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Demonstrating lower polluting solutions for sustainable airports across Europe

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Demonstration Plan for the Hydrogen Tow Tractor

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Abstract

The aviation sector seeks zero emission airport operations by 2030. This adaption presents various challenges and opportunities. The TULIPS project was established within EU's vision for sustainable airports. The fourth work package of TULIPS focus on reducing emissions from the airside operations, specifically operation and propulsion of zero-emission ground support equipment. The work package will contribute by developing and demonstrating two hydrogen-powered vehicles—an airside ground power unit and a tow tractor. This report outlines the tow tractor's demonstration plan at Schiphol airport, covering planning, stakeholder roles, site selection, timeline, and dissemination. The prototype's development, including design, in-house testing, and compliance with standards, is detailed. Safety and demonstration preparations are emphasized, followed by execution aspects like safety briefings, test protocols, monitoring, and data analysis.

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VI. LIST OF ACRONYMS

Acronym	Meaning
CNG	Compressed Natural Gas
EN	European Standard
FAT	Factory Acceptance Test
FC	Fuel Cell
GHG	Greenhouse Gas
GPU	Ground Power Unit
GSE	Ground Support Equipment
HFCV	Hydrogen-Fueled Vehicle
ISO	International organization for Standardization
KSM	Key Success Metric
LNG	Liquified Natural Gas
MoSCoW	Must have, Should have, Could have, Will not have
NEN	Dutch Standard
NFPA	American National Fire Protection Agency
PGS	Publication Series Hazardous Substances
PM	Performance Metrics
RTM	Requirement Traceability Matrix
TPRD	Temperature Pressure Relief Valve
WP	Work Package
ZE	Zero Emission

1 Executive Summary

The fourth work package (WP) in the TULIPS project concentrates on zero-emission (ZE) airside operations, by developing and demonstrating fuel cell (FC)-battery hybrid electric ground support equipment (GSE). Despite GSE emissions playing a modest role in the overall emission from the air industry, reducing and ultimately removing pollution from this sector as well is vital for reaching the ambitious net-zero goals. WP4 will develop and demonstrate a hydrogen-powered ground power unit (GPU) and tow tractor, acknowledging their substantial contribution to GSE emission. The demonstration aligns well with TULIPS overarching goal of reducing the carbon footprint related to air traffic.

The demonstration of the hydrogen-powered tow tractor will take place at Schiphol airport in a real operational environment and is central in showing and validating the feasibility of ZE alternatives to fossil fuels. The output real-world data will contribute to further studies, fleet considerations, design refinement, and strengthen industry and academia collaboration. In addition, with the dissemination activities related to the demonstration, it may also bolster the public acceptance of such technologies.

This document highlights the collaborative steps taken towards executing the demonstration, including the identification of stakeholders, requirement establishing and classification, timeline development, and dissemination activities. Further, key aspects of the tow tractor development and the safety and compliance related to the operation of the vehicle is also put forth. Lastly, preparations for the demonstration, and the planning of the demonstration itself is described. This approach contributes to ensuring safe and timely execution of the demonstration.

The hydrogen-powered tow tractor is developed by adapting an electric towbar-less tractor, and integrating Ballard's FCmove®-HD+ together with a 100 kW battery pack, providing a combined power output of 250 kW. With 10 kg hydrogen storage onboard the vehicle, the operational autonomy is ensured in accordance with the technical specifications.

The planning phase of the demonstration is conducted through collaborative workshops, one-on-one meetings, and plenum meetings, conducted by SINTEF. Stakeholder identification and role delineation ensures that relevant stakeholders are aware of their responsibilities. A structured timeline, developed with the aid of a Requirement Traceability Matrix (RTM), ensures a systematic approach to development, production, and the demonstration planned in December 2024. A comprehensive dissemination plan is developed and emphasizes communication strategies throughout the demonstration. Direct engagement with stakeholders, documentation through reports and visuals, and participation in conferences will amplify visibility of the demonstration. Dedicated deliverables capture insights and findings, supporting stakeholders, partners, and industry professionals.

Safety measures include compliance with relevant standards, risk analysis, and adherence to safety documents formulated by Schiphol Airport. A permit checklist specific to Schiphol ensures compliance with necessary approvals.

Preparations involve the deployment of a semi-mobile refuelling facility and contingency planning for towing demonstrations. Training responsibilities are divided among Ballard, TLD, and Fraunhofer, ensuring appropriate knowledge transfer between stakeholders. On-site setup includes a health check, testing, and collaboration with the KLM Towing Department.

A safety briefing tailored for various stakeholders ensures safe and efficient demonstration. Test protocols cover safety, regulation compliance, performance, efficiency, and interoperability. A validation checklist, derived from the RTM, will be systematically confirmed throughout testing phases, contributing to the success of the demonstration.

Data collection involves noise measurement, visual records, hydrogen consumption data, stakeholder interviews, and technical data from the tow tractor. Collected data will be stored securely, adhering to data protection regulations, and used for evaluation, reporting, documentation, and guiding future development efforts.

The TULIPS hydrogen tow tractor demonstration at Schiphol Airport represents a significant stride towards greener airport operations, addressing emissions from GSE and advancing the industry's transition to ZE technologies.

2 Introduction

2.1 Project overview

Work Package 4 (WP4) is a vital component of the TULIPS project, with the overarching goal of reducing the carbon footprint associated with air traffic. This work package focuses on the development and demonstration of hydrogen-powered Ground Support Equipment (GSE) at various airports, as well as the implementation of an economically and technically feasible plan for the evolution of the hydrogen supply chain.

The main objectives of WP4 are twofold. Firstly, it aims to develop and demonstrate a hydrogen-powered GPU (Ground Power Unit) at Amsterdam Schiphol, as well as at selected fellow airports in Torino and Larnaca. Secondly, it seeks to showcase a hydrogen-powered tow tractor at Amsterdam Schiphol. These demonstrations serve as crucial steps towards incorporating zero-emission (ZE) technologies into airside operations.

To achieve these objectives, WP4 includes a series of tasks outlined in the TULIPS Grant Agreement. These tasks encompass the concept development, selection, and planning of the hydrogen GPU and tow tractors (Task 4.1), the development of hydrogen GSE prototypes (Task 4.2), and the subsequent demonstration of these prototypes at the designated airports (Task 4.3). Furthermore, WP4 also encompasses the provision of detailed guidance material and perspectives on hydrogen logistics (Task 4.4 and 4.5). This WP is focused on ZE technologies for airside operations, with a specific emphasis on integrating hydrogen FC-battery hybrid powertrains into GPU and tow tractor. This is due to the findings reported in D4.1 where it was established that in terms of contributions to greenhouse gas (GHG) emissions, tow tractors and GPUs are the highest.

Building upon the insights gained from D4.1 ‘Demonstration Plan and Operational Concept for the Hydrogen GPU’, Deliverable D4.9 represents the equivalent documentation but with a focus on the hydrogen tow tractor. Both deliverables provide a comprehensive description of the concept and demonstration plan for the two hydrogen GSE prototypes. These deliverables serve as the foundation for the subsequent tasks, enabling the development of prototypes (Task 4.2) and the demonstration of their capabilities at the designated airports (Task 4.3).

2.2 Purpose of Tow tractor demonstration

While Deliverable D4.1 [1] outlined the demonstrational and operational aspects of the hGPU's development, the current deliverable shifts its focus to the investigation of the hTowTractor. Despite the evident similarities between developing and planning for demonstration of these two vehicles, this document aims to elucidate the distinctions and report on the challenges that have emerged in the development of the hTowTractor. The importance and purpose of demonstrating a vehicle such as the hTowTractor in a setting such as in real-world airport operations, is crucial to for validating and advancing the application of the technology. In the context of the TULIPS demonstration, the demonstration not only shows the viability and efficiency of the technology, but also provides data for the relevant stakeholders that can be used to scale up the proposed vehicle on a fleet level, improve the current design of the vehicle, and identify the potential other GSE that could benefit from transitioning to ZE technologies. Furthermore, vehicle demonstration in active environment such as this plays a crucial role in further fostering collaboration and initiative from the industry and regulatory bodies, in addition to strengthen the public acceptance to ZE technologies as a substitution for conventional equivalents.

2.3 Scope and objectives

The main objective of WP4 involve demonstrating the hTowTractor at the lighthouse airport, Schiphol, Amsterdam. The tasks, described above, is structured to address the development and demonstration of both the hGPU and hTowTractor, and will ensure the successful demonstration of the hydrogen-based technologies in airport operations, aligning with the overarching goals of the TULIPS project.

In this report, similarly to the first corresponding deliverable, the demonstration plan of the hTowTractor is established, corresponding to Task 4.1. At first, the appropriate stakeholders for the demonstration are identified, their roles and responsibilities are clarified. The tow tractor requirements are established through workshops, including the relevant standards and certificates necessary, as well as green hydrogen certification schemes. Secondly, requirements are used as input when defining concrete steps to achieve the demonstration, systematized into a timeline in a GANNT-chart format. Then methods for data collection and monitoring are defined. Also, to assess the outcome of the demonstration, a validation plan is developed. By following the above-mentioned contributions, the execution of the demonstration can be successfully done in a timely, safe manner.

3 Background

3.1 Tow tractor operation and airside operation emission

The air transport industry seeks to reduce their emissions and ultimately seek net-zero carbon emissions by 2050 [2] [3]. To achieve this ambitious objective, multiple avenues for emission reduction must be considered, and not only specifically emissions related directly to the aircraft propulsion. One such area is airside operation related emissions. From the point an aircraft lands at an airport until it takes off again, a long list of vehicles and equipment (GSE) are involved in servicing the aircraft. These vehicles and equipment have the role of, among but not limited to, passenger dis-embarkment and embarkment, aircraft refuelling, preparations for passengers and freight, and aircraft towing, pushback and taxing. The majority of this equipment is still powered by fossil fuel, and thus emit GHG. While GSE has a relatively small role in the total emissions related to the air industry [4], it still requires attention when moving towards a ZE industry.

At the top of the list of most polluting GSE equipment is the GPU and the pushback tow tractor [5], which is the focus of the TULIPS WP4. The GPU is thoroughly described in “Demonstration Plan and Operational Concept for the Hydrogen GPU” [1]. When it comes to the tow tractor, also called aircraft tractor or pushback tractor, it has the role of providing aid for aircraft movement, such as being pushed back from terminals, towing aircraft for service and maintenance, and taxing operations. ZE battery-powered GSE such as electric pushbacks, electric GPUs, electric buses, etc., already exist [6], but for heavy duty tow tractors hydrogen powered vehicles might be more beneficial due to its higher relative energy density and faster refuelling time. Still, hydrogen is a new type of fuel used at domestic and international airports which require that the units using it, the filling infrastructure and storage satisfy existing regulation related to operation, handling and safety at airports.

Hydrogen poses as an attractive alternative to the traditional fossil fuels. It can be produced from renewable energy and water through electrolysis, making it a ZE fuel. When used in a FC, the only biproduct is water and heat. When used as fuel, in can also be compressed and stored in a variety of manners. The current main disadvantages of using green hydrogen as a fuel is it current cost of production, and costly equipment (FC and electrolysers). The cost disadvantage is expected to be bridged as hydrogen production and utilization increases.

4 Planning Phase

Following the closely outlined task description in WP4, this section deals with the definitions of requirements in relation to the second demonstration, the hTowTractor, and the detailed planning for demonstration activities, inputs to T4.2 and T4.3. A notable difference between the hTowTractor and the hGPU, reported in D4.1, is that the hGPU would undergo demonstration at the fellow airports Larnaca and Torino, while the hTowTractor will only undergo demonstration at the lighthouse-airport Schiphol. As part of T4.1, a requirements traceability matrix (RTM) was used to define the requirements for the hTowTractor and operations related to it, using the MoSCoW method. The input was gathered from relevant partners, SINTEF, KES, TLD, Ballard, FHG, Schiphol, KLM, through a series of workshops held spring/summer 2023. From the RTM and more workshops, a demo planner document was developed. The documents serve as a detailed document outlining the demonstration, the tasks, the responsibilities, and the timeline, for the demonstration. The document is meant to be continuously updated during the demonstration planning and execution.

4.1 Requirements

Collaboration between different stakeholders to define requirements early in the project phase is vital for product development and financial decisions. When several requirements are gathered from the stakeholders, a crucial workflow element is to categorize the importance of said requirements. The significancy of the requirements can vary, and by systematically define if a requirement is necessary or simply wanted for the project can aid in the consensus between all stakeholders and help understand the main outcomes of the project. It can also reduce the risk of project resources being misspent on lesser priority areas [7]. Prioritizing the requirements can also avoid several challenges typically related to projects involving prototyping. These challenges are: time and personnel availability, budgetary constraints, lack of available competence, stakeholders competing needs.

Multiple requirement definition and periodization tools are available, capable of sorting and structuring defined requirements efficiently. For this project, the MoSCoW method was elected as the appropriate one due to the ease of use, the suitableness for gathering requirements from multiple stakeholders, and familiarity and experience from the first demonstration planning, for the hGPU.

The MoSCoW-method [8] is a four-step approach for prioritizing requirements in terms of best return of investment, feasibility, and execution possibility. MoSCoW is the acronym for how one can define the requirements and stands for “Must have”, “Should have”, “Can have”, and “Will not have”. Requirements defined as “Must have” is vital for the product, project, or release, which cannot be completed without it. “Should have” is requirements that significantly improve the product, project, or release, but is not completely necessary. “Can have” requirements are improvements that can be included, but will not significantly improve the product, project, or release. “Will not have” are considered to be outside the scope.

Through multiple workshops conducted within the project with the relevant stakeholders in the spring and summer of 2023 requirements were gathered and prioritized using the methodology. Stakeholders that were present in these workshops were GSE handlers, GSE provider, FC system integrator, FC manufacturer, and fire department. High level requirements were collected and consolidated into four thematic areas, namely operational, technical, safety, and other requirements. In addition to the requirements, responsible actors for completion and validation of the requirements, and deadlines, is also collected and documented.

The requirements defined as operational are the necessary capabilities of the product during operation. In this case that includes refuelling, training, monitoring, etc. The hTowTractor’s operational requirements include:

- During maintenance towing operations the vehicle must be able to supply an onboard E-GPU at the same time as towing.
- Instructional information (PowerPoints, videos, etc.) on Do’s and Don’ts and operation of the vehicle must be provided.
- Health monitoring should be available remotely for timely response of the GSE supplier.
- The GUI of the tow tractor should be use friendly so that little to none extra training is required.

The technical requirements are baseline requirements related to the product before operation. These requirements should be formal and concrete and defined by technical experts with good knowledge of the reference and planned product. The hTowTractor technical requirement include:

- The vehicle must be able to operate without significant performance loss in an ambient temperature range from -25°C to 40°C.
- The vehicle must comply with the relevant standards and certificates for this type of equipment.
- The refuelling equipment and nozzles should be the same as for the hGPU.
- The vehicle could have remote diagnostics capability.

Safety requirements are strictly related safety aspects that the product must comply with for safe handling. Safety requirements are typically defined as “Must have” due to them being related to the safety of the product or personnel handling it, and thus an absolute requirement. The hTowTractor safety requirements include:

- The vehicle must be equipped with hydrogen leak sensor.
- The tow tractor must be easily removable in case of fire (a “neutral” equivalent position must be available for towing).

- The pressure release valve points must point away from any aircraft and other vehicles.
- Hydrogen safety risks must be included in the emergency response plan of the airport operator.

Lasty, other requirements are viewed as a category where defined requirements that does not fit under any of the other categories is placed. The hTowTractor other requirements include:

- The vehicle must significantly reduce or eradicate operational emission compared to diesel equivalent.
- Certified green hydrogen could be used for refuelling.
- Detailed data of the vehicle should be logged for further analysis.

4.2 Stakeholder identification

Though most of the stakeholders are the same compared to the hGPU, some key stakeholders involved have changed. Thus, the project internal stakeholders, their roles and their responsibilities are summarised in the below table.

Table 1 - Relevant stakeholders for the hTowTractor demonstration.

Stakeholder name	Role	Responsibilities
FhG	WP4 coordinator, lead of Task 4.4	Coordination, risk assessment for demonstration, develop guidance material.
HyCC	Consultant	Green hydrogen supply: certification schemes
KES	Lead of Task 4.2 and 4.3	Site preparation, hydrogen-refuelling responsible, personnel training, service
KLM	Airline	Provider of aircraft
SIN-AS	Lead of Task 4.1	Planning of demonstration, technical support
SNBV	Airport	Facilitate demonstration at their airport, obtain approvals, agreements, clearances from relevant stakeholders
Ballard	Fuel cell system provider/OEM + integration	Develop/deliver suitable FC system for tow tractor, Integrate tow tractor with hybrid FC system
TLD	GSE vehicle provider + integration (fuel cell system integration)	Develop/deliver suitable tow tractor to be fitted with hybrid FC system, Integrate tow tractor with hybrid FC system
Fire brigade at Schiphol airport	Fire Brigade	Assistance in safety aspects of demonstration, standby for testing
Ground handler at Schiphol airport	Ground handlers	Will operate vehicle during testing and demonstration

Airport authority at Schiphol airport	Airport authorities	Will be responsible for overall management and operation of the airport including compliance with regulatory requirements and infrastructure deelopment and maintenance
Airport security at Schiphol airport	Airport security	Assistance in safety aspects of demonstration

4.3 Site selection

The selection of Schiphol Airport as the host for the demonstration is underpinned by a series of compelling factors, in addition to the airport being the lighthouse airport in TULIPS. Schiphol Airport, one of the busiest airports in Europe, has established itself as a progressive leader in the aviation industry, setting an ambitious vision for 2050 aimed at significant reductions in GHG emissions and bolstering resilience against climate change [9]. Notably, the airport has set an intermediate target of achieving ZE and zero-waste airport operations by 2030, demonstrating a strong commitment to sustainability and environment. This commitment to sustainable practices, combined with its operational capacity and experience, makes Schiphol ideal for hosting the demonstration.

4.4 Timeline development

Through collaborative engagement with stakeholders within the project, the RTM [10] was meticulously devised. This comprehensive document served as the foundation for the formulation of a Demonstrative Strategic Plan, wherein various requirements were methodically interlinked with vital informational parameters, including timeline considerations, designated responsible entities, and geographical location. The Demonstrative Strategic Plan, coupled with organization-specific deadlines and significant milestones, played a pivotal role in the establishment of overarching milestones associated with the project's WPs. This was particularly instrumental in defining key developmental and demonstrational phases of the hTowTractor.

The bullet point list, as seen below, presents the principal milestones for the forthcoming demonstration, along with their estimated time of occurrence:

- Completion of the FC Integration Concept: July 2023
- Completion of the Detailed Design for FC Integration: January 2024
- Start of Vehicle Production: June 2024
- Completion of Vehicle Production: September 2024
- Vehicle Commissioning and Testing is Finished: November 2024
- Vehicle Demonstration at Schiphol: December 2024

4.5 Dissemination plan

The hTowTractor demonstration will be communicated and disseminated in line with the overall TULIPS Communication and Dissemination Strategy as defined in WP12. The focus will be on effective communication before, during and after the demonstration, communicating directly with relevant stakeholders, such as airport authorities, airlines, the fire brigade, and ground handling companies. This involves informing them about the scheduled demonstration, its purpose, implications (operational and safety) for their work, and the benefits it can bring to the industry. By engaging these stakeholders, their support and involvement can be obtained, leading to increased visibility and acceptance of the hTowTractor.

For the dissemination of the results, the documentation of planning, executing and validating the demonstration is crucial. In this context, also capturing visual content of the demonstration through pictures and videos will be done. This documentation helps showcase the innovative features of the GSE and provides evidence of its performance. These visuals can be used for promotional purposes across various communication channels, including social media, the project website, and presentations.

Developing a demonstration report, the deliverable in this WP, and the transfer and guidance material is essential to ensure effective knowledge transfer. Creating informative materials that provide adapted information, lessons-learned, and guidance on operating and utilizing the hTowTractor will facilitate its adoption. These materials can be shared with potential users, stakeholders, and interested parties, enabling them to understand the benefits and effectively implement the technology.

Lastly, actively participating in conferences, exhibitions, and industry events is crucial to communicate and disseminate information about the hTowTractor. These platforms provide opportunities to showcase the equipment's features, benefits, and real-world applications to a wider audience. By presenting at these events, the project gains visibility among industry professionals, potential customers, and stakeholders, further enhancing the dissemination of its results.

In addition to the previously mentioned elements, the results of the hTowTractor demonstration will be displayed in the following deliverables:

- D4.3 Report on the hTowTractor prototype: This deliverable will provide a comprehensive report on the prototype of the hTowTractor, detailing its design, development process, technical specifications, and performance characteristics.

- D4.5 Demonstration report of hGPU and hTowTractor in use for lighthouse and fellow airports: This deliverable will document the demonstration of both the hGPU and the hTowTractor at lighthouse airports and fellow airports. It will include detailed information about the demonstration process, the equipment's performance, user feedback, and any lessons learned during the demonstrations. These deliverables will serve as important documentation and reference materials for stakeholders, project partners, and interested parties to understand the outcomes and findings of the technological demonstration and the innovative GSE.

- D4.8 Transferability and guidance material for ZE GSE: This deliverable will focus on the transferability and guidance material specifically related to ZE GSE. It will provide information on the technology, implementation strategies, operational considerations, and best practices for using ZE GSE in airport environments, focusing on implications for the hGPU and the hTowTractor

5 Tow Tractor Prototype Development

5.1 Design and build

The hTowTractor is derived from an electric towbar-less tractor design. At its core, the powertrain incorporates Ballard's FCmove®-HD+, Ballard's state-of-the-art FC module for medium-duty ZE motive applications. This integrated system is designed with a focus on compactness and ease of integration, encompassing requisite subsystems and featuring a centralized interface for maintenance and connection purposes.

Figure 1 – Ballard FCmove®-HD+ Fuel Cell Module: Advanced Technology for Zero-Emission Medium-Duty Motive Applications.

The FC module has a net output power rating of 100 kW and interfaces with a 100 kW DCDC converter, thereby connecting to the high voltage DC bus. In order to meet the power demands of maintenance towing operations, a parallel installation of a battery pack elevates the combined power output to 250 kW.

To ensure operational autonomy, the vehicle is equipped with a hydrogen storage system capable of accommodating 10 kg of hydrogen. This configuration results in a vehicle autonomy exceeding 15 km for maintenance towing and an equivalent range for unrestricted driving. This is expected to represent the most energy-intensive operating condition requirement.

5.2 In-house testing and validation

Before the FC module is handed over to TLD for integration into the tow tractor, it undergoes thorough and comprehensive in-house Factory Acceptance Test (FAT) at Ballard's factory. FATs play a pivotal role for both end users and the manufacturing team when dealing with intricate products. This testing process provides assurance to both parties that the equipment complies with all pre-established specifications. Furthermore, it serves as a valuable tool to identify and resolve any functional issues prior to the equipment being deployed.

When TLD constructs the vehicle, it undergoes a step-by-step commissioning process to ensure that the system is correctly assembled and safe for startup. Checks related to component installation are performed, followed by electrical connections checks. The hTowTractor is then tested in battery mode, where the FC will remain off, checking that the standard features of the vehicle are working as expected. Once the usual tests are completed, the hydrogen system is filled using a special flushing/bleeding process to make sure the hydrogen is of necessary purity for the FC start-up. Proper control of the FC and DCDC converter during start-up, operation, and shutdown, is tested with support from Ballard. When everything is validated to work as expected, the focus will shift to power and performance testing, where power of the FC is gradually increased, and the energy flow between the FC and battery is checked to be well balanced from the consumption of the vehicle. Further, performance and endurance tests are done. Firstly, static tests on a test bench are done to ensure that the vehicle can deliver the required traction force. Then, a test trailer, emulating an aircraft is towed to check the hTowTractor maximum power output at various speeds. The vehicle is tested up to 200 kW and 32 km/h, including measuring the autonomy at the same time.

5.3 Standardization and certification

Standardization and certification are crucial in the aircraft sector, as cost of equipment and aircrafts are high, and safety is on top of priorities. Despite this, there are currently no applicable standards for the usage of hydrogen in GSE environment. However, in the following table, the relevant standards for a tow tractor ground support vehicle are listed, together with short abstract and source.

Table 2 - Standards relevant for tow tractor GSE.

Standard	Standard full name	Description	Source
EN 1915-1	Aircraft ground support equipment – General requirements – Part 1: Basic safety requirements	This European Standard specifies the technical requirements to minimise the hazards listed in Clause 4 which can arise during the commissioning, operation and maintenance of GSE when used as intended including misuse reasonably foreseeable by the manufacturer, when carried out in accordance with the specifications given by the manufacturer or his authorised representative.	[11]
EN 1915-2	Aircraft ground support equipment	This Part of EN 1915 specifies the conditions to be taken into consideration	[12]

	– General requirements – Part 2: Stability and strength requirements, calculations and test methods	when calculating the strength and the stability of GSE according to EN 1915-1 and the EN 12312 series under intended use conditions. It also specifies general test methods.	
EN 1915-3	Aircraft ground support equipment – General requirements – Part 3: Vibration measurement methods and reduction	This European Standard deals with whole body vibration as a significant hazard. It also specifies the methods for determining the vibration emission transmitted to the whole body of drivers standing and/or seated on freely moveable GSE, when driving for purposes of type evaluation, declaration and methods of verifying vibration emission.	[13]
EN 1915-4	Aircraft ground support equipment – General requirements – Part 4: Noise measurement methods and reduction	This document deals with noise reduction as a safety requirement. It also specifies the methods for determining the sound pressure level at workstations, other specified positions and the sound power level of GSE during intended use.	[14]
EN12312-7	Aircraft ground support equipment – Specific requirements – Part 7: Aircraft movement equipment	This document specifies the technical requirements to minimize the hazards listed in Clause 4 which can arise during the commissioning, operation and maintenance of aircraft movement equipment when used as intended, including misuse reasonably foreseeable by the manufacturer, when carried out in accordance with the specifications given by the manufacturer or his authorized representative.	[15]
ISO 12100	Safety of machinery – General principles for design – Risk assessment and risk reduction	ISO 12100:2010 specifies basic terminology, principles and a methodology for achieving safety in the design of machinery. It specifies principles of risk assessment and risk reduction to help designers in achieving this objective. These principles are based on knowledge and experience of the design, use, incidents, accidents and risks associated with machinery. Procedures are described for identifying hazards and estimating and evaluating risks during relevant phases of the machine life cycle, and for the elimination of hazards or sufficient risk reduction.	[16]
ISO 13849-1	Safety of machinery – Safety-related parts of control systems – Part 1:	This document specifies a methodology and provides related requirements, recommendations and guidance for the design and integration of safety-related parts of control systems (SRP/CS) that	[17]

	General principles for design	perform safety functions, including the design of software.	
EN 60204	Safety of machinery – Electrical equipment of machines	IEC 60204-1 is scoped to cover the electrical equipment of machines that operate in the low-voltage range, generally accepted to be 1000 V a.c. or less, or 1500 V d.c. or less. Equipment within the scope is typically built from off-the-shelf components assembled into a suitable electrical enclosure, with the necessary interconnecting wiring and mechanical supporting structures.	[18]
EN 1175-1	Safety of industrial trucks – Electrical requirements – Part 1: General requirements for battery powered trucks	This standard specifies electrical and related mechanical safety requirements for design and construction of the electrical installation in battery powered industrial trucks hereinafter referred to as trucks, with nominal voltages of the truck system up to 240 V.	[19]
EN 12895	Industrial trucks – Electromagnetic compatibility	This European Standard is applicable to industrial trucks, regardless of the power source (called only trucks) as defined in ISO/DIS 5053 1, and their electrical/electronic systems when used in residential, commercial, light industry and industrial environments (specified in EN 61000-6-3:2007 and EN 61000-6-2:2005).	[20]
ISO 4413	Hydraulic fluid power – General rules and safety requirements for systems and their components	ISO 4413:2010 specifies general rules and safety requirements for hydraulic fluid power systems and components used on machinery as defined by ISO 12100. ISO 4413:2010 deals with all significant hazards associated with hydraulic fluid power systems and specifies the principles to apply in order to avoid those hazards when the systems are put to their intended use.	[21]
UN R134A	Safety-related performance of hydrogen-fuelled vehicles (HFCV)	Regulation No 134 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen-fuelled vehicles (HFCV)	[22]
ISO 23273:2013	Fuel cell road vehicles – Safety specifications – Protection against hydrogen hazards for vehicles fuelled with compressed hydrogen	ISO 23273:2013 specifies the essential requirements for fuel cell vehicles (FCV) with respect to the protection of persons and the environment inside and outside the vehicle against compressed hydrogen-related hazards.	[23]
EN-NEN-ISO 11439:2013	Gas cylinders – High pressure	ISO 11439:2013 specifies minimum requirements for light-weight refillable gas	[24]

	cylinders for the on-board storage of natural gas as a fuel for automotive vehicles	cylinders intended only for the on-board storage of high pressure compressed natural gas as a fuel for automotive vehicles to which the cylinders are to be fixed. The service conditions do not cover external loadings that can arise from vehicle collisions, etc.	
NEN-ISO 12991:2012	Liquefied natural gas (LNG) – Tanks for on-board storage as a fuel for automotive vehicles	ISO 12991:2012 specifies the construction requirements for refillable fuel tanks for liquefied natural gas (LNG) used in vehicles as well as the testing methods required to ensure that a reasonable level of protection from loss of life and property resulting from fire and explosion is provided. It is applicable to fuel tanks intended to be permanently attached to land vehicles but can be used as a guide for other modes of transport.	[25]
NEN-ISO 15500:2012	Road vehicles – Compressed natural gas (CNG) fuel system components	NEN-ISO 15500:2012 parts 1 to 20 specifies requirements for components used in CNG fuel systems.	[26]
NEN-ISO 21266-1:2018	Road vehicles – Compressed gaseous hydrogen and hydrogen/natural gas blends fuel systems – Part 1: Safety requirements	This document specifies the minimum safety requirements applicable for the functionality of compressed gaseous hydrogen (CGH2) and hydrogen/natural gas blends on-board fuel systems intended for use on the types of motor vehicles defined in ISO 3833.	[27]
NEN-ISO 21266-2:2018	Road vehicles – Compressed gaseous hydrogen and hydrogen/natural gas blends fuel systems – Part 2: Test methods	This document specifies the test methods for checking the minimum safety requirements specified in ISO 21266-1. It is applicable to the functionality of the fuel systems designed to operate on compressed gaseous hydrogen and hydrogen/natural gas blends of motor vehicles as defined in ISO 3833.	[28]
ISO 3833:1977	Road vehicles – Types – Terms and definitions	Defines terms relating to some types of road vehicles designated according to certain design and technical characteristics. Applies to all vehicles designated for road circulation, except for agricultural tractors which are only incidentally used for the carriage of persons or goods by road.	[29]
NFPA 52 (2019)	Vehicular natural gas fuel systems code	NFPA 52 safeguards people and installations with requirements that mitigate the fire and explosion hazards associated with compressed natural gas (CNG) and liquefied natural gas (LNG) engine fuel systems and fuelling facilities.	[30]

PGS 26:2021	CNG and LNG – Guideline for the safe commercial storage, maintenance and repair of motor vehicles	This PGS 26 New Style contains measures to control the risks of the commercial storage, maintenance and repair of motor vehicles equipped with a CNG and/or LNG installation.	[31]
PGS 35:2021	Hydrogen plants for delivering hydrogen to vehicles and equipment	This PGS 35 New Style contains measures to control the risks of hydrogen refuelling.	[32]
PGS 33:2021	LNG delivery facilities for vehicles and equipment	This PGS 33-1 New Style contains measures to control the risks of LNG refuelling.	[33]

For the integration of the FC power module and hydrogen storage systems onboard the vehicle, UN R134A is highlighted and will be followed as a reference together with ISO 23273.

6 Safety and Compliance

6.1 Safety regulations

Schiphol airport has prepared multiple documents related to the safety aspects of introducing hydrogen powered vehicles at airports, and related to the refuelling process of hydrogen. The purpose of these documents describing basic requirements is to provide fire-safe framework to mitigate risks of introducing new energy carriers at Schiphol. These requirements clearly outlines the principles and control measures for utilizing hydrogen or biogas powered vehicles and GSE, specifically at Schiphol airport. In this section, key takeaways from the documents are summarized.

The fuel tanks on the vehicle, and refuelling infrastructure should be equipped with Temperature Pressure Relief Valve (TPRD). This device releases the content of the tanks when the temperature around in becomes high (110 °C). This is to ensure that in case of fire, or any other unexpected thermal events, the tanks will be emptied in a controlled manner instead of exploding.

Schiphol has elected to fill the gap of lacking requirements regarding parking, storing, and operating hydrogen vehicles through a guidance document. The document of requirements provides guidance to safely utilize hydrogen vehicles in an operational airport. The document provides, but are not limited to the following list of basic requirements:

- Parking and storage of hydrogen or (bio)gas-powered vehicles
- Personnel and visitor best-practise information
- Distances to parked vehicles
- Safety of structures surrounding the vehicles
- Markings, identification and accessibility of parked vehicles
- Water availability around parked vehicles
- Technical specifications of vehicles (such as TPRD and sensors)
- Gas detection and emergency shutdown procedures
- Lifetime and specifications of tanks on the vehicle and refuelling infrastructure
- Specifications related to depressurization of the systems
- License plate and identifiable marking of vehicles
- Towing specifications

6.2 Permits and approvals

To tackle the multiple permits and approvals that are necessary to perform the demonstration at Schiphol airport, a permit checklist for Schiphol will be prepared. This list will serve as a checklist ensuring that the necessary permits and approvals for the demonstration is gathered and followed.

In addition, an environmental permit distributed by Schiphol is also necessary to gather and follow before and during the demonstration.

7 Demonstration Preparation

7.1 Site infrastructure

For a demonstration of considerable size, at an operational airport, many preparations and considerations need to be made with respect to site infrastructure. One key element is the refuelling of the vehicle. Hydrogen refuelling infrastructure is not something that exists on most airports as of today. Nevertheless, refuelling, both fuel supply and refuelling equipment, with respect to both safety and operational effectiveness, is a vital aspect of the demonstration. A semi-mobile refuelling facility will be strategically made available for the demonstration. Semi-mobile, in this context, refers to a facility that is not fully fixed and can be reallocated during the demonstration timeline, such as a hydrogen refuelling vehicle. With this decision, preparation for the reservation of such a vehicle is necessary, as it may be costly. Such preparations include a detailed timeline for the demonstration, cost analysis of the potential vehicle candidates, risk analysis of the presence of such a vehicle at an operational apron/airport, and detailed locational timeline (where the vehicle would be located at each point of time). These preparations, together with the refuelling process must be in accordance with Publicatiereeks Gevaarlijke Stoffen 35 (PGS 35), a dutch standard “Hydrogen: Installations for delivery of hydrogen to road vehicles”, which applies to hydrogen delivery stations on land, with a delivery pressure between 350 and 700 bar of gaseous hydrogen, for refuelling to road vehicles with European type approval [32].

As a starting point for demonstrating and testing the hTowTractor, it will tow a specific aircraft from a specific location to a specific location. Schiphol is one of Europe’s busiest airports, and any disruption in the normal traffic can be costly. Thus, suitable aircraft and locations needs to be defined, should issues and delays arise in the demonstration. Furthermore, after the initial testing of the vehicle, it will be put into day-to-day operation, and it will demonstrate its useability with operating like a diesel equivalent vehicle. However, as this is still a demonstration, and prototypes are prone to delays, errors, problems, or delays, a backup vehicle should always be available to avoid any major disruptions of the normal airport traffic.

7.2 Training

Involved in the development of training material and the training related to the hTowTractor, is mainly split between three stakeholders: Ballard, TLD, and Fraunhofer.

Ballard shares training material, learnings, and best practices for the FC module through their service organization. The information is conveyed via HubSpot Academy, inhouse/online training/learning sessions, and through virtual reality service operation simulations. Ballard usually includes the training academy in their product deliveries solutions to improve product know-how and reduce downtime of operation. The employees at Ballard HQ are securing continuous optimization of all the processes, documentation and training materials for improved and better training experience ready for you when needed.

TLD will provide a specific training about the standard features of the TPX-200-MTX-E vehicle, including the way to drive the vehicle in solo, how to load an aircraft, and how to do pushback or maintenance towing operation. TLD will also focus on the hydrogen system. Operators will be trained in the refuelling process of the hTowTractor, given explanations of the FC management logic, start-up/shutdown procedures, and the power distribution depending on the type of operation. There will also be focus on hydrogen safety and emergency shutdown procedures. The operation and maintenance manuals will be used as reference during the training.

Fraunhofer will develop training and guidance materials for stakeholders based on technical and functional specifications, safety considerations, and operational considerations provided by the FC supplier and the manufacturer. These materials will be in the form of posters, leaflets, and training presentations.

The comprehensive training materials will cover key aspects of the hTowTractor, including its features, operational procedures, safety protocols, and maintenance requirements. These materials can include manuals, guides, videos, and presentations.

Training sessions for different stakeholder groups to provide hands-on training and information about the hTowTractor will be organized. These sessions can be conducted on-site at the airport or through remote online platforms, depending on the feasibility and convenience for the stakeholders.

In addition, practical demonstrations and simulations to stakeholders, allowing them to observe the hTowTractor in action and understand its capabilities will be provided. This will include showcasing its manoeuvrability, power supply, and ZE features. The goal is to ensure that stakeholders are well-equipped and knowledgeable about the hTowTractor, enabling them to operate and maintain it effectively and safely.

7.3 On-site tow tractor setup

Upon arrival at Schiphol airport, the hTowTractor is equipped and ready for operation. The FC module has already undergone meticulous FATs at Ballard's site, while the complete vehicle will undergo and pass detailed testing at TLD's facilities before being commissioned to Schiphol airport.

In addition to the prior testing, a health check will be conducted upon arrival at Schiphol to ensure the vehicle's operational readiness. Further testing and training will be organized in collaboration with the KLM Towing Department, who will be operating the unit.

8 Demonstration Execution

8.1 Safety course/briefing

The purpose of the safety briefings is to ensure a safe and efficient hTowtractor demonstration by providing comprehensive information to all stakeholders involved. The briefings will address the specific considerations and communication methods required to train and inform various stakeholders, including the fire brigade, airport security/local police, airport officials, control tower officials, tow tractor operators, refuelling responsible, service crew, other ground support crew in proximity to tow tractor, and pilot of serviced aircraft.

Understanding the diverse roles and responsibilities of stakeholder, it is essential to tailor the information accordingly. This includes customizing the briefings to suit the specific needs and concerns of each audience, providing relevant details about the hydrogen and equipment technology being demonstrated, and highlighting its impact on safety and operational considerations.

To ensure effective training and information dissemination, a combination of communication methods will be employed. These methods may include meetings, posters, presentations, information leaflets, and being available for questions before, during, and after the demonstration. By utilizing different approaches, we aim to reach all stakeholders and ensure easy access to the information provided.

The safety briefing will provide clear instructions and guidelines to enable a safe and efficient operation during the technology demonstration. This will involve addressing emergency (response) procedures, potential risks, and appropriate reactions in case of an emergency or irregularities. By emphasizing safety and operational considerations, we aim to facilitate timely responses and minimize any potential hazards.

Upon finalization of the hTowTractor prototype, the information material will be continuously updated. This will ensure that all relevant details are included, and any specific concerns raised by the stakeholders involved are addressed effectively. By providing up-to-date information, the aim is to maintain transparency and instil confidence among all stakeholders.

The KLM Towing Department, who will operate the vehicle, will undergo user training provided by TLD and KES at the KES facility. As of now, the fire brigade does not necessitate additional training; however, they need to be informed and acquainted with the unit's design and emergency procedures. TLD and KES will coordinate the exchange of this crucial information.

For technical support of the vehicle, mechanic personnel from KES will receive training from TLD and Ballard, with specific focus on the FC module. This training will ensure proficient handling of the technical aspects of the vehicle.

8.2 Test protocols

Test protocols for the hTowTractor were meticulously developed during the planning phase of the vehicle's development. This process involved collaborative input from stakeholders, incorporation of standardized and certified guidelines, and consideration of general requirements pertinent to such a vehicle. While the FC module is thoroughly tested at the manufacturers, Ballard, factory, and the vehicle manufacturer and integrator, TLD, does similar testing for the tractor, the combination of power module in the tractor is tested as part of the development. By going through these protocols, a validation checklist, which is further discussed in Section 9, is completed.

Three distinct locations are considered in designing the test procedures: *in-house testing* is conducted in a local workshop at the airport and provides a safe, controlled environment for the evaluation. *Remote testing* will happen on a remote apron free of actual commercial air-traffic and provides a safe, but realistic environment for testing procedures. Lastly, *actual operation,* happens at the airport, Schiphol, where the vehicle will be tested in real conditions and is expected to operate the same way as its diesel equivalent.

Testing a new product thoroughly before and during the implementation into the operation is vital, especially for operations related to airport industry, where safety is a high priority and cost of equipment and delays are high. The protocols are designed with the following key aspects in mind to ensure high quality:

- *Safety:* Ensure that the vehicle meets the strict safety requirements as are expected at an airport. This is to reduce risk and to ensure the well-being of the passengers, airport personnel, the vehicle, and the surrounding equipment and environment.
- *Regulation Compliance:* Even though there exist no standards or certifications for the hTowTractor, the vehicle will still follow the appropriate standardization for airport equipment and for hydrogen powered vehicles.
- *Performance and Efficiency:* Validation that the vehicle have sufficient performance and can be operated without a loss in operational efficiency, which can lead to costly delays.
- *Interoperability:* Seamless integration with the environment where the vehicle will operate, such as with refuelling infrastructure, communication with logistic management, as well as others.

8.3 Validation

To substantiate the demonstration of the hTowTractor, a validation checklist will be evaluated and confirmed by the various stakeholders of the demonstration. The checklist will be derived with basis of the RTM and the test protocols as described in section 8.2. The objective of the validation checklist is to ensure that the demonstration, and the performance of the product, aligns with the stipulated product requirements. The checklist will be systematically confirmed throughout the testing phases at the workshop, test apron, and actual operation scenarios, scheduled to take place December 2024 at Schiphol airport. The process servers to affirm the demonstration successfulness.

8.4 Key success metrics

Following D9.1 "Identification of key criteria for future deployment" [34], a public report within WP9 of TULIPS, where a methodology for identifying key criteria related to the demonstration, a Key Success Metric (KSM) matrix is developed also for the hTowTractor. The methodology provides important background and references for developing key criteria's for deployment/commercialisation, but also mandatory machine safety to guarantee safe deployment. Performance Metrics (PMs) are the high-level metrics that the key success indicators contribute to. These can for example be categorized as noise, energy use, GHG emissions, or air quality. The PMs should be specific but not go into detail on number/percentage level. The KSMs on the other hand should be more specific, preferably related to numbers and percentages that can signify and measure the progress and achievements within the demonstrations. The definition of the KSMs should be a collaborative effort between the involved stakeholders, WP leaders, demonstration leaders, but also the participants of within the relevant WP and WP 8, 9, and 10, to ensure that the outcome is evaluated in correspondence within the TULIPS project.

The KSM matrix is a working document that is planned to continuously be updated until the demonstration. Some KSMs are already defined, presented in the table below.

Table 3 - Key Success Metrics.

Key Success Metric	Quantifiable Variables
Perform one maintenance-tow with hTowTractor	distance travelled; time travelled; starting point; end point
hTowTractor can operate a shift without refuelling	starting time; end time; operational time; hydrogen level; ambient temperature
Achieve emission savings by other means than electrification	emissions; trip; a/c type; fuel type
User acceptance of hTowTractor is satisfactory or higher	user acceptance score
Perform couple of refuelling cycle with a mobile hydrogen refuelling truck	installation time; arrival time; departure time; refuelling time

8.5 Data collection and analysis

1. Noise data: Measure and record the noise levels generated by the hTowTractor during operation. This data will help assess the environmental impact and compliance with noise regulations.

2. Pictures: Capture images of the test and demonstration processes, as well as the operational environment. These visual records will provide documentation for analysis, reporting, and future reference. In addition, pictures and videos may be used for communication and dissemination purposes.

3. Consumption data: Collect data on the hydrogen consumption of the hTowTractor during the demonstration. This information will be useful in evaluating the efficiency of the hydrogen fuel system and assessing the feasibility of its implementation.

4. Interviews with stakeholders: Conduct interviews with relevant stakeholders, such as operators, ground crew, and other personnel involved in the demonstration. These interviews can provide valuable insights, feedback, and perspectives on the performance and usability of the hTowTractor.

5. Technical data from the hTowTractor: Gather technical data directly from the hTowTractor itself. This data may include operational parameters, performance metrics, and any other relevant information that can be derived from the hTowTractor 's onboard systems.

6. Data Storage and Usage: The collected data should be stored in a secure and organized manner. The specific storage location and method will depend on the protocols and requirements set by TLD/Ballard, the entities responsible for the demonstration. It is crucial to adhere to data protection and privacy regulations when storing and handling the collected information.

The data collected during the demonstration will serve multiple purposes, such as:

1. *Evaluation and Analysis:* The data will be used to evaluate the performance and effectiveness of the hTowTractor in real-world conditions. This analysis will help identify strengths, weaknesses, and areas for improvement.

2. *Reporting and Documentation:* The collected data will be utilized in generating comprehensive reports and documentation on the demonstration. These reports may include technical specifications, performance summaries, and analysis of the data collected.

3. *Future Development:* The data will contribute to the ongoing development and refinement of the hTowTractor technology. Insights gained from the demonstration will guide further research, design enhancements, and potential commercialization efforts.

9 Summary and Outlook

In this report the collaborative effort to demonstrate a hydrogen-powered tow tractor at Schiphol airport is presented. The emphasis is placed on planning and operational concept of the demonstration. The MoSCoW method was employed systematically to recognize and categorize the technical, operational, safety, and other requirements. The relevant stakeholders for the demonstration are identified and their roles and responsibilities delineated. Schiphol, the lighthouse airport in the TULIPS project, will host the demonstration due to their European relevance and commitment to becoming a net-zero airport. A demonstration timeline is carefully developed and put forth with key milestones to be reached in 2024.

The dissemination activities are described and put into system through the demonstration dissemination plan. Highlighted are also other relevant deliverables, such as *D4.3 Report on the hTowTractor prototype, D4.5 Demonstration report of hGPU and hTowTractor,* and *D4.8 Transferability and guidance material for ZE GSE.*

The design and construction of the tow tractor, on a high level, is put forth together with relevant in-house testing procedures and validation. The prototype is developed by fitting Ballards FCmove®-HD+ together with a 100-kW battery pack on an electric towbar-less tractor from TLD, providing a combined power of 250 kW. With an onboard hydrogen storage system capable of carrying 10 kg hydrogen, the necessary autonomy of the vehicle is secured. The implementation, commissioning, testing, and operation is all done in accordance with the relevant standards and certifications. Guided by Schiphol’s internal procedures for safe handling of hydrogen, and hydrogen powered vehicles, the safety of the demonstration is kept at an acceptable level.

Site and infrastructure preparations involve considerations for a semi-mobile refuelling facility and contingency planning for towing tests and operations. Training responsibilities are divided between Ballard, TLD and Fraunhofer, who will ensure that the relevant information for each of the stakeholders are transferred in an efficient manner. After the vehicle is commissioned to Schiphol, it will undergo a health check before being thoroughly tested. This will be coordinated with KLM Towing Department.

Appropriate safety courses and briefings will provide a safe demonstration. To measure the performance of the vehicle, and thus the success of the demonstration, the vehicle will go through rigorous testing and validation scheme outlined in this report. During the testing data will be collected on noise measurement, visual records, consumption data, interview, and technical data from the vehicle, in accordance with data protection regulations. The data will be further used for evaluation, reporting, documentation, and as input to future efforts.

Looking ahead towards 2024, the key activities for the demonstration will be done. The complete detailed design for the FC integration to the electric towbar-less tractor will be completed early 2024. The building and integration process will start in June and be completed in September 2024.

The internal testing procedures at Ballard and TLD will be completed within November 2024 before the vehicle is commissioned to Schiphol airport. Lastly, the vehicle demonstration is scheduled to begin in December 2024.

The TULIPS hTowTractor demonstration at Schiphol Airport marks a significant advancement towards greener airport operations, addressing emissions from GSE and advancing the industry's transition to ZE technologies.

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