

Document Version

Final published version

Citation (APA)

Revidat, S., Rukanova, B. D., & Chirvisuta, T. (2025). Real-life Pilot of the Battery Product Passport for Electric Vehicle Batteries. *ATZelectronics worldwide*, 20, 36-41. <https://doi.org/10.1007/s38314-025-2066-2>

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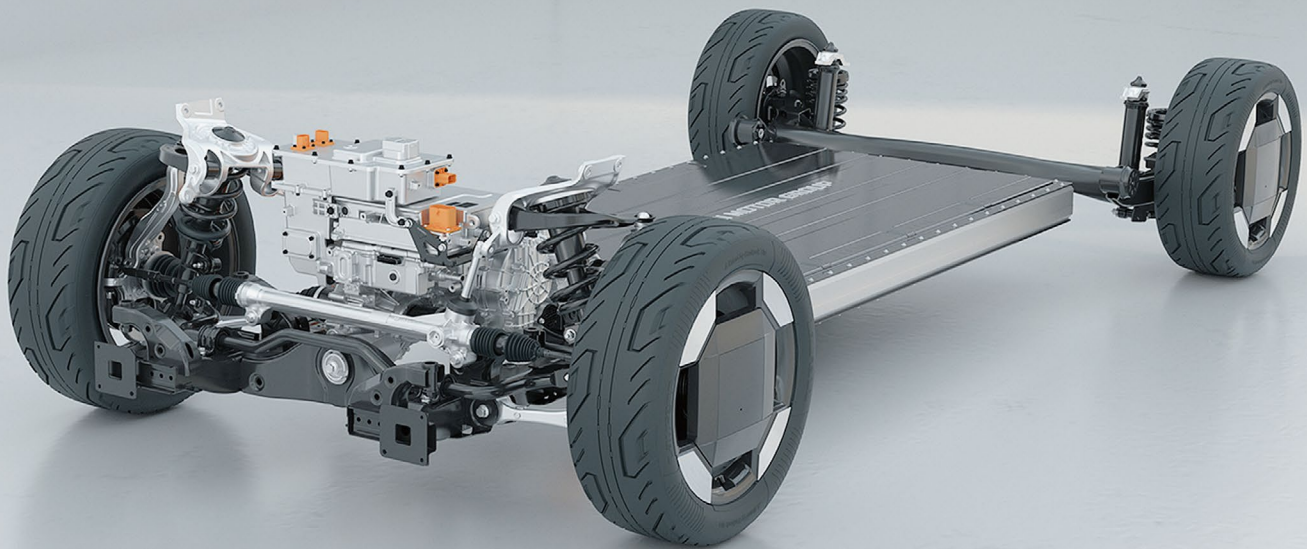
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Real-life Pilot of the Battery Product Passport for Electric Vehicle Batteries

As part of the EU's Green Deal, a digital battery product passport is to be introduced, including the availability of dynamic live data during use. In a pilot project conducted by TU Delft and the Hyundai Motor Europe Technical Center, with the participation of Dutch authorities (Customs and RDW), as well as TNO, ARN, Dukosi, Mobis, and Kia Europe, and in cooperation with the EU-funded Datapipe project, experience with the cell battery passport was gained through collaboration between industry, research, and authorities.

The battery regulation introduced in the EU will require economic operators placing batteries on the EU market to provide a digital battery passport [1]. This inevitably affects the automotive sector and EU and foreign companies placing Battery Electric Vehicles (BEVs) on the EU market. A challenge for businesses is that the battery passport information covers a broad range of data points including static data about the battery, its producer, material composition, recycled content, but also dynamic data such as state-of-charge. For authorities, and other parties such as extended producer responsible organizations, they need to be able to access and make use of this

information for compliance monitoring, as well as to increase circularity.

While other battery passport projects were mainly looking at understanding the data attributes for the battery passport required by the battery regulation, or solving the required IT challenges, this project is working on a real-life use case, including both businesses and authorities, with a real vehicle where a cell battery passport was implemented after car production in Korea and the car was imported to Europe. The pilot focused on gaining lessons learned, taking both technical and organizational aspects into account. It is therefore not more and less than a trial of a real-world

lived battery passport in a multi-stakeholder business-government context.

PILOT SET-UP

The collaboration was set-up for joint learning based on real-life piloting. The pilot was coordinated by Delft University of Technology (TU Delft) and Hyundai Motor Europe Technical Center. This pilot was performed in collaboration with the Datapipe EU-funded project [2], where Dutch Customs represented the Border Authorities. On the authorities side, also the vehicle authority (RDW) for the registration and type approval was involved. In addition, the extended producer or-

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ganization for end-of-life vehicles and BEV batteries in the Netherlands (ARN) also participated. A test semantic data sharing environment developed by TNO was used to allow authorities to access battery passport data.

On the business side key stakeholders include Dukosi as a cell monitor chip manufacturer for the chip which contains the cell passport information, Mobis as a provider of the infotainment system linked to the cell battery passport, Hyundai Motor Europe Technical Center as a technical research partner responsible for the technical environment for the pilot realization. Kia Europe was the major partner on providing supply chain information.

Regarding the physical process, there were several stages defined as follows, **FIGURE 1**:

- Preparation of the car and equipping the car with a cell passport in South Korea
- import and registration of the car in the EU
- use of the car to collect data during use especially dynamic data
- end-of-life phase.

On the content side, two working groups were defined – a technical group addressing the technical aspects, and an organizational group working on the stakeholder information requirements.

ANALYSIS OF INFORMATION NEEDS

The work of the organizational group was let by TU Delft. A major part of the organizational group work was to identify the relevant information from the battery passport for the stakehol-

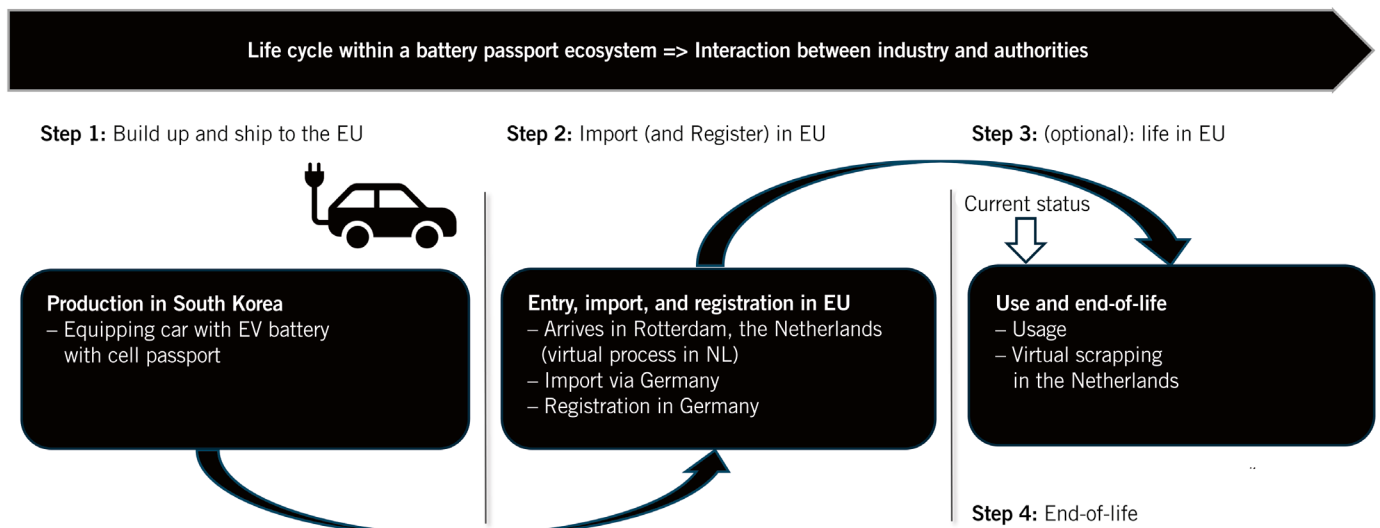
ders involved in the trial. The group decided to focus primarily on the battery regulation. A decision was taken to use the Battery Pass Data Attributes Longlist [3] as a starting point, as the data attributes identified were derived based on the battery regulation. The stakeholders (authorities, as well as the producer responsible organization) were asked to identify which data elements from the Battery Pass Data Attributes Longlist (>100 elements) they would consider relevant for their tasks. Parties discussed that they are not legal experts, that the battery regulation is not yet implemented, and that they do not know for sure what their roles exactly would be. However, based on their expert knowledge, they provided their own opinion on which battery passport data they would consider relevant for their tasks, based on the knowledge they had at that point in time.

TABLE 1 provides examples of user needs using the Battery Pass Data Attributes Longlist. This analysis was used as a basis for setting up the battery passport data sharing environment.

BATTERY PASSPORT TECHNOLOGY

The greater challenge in realizing such a digital passport, is to maintain all data at the same time. This includes data from production, specification, procurement and even live data. As a result, two worlds have to be combined: the battery in the car, and its

FIGURE 1 Monitoring using a battery product passport (© TU Delft | Hyundai | TNO)



Battery passport data attribute (extract from Battery Pass Data Attributes Longlist [3])					User needs analysis
No	BEV	Attribute category	Attribute sub-category	Attribute	Relevance for border authority, vehicle authority, and/or producer responsible organization
7	x	General battery and manufacturer information	General characteristics	Battery category	Relevant for all three stakeholders
8	x	General battery and manufacturer information	General characteristics	Battery weight	Relevant for all three stakeholders
10	x	Compliance, labels and certifications	Conformity	EU declaration of conformity	Relevant for all three stakeholders
17	x	Battery materials and composition	Materials	Battery chemistry	Relevant for two out of the three stakeholders
27	x	Carbon footprint	Carbon footprint	Battery carbon footprint	Relevant for two out of the three stakeholders

TABLE 1 User requirements based on [3] (x: mandatory according to battery regulations, as specified in the longlist) © TU Delft | Hyundai)

connection to the outer world. As first setup, the Dukosi cell monitoring system brings a first matching approach, the Battery Cell Passport concept.

Having the accurate data in place is complicated. The often “simplest” solution is a server or another solution (e.g. blockchain-based solutions) which contains all information of the passport. Such a concept can be seen already in earlier published battery passport pilots. In the battery passport trial, the focus was on the real-time piloting in a multi-stakeholder business-government context with a car equipped with a cell monitoring system. Further-

more, the concept question on how the data shall be accessible had to be answered. To solve this issue, a group focusing on the technical challenges came together and worked out such a solution. The group consists of members of TNO, Hyundai Mobis, Dukosi, and Hyundai Motor Europe Technical Center (HMETC). Every party had one piece of the technical puzzle at hand and the willingness to have a running passport system.

As a start, a system had to be defined as carrier for all information. The cell monitoring chipset technology by Dukosi and its embedded cell passport was a

first available system for this operation. It is capable to store all battery relevant data for a passport and send them via an own protocol towards a computer. This feature including its near field communication based wireless battery management allows also the upkeep of information by automation. In other words, the battery passport does not require a direct human interaction.

The passport is generated by the summation of all contents. This means, every cell receives an own unique identifier chip containing all relevant information, the entire battery passport for this vehicle is accurate and

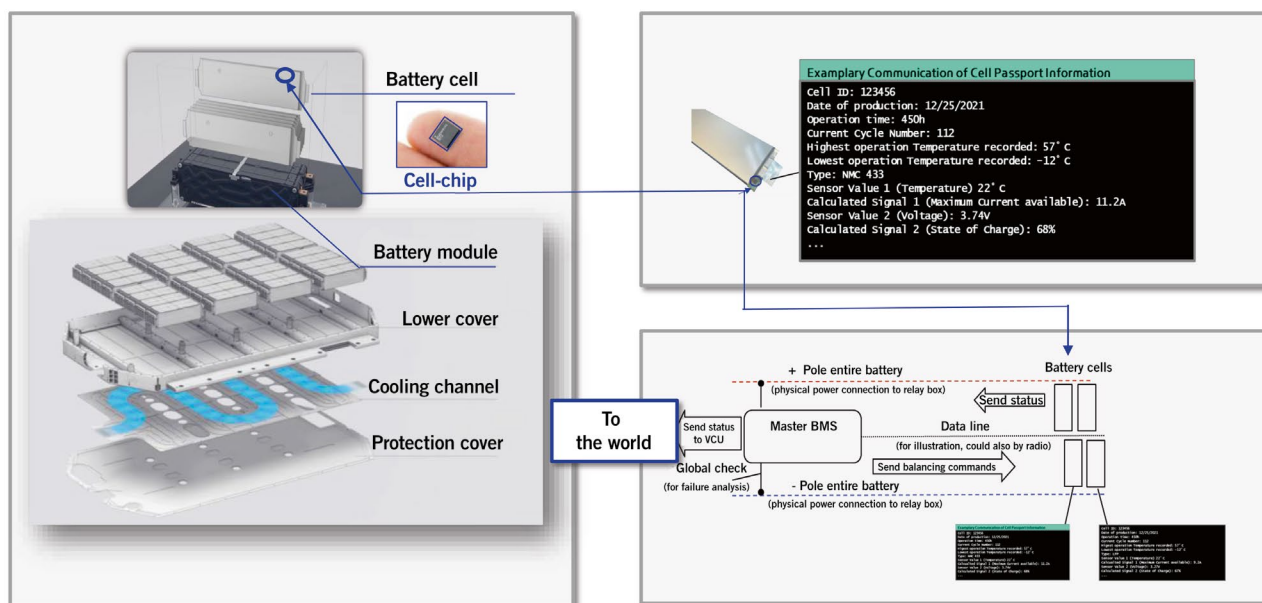


FIGURE 2 Technical approach of cell passport in vehicle © Hyundai)

always up to date. **FIGURE 2** demonstrates this functionality in an overview. This alone does make the entire battery passport, also the connection of the data towards the world as the next technical challenge. HMETC as the provider of a car as test subject took the lead to prepare such a vehicle.

DATA GENERATION AND MAINTENANCE

Further steps must be done to find the data. Especially in having a „reality check“ a real physical hardware must be used. Therefore, Hyundai-Kia Motor Group provided a Kia EV3 as carrier for this trial. On this vehicle, the Dukosi cell monitoring system had to be implemented and connected to the infotainment system. This has the possibility to send all relevant data Over the Air (OTA) to the Nodes of TNO from the Datapipe project. The TNO Nodes provide a lean method to connect to any information object via an Application Programming Interface (API) interface.

Hyundai Mobis major step is to utilize all battery passport data from the battery and collect that information in

the information system. As visible in **FIGURE 3** also simple graphical user interface is available to access the data. In the next step, the data are transmitted via the car’s own communication hardware to the Node URL provided by TNO. Here the data can be opened and viewed by any device connected to the internet or with an own node. In addition, since standard protocols and visualization are used, especially safety and durability status can be reviewed. In a battery passport ecosystem, this information could be used to increase confidence in the safety and longevity of BEV batteries. The car itself is today fully functional and is still in use to develop functionality in collaboration with Dutch authorities.

TNO NODE

The TNO node has been used to reduce administrative burden and complex, not standardized, connectivity to authorities risk assessment systems. The TNO node represents an implementation of the open source FEDeRATED node, deployed as a proof of concept pilot, deployed on Kubernetes in a pilot

environment [4]. For this pilot, two nodes have been utilized, one representing the Hyundai Mobis and the other, the compliance authorities. As no confidential data has been agreed to be shared in the infrastructure, the versatility and easy (re-)configuration of the FEDeRATED node has been tested as well. Consequently, both data sharing nodes have been reused from an existent Kubernetes deployment, by creating two specific API configurations on the Hyundai Mobis representative node, one for the static battery passport data, and one for the dynamic data [5].

The technology behind the node allows for easy integration with any Internet-enabled device, as the communication interface from the end user system to the node is built based on OpenAPI and the accepted input format is JSON. At the same time, the system takes advantage of semantically linked data. To simplify the application of semantic techniques, a separation of the required expertise was introduced. An initial configuration step requires limited semantic knowledge, to leverage the Graphical User Interface (GUI) ab-

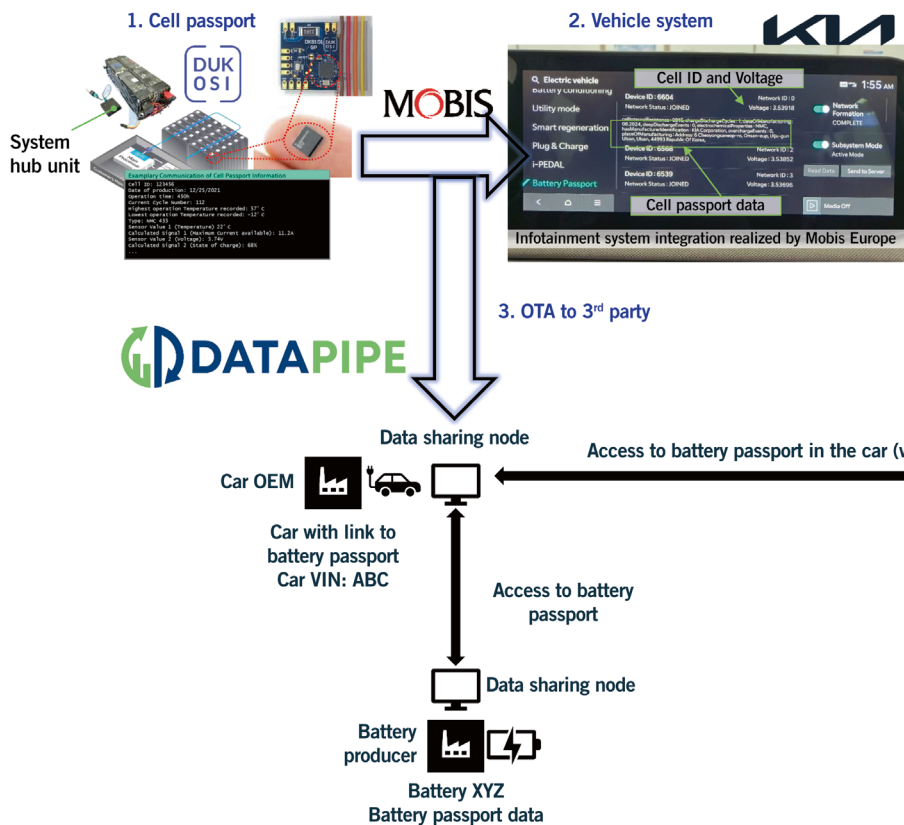


FIGURE 3 Technical approach to connect the battery to the world (© TU Delft | Hyundai | TNO)

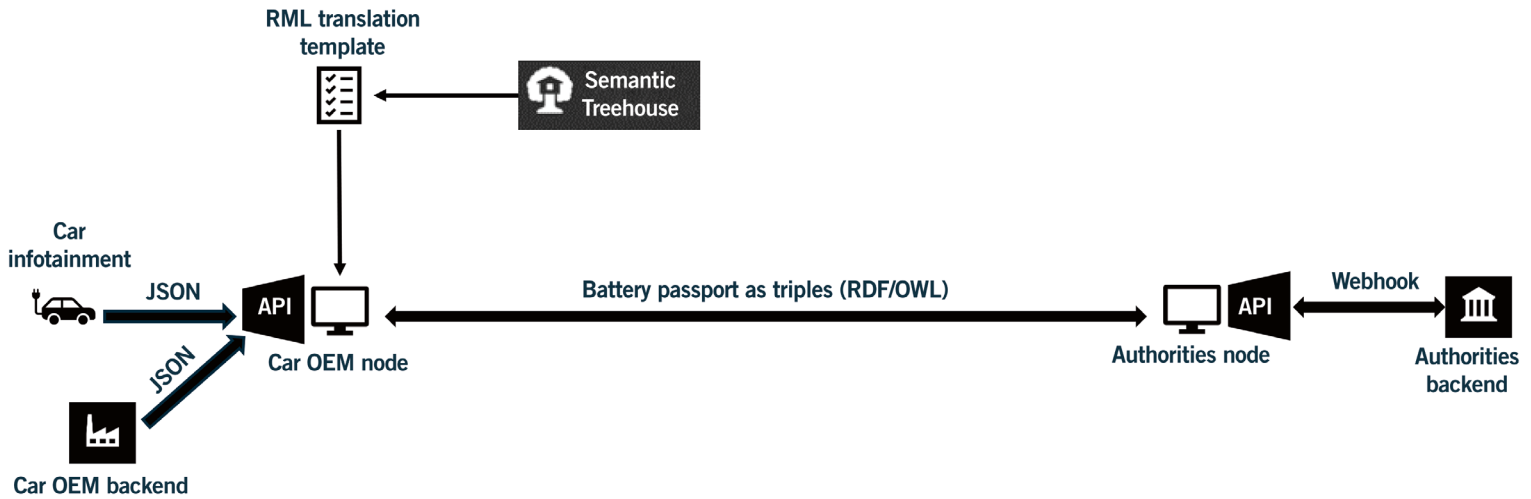
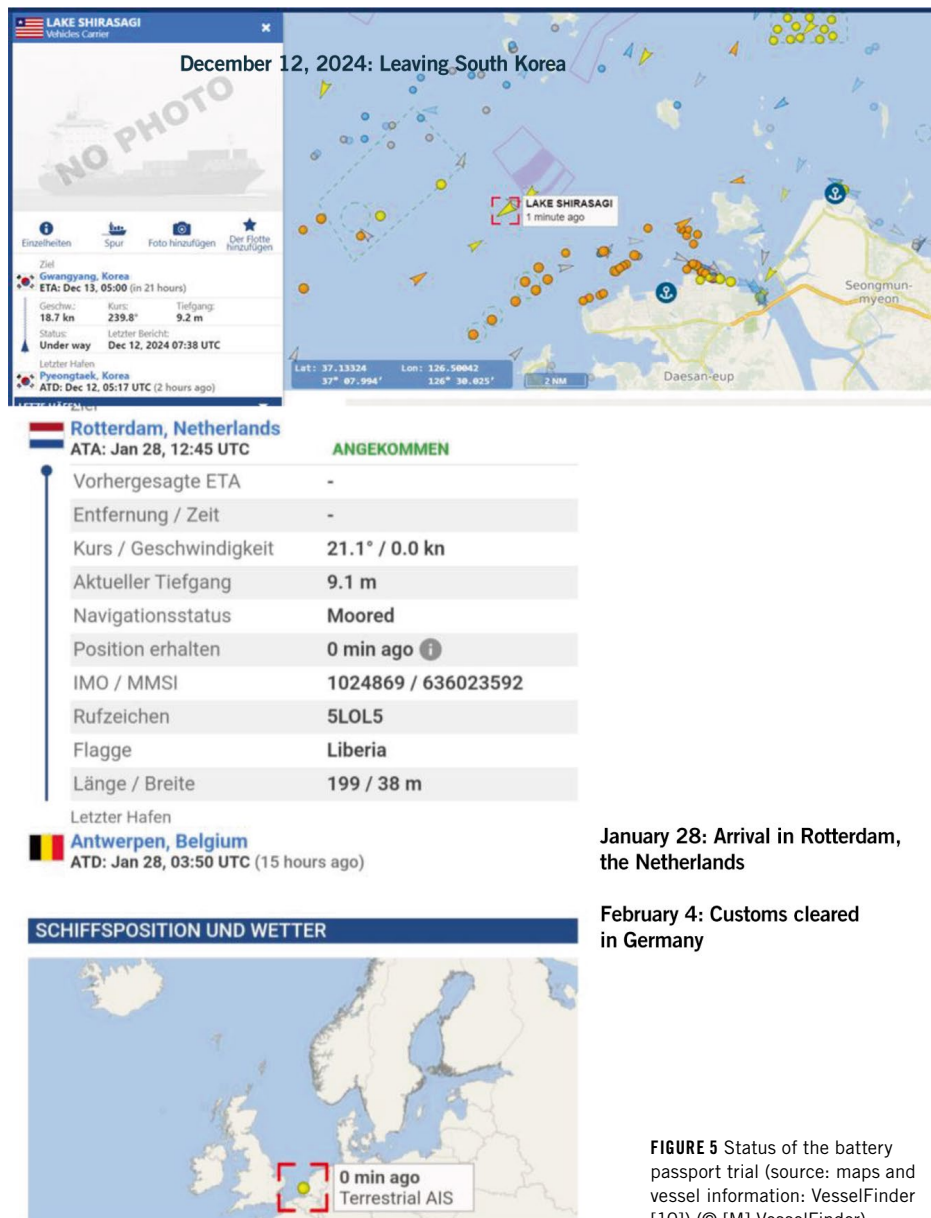


FIGURE 4 Data sharing infrastructure overview (© TU Delft | Hyundai | TNO)



January 28: Arrival in Rotterdam, the Netherlands

February 4: Customs cleared in Germany

FIGURE 5 Status of the battery passport trial (source: maps and vessel information: VesselFinder [10]) (© [M] VesselFinder)

straction of a vocabulary hub (semantic treehouse in the pilot) to create a translation template (written in RDF Mapping Language (RML)) [6]. Based on this configuration, end-users can input JSON data (cheaper to integrate with existent end-systems) and further share linked data with collaborators. In turn, this approach leverages the added business value of extensibility, flexibility, and combinability of the semantic linked data while limiting the adoption costs of the non-authorities end-users (Hyundai Mobis in this pilot). More details on these capabilities are provided in [7, 8]. **FIGURE 4** provides an overview of the components of the data sharing infrastructure. The data sharing procedure goes as follows: the car infotainment systems sends a JSON payload to the Hyundai node API, the semantically configured node converts JSON data to triples (RDF) data. The triples data is then forwarded to the authorities node. At this point, authorities can write SPARQL queries on the received data to benchmark for compliance. The technical configuration details of the Hyundai Mobis node and the technical usage of gathering data from the authorities' side data sharing infrastructure is further documented and explained in the Datapipe GitHub page dedicated to this pilot [5].

STATUS OF THE BATTERY TRIAL

The car was produced and equipped after nearly six months of preparation in November 2024 with all related

technology. As visible in **FIGURE 5** the car left South Korea in December 2024 and arrived in Europe in January 2025. After first solved issues with the mobile network connectivity, the car is now operational, and its passport data are available via internet connection. As this happens, first evaluation for authority processes has already been done. By nature of some involved parties, not all details can be shared. Further tests are planned and will be executed. As the car needed to be used further for other purposes after the pilot, for the last phase only virtual scrapping was planned to be performed. In this virtual scrapping the goal is to mirror an end-of-life process and is relevant for the extended producer responsible organizations, as they perform end-of-life treatment of vehicles and EV batteries.

CONCLUSIONS

Digital product passports will affect different product groups in the future, as well as business supply chains and authorities [9]. Battery passports are on the high-end of complexity to be implemented, especially due to the dynamic data. The technical and organizational lessons learned from this real-life cell battery passport trial can be of value to businesses, autho-

rities and policy makers in the context of battery passport developments, as well as in the wider discussion around digital product passports and their potential for businesses and government.

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THANKS

This research was partially funded by the Datapipe project, which has received funding from the European Union's Technical Support Instrument (TSI) programme under grant agreement No 101094495. Ideas and opinions expressed by the authors do not necessarily represent those of all partners. The authors would like to thank all the participants and contributors to the Datapipe project. The authors would like to also especially thank to the other key participants from the key involved organizations in the Battery Passport Trial, namely Yao-Hua Tan (TU Delft), Norbert Kouwenhoven, Mitchell Out, Maarten Veltman and Marcel Molenhuis (Dutch customs), Mark Wortman and Gerard Boukes (RDW), Janet Kes (ARN), Elmer Rietveld and Sjoerd Rongen (TNO), Simon Gellineck, Timo Unger and Oliver Schmid (Hyundai Motor Europe Technical Center), Uday Dandamudi and Murali Dinakar (Hyundai Mobis), Markku Vaatanen (Dukosi), Haiko Müller and Magdalena Punshon (Kia). The authors would like to thank also to all the other people and participants that supported the pilot in different stages of the process for their support, inputs and feedback.

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