Demonstrating lower polluting solutions for sustainable airports across Europe

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Abstract
The purpose of this report is to summarise the understanding of the current status of TULIPS demonstrators deployability. A series of workshops, surveys and other interactions with the demonstrators provide us the best snapshot of all demonstrations, delving into the use case, problem-solution fit and deployability status of each work package demonstrators. Finally, learnings and insights are summarised, and a technical assessment of the safety and certification requirements is provided.

Disclosure Statement:

II. DOCUMENT HISTORY

Date	Version	Modified by	Remarks
28/08/2024	V1	Beta-i, Manuel Baptista and Ines Tenente	First draft on subset of demos from workshop and survey data, to check with Karina Ospina on structure and relevance of content
02/10/2024	V2	Beta-i, Manuel Baptista and Ines Tenente	After feedback from Karina Ospina and Q&A with all demo and task leads
21/10/2024	V2.1	Beta-i, Manuel Baptista and Ines Tenente	After feedback from shared v2 with all demo and task leads. Includes final formatting, Abstract, Acronyms, Methods, Conclusion.
25/10/2024	V3	Beta-I, Manuel Baptista and Ines Tenente	Checked by Gustavo Magalhães, Beta-i
23/12/2024	V4	Beta-I, Manuel Baptista and Ines Tenente	Validated by Fokko Kroesen (Schiphol), includes Safety and Regulation section from NLR
09/07/2025	V4f	Beta-I, Manuel Baptista,	EU feedback processed .

III. TABLE OF CONTENTS

IV. LIST OF ACRONYMS

Acronym	Meaning
AMS	Amsterdam Schiphol
API	Application programming interface
BCI	Building circularity index
BIM	Business impact model
BMS	Battery management system
CAA	Civil Aviation Authority
DC	Direct current
E-GPU	Electric ground power unit
EASA	European Authority for Aviation Safety
EME	Excess materials exchange
EV	Electric vehicle
FAT	Factory acceptance test
FPU	Floating power unit
GPU	Ground power unit
GSE	Ground support equipment

hGPU	Hydrogen ground power unit
HSE	Health safety environment
ICD	Interface control document
IFB	Iron flow battery
KES	KLM equipment services
LH2	Liquid hydrogen
MAAS	Mobility as a service
MOC	Management of change process
OEM	Original equipment manufacturer
PV	photovoltaic
QR	Quick response
SAF	Sustainable aviation fuel
UFP	Ultrafine particles

1. Executive Summary

This report provides an overview of the deployability status of all demonstrators within TULIPS.

Specifically, the purpose of the deliverable is to provide a snapshot in terms of deployment of all demos, allowing a common understanding around aspects such as the challenges faced by each demonstrator team, results and expected next steps, including expected deployment timings.

In addition to information on the Grant Agreement, we gathered information shared by demo-related work package owners (WP1-7), including: demo objectives, technical approaches, test scenarios, test locations, KSMs, expected timelines, status and any updates. In addition, we have conducted an online workshop in May-June-July 2024 with each separate work package (work package leads and task leads) so as to gather an updated perspective of the deployability status of each demo; provide support in further planning; and understand and address any potential roadblocks.

The measure of the Technological Readiness Level (TRL) of each demonstrator was determined based on a standard approach from NASA's TRL definition. Moreover, we have adapted the use of the TRL framework to assess (during the workshops or additional interactions with the demo teams) the development stage of the demonstration within the context of TULIPS, not the assessment of the technology within the broader current market.

Overall, the information gathered indicates that eight demonstrators are demonstrating, two have been already demonstrated, five are developing or optimising a prototype. The remaining demonstrators have gone through amendments to the initial plan and are either on hold for a solution to those barriers or are restarting after only recently having lifted them.

Several learnings have been extracted throughout the process thus far and are being applied where secondary demonstrations are being planned by demonstrator teams. A few demonstrators are iterating and testing new applications of their demonstration on different partner airports, using the primary use case reported as the baseline.

To provide a more robust set of information, a technical overview of the safety and certification requirements for the technologies being tested is provided, giving further insights into what is the current regulatory landscape and insights into these new emerging domains within aviation.

2. Methodology:

A tailored methodology, based on a Design Thinking approach, was developed to conduct workshops (May - July 2024) with most demo teams and gather relevant data around the problem space and the solution deployability and exploitation. Complementarily, information from the Grant Agreement and from the Deep Dive Sessions (April 2024) presentations, and TULIPS web news publications were also considered to provide more robustness. Additionally, a survey was shared (August - October 2024) to gather or validate specific information gaps and further interactions were had with the demonstrators (Q&A and review process in September and October 2024), allowing an updated understanding of the deployability of each.

2.1 Online Workshop Details

Beta-i designed a workshop methodology to conduct with work packages to increase awareness on the status of the demonstrations within the TULIPS consortium. The methodology intends to grasp a better understanding on what problems are the demonstrations trying to solve, what is the value proposition that each brings to TULIPS and what has been achieved so far. At the end, Beta-i concluded on the TRL regarding the development stage of the solution at the time the workshop was conducted (or additional updates).

The workshop was divided into two steps (*See Figures 1 and 2*). This format allowed for two main assessments to be conducted in a single working session, the deployability status and the exploitation plans:

- Step 1 focused on validating the fundamentals of each demonstration, deep-diving into the demonstration needs.
- Step 2 focused on exploring possible exploitation opportunities for the demonstration. Other assessment work-packages (WP8) were invited to attend Step 2 of the workshop, to analyse the socio-economic impact of each demonstration. Also, NLR presented their expertise in the safety and certification requirements for each demonstration.

The Agenda for the workshop was as follows:

Workshop Step 1

- Deployability Awareness Status & TRL Assessment

Workshop Step 2

- Exploitation Plan (WP9)
- Impact assessment (WP8)
- Key Exploitable Results (WP12)
- Safety and Certification (WP9)

To conduct the workshops, Beta-i developed two tailored canvases, building upon design-thinking and ideation methodologies, to foster the creative process and critical thinking of the stakeholders involved in each demonstration. This culminated in the canvases presented below (*"Demo Deployability Status"* and *"TRL Assessment"*). Both canvases were adjusted to fit the needs of the demonstrations and resulted from several iterations with other assessment work-packages in order to collect the most adequate information. The examples shown here are from our final workshop conducted with WP2.

Figure 1: Workshop Canvas - Part 1: Demo Deployability Status

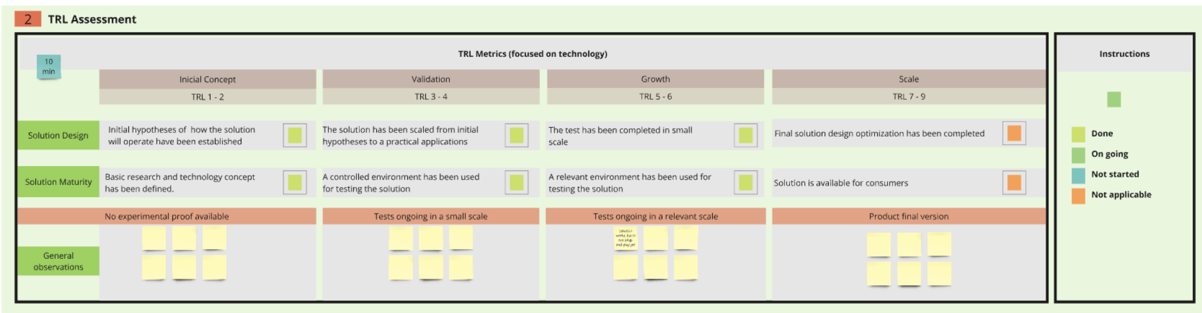

Figure 2: Workshop Canvas - Part 2: TRL assessment

The canvas “Demo Deployability Status” allowed us to get a better understanding of what are the solutions being developed and what is the problem they seek to tackle. Building on that information, we also collected each demonstration execution status, lessons learned, and any required action from the consortium side, to make sure that all demonstrations can achieve the best results possible.

The canvas "TRL Assessment" dives into the Technological Readiness Level (TRL) of each solution. Given that one of the goals of the TULIPS project is to develop all demonstrations up to at least TRL 7, this canvas is a qualitative assessment of where the demonstration was at the time of the workshop or latest evidence gathered and what steps need to be taken to achieve this TRL 7.

The scale of TRL used within WP9 follows a standard approach from NASA's TRL definition (see APPENDIX A. LIST OF REFERENCES). Nevertheless, what is important to understand is that the TRL assessed during the workshops (or additional interactions with the demo teams) is the TRL of the demonstration within the context of TULIPS, not the assessment of the technology within the broader current market.

2.2 Online Survey Details

We designed a second approach to collect and extract information from all demonstrations, using a survey as a way to fill in gaps when a workshop was not held or to collect additional information or updates from the demonstration teams.

The survey was designed to inquire the demonstration teams on the following topics:

Part I | Deployability Assessment

1. *Problem Statement*
2. *Execution Status*
3. *Technology Readiness Level (TRL)*

Part II | Exploitation Assessment

This approach allowed Beta-i to be agile when interacting with the demonstration teams, making sure that there was always a way to collect information from the demonstrators.

3. Deployability Status

In this section, we describe the work package demo activities that have been planned as per the Grant Agreement and respective *Adenda* and how demos in each work package collectively aim to achieve the work package goal.

We then summarise each work package demo in four items:

- Evidence level - describes the data sources used for developing the report for each work package;
- Use Case - summarises demo activities planned and key success metrics;
- Problem-solution fit - describes the problem statement, value proposition, stakeholders and end users;
- Deployability status overview
- Current TRL (as defined in methodology section)
- Expected TRL at end of TULIPS

Further details on all demonstrations are captured in APPENDIX B.

WP1 - Sustainable impact intermodal transport connections

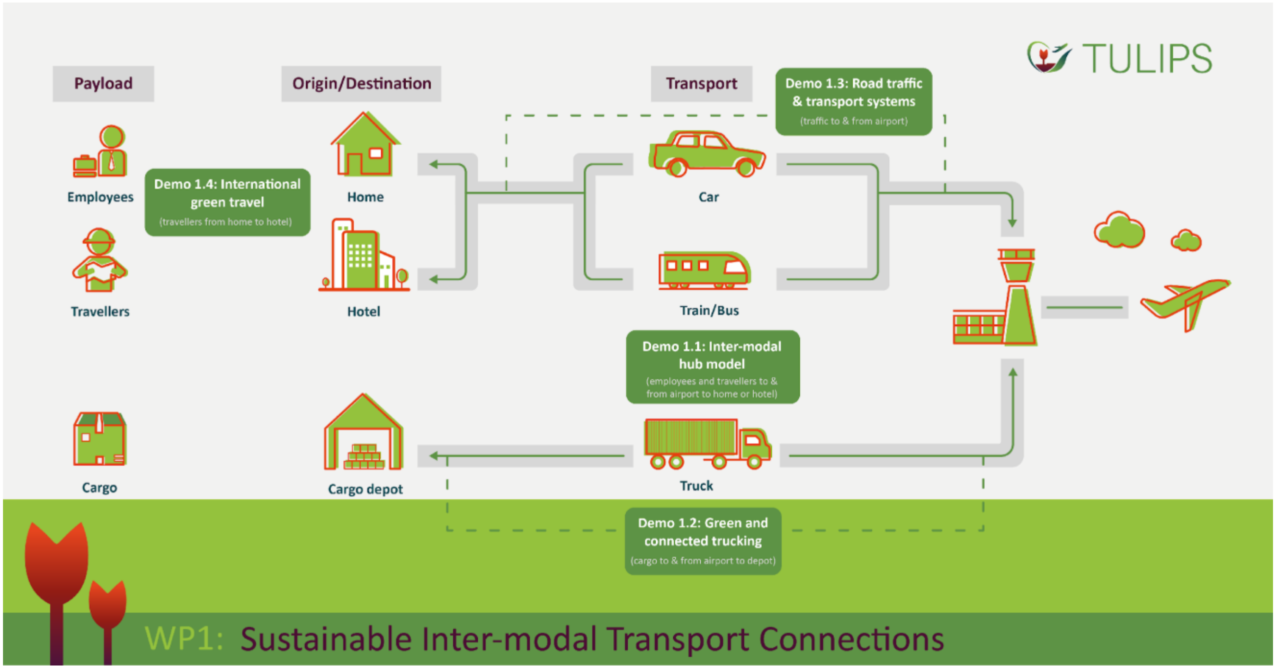

Figure 3: WP1 Summary

The objective of this work package is to enable sustainable intermodal transport connections, through:

- Creation of an open (federated) interconnected ecosystem or “marketplace” combining (access to) different data sources and data enhancing services (including outlier detection, data fusion, short term prediction), establishing a single source of truth;
- Distribution of information to services (e.g. APIs)

WP1 begins with the elaboration and specification of the technologies and required real time data which will be the starting point for the development of the data ecosystem.

First, a functional and technical design of the data ecosystem was planned (T1.1). Existing and available data, standards, tools and experience concerning data platforms will be used as much as possible and combined. The technology shall be state of the art, considering new concepts like federated networks, digital twins and single source of truth. Next to the data that will be delivered by the data ecosystem, several tools to manage the intermodal transport alternatives will be developed.

In total, four demonstrations are planned to be developed, demonstrated and evaluated in parallel:

1. **Demo #1 (T1.4) Enabling travellers multi modal shift with support from MaaS solution (development):** an intermodal hub model of the airport hub area (T1.4a) is to be created which together with a MaaS app (T1.4b) is to provide travellers with pro-active real time travel information. The multimodal travel model and prototype developed shall be evaluated on the impact of at least 5 scenarios on enabling travellers' modal shift towards emission reduction at the lighthouse airport.

2. **Demo #2 (T1.3) Logistic solutions - green and connected trucking:** is to be demonstrated and evaluated with heavy trucks in combination with the operation of decoupling points at or near the lighthouse airport area for landside freight transport to and from the ground handlers at the airport. Further analyses and key findings shall aid specification of the most optimal and effective design of green and connected trucking, concerning sustainability, efficiency and reliability.

3. **Demo #3 (T1.5) Road Traffic and Transport Systems**: based on the identification of bottlenecks and hotspots, increased vehicle emissions, current and feasible traffic management measures and interventions, optimised control strategies and implementation of operational applications are to be evaluated in a real life demonstration at the lighthouse airport.

4. **Demo #4 (T1.6) International green travel:** Door-to-door international green travel is to be demonstrated on an integrated digital platform, based on a decentralised, distributed solution integrating several stakeholders by a federated architecture, supporting passengers in planning and execution of a door-to-door journey. Real-time information and demand forecasting, both fed from an operating system (e.g. MaaS app) are to be implemented in the platform, as well as integration of different travel modes services, public and private transport and micro-mobility. Key-findings from development, demonstration and evaluation at the lighthouse and fellow airports are to be reported.

Demo #1 - Enabling travellers modal shift with support from MaaS solutions (T1.4a and T1.4b)

EVIDENCE LEVEL

Reporting of deployability of Demo #1 (T1.4a and b) is based on answers to a survey form (September 2024) and the Deep Dive Demo progress presentation (April 2024).

USE CASE

This demo is being led by TNO with the participation of MOBCON, TUD, FHG, SNBV, HERMES, and AVINOR. The demo aims to develop a model and MaaS app which considers Schiphol Airport and surrounding commuter areas, including 5 scenarios:

1. Creation of a Zero Emission zone at Schiphol Centre (location: Schiphol city)
2. An extension of the metro (North-South line) to Schiphol airport (location: Hoofrop, etc.)
3. An option of remote check-in (location: cities in the Netherlands, including Utrecht, Groninger, Nijmegen and de Haag (v1) and local areas and highways surrounding Schiphol city (v2))
4. A car free Schiphol centre (location: Schiphol centre)
5. A model of a combination of all of the above

As per the Grant Agreement, this demo work shall include the following activities:

- Obtain passenger access/egress data (GDPR approved) from surveys (SNBV) to add to the existing (anonymised) employee commuting data (MOBCON).
- Create an intermodal hub model of the airport hub area (TNO) that exchanges data with the MaaS app (MOBCON).
- Provide alternative ways of commuting for employees at the airport. *Here valuable experience from the on-going Dutch program will be integrated to the intermodal hub model that exchanges data with the MaaS app*[1] (SNBV,MOBCON, TNO, BAM)
- Extend the MaaS app for use by arriving passengers at airports (MOBCON). *Supported by the output of the hub model simulations*[1] (TNO)
- Visualise in the intermodal hub model the access/egress choices of airline passengers (TNO).
- Provide proactive real time travel information; provide alternative modalities in case of disruptions to achieve on-time arrival at the airport and also convenient departures from the airport (SNBV, TNO, MOBCON).
- Integrate into the intermodal hub model a remote check-in to demonstrate secured remote check-in (SNBV, KLM,TNO)

[1]This is no longer the case, as the MaaS app being developed accounts for traffic on a micro level (i.e. individual user level) whereas the Urban Strategy Tool (Dutch program) incorporates traffic on a macro level.

- Obtain travellers' experience from using the MaaS app by ex-post survey (MOBCON) and enhance/refine the model and the scenarios (TNO[2], MOBCON, TUD).

LEARNINGS & INSIGHTS

In summary, the Commuter App (T1.4b) has reached TRL6 after a pilot in a Schiphol-area company, though full deployment will require secure access to employee commuting data to gauge modal shifts effectively. The Passenger App, currently at TRL 3-4, has been tested among some workshop participants, featuring planning and booking capabilities; ongoing development will add a payment functionality, advancing its readiness as it aims to reach full deployment in 2025.

Meanwhile, the Scenarios and Policy Packages (T1.4a) are under prototyping, with an expected TRL of 6-7 upon completion in June 2025. Each scenario targets emission reductions through initiatives like creating a zero-emission zone at Schiphol and remote check-in options, with progress hinging on data availability for scenario validation. Key risks involve data access for the Commuter App, scaling data processing for the Passenger App, and potential gaps in validating scenarios due to limited data. Mitigation efforts include privacy assessments for commuter data, integration of international payment options, and proactive outreach to enhance app adoption among passengers.

Next steps focus on data analysis from commuter app use to assess behaviour shifts, implementing surveys for passenger feedback, and stakeholder consultations for scenario fine-tuning.

Altogether, success of this demo depends on several factors for each of its components (commuter and passenger apps and scenario packages), of which the most important ones are:

- Successful stakeholder engagement: overcoming barriers for data access and collection with corporates (commuter app)
- Continued data gathering and analysis beyond the TULIPS timeline: analysis of results need to happen after collecting data over a period of time (3 years for the commuter app)

[2] No longer involves TNO

- Investment: iterative development of the digital products requires financial, people and time investment that might be above that provided by TULIPS.
- User acquisition: efforts have to be put toward user acquisition and app release, which are beyond the technical development of the solutions and require support from Schiphol and other airports.

Demo #2 - Logistic solutions: green and connected trucking (T1.3)

EVIDENCE LEVEL

Reporting of deployability of Demo #2 (T1.3) is based on answers to a survey form (September 2024) and the Deep Dive Demo progress presentation (April 2024) and news articles from TULIPS (January and June 2023). Additional updates during review process in September-October 2024 have been considered.

USE CASE

This demo is being led by TNO with the participation of SNBV, POA, DHL, and FHG.

Green and connected trucking will be demonstrated and evaluated with heavy trucks in combination with the operation of decoupling points at or near the lighthouse airport area for landside freight transport to and from the ground handlers at the airport. Further analyses and key findings will aid specification of the most optimal and effective design of green and connected trucking, concerning sustainability, efficiency and reliability.

Specifically, the demo work includes:

- Development of the demonstration for electric driving with heavy trucks in combination with the operation of decoupling points at or near the airport area for landside freight transport to and from the ground handlers at the airport (TNO, DHL, POA).
- Inventory of possibilities for modal shift from road to intermodal rail connections for long distance transport to and from the Amsterdam airport via a decoupling point in the Amsterdam port region (POA).

- Development and application of data driven decision making to select and control the most sustainable, efficient and reliable (electric) intermodal transport alternatives via decoupling points (TNO, FHG, SNBV).
- Execution of the green and connected trucking concept running in regular operation with stakeholders over a period of a couple of months to test, demonstrate, evaluate and modify the concept (SNBV, DHL and its transport companies).
- Analysis of results to specify the most optimal and effective design of the green and connected trucking case with highest impact on both reduction of emissions and efficient and reliable organisation of logistics processes (TNO).

Key Performance Indicators (KPIs) of the technical solution are:

- Environmental: CO2e (ton), energy usage (joule), emissions of pollutant x (ton) such as PM10, NOx
- Operational: Lead time freight
- Socio-economic: Operational expenditures (OPEX), capital expenditures (CAPEX), Amount of green investment (OPEX/CAPEX), social acceptance.

LEARNINGS & INSIGHTS

In summary, the deployability of Demo #2 illustrates the ongoing efforts to establish sustainable and efficient logistics at Schiphol Airport. This demo showcases two electric heavy-duty trucks (one from Bos Logistics and one from DJMiddelkoop) actively engaged in freight transport operations. These trucks are supported by decoupling points at or near the airport, which facilitate efficient landside freight logistics. The delay in delivering a third truck has impacted the initial plan, but the team plans to meet project Key Success Metrics (KSM) by basing evaluations on the performance of the two operational trucks.

The demo has achieved TRL 6, demonstrating electric trucking in a relevant environment with data feeds and monitoring in place. With these trucks in operation and yielding usable insights, the project may reach TRL 7 within the TULIPS timeframe (M48) if KSM is adapted to reflect the current fleet size. Early driver feedback indicates positive driving experiences and improved handling with the electric trucks. However, technical limitations, particularly regarding range and charging issues in colder weather, might present challenges, impacting load capacity and requiring dependence on external charging facilities. The limited power supply for charging also hampers scalability, as the trucks require access to sufficient charging infrastructure to operate reliably.

Key lessons learned are the slower-than-anticipated adoption rate for electric trucking and logistical constraints related to infrastructure. While two trucks are operational and demonstrating viable electric freight solutions, fully achieving the demo’s goals will rely on addressing charging and range limitations to further electrify heavy-duty trucking at Schiphol. No immediate next steps are planned beyond the continued operation and data analysis of the two electric trucks in service, reinforcing TULIPS’ commitment to advancing emissions reductions in airport logistics.

Demo #3 - Road traffic and transport Systems (T1.5)

EVIDENCE LEVEL

Reporting of deployability of Demo #3 (T1.5) is not possible at this time due to constraints on deployment requiring action by TULIPS. At this stage, this demo is not deployable.

USE CASE

As per the Grant Agreement, this demo is being led by TUD with the participation of EGIS and SNBV. The Demo aims to establish a traffic management system, where based on i.a. identification

of bottlenecks and hotspots, increased vehicle emissions, current and feasible traffic management measures and interventions, optimised control strategies and implementation of operational applications will be evaluated in a real-life demonstration at the lighthouse airport

This demo work includes:

- Identify local airport and regional road traffic bottlenecks and hotspots of increased vehicle emissions (SNBV)
- Identify current and feasible traffic management measures and interventions, and propose a set of measures and interventions that can be applied to ensure optimal traffic operations, including an initial estimation of their potential benefit (EGIS, SNBV)

- Perform simulation-based analysis of the proposed solutions for feasibility and effectiveness to reduce emission (TUD)
- Design of strategic control strategies and implementation in SNBV dashboard and road authority systems (SNBV, EGIS)
- Real-life demonstration of the approach for validation and, if required, calibration (SNBV, TUD).
- Evaluation of real-life demonstration (TUD).

Demo #4 - International green travel (T1.6)

EVIDENCE LEVEL

Reporting of deployability of Demo #4 (T1.6) is not possible at this time due to constraints on deployment requiring action by TULIPS. A dedicated workshop was not held with the demo team. At this stage, this demo is not deployable.

USE CASE

As per the Grant Agreement, this demo is being led by SINTEF with the participation of TNO, TUD, NLR, SNBV, AVINOR, and SAGAT. Door-to-door international green travel is to be demonstrated on an integrated digital TRIP platform, based on a decentralised, distributed solution integrating several stakeholders by a federated architecture, supporting passengers in planning and execution of a door-to-door journey (related to T1.4 and the MaaS app).

Specifically, this demo work is to include:

- Demonstrate an integrated digital TRIP platform based on a de-centralized, distributed solution integrating several stakeholders through a federated architecture to support passengers in planning and execution of a door-to-door journey (SINTEF)
- Obtain travellers' needs and desires for and experiences with using the TRIP platform (TUD), evaluate travellers' decisions (TUD) and enhance/refine the TRIP platform (SINTEF).
- Implement journey execution real-time information and demand forecasting, both fed from operational systems (TNO)
- Integrate into the platform certain travel modes services, public and private transport and Micro-mobility (SNBV,NLR)

- Specify data and system requirements (interfacing to T1.1 and T1.2) (TUD)
- Development of use case specific prototypes: Federated service, passenger frontend (TUD)
- Development of federated optimization algorithm for proposing passenger journeys that optimise travel with respect to given personalised, multi-objective criteria (SINTEF)
- Investigate feasibility of additional options: i) Tracking the passenger to vehicle assignment throughout the whole journey (This would enable the mobility service providers to decide about waiting at modal interconnections) ii) Booking trips and iii) Apply the same architecture for the multimodal planning and execution for transport of goods.

WP1 DEPLOYABILITY STATUS SUMMARY

Lead Partner	ID	Task	GA Description	POC	Deployability	Help Needed	Current TRL	Next Steps	Expectations
TNO	1	T1.4a	Enabling travellers modal shift with support from MaaS solutions (M3-M48): Multi-modal hub	TNO	Prototyping	No	TRL 3-4	First measurements (Jun 2025)	TRL 6-7
TNO	1	T1.4b	Enabling travellers modal shift with support from MaaS solutions (M3-M48): MaaS App	TNO/ MOBC	Prototyping	Yes*	TRL 3-4	Launch and data gathering	TRL 6-7
TNO	2	T1.3	Logistic solutions: green and connected trucking (M3-M39)	TNO	Demonstrating (2 out of 3 trucks)	No	TRL 6	Conclusion of measurements (M48)	TRL 7
TNO	3	T1.5	Road traffic and transport Systems (M1-M48)	TUD	On Hold**	Yes			
SINTEF	4	T1.6	International green travel (M3-M48)	SINTEF	On Hold**	Yes			

** MOBC would like help in acquiring users for passenger app from SNBV and from TUD with the passenger survey*
*** Constraints on deployment of demo requiring action, not included in Deployability report at the moment*

Figure 4: WP1 deployability status summary

WP2 - Energy supply future aircraft

As per the Grant Agreement, the objectives of this work package are to:

- Demonstrate an unattended charging module for large scale applications
- Demonstrate future-proof, modular charging module for larger (hybrid)-electric aircraft
- Showcase liquid hydrogen (LH2) fuelling facilities for LH2-powered aircraft.

In reality, WP2 is focusing on showing that LH2-fueling and charging can be done safely so that hopefully the regulations will follow by allowing unattended charging, which can then be done on a large scale. Hence, WP2 is working towards building a strong facilitating role for airports by lifting barriers in charging infrastructure and hydrogen fuelling of aircraft by building knowledge and operational experience, as well as challenging the current regulation of aviation. Alongside this, the necessary safety and operational procedures will be developed.

Demo #5 - Unattended charging demo development (T2.2)

EVIDENCE LEVEL

Reporting of deployability of Demo #5 (T2.2) is based on participation in an online workshop with the demo team and leads (June 2024) and subsequent update via questions sent to the demo team (September 2024). The Deep Dive Demo progress presentation was also used to add additional data and context (April 2024). Additionally, news articles by TULIPS were consulted.

USE CASE

The Demo took place at Rotterdam The Hague airport on September 17th and is being led by PIPISTREL with participation of Royal NLR (NLR) and Rotterdam the Hague Airport (RTHA).

This Demo wants to show how one can safely monitor the charging with the help of smart software, data sharing and camera images and prove that safely charging an electric aircraft without physical supervision is possible.

This demo work includes:

- Obtaining of EASA approved test plan (PIPISTREL)
- Provision of electric research aircraft (NLR, for OSL validation: AVINOR)
- Modification of BMS (Battery Management System) and commercial charger system (PIPISTREL)
- Implementation of innovative remote surveillance devices (PIPISTREL)
- Integration between charging equipment and airport management system (PIPISTREL, supported by AVINOR)

- Trialling of several contingencies and redundancy concepts with aircraft and charging system OEMs, airport authorities, ATM, first responders and other airport parties (PIPISTREL)

LEARNINGS & INSIGHTS

The deployability assessment for Demo #5 on unattended electric aircraft charging at Rotterdam The Hague Airport demonstrates progress toward safer, efficient, and remote aircraft charging, managed through smart software, data sharing, and camera surveillance. The demo tested remote anomaly detection and emergency response capabilities, a key development for EASA and other aviation regulatory bodies aiming to standardise unattended electric charging. The demo faced some initial delays in June due to technical installation issues with the Bosch smart camera system but was deployed successfully by September, reaching Technology Readiness Level (TRL) 7.

Key test scenarios focused on detecting fire/smoke, monitoring power interruptions, identifying battery safety issues, and sharing data via open networks with the airport authority and emergency services. The demo team achieved success with each contingency test, confirming the operational effectiveness of remote surveillance and anomaly detection. With the demo day on September 17, 2024, the solution demonstrated reliable monitoring capabilities and fast response, validating that unattended charging with smart surveillance can function safely in a live airport environment. Though achieving TRL 7, further progression toward TRL 8-9 would require a finalised, customer-ready product design, which is not anticipated within the TULIPS timeline.

Challenges encountered included inconsistent Wi-Fi connections due to metal-coated windows, the use of outdated terminology in regulatory language (fueling terms instead of charging), and system sensitivity to environmental factors like cloud reflections, which triggered false smoke alarms. These insights reveal areas for refinement in remote monitoring reliability and airport infrastructure compatibility, supporting the demo's value proposition for unattended charging to reduce personnel hours and improve safety response.

Looking ahead, the successful deployment at Rotterdam The Hague Airport provides a proof-of-concept to be analysed for scalability to other airports. This demo offers valuable regulatory and operational insights, setting the foundation for broader implementation and contributing to the regulatory roadmap for unattended charging in the aviation sector.

Demo #6 - Modular charging system demo development (T2.3)

EVIDENCE LEVEL

Reporting of deployability of Demo #6 (T2.3) is based on participation in an online workshop with the demo team and leads (June 2024) and subsequent update via questions sent to the demo team (September 2024). The Deep Dive Demo progress presentation was also used to add additional data and context (April 2024).

USE CASE

The Demo is led by PIPISTREL with the participation of SIN-EN, AVINOR and SNBV and is due to take place at Rotterdam The Hague Airport and the Oslo Airport, where a thermal runaway incident will take place to fire test with all batteries and investigate first responder reaction.

The first Demo was scheduled for July/August 2024, a second demo to November/December and the fire test for February/March 2025.

This demo work includes:

- Initial mapping of requirements of battery technology, safety requirements (T2.1), airport infrastructure and suitable charger topologies for modular charging infrastructure (SIN-EN, support from SNBV, RTHA)
- Conceptual design of universal charging infrastructure to permit airports to charge electric aircraft that will feature different battery voltage requirements, i.e., 270 to 1500 VDC or above (SIN-EN, support from RTHA).
- Design and fabrication of a mobile battery bank (hundreds of kWh) using aerospace certified propulsion batteries and charger modifications to simulate representative future electric aircraft and converters which can work with charging infrastructure. (PIPISTREL)

LEARNINGS & INSIGHTS

Demo #6 addresses the need for adaptable, universal charging infrastructure across varying aircraft voltage requirements. This demo includes key safety tests, such as thermal runaway incidents, to evaluate first responder readiness. With a design aimed at significant infrastructure cost reductions (over 50%) compared to traditional EV charging, the demo seeks to enhance the feasibility of electric aviation through a modular, voltage-agnostic system.

The current status is prototyping at Technology Readiness Level (TRL) 3, with a progression to TRL 4 anticipated after initial qualification tests are complete. Planned tests include verifying battery pack parameters, integrating modular junction boxes, and completing a series of qualification and scale-up tests. The team faced design challenges, including space constraints that have prompted modifications to the junction box design, availability of critical electronic components, and coordination with airport stakeholders to finalise the testing environment. To support progression, the consortium may need to aid in navigating these dependencies to ensure readiness for TRL 6-7 within TULIPS' timeline.

Risks include fire hazards, potential procurement delays, and transportation issues related to the modular system's classification as dangerous goods. The team has identified specific components for early procurement and is conducting reliability tests to mitigate these risks. The transportation and modular system design challenges highlighted that additional space and safety considerations are necessary, and that battery configurations within modules may need to be simplified for feasible deployment.

Looking forward, the demo's success relies on completing qualification tests (planned for Q2 2024) and fabricating the full system by Q3 2024, with demonstration scheduled for Q4 2024. These insights are crucial for designing flexible, cost-effective charging infrastructure that accommodates diverse electric aircraft, addressing a critical barrier to scaling sustainable aviation.

Demo #7 - Airport-facilitated hydrogen flight demo development (T2.4)

EVIDENCE LEVEL

Reporting of deployability of Demo #7 (T2.4) is based on participation in an online workshop with the demo team and leads (June 2024) and subsequent update via questions sent to the demo team (September 2024). The Deep Dive Demo progress presentation was also used to add additional data and context (April 2024). Additionally, a news article by TULIPS was consulted (April 2024).

USE CASE

The Demo is led by NLR with the participation of SNBV, AVINOR, SIN-EN and PIPISTREL and is due to take place at Rotterdam The Hague Airport and another lighthouse airport (TBD with AVINOR).

The liquid hydrogen (LH2) storage facility construction work is due to start in the summer 2024, the test and validation of a large part of the demo is planned for October 2024 and the execution should be complete in Q4 2024.

This demo work includes:

- Mapping of technical requirements for operation of hydrogen powered aircraft, H2 transport and handling, and hydrogen fuelling infrastructure on active airports, in liaison with airport stakeholders (NLR, with support from SNBV and PIPISTREL).
- Model based validation of the refueling process, and evaluation of liquid H2 fuelling infrastructure (different from gaseous hydrogen in WP4), procedures and regulation towards future large scale H2 needs, with focus tuned to GSE and aviation (SIN-EN, with support from AVINOR)
- Composing necessary test plan documents for performing the demo (NLR with support from PIPISTREL)
- Shake-down: test demonstration of fuelling infrastructure at NLR Marknesse (NLR)
- Evaluation of liquid hydrogen refuelling and tank swap system of hydrogen tanks (NLR)Initial mapping of requirements of battery technology, safety requirements (T2.1), airport infrastructure and suitable charger topologies for modular charging infrastructure (SIN-EN, support from SNBV, AVINOR)
- Analysis & evaluation of obtained data and lessons learned (NLR)

LEARNINGS & INSIGHTS

Demo #7 aims to establish a proof-of-concept ecosystem for LH2-fueled flights. It includes constructing an LH2 storage facility, testing LH2 handling procedures, and ultimately demonstrating a flight with an LH2-powered drone. Initial work includes partnerships with AIRPRODUCTS for LH2 supply, a designated transport route, and a storage facility provided by CRYOWORLD. With construction underway and permits in place, the project now awaits the development of a certified airworthy drone by NLR to enable deployment.

As of the latest updates, the project remained in prototyping at TRL 3, with proof-of-concept complete but contingent on drone readiness to demonstrate. The demonstration of the LH2 fueling process at an active airport is expected to validate the infrastructure's viability and safety for broader application, aiming to achieve up to TRL 7 by providing LH2-fueled flight in a real-world setting. The demo is expected to advance regulatory standards and develop best practices for LH2 handling and storage at airports, alongside comprehensive safety training for personnel and collaboration with regulatory bodies. Completion and deployment of the LH2 drone could enable the demonstration by Q1 2025.

Key risks include limited LH2 supply due to low demand, dependence on regulatory permits, readiness of the LH2 drone, and safety concerns regarding handling and storage. Mitigations include early inclusion of LH2 experts, detailed safety studies, and conservative risk assessments with additional safety factors. Insights from the demo have underscored the complexity of regulatory requirements, unexpected costs of LH2-specific hardware, and challenges in small-volume LH2 supply chains. The successful deployment of this demo will pave the way for future large-scale adoption of LH2 fuel in aviation, contributing essential knowledge and experience to support a transition toward sustainable, zero-emission air travel.

WP2 DEPLOYABILITY STATUS SUMMARY

Lead Partner	ID	Task	GA Description	POC	Deployability	Help Needed	Current TRL	Next Steps	Expectations
PIPISTREL	5	T2.2	Unattended Charging demo development (M12-M24)	PIPISTREL	Demonstrating	No	TRL 7	Demo (17 Sep) completed	TRL 7
PIPISTREL	6	T2.3	Modular charging system demo development (M12-M30)	PIPISTREL	Prototyping	Yes - permit extension	TRL 3	Demo (Q4 2024)	TRL 6-7
NLR	7	T2.4	Airport-facilitated hydrogen flight demo development (M10-M24)	NLR	Prototyping	No	TRL 4	Demo (Q1 2025)*	TRL 6-7

** if LH2 Drone (NLR supply) is ready*

Figure 5: WP2 deployability status summary

WP3 - Smart airport energy hub

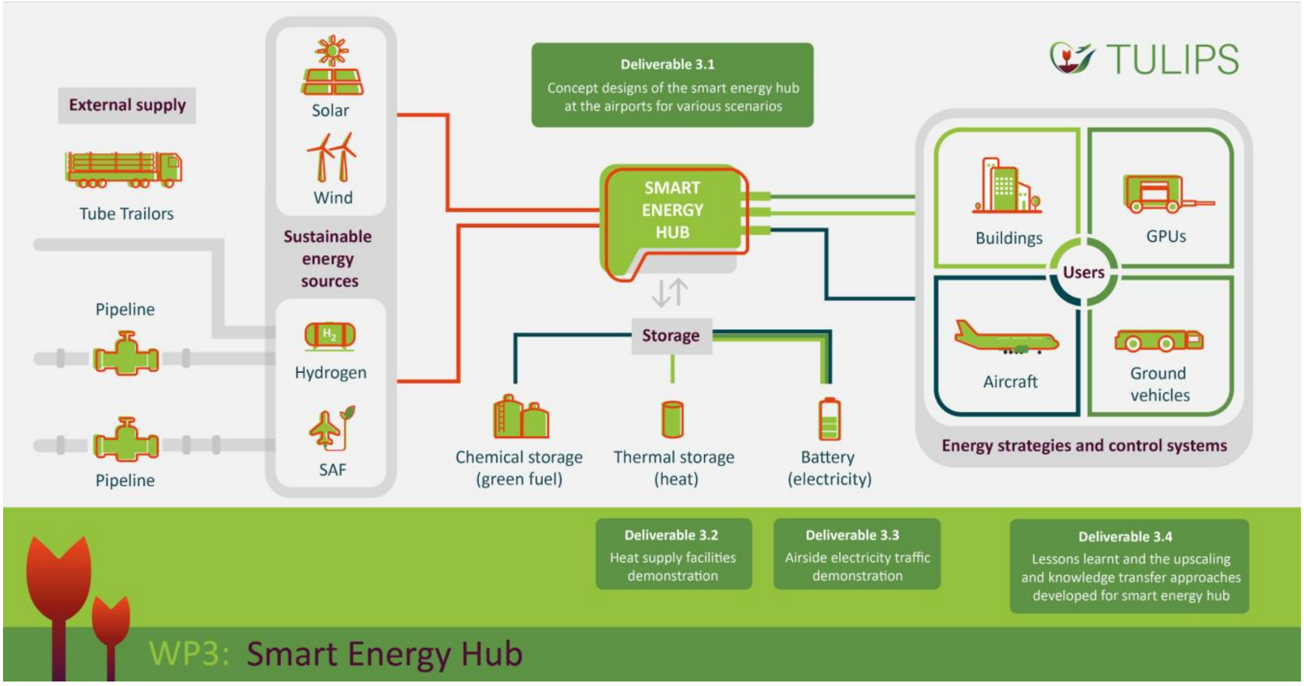

Figure 6: WP3 Summary

Relevant findings from WP2 are to be used by WP3.

The main objectives of this work package are to:

- Design a smart resilient Energy System at airports to enable their transition to a zero-emission situation by 2030. The systems should integrate electricity, heat, and hydrogen;
- Develop integration, monitoring & control system concepts that will manage a higher and more frequent energy supply and demand fluctuations; and
- Set up a methodology to iteratively improve and implement the energy strategy

WP3 focus is on the overall energy system and its transformation towards a Smart Energy Hub. As such, first a comprehensive overall system analysis is to be done that includes all relevant infrastructure and operational data from the airports and will feed into the novel design of the future Smart Energy Hub for several scenarios. The Smart Energy Hub design will also include monitoring and control systems needed to enable energy- and cost-efficient Smart Energy Hub operation.

The ultimate goals for the Mini SMART Grid Schiphol Northwest are:

- Phasing out of natural gas (~250000 m3)
- CO_2 reduction ~450 tons/year.
- Base load power reduction of 10 to 15%
- Increase in SMART charging units (# tbd)
- Battery storage capacity increase tbd in MW
- Solar Energy (PV) 1,2MWp in crease
- Potentially, provide proof of concept of load grid balancing capacity; continue to develop skills and knowledge and fully realise the vision of a SMART Energy Hub.

This work includes two demonstrations:

- Demo #8 (T3.3): Airside electricity 'traffic' demonstration, showing solar powered, modular, intelligent, direct DC charging infrastructure for electric vehicles; and
- Demo #9 (T3.4): Heat supply facilities demonstration, demonstrating successful integrated heat management systems.

Demo #8 - Airside electricity 'traffic' demonstration (T3.3)

EVIDENCE LEVEL

Reporting of deployability of Demo #8 (T3.3) is based on participation in an online workshop with the demo team and leads (May 2024) and subsequent update via questions sent to the demo team (September 2024). The Deep Dive Demo progress presentation was also used to add additional data and context (April 2024). Additionally, news articles by TULIPS were consulted (June 2024).

USE CASE

The Demo was planned to be led by SNBV with the participation of TNO, TUD and HERMES. However, TUD and HERMES do not have a direct involvement in the demonstration. Instead, SNBV is executing the demo and TNO is supporting it with monitoring.

As per the Grant Agreement, the demo work was planned to include:

- Defining the interaction and overlap with the planned project at Schiphol (upgrade of the Terminal E – ROEV project) that will be supporting this demonstration. (SNBV, TNO, TUD)
- Full integration of the Terminal E facilities with the available photovoltaic (PV) systems, charging infrastructure and novel energy storage systems and apply the integral control system developed in T3.2, incl. novel solar powered, direct DC charging infrastructure for electric vehicles (EV) (link with WP4) (SNBV)
- Establishing the connection of PV self-produced power to the main terminal building of Larnaca Airport, optimising renewable energy use though modelling power storage to achieve peak shaving and redistribution of power as per needs. Utilising smart building controlling know-how developed in T3.2 (HERMES)
- Implementation of an energy management system to reduce the grid impact of the charging infrastructure, floating production units (FPU)/electronic GPU (e-GPU) and provide peak shaving and congestion management at Schiphol and Larnaca airports (SNBV, HERMES)
- Supporting the demonstration activities at Schiphol (TNO, TUD)
- Performing the measurement campaigns at Schiphol and Larnaca airport and reporting of the results (SNBV, HERMES)

However, the final demo planned tasks are:

- Implementation of an energy management system to reduce the grid impact of the charging infrastructure, floating production units (FPU)/electronic GPU (e-GPU) and provide peak shaving and congestion management at Schiphol (SNBV)
- Supporting the demonstration activities at Schiphol (TNO)
- Performing the measurement campaigns at Schiphol and reporting of the results (SNBV)

The demonstration was initially planned for Schiphol Airport Terminal E but instead is taking place at the AB Terminal.

LEARNINGS & INSIGHTS

Demo #8 showcases an iron-flow battery and an energy management system to support sustainable, grid-efficient power for ground operations. Initially planned for

Terminal E, the demo is instead being conducted at the AB Terminal, which has limited grid capacity and thus higher unmet need. This solution aims to replace diesel ground power units (GPUs) with e-GPUs and floating production units (FPUs), enabling renewable power integration and addressing grid congestion.

With a successful demonstration conducted on July 25, 2024, the project has achieved TRL 7. Testing continues on the AB platform, where the energy management system supports congestion management and peak shaving, increasing renewable power utilisation. However, the team requires a permit extension to complete the integration of photovoltaic (PV) systems, essential for scaling this solution across airport operations.

Key risks include delays in permit approval, which could affect PV system integration, and scalability limitations due to prototype constraints. In mitigation, the team is coordinating with permitting authorities, KES, and KLM Ground Service to align the demo with operational needs.

Insights reveal that full-scale deployment will need more equipment (e-GPUs) and trained personnel, underscoring the operational complexities of transitioning to sustainable energy solutions. Upon scaling, this demo could reduce CO_2 emissions by ~400 tons, reinforcing Schiphol's goal to be emission-free by 2030 and demonstrating the viability of iron-flow batteries as a sustainable power solution in aviation environments.

Demo #9 - Heat supply facilities demonstration (T3.4)

EVIDENCE LEVEL

Reporting of deployability of Demo #9 (T3.4) is based on participation in an online workshop with the demo team and leads (May 2024) and subsequent update via questions sent to the demo team (September 2024). The Deep Dive Demo progress presentation was also used to add additional data and context (April 2024).

USE CASE

As per the Grant Agreement, the Demo work was to be led by SNBV with the participation of TNO, SAGAT and POLITO. However, the work is led by SNBV with the participation of TNO and is taking place at Schiphol.

The Hilton Hotel Infrastructure had been planned as the target building to influence. However, the Fire Brigade Building has been chosen instead because it has a 24 hours per day operation and uses the showers multiple times per day. This technical solution fits very well with the needed amount of hot water.

Note: another demo is subsequently being developed at Torino airport, also at the local fire brigade.

As per the Grant Agreement, this demo work was planned to include:

- Defining detailed performance parameters of the demand and supply side at Schiphol airport (SNBV, TNO)
- Translate predicting models and control algorithms applicable for this demonstration from T3.1 and T3.2 (TNO,SNBV)[3]
- Fully integrate heat storage systems with a storage time of several days into existing Hilton hotel infrastructure (SNBV). The Fire Brigade Building of Platform AB has been chosen instead because it has a 24 hours per day operation and uses the showers multiple times per day. This technical solution fits very well with the needed amount of hot water.
- Implement specific energy management system that will focus on minimising the demand peaks in hot water use (SNBV)
- Demonstrate fuel cell-based co-generation system for use as heat energy source at Torino airport (SAGAT, POLITO)[3]
- Support demonstration activities at Schiphol (TNO)
- Perform measurement campaigns at Schiphol and Torino airports and report the results (SNBV, SAGAT)[4]

LEARNINGS & INSIGHTS

The demo team learned that it is important to better account for the bureaucratic processes that shall be addressed at the airport for such a project and also for contractor delays.

[3] These item is not considered
[4] Focus is on Schiphol airport, SAGAT is not participating in this task.

WP3 DEPLOYABILITY STATUS SUMMARY

Lead Partner	ID	Task	GA Description	POC	Deployability	Help Needed	Current TRL	Next Steps	Expectations
SNBV	8	T3.3	Airside electricity 'traffic' demonstration (M10-M44)	SNBV	Demonstrated	No	TRL 7	Exploitation	TRL 7 or above
SNBV	9	T3.4	Heat supply facilities demonstration (M10-M44)	SNBV	Demonstrating	No	TRL 5	First experiments (end 2024)	TRL 6-7

Figure 7: WP3 deployability status summary

WP4 - Zero-emissions airside operations

WP3 Airside electricity traffic for EV Demo 3.3 links with WP4.

The objectives of this work package are to:

- Develop and demonstrate a GPU (Demo 4.1) and a tow tractor (Demo 4.2) which uses hydrogen powered fuel cells.
- Demonstrate H2-GPU at the lighthouse and selected fellow airports and demonstrate the H2- tow tractor at lighthouse
- Establish an economically and technically sound development plan for the evolution of the hydrogen supply chain to the airport, focusing on upscale of production and transmission/transport for future investments

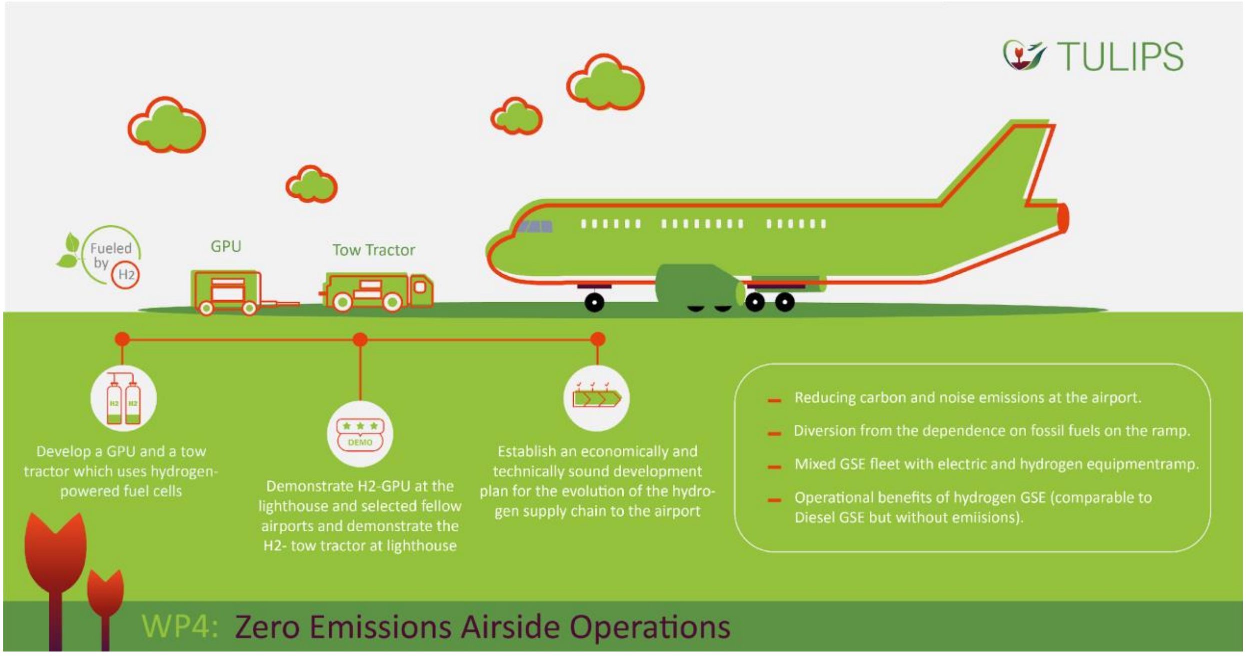

Figure 8: WP4 deployability status summary

As per the Grant Agreement, WP4 intends to develop demonstrated prototypes for hydrogen fuel cell-powered ground support equipment (GSE). First, a theoretical background study should be developed, creating a baseline for the demonstrations. This process and baseline assessment is the first step in developing the concept for demonstrations and developing the prototypes. In addition, a study was conducted to investigate the best source of zero-emission energy for different types of GSE operating under different circumstances and at different airports.

Based on these studies and concepts, prototypes for the demo are to be developed: H2-GPU (Demo T4.3.1) and H2 Tow tractor (Demo T4.3.2) to be demonstrated at Schiphol Airport to gather data for further improvements of the prototypes and the operating environment.

Importantly, safety testing and certification shall be carried out as part of this Work Package, and NOBIAN should supply certified green H2, with guarantees of origin generated from CertifHy, the EU certification institute for hydrogen, initiated by Fuel Cell and Hydrogen Joint Undertaking, during and after testing,

Further scaling and exploitation in fellow airports will be also addressed by the work package, including identifying robust and rational H2 supply chains and modelling mathematical models and scenarios for Schiphol and fellow airport, which will consider modes of transport such as gas transport in pipelines, barges, gas or liquid transport on trucks. The last deliverable of the work package will derive lessons learnt and other guidance material for exploitation in other European airports.

In fact, WP4 lead has confirmed the work is centered around the development, demonstration, and transferability of hydrogen-powered Ground Support Equipment (GSE), specifically a Ground Power Unit (GPU) and a tow tractor. These efforts aim to advance the integration of hydrogen fuel cells in airport operations, contributing to the decarbonization of the aviation industry. The evaluation revolves around the utilisation of hydrogen (H2) fuel cell (FC)-battery hybrid systems for this equipment. Integrating hydrogen as an energy carrier in airside operations introduces challenges, including safe operation and the development of new logistics for hydrogen-powered GSE at airports. Additionally, the supply of hydrogen to the airport is another challenge that must be addressed.

The planning for the demonstration and associated background studies have been completed and are detailed in D4.1 for the hGPU and D4.9 for the hTowtractor. These documents encompass the demonstration plan and operational concepts for both prototypes, as well as extensive information on airside operations, ground support equipment, the use of hydrogen as a fuel, and additional relevant studies. Furthermore, they outline the impact assessment, demonstration requirements, methodology, demonstration plan, and validation concept.

The objective of developing Hydrogen Supply Chain Plans is to create a comprehensive and economically viable strategy for scaling the hydrogen supply chain to airports, emphasising production, transmission, and future investments. The outcome of this initiative will be a strategic roadmap that outlines the necessary hydrogen infrastructure to support the widespread adoption of hydrogen-powered ground support equipment (GSE), ensuring the long-term sustainability and economic feasibility of hydrogen in airport operations.

Further scaling and exploitation in fellow airports will be also addressed by the work package in a dedicated task on transferability and guidance for fellow airports and beyond.

Demo #10 - Hydrogen GPU demonstration (T4.3.1)

EVIDENCE LEVEL

Reporting of deployability of Demo #10 (T4.3.1) is based on participation in an online workshop with the demo team and leads (June 2024) and subsequent update via questions sent to the demo team (September 2024). The Deep Dive Demo progress presentation was also used to add additional data and context (April 2024). Additionally, news articles by TULIPS were consulted (July, August 2024).

USE CASE

As per the Grant Agreement, Demos were to be led by KES with the participation of SNBV, (ZEPP/BALLARD), TNO, FHG, SINTEF, NLR, SAGAT, POLITO, and AVINOR and the first deployment was planned to take place at Schiphol. Specifically, ZEPP was the lead in developing the prototype for the demonstration.

In reality, the hGPU demonstration is being led by KES with primary contributions from SNBV, ZEPP, SINTEF, FHG, Torino airport, Larnaca airport. Specifically, ZEPP together with the GSE manufacturer Dynell developed and provided the hGPU for demonstration.

Activities performed to develop a hydrogen fuel cell powered GPU based on a battery GPU base will be key design and exploitation aspects such as:

- Operational profile for the H-GPU service for a typical day
- Develop hybrid power design, form factor/space limitations, integration strategy, hybrid hydrogen + battery power solution design choices, general arrangement of components in the available spaces, hydrogen system sizing
- Integration design
- Factory and commissioning testing activities performed.
- Additionally, the demo preparation work for both demos was planned to include:
- Set up test area on apron of lighthouse airport (KES, SNBV, FHG support)
- Site preparation and installation of H2-refuelling station, training of personnel (KES)
- Training of personnel for operation of GSE and fuelling and charging operations and Tier 2 service (KES, BALLARD,ZEPP)

- Obtain agreement/availability of necessary stakeholders, typically the ramp handlers (KES, SNBV)
- Show necessary compliance to applicable regulations to obtain all the necessary permits for demonstration (KES, SNBV)
- Use prototype in actual operation and do a Verification and Validation of concept: use during 3 months per wave, to monitor behaviour of equipment and operators. (KES, SNBV)
- Provide demo support, including monitoring and data collection, technical troubleshooting (SINTEF, SIN-EN, FHG, SNBV, NLR, BALLARD, ZEPP).
- Transferred knowledge of current use of eGSE and demonstrated h-GSE at Amsterdam Airport Schiphol, combined with action plan to demonstrate the h-GPU at fellow airports (KES, FHG, SNBV)
- Demonstration of the h-GPU at fellow airports (SAGAT, supported by all WP partners)[5]

LEARNINGS & INSIGHTS

Demo #10 showcases another sustainable alternative to diesel GPUs at Schiphol Airport. The hGPU uses a hybrid hydrogen and battery design, addressing challenges of airside traffic congestion and reliance on polluting energy sources. The project includes designing the hGPU, setting up refuelling infrastructure, training personnel, and executing on-site demos, with additional demonstrations planned at Torino and Larnaca airports.

The demo at Schiphol, completed in June 2024, reached TRL 7 by demonstrating the hGPU's operational feasibility under real airport conditions. The hGPU met key success metrics such as performing a full aircraft turnaround and operating without refuelling interruptions, with further evaluation on refuelling efficiency and emissions reductions ongoing. Through close collaboration with the permit office, extensive training for ground personnel, and a telemetry system to mitigate tethering issues, the team addressed risks related to safety, regulatory compliance, and technical challenges.

Initial insights revealed gaps in hydrogen knowledge among airport personnel, limited supplier availability, and the need for clear standards around hydrogen use in aviation. These learnings emphasise the need for robust training and streamlined permitting processes. Successful deployment at Schiphol paves the way for further tests at Torino

[5] Demonstrations are being developed in Torino and Larnaca Airports.

and Larnaca, with the potential to inform hydrogen logistics planning and support hydrogen adoption as a clean fuel across European airports.

Demo #11 - Hydrogen tow tractor demonstration (T4.3.2)

EVIDENCE LEVEL

Reporting of deployability of Demo #11 (T4.3.2) was not possible due to constraints on deployment requiring action by TULIPS. A dedicated workshop for this demo specifically was not held with the demo team. However, the WP lead has provided an update in October 2024 which was used on the Deployability section (detailed APPENDIX B) and a summary is presented below.

USE CASE

Grant agreement plans for Demo #11 are described in the “Use Case” section of Demo #10 (T4.3.1).

LEARNINGS & INSIGHTS

Building on insights from the hydrogen GPU demo (Demo #10), this demo aims to validate the hTowtractor’s ability to perform maintenance tows, operate up to four hours without refuelling, and achieve zero emissions in line with Schiphol’s goal of becoming emission-free by 2030.

As of October 2024, the project is in the prototyping phase. Following a timeline adjustment in July 2024, TLD and BALLARD have resumed development and expect to deliver the prototype to Schiphol by May 2025, with demonstrations scheduled to begin in the summer 2025. Risks include potential delays in securing the necessary permits and ensuring operational readiness among ground support teams. To mitigate these, the team is focusing on close coordination with permitting offices and engaging stakeholders early for training and operational planning. Next steps involve finalising prototype development and preparing the demo environment at Schiphol, aligning all logistics to support a successful demonstration.

Insights so far underscore the importance of aligning hydrogen knowledge and infrastructure with operational needs at airports, with early-stage collaboration proving essential. The anticipated deployment at Schiphol will provide valuable proof-of-concept data and support scaling hydrogen-powered solutions for broader adoption in airport ground support, contributing to TULIPS' vision for sustainable aviation.

WP4 DEPLOYABILITY STATUS SUMMARY

Lead Partner	ID	Task	GA Description	POC	Deployability	Help Needed	Current TRL	Next Steps	Expectations
FHG	10	T4.3.1	Hydrogen GPU demonstration	FHG	Demonstrated	No	TRL 7	Additional demos*	TRL 7
FHG	11	T4.3.2	Hydrogen tow tractor demonstration	FHG		*NA*	*NA*	*NA*	*NA*

** Additional demos are expected in Sep and Nov at Larnaca and Turin*

Figure 9: WP4 deployability status summary

WP5 - Scaling up SAF market

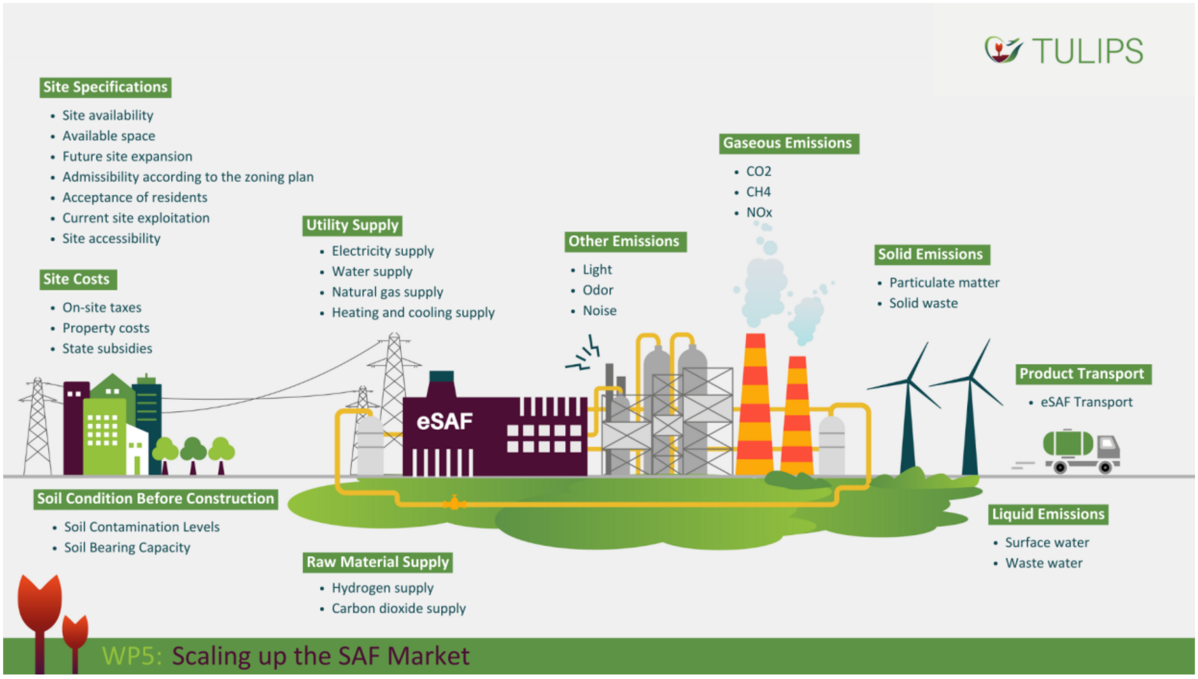

Figure 10: WP5 Summary

As per the Grant Agreement, the main objectives of this work are to:

- Develop and evaluate large scale and continuous SAF supply at Schiphol Airport for the first time, and develop a blueprint for large scale supply to other European airports.

- Develop the Power to Liquids (PtL) pathway for SAF production using inputs from three existing projects.
- Develop an EU Clearing House platform that will support potential EU fuel producers through the early stages of the ASTM approval process, facilitates tests complementary to the US Clearing House and characterises other factors not covered in the ASTM.
- Assess different models to incentivize SAF usage and demonstrate the effect of an SAFpassenger awareness program.
- All four tracks in WP5 (large-scale SAF supply, PtL SAF production, EU Clearing House, SAF support by airports) were planned to be developed simultaneously.
- Within this work package there are two demonstrations:
- Demo #12 (T5.2): Executing large scale SAF supply chain, where continuous SAF supply to an airport was to be executed on this scale for the first time. It was anticipated that the learnings from this demo would inform a blueprint for other similar supply chains.
- Demo #13 (T5.5): Incentivizing SAF as an airport, where support options for airports were to be long-listed, determined for each airport in the consortium and finally a specific option, a passenger awareness campaign was to be demonstrated.

However, for the purposes of this report we will only focus on Demo #12 (T5.2) since Demo #13 is being tackled as an awareness campaign for passengers.

Demo #12 - Executing large-scale SAF supply chain (T5.2)

EVIDENCE LEVEL

Reporting of deployability of Demo #12 (T5.2) is based on answers to a survey form (October 2024) and the Deep Dive Demo progress presentation (April 2024).

USE CASE

As per the Grant Agreement, the Demo work is being led by SKYNRG with the participation of KLM and is taking place at Schiphol Airport.

The work planned includes:

- Prepare and operationalize the supply chain from the SAF production plant “DSL-01” to Schiphol Airport as defined in task 5.1 (developing the supply chain). In this demo, 30,000 mt of neat SAF will be supplied over a 4-month period. This volume is based on DSL-01’s full production capacity, which might not yet be reached during the first months of operation due to start-up challenges (out of scope for this project). Nevertheless, the supply chain will be set up for the entire volume of 30,000 mt. This task will be considered completed when 30,000 mt has been supplied, which will take more than 4 months in case full production capacity is not reached. (SKYNRG, KLM)
- Shipment of neat SAF to the blending terminal in Port of Amsterdam. (SKYNRG, KLM)
- Blending the neat SAF with conventional jet fuel, adding required additives and certification to Jet A-1 specifications(SKYNRG, KLM). Integrating the SAF blend into the conventional jet fuel supply chain to Schiphol Airport. (KLM)
- Handling of the administrative processes required to claim these volumes under the RED-II, including full traceability and sustainability reporting of the supply chain. (SKYNRG, KLM)
- Monitoring and evaluating the effects of the long-term presence of SAF in the pre-airport’s infrastructure, i.e. by monitoring the performance and renewal frequency of filters. (KLM) and by analysis of the import and hydrant filters and filter water separators. (KLM). Evaluating all encountered challenges and issues. (SKYNRG, KLM)

LEARNINGS & INSIGHTS

The deployability of Demo #12, focusing on establishing a large-scale Sustainable Aviation Fuel (SAF) supply chain at Schiphol Airport, represents a significant step toward reducing GHG emissions in aviation. Led by SKYNRG with participation from KLM, this demo aims to set up a supply chain from the SAF production plant "DSL-01" to Schiphol, delivering 30,000 metric tons of SAF over four months. This involves transporting SAF to the Port of Amsterdam for blending with conventional jet fuel, integrating it into Schiphol's fuel infrastructure, and ensuring compliance with sustainability standards under RED-II.

Currently in the planning phase, the project experienced delays as the timeline for SAF production from SKYNRG's DSL-01 plant did not align with TULIPS. KLM is now pursuing alternative SAF sources to keep the project moving. Initial activities for supply chain setup are underway, though full demonstration deployment is now expected by Q2 2026.

Key risks include SAF availability, high sourcing costs, and technical challenges at the blending site. To mitigate these, the team is exploring alternative SAF options and bringing in expertise to navigate infrastructure and regulatory challenges.

Early insights indicate that the SAF market remains in a nascent stage, with limited supply and developing supply chain infrastructure. This demo will provide critical knowledge to scale SAF integration across airports, potentially setting a foundation for the broader adoption of sustainable fuels in aviation.

WP5 DEPLOYABILITY STATUS SUMMARY

Lead Partner	ID	Task	GA Description	POC	Deployability	Help Needed	Current TRL	Next Steps	Expectations
SKYNRG	12	T5.2	Executing large-scale SAF supply chain (M37-M48)	SKYNRG	Planning	*NA*	*NA*	*NA*	*NA*
AVINOR	13	T5.5	Incentivizing SAF as an airport (M1-M48)	AVINOR	*On Hold**	*NA*	*NA*	*NA*	*NA*

** Constraints on deployment of demo requiring action, not included in Deployability report at the moment*

Figure 11: WP5 Deployability status summary

WP6 - Circular airports

Figure 12: WP6 Summary

As per the Grant Agreement, the objectives of this work package are to:

- Map and understand specific waste streams within airports and identify those with greater impact in order to make informed decisions about how to embed circular principles;
- Engage the airport value chain to eliminate waste (passengers, offices), improve consumer behaviour and educate passengers[6]; and
- Increase the re-use of secondary materials in building projects using materials passports, circular design principles and strategic planning.

WP6 focused on transforming airport infrastructure and operations by applying circular economy principles, thus achieving the concept of circular airports. As such, first it was necessary to map and understand incoming resources and waste streams at airports and, with the participation of key stakeholders of the value chain, define a baseline upon which there will be a selection of the most impactful resources to be addressed.

To fully achieve the concept of circular airports, one needs to integrate the entire value chain to move forward with impactful solutions. Thus, two streams to be demonstrated within TULIPS were planned:

[6] In fact, the focus is more correctly to educate passengers and nudge their behaviour.

1. Operational and terminal/passenger waste streams:
    - Organise a series of co-creation sessions with all relevant stakeholders in the value chain including waste processors, logistical experts, retailers, and passengers;[7]
    - Implement the co-created solutions as demonstration projects and tested at Schiphol. Demo projects to be copied at fellow airports to evaluate location, culture and airport use effect (hub vs regional, business vs leisure travel)
2. Infrastructural waste streams: the focus here is to maximise the use of secondary materials through the systematic alignment of demolition and new construction and the development of design guidelines that enable the reuse and deconstruction of components, matching in and out flow of resources at the airport's projects.
    - For this, a digital platform is to developed as an assured information model to make excess assets available inside or even outside the airports environment..
    - The circular buildings principles will be developed, refined and tested at the lighthouse airport and validated at fellow airports.

The concept of Circular Economy was defined on D6.1, serving as the basis for the language used throughout this work package work: the circular economy is a system solution framework. A circular economy decouples economic activity from the consumption of finite resources to stay within planetary boundaries. It's a model that maintains the highest possible value of raw materials, components and products, either by lengthening their lifetime or by looping them back in the system to be reused. Waste is eliminated or used as a resource, both by smart circular design and value retention processes (R strategies). Also, a circular economy aims to prioritise the regeneration of nature so that resources can restore, renew or revitalise their own sources of energy and materials.

[7] In fact, a ‘co-creation’ session was held with Tulips partners and the demo team has done several interviews with operational partners at Schiphol but were never allowed to contact them to do a session despite repeated requests.

Demo #14 - Design waste out of terminal environment taking into account passenger behaviour (T6.2)

EVIDENCE LEVEL

Reporting of deployability of Demo #14 (T6.2) is based on participation in an online workshop with the demo team and leads (June 2024) and subsequent update via questions sent to the demo team (September 2024). The Deep Dive Demo progress presentation was also used to add additional data and context (April 2024).

USE CASE

As per the original Grant Agreement, the work was to include:

- Design waste out of terminal environment taking into account passenger behaviour (M10-M48), Lead: TUD. Participants: SNBV, EME, TUD, AVINOR, HERMES
- Organise a series of co-creation sessions with all relevant stakeholders in the value chain including waste processors, logistical experts, retailers, and passengers (SNBV, TUD)
- Implement the co-created solutions as demonstration projects and tested at Schiphol. Demo projects to be copied at fellow airports to evaluate location, culture and airport use effect (hub vs regional, business vs leisure travel) (SNBV,AVINOR + all task participants)

The demonstration is led by AVINOR as per an amendment to the original Grant Agreement, and comprises of six initiatives:

A. Improve the analysis of information by the waste bins. Instead of visualising the sorting of waste by material, it takes into account the type of product;

B. New solution to collect PET bottles/cans;

C. Implement a reusable coffee cup system to replace disposable cups;

D. Implement a dishwashing service with reusable to-go tableware;

E. Incentivise zero-packaging at the airport;

F. Implement an internal centralised system for waste logistics;

All initiatives were developed using co-creation sessions with relevant stakeholders in the value chain waste processors, logistical experts, retailers, and passengers. The last three co-created solutions are being implemented as demonstration projects and tested at AVINOR. Based on findings from these demonstrators, applicability and adaptability to fellow airports will be evaluated and implemented where possible.

LEARNINGS & INSIGHTS

The deployability of Demo #14, aimed at reducing waste in airport terminals by considering passenger behaviour, involves six key initiatives across the waste management value chain. These initiatives include enhancing waste sorting information, introducing reusable systems for coffee cups and food containers, incentivizing zero-packaging practices, and implementing centralised waste logistics. Led by AVINOR with input from multiple partners, this demo has progressed through co-creation sessions with stakeholders like waste processors, logistical experts, and passengers, resulting in pilot tests now underway at AVINOR's Oslo Airport.

Currently, the demonstration is at TRL 4, with initiatives in prototyping and pilot stages. As these pilots are evaluated and refined, the demo is on track to reach TRL 6 by implementing validated solutions more broadly. However, implementation of three initiatives at Schiphol awaits approval, limiting initial planned testing in those areas.

Key risks include staffing shortages for managing the pilots and potential challenges in employee adaptation to new waste management behaviours. The team is addressing these by engaging employees through training and deploying a feedback system on waste separation. Insights gained so far emphasise the value of co-creation across the waste management chain and tailoring initiatives to various airport environments, with the broader goal of establishing circular waste practices and generating actionable data for future airport waste management innovations.

Demo #15 - Re-use secondary materials through the application of circular building principles (T6.3)

EVIDENCE LEVEL

Reporting of deployability of Demo #15 (T6.3) is based on participation in an online workshop with the demo team and leads (June 2024) and subsequent update via questions sent to the demo team (September 2024) and update via review of v2 draft of this deliverable section (October 2024). The Deep Dive Demo progress presentation was also used to add additional data and context (April 2024).

USE CASE

The demonstration is led by EME with the participation of SNBV, AVINOR, EGIS and HERMES.

As per the Grant Agreement, this demo work shall include:

- Define common elements in the airport building portfolio and collect and manage data, using the tools developed by EME like material passports. (EGIS).
- Propose low-carbon scenarios of reuse by Life Cycle Analysis. (EGIS)
- Define construction standards for optimal specifications for reuse. (SNBV)
- Create a database of functional requirements for all disciplines at the airport, regarding the common elements. (SNBV)
- SNBV and AVINOR will match timing of projects to possible release of common elements from the building portfolio (SNBV, AVINOR). This will be supported by EME.
- Initiative: A Tracking & Tracing module to connect Resources Passports with real-life assets and follow them through value chains will be demonstrated by EME at SNBV and validated at fellow airports. (EME)
- Investigate novel building design approaches to be integrated in current development asset management processes (systems engineering) (SNBV)

Maximise secondary material use in new project designs (using EME platform) measured by the Building Circularity index (EME)

- Test circular building principles in a zero-carbon design project in co-creation with architects and stakeholders (with support of EGIS). This will be validated at fellow airports (HERMES, EGIS – SNBV - AVINOR)
- EGIS and SNBV will establish design guidelines and reference, standardised component design will be provided. This will be validated at fellow airports (EGIS-SNBV, AVINOR).

As part of this work, two initiatives are being conducted to demonstrate the re-use of secondary materials through the application of circular building principles:

1. Re-use Materials (track & trace); and
2. Circular Principles Handbook.

LEARNINGS & INSIGHTS

Demo #15 is prototyping, at TRL 5, being validated at Larnaca, Oslo, and Schiphol airports. QR codes and digital passports are active, though real-time tracking remains a challenge as assets need to be manually updated each time they move. The Circular Principles Handbook, still in development, shall provide a structured checklist for airports to implement circular design practices.

Key insights reveal that manual updating of QR code locations is resource-intensive, and the handbook must be structured flexibly to cater to diverse users across construction stages. Formats under consideration for the handbook include a checklist or a potential app. Next steps involve finalising pilot data and completing the environmental impact assessment to reach TRL 6, with full demonstration expected in 2025.

WP6 DEPLOYABILITY STATUS SUMMARY

Lead Partner	ID	Task	GA Description	POC	Deployability	Current TRL	Help Needed	Next Steps	Expectations
TUD	14	T6.2	Design waste out of terminal environment through passenger behaviour (M10-M48)	TUD	Prototyping	TRL4	Yes*	Perform the final demo of three of six initiatives	TRL 6-7
EME	15	T6.3	Re-use secondary materials through the application of circular building principles (M13-M48)	EME	Demonstrating	TRL5	Yes*	Finalise data collection from pilots	TRL 6-7

** Help needed from Schiphol*

Figure 13: WP6 Deployability status summary

WP7 - Green Air and Land

Figure 14: WP7 Summary

The objectives of this work-package are:

- Gaining insight in airport outdoor air quality by working towards a standardised approach of measuring UFP levels in the airport environment and determining the effect of various UFP mitigation strategies (Airside, local communities);
- Providing clear guidelines towards measuring and mitigating UFP for airport environments.
- Optimise the carbon sequestration potential of Airport land assets, leveraging 1) nature-based solutions (Land Carbon Sequestration Study) and 2) biochar incorporation into soil.

WP7 focuses on improving air quality around and within the vicinity of airports. Two different approaches are taken to tackle this issue from two different perspectives - airside and land.

On airside, the goal is to standardise an approach of measuring UFP levels in the airport environment and determining the effect of various UFP mitigation strategies. On land, carbon sequestration is being explored as a way to optimise the potential of Airport land assets, leveraging nature-based solutions and biochar incorporation into soil.

Demo #16 - Airside UFP Mitigation (T7.1)

EVIDENCE LEVEL

Reporting of deployability of Demo #16 (T7.1) is based on answers to a survey form (September 2024) and the Deep Dive Demo progress presentation (April 2024).

USE CASE

This demonstration is being led by SNBV with the participation of NLR.

The following work is to be conducted:

- Continuous on-site air quality measurements and Modelling mitigation impact of mitigation strategies (NLR)
- Prototyping ionised mist installation (SNBV)
- Creating overview of air quality ‘hyper locally’ at the airport, understanding the geographical, meteorological impact on measurements itself over time (meaning: during various seasons with various conditions) (NLR)
- Mapping the airport processes’ influence on these measurements (SNBV)
- Implementing mitigation strategies to reduce concentrations of air pollutants hyper locally (various airport locations), map its effect on airport local air quality to determine the effectiveness of the strategy (SNBV)

LEARNINGS & INSIGHTS

The deployability of Demo #16, focused on reducing ultra-fine particle (UFP) concentrations airside at Schiphol Airport, involved testing a water droplet installation designed to filter UFP from the air. The demo included continuous air quality measurements to model and evaluate the effectiveness of this mitigation strategy in reducing local UFP concentrations by 20%. Currently at TRL 5, the technology was tested in a relevant environment but did not achieve the desired reduction levels, leading the team to conclude that further progression on the TRL scale is not viable. Key insights indicate that the water droplet method is not sufficiently effective, and a cost-benefit analysis revealed that the costs outweigh the potential benefits. Weather conditions and the variability of UFP emissions further impacted reliability.

Next steps involve continuing air quality measurements to explore alternative mitigation strategies, with support from WP8 as needed for ongoing monitoring. This demo provided valuable insights, highlighting the challenges in UFP mitigation and the need for cost-effective solutions in airport environments.

Demo #17 - Airport Land Carbon Sequestration (T7.2)

EVIDENCE LEVEL

Reporting of deployability of Demo #17 (T7.2) is based on answers to a survey form (September 2024) and the Deep Dive Demo progress presentation (April 2024).

USE CASE

This task is led by EGIS with the participation of SNBV,POLITO, HERMES and SAGAT.

Task 7.2 is divided into two parts:

1. Perform Land Carbon Sequestration Study (EGIS)
2. Perform biochar experimentation at all airports (POLITO)

For the purpose of this report, we will focus on the second part, since it refers to the solution being demonstrated within TULIPS.

The demonstration is led by POLITO. The aim of this demo is to demonstrate the possibility of storing biogenic carbon, and generating Carbon Credits, in the land owned or managed by the airports, via biochar incorporation into soil. Biochar was produced by residual wood, but investigations have been carried out to evaluate the potential recovery of the organic fraction of solid waste collected at the airport and its conversion into biochar. Afterward, the biochar is produced and rolled out in field trials in Schiphol will host the proof of concept, and then shall be extended to Larnaca Airport. The roll-out will be followed by periodic assessment and measurement by an agronomist on crops and soil in each field trial location. Ultimately, POLITO will provide guidance for quantifying the potential benefits resulting from the carbon credits, starting from a revision of existing practices and methodologies.

LEARNINGS & INSIGHTS

This demo involved producing biochar from residual wood and organic waste, which is then incorporated into soil in field trials. Initial tests at Schiphol serve as proof of concept, with plans to extend trials to Larnaca Airport. Periodic assessments by agronomists measure biochar's impact on soil and crop health, guiding the potential for carbon credit quantification.

Currently at TRL 6, the technology has been deployed in relevant environments, with field tests nearing completion. Despite extreme weather conditions that may impact outcomes, preliminary observations suggest potential benefits for soil moisture retention. Finalising field data across airports will support reaching TRL 7, while large-scale deployment is required for higher TRL progression.

Key insights show that biochar application supports the concept of a "circular airport" by turning organic waste into a valuable resource for carbon sequestration. Further testing across multiple years and locations is essential to confirm effectiveness and carbon credit viability.

WP7 DEPLOYABILITY STATUS SUMMARY

Lead Partner	ID	Task	GA Description	POC	Deployability	Help Needed	Current TRL	Next Steps	Expectations
SNBV	16	T7.1	Airside UFP Mitigation (M1-M48)	SNBV	Demonstrated	Yes*	TRL5	Continuous measurements	TRL5
EGIS	17	T7.2	Airport Land Carbon Sequestration (M1-M48) - Biochar	POLITO	Demonstrating	No	TRL6	Monitoring and measuring	TRL6-7

** Deployment of UFP sequestration device is complete showing it is not deployable. Demo requests help with living lab, with continuous measurements around terminal (NLR support) [outside TULIPS scope]*

Figure 15: WP7 Deployability status summary

4. Input on safety and certification

Background

To support the workshops delivered by Beta-i, NLR provided safety and certification information to support:

- Work Package 2: Energy supply of future aircraft (electric and hydrogen refuelling)
- Work Package 3: Smart airport energy hub
- Work Package 4: Zero emissions airside operations
- Work Package 6: Circular airports

In addition, NLR identified safety and certification aspects related to WP1 (Sustainable Intermodal connections), WP5 (Scaling up SAF), and WP7 (Green Air and Land). After evaluation of each of the aforementioned work packages, NLR has assessed WP5 and WP7 (only focusing on Biochar). WP1 was not assessed given that the scope of work being done is outside of the aviation safety and certification domain.

The next section will focus on the safety issues related to the energy supply of future aviation. The section will provide the safety of new energy sources and the current state of certification and regulation requirements.

General issues related to the use of new fuels in aviation

General remarks on hazards of new fuels

The following operational issues should be considered when introducing any form of new energy for use in the aviation sector:

- Regulation / Permits / Certification
- Fire risk (e.g. battery, hydrogen)
- Explosion risk
- Operational disruption
    - Functional limitations (e.g. SAF)
    - Less weather robust
    - Availability

Mitigating measures related to the introduction of new fuels

Mitigation measures that should be considered when introducing new energy forms in aviation:

- System design
- System build quality
- Testing
- Compliance with standards and regulations
- Procedures
- Training

General remarks on regulations for new energy solutions in aviation

The operational issues identified for new energy solutions for aviation:

- Specific aviation regulations are still lacking/lagging for new energy solutions;
- Some aviation-specific guidelines and standards exist.

Take into account:

- International/national regulation and certification
- Standards
- Permits
- Insurance requirements
- Fire risk adaptation (e.g. lithium battery and hydrogen)
- Operational disruption assessment (e.g. power availability, grid stability)
    - Functional limitations
    - Less weather robust

Battery technology in aviation

Lithium battery technology in aviation

Although batteries have a much lower energy density than AVGAS or kerosene, Lithium Ion battery (LIB) technology is seen as a promising solution for the electrification of certain operations in aviation. Electric propulsion has no emissions, especially when combined with green electric energy.

When designing a vehicle using batteries for energy storage then lithium-ion batteries not only have the most capacity and density of any battery in its class, but it is also the lightest in weight when compared to other batteries. In addition, lithium-ion batteries have relatively good high-temperature performance and low self-discharge rate. In addition, most components of lithium-ion batteries can be recycled, making them a good choice for aviation and road transport applications.

Safety aspects of lithium Ion batteries (LIB)

Apart from the advantages of Lithium-Ion batteries, there are specific points that need attention. Lithium batteries do not handle physical abuse well. Also charging, discharging, and storage all need to be done to standards in order to assure battery quality and life span. Especially the Battery Management System that supervises the charging and discharging of the cells in the battery pack is paramount to the safety of the operation.

When lithium-ion battery packs are physically or electrically mishandled internal chemical processes can lead to degradation of the battery health or even to overheating, fire, or explosion. The same goes for incorrect battery design or build quality, bad quality cells, or faulty design and condition of the electrical system connected to the battery system.

The following hazards have been identified when using Lithium Ion batteries as a power source:

- Heating of battery pack (any lithium-ion battery pack will heat up when in use. However, the BMS, battery sensor system, and the electrical system design should be limited to the heating to remain below limits (typically 50 to 55 degrees Celsius).

- Fire (mishandled lithium Ion battery packs can experience internal combustion when internal heating exceeds limits or when physically damaged).
- Toxic gases released when overheating or on fire (hydrogen fluoride, hydrogen chloride, etc.)
- Explosion (mishandled lithium Ion battery packs can explode, under certain conditions, when internal combustion occurs)
- High Voltage / High current (in order to achieve the desired performance at a low weight the designs tend to use high voltage and high current DC. This is a hazard when not shielded.
- Heavyweight (battery packs are physically heavy and as such provide a hazard for maintenance crew during handling)

Contributing factors to these hazards are:

- Excessive heat build-up in the battery
    - External heat
    - Overcharging (wrong BMS, charging failure by the BMS, or no BMS)
- Excessive current, and short circuits (internal battery cell or external)
- Intermitted power in wiring or connections
- Physical / Mechanical damage (bending / puncture, shocks, and vibration)
- Incorrect wiring / incorrect connections
- High cycle
- High electrical loads when the battery is full or nearly empty
- External fire
- Water exposure
- Over-charging
- Misuse of battery (wrong build, wrong use)

In order to minimise the risk of lithium-ion battery use the following mitigation measures have been identified:

- Safety management measures
    - The use of a Hazard Identification and Risk Assessment program (identify potential hazards, classify them, and take mitigating measures)
    - Ensure proper training on safe work practices, hazard identification, emergency preparedness,

- Develop Safe Work Practices (SOPs) for handling and operating lithium batteries and responding to emergencies
- Provide Personal Protective Equipment (PPE)
- Design and built
  - Proper battery design and build: including, correct cell selection (type, build quality, suitability (voltage, current, capacity))
  - Use of correct Battery Management System (BMS) for charging and battery use
  - Safe design of the electric system (correct dimensions, prevention of spikes and sparks, gas vents, fuses, current and heat controls, provision of detection and recording). Apply engineering controls for the installation. (e.g. ventilation, machine guarding)
  - Build as designed including checks and tests
  - Application of safety measures in the design
- Monitoring
  - Design and apply Battery monitoring system and data recording. This data needs to be analyzed regularly and timely use of a life cycle management system should be considered that includes State of Health (SOH) and State of Charge (SOC) monitoring
- Maintenance
  - Good and timely maintenance
- Replacement of faulty parts
- Update and modifications when needed

- Crisis response
  - First responders should be equipped with appropriate protective clothing and breathing protection for Lithium Ion fires. Further, they should possess an adequate level of knowledge and skills through training to deal with the hazards of Lithium Ion battery fires. Specific fire retardants for lithium-ion fire suppression should be used.

The following figure provides a general schematic of what the introduction of lithium-ion battery technology means for aviation applications.

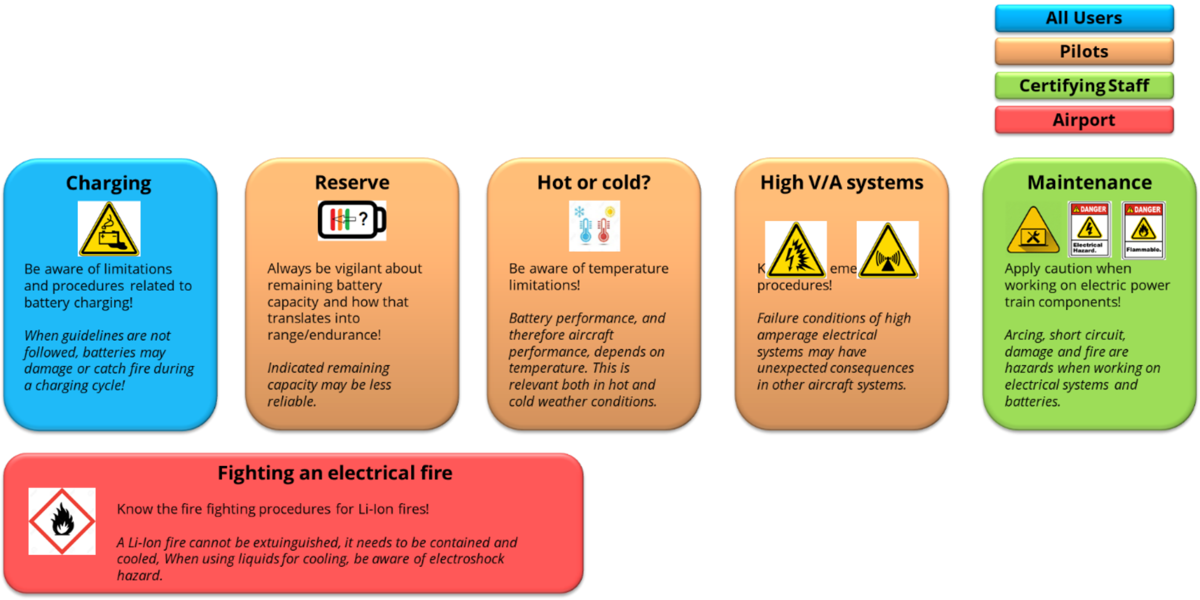

Figure 16: battery-powered electric flight infographic. Source: NLR-CR-2020-286 E-flight safety assessment 2020.

Regulations concerning Li-ion use in aviation

Generally, there are limited regulations available for electric aircraft design, certification, and operation. The following sections provide a general overview based on the current situation.

Lithium – Ion batteries for aircraft propulsion

- EASA – Unmanned Aircraft Systems (UAS) ->Battery
- EASA - Fourth Publication of Proposed Means of Compliance with the Special Condition VTOL – MOC-4 SC-VTOL Issue 1
- EASA CS22 has some guidelines for sailplanes
- EASA CS23 and CS25 no guidelines

Lithium Ion batteries powered ground equipment

- IATA working group Airport Handling Manual – chapter on electric ground equipment

Lithium Ion batteries on board for avionics and passenger functions

- Regulations on the transport of dangerous goods by passengers and crew, including mobility aids, medical equipment, and PEDs, are contained in: ICAO Doc. 9284 Technical Instructions for the Safe Transport of Dangerous Goods by Air in Part 8 PROVISIONS CONCERNING PASSENGERS AND CREW.
- EASA – Air Operations –> p595, 628, 666, 703 – Lithium battery fire mentioned (PEDs?)
- EASA – Light -> Sources:

    - here
    - Here
    - Here
    - Here
- Damaged batteries: EASA Source here
- On board loose lithium battery use: EASA source here

There are however gaps ('loopholes') identified in regulations related to lithium batteries. As mentioned in TULIPS document D2.2 in section 3, these are:

- ADR.OPS.B.010(a)(2) Rescue and firefighting services
- AMC2 ADR.OPS.B.010(d) Rescue and firefighting services
- ADR.OR.D.017 Training and proficiency check programs
- AMC1 ADR.OPS.C.005 Maintenance
- ADR.OR.F.085 Apron management service
- ADR.OPS.D.001 Apron management safety-related activities
- ADR.OPS.D.025 Aircraft stand allocation
- ADR.OPS.D.045 Dissemination of information to organisations operating at the apron
- ADR.OPS.B.055 Fuel quality
- ADR.OPS.D.060 Aircraft refuelling

Iron /Redox flow batteries

For stationary applications, like ground power supply, large amounts of energy are needed. Especially in remote parking positions, it might be advantageous to use battery-based solutions. In these cases, weight and volume restriction are less of a factor. As such less performant, but also less expensive and sensitive battery technology is explored.

The Iron Redox Flow Battery, also known as Iron Salt Battery, stores and releases energy through the electrochemical reaction of iron salt. This type of battery belongs to the class of redox-flow batteries (RFB), which are alternative solutions to Lithium-Ion Batteries (LIB) for stationary applications.

Safety aspects Iron Redox Flow batteries

Iron flow batteries are safer than lithium-ion batteries as they use less challenging chemicals.

The following hazards have been identified for the use of iron flow batteries:

Electric:

- Direct and indirect contact with live parts of the system (danger of electric shock)
- Short-circuit of the terminals
- Leakage currents
- External over-voltage

Chemical:

- Gases
- Liquid leakage

Mitigating measures identified for iron flow batteries use:

- Safety management
  - SMS, Procedures, Culture, Training, Maintenance
- System
  - Electric isolation and system design
- Post-event
  - Chemical isolation and ventilation

Regulations related to Iron Redox Flow batteries

As for regulations, no EASA or other international regulations or guidelines are found. However, national regulations might be applicable.

Hydrogen in aviation

Hydrogen is seen as a performant candidate to replace carbon fuels in the portfolio of sustainable energy sources for aviation.

Hydrogen has unique characteristics. It has high energy per mass. However low energy per volume. It can be burned in a gas turbine leading to a relatively clean combustion process that will emit water and NOx. Very clean hydrogen can also be used in fuel cells to generate electricity for flight or ground vehicles. This has a lower well-to-wake efficiency than battery-powered flight, but due to the much lower weight penalty is considered to be a valuable option for future use in aviation. Also, re-fuelling times could be shorter than battery-based systems.

Safety issues related to hydrogen as a fuel in aviation

In this section, hazards related to the use of hydrogen in aviation are presented. The hazards are divided into several use cases, as each has specific points of interest.

Hazards related to hydrogen at atmospheric pressure

In this scenario, hydrogen escapes from tanks or piping.

- Fire hazard
  - Hydrogen has a low ignition energy. In fact, this energy level is so low that the static energy from the edge of a leak is considered to be able to generate enough static electricity to ignite the hydrogen
  - When on fire hydrogen produces a very clear flame that might be difficult to see in daylight
  - The flame has low radiation energy, meaning that one can approach the flame without feeling the heat
- Explosion hazard.
  - Hydrogen is explosive between 4%-77% and has low ignition energy.

- Asphyxiation
  - When hydrogen gas replaces oxygen in a closed volume then persons have a risk of suffocating. Hydrogen has no smell, so is hard to detect without tools.
- Fire risk accelerator
  - From 1% concentration, hydrogen can work as an accelerator for a fire condition

Hazards related to the pressured storage of hydrogen (GH2) at 300 bar to 700 bar.

- High-pressure leakage
- Jet flame (after a venting valve opening or after puncture of the pressure vessel. A jet flame produces heat and loud sound (140 dB)
- Explosion (including boiling liquid expanding vapour explosion (BLEVE))
  - Fireball
  - Pressure wave

Hazard of Liquid Hydrogen (LH2)

Additional hazards related to liquid hydrogen are mostly related to the cryogenic state in which it is stored as hydrogen liquifies at minus 253 degrees Celsius.

Hazards related to the use of liquid hydrogen (LH2) are:

- Frostbite
- Fire
  - The flammability limits of hydrogen in air are very wide, from 4% to 75% at atmospheric pressure
- Explosion
  - the detonation limits are somewhat narrower compared to the flammability limits at 18.3% to 59% at atmospheric pressure. Leading to a fireball and pressure wave.
- Freezing of air/oxygen in the tank
  - This can occur when the tank is not purged correctly before loading liquid hydrogen. This leads to solid air particles in the liquid hydrogen.
    - This can lead to internal friction in the fluid. Potentially leading to an explosion.
    - The solid particles have the potential to block valves or outflow pipes. Leading to overpressure or supply restriction
- Build quality
  - Sharp edges in a cryogenic tank can lead to static electricity build-up, creating an explosion risk. The manufacturer of the vessel should prevent this condition during the design and build process. Underlining the need for a high-quality supplier
  - Cryogenic temperatures can lead to embrittlement of materials (underlining the need for suitable material selection).
- LH2 leakage can create liquid hydrogen pooling outside the vessel. Creating a frostbite risk, a metal embrittlement risk, and a fire risk.

- Isolation defects in LH2 piping or storage containers can potentially lead to air condensation (liquefication of air when exposed to a cryogenic cold surface). This can cause a puddle of liquid air. When the nitrogen boils off then, for a period, a pool of liquid oxygen will remain. This is a corrosive and fire risk.
- Freezing of valves and vents. Unexpected conditions can occur during refueling when elements of the installation cool down. Elements can freeze, especially when humid air is present.
- Breakage/leakage of (re)fuel hoses due to dry ice / ill-fitting clamps / expansion /contraction / human error (departing browser with hose attached)
- Boil-off of liquid hydrogen.
    - Liquid hydrons will always absorb heat from the environment. This leads to the heating of the liquified hydrogen and produces excess gaseous hydrogen. To prevent excessive pressure built-up this gaseous hydrogen needs to be removed from the storage container. Vented or processed for use at other locations.
- Warming up of an untreated empty LH2 vessel can lead to a potential flammable or explosive mixture in the tank. Especially when frozen solid oxygen was present in the liquid hydrogen as a result of contamination.

Mitigation measures for the handling of hydrogen

Hydrogen safety culture

- Develop Safe Work Practices (SOPs) for handling and operating hydrogen systems, including:
- Hazard Identification and Risk Assessment (identify potential hazards)
- Ensure proper training on :
    - Safe Work Practices (SOPs) for handling and operating hydrogen systems and responding to emergencies
    - Hazard identification
    - Emergency Preparedness
- Personal Protective Equipment (PPE)

Design of hydrogen installation:

- Engineering Controls (e.g. ventilation, machine guarding, current and heat controls), including good maintenance
- Proper design:
    - Materials that can handle cryogenic LH2
    - No sharp edges
    - Pressure relief valves
    - Insulation
    - Being able to handle the load of sloshing LH2 in the tank
- Proper build quality
- Leakage detection.
- Prevention of static electricity build-up:
    - Electrical Bonding (grounding etc)

    - Elimination of sharp edge in tank
    - Material selection
    - Prevent contamination of hydrogen
- Prevent hydrogen lock-up when leakage occurs
- Robustness against contaminants (preventions)
- Lighting strike protecting
- Permanent ventilation (especially during storage/vehicle parking)
- Inerting when and where needed (e.g. by using nitrogen)
- Hydrogen detectors in temperature sensors

Safe Operation

- Safety measures (gas vents, detection, monitoring and data recording),
- Life cycle management
- Testing with helium
- Continuous inspections
- Leakage detection

Safety aspects related to the road transport of hydrogen:

- Road and infrastructure design (limit turns and crossings), ramps, etc.

Safety Aspects for First Responders

For first responders, the following aspects should be considered:

- Education. Knowledge of characteristics of hydrogen, such as hydrogen fire and explosion characteristics, pressure vessels, cryogenic storage, etc.).
- Means to detect an H2 fire (IR/UV camera or water spray)
- Hydrogen firefighting training
- Hydrogen-specific fire retardant
- Sound protection
- Protection against cryogenic risks

Regulation for hydrogen use in aviation

Currently, there are few regulations concerning the use of hydrogen as fuel in aviation. Although there is a lot of work in progress. E.g. **ICAO** recognizes hydrogen as a potential element in the future energy mix for aviation.

The **UK Civil Aviation Authority (CAA)** is aiming to develop guidelines and regulations for the safe use of hydrogen as an aviation fuel through its Hydrogen Challenge initiative using a sandbox approach. E.g. by getting the safety assessment and standards from the industry.

Ongoing activities are:

- CAA-UK has an academic partnership with UCL and Swansea on H2 combustion

- Gap analysis on primary and secondary UK legislation and CS-23
- Literature review: Report on research and tests
- Standards assessment from other industries: from automotive, shipping, etc

EASA is working on an approach for certification: CM-21.A-004 here.

These are guidelines, not requirements. It shows a way forward. Full aircraft would also comply with CS E, CS 2X as this will be part of the certification.

EASA works closely with the FAA, CAA UK, Brazilians Authority, and Transport Canada.

EASA has a harmonisation COB working group on Hydrogen specific. Electric and EVOTL are different from other working groups. Hydrogen is excluded from special condition E19. EASA is working on a white paper with special conditions and concerns for the safety of hydrogen. There might be several special conditions from the different parts of a hydrogen system.

FAA has COB Hydrogen technology WG. Report planned for the end of 2025. In addition, FAA is coordinating with other regulators and FAA recognizes CM21A004.

Guidelines for the use of hydrogen in aviation

The importance of hydrogen as a potential fuel for future aviation is acknowledged by different standard development organizations. Currently, guidelines are under development at The European Organisation for Civil Aviation Equipment (EUROCAE) in Europe and the Society of Automotive Engineers (SAE) in the USA.

These include the following developments:

- EUROCAE WG-80 Hydrogen Fuel Cell Systems https://www.eurocae.net/news/posts/2017/november/wg-80-hydrogen-fuel-cell-systems/

SAE developments

- AIR 8466 https://www.sae.org/standards/content/air8466/ - Hydrogen Fueling Stations for Airports, in both gaseous and liquid form (will be published November 2024)
- ARP 8676 - https://www.sae.org/standards/content/arp8676/ Nomenclature and Definitions for Electrified Propulsion Aircraft ARP8676
- AIR 8678 - https://www.sae.org/standards/content/air8678/ Architecture Examples for Electrified Propulsion Aircraft AIR8678
- AIR 8677 - https://www.sae.org/standards/content/air8677/ Safety Considerations for Electrified Propulsion Aircraft AIR8677
- ARP 8689 - https://www.sae.org/standards/content/arp8689/ - Endurance tests for Aircraft Electric Engine ARP8689
- AIR 7128 - https://www.sae.org/standards/content/air7128/ - Integration and Certification Considerations for Electrified Propulsion Aircraft AIR7128

- AIR XXX – Electric Engine Ingestion
- AIR 7130 https://www.sae.org/standards/content/air7130/ - Assessment of Electric Engine Failures Leading to LOPC AIR7130
- SAE A R8999 https://www.sae.org/standards/content/air8999/ High Flow Liquid Hydrogen Fueling Process and Couplings for Aerospace & Heavy Transport Applications (Will be published in November 2024)

ISO standards are:

1. ISO TC 197/SC1 concerns Hydrogen at scale and horizontal energy systems - https://www.iso.org/committee/9387084.html
2. ISO/AWI 19888-1 - Hydrogen Technologies — Aerial Vehicles - Part 1: Liquid Hydrogen Fuel Storage System

Exclude drone < 25 kg

Exclude equal and smaller part 23 class

Include: LHSC, Sensor units, Balance of tanks (pRVs, Valves, Tubes, Auxilary parts

Exclude FGSS (fuel gas supply system)

Include:

1. ISO PAS 15594:2002 Airport hydrogen fuelling facility operations

- Procedures
- H2 management
- Storage of H2
- Ground support equipment characteristics

Fuel cells in aviation

Apart from injecting hydrogen in combustion engines, it can also be used to generate electricity via fuel cells.

This requires hydrogen with a low level of contaminants.

The following sections discuss safety and certification issues related to the use of fuel cells in aviation.

Safety issues related to fuel cells

Fuel cell hazards, other than the hydrogen-related hazards are:

- Chemical spillage (coolant fluid)
- Physical injuries (rotating fans)
- Hot areas (heat exchangers)
- Dissipated heat from the fuel cell system
- Electrical hazards from the electrical system
- Contaminants in hydrogen

Mitigating measures for fuel cell hazards

The mitigating measures for fuel cell hazards are:

- Cooling systems
- Monitoring
- Procedures
- Clean hydrogen (contaminant prevention)

Regulation for fuel cell use

No aviation regulations are currently directly aimed at the use of fuel cells in the aviation domain.

Guidelines are currently under development within :

- The EUROCAE WG-80 working group on Hydrogen Fuel Cell Systems
- SAE
- ISO

Sustainable Aviation Fuels (SAF) for aviation

Introduction to SAF

Currently, SAF is defined as Conventional Aviation Fuel + Synthetic Blending Component (SBC)+ Sustainability Criteria.

Conventional Aviation Fuel are defined as fuels certified to ASTM D1655 (typically made from fossil resources). The Certified SBCs are defined in ASTM D7566, and are certified as a drop-in fuel for ASTM D1655 type fuels and as such can be blended with Jet A.

Sustainability Criteria are set by governments (RED II), NGOs (e.g. The Roundtable on Sustainable Biomaterials (RSB)), or the market. Note: RSB translates the norms set by the EU into standards.

There are several types of SAF products being developed. One of the most promising technologies relates to eSAF.

eSAF is made via power-to-liquid (PtL) technology where renewable electricity (from sources such as solar, hydro, or wind) is used to break water into its components of hydrogen and oxygen via an electrolysis process. Carbon dioxide captured from the air, or from biogenic or industrial sources, together with this hydrogen is then converted to carbon monoxide and water through the reverse water gas shift process. Using Fischer-Tropsch (FT) synthesis technology, more hydrogen and carbon monoxide are converted into a wax – a sort of synthetic crude oil that can be upgraded to different fuels, including eSAF.

The carbon neutrality of eSAF originates from the fact that the fuel only emits when burnt as much carbon as was input into the production process from direct carbon capture or existing emissions from other industrial sectors. Electricity from renewable sources is used in the production.

Safety aspects related to the use of SAF

The safety aspects of SAF are similar to the type of conditions set for kerosene type of fuels. Such as:

Engine and Component Performance

- SAF must be tested to ensure it meets the required performance standards for aircraft engines.
- Engine components, such as seals and hoses, must be compatible with SAF.

Fire and Explosion Risks

- SAF can be more prone to ignition than traditional fossil fuels. Special precautions must be taken to prevent fires and explosions during handling and storage

Production and Handling

- SAF production involves the use of chemicals and biological processes, which can pose risks if not handled properly.
- The handling and storage of SAF require special precautions to prevent accidents and ensure safe transportation.

Fuel System Compatibility

- SAF must be compatible with existing fuel systems, including aircraft fuel tanks, fuel lines, gaskets, and engine components.
  - Note: earlier versions of alternative fuels contained higher levels of fatty acid methyl esters (FAME). This product had specific challenges since traditional gaskets designed for kerosene proved to be less suited for FAME-type fuels. Causing some gasket materials to swell or degrade, leading to a loss of sealing properties. Also, FAME fuels were prone to bacteria growth. Modern SAF fuels do not contain FAME and are less of a risk consequently.

Prevention and Mitigation Strategies for SAF Hazards

To mitigate risks, it is essential to follow safety protocols and guidelines during SAF production, handling, and use. Additionally, ongoing research and testing are necessary to ensure the safe and effective use of SAF in commercial aviation.

Regulations related to SAF

The requirements for alternative fuels in aviation are derived from the EU Renewable Energy Directive II(I). The Renewable Energy Directive establishes common rules and targets for the development of renewable energy across all sectors of the economy.

- The directive is the legal framework for the development of renewables across all sectors of the EU economy.
- The revised Renewable Energy Directive (EU/2023/2413) raises the EU's binding renewable target for 2030 to a minimum of 42.5%, up from the previous 32% target.
- Share of renewable energy within final consumption of energy in transport sector of 29%c by 2030.

Relevance for SAF:

- Provides guidance on the calculation of carbon intensity of renewable fuels
- Defines feedstocks for (advanced) biofuel production (Annex IX - Part A & B)
- Defines minimum GHG emission savings for (advanced) biofuels

In addition, the EU Commission Mobility and Transport initiative ReFuelEU Aviation promotes the increased use of sustainable aviation fuels (SAF) as the single most powerful tool to decrease aviation CO2 emissions. The measure is part of the Fit for 55 package to meet the emissions reduction target of 55% by 2030. It sets requirements for aviation fuel suppliers to gradually increase the share of SAF blended into the conventional aviation fuel supplied at EU airports.

Year	2025	2030	2035	2040	2045	2050
SAF (min.)	2%	6%	20%	34%	42%	70%
Synthetic aviation fuel sub-mandate (min.)		2%	5%	10%	15%	35%

Figure 17: SAF minimum values demanded per year from 2025 to 2050.

ReFuelEU Aviation establishes a SAF mandate in the EU and is enforced by:

- The mandate is for Fuel Suppliers (according to the table above)
- Non-compliance penalty of at least 2x price differential between conventional aviation fuel and SAF, per tonne of SAF not supplied
- Following sustainability requirements of RED II(I)
- Refueling obligation for Aircraft Operators (90% of fuel uplift from Union Airport, no tankering)
- Non-compliance penalty of at least 2x price differential between conventional aviation fuel and SAF, per tonne of SAF not uplifted

Other regulations and incentives that relate to the development of SAF:

- EU Emissions Trading Scheme (EU ETS)

- International Civil Aviation Organization (ICAO) adopted the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to address CO2 emissions from international aviation till 2035
- SAF Grand Challenge (USA)
- Renewable Fuels Standard (USA)
- Low-Carbon Fuels Standard (USA, state-level)
- Long-Term Aspirational Goal (Global - ICAO)

In addition: the following countries are implementing mandates for the adaptation of SAF:

- Norway, Sweden, and France, currently in effect
- Other countries/states are developing mandates (China, Brazil, and more).

Standards related to SAF

Sustainable Aviation Fuel (SAF) is subject to the following standards:

1. American Society for Testing and Materials (ASTM) International Standards

- ASTM D7566: Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons
- ASTM D1655: Standard Specification for Aviation Turbine Fuel
- ASTM D4054: Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives

2. International Air Transport Association (IATA) Guidelines

- IATA Guidance on Sustainable Aviation Fuels (SAF)
- IATA Alternative Fuels Roadmap

3. International Organization for Standardization (ISO) Certification

- ISO 9001:2015 Quality Management Systems
- ISO 14001:2015 Environmental Management Systems

4. Roundtable on Sustainable Biomaterials (RSB) Certification

- RSB Certification for Sustainable Aviation Fuel (SAF)

Smart airport energy hub

For the Smart airport energy hub, the Certification and Safety aspects are related to:

- Lithium power
- Iron Flow power
- Hydrogen power
- Fuel Cell
- Heat batteries

This section will cover the regulations and safety aspects not covered by the previous sections.

Regulations for Smart airport energy hub

EASA has no relevant regulations that are explicitly detailed for power supply requirements at the airport. However, such requirements are likely to be part of broader safety and operational standards for aerodromes. Airport operators would need to ensure their power supply systems meet the necessary safety and reliability standards to support critical airport operations.

National requirements identified are :

- The NEN 1010, 3040

Other non-aviation, mainly national, regulations that are useful in this topic are :

- Environmental regulations
- First responder requirements and procedures (E.G. in the Netherlands the PGS (Publicatiereeks Gevaarlijke Stoffen and SEVESO are incorporated in national Environmental laws)
- National regulations concerning permits and (external)risk acceptance (e.g. in the Netherlands the Omgevingsdienst, Veiligheidsregio)

Heat batteries

Hazards of Heat Batteries

- Bacterial growth in water supply (legionella)
- Operational risk: shortage of warm water availability

Mitigating measures

- Mitigate bacterial risks by chemical or heat treatment
- Mitigate operational risks by assuring sufficient alternative warm water availability. E.g. by electrical heating

Regulations

There are no aviation regulations in place for heat batteries.

Zero emissions airside operations

In this TULIPS Work Package, the focal point is the Ground Support Equipment (GSE) that is used to support the operation of Electric and Hydrogen aircraft. The safety and certification aspects of GSE are briefly addressed here. The safety and certification aspects for electric and hydrogen aircraft, have already been covered in Section 2. The interested reader is advised to refer to that Section.

Regulations for Ground Support Equipment (GSE) and its operations

The following regulations relate to ground equipment:

- ICAO - Doc 10121: Manual on Ground Handling, 1st Edition, 2019
- EASA - Rules for Aerodromes (Regulation (EU) No 139/2014)
- EASA - Opinion No 01/2024 - Ground handling requirements

Guidelines for ground equipment

The following guidelines relate to ground equipment:

- IATA Ground Operations Manual (IGOM),
- IATA Airport Handling Manual (AHM), which includes guidelines on electrical ground equipment
- IATA Safety Audit for Ground Operations (ISAGO) Standards Manual, 10th Edition, International Air Transport Association (IATA)
- IATA Ground Damage Report: The Case for Enhanced Ground Support Equipment, December 2022

However, currently, there are no aviation regulations directly aimed at aviation GSE using new fuels.

The guidelines that are found with some connection on this matter is the IATA Airport Handling Manual (AHM), which includes guidelines on electrical ground equipment.

The operational hazards identified for new energy GSE

- Hydrogen delivery, production, storage (infrastructure)
- Regulation / Permits / Certification
- Fire risk (battery and hydrogen)
- Operational disruption
- Functional limitations
- Less weather robust

Mitigating measures for GSE

Mitigating measures for new energy for GSE are:

- System design
- System build quality
- Testing
- Compliance with standards and regulations
- Procedures
- Training

Circular airports

This Work Package focuses on the management of residual streams (waste management and material recycling)

The following figure presents for example the distribution of various waste types for a typical large airport.

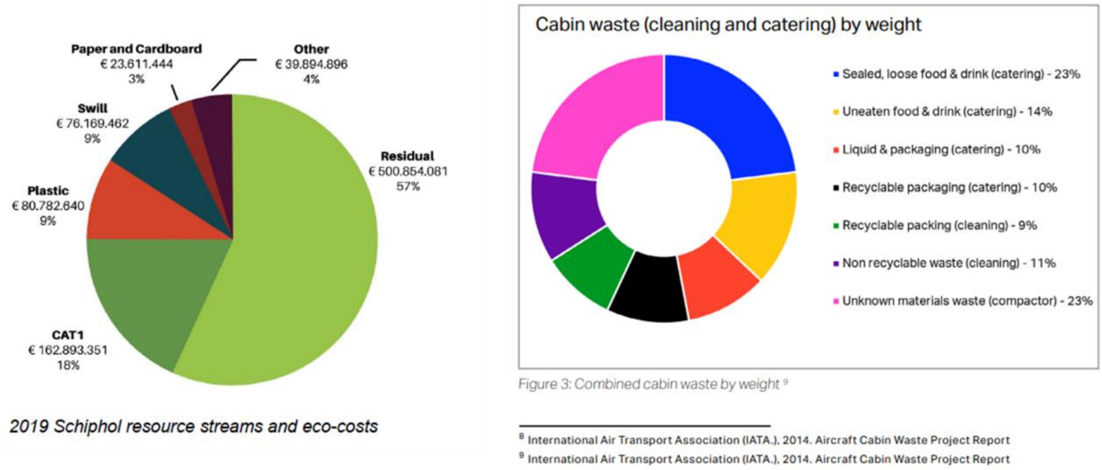

Figure 18: distribution of various waste types for a typical large airport (Schiphol) including all waste (left) and cabin waste (right).

Safety issues related to residual streams

The following hazards can be identified in relation to handling residual streams

- Biohazardous materials
- Plant and animal diseases
- Chemicals
- Sharps
- FOD
- Insect-borne diseases (viral and bacterial illnesses from insect bites)
- (Storm)water (volume, chemical pollution)
- Lithium Ion battery fire

Other hazards are not caused directly by the waste, but due to the presence of waste. Such hazards are caused by being attracted by waste.

Hazardous wildlife (e.g. due to landfill near the airport) examples are:

- Avian risks (birds)
- Rodents (rats, mice)
- Mammals (foxes, wild boars)

Mitigating measures for residual streams

The following mitigating measures for handling residual streams can be identified:

- Waste reduction program
- Protective packaging of waste
- Personal Protective Equipment (PPE)
- Containment of waste materials
- Controlled waste processing
- Procedures
- Infrastructure design
- Battery handling equipment/infrastructure and procedures
- Hazardous wildlife control

Regulations related to waste management

The EU defines International Catering Waste (ICW) as catering waste from means of transport operating internationally. The EU categorizes ICW as a Category 1 Animal By-Product – the highest category (of 3 categories) because of its perceived high risk for animal health. Although the term "Operating internationally" is not defined in the EU legislation, it has been interpreted by several EU Member States as being only applicable to aircraft arriving from countries outside the EU. Many Member States classify all waste material from aircraft as ICW, without any consideration of the origin of the waste, whereas others apply a more risk-based approach.

Source: IATA

Consequence: all waste from international flights needs to be disposed of (incinerated)

The following types of residual streams are differentiated by ICAO:

- MUNICIPAL SOLID WASTE (MSW)
- CONSTRUCTION AND DEMOLITION DEBRIS (CDD)3
- WASTE FROM AIRCRAFT FLIGHTS (DEPLANED WASTE)
- INTERNATIONAL WASTE
- COMPOSTABLE AND BIODEGRADABLE WASTE
- HAZARDOUS AND INDUSTRIAL WASTE
- LAVATORY WASTE

In comparison, IATA differentiates only the following types:

- Medical Waste
- Electronic waste
- Textiles and toiletries

No specific aviation regulations exist for sustainable or circular design, building or operation of airport infrastructure.

Safety of Sustainable/Circular Airport Infrastructure

The following hazards might influence Sustainable/Circular Airport Infrastructure

1. PV solar panels
a) Glare
b) Off runway landing
c) Stability of the electrical grid
d) Availability of electrical power

2. Windmills
a) Obstacle
b) Visibility
c) Turbulence (small aircraft)
d) Stability of the electrical grid
e) Availability of electrical power

3. Fire risks from bio-based building materials might influence Sustainable/Circular Airport Infrastructure

Regulations for circular residual streams

Several key regulations and guidelines for waste management provide a certification basis for circular residual streams:

- 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL Directive on waste of 19 November 2008 -
- Cabin Waste Handbook - IATA -Research date: December 2017 - Publication Date: August 2019
- Waste Management at Airports – ICAO - ECO AIRPORT TOOLKIT

Certification of recycled materials for re-use can be a challenge in certain countries.

Biochar

Introduction to biochar

To achieve carbon neutrality on a global scale, we can act on two pillars: on the one hand by drastically reducing emissions, and on the other hand by increasing carbon sinks. Natural spaces can play a decisive role because they are able to sequestrate carbon from the atmosphere, and store it in soils and biomass. Airports soils assets have been identified as one of the possible options for allowing carbon sequestration, and therefore support the efforts to decarbonize the sector. The TULIPS project aims at evaluating the potential in terms of carbon sequestration at airports level, based on the lands assets for implementing Nature Based Solution, in Turin, Larnaca and Schiphol airports. One of the tested solutions is based on the use of biochar.

Biochar is a carbon-rich material that is made from biomass through a thermochemical conversion process known as pyrolysis. Biochar is made by heating biomass such as herbaceous or woody crop residues, non-salvageable timber and slash, or animal manure, in a contained system. This produces a charcoal type of organic material. There are many potential uses for biochar including water treatment, land reclamation, and carbon sequestration. Biochar may also be used as a soil amendment for two purposes – to improve plant health and to store carbon. It is predicted that at least 50% of the carbon in any piece of waste turned into biochar becomes stable, locking away that carbon for a period of several to hundreds of years, offsetting its contribution as a greenhouse gas in the form of carbon dioxide.

Biochar safety

Some safety aspects to be aware of when using biochar are:

Production Safety

- The pyrolysis process used to create biochar can generate potentially hazardous gases and vapors. Proper ventilation and safety equipment are essential during production.
- Flammability and Combustion Risk - While biochar itself is not considered intrinsically flammable, it does have some flammability potential that requires precautions: Fast pyrolysis biochar tends to be more flammable than slow pyrolysis biochar.
- Dry biochar dust can potentially combust spontaneously in enclosed spaces.
  Mitigation: adding 20-50% moisture content significantly reduces ignition risk.

Handling and Storage

- Proper moisture content (20-50%) helps suppress flammability during handling and storage.
- Dust control measures are important to prevent inhalation hazards.
  Mitigation: Storage away from ignition sources is recommended.

Contaminants

There are some concerns about potential contaminants in biochar:

- Polycyclic aromatic hydrocarbons (PAHs) and other carcinogenic/mutagenic compounds may be present.
- Heavy metals from feedstock can concentrate in biochar.

Mitigation: Proper feedstock selection and production conditions help minimize contaminants.

Application Safety

When applying biochar to soil:

- Use appropriate dust control measures and personal protective equipment.
- Be aware that biochar can alter soil pH, potentially affecting nutrient availability. Long-term effects on soil and crops should be monitored.

Environmental Considerations

- Biochar is difficult to remove once applied to soil, so careful consideration is needed before large-scale application.
- Consider the impact on soil microorganisms and long-term soil health.

While biochar offers potential benefits for agriculture and carbon sequestration, ongoing research is needed to fully understand its long-term safety implications. Proper precautions during production, handling, and application can help mitigate known risks. Especially since there is still research needed.

- There is a lack of long-term experiments worldwide, especially considering the diversity of biochar types and soil conditions. Most current studies on biochar effects are short-term.
- Research is needed on the effect of high doses of biochar to better understand the effects on soil, soil life, water availability, and soil erosion.
- The long-term effects of biochar presence in soil are still unknown because it can persist in soil over centuries. Especially since biochar application to soil is difficult or impossible to remove once applied.

Regulations related to biochar production and use

In the European Union the following regulations cover biochar production, quality, and use, particularly:

European Union Regulations

- EU Fertilizer Products Regulation (FPR) - Biochars certified as EBC-Agro and EBC-AgroOrganic meet all requirements of this new regulation. It sets standards for biochar used as a fertilizer or soil amendment in the EU.
- EU Commission Regulation on Organic Production - The EBC-AgroOrganic certificate meets all requirements of this regulation.
- REACH Regulation - Applies to biochar cases where the material is considered a chemically modified substance.

National Regulations

Several EU countries have their own regulations for biochar use:

- Austria, Sweden, and Hungary have approved biochar use according to EBC-Agro requirements.
- Switzerland requires EBC-AgroOrganic certification and only allows woody biomass as feedstock for pyrolysis.
- Germany requires a minimum carbon content of 80% for biochar and must be produced from untreated wood.
- Sweden - Has defined limits beyond the EU regulation and EBC-Agro standards.

Voluntary Standards

- European Biochar Certificate (EBC) provides guidelines for sustainable biochar production, processing, and sale. It offers several certification classes: EBC-Feed, EBC-Agro, EBC-AgroOrganic, EBC-Urban, EBC-BasicMaterial, and EBC-ConsumerMaterial.
- World Biochar Certificate (WBC). This is developed based on EBC guidelines for use beyond Europe in three classes: Premium, Agro, and Material.
    - International Biochar Initiative (IBI) Biochar Standards: provides guidelines for defining biochar and ensuring its safe use as a soil amendment.

Note: These regulations are likely to be updated in the future to reflect ongoing research into best practices.

Final Remarks on Safety

The aviation system is a crucial element in the world economy. The transportation of persons, goods, and services cannot easily be replaced by other transport due to geographical, speed, or flexibility considerations. The importance of the aviation sector is underlined by the extensive growth after the COVID-19 pandemic.

Although fossil carbon-based fuels like kerosene have uniquely low costs, high energy density, and relatively easy storage and handling properties, the sector is well aware of the climate impact of fossil fuels. The stakeholders recognize the need for change to work towards climate-neutral aviation. This is no easy feat (technologically and operationally). First, studies show that to work toward climate-neutral aviation a range of energy solutions need to be developed, both for ground operations and flight operations. The research in TULIPS analyzed some of the most promising solutions, ranging from battery technology to hydrogen to sustainable replacement fuels for kerosene.

From a safety perspective most of these new fuel types have different hazards compared to kerosene. Some critics point to this as a disadvantage, but we should remember that the excellent safety record of current aviation has been achieved by constant improvements that incorporate the hazards related to the use of fossil fuels. We have adopted to handle this in an appropriate manner.

There is reason to believe that the aviation system will, over time, be able to adjust to the use of different fuels with different hazards. This will be achieved by a combination of research, testing, standards & regulations, controls, procedures and constant updating and improvement .

This study shows that the technology for battery use and hydrogen application in aviation is still under development. Lithium-ion batteries have specific risks related to their capacity to heat and/or ignite when mishandled.

Hydrogen hazards relate to the type of storage (high pressure or cryogenic) and to the specific characteristics of hydrogen (low ignition energy and potential for explosive combustion).

Sustainable Aviation Fuels have relatively similar hazards to the kerosene that they replicate.

On the side of regulation and standards, the authorities and organizations are in the process of developing guidance material for the use of new fuels. For hydrogen, fuel cells, lithium-ion batteries, and electric flight both European and North American regulators are still in the process of developing regulations, both for ground operations and in-flight applications.

Sustainable and Circular airports

In order to meet climate goals airports are looking into new technologies to help them. Smart energy grids and the re-use and re-cycling of materials are part of their developing strategies. Aviation regulations in these field are sometimes missing, although other national regulations and standards may cover part of the spectrum.

Hazards for new energy grids are especially related to the continuity of service.

For recycling and re-use of materials most hazards relate to the properties of the materials and the way they are processed. Also, certification of recycled materials for reuse can be a challenge in certain countries.

The TULIPS project has explored various aspects of sustainable aviation fuels, electric propulsion, hydrogen power, fuel cells, and circular airports. This report provides an overview of the safety and certification aspects related to these topics.

The introduction of new energy sources in aviation poses significant challenges, including regulatory gaps, safety concerns, and environmental impacts. However, these challenges also present opportunities for innovation and growth.

The report highlights the importance of developing safety management measures, designing safe systems, ensuring compliance with standards and regulations, providing proper training, and implementing procedures to mitigate risks associated with new energy sources.

The use of lithium-ion batteries, iron flow batteries, hydrogen fuel cells, and sustainable aviation fuels requires careful consideration of safety aspects, including fire risks, explosion hazards, and environmental impacts.

The development of circular airports also presents opportunities for sustainable waste management and material recycling.

Recommendations

1. Develop comprehensive safety management measures for new energy sources in aviation.
2. Establish clear regulations and guidelines for the use of new energy sources in aviation.
3. Ensure compliance with existing standards and regulations.
4. Provide proper training for personnel handling new energy sources.
5. Implement procedures to mitigate risks associated with new energy sources.

Future Directions

1. Continue research on safety aspects related to new energy sources in aviation.
2. Develop guidelines for sustainable aviation fuels.
3. Explore opportunities for circular airports.
4. Encourage international cooperation to address global challenges related to sustainable aviation.

By addressing these challenges and opportunities, we can work towards a more sustainable future for aviation while ensuring safety and minimizing environmental impacts.

Limitations

This report provides an overview of safety and certification aspects related to new energy sources in aviation but does not provide an exhaustive analysis.

Further research is needed to fully understand the implications of new energy sources on aviation safety.

Recommendations for Future Research

1. Investigate safety aspects related to new energy sources in aviation.
2. Develop guidelines for sustainable aviation fuels.
3. Explore opportunities for circular airports.

By continuing research in these areas, we can work towards a more sustainable future for aviation while ensuring safety and minimizing environmental impacts.

Final Considerations

The introduction of new energy sources in aviation presents significant challenges but also opportunities for innovation and growth.

By working together to address these challenges, we can ensure a safe and sustainable future for aviation.

5. Conclusion

The TULIPS demonstrations across the seven work packages (WPs) reflect a broad-based effort to pioneer sustainable aviation solutions. These demonstration projects provide invaluable insight into creating future-ready, eco-efficient airports. As airports worldwide explore sustainable pathways, the findings from TULIPS offer several critical trends, takeaways, and learnings for implementing and scaling these innovations.

Demonstrations on multimodal transport (WP1) reveal that achieving significant reductions in emissions and traffic congestion lies on successfully integrating passenger and cargo services into cohesive, user-friendly systems. Airports and their mobility partners should continue developing solutions such as the Mobility-as-a-Service (MaaS) app and multimodal infrastructure to enable a seamless passenger experience and efficient transportation shift. Expanding these platforms to cover wider geographic areas while building partnerships with local transport authorities will be essential for greater adoption.

As for the demonstrations on Energy Infrastructure for Future Aircraft (WP2), the shift toward hydrogen and electric energy for aircraft, demonstrated in hydrogen and electric charging solutions, shows that substantial investment in energy storage, refuelling infrastructure, and regulatory adaptations are necessary to achieve more sustainable air travel. Establishing clear frameworks for hydrogen refuelling and energy storage might facilitate smoother deployment and scale-up of these technologies.

The successful demonstrations of energy storage and peak shaving technologies (WP3) reveal that smart energy management might indeed be a viable pathway to manage high-demand energy areas at airports. As learnings from the work conducted thus far, airports aiming to decarbonise will need to prioritise investments in advanced battery solutions, renewable energy sources, and energy hubs that are both modular and scalable. Developing a strong business case for these systems, including clear returns on investment, is vital for wider adoption.

As for the demonstrations on zero-emission ground support equipment (WP4), replacing diesel GPUs and ground service equipment with hydrogen and electric models demonstrates zero-emission potential on the airside. This shift requires substantial investment in charging and refuelling infrastructure, as well as staff training on operational standards for new equipment. Hydrogen-based solutions are particularly promising for heavy-duty applications, but logistical and regulatory support is needed to make these scalable and feasible for daily airport operations.

For Scaling Sustainable Aviation Fuel (WP5), efforts to integrate SAF into airports' fuel supply chains highlight both the challenges and opportunities in scaling SAF. Supply chain constraints, high production costs, and limited availability highlight the need for robust partnerships to stabilise supply and reduce costs. As policies incentivize SAF use only to a very limited level, airlines must develop strategic partnerships with fuel providers and public authorities to scale production and leverage policy-driven incentives to enable SAF as a viable component of regular operations, particularly focusing on local supply infrastructure.

Regarding circular economy (WP6), closed-loop systems are cornerstones of sustainability as seen in initiatives being demonstrated for managing waste and reusing materials throughout airport infrastructure. These underscore the importance of shifting from linear to circular models in waste management. Projects involving material passports and digital asset tracking systems might point to a path forward, allowing airports to extend the life of materials and components, reduce waste, and improve resource efficiency. However, successful implementation is difficult as it requires airport-wide buy-in and integrated data systems that connect stakeholders across operations. Further, demonstrations with reusable systems (such as reusable coffee cups and food containers) emphasise that consumer education is crucial for success. Airports can focus on designing intuitive systems for waste sorting and reuse and integrating behaviour-change strategies for both passengers and employees. Testing these systems across different airport environments has shown that adaptability to cultural and operational contexts is key.

Finally, as for air quality and emissions reduction (WP7), trials of water droplet-based UFP mitigation and biochar applications aimed at responding to the growing importance of localised environmental management. For future green airports, integrating such solutions must be balanced against considerations of cost, effectiveness, and adaptability to local conditions. In particular, the trialled UFP solution was not effective due to the wide range of local operational variables. Other mitigation strategies are required to enable UFP emission reductions .

Biochar might offer a promising pathway for airport land carbon sequestration, yet continuous testing and scaling are required to validate long-term benefits. Both nature-based solutions (such as biochar) and technological interventions (such as UFP filtration) demonstrated the need for resilience and flexibility. Weather dependency, varying pollutant levels, and regional environmental regulations affect deployment success, underscoring the importance of adaptable, resilient strategies in air quality management.

The learnings from this report demonstrate that the path to a Green Airport of the Future requires a multi-faceted approach, aligning technology, policy, and consumer behaviour. Particularly, some recommendations can be drawn for future deployment of solutions in this space:

- Foster cross-sector collaboration: sustainable transformation depends on strong collaboration between airports, technology providers, regulatory bodies, and airlines. Each sector brings unique insights and resources, and partnership models should be explored to foster integrated solutions across energy, transport, and operational technologies.
- Build adaptable and scalable Models: solutions need to be designed for flexibility and scalability. For instance, SAF production and hydrogen infrastructure should cater to varying demand levels while retaining the capacity for scale as policies and market conditions shift toward more sustainable levels.
- Embed circular economy practices in airport culture: the transition to circular principles must involve clear communication, employee training, and passenger engagement. Airports should embed circularity in their mission and operationalize it through standardized tools and processes.
- Invest in smart energy and resource management: a green airport will benefit from robust, interconnected energy systems, with technology playing a central role. Airports should prioritise investment in smart energy hubs, peak shaving tools and renewable energy sources to create resilient, efficient energy networks.
- Continue testing and adjusting for environmental solutions: climate considerations impact all facets of airport sustainability, and continuous testing is necessary to refine solutions to better tackle challenges such as UFP mitigation and biochar applications..

The TULIPS demonstrations provide a valuable foundation for developing more sustainable airport models, pushing forward the agenda for the Green Airport of the Future. Each work package has contributed critical insights and practical solutions that are key to scaling green practices in aviation. Airports aiming to adopt these practices should build on the project experiences, ensuring that innovative solutions are supported by collaborative methodologies, robust infrastructure, and a commitment to resilient, more sustainable growth in airport operations.

APPENDIX A. LIST OF REFERENCES

GENERAL

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APPENDIX B. DETAILED DEMO DEPLOYABILITY STATUS

Demo #1 - Enabling travellers modal shift with support from MaaS solutions (T1.4a and T1.4b)

EVIDENCE LEVEL

Reporting of deployability of Demo #1 (T1.4a and b) is based on answers to a survey form (September 2024) and the Deep Dive Demo progress presentation (April 2024).

USE CASE

This demo is being led by TNO with the participation of MOBCON, TUD, FHG, SNBV, HERMES, and AVINOR. The Demo aims to develop a model and MaaS app which considers Schiphol Airport and surrounding commuter areas, including 5 scenarios:

1. Creation of a Zero Emission zone at Schiphol Centre (location: Schiphol city)
2. An extension of the metro (North-South line) to Schiphol airport (location: Hoofrop, etc.)
3. An option of remote check-in (location: cities in the Netherlands, including Utrecht, Groninger, Nijmegen and de Haag (v1) and local areas and highways surrounding Schiphol city (v2))
4. A car free Schiphol centre (location: Schiphol centre)
5. A model of a combination of all of the above

As per the Grant Agreement, this demo work shall include the following activities:

- Obtain passenger access/egress data (GDPR approved) from surveys (SNBV) to add to the existing (anonymised) employee commuting data (MOBCON).
- Create an intermodal hub model of the airport hub area (TNO) that exchanges data with the MaaS app (MOBCON).

- Provide alternative ways of commuting for employees at the airport. *Here valuable experience from the on-going Dutch program will be integrated to the intermodal hub model that exchanges data with the MaaS app*[8] (SNBV,MOBCON, TNO, BAM)
- Extend the MaaS app for use by arriving passengers at airports (MOBCON). *Supported by the output of the hub model simulations*[1] (TNO)
- Visualise in the intermodal hub model the access/egress choices of airline passengers (TNO).
- Provide proactive real time travel information; provide alternative modalities in case of disruptions to achieve on-time arrival at the airport and also convenient departures from the airport (SNBV, TNO, MOBCON).
- Integrate into the intermodal hub model a remote check-in to demonstrate secured remote check-in (SNBV, KLM,TNO)
- Obtain travellers' experience from using the MaaS app by ex-post survey (MOBCON) and enhance/refine the model and the scenarios (TNO[9], MOBCON, TUD).

Key Performance Indicators of scenarios:

1. Creation of a Zero Emission zone at Schiphol Centre: CO2e emissions (Mton)
2. Extension of the metro (North-South line) to Schiphol airport: NO2 Emissions (µg/m3)
3. Remote check-in: Energy use
4. Car free Schiphol centre: Modal car share
5. Combination of all of the above: PM10 emissions (µg/m3)
6. Zero : CO2e emissions (Mton), Energy use

Key Success Metrics (KSM):

- KSM1: Achieve 20% modal shift from cars to green modes for commuting airport employees (25,000) at Schiphol Airport;
- KSM 2: Validate the possibility of increasing passenger use of public transport by 5%.

[8] This is no longer the case, as the MaaS app being developed accounts for traffic on a micro level (i.e. individual user level) whereas the Urban Strategy Tool (Dutch program) incorporates traffic on a macro level.
[9] No longer involves TNO

PROBLEM SOLUTION FIT

Problem Statement

Currently, commuters and travellers to and from Schiphol use public and private transportation routes without a coordinated effort to choose routes and options with lower emissions impact. As part of the transition to a Net Zero Airport, integrated options should be provided to commuters and passengers at Schiphol and other airports.

Value Proposition

Through the demonstration, Mobility Concept is deploying two MaaS apps - one for commuters (T1.4b, A. Commuter app) and one for passengers (T1.4b, B. Passenger app) travelling to and from Schiphol airport.

The MaaS apps shall present zero/low-carbon alternatives to using a car to the passengers. The app will incorporate and facilitate planning, booking, travelling and paying for different modalities including public transport, shared vehicles (bike, scooter and car), taxi and micro-mobility options for first/last mile connectivity. The planning tool available in the apps presents a comparison of costs, time and CO2 emissions between different travel options available. The solutions aim to drive a modal shift in commuters and passengers to opt for sustainable modes of transport when available.

Five scenarios of modal shift will be assessed in the Inter-modal shift model through the implementation of different policy packages (T1.4a, C. Scenarios and Policy packages) in the MaaS app.

Stakeholders and End users

A. **Commuter App (T1.4b):** End users are the Schiphol Airport area commuters, i.e. employees from Schiphol area companies, including regular commuters with annual Schiphol subscription pass (JAS), shared vehicles (bikes, scooters and cars), taxi and micro-mobility options). Mobility concept is the provider of the MaaS App development; and corporates and Schiphol and Transport companies are stakeholders of this solution.

B. **Passenger app (T1.4b):** End users are the Schiphol Airport area passengers i.e. visitors and passengers - with or without annual Schiphol subscription pass (JAS), shared vehicles (bikes, scooters and cars), taxi and micro-mobility options. Mobility concept is a stakeholder as the provider of the MaaS App development. Schiphol Group can also be a stakeholder for app promotion and increased adoption of its final version.

C. **Scenarios and Policy packages (T1.4a):** End users are the Schiphol airport and other airports. Additional stakeholders include public transport companies, research institutes and the government.

DEPLOYABILITY

Status overview

Current Demo Status: Prototyping - MaaS versions are still being developed and not fully deployed.

A. Commuter App (T1.4b)

Deploying. No action from TULIPS needed. The MaaS platform is currently successfully being demoed with a large company in the Schiphol area.

This demo is currently at TRL 6, having already been applied in one Schiphol area company with their employees, which is a relevant environment for testing the solution. Subsequent development requires gathering employee data and there is still uncertainty regarding the availability of this employer to share said data. However, if reporting positive data on modal shift and user uptake of this version, the final developed version may be able to achieve TRL 7.

B. Passenger App (T1.4b)

Prototyping. Help from TULIPS might be needed to ensure extension to December 2025 and from Schiphol to help with passenger awareness and user acquisition.

A version of the MaaS platform with payment options through the app is being developed, after a limited MaaS app version was showcased amongst TULIPS participants in April 2024. The App already allows for planning, booking and travelling by public transports and other mobility options.

This demo is currently at TRL 3-4, as a prototype has already been tested and a new prototype with a new feature (in-app payment option) is being developed. Once the final solution is tested and iterated by a sample of test users in the Schiphol area, it will achieve TRL 5-6 and once optimised and released to passenger users it will have achieved TRL 6-7 depending on impact on modal shift.

C. Scenarios and Policy packages (T1.4a):

Prototyping. Help from TULIPS is not needed.

So as to measure the impact of five scenarios in terms of emission reduction, policy packages are being developed under the twin digital environment of the Apps.

At the moment, the team is designing and implementing the various scenarios and developing the base model, so our assessment is that TRL is roughly at 3-4. With the planned conclusion of the development and measurements from each scenario planned to June 2025, the demo might achieve TRL 6-7.

Risks, external dependencies and mitigation plans.

A. Commuter App (T1.4b):

One of the biggest risks foreseen with the commuter App is that the company where the solution has been deployed has not yet enabled access to employee data for analysis of modal shift and for app improvements. To mitigate this risk, the team has already discussed this topic with the company and submitted answers to their privacy assessment questionnaire so as to obtain the required permissions.

B. Passenger App (T1.4b):

Some of the anticipated risks or challenges include:

- Availability of the app in different countries
- Scaling the app data processing to ensure handling of passenger volume
- Acceptance of international passengers
- Acceptance of international credentials for mobility options like shared vehicles
- Availability of payment providers to support international payment options

- Insufficient outreach/promotion to increase awareness of availability of such an app to passengers.

The demo team is already working on making the app available across as many geographies as possible and migrating to a cloud-based environment capable of scaling to accommodate increasing passenger volume. They are also assessing payment providers for integration and ensuring integration will be carried out with providers that support international payment options. As a measure to mitigate awareness, Schiphol Airport could help and participate in promotion and information campaigns to passengers.

C. Scenarios and Policy packages (T1.4a):

There is a risk that there will not be enough data to validate these scenarios. As such, the demo team is planning to tap into available and alternative data sources and also talking with more experts to outline different future developments so as to include them in the digital twin environment.

Next steps

A. Commuter App (T1.4b):

The planned next steps include analysis of the commuter data collected over the period of three years to assess modal shift in commuter behaviour.

B. Passenger App (T1.4b):

The planned next steps include a survey to be planned and conducted by TU Delft. The survey would introduce a MaaS app to passengers at Schiphol airport and receive feedback on the likelihood of the passengers to opt for green modes of transport in case of easy availability of such an MaaS app. Full deployment is planned for December 2025.

C. Scenarios and policy packages (T1.4a):

After development of the base model and different policy packages reflecting the scenarios, the planned next steps are to gather measurements from each scenario, discuss findings with stakeholders, fine-tune the packages and validate the findings, which should be completed by June 2025.

LEARNINGS & INSIGHTS

In summary, the Commuter App (T1.4b) has reached TRL6 after a pilot in a Schiphol-area company, though full deployment will require secure access to employee commuting data to gauge modal shifts effectively. The Passenger App, currently at TRL 3-4, has been tested among some workshop participants, featuring planning and booking capabilities; ongoing development will add a payment functionality, advancing its readiness as it aims to reach full deployment in 2025.

Meanwhile, the Scenarios and Policy Packages (T1.4a) are under prototyping, with an expected TRL of 6-7 upon completion in June 2025. Each scenario targets emission reductions through initiatives like creating a zero-emission zone at Schiphol and remote check-in options, with progress hinging on data availability for scenario validation. Key risks involve data access for the Commuter App, scaling data processing for the Passenger App, and potential gaps in validating scenarios due to limited data. Mitigation efforts include privacy assessments for commuter data, integration of international payment options, and proactive outreach to enhance app adoption among passengers.

Next steps focus on data analysis from commuter app use to assess behaviour shifts, implementing surveys for passenger feedback, and stakeholder consultations for scenario fine-tuning.

Altogether, success of this demo depends on several factors for each of its components (commuter and passenger apps and scenario packages), of which the most important ones are:

- Successful stakeholder engagement: overcoming barriers for data access and collection with corporates (commuter app)
- Continued data gathering and analysis beyond the TULIPS timeline: analysis of results need to happen after collecting data over a period of time (3 years for the commuter app)
- Investment: iterative development of the digital products requires financial, people and time investment that might be above that provided by TULIPS.

- User acquisition: efforts have to be put toward user acquisition and app release, which are beyond the technical development of the solutions and require support from Schiphol and other airports.

Demo #2 - Logistic solutions: green and connected trucking (T1.3)

EVIDENCE LEVEL

Reporting of deployability of Demo #2 (T1.3) is based on answers to a survey form (September 2024) and the Deep Dive Demo progress presentation (April 2024) and news articles from TULIPS (January and June 2023).

USE CASE

This demo is being led by TNO with the participation of SNBV, POA, DHL, and FHG.

Green and connected trucking will be demonstrated and evaluated with heavy trucks in combination with the operation of decoupling points at or near the lighthouse airport area for landside freight transport to and from the ground handlers at the airport. Further analyses and key findings will aid specification of the most optimal and effective design of green and connected trucking, concerning sustainability, efficiency and reliability.

Specifically, the demo work includes:

- Development of the demonstration for electric driving with heavy trucks in combination with the operation of decoupling points at or near the airport area for landside freight transport to and from the ground handlers at the airport (TNO, DHL, POA).
- Inventory of possibilities for modal shift from road to intermodal rail connections for long distance transport to and from the Amsterdam airport via a decoupling point in the Amsterdam port region (POA).
- Development and application of data driven decision making to select and control the most sustainable, efficient and reliable (electric) intermodal transport alternatives via decoupling points (TNO, FHG, SNBV).

- Execution of the green and connected trucking concept running in regular operation with stakeholders over a period of a couple of months to test, demonstrate, evaluate and modify the concept (SNBV, DHL and its transport companies).
- Analysis of results to specify the most optimal and effective design of the green and connected trucking case with highest impact on both reduction of emissions and efficient and reliable organisation of logistics processes (TNO).

Key Performance Indicators (KPIs) of the technical solution are:

- Environmental: CO2e (ton), energy usage (joule), emissions of pollutant x (ton) such as PM10, NOx
- Operational: Lead time freight
- Socio-economic: Operational expenditures (OPEX), capital expenditures (CAPEX), Amount of green investment (OPEX/CAPEX), social acceptance.

Key Success Metrics (KSM):

- KSM3: Monitoring and evaluation of three heavy duty trucks in regular logistics operation for a period of 12 months. Results will be used to contribute to an increase of the use of heavy duty electric trucks towards 2030.

PROBLEM SOLUTION FIT

Problem statement

Cargo is an important component at many airports, including Schiphol. Goods such as pharmaceuticals, food and flowers are transported by air, but there are also high-tech consumer electronics which need to be transported to and from the airport. TULIPS aim is to reduce CO2 emissions in the cargo chain as well.

Currently, heavy duty trucks rely on diesel for operation with an associated impact in GHG emissions. As part of the transition to a Net Zero Airport, alternatives shall be explored for logistics operations for heavy duty transport to and from ground handlers at Schiphol.

Value proposition

Heavy duty electric trucks can be used by transport companies to replace use of diesel vehicles.

End users and stakeholders

End users are transport companies operating at airports for logistics to and from ground handlers at Schiphol airport. Stakeholders involved include the companies DJ Middelkoop, Bos Logistics, DHL, the Port of Amsterdam, Schiphol airport, and ACN.

DEPLOYABILITY

Status Overview

Current Demo Status:

Demonstrating. No Help needed.

Two trucks are currently running in logistics operations (a Volvo FH Electric from Bos Logistics and one truck from DJMiddelkoop). One of the three planned trucks is not in operations yet (delivery is delayed). Additionally, the data feed has been established, and monitoring and data analysis is ongoing.

This solution is currently at TRL 6 as two of the three trucks are currently demonstrating and being monitored in a real-world relevant environment until M48 of TULIPS. TRL 7 is achievable within the expected timeframe if KSM is altered to only include 2 trucks.

Risks, external dependencies and mitigation plans

Delivery of a third truck is delayed. The demo team will measure and base results on only two out of the three planned trucks as mitigation.

Next Steps

Two trucks are demonstrating. No next steps are foreseen beyond this scope.

LEARNINGS & INSIGHTS

In summary, the deployability of Demo #2 illustrates the ongoing efforts to establish sustainable and efficient logistics at Schiphol Airport. This demo showcases two electric heavy-duty trucks (one from Bos Logistics and one from DJMiddelkoop) actively engaged in freight transport operations. These trucks are supported by decoupling points at or near the airport, which facilitate efficient landside freight logistics. The delay in delivering a third truck has impacted the initial plan, but the team plans to meet project Key Success Metrics (KSM) by basing evaluations on the performance of the two operational trucks.

The demo has achieved TRL 6, demonstrating electric trucking in a relevant environment with data feeds and monitoring in place. With these trucks in operation and yielding usable insights, the project may reach TRL 7 within the TULIPS timeframe (M48) if KSM is adapted to reflect the current fleet size. Early driver feedback indicates positive driving experiences and improved handling with the electric trucks. However, technical limitations, particularly regarding range and charging issues in colder weather, might present challenges, impacting load capacity and requiring dependence on external charging facilities. The limited power supply for charging also hampers scalability, as the trucks require access to sufficient charging infrastructure to operate reliably.

Key lessons learned are the slower-than-anticipated adoption rate for electric trucking and logistical constraints related to infrastructure. While two trucks are operational and demonstrating viable electric freight solutions, fully achieving the demo's goals will rely on addressing charging and range limitations to further electrify heavy-duty trucking at Schiphol. No immediate next steps are planned beyond the continued operation and data analysis of the two electric trucks in service, reinforcing TULIPS' commitment to advancing emissions reductions in airport logistics.

Demo #3 - Road traffic and transport Systems (T1.5)

EVIDENCE LEVEL

Reporting of deployability of Demo #3 (T1.5) is not possible at this time due to constraints on deployment requiring action by TULIPS. At this stage, this demo is not deployable.

USE CASE

As per the Grant Agreement, this demo is being led by TUD with the participation of EGIS and SNBV. The Demo aims to establish a traffic management system, where based on i.a. identification

of bottlenecks and hotspots, increased vehicle emissions, current and feasible traffic management measures and interventions, optimized control strategies and implementation of operational applications will be evaluated in a real-life demonstration at the lighthouse airport

This demo work includes:

- Identify local airport and regional road traffic bottlenecks and hotspots of increased vehicle emissions (SNBV)
- Identify current and feasible traffic management measures and interventions, and propose a set of measures and interventions that can be applied to ensure optimal traffic operations, including an initial estimation of their potential benefit (EGIS, SNBV)
- Perform simulation-based analysis of the proposed solutions for feasibility and effectiveness to reduce emission (TUD)
- Design of strategic control strategies and implementation in SNBV dashboard and road authority systems (SNBV, EGIS)
- Real-life demonstration of the approach for validation and, if required, calibration (SNBV, TUD).
- Evaluation of real-life demonstration (TUD).

Key Performance Indicators (KPIs) are:

- CO change (g, % vs. without coordination)
- NOx change (g, % vs. without coordination)
- FC change (L, % vs. without coordination)
- Veh delay (s, % vs. without coordination)
- Stop delay (s, % vs. without coordination)

Key Success Metrics (KSMs) of this demo are:

- KSM5: Propose evidence-based interventions to reduce late arrivals (passengers and freight) by over 25%.
- KSM6: Identify evidence-based required interventions to reduce time spent in traffic jams in and around the airport by 40%.

Demo #4 - International green travel (T1.6)

EVIDENCE LEVEL

Reporting of deployability of Demo #4 (T1.6) is not possible at this time due to constraints on deployment requiring action by TULIPS. A dedicated workshop was not held with the demo team. At this stage, this demo is not deployable.

USE CASE

As per the Grant Agreement, this demo is being led by SINTEF with the participation of TNO, TUD, NLR, SNBV, AVINOR, and SAGAT. Door-to-door international green travel is to be demonstrated on an integrated digital TRIP platform, based on a decentralised, distributed solution integrating several stakeholders by a federated architecture, supporting passengers in planning and execution of a door-to-door journey (related to T1.4 and the MaaS app).

Specifically, this demo work is to include:

- Demonstrate an integrated digital TRIP platform based on a de-centralized, distributed solution integrating several stakeholders through a federated architecture to support passengers in planning and execution of a door-to-door journey (SINTEF)

- Obtain travellers' needs and desires for and experiences with using the TRIP platform (TUD), evaluate travellers' decisions (TUD) and enhance/refine the TRIP platform (SINTEF).
- Implement journey execution real-time information and demand forecasting, both fed from operational systems (TNO)
- Integrate into the platform certain travel modes services, public and private transport and Micro-mobility (SNBV,NLR)
- Specify data and system requirements (interfacing to T1.1 and T1.2) (TUD)
- Development of use case specific prototypes: Federated service, passenger frontend (TUD)
- Development of federated optimization algorithm for proposing passenger journeys that optimise travel with respect to given personalised, multi-objective criteria (SINTEF)
- Investigate feasibility of additional options: i) Tracking the passenger to vehicle assignment throughout the whole journey (This would enable the mobility service providers to decide about waiting at modal interconnections) ii) Booking trips and iii) Apply the same architecture for the multimodal planning and execution for transport of goods.

The Key Success Metric (KSM) is KSM8: Test at least 5 interventions to achieve a 1% reduction in the carbon footprint of traveller's journeys by shifting to alternative transport modes (such as air to rail, using lower emission aircraft).

Demo #5 - Unattended charging demo development (T2.2)

EVIDENCE LEVEL

Reporting of deployability of Demo #5 (T2.2) is based on participation in an online workshop with the demo team and leads (June 2024) and subsequent update via questions sent to the demo team (September 2024). The Deep Dive Demo progress presentation was also used to add additional data and context (April 2024). Additionally, news articles by TULIPS were consulted.

USE CASE

The Demo is taking place at Rotterdam The Hague airport on September 17th and is being led by PIPISTREL with participation of Royal NLR (NLR) and Rotterdam the Hague Airport (RTHA).

This Demo wants to show how one can safely monitor the charging with the help of smart software, data sharing and camera images and prove that safely charging an electric aircraft without physical supervision is possible.

This demo work includes:

- Obtaining of EASA approved test plan (PIPISTREL)
- Provision of electric research aircraft (NLR, for OSL validation: AVINOR)

- Modification of BMS (Battery Management System) and commercial charger system (PIPISTREL)
- Implementation of innovative remote surveillance devices (PIPISTREL)
- Integration between charging equipment and airport management system (PIPISTREL, supported by AVINOR)
- Trialling of several contingencies and redundancy concepts with aircraft and charging system OEMs, airport authorities, ATM, first responders and other airport parties (PIPISTREL)

Key Success Metrics (KSM) are:

- KSM9: Save 1.5hrs personnel hours per charging session
- KSM10: Develop BMS system functions that detects any anomaly, with identification of unseen anomalies and false positive minimization
- KSM11: Get zero (0) human interventions during detected anomaly while charging of electric aircraft.
- KSM12: Achieve less than 5 sec. reaction time from charging malfunction to stakeholder notification

PROBLEM-SOLUTION FIT

Problem Statement

According to the demo leaders, the main challenges stemming from the lack of specific regulations for electric aircrafts are:

- Unattended charging is not permitted today;
- The charging process is not monitored remotely; and
- A person is required to attend the charging process (which leads to personnel costs)

Value Proposition

For airports, this is an unattended and remote-monitoring solution to charging electric aircrafts, enabling a reduction of ~2700 human resource hours/year (assuming 5 aircrafts charging per day) with faster response to anomalies and without human intervention on-site, including at nightime.

This solution will demonstrate efficacy and safety of aircraft charging and remote monitoring without on-site human intervention to EASA and other CAA, thus informing the development of new electric aircraft-specific regulations.

End users and Stakeholders

The end users are the Airports where the solution might be implemented and EASA and other CAA.

DEPLOYABILITY

Demo requirements

In order for the demo to be successful, all partners need to be present, aircraft needs to be airworthy (i.e. fit to fly, with certificate of airworthiness), the wi-fi/VPN/smart camera system needs to be functional, aircraft needs to be discharged (i.e. static charge must be eliminated for safety reasons) and it is ideal if the fire brigade can participate.

Status overview

Current Demo Status:

Deployed (Source: September update). No action from TULIPS is needed.

The objective of the feasibility study demonstration is to show that unattended charging of an electric aircraft can be done safely.

The planned test scenarios were as follows:

Test	Description	Data source	Desired response
1	Automatic detection of smoke/fire.	Smart camera	Stop charging, inform the fire brigade and airport authority.

2	Charging cables/power supply interruption test.	Aircraft	Stop charging, inform airport authority.
3	Safety issues inside battery pack (overvoltage, overtemperature, etc.)	BMS	Stop charging, inform airport authority and (depending on priority) fire brigade.
4	Sharing of charging data and other analytical data over the air via an internet connection to relevant parties	NA	Inform airport authority
5	Sharing of detected abnormalities in an open data environment.	NA	Inform airport authority and fire brigade

The technical tests with the aircraft and BMS were completed in April at PIPISTREL in Slovenia but additional testing only ended in May.

Further, there were issues with the installation of the Bosch smart camera system on location at Rotterdam The Hague, hence the delay in deployability (September vs. planned deployment in June) of this demo.

Prior to the September update, this demo was at TRL 6, having already completed technical tests on-site at Rotterdam The Hague airport, which is a relevant environment for this solution.

The understanding of the demonstration team regarding the deployment of the solution was that it was not expected to achieve TRL 8-9 in TULIPS. Our understanding is that after the full deployment of the demonstration at Rotterdam The Hague with a successful demo day, the solution would achieve TRL 7, as it would have been fully deployed in an operational environment. However, to further develop to TRL 8 and above, the final design of the solution would have to be ready to be used by customers. The demo team does not expect that the solution will be a “plug-and-play” type of solution by the end of TULIPS, hence TRL 7 is expected to be the highest achievable technology readiness level of this solution within

TULIPS. With the successful demo day at Rotterdam The Hague in September, we assess that it has achieved TRL 7.

Risks, external dependencies and mitigation plans

The greater risk for the demo success anticipated at the time of the workshop were weather conditions, an operational occurrence happening at the airport during the Demo Day, and operational challenges with running the Demo Day event sessions and activities with the guests.

In order to mitigate these risks, a back-up Demo Day date was planned and an event manager was considered. The Demo day occurred without any constraints to report (source: September update).

Next steps

The Demo Day was scheduled for September 17th and has been announced by TULIPS to the public (the September update confirmed it was held and successful).

LEARNINGS & INSIGHTS

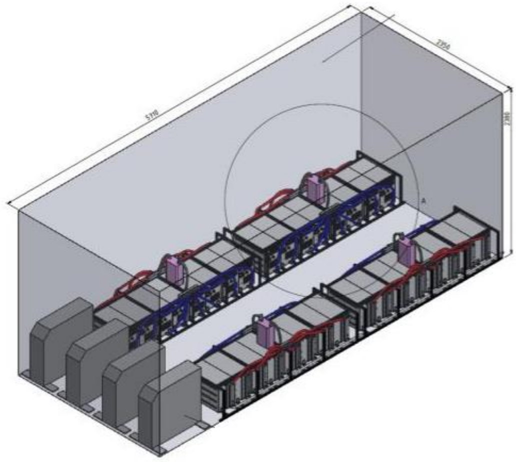
The deployability assessment for Demo #5 on unattended electric aircraft charging at Rotterdam The Hague Airport demonstrates progress toward safer, efficient, and remote aircraft charging, managed through smart software, data sharing, and camera surveillance. The demo tested remote anomaly detection and emergency response capabilities, a key development for EASA and other aviation regulatory bodies aiming to standardise unattended electric charging. The demo faced some initial delays in June due to technical installation issues with the Bosch smart camera system but was deployed successfully by September, reaching Technology Readiness Level (TRL) 7.

Key test scenarios focused on detecting fire/smoke, monitoring power interruptions, identifying battery safety issues, and sharing data via open networks with the airport authority and emergency services. The demo team achieved success with each contingency test, confirming the operational effectiveness of remote surveillance and anomaly detection. With the demo day on September 17, 2024, the solution demonstrated reliable monitoring capabilities and fast response, validating that unattended charging with smart surveillance can function safely in a live airport environment. Though achieving TRL 7, further progression toward TRL 8-9 would require a finalised, customer-ready product design, which is not anticipated within the TULIPS timeline.

Challenges encountered included inconsistent Wi-Fi connections due to metal-coated windows, the use of outdated terminology in regulatory language (fueling terms instead of charging), and system sensitivity to environmental factors like cloud reflections, which triggered false smoke alarms. These insights reveal areas for refinement in remote monitoring reliability and airport infrastructure compatibility, supporting the demo's value proposition for unattended charging to reduce personnel hours and improve safety response.

Looking ahead, the successful deployment at Rotterdam The Hague Airport provides a proof-of-concept to be analysed for scalability to other airports. This demo offers valuable regulatory and operational insights, setting the foundation for broader implementation and contributing to the regulatory roadmap for unattended charging in the aviation sector.

Demo #6 - Modular charging system demo development (T2.3)



EVIDENCE LEVEL

Reporting of deployability of Demo #6 (T2.3) is based on participation in an online workshop with the demo team and leads (June 2024) and subsequent update via questions sent to the demo team (September 2024). The Deep Dive Demo progress presentation was also used to add additional data and context (April 2024).

USE CASE

The Demo is led by PIPISTREL with the participation of SIN-EN, AVINOR and SNBV and is due to take place at Rotterdam The Hague Airport and the Oslo Airport, where a thermal runaway incident will take place to fire test with all batteries and investigate first responder reaction.

The first Demo was scheduled for July/August 2024, a second demo to November/December and the fire test for February/March 2025.

This demo work includes:

- Initial mapping of requirements of battery technology, safety requirements (T2.1), airport infrastructure and suitable charger topologies for modular charging infrastructure (SIN-EN, support from SNBV, RTHA)

- Conceptual design of universal charging infrastructure to permit airports to charge electric aircraft that will feature different battery voltage requirements, i.e., 270 to 1500 VDC or above (SIN-EN, support from RTHA).
- Design and fabrication of mobile battery bank (hundreds of kWh) using aerospace certified propulsion batteries and charger modifications to simulate representative future electric aircraft and converter which can work with charging infrastructure. (PIPISTREL)

Key Success Metric (KSM13): Reduce infrastructure needed by developing a universal voltage agnostic charging point for hardware and battery for different aircraft and battery types

PROBLEM-SOLUTION FIT

Problem Statement

According to the demo team, the main current challenges regarding charging infrastructure availability for electric aircrafts are:

- Lack of charging stations at airports for aeronautical applications
- Varying voltage needs
- Lack of regulatory framework for aeronautical electric charging stations
- Safety issues related with process of electric aircraft charging
- Lack of incentives to attract companies to electric aircraft charging systems
- Uncertain market need

Value Proposition

For airports, airlines, and electric aircraft manufacturers, who currently lack a suitable infrastructure to deploy electric aircrafts, this solution is safe and reliable, has a modular setup allowing for charging of various types of aircrafts (thus requiring a reduced amount of infrastructure) through the use of aerospace batteries. This solution leads to an estimated greater than 50% cost-reduction when compared with regular EV charging infrastructure.

End users and Stakeholders

The end users are aviation in general, including airports, airlines and electric aircraft manufacturers.

DEPLOYABILITY

Demo requirements

The demo requires electric grid power of 80kW , space allocation, safety analysis by the airport, 32 propulsion batteries, 4 chargers, a 40ft shipping container, external electric components (HV cables, contactors) and validated testing protocols.

Status overview

Current Demo Status:

Prototyping. Help is needed to ensure that the airport plan is approved for demo to occur (specifically there are details yet to be agreed with RTHA and AVINOR).

The objective of the study was to design and deploy a modular charging infrastructure for a wide range of aircraft with different voltage level requirements.

The planned tests are as follows:

Test	Test procedure	Description
1	Initial inspection	8 Velis battery pack parameters will be tested using in-house equipment and PeakCAN software.
2	Small junction box integration	A single junction box including all the components such as contactors and PLCs are integrated into 2 battery sub-modules (8 Velis battery boxes)
3	Big junction box integration	Big junction box is integrated and tested according to the design attributes

4	Initial qualification test	8 Velis battery packs will be charged to maximum voltage in parallel using 1 Skycharge M20 chargers (Max charge power 20 kW)
5	Final inspection	Additional 24 battery packs will be tested using in house equipment hardware and PeakCAN
6	System scale-up	In addition to 8 Velis batteries, 24 Velis batteries will be integrated into the modular charging system.
7	Final qualification test	The complete 32 batteries will be charged and discharged including small junction boxes and large junction box with 4 Skycharge M20 (80 kW)
8	Demo preparation	The container is prepared to be ship to The Netherlands and Norway

At the time of the workshop, the team had identified and characterised the batteries to be used and has been preparing for the initial qualification test (4) while introducing modifications to the junction box design due to the space constraints discussed earlier.

With the information we have at the moment, we assess Demo #6 as being at TRL3. In order to begin the initial qualification test, a set of tests have already occurred which are representative of an experimental proof of concept. Once the test has been completed, the demonstration will be in condition to move to TRL4. The initial hypotheses of how the solution will operate were established and the technology concept of the demonstration has been defined. The initial qualification test was being prepared standardly known as TRL3 to establish the proof of concept to then proceed to TRL4.

There was a concern regarding the delays in the demonstration and the consortium could help the demonstration team to meet all the requirements to proceed with the necessary test scenarios, so as to achieve TRL 6-7.

Risks, external dependencies and mitigation plans

The main risks identified are:

- Fire hazards
- Availability of electronic components on time (for the prototype and also when thinking about scaling)
- Uncertainty regarding the airport plan
- Procurement delays

In order to mitigate these risks, the team was conducting internal reliability tests as well as the identification of the most critical components that should be ordered as early as possible.

Regarding the dependence on airport stakeholders, the team was actively engaging to remove any roadblocks.

Next Steps

The qualification test was scheduled for Q2 2024 and the fabrication of the complete system was due in Q3 2024, with a planned Demo in Q4 2024 (roughly October/November).

LEARNINGS & INSIGHTS

Demo #6 addresses the need for adaptable, universal charging infrastructure across varying aircraft voltage requirements. This demo includes key safety tests, such as thermal runaway incidents, to evaluate first responder readiness. With a design aimed at significant infrastructure cost reductions (over 50%) compared to traditional EV charging, the demo seeks to enhance the feasibility of electric aviation through a modular, voltage-agnostic system.

The current status is prototyping at Technology Readiness Level (TRL) 3, with a progression to TRL 4 anticipated after initial qualification tests are complete. Planned tests include verifying battery pack parameters, integrating modular junction boxes, and completing a series of qualification and scale-up tests. The team faced design challenges, including space constraints that have prompted modifications to the junction box design, availability of critical electronic components, and coordination with airport stakeholders to finalise the testing environment. To support progression, the consortium may need to aid in navigating these dependencies to ensure readiness for TRL 6-7 within TULIPS' timeline.

Risks include fire hazards, potential procurement delays, and transportation issues related to the modular system's classification as dangerous goods. The team has identified specific components for early procurement and is conducting reliability tests to mitigate these risks. The transportation and modular system design challenges highlighted that additional space and safety considerations are necessary, and that battery configurations within modules may need to be simplified for feasible deployment.

Looking forward, the demo's success relies on completing qualification tests (planned for Q2 2024) and fabricating the full system by Q3 2024, with demonstration scheduled for Q4 2024. These insights are crucial for designing flexible, cost-effective charging infrastructure that accommodates diverse electric aircraft, addressing a critical barrier to scaling sustainable aviation.

Demo #7 - Airport-facilitated hydrogen flight demo development (T2.4)

EVIDENCE LEVEL

Reporting of deployability of Demo #7 (T2.4) is based on participation in an online workshop with the demo team and leads (June 2024) and subsequent update via questions sent to the demo team (September 2024). The Deep Dive

Demo progress presentation was also used to add additional data and context (April 2024). Additionally, a news article by TULIPS was consulted (April 2024).

USE CASE

The Demo is led by NLR with the participation of SNBV, AVINOR, SIN-EN and PIPISTREL and is due to take place at Rotterdam The Hague Airport and another lighthouse airport (TBD with AVINOR).

The liquid hydrogen (LH2) storage facility construction work is due to start in the summer 2024, the test and validation of a large part of the demo is planned for October 2024 and the execution should be complete in Q4 2024.

This demo work includes:

- Mapping of technical requirements for operation of hydrogen powered aircraft, H2 transport and handling, and hydrogen fuelling infrastructure on active airports, in liaison with airport stakeholders (NLR, with support from SNBV and PIPISTREL).
- Model based validation of the refueling process, and evaluation of liquid H2 fuelling infrastructure (different from gaseous hydrogen in WP4), procedures and regulation towards future large scale H2 needs, with focus tuned to GSE and aviation (SIN-EN, with support from AVINOR)
- Composing necessary test plan documents for performing the demo (NLR with support from PIPISTREL)
- Shake-down: test demonstration of fuelling infrastructure at NLR Marknesse (NLR)
- Evaluation of liquid hydrogen refuelling and tank swap system of hydrogen tanks (NLR)Initial mapping of requirements of battery technology, safety requirements (T2.1), airport infrastructure and suitable charger topologies for modular charging infrastructure (SIN-EN, support from SNBV, AVINOR)
- Analysis & evaluation of obtained data and lessons learned (NLR)

Key Success Metric (KSM14): Perform H-refuelling process at commercial airport.

PROBLEM-SOLUTION FIT

Problem Statement

Liquid hydrogen has been advanced as a major fuel option for the transition away from polluting and resource-limiting fossil fuels in aviation.

Currently, liquid hydrogen is not available at airports. Additional knowledge and experience with liquid hydrogen (LH2) is insufficient so as to develop deployable technologies and move from theoretical studies into practice. This experience would include: operational experience for airport operations handling of LH2 fuel; experience with the supply chain of LH2 to airports from local hydrogen production organisations; experience in LH2 safe handling; demonstrated feasibility of LH2-fueled flights and the set-up of regulatory and airport rules for LH2 infrastructures. For this to happen airport personnel (including the airport fire brigade) also would need specific training.

Value Proposition

This demonstration of a reliable infrastructure for liquid hydrogen flights will lead to the development of a proof-of-concept LH2 ecosystem to enable LH2-fueled aviation.

Specifically, it will build a storage facility at an airport capable of storing 8.6kg of LH2, supplied through an industry-wide LH2 trailer; provide access to LH2 on an active airport (for test or operational use; provide access to LH2 small scale hardware; produce a knowledge-base in LH2 infrastructure for airports, including LH2 supply, storage and dispensing procedures involving multiple stakeholders; train personnel on LH2 handling and safety (including fire brigade); and culminate with the demonstration of a LH2-powered drone flight, operated in an active airport.

End users and Stakeholders

The end users of this demonstration are the whole airport, aviation and LH2 fuel ecosystem, including airports and management, airport infrastructure developers and construction companies, local and national regulatory authorities, government ministries, producers of LH2 and of LH2 hardware, research institutes and owners and operators of (small scale) LH2 aircrafts. Ultimately the public are end users given the novelty and high potential of this fuel source for the green energy transition.

DEPLOYABILITY

Demo Requirements

This demo requires the following:

- Access to LH2 from hydrogen producers (AIRPRODUCTS)
- LH2 dewar (storage tank) at the airport, including obtaining a 'construction permit' to construct the LH2 dewar facility
- LH2 drone (the aircraft used to dispense the LH2) and LH2 drone tank is a major risk for the success of the demo as it is not completely under control of the TULIPS team.
- Local permits: Having an environmental permit (which allows the operation of the facility)
- Local permits: Having an approved 'change' through the Dutch CAA (IL&T) according ADR.OR.B.040
- Procedures/documents in place, including a LH2 filling procedure, a site survey and evaluation, a fire safety card, an explosion safety document, an evaluation of the installation (Dutch PGS 35 regulations and any changes in existing airport documents
- Trained personnel
- Interconnected hardware; hoses, valves and LH2 filling adapter

Status overview

Current Demo Status:

Prototyping. Help Needed. Demo team is waiting for the LH2 drone to be developed by NLR.

Through a partnership with AIRPRODUCTS, the supply of LH2 has been secured and routing has been planned. LH2 will be transported by trailer using the “basisnet” - national roads assigned for transport of dangerous goods - with the “last-mile” municipal permit for transportation of dangerous goods, and avoiding Beneluxtunnel along the way.

The authorization for the construction process for the LH2 Dewar has been granted, the environmental permit has been issued and CRYOWORLD has been selected as the dewar provider.

Initial training of the airport fire brigade has taken place.

At the time of the workshop (and confirmed on the September update), an LH2 drone is not ready for operations due to the technical readiness of the drone fuel cell and the LH2 dewar (storage tank) is not operational. If it is not operational, there will not be any dispensing of the LH2 to the storage tank. Currently the team is awaiting for an airworthy LH2 drone being supplied by NLR.

The definition of the concept behind the demonstration is complete. At the moment, the demonstration team is prepared to perform their first set of tests, and only needs to make sure that there is an aircraft airworthy for this purpose to proceed with the tests.

Conditions have been met for achievement of TRL3 (i.e. proof of concept has been established), but testing of the LH2 drone (prototype) has not yet occurred. Thus, TRL4 cannot be achieved until the completion of the first tests in the final provided LH2 prototype. This demonstration's main goal is to provide a proof of concept that flying an LH2 aircraft is possible, for an audience of airports, airlines and the scientific community. Given this scenario, it is expected that the demonstration achieves not more than TRL7, provided the LH2 drone is successfully tested as planned.

Risks, external dependencies and mitigation plans

The main risks and external dependencies are:

- Potential low willingness of LH2 suppliers to provide LH2 to the airport (due to low volume needed for the test)
- Dependance on permits to be issued by regulatory bodies
- Access to LH2 drone (the aircraft used to dispense the LH2) and LH2 drone tank, as this is not completely under control of the demo team

- Not having available personnel willing to work with LH2 and be trained
- Hardware not operating as expected
- Lack of knowledge on LH2 at airports can delay deployment.

In order to mitigate these issues, the team has considered including LH2 experts in the early stages of development. Additionally to extensive safety studies to respond to regulatory requirements, the team has planned a small scale "shake-up" activity in order to gain practical experience in handling of LH2 as well as involve local regulatory bodies upfront to get them engaged in the entire demo deployment process.

The team has been very conservative regarding safety risks, and has performed extensive safety assessments including risk mitigations for risks already perceived to be low and has included extra (more than prescribed or necessary) safety factors in hardware design.

Next Steps

Completion of the LH2 Dewar construction site and obtaining of a certified and airworthy LH2 drone to perform the demo. The demo is not yet scheduled, but if the drone is ready by the end of the year, the demonstration can be scheduled for Q1 of 2025.

LEARNINGS & INSIGHTS

Demo #7 aims to establish a proof-of-concept ecosystem for LH2-fueled flights. It includes constructing an LH2 storage facility, testing LH2 handling procedures, and ultimately demonstrating a flight with an LH2-powered drone. Initial work includes partnerships with AIRPRODUCTS for LH2 supply, a designated transport route, and a storage facility provided by CRYOWORLD. With construction underway and permits in place, the project now awaits the development of a certified airworthy drone by NLR to enable deployment.

As of the latest updates, the project remained in prototyping at TRL 3, with proof-of-concept complete but contingent on drone readiness to demonstrate. The demonstration of the LH2 fueling process at an active airport is expected to validate the infrastructure's viability and safety for broader application, aiming to achieve up to TRL 7 by providing LH2-fueled flight in a real-world setting. The demo is expected to advance regulatory standards and develop best practices for LH2 handling and storage at airports, alongside comprehensive safety training for personnel and collaboration with regulatory bodies. Completion and deployment of the LH2 drone could enable the demonstration by Q1 2025.

Key risks include limited LH2 supply due to low demand, dependence on regulatory permits, readiness of the LH2 drone, and safety concerns regarding handling and storage. Mitigations include early inclusion of LH2 experts, detailed safety studies, and conservative risk assessments with additional safety factors. Insights from the demo have underscored the complexity of regulatory requirements, unexpected costs of LH2-specific hardware, and challenges in small-volume LH2 supply chains. The successful deployment of this demo will pave the way for future large-scale adoption of LH2 fuel in aviation, contributing essential knowledge and experience to support a transition toward sustainable, zero-emission air travel.

Demo #8 - Airside electricity ‘traffic’ demonstration (T3.3)

EVIDENCE LEVEL

Reporting of deployability of Demo #8 (T3.3) is based on participation in an online workshop with the demo team and leads (May 2024) and subsequent update via questions sent to the demo team (September 2024). The Deep Dive Demo progress presentation was also used to add additional data and context (April 2024). Additionally, news articles by TULIPS were consulted (June 2024).

USE CASE

The Demo was planned to be led by SNBV with the participation of TNO, TUD and HERMES. However, TUD and HERMES do not have a direct involvement in the demonstration. Instead, SNBV is executing the demo and TNO is supporting it with monitoring.

As per the Grant Agreement, the demo work was planned to include:

- Defining the interaction and overlap with the planned project at Schiphol (upgrade of the Terminal E – ROEV project) that will be supporting this demonstration. (SNBV, TNO, TUD)
- Full integration of the Terminal E facilities with the available photovoltaic (PV) systems, charging infrastructure and novel energy storage systems and apply the integral control system developed in T3.2, incl. novel solar powered, direct DC charging infrastructure for electric vehicles (EV) (link with WP4) (SNBV)
- Establishing the connection of PV self-produced power to the main terminal building of Larnaca Airport, optimising renewable energy use though modelling power storage to achieve peak shaving and redistribution of power as per needs. Utilising smart building controlling know-how developed in T3.2 (HERMES)
- Implementation of an energy management system to reduce the grid impact of the charging infrastructure, floating production units (FPU)/electronic GPU (e-GPU) and provide peak shaving and congestion management at Schiphol and Larnaca airports (SNBV, HERMES)
- Supporting the demonstration activities at Schiphol (TNO, TUD)
- Performing the measurement campaigns at Schiphol and Larnaca airport and reporting of the results (SNBV, HERMES)

However, the final demo planned tasks are:

- Implementation of an energy management system to reduce the grid impact of the charging infrastructure, floating production units (FPU)/electronic GPU (e-GPU) and provide peak shaving and congestion management at Schiphol (SNBV)

- Supporting the demonstration activities at Schiphol (TNO)
- Performing the measurement campaigns at Schiphol and reporting of the results (SNBV)

The demonstration was initially planned for Schiphol Airport Terminal E but instead is taking place at the AB Terminal.

The metrics for minimum success of this demo are to:

- Increase the amount of charging facilities by implementing and energy storage system on the existing grid capacity
- Reduce CO2 produced in ~100 tons
- Provide 5 aircraft stands with enough power through one iron-flow battery and a pool of 6 E-GPU's

PROBLEM-SOLUTION FIT

Problem Statement

Currently airports rely mostly on polluting energy sources and shall transition to non-polluting renewable energy sources to align with the goal of Schiphol to be emission-free by 2030. As part of the transition to a new Smart Energy Hub, the airport shall replace diesel ground power units (GPUs) with FPU/e-GPUs and solve grid capacity challenges - it shall handle grid integration with existing and new infrastructure (e.g. photovoltaic systems) and reliably address power needs.

Value Proposition

An iron-flow battery solution is a more sustainable choice vs. lithium-ion batteries and is easier to implement when compared with power grid reinforcements that could be applied to replace diesel GPUs and address grid capacity challenges at Schiphol’s airport AB platform.

End users and Stakeholders

The end users are maintenance companies (i.e. KES) as electric vehicle owners and the KLM Ground Service operating in AB Platform of Schiphol Airport.

DEPLOYABILITY

Status overview

Current Demo Status:

Demonstrating.

The solution has been tested on the AB platform of Schiphol's. The AB Platform was chosen given it has limited grid capacity, and is an area of the airport where short-term scaling is a challenge for the airport. It has 20 stands and the goal is to replace GPUs with E-GPUs. The solution provided by this demo would thus provide local energy storage through an iron flow battery and overcome those challenges.

The system has been installed on site, site acceptance tests have been conducted, permits have been granted, a demo happened on July 25th, but testing is still ongoing (planned until 31-12-2024) and the demo team requires a permit extension (6 months) so as to perform the additional tasks:

- Integration of the demo solution system with the available PV system has a risk of not being completed if permit extension is not granted (within scope of Grant Agreement)
- Implementation of an energy management system to reduce the grid impact of the charging infrastructure, FPU/eGPU and provide peak shaving and congestion management is on track
- The team will prepare for scale-up of the solution so as to:
- Provide a proof-of-concept of the flow battery in a larger scale of airport operations, energy grid and buildings;
- Continue to develop skills and knowledge so as to provide airside solution for GPUs;
- Achieve CO_2 reduction of ~400 tons, aligned with the plans for the Mini SMART Grid Schiphol Northwest.

The demonstration defined the usage of the iron flow battery as the ideal type of battery for the demonstration in the initial definition of the concept. Afterwards, a set of initial testing at Schiphol began to start validating the requirements needed for a deployment of the demonstration.

At the time of the workshop (May 2024), the demonstration team self-evaluated their TRL level as TRL4. This is coherent with the fact that initial testing was already completed and further validation was already taking place to achieve TRL6. After the workshop delivery, the team has already successfully deployed the demonstration at Schiphol, confirming that the solution has achieved TRL7, being validated in an operational environment. To achieve higher levels of the TRL, a full deployment of the solution into large-scale operations is needed.

Risks, external dependencies and mitigation plans

Beyond safety risks related to system handling, there are some risks anticipated by the demo team:

- Risks of non-integration with existing PV system if permit extension is not granted
- Non-scalability of the prototype system being tested in this demo to a full operation.

In order to mitigate these risks, the team has been in close contact with the permit office to understand the requirements for the permit extension and be prepared to address them in a timely manner. Also, they have been in close contact with KES and KLM Ground Service to tailor the prototype to the end-user needs and prepare for scaling.

Next Steps

As immediate next steps, the demo team has requested a 6 month extension of the operation permit so as to test PV integration and scale the solution implementation as described in the “overall status” section, and is awaiting for approval.

LEARNINGS & INSIGHTS

Demo #8 showcases an iron-flow battery and an energy management system to support sustainable, grid-efficient power for ground operations. Initially planned for

Terminal E, the demo is instead being conducted at the AB Terminal, which has limited grid capacity and thus higher unmet need. This solution aims to replace diesel ground power units (GPUs) with e-GPUs and floating production units (FPUs), enabling renewable power integration and addressing grid congestion.

With a successful demonstration conducted on July 25, 2024, the project has achieved TRL 7. Testing continues on the AB platform, where the energy management system supports congestion management and peak shaving, increasing renewable power utilisation. However, the team requires a permit extension to complete the integration of photovoltaic (PV) systems, essential for scaling this solution across airport operations.

Key risks include delays in permit approval, which could affect PV system integration, and scalability limitations due to prototype constraints. In mitigation, the team is coordinating with permitting authorities, KES, and KLM Ground Service to align the demo with operational needs.

Insights reveal that full-scale deployment will need more equipment (e-GPUs) and trained personnel, underscoring the operational complexities of transitioning to sustainable energy solutions. Upon scaling, this demo could reduce CO2 emissions by ~400 tons, reinforcing Schiphol's goal to be emission-free by 2030 and demonstrating the viability of iron-flow batteries as a sustainable power solution in aviation environments.

Demo #9 - Heat supply facilities demonstration (T3.4)

EVIDENCE LEVEL

Reporting of deployability of Demo #9 (T3.4) is based on participation in an online workshop with the demo team and leads (May 2024) and subsequent update via questions sent to the demo team (September 2024). The Deep Dive Demo progress presentation was also used to add additional data and context (April 2024).

USE CASE

As per the Grant Agreement, the Demo work was to be led by SNBV with the participation of TNO, SAGAT and POLITO. However, the work is led by SNBV with the participation of TNO and is taking place at Schiphol.

The Hilton Hotel Infrastructure had been planned as the target building to influence. However, the Fire Brigade Building has been chosen instead because it has a 24 hours per day operation and uses the showers multiple times per day. This technical solution fits very well with the needed amount of hot water.

Note: another demo is subsequently being developed at Torino airport, also at the local fire brigade.

As per the Grant Agreement, this demo work was planned to include:

- Defining detailed performance parameters of the demand and supply side at Schiphol airport (SNBV, TNO)
- Translate predicting models and control algorithms applicable for this demonstration from T3.1 and T3.2 (TNO,SNBV)[10]
- Fully integrate heat storage systems with a storage time of several days into existing Hilton hotel infrastructure (SNBV). The Fire Brigade Building of Platform AB has been chosen instead because it has a 24 hours per day operation and uses the showers multiple times per day. This technical solution fits very well with the needed amount of hot water.
- Implement specific energy management system that will focus on minimising the demand peaks in hot water use (SNBV)
- Demonstrate fuel cell-based co-generation system for use as heat energy source at Torino airport (SAGAT, POLITO)[3]
- Support demonstration activities at Schiphol (TNO)
- Perform measurement campaigns at Schiphol and Torino airports and report the results (SNBV, SAGAT)[11]

The minimum success metrics set by the demo team were to:

- Phase out natural gas (~19,000 m3)
- Reduce CO2 produced in ~161 tons
- Increase battery storage increase (tbd MW)
- Provide a proof of concept heat battery

Key success metrics of Demo #9 are:

[10] These item is not considered
[11] Focus is on Schiphol airport, SAGAT is not participating in this task.

- KSM23: Minimise heat supply system implementation time with >30% investment reduction of the hot water demand with no loss of convenience in hot water use
- KSM24: Emission reduction of the water demand system
- KSM25: Cost decrease: abatement cost.
- KSM26: Cost decrease: LCOE
- KSM27: Reliability
- KSM28: User experience
- KSM29: Heat battery user acceptance is satisfactory or higher

PROBLEM-SOLUTION FIT

Problem Statement

Currently, airports rely mostly on polluting energy sources and shall transition to non-polluting renewable energy sources to align with the goal of Schiphol to be emission-free by 2030. As part of the transition to a new Smart Energy Hub, the airport shall phase out natural gas as a source of hot water and save energy with an energy-efficient system.

Value Proposition

The system has greater energy efficiency and relies on sustainable sources vs. current natural-gas water systems used at Schiphol. It has been designed so as to store heat for a longer period than water systems requiring natural-gas and is better insulated leading to a reduced heat dissipation and greater energy efficiency.

End users and Stakeholders

The end user is the Schiphol Fire Brigade building and brigade, but ultimately scaling of this solution shall impact all buildings with warm water usage. The owner of the Schiphol Fire Brigade Building, the fire brigade and the main contractor are involved stakeholders.

DEPLOYABILITY

Demo requirements

At Schiphol, this demonstration needs to be installed and measured for at least one full year so as to account for seasonal differences in hot water and heat usage. It is of great importance to have in place a supervising system to support and properly analyse all the data being generated from the usage of the solution system.

Risks, external dependencies and mitigation plans

The main risks identified were:

- The possibility that the system does not supply enough warm water
- That users are not happy with the speed of the water dispensing provided by the system
- That the system is too slow

In order to mitigate these risks, the team was to set up a back-up system that shall be in place in case water supply is suboptimal. Also, the team is planning user interviews so as to improve the design of the system and address their eventual concerns.

Status overview

Current Demo Status:

Demonstrating. Deployment on track at Schiphol. Installation of components has been completed in the first semester. First experiments will be run in the last part of the year. Technical documents have been prepared to inform the regional fire brigade and the national civil authority.

The solution was designed and the chosen thermal storage system is based on storing energy in the form of hot water for use in households and commercial buildings. It stores renewable energy as hot water in a double walled stainless steel vacuum insulated container (GVI®). The technology is able to keep water at very high temperatures for weeks without any significant energy loss. This makes the system a solution for hot water or heating needs in buildings with limited space and large renewable power generation.

The implementation phase has started on the fire brigade building of Schiphol Airport and not at the Hilton hotel as was in the GA. This is because they have a 24h day operation and use the showers multiple times per day, which fits well with the water supply expected capacity of the solution being demoed.

There has been a delay vs. planned execution in April/May, due to low personnel availability for the contractor and the low speed of internal airport processes and bureaucracy.

We understand that the solution is currently at TRL 5. The solution is being used at Schiphol and has already been validated in other environments than an airport environment and not for this use case.

This demonstration focuses on:

- A largely improved thermal storage unit, enabling medium-time storage, for which the first prototypes are installed in a domestic (= different) context
- The dynamic use in a new application and new environment

Thus, if this demonstration is successful, the solution would achieve TRL 7.

Next Steps

At the time of the workshop, the team was to conduct user interviews at the fire brigade building at Schiphol so as to improve the system design. Next, they were also to implement a specific energy management system that focuses on minimising demand peaks and hot water usage of the fire brigade.

The team also intended to demonstrate a fuel cell-based co-generation system for use as a heat energy source at Torino Airport. This was confirmed by the Torino demo owner in the September 2024 update, which shared that components installation has finished in the first semester of 2024 and that the first experiments will be done by the end of 2024.

Additionally, measurement campaigns are to be performed both at Schiphol and at Torino airports.

LEARNINGS & INSIGHTS

The demo team learned that it is important to better account for the bureaucratic processes that shall be addressed at the airport for such a project and also for contractor delays.

Demo #10 - Hydrogen GPU demonstration (T4.3.1)

EVIDENCE LEVEL

Reporting of deployability of Demo #10 (T4.3.1) is based on participation in an online workshop with the demo team and leads (June 2024) and subsequent update via questions sent to the demo team (September 2024). The Deep Dive Demo progress presentation was also used to add additional data and context (April 2024). Additionally, news articles by TULIPS were consulted (July, August 2024).

USE CASE

As per the Grant Agreement, Demos were to be led by KES with the participation of SNBV, (ZEPP/BALLARD), TNO, FHG, SINTEF, NLR, SAGAT, POLITO, and AVINOR and the first deployment was planned to take place at Schiphol. Specifically, ZEPP was the lead in developing the prototype for the demonstration.

In reality, the hGPU demonstration is being led by KES with primary contributions from SNBV, ZEPP, SINTEF, FHG, Torino airport, Laranaca airport. Specifically, ZEPP together with the GSE manufacturer Dynell developed and provided the hGPU for demonstration.

Activities performed to develop a hydrogen fuel cell powered GPU based on a battery GPU base will be key design and exploitation aspects such as:

- Operational profile for the H-GPU service for a typical day

- Develop hybrid power design, form factor/space limitations, integration strategy, hybrid hydrogen + battery power solution design choices, general arrangement of components in the available spaces, hydrogen system sizing
- Integration design
- Factory and commissioning testing activities performed.
- Additionally, the demo preparation work for both demos was planned to include:
- Set up test area on apron of lighthouse airport (KES, SNBV, FHG support)
- Site preparation and installation of H2-refuelling station, training of personnel (KES)
- Training of personnel for operation of GSE and fuelling and charging operations and Tier 2 service (KES, BALLARD,ZEPP)
- Obtain agreement/availability of necessary stakeholders, typically the ramp handlers (KES, SNBV)
- Show necessary compliance to applicable regulations to obtain all the necessary permits for demonstration (KES, SNBV)
- Use prototype in actual operation and do a Verification and Validation of concept: use during 3 months per wave, to monitor behaviour of equipment and operators. (KES, SNBV)
- Provide demo support, including monitoring and data collection, technical troubleshooting (SINTEF, SIN-EN, FHG, SNBV, NLR, BALLARD, ZEPP).
- Transferred knowledge of current use of eGSE and demonstrated h-GSE at Amsterdam Airport Schiphol, combined with action plan to demonstrate the h-GPU at fellow airports (KES, FHG, SNBV)
- Demonstration of the h-GPU at fellow airports (SAGAT, supported by all WP partners)[12]

Key Success Metrics are:

[12] Demonstrations are being developed in Torino and Larnaca Airports.

- KSM30: hGPU to successfully perform one turnaround of a narrow-body aircraft
- KSM31: hGPU to successfully perform a full-shift without refuelling, comparable to the current Diesel GPU
- KSM32: Get the hGPU user acceptance survey result satisfactory or higher
- KSM33: Achieve hGPU refuelling time comparable to the Diesel derivate
- KSM34: Reduce hGPU noise to at least 5-10dB below Diesel GPU noise, should be similar as eGPU.
- KSM35: Ensure that the operational costs (excluding direct energy cost, i.e. fuel and electricity) per 1 kWh generated by hGPU is less than or equal to the cost of 1 kWh by (E-GPU)
- KSM36: Achieve successful refuelling of the hGPU with a process efficiency comparable to Diesel GPU (using the rented mobile refuelling station).
- KSM42: Achieve GHG emission reduction with the potential to zero emissions in operations due to hGPU.

PROBLEM-SOLUTION FIT

Problem Statement

Airports rely mostly on polluting energy sources and shall transition to non-polluting renewable energy sources to align with the goal of Schiphol to be emission-free by 2030. As part of this transition, electric-powered GSE operations have some challenges that might be addressed by other non-polluting power sources.

Value Proposition

Hydrogen-powered GSE (h-GPU and tow tractor/vehicles) solutions have several potential advantages, particularly when compared with electric-powered GSE solutions, as these:

- Are zero-emission GSE solutions which can cover heavy-duty GSE
- Can potentially reduce airside traffic compared to battery-powered GSE

- Have low net congestion by not requiring electricity use
- Are potential ground power solutions for wide body aircrafts that do not require long charging times on battery GPUs, thus reducing downtime when compared to battery-powered electric vehicles
- Enable GSE in areas where power is not available nearby to transition away from diesel
- Require lighter cables, thus reducing strain on GSe personnel
- Allow for more flexible operations in terms of power source location.
- Allow for live refuelling similar to current diesel refuelling practices
- Typically allow for larger autonomy

End users and Stakeholders

The end users of this demo are: ground handling service providers, Schiphol airport (demo phase), fellow TULIPS airports (subsequent phases) and ultimately European airports, airlines (incl. self-handling airlines), maintenance providers and airport GSE providers.

DEPLOYABILITY

Demo requirements

In this demonstration, there were no changes needed regarding people nor equipment when using diesel GPUs or electric GPUs. It was necessary to have in place a hydrogen ground power unit and there were no additional resources required. Nevertheless, it is worth noting that the main efforts were made in the following areas:

- Equipment: mobile refuelling truck rented – after a problem with hydrogen quality, the hGPU was driven to a nearby refuelling station outside the airport to be refuelled.
- People: many hours were needed to gain the permits and inform and educate all stakeholders involved. No additional human resources were needed to deploy the demonstration.
- Other resources: mainly time needed for the preparation (meetings for permits, meetings with stakeholders such as the involved airline).

Risks, external dependencies and mitigation plans

The main risks and external dependencies for the success of this demo were anticipated as the following:

- Airport permit process and requirement
- Approval within the GSE operations
- Lack of general knowledge and experience of operations personnel about safety and handling of H2
- Potential H2-GPU tethering problems

In order to mitigate these problems the team has explored the following actions:

- Constant and close communication with the permit office at the airport
- Training of handling teams
- A telemetry system can be deployed to address eventual tethering problems

Status overview

Current Demo Status:

Prototyping. Deployment on track. *No action required by TULIPS.*

At the time of the workshop, the demo at Schiphol Airport was scheduled for June 25th and demo happened as planned, as per news article from TULIPS.

The planned actions for the demo were the following:

- The Planning Phase includes the development of test protocols, validation checklists, and obtaining approvals and clearances from authorities. It also involves setting up high-level requirements and conducting workshops with stakeholders.
- The Research Phase includes collecting necessary GPU data, equipment sizing, and reporting of results. Inputs were gathered from stakeholders, including a 5-day battery GPU power profile from Schiphol airport.
- The Development Phase includes identifying a GPU OEM, designing and developing the hGPU, beta testing, commissioning, and developing training materials.

- In the Demonstration Phase, the hGPU will undergo testing in two phases to ensure its safety and performance. The first phase involves testing in a workshop, followed by testing at a gate under normal operating conditions with passengers. During testing, various stakeholders including airport operators, authorities, fire brigade, refueler, ground handlers, hGPU manufacturer, airline, and aircraft technicians will be involved. Operations will be monitored, and any issues that arise will be addressed. At Schiphol airport, the hGPU will also be refuelled with hydrogen during the demonstration. The refuelling involves an external party providing hydrogen at airside using a refuelling truck. Press releases will be issued to accompany the demonstrations. The results from these tests can be used for hydrogen logistics planning and provide guidance for the future adoption of hydrogen as a clean fuel at other airports.

At the time of the workshop, the external permit was almost ready and safety and compliance at Schiphol were ready as well. The demo location within Schiphol had been selected and an emergency plan was ready (with the fire brigade involved). Regarding the product development, the H2-GPU prototype design was ready, a refuelling bowser had been selected, and the H2-GPU prototype manufacturing was almost done. Additional demos were expected at Larnaca Airport and Torino Airport, respectively.

Early stages of the solution development were thoroughly completed in the planning and research phase of the demonstration. Further beta testing had then also been completed to validate the solution and TRL4 had been already achieved by the time of the workshop.

Preparations for the achievement of TRL6 were in place at the time of the workshop with the execution of further testing.

Currently, with the deployment of the first demonstration at Schiphol, the demo at Schiphol has finished and additional demos are scheduled for Torino (November 2024) and Larnaca Airports (March 2025). Hence, the solution has achieved TRL 7.

Next Steps

At the time of the workshop, the permit was to be granted, manufacturing of the hGPU prototype was to be completed and the demo carried out. After this, further demos at fellow airports Larnaca and Torino were to be carried out, including all preparations on-site.

LEARNINGS & INSIGHTS

Demo #10 showcases another sustainable alternative to diesel GPUs at Schiphol Airport. The hGPU uses a hybrid hydrogen and battery design, addressing challenges of airside traffic congestion and reliance on polluting energy sources. The project includes designing the hGPU, setting up refuelling infrastructure, training personnel, and executing on-site demos, with additional demonstrations planned at Torino and Larnaca airports.

The demo at Schiphol, completed in June 2024, reached TRL 7 by demonstrating the hGPU's operational feasibility under real airport conditions. The hGPU met key success metrics such as performing a full aircraft turnaround and operating without refuelling interruptions, with further evaluation on refuelling efficiency and emissions reductions ongoing. Through close collaboration with the permit office, extensive training for ground personnel, and a telemetry system to mitigate tethering issues, the team addressed risks related to safety, regulatory compliance, and technical challenges.

Initial insights revealed gaps in hydrogen knowledge among airport personnel, limited supplier availability, and the need for clear standards around hydrogen use in aviation. These learnings emphasise the need for robust training and streamlined permitting processes. Successful deployment at Schiphol paves the way for further tests at Torino and Larnaca, with the potential to inform hydrogen logistics planning and support hydrogen adoption as a clean fuel across European airports.

Demo #11 - Hydrogen tow tractor demonstration (T4.3.2)

EVIDENCE LEVEL

Reporting of deployability of Demo #11 (T4.3.2) was not possible due to constraints on deployment requiring action by TULIPS. A dedicated workshop for this demo specifically was not held with the demo team. However, the WP lead has provided an update in October 2024 which was used on the Deployability section below.

USE CASE

Grant agreement plans for Demo #11 are described in the "Use Case" section of Demo #10 (T4.3.1).

Key Success Metrics as per GA are:

- KSM37: hTowtractor to successfully perform one maintenance tow
- KSM38: hTowtractor to operate a shift without refuelling for approx. 4h or 30km of autonomy, with a half loaded/ half empty Narrow Body aircraft
- KSM39: Achieve successful refuelling of the hTowtractor with a process efficiency comparable to Diesel GPU (using the rented mobile refuelling station).
- KSM40: hTowtractor to successfully perform a set of tow operations until refuelling (compared to Diesel Towtractor)
- KSM41: Get hTowtractor user acceptance score satisfactory or higher
- KSM60: Achieve GHG emission reduction with the potential to zero emissions in operations due to hGPU

DEPLOYABILITY

Status overview

Current Demo Status:

Prototyping.

As per the October review by the WP lead, we understand that after amendment 2 was completed in July 2024, the further planning and development could be recovered and TLD and BALLARD are working to finish the prototype. The prototype should be delivered to Schiphol airport no later than May 2025 to be demonstrated in real operation during and right after summer 2025. Prototype development and demo planning (incl. Stakeholder engagement and permit planning) is already underway.

LEARNINGS & INSIGHTS

Building on insights from the hydrogen GPU demo (Demo #10), this demo aims to validate the hTowtractor's ability to perform maintenance tows, operate up to four hours without refuelling, and achieve zero emissions in line with Schiphol's goal of becoming emission-free by 2030.

As of October 2024, the project is in the prototyping phase. Following a timeline adjustment in July 2024, TLD and BALLARD have resumed development and expect to deliver the prototype to Schiphol by May 2025, with demonstrations scheduled to begin in the summer 2025. Risks include potential delays in securing the necessary permits and ensuring operational readiness among ground support teams. To mitigate these, the team is focusing on close coordination with permitting offices and engaging stakeholders early for training and operational planning. Next steps involve finalising prototype development and preparing the demo environment at Schiphol, aligning all logistics to support a successful demonstration.

Insights so far underscore the importance of aligning hydrogen knowledge and infrastructure with operational needs at airports, with early-stage collaboration proving essential. The anticipated deployment at Schiphol will provide valuable proof-of-concept data and support scaling hydrogen-powered solutions for broader adoption in airport ground support, contributing to TULIPS' vision for sustainable aviation.

Demo #12 - Executing large-scale SAF supply chain (T5.2)

EVIDENCE LEVEL

Reporting of deployability of Demo #12 (T5.2) is based on answers to a survey form (October 2024) and the Deep Dive Demo progress presentation (April 2024).

USE CASE

As per the Grant Agreement, the Demo work is being led by SKYNRG with the participation of KLM and is taking place at Schiphol Airport.

The work planned includes:

- Prepare and operationalize the supply chain from the SAF production plant “DSL-01” to Schiphol Airport as defined in task 5.1 (developing the supply chain). In this demo, 30,000 mt of neat SAF will be supplied over a 4-month period. This volume is based on DSL-01’s full production capacity, which might not yet be reached during the first months of operation due to start-up challenges (out of scope for this project). Nevertheless, the supply chain will be set up for the entire volume of 30,000 mt. This task will be considered completed when 30,000 mt has been supplied, which will take more than 4 months in case full production capacity is not reached. (SKYNRG, KLM)
- Shipment of neat SAF to the blending terminal in Port of Amsterdam. (SKYNRG, KLM)
- Blending the neat SAF with conventional jet fuel, adding required additives and certification to Jet A-1 specifications(SKYNRG, KLM). Integrating the SAF blend into the conventional jet fuel supply chain to Schiphol Airport. (KLM)
- Handling of the administrative processes required to claim these volumes under the RED-II, including full traceability and sustainability reporting of the supply chain. (SKYNRG, KLM)
- Monitoring and evaluating the effects of the long-term presence of SAF in the pre-airport’s infrastructure, i.e. by monitoring the performance and renewal frequency of filters. (KLM) and by analysis of the import and hydrant filters and filter water separators. (KLM). Evaluating all encountered challenges and issues. (SKYNRG, KLM)

PROBLEM SOLUTION FIT

Problem Statement

The demo aims to reduce GHG emissions related to air transport and focuses on scaling of the SAF market by demonstrating the feasibility of large scale SAF supply at Schiphol Airport.

Value Proposition

The demonstration includes defining the boundary conditions for large scale SAF supply, covering the logistical challenges, blending requirements as well as SAF accounting, sustainability compliance and contracts together with relevant stakeholders such as the airline responsible for fuel procurement (KLM), the (blending) infrastructure owner and the airport (Schiphol).

End users and Stakeholders

The end user is the airline (KLM). The Schiphol Airport, fuel supplier (SkyNRG) and infrastructure owners (blend terminal & port of Amsterdam) are involved stakeholders.

DEPLOYABILITY

Risks, external dependencies and mitigation plans

The main risks are:

- Shortage of SAF availability;
- High costs for sourcing of SAF;
- Technical challenges at blending location (revamping);
- Unclear policy and accountability of SAF supply chains.

The first two risks are under discussion by the demo team. Others are mitigated by sharing learnings and including relevant expertise as needed.

Status overview

Current Demo Status: Planning.

The task has recently been amended since the foreseen SAF provider (SkyNRG) timeline does not match TULIPS. The airline (KLM) is now working on an alternative supply of SAF.

This demo work is not on track, neither demonstrating, but is delayed due to amendment and carry-over of responsibilities. Restart is being prepared with relevant partners so there is no need for additional help by consortium at this moment. Initial activities to set up the supply chain are ongoing.

Next steps

Since the Amendment has recently been approved, the demo team is now reengaging in planning next steps. The estimated deadline to fully deploy the demonstration is Q2 2026.

LEARNINGS & INSIGHTS

The deployability of Demo #12, focusing on establishing a large-scale Sustainable Aviation Fuel (SAF) supply chain at Schiphol Airport, represents a significant step toward reducing GHG emissions in aviation. Led by SKYNRG with participation from KLM, this demo aims to set up a supply chain from the SAF production plant “DSL-01” to Schiphol, delivering 30,000 metric tons of SAF over four months. This involves transporting SAF to the Port of Amsterdam for blending with conventional jet fuel, integrating it into Schiphol’s fuel infrastructure, and ensuring compliance with sustainability standards under RED-II.

Currently in the planning phase, the project experienced delays as the timeline for SAF production from SKYNRG’s DSL-01 plant did not align with TULIPS. KLM is now pursuing alternative SAF sources to keep the project moving. Initial activities for supply chain setup are underway, though full demonstration deployment is now expected by Q2 2026.

Key risks include SAF availability, high sourcing costs, and technical challenges at the blending site. To mitigate these, the team is exploring alternative SAF options and bringing in expertise to navigate infrastructure and regulatory challenges.

Early insights indicate that the SAF market remains in a nascent stage, with limited supply and developing supply chain infrastructure. This demo will provide critical knowledge to scale SAF integration across airports, potentially setting a foundation for the broader adoption of sustainable fuels in aviation.

Demo #14 - Design waste out of terminal environment taking into account passenger behaviour (T6.2)

EVIDENCE LEVEL

Reporting of deployability of Demo #14 (T6.2) is based on participation in an online workshop with the demo team and leads (June 2024) and subsequent update via questions sent to the demo team (September 2024). The Deep Dive Demo progress presentation was also used to add additional data and context (April 2024).

USE CASE

As per the original Grant Agreement, the work was to include:

- Design waste out of terminal environment taking into account passenger behaviour (M10-M48), Lead: TUD. Participants: SNBV, EME, TUD, AVINOR, HERMES
- Organise a series of co-creation sessions with all relevant stakeholders in the value chain including waste processors, logistical experts, retailers, and passengers (SNBV, TUD)
- Implement the co-created solutions as demonstration projects and tested at Schiphol. Demo projects to be copied at fellow airports to evaluate location, culture and airport use effect (hub vs regional, business vs leisure travel) (SNBV,AVINOR + all task participants)

The demonstration is led by AVINOR as per an amendment to the original Grant Agreement, and comprises of six initiatives:

G. Improve the analysis of information by the waste bins. Instead of visualising the sorting of waste by material, it takes into account the type of product;

H. New solution to collect PET bottles/cans;

I. Implement a reusable coffee cup system to replace disposable cups;

J. Implement a dishwashing service with reusable to-go tableware;

K. Incentivise zero-packaging at the airport;

L. Implement an internal centralised system for waste logistics;

All initiatives were developed using co-creation sessions with relevant stakeholders in the value chain waste processors, logistical experts, retailers, and passengers. The last three co-created solutions are being implemented as demonstration projects and tested at AVINOR. Based on findings from these demonstrators, applicability and adaptability to fellow airports will be evaluated and implemented where possible.

The Key Success Metrics are:

- KSM49: 20% waste reduction per passenger
- KSM50: Smarter product use and manufacture: Of 20% waste reduction, partly go through R0-2 prevention strategies before ending up in R8.
- KSM51: Extend lifespan of product and its parts: Of 20% waste reduction, partly go through R3-7 extending lifetime strategies at least once before ending in R8.
- KSM52: Useful application of materials: Of 20% waste reduction, partly go straight to R8 improve recycling strategy.

PROBLEM-SOLUTION FIT

Problem Statement

The problem that this demonstration seeks to address is the lack of knowledge and siloed ways of working of airports stakeholders on how to manage waste.

Currently, high quantities of waste are unnecessarily incinerated due to incorrect source separation and lack of implemented 9R-strategies.

Value Proposition

Four initiatives seek to give consumers better conditions to correctly dispose of their waste, by providing better information on how to do so, install more user friendly waste collection points, and encourage the usage of reusable items. Two initiatives focus on improving internal operational processes, particularly when related to logistical aspects and recycling efforts of the airport. By deploying these initiatives, the demonstration covers the entire waste management value chain, enabling the introduction of new processes and services that integrate with each other will allow for a circular management of waste within an airport.

End users and Stakeholders

The main audience of this demonstration are airport passengers and employees. Nevertheless, given the necessity to include the value-chain, and the challenges in waste management faced on the back-end, additional stakeholders that engage with airports are also involved, mainly food and beverage companies, business partners and waste handlers.

DEPLOYABILITY

Demo requirements

For the waste logistics system, containers and weighing systems need to be rented and AVINOR and TU Delft partners involved in the TULIPS project need to spot-check waste bags, give feedback, and transport waste to the basement. Furthermore, employees of the participating units need to be trained on the new system and people need to be hired to dispose waste on the waste station.

For the reusable tableware, communication materials, reusable containers and drop-off boxes, where passengers can scan their container and receive their deposit back need to be customised and ordered. Furthermore, people need to be hired to collect, wash, and return the containers.

Risks, external dependencies and mitigation plans

The main risk identified by the demonstration team is the lack of manpower to pilot all these initiatives due to challenging hiring processes within the airport environment. Other risks involve employees not learning fast enough new behaviours when it comes to waste weighting and communication with passengers about the reusable bowls. Further, there is a risk of units dropping out of the pilot and not having representative numbers to analyse.

Status overview

Current Demo Status:

Prototyping. Deployment on track. The last three co-created solutions are being implemented as demonstration projects and tested at AVINOR. Based on findings from these demonstrators, applicability and adaptability to fellow airports will be evaluated and implemented where possible. Specifically, *help is needed from Schiphol airport to enable implementation of three of the initiatives as described below.*

Status by initiatives:

A. Improve the analysis of information by the waste bins. Instead of visualising the sorting of waste by material, it takes into account the type of product:

No testing was done at Schiphol due to capacity issues at the airport. Further implementation awaits Schiphol's decision.

B. New solution to collect PET bottles/cans;

Minimal testing was done at Schiphol. Small-scale test at Rotterdam The Hague is being conducted. Further implementation awaits Schiphol's decision.

C. Implement a reusable coffee cup system to replace disposable cups:

No testing besides stakeholder feedback was done at Schiphol. Further implementation awaits Schiphol's decision.

D. Implement a dishwashing service with reusable to-go tableware;

Initiative D is being implemented at AVINOR Oslo Airport focusing on reusable tableware. A system was developed to replace single-use takeaway food containers with reusable takeaway food containers using a deposit system. This includes the disposable food containers used for serving passengers at AVINOR's food and beverage partners and the containers used for making pre-packaged food in the central kitchen. Pilot will commence on November 2024 at AVINOR at the international section with two serving units and six return stations for the reusable food containers.

E. Incentivise zero-packaging at the airport;

This initiative is to be deployed at AVINOR Oslo Airport, where the demo team has re-designed the waste and recycling area in the basement by proposing a new layout, making use of different methods of wayfinding, and optimising the space with signage. The intent is to enable workers who are returning packaging solutions to easily detect the designated areas for these items, enhance trust in the circular packaging economy, and increase capacity for future circular solutions. Other initiatives around diverse packaging items to achieve a packaging-free airport were identified and a roadmap was developed.

The new waste station structure was tested in a virtual reality environment with employees at AVINOR. Further, interviews were conducted to receive feedback on the roadmap. Implementation timeline is to be determined, but expected next year.

F. Implement an internal centralised system for waste logistics:

For this initiative, a conceptual service design was tailored for AVINOR. The proposed service includes a centralised waste station in the form of container hubs placed throughout the terminal, a feedback system for improper waste separation, and a weighing solution for waste measurement, supplemented with a financial disincentive mechanism to stimulate waste reduction. The pilot stated in October 2024 and will be running for the whole month. Evaluations are based on the quantified waste separation rate and qualitative employee interviews.

In conclusion, given that all the initiatives on this demonstration are a result of academic work, what is intended as an outcome is to generate knowledge to then translate into new practices and generate better engagement with passengers. Due to this, no commercial application is expected and the TRL to be reported here only considered the phase of testing on which they were present at the time of the workshop. Since all initiatives are already ongoing and preparing for the deployment of their final versions, we can conclude that they are in TRL4, given that a practical application has already taken place. Once all initiatives have been successfully tested in the partner airport, the demonstration will achieve TRL6. In order to achieve TRL7, the final version must be obtained and successfully deployed.

Next Steps

Perform the final demonstration of initiatives D, E and F at AVINOR, already taking into account all the results obtained from the data gathered so far.

The team is also considering the potential development of a scientific publication entitled: “Passenger nudging strategies based on bin iconography”. This is still pending confirmation.

LEARNINGS & INSIGHTS

The deployability of Demo #14, aimed at reducing waste in airport terminals by considering passenger behaviour, involves six key initiatives across the waste management value chain. These initiatives include enhancing waste sorting information, introducing reusable systems for coffee cups and food containers, incentivizing zero-packaging practices, and implementing centralised waste logistics. Led by AVINOR with input from multiple partners, this demo has progressed through co-creation sessions with stakeholders like waste processors, logistical experts, and passengers, resulting in pilot tests now underway at AVINOR’s Oslo Airport.

Currently, the demonstration is at TRL 4, with initiatives in prototyping and pilot stages. As these pilots are evaluated and refined, the demo is on track to reach TRL 6 by implementing validated solutions more broadly. However, implementation of three initiatives at Schiphol awaits approval, limiting initial planned testing in those areas.

Key risks include staffing shortages for managing the pilots and potential challenges in employee adaptation to new waste management behaviours. The team is addressing these by engaging employees through training and deploying a feedback system on waste separation. Insights gained so far emphasise the value of co-creation across the waste management chain and tailoring initiatives to various airport environments, with the broader goal of establishing circular waste practices and generating actionable data for future airport waste management innovations.

Demo #15 - Re-use secondary materials through the application of circular building principles (T6.3)

EVIDENCE LEVEL

Reporting of deployability of Demo #15 (T6.3) is based on participation in an online workshop with the demo team and leads (June 2024) and subsequent update via questions sent to the demo team (September 2024) and update via review of v2 draft of this deliverable section (October 2024). The Deep Dive Demo progress presentation was also used to add additional data and context (April 2024).

USE CASE

The demonstration is led by EME with the participation of SNBV, AVINOR, EGIS and HERMES.

As per the Grant Agreement, this demo work shall include:

- Define common elements in the airport building portfolio and collect and manage data, using the tools developed by EME like material passports. (EGIS).
- Propose low-carbon scenarios of reuse by Life Cycle Analysis. (EGIS)
- Define construction standards for optimal specifications for reuse. (SNBV)
- Create a database of functional requirements for all disciplines at the airport, regarding the common elements. (SNBV)
- SNBV and AVINOR will match timing of projects to possible release of common elements from the building portfolio (SNBV, AVINOR). This will be supported by EME.

- Initiative: A Tracking & Tracing module to connect Resources Passports with real-life assets and follow them through value chains will be demonstrated by EME at SNBV and validated at fellow airports. (EME)
- Investigate novel building design approaches to be integrated in current development asset management processes (systems engineering) (SNBV) Maximise secondary material use in new project designs (using EME platform) measured by the Building Circularity index (EME)
- Test circular building principles in a zero-carbon design project in co-creation with architects and stakeholders (with support of EGIS). This will be validated at fellow airports (HERMES, EGIS – SNBV - AVINOR)
- EGIS and SNBV will establish design guidelines and reference, standardised component design will be provided. This will be validated at fellow airports (EGIS-SNBV, AVINOR).

As part of this work, two initiatives are being conducted to demonstrate the re-use of secondary materials through the application of circular building principles:

1. Re-use Materials (track & trace); and
2. Circular Principles Handbook.

The Key Success Metrics are:

- KSM53: Achieve 60% building circularity index for at least one new building.
- KSM55: Extend lifespan of product and its parts: 100% of the products in the pilot program are equipped with a digital passport and that 60% of these passport-equipped products are reused in the airport facilities

PROBLEM-SOLUTION FIT

Problem Statement

The construction sector is one of the most polluting sectors in the world. This happens, in part, because the mainstream opinion is that the materials used are not reusable.

This general idea is supported by the lack of information on what type of materials are being used in this sector, since there isn't any sort of physical or digital inventory that could provide a clear identity of each material so that it could be possible to associate value for those materials and to support which materials are suited to be reused.

One additional point that contributes to this problem is that there are many stakeholders involved in airport construction, which makes change very difficult to implement circular economy principles, since this systemic change needs to be collaboratively addressed by all parties involved. Also, even though there are good practices for circular design, they are too general and high level. The same is true to publications being made about circular economy related to the construction sector, but none specific for airports. Here lies a gap between the knowledge that exists regarding circular economy that not only does not meet the needs of construction at airports but also provides guidance through best practices that are not feasible or only focused on one part of the value chain.

Value Proposition

The digital passport solution will allow for materials to gain an identity. This passport will be available on the EME marketplace and this facilitates reuse of the materials by bringing together supply and demand onto the same platform. Even though the platform allows for preventing new purchases, reducing waste and reusing materials, the ambition to apply circular economy principles at airports stretches further. Hence a circular economy handbook will be set-up and tested that will provide a user-friendly checklist of procedures in all construction processes (also demolition, construction with new materials or dealing with organisational challenges).

End users and Stakeholders

From the client side, the end users are the construction or infrastructure departments of airports. All involved stakeholders such as contractors, architects, engineers, designers, etc. in the construction phase are relevant to this demo.

DEPLOYABILITY

Demo requirements

Mainly hours. EME took over the main role from Schiphol to develop the handbook, which is part of Amendment 3.

Risks, external dependencies and mitigation plans

No risks were identified

Status overview

Current Demo Status:

Prototyping.

At the time of data collection, the demo team has informed us that TULIPS should be able to help with getting access to assets from Schiphol. By assets, we mean construction resources (could be doors, windows, steel beams, roofs, etc). The team had been waiting for assets to follow at Schiphol and had not received assets that are either on the move or are valuable enough to track and trace with active codes. Since then, the QR codes linked to passports were already developed, but real-time tracking is something more unique which is therefore also the aim of Schiphol and EME implementing the system of tracing those (15.000 implemented tags are needed). Up to September, the team did not have any assets and no confirmation of using real-time tags at the airport.

In the meantime, EME took over as part of amendment 3, and the QR codes linked to passports have already been piloted at Larnaca, Amsterdam and Oslo to test the track & reuse initiative. Nevertheless, the active tags and real-time tracking is to be developed and tested at Schiphol by EME in the upcoming months.

Regarding the Circular handbook, two processes are taking place: collection of examples/practices from Schiphol airport; desk research to find theoretical examples and practices by EME.

For this demonstration, TRL level will be assessed according to the developments achieved with the track & reuse initiative. Given the conceptual nature of the guidebook, it is not something that we can establish a TRL for. Following this disclaimer, we assess that the demonstration is at TRL5 since it is currently being validated in a relevant environment. Taking into consideration that pilots are already ongoing, once we have their conclusion, the demonstration will reach TRL6. In order to progress to TRL7, the final version of the solution needs to be successfully demonstrated.

Next Steps

Finalise data collection from pilots at Larnaca, Oslo and Schiphol, feeding the digital passport and finalise it. Additionally, the environmental impact assessment is to be performed by EGIS. The ultimate goal is to prove the track & reuse initiative and to close this pilot.

For the handbook, validation of principles are scheduled to happen at the participating airports in Q1 and Q2 2025.

LEARNINGS & INSIGHTS

Demo #15 is prototyping, at TRL 5, being validated at Larnaca, Oslo, and Schiphol airports. QR codes and digital passports are active, though real-time tracking remains a challenge as assets need to be manually updated each time they move. The Circular Principles Handbook, still in development, shall provide a structured checklist for airports to implement circular design practices.

Key insights reveal that manual updating of QR code locations is resource-intensive, and the handbook must be structured flexibly to cater to diverse users across construction stages. Formats under consideration for the handbook include a checklist or a potential app. Next steps involve finalising pilot data and completing the environmental impact assessment to reach TRL 6, with full demonstration expected in 2025.

Demo #16 - Airside UFP Mitigation (T7.1)

EVIDENCE LEVEL

Reporting of deployability of Demo #16 (T7.1) is based on answers to a survey form (September 2024) and the Deep Dive Demo progress presentation (April 2024).

USE CASE

This demonstration is being led by SNBV with the participation of NLR.

The following work is to be conducted:

- Continuous on-site air quality measurements and Modelling mitigation impact of mitigation strategies (NLR)
- Prototyping ionised mist installation (SNBV)
- Creating overview of air quality ‘hyper locally’ at the airport, understanding the geographical, meteorological impact on measurements itself over time (meaning: during various seasons with various conditions) (NLR)
- Mapping the airport processes’ influence on these measurements (SNBV)
- Implementing mitigation strategies to reduce concentrations of air pollutants hyper locally (various airport locations), map its effect on airport local air quality to determine the effectiveness of the strategy (SNBV)

The Key Success Metric is KSM56: A reduction of 20% in hyperlocal UFP concentrations [PPM] from measured baseline by using specifically engineered water droplets.

PROBLEM-SOLUTION FIT

Problem Statement

Not specified

Value Proposition

A solution based on a water droplet installation that can create specific droplets that should be able to filter UFP from the air.

End users and Stakeholders

The end user of this demonstration would be Schiphol. As key stakeholder is NLR.

DEPLOYABILITY

Demo requirements

No information provided

Risks, external dependencies and mitigation plans

Weather is a crucial factor. Also, one needs to account for the possible lack of reliability in a UFP emission.

Status overview

Demonstrated. The demonstration team could use help with their continuous measurements from WP8.

This demonstration has achieved TRL5 since it was tested in a relevant environment to validate it. As a result of demonstration, it was proven that the technology does not produce the desired results and, as such, is not able to progress any further in the TRL scale.

Next Steps

Continue measuring results.

LEARNINGS & INSIGHTS

The deployability of Demo #16, focused on reducing ultra-fine particle (UFP) concentrations airside at Schiphol Airport, involved testing a water droplet installation designed to filter UFP from the air. The demo included continuous air quality measurements to model and evaluate the effectiveness of this mitigation strategy in reducing local UFP concentrations by 20%. Currently at TRL 5, the technology was tested in a relevant environment but did not achieve the desired reduction levels, leading the team to conclude that further progression on the TRL scale is not viable. Key insights indicate that the water droplet method is not sufficiently effective, and a cost-benefit analysis revealed that the costs outweigh the potential benefits. Weather conditions and the variability of UFP emissions further impacted reliability.

Next steps involve continuing air quality measurements to explore alternative mitigation strategies, with support from WP8 as needed for ongoing monitoring. This demo provided valuable insights, highlighting the challenges in UFP mitigation and the need for cost-effective solutions in airport environments.

Demo #17 - Airport Land Carbon Sequestration (T7.2)

EVIDENCE LEVEL

Reporting of deployability of Demo #17 (T7.2) is based on answers to a survey form (September 2024) and the Deep Dive Demo progress presentation (April 2024).

USE CASE

This task is led by EGIS with the participation of SNBV,POLITO, HERMES and SAGAT.

Task 7.2 is divided into two parts:

3. Perform Land Carbon Sequestration Study (EGIS)
4. Perform biochar experimentation at all airports (POLTO)

For the purpose of this report, we will focus on the second part, since it refers to the solution being demonstrated within TULIPS.

The demonstration is led by POLITO. The aim of this demo is to demonstrate the possibility of storing biogenic carbon, and generating Carbon Credits, in the land owned or managed by the airports, via biochar incorporation into soil. Biochar was produced by residual wood, but investigations have been carried out to evaluate the potential recovery of the organic fraction of solid waste collected at the airport and its conversion into biochar. Afterward, the biochar is produced and rolled out in field trials in Schiphol will host the proof of concept, and then shall be extended to Larnaca Airport. The roll-out will be followed by periodic assessment and measurement by an agronomist on crops and soil in each field trial location. Ultimately, POLITO will provide guidance for quantifying the potential benefits resulting from the carbon credits, starting from a revision of existing practices and methodologies.

The Key Success Metrics are:

- KSM57: Produce x-kg of high-quality biochar from residual wood
- KSM58: Create opportunity for carbon credits to be sold on the carbon market
- KSM59: Perform the incorporation of carbon into soil to sequester CO2.

PROBLEM-SOLUTION FIT

Problem Statement

Currently carbon credits on decarbonisation initiatives can be used to offset carbon emissions. There is a need to investigate innovative solutions for generating carbon credits, aiming at supporting airports' decarbonization by recovering and sequestering carbon, and offsetting emissions. Biochar and other nature-based solutions are to be tested in the three airports. The possibility to produce biochar for the organic fraction of the airport waste management offers an opportunity for strengthening the concept of a “circular airport”.

Value Proposition

The solution enables airport land carbon sequestration via the use of biochar produced from organic materials and/or residual biomass.

End users and Stakeholders

Airports and operators

DEPLOYABILITY

Demo requirements

No data has been provided

Risks, external dependencies and mitigation plans

The field tests and measurements have to be replicated in the three airports and over multiple years to achieve statistical significance and capture any effect.

Status overview

Demonstrating a full field test in each airport, involving biochar incorporation into soil, and agronomic tests.

The demo has been performed and field tests are almost completed. As there was an instance of extreme weather conditions these may affect the results, but there might be a positive effect on soil moisture and improved agricultural practice.

This demonstration has achieved TRL6 since the technology was deployed in a relevant environment. After all field tests are completed, the demonstration should have achieve TRL7. To achieve higher levels of the TRL, a full deployment of the solution into large-scale operations is needed.

Next Steps

Finalise the field measurements in all the airports and derive the potential for credit generation.

LEARNINGS & INSIGHTS

This demo involved producing biochar from residual wood and organic waste, which is then incorporated into soil in field trials. Initial tests at Schiphol serve as proof of concept, with plans to extend trials to Larnaca Airport. Periodic assessments by agronomists measure biochar's impact on soil and crop health, guiding the potential for carbon credit quantification.

Currently at TRL 6, the technology has been deployed in relevant environments, with field tests nearing completion. Despite extreme weather conditions that may impact outcomes, preliminary observations suggest potential benefits for soil moisture retention. Finalising field data across airports will support reaching TRL 7, while large-scale deployment is required for higher TRL progression.

Key insights show that biochar application supports the concept of a "circular airport" by turning organic waste into a valuable resource for carbon sequestration. Further testing across multiple years and locations is essential to confirm effectiveness and carbon credit viability.