection with ignition source shutdown and pressure relief.				Regular inspection intervals for corrosion and wear must be established				
H07	Permanent station Mobile solution	Hydrogen station (storage tanks, piping, valves)	Overpressure due to freezing of safety valves or vents	Freezing of safety valve which blocks the function of the valve	System overpressure Physical damage to the installation	Pressure monitoring in pressurized systems.				Pressure gauge in vent mast with alarm for abnormally high pressure Heat tracing of safety systems Regular inspection				

										intervals for functionality must be established				
H08	Permanent station Mobile solution	Hydrogen station (storage tanks, piping, valves)	Short circuit	Lightning strike ignites hydrogen or creates damage to the station infrastructure/equipment	Damage to the components of the hydrogen plant	Ensure surge arresters are implemented in design								
H09	Permanent station Mobile solution	Hydrogen station (storage tanks, piping, valves)	Leakage from tank due to drone attack	Drone attack	Explosion due to gas leaking from the tank or related piping Physical damage to the installation	Drone detection system is installed at Flesland Airport. It will not take down the drone, but will alert ground personnel and authorities.				Systems that will ground the drone.				
H10	Permanent station Mobile solution	Hydrogen station (storage tanks, piping, valves)	Hacking and override of the control system via external access	Hacking and override of the control system via external access can damage the hydrogen plant by means of leaving the operator unaware of the system condition.	Leakage of hydrogen	Firewalls Industry standard protection systems				Detection in the network Dedicated user accounts				
H11	Permanent station Mobile solution	Dispensing station	Leakage from connection from dispenser station to vehicle	Faulty connector of the dispenser station Car that rolls due to brake failure	The consequence is material damage to the dispenser hose. If the gas cloud comes into contact with ignition sources, it may ignite. Possible frost injuries to personnel due to the temperature of the hydrogen.	Gas detection with ignition source shutdown and pressure relief.				Break-away coupling that automatically shuts off.				This is most likely a common design feature of dispensing systems as per today
H12	Permanent station Mobile solution	Surrounding areas, North West: Fuel storage (650 m3 Jet A to the North West)	Fire/explosion in fuel depot (650 m3 Jet A) to the North West of the hydrogen station	External events causing fires/explosions in the fuel depot area	Heat radiation or explosion pressure affecting the equipment in the hydrogen station					Establish an embankment in the most exposed direction, e.g. towards chemical tanks and facilities with buried fuel tanks. Fire walls at relevant locations Heat shields towards exposed areas				Domino effects must most likely be defined according to DSBs requirements.
H13	Permanent station Mobile solution	Surrounding areas, North: Fuel storage (60 m3 gasoline storage) North of the hydrogen station by the helipad.	Fire/explosion in fuel depot (60 m3 gasoline) to the North of the hydrogen station	External events causing fires/explosions in the fuel depot area	Heat radiation or explosion pressure affecting the equipment in the hydrogen station	No barriers needed. The gasoline storage is approximately 300 m north of the hydrogen station and is not considered to pose a risk given the current location.								

H14	Permanent station Mobile solution	Surrounding areas, South (chemical tanks): 50 m3 diesel for reservepower 50 +10 m3 diesel for vehicles 50+50+30 m3 formiate (formic acid 50%)	Fire/explosion in chemical depot to the South of the hydrogen station	External events causing fires/explosions in the fuel depot area	Heat radiation or explosion pressure affecting the equipment in the hydrogen station					Establish an embankment in the most exposed direction, e.g. towards chemical tanks and facilities with buried fuel tanks. Fire walls at relevant locations Heat shields towards exposed areas				
H15	Permanent station Mobile solution	General	Earthquake magnitude 6.5 in the Bergen area	Earthquake	Damage to the components of the hydrogen plant	Building regulations, particularly the European standard for the design of earthquake-resistant structures, Eurocode-8, are existing barriers.				Hazard mapping Monitoring Information to stakeholders.				Earthquake warning systems are not considered appropriate in Bergen municipality due to the low frequency of such events Ref: "Bergen ROS 2024 - Et tryggere samfunn – sammen"

Appendix D - Cost sensitivity analysis

This appendix presents a cost sensitivity analysis, based on the data presented in chapter 6.

The values and assumptions presented in chapter 6 are subject to uncertainty at feasibility level and are therefore complemented by a sensitivity assessment. Rather than focusing on absolute cost figures, the sensitivity analysis is intended to illustrate the relative impact of key assumptions on CAPEX and OPEX. In particular, it highlights the influence of container utilization, logistics frequency, and operational configuration on overall cost performance for container-based hydrogen supply concepts.

Table 18 OPEX Sensitivity (logistics - driven)

Parameter	Low case	Base case	High case
Weekly hydrogen demand	1.5 t/week	2.0 t/week	2.5 t/week
Usable H_2 per container	1.1 t	1.0 t	0.8 t
Container exchanges per week	2–3	4–5	6–7
Relative OPEX impact	↓	Reference	↑↑

Table 19 CAPEX Sensitivity (configuration - driven). . Suppliers have provided their estimates in Euros, the conversion to NOK is as per 2026-03-09, 1 EUR = 11.14 NOK. Worth noting that the EUR/NOK has been quite volatile lately (52-week range 11.1–12.2).

Parameter	Lower bound	Reference	Upper bound
Container unit cost	NOK 6 683 /kg H_2	NOK 7 241 /kg H_2	NOK 7 798 /kg H_2
Refueling concept	Simplified	–	Integrated station
Number of containers	2	2	3
Relative CAPEX	↓	Reference	↑

The OPEX sensitivity analysis illustrates that operational expenditure is primarily driven by hydrogen logistics rather than energy consumption or on-site equipment. Variations in weekly hydrogen demand and usable hydrogen per container have a direct impact on the number of container exchanges required, which in turn dominates OPEX. Reduced usable hydrogen per container, for example due to higher residual pressure on return, leads to a disproportionate increase in logistics frequency and cost. This confirms that container utilization and logistics strategy are key cost drivers for container-based hydrogen supply concepts at pilot scale. For CAPEX, the sensitivity analysis indicates that overall cost is mainly driven by high-level configuration choices, such as container count and refueling concept, rather than detailed equipment sizing at this stage.

Both Option A and Option B are technically feasible at pilot scale. However, operational robustness, refueling predictability, and sensitivity to utilization differ significantly. Integrated turnkey station concepts provide a

more stable operating envelope for early pilots involving airport ground equipment and potential aircraft refueling, while simplified concepts remain sensitive to logistics intensity and operating conditions.

Appendix E – Layout

Figure 22 presents a proposed layout for the hydrogen infrastructure at Flesland airport for both concepts: option A (stationary solution) and option B (mobile solution). See chapter BoD for concept definitions.

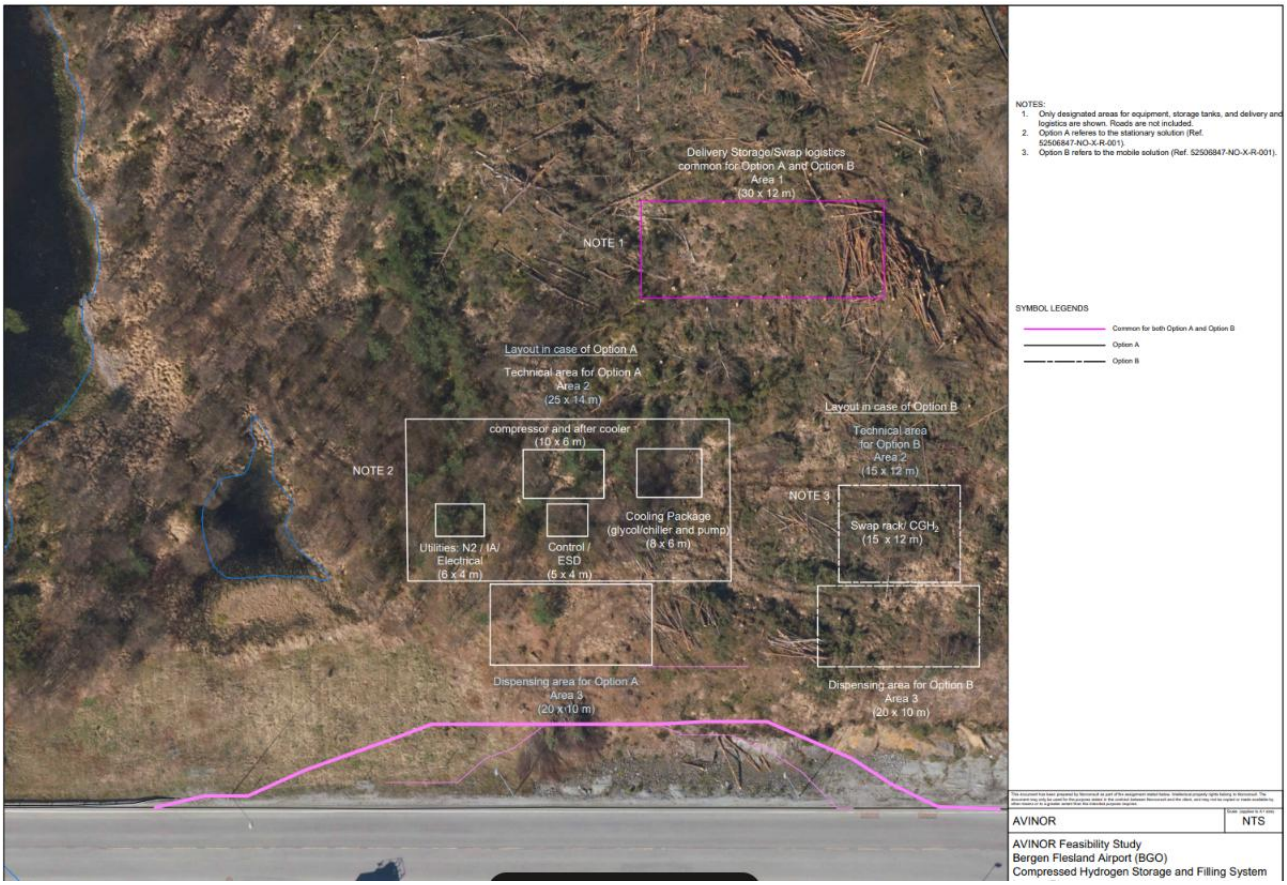


Figure 22: Layout of hydrogen infrastructure at Flesland airport (document 52506847-NO-PM-D-002)

Appendix F – Estimated Regulatory Timeline

Based on the identified relevant act and regulations (presented in subchapters 4.2-4.7), a complete estimated timeline for the regulatory framework and permits has been established and can be seen below.

Estimated timeline regulatory frameworks and permits hydrogen Avinor Flesland			Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	**Remarks**
	Handling authority	**Sub activity**																									
Aviation Act	Norwegian Civil Aviation Authority																										
		Approval of distance between parked aircrafts using hydrogen as aviation fuel		?	?	?	?	?																			Must expect revised calculation and approval of distance between parked aircraft if hydrogen is used as aviation fuel (also applies to batteries)
																											(Stay informed about developments in the use of hydrogen as aviation fuel)
Planning and Building Act	Bergen Municipality																										
Building permit(s)																											
		Preparation of notice to neighbours																									
		Neighbour notice (nabovarsel)																									
		Preparation of general application (rammesøknad)/application for building permit																									
		Application review of general application/building permit and issue of consent																									
		Preparation of application to start work																									It is theoretically possible to have parallell process with zoning and general application. It requires knowledge of details of each construction early for the general application, and an appointment and goodwill from municipality. Otherwise the process for building permits start at a later stage.
		Application review of start-up permission (søknad om igangsettingstillatelse IG)																									Need thorough planning to coordinate the applications and zoning. Several IGs are likely, amount not known now. Also dependant on Step I and Permit pollution below before applications can be approved.
		Preparation of application for certificate of completion																									
		Application for certificate of completion (ferdigattest)																									
Fire and Explosion Prevention Act	The Norwegian Directorate for Civil Protection																										
		Application for consent for construction (step I)																									The estimate does not include preparation of supporting documents incl. QRA and security risk assessment regarding hazardous substances. No fee is normally paid to DSB for case processing of the application for consent - step I, but in connection with the public consultation an announcement in the local newspaper is required. The cost for this must be covered by the company.
		Preparation of application incl. meeting(s) with DSB																									
		Application review (3 months)																									
		Kick-off meeting with municipality and fire brigade																									
		Public consultation (6 weeks)																									
		Follow up comments from public consultation																									If hearing input leads to further need og clarifvcation, this timeline will be prolonged.
		Issue of consent for construction																									
		Application for consent for operation (step II)																									The estimate does not include preparation of supporting documents. No fee is normally paid to DSB for case processing of the application for consent - step II
		Preparation of application incl. meeting(s) with DSB																									
		Application review and issue of consent for operation (2 months)																									
Pollution Control Act	The County Governor/Municipality																										
	County Governor Vestland	Remedial action plan and permit for land-disturbing activity																									Relevant startup is depending on maturity of technical and engineered input.
	County Governor Vestland	(Possible revision and application of Emission Permit)																									Relevant startup is depending on maturity of technical and engineered input
Working Environment Act	Norwegian Labour Inspection Authority																										
		Application for consent from the Norwegian Labour Inspection Authority																									
		Application review and issue of consent																									
Regulations relating to Systematic Health, Environmental and Safety Activities in Enterprises	The Norwegian Industrial Safety Organisation (NSO)																										
		Notice to NSO, §4																									
		Risk evaluation §5																									
		Emergency Response Analysis §5																									
		Emergency Response plan §7																									
Contractor/consultant work periode																											
Handling at authority																											
Other external handling																											
Relevant for operational phase																											
Might not be relevant for Avinor Flesland																											
***There is a degree of uncertainty in the progress shown in this timeline, as the project is in an early phase. Many of the application processes rely on the maturity of the**																											
There might be a need to develop other key deliverables for the applications that are not mapped at this early stage in the project, this can impact the timeline.																											

Figure 23: Estimated detailed timeline for regulatory framework and permits