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FASTEST

Fast-track hybrid testing platform for the development of battery systems

Deliverable D6.6: Final validation in exemplary environment

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Project Abstract

Current methods to evaluate Li-ion batteries safety, performance, reliability and lifetime represent a remarkable resource consumption for the overall battery R&D process. The time or number of tests required, the expensive equipment and a generalized trial-error approach are determining factors, together with a lack of understanding of the complex multiscale and multi-physics phenomena in the battery system. Besides, testing facilities are operated locally, meaning that data management is handled directly in the facility, and that experimentation is done on one test bench.

The FASTEST project aims develop and validate a fast-track testing platform able to deliver a strategy based on Design of Experiments (DoE) and robust testing results, combining multi-scale and multi-physics virtual and physical testing. This will enable an accelerated battery system R&D and more reliable, safer and long-lasting battery system designs. The project's prototype of a fast-track hybrid testing platform aims for a new holistic and interconnected approach. From a global test facility perspective, additional services like smart DoE algorithms, virtualized benches, and digital twin (DT) data are incorporated into the daily facility operation to reach a new level of efficiency.

During the project, FASTEST consortium aims to develop up to TRL 6 the platform and its components: the optimal DoE strategies according to three different use cases (automotive, stationary, and off-road); two different cell chemistries, 3b and 4 solid-state (oxide polymer electrolyte); the development of a complete set of physics-based and data driven models able to substitute physical characterization experiments; and the overarching Digital Twin architecture managing the information flows, and the TRL 6 proven and integrated prototype of the hybrid testing platform.

LIST OF ABBREVIATIONS, ACRONYMS AND DEFINITIONS

Acronym	Name
DoE	Design of Experiments
DT	Digital Twin
E2E	End-to-End
FMU	Functional Mock-up Unit
GUI	Graphical User Interface
HiL	Hardware-in-the-Loop
ID	Identifier
JSON	JavaScript Object Notation
LIMS	Laboratory Inventory Management System
MQTT	Message Queuing Telemetry Transport
OCV	Open-Circuit Voltage
R&D	Research and Development
SoC	State of Charge
SoH	State of Health
TRL	Technology Readiness Level
UI	User Interface
UUT	Unit Under Test
UUID	Universally Unique Identifier

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1. EXECUTIVE SUMMARY

Deliverable D6.6 documents the final validation of the FASTEST hybrid virtual-physical testing platform in an exemplary environment. The validation focuses on demonstrating that the key platform components developed in FASTEST can operate together in an end-to-end workflow, including user test request submission, Digital Twin (DT)-based model and test procedure handling, Design of Experiments (DoE)-based parameter optimization and test virtualization decisions, LIMS-based scheduling and distribution, virtual or physical test execution, and result visualization through the DT dashboard.

The validation activities were structured in a stepwise manner. First, the LIMS pipeline and virtual test bench were tested within FEV using simulated DT and DoE components to verify the internal workflow before integration with partner components. Second, an integration workshop demonstrated the FASTEST platform workflow with real DT and DoE interaction, concurrent virtual and physical test requests, and the distribution of test requests to the virtual test bench and the Flanders Make physical test bench. Third, a WP3 Functional Mock-up Unit (FMU), was integrated into the virtual test bench to verify compatibility between the FASTEST co-simulation environment and project-developed battery models. Further integration activities covered the HiL test bench from Ikerlan and the physical test bench from Flash Battery.

Overall, the validation confirms that the FASTEST platform can orchestrate hybrid battery testing workflows across virtual and physical resources, exchange structured test requests and results, and support near-real-time result publication through MQTT.

2. OBJECTIVES

The objective of Deliverable D6.6 is to validate the integrated FASTEST hybrid testing platform in an exemplary environment. The validation aims to demonstrate that LIMS can act as the central orchestration layer for test request handling, DT interaction, DoE-based optimization, schedule generation, test distribution, and result exchange.

The deliverable verifies the platform through stepwise end-to-end tests. These tests cover the LIMS and virtual test bench workflow, the integration of DT and DoE components, concurrent virtual and physical testing, compatibility with a WP3 FMU, and the connection to partner test benches. The objective is not only to test individual interfaces, but also to demonstrate that the complete FASTEST workflow can execute coordinated hybrid virtual-physical battery test requests and return test results for visualization and further use.

3. INTRODUCTION

Figure 1 illustrates the end-to-end workflow of the FASTEST hybrid virtual–physical testing platform. The workflow starts in LIMS, where the user defines a test request by specifying the due date, unit under test (UUT), use case, applicable standard, and test name. The request is then forwarded to the Digital Twin (DT) component, which checks the availability of the required model and test procedure and decides whether the requested test can be virtualized. If virtualization is possible, the DT provides the Functional Mock-up Unit (FMU) and the corresponding test procedure to LIMS for virtual test execution.

The Design of Experiments (DoE) component subsequently calculates optimized test parameters and evaluates whether the test should be executed virtually or physically based on the expected optimality of the result. If a physical execution is required, DoE also supports the selection of the suitable physical test bench. LIMS then schedules the test request and distributes it to the corresponding execution resource.

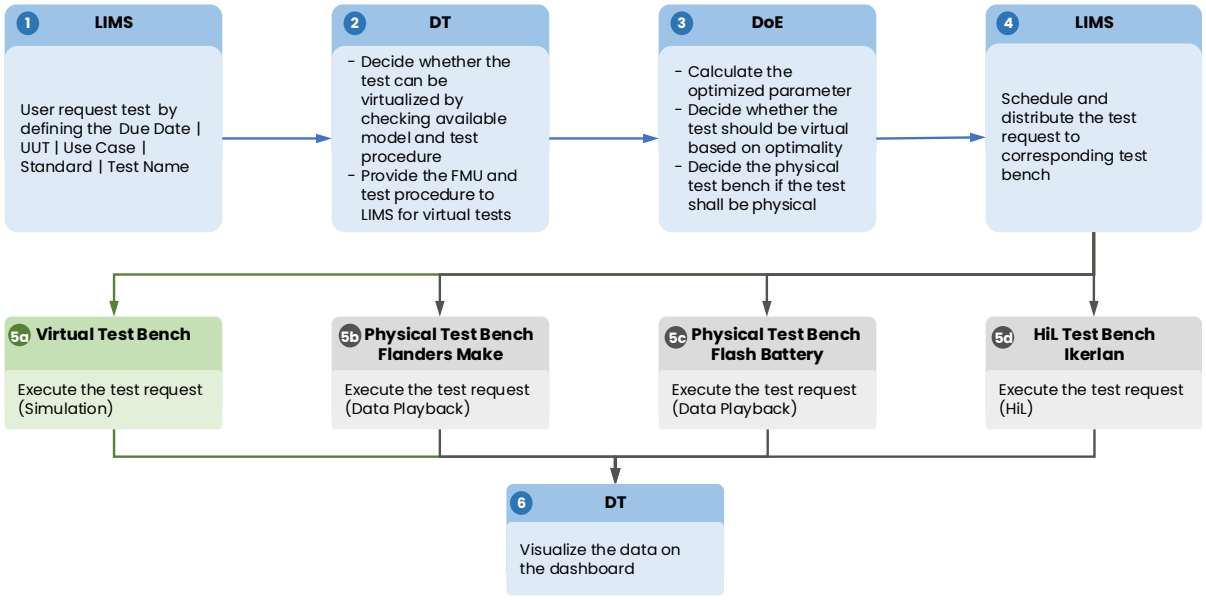


Figure 1 Workflow for scheduling, distributing, executing, and visualizing hybrid virtual–physical battery test requests in the FASTEST platform.

The lower part of the figure shows the available execution paths. A virtual test bench performs simulation-based execution, while physical test benches at Flanders Make and Flash Battery execute the request through data playback. In addition, the Ikerlan HiL test bench executes the request in a Hardware-in-the-Loop environment. After execution, the generated test results are transferred back to the DT, where they are visualized on a dashboard. The figure therefore summarizes how LIMS, DT, DoE, virtual testing resources, physical test benches, and HiL infrastructure interact to support coordinated hybrid battery testing.

Thus, the testing activities have been arranged to validation the system stepwise, but also demonstrate the capability of the hybrid system in a wholistic view:

Table 1 - Testing activities

#step	Section	Relevant Components	Partner	Date	Description
1	4.1	1 - LIMS 2 - DT (simulated) 3 - DoE (simulated) 4 - LIMS 5a - Virtual Test Bench	FEV	2026-05-05	This test aims to test the LIMS pipeline and the virtual testing bench integration, as preparation for the next testing step.
2	4.2	1 - LIMS 2 - DT 3 - DoE 4 - LIMS 5a - Virtual Test Bench 5b - Physical Test Bench Flanders Make 6 - DT	FEV INEGI COMAU FHG Flanders Make (ABEE) (Mondragon) (Ikerlan)	2026-05-08	This test is the major pipeline test of the FASTEST platform and demonstrates the following: 1. The virtual testing pipeline 2. The physical testing pipeline 3. The capability of FASTEST platform to handle virtual and physical testing request con-currently Note the partner in () has witnessed the demonstration but their components were not integrated during the test.
3	4.3	5a - Virtual Test Bench	FEV Mondragon Ikerlan		Before this step, all results showing in the tests for the virtual testing track is from a demo FMU implemented by FMU. Thus, it is necessary to integrate a functional FMU from WP3 to demonstrate the virtual test bench compatibility with FASTEST FMUs as described in D6.4.
4	4.4	1 - LIMS 2 - DT (simulated) 3 - DoE 4 - LIMS 5d – HiL Test Bench Ikerlan	FEV Ikerlan	2026-05-12	The integration of HiL Test Bench Ikerlan for the completeness of the physical testing integration.
5	4.5	1 - LIMS 2 - DT (simulated) 3 - DoE 4 - LIMS 5c – Physical Test Bench Flash Battery	FEV Flash Battery	2026-05-21	The integration of Physical Test Bench Flash Battery for the completeness of the physical testing integration.

With these steps, all components in the FASTEST system have been validated and verified at least once in the FASTEST pipeline.

4. Testing and Validation Results in Exemplar Environment

4.1 E2E testing within FEV applying simulated components

This test aims to test the LIMS pipeline and the virtual testing bench integration, as preparation for the next testing step.

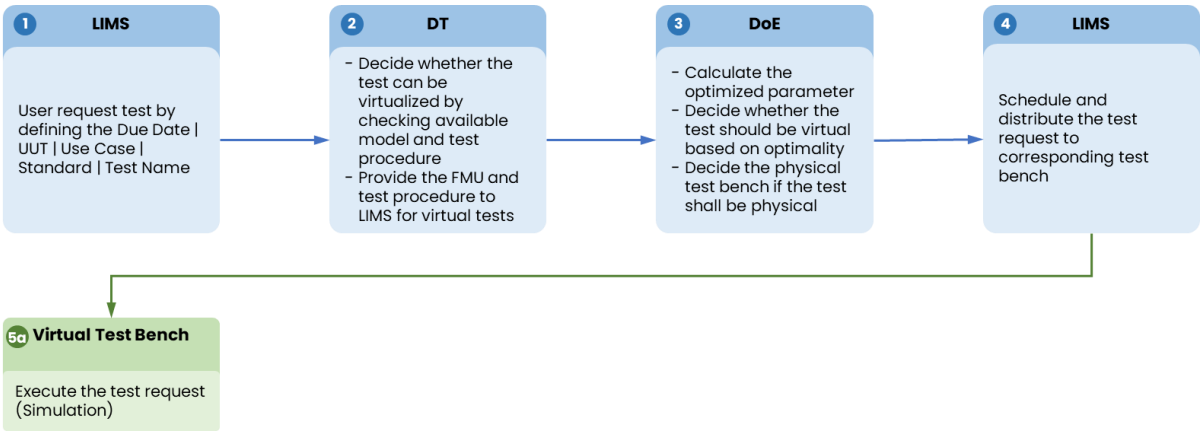
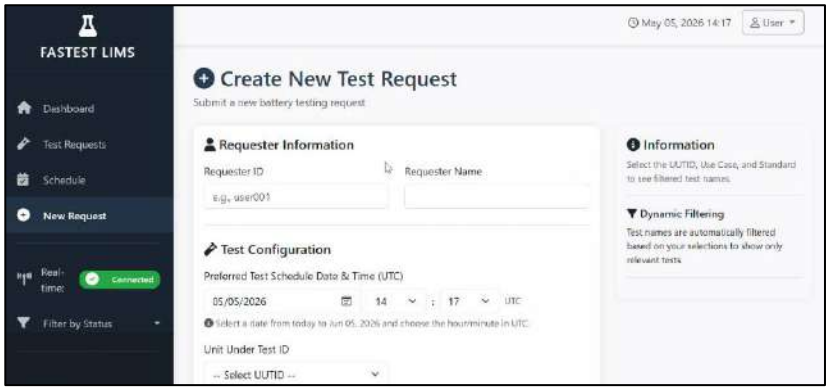


Figure 2 Validation of the virtual testing pipeline.

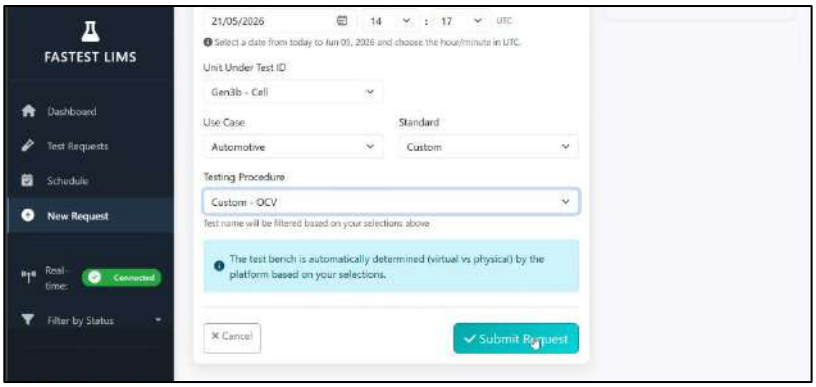
In *Figure 2* the DT and DoE components are simulated by FEV for testing purposes with the same interfaces as the real DoE and DT components, which will be replaced in later steps.

Dashboard Overview

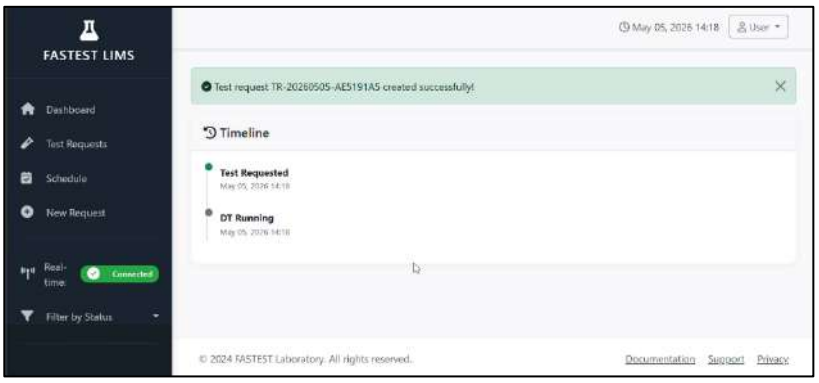
Create New Test Request – user enter inputs for test:
- Requester ID
- Requester Name
- Test Schedule Date
- UUT ID
- Use Case
- Standard
- Test Procedures



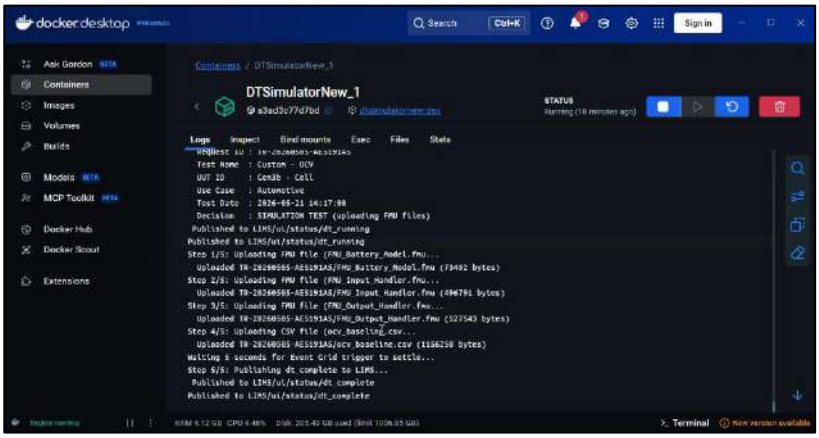
For the demo, the testing procedure "Custom – OCV" will be used, which will use a dedicated Baseline profile for the DoE Algorithm to generate an optimized profil.



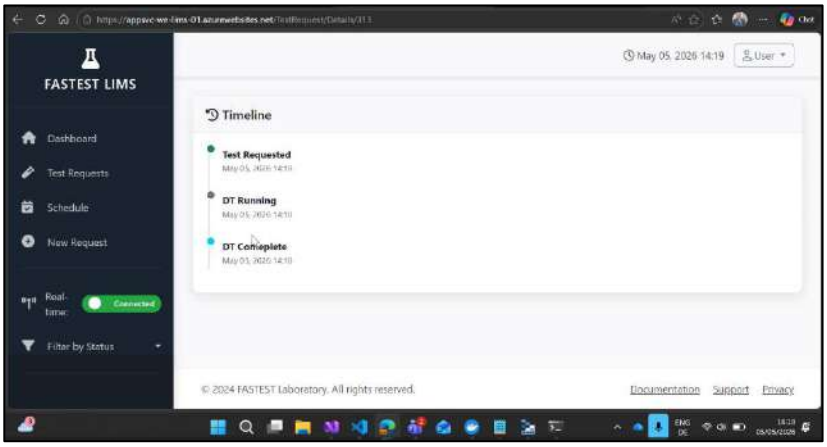
After submitting the request, the DT starts.



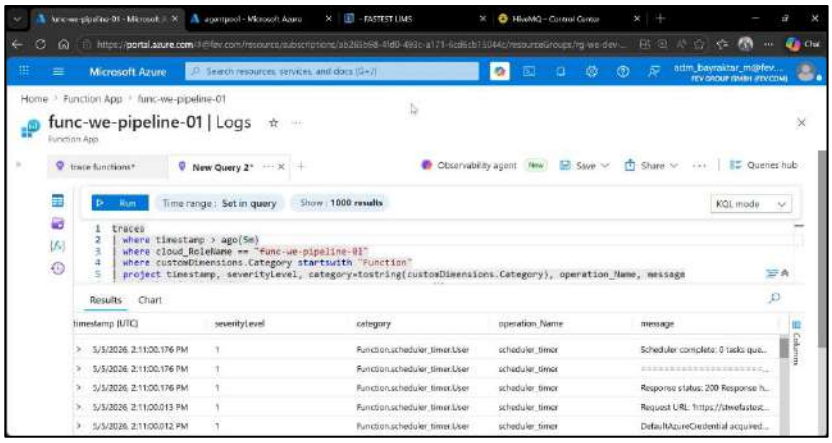
The log of DT can be monitored in docker.desktop – As we can see, the steps are executed, FMUs are uploaded and the results are published.



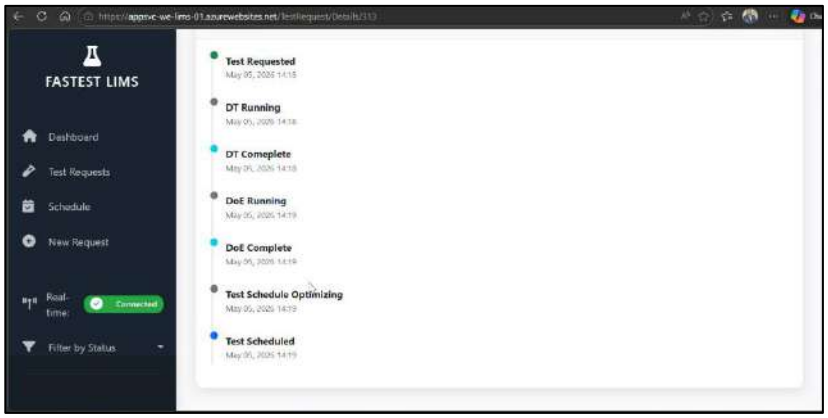
LIMS GUI shows that DT is completed



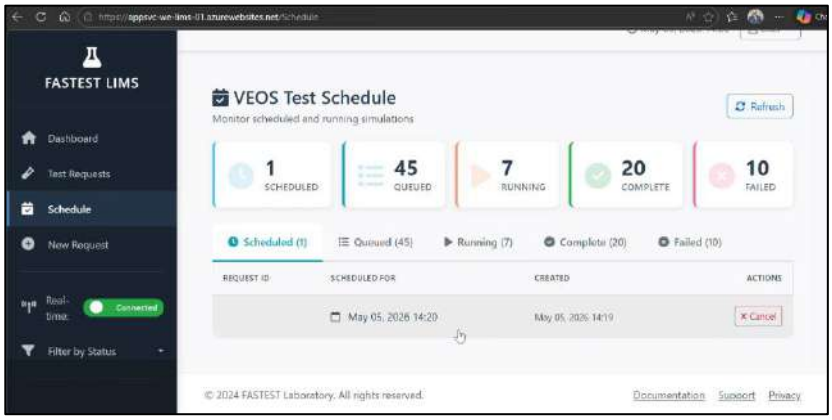
The log of DoE and the Test scheduling optimization is monitored in Azure Portal



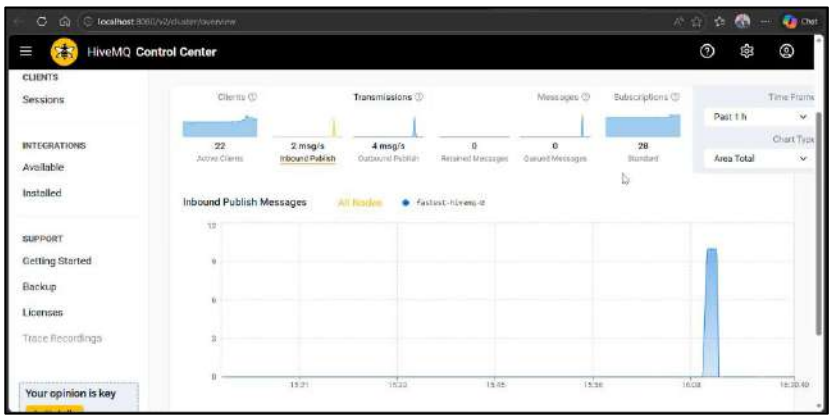
DoE and Test Scheduling Optimization is finished successfully



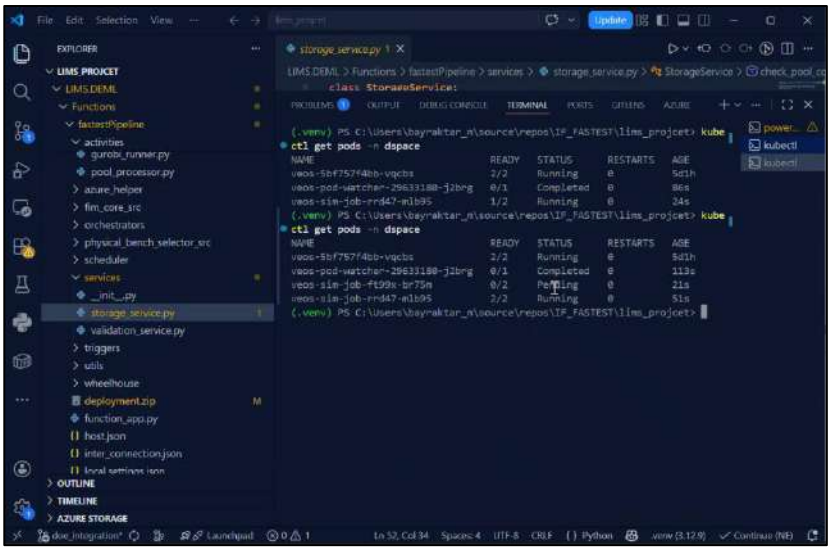
Scheduled test can be found in the overview of scheduled tests



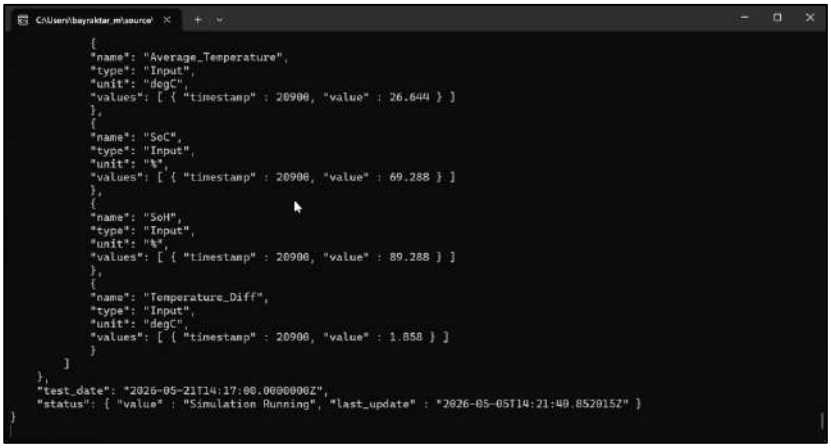
When the Schedule Date is met and the test starts, we can see published MQTT messages in the HiveMQ Control Center



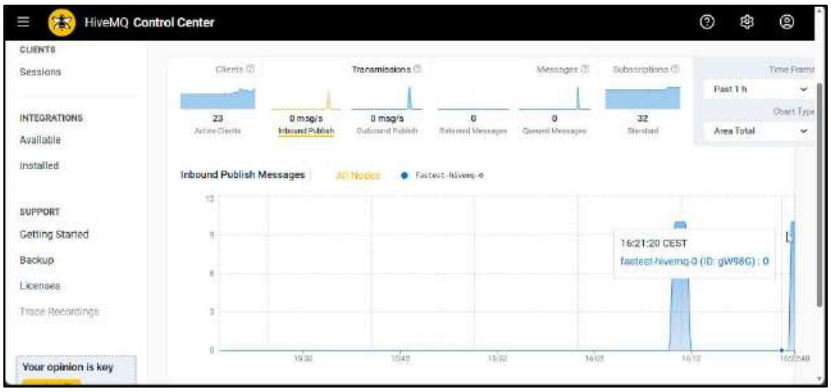
The status of the VEOS pods in the docker is shown here and we can see that the simulations is running



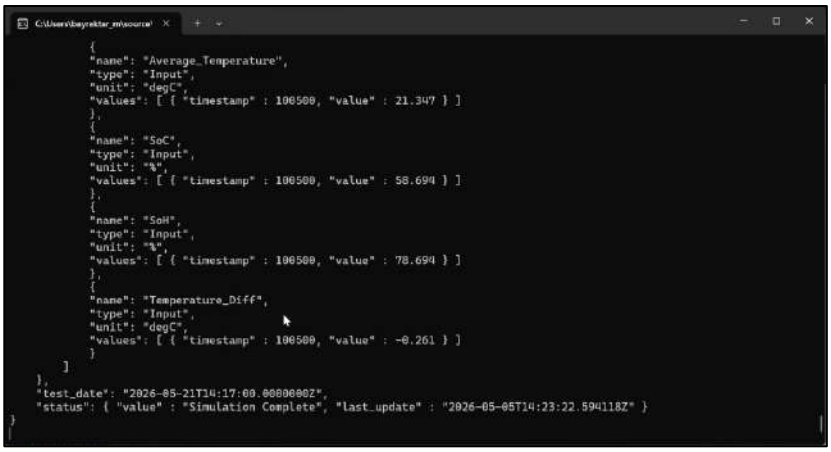
Subscribing to the MQTT topic allows us to see the published messages.



MQTT messages also monitored in HiveMQ again.



End of test after last timestamp is reached



4.2 E2E testing of FASTEST System within Integration Workshop

This test aims to demonstrate the virtual and physical testing capabilities of FASTEST platform concurrently.

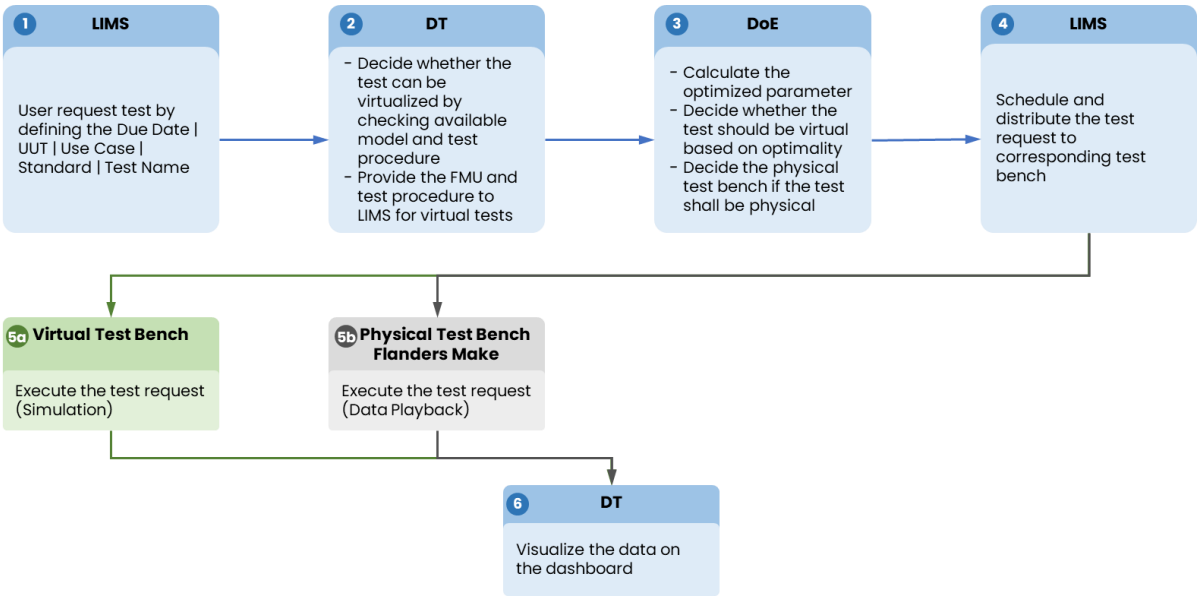


Figure 3 E2E validation of FASTEST platform with concurrent virtual-physical testing pipeline.

The testing procedures give in the *Figure 3* are described as follows:

	VIRTUAL TESTING PROCESS	PARTNER
1	User select "Custom – OCV Test"	FEV
2	DT received "Custom – OCV Test" and send following to LIMS	INEGI, COMAU

	• FMU • test procedure (in test request JSON) • ocv_baseline.csv and decide at this stage virtual test possible for further decision of DoE	
3	**DoE running** with • test request (JSON) • ocv_baseline.csv and decide the test is a virtual test	FHG, FEV
4	**LIMS** distribute the test request to the Virtual Test Bench	FEV
5A	Virtual test running with • test request (JSON) • optimized_profile.csv • **Demo FMU from FEV**	FEV, Mondragon, Ikerlan
6	LIMS forward the test metrics to DT for visualization	INEGI, COMAU, FEV

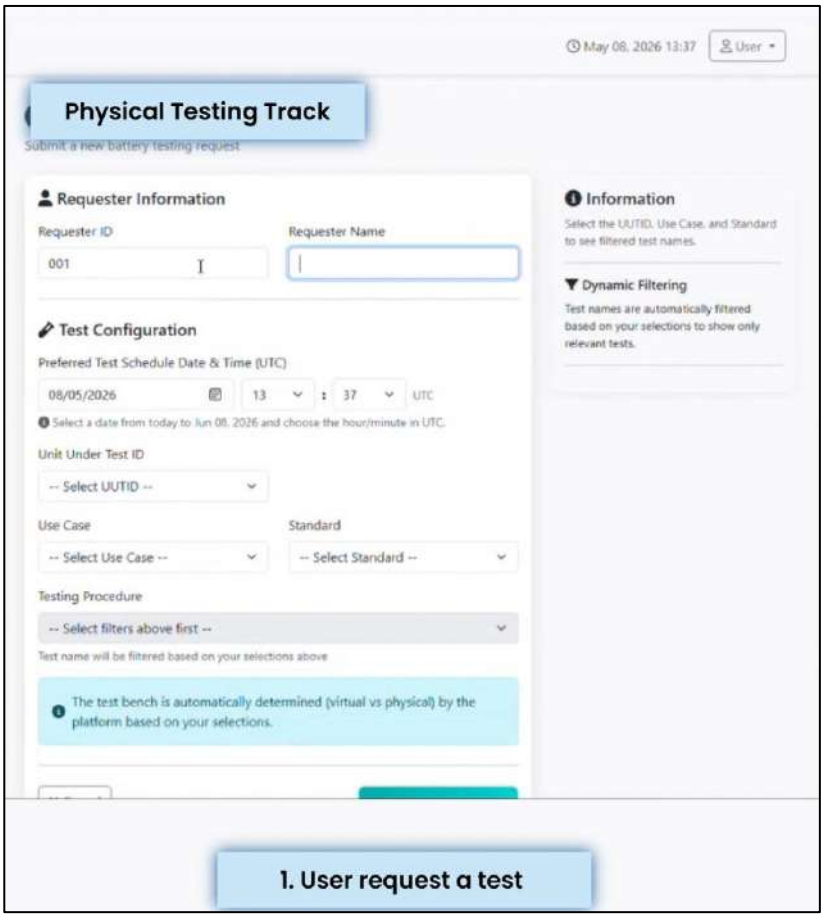
	PHYSICAL TESTING PROCESS	**PARTNER**
1	User select "Aging and Performance - Capacity Test"	FEV
2	DT received "Aging and Performance - Capacity Test" and send following to LIMS • test procedure (in test request JSON) and decide the test is a physical test	INEGI, COMAU
3	DoE running with • test request (JSON) and select Flanders Make as physical test bench	FEV, FHG
4	**LIMS** distribute the test request to the Physical Test Bench – Flanders Make	FEV, Flanders Make
5B	Physical test bench **return the test result based on** • test request (JSON) by Flanders Make	FEV, Flanders Make

6	LIMS forward the test metrics to DT for INEGI, COMAU, FEV visualization

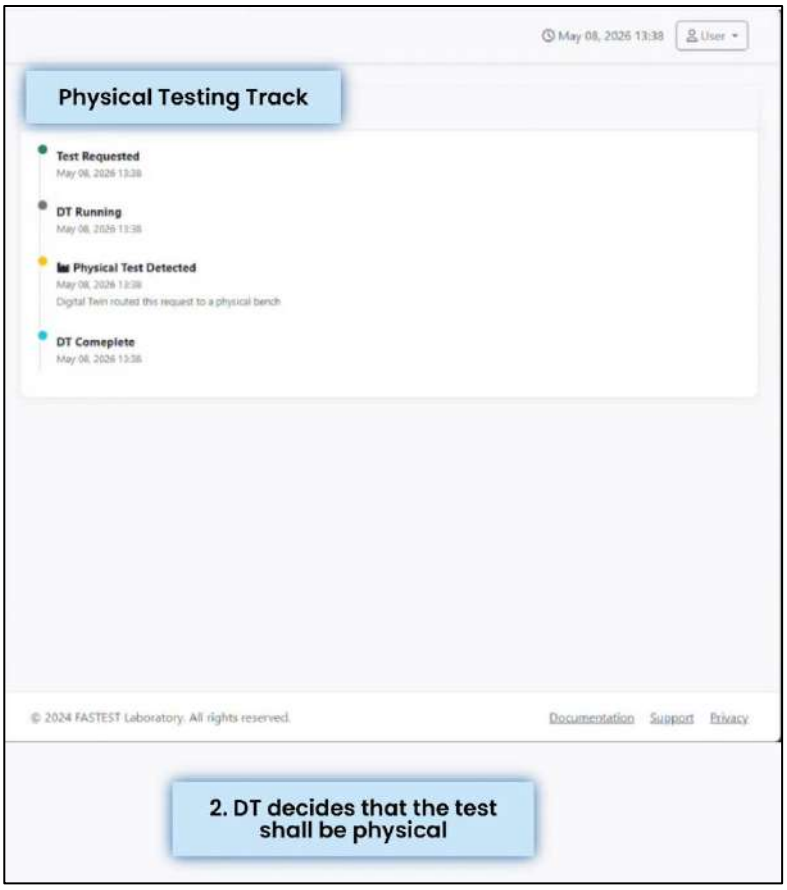
The test results of the pipeline integration are given as follows:

Physical Test

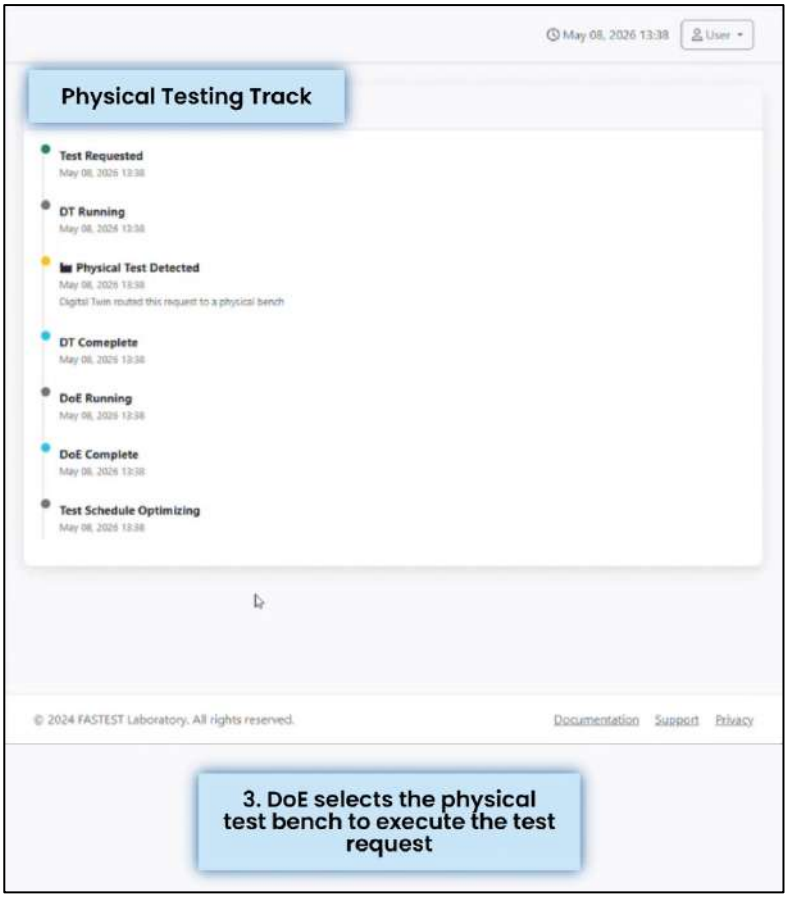
#Step 1



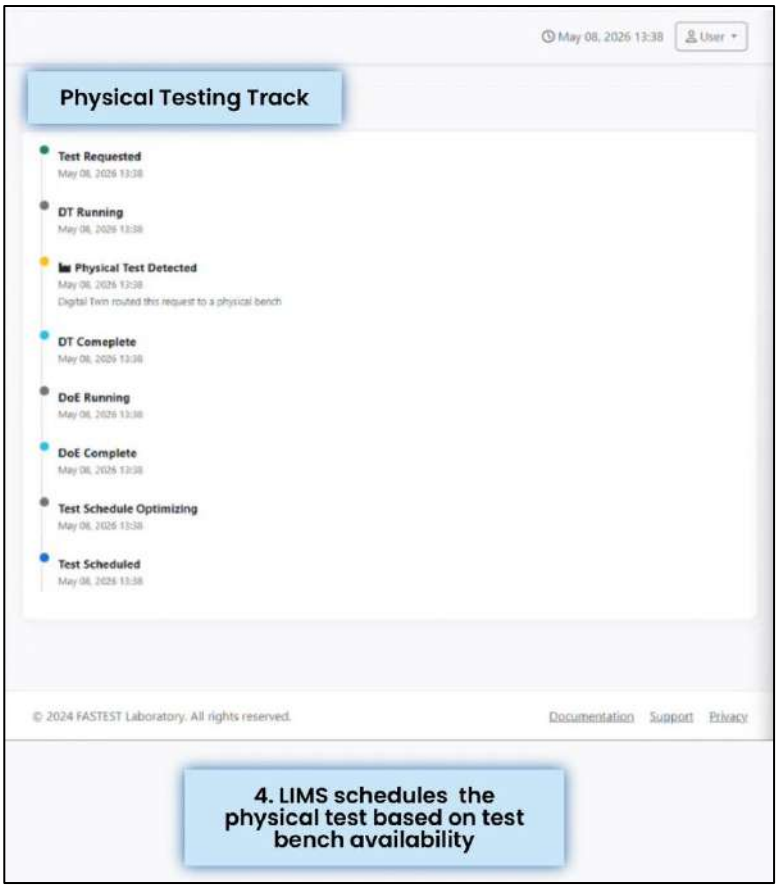
#Step 2



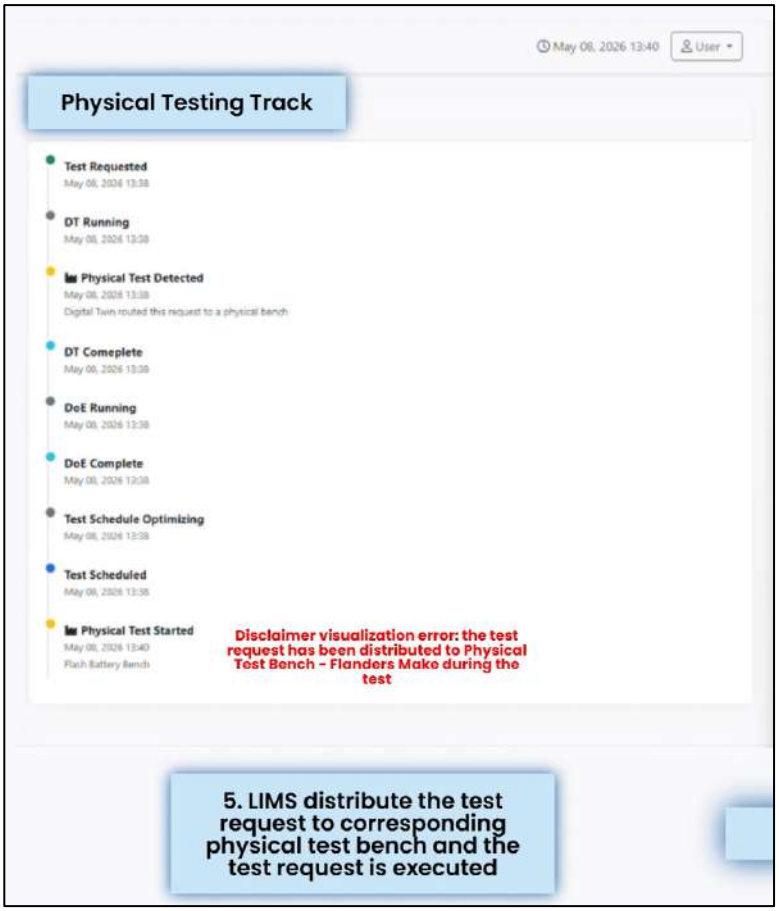
#Step 3



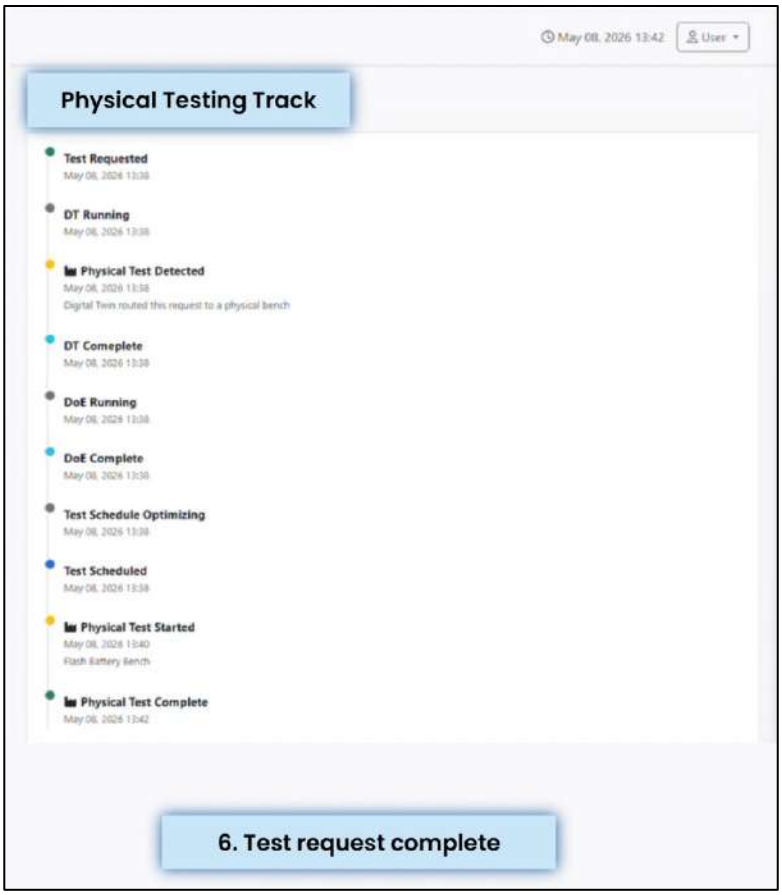
#Step 4



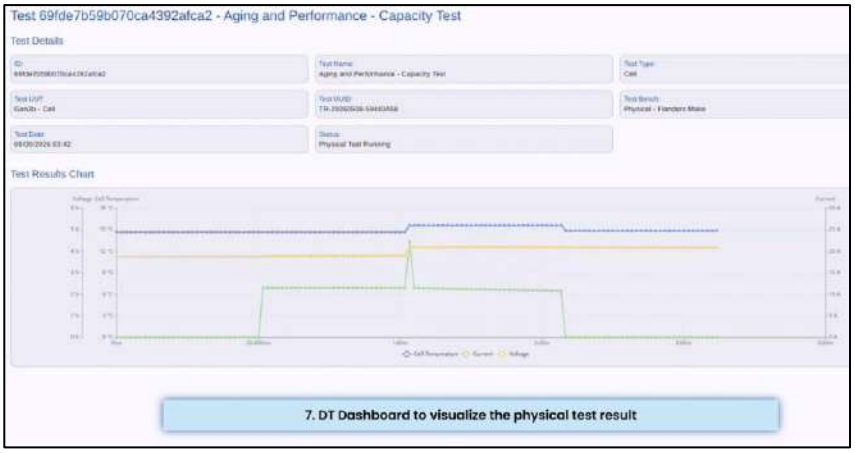
#Step 5



#Step 6



#Step 7

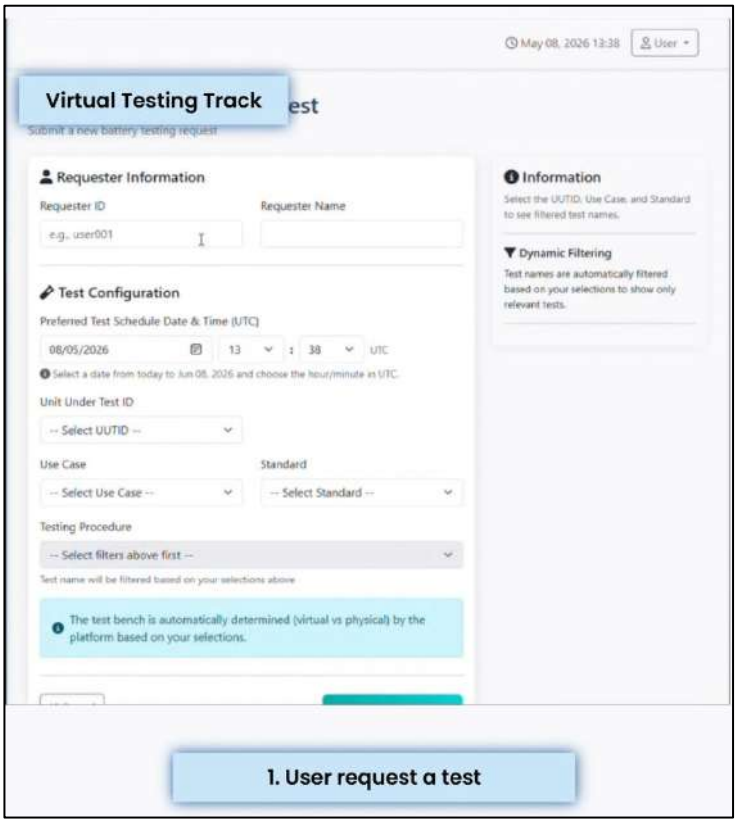


DoE Output Physical

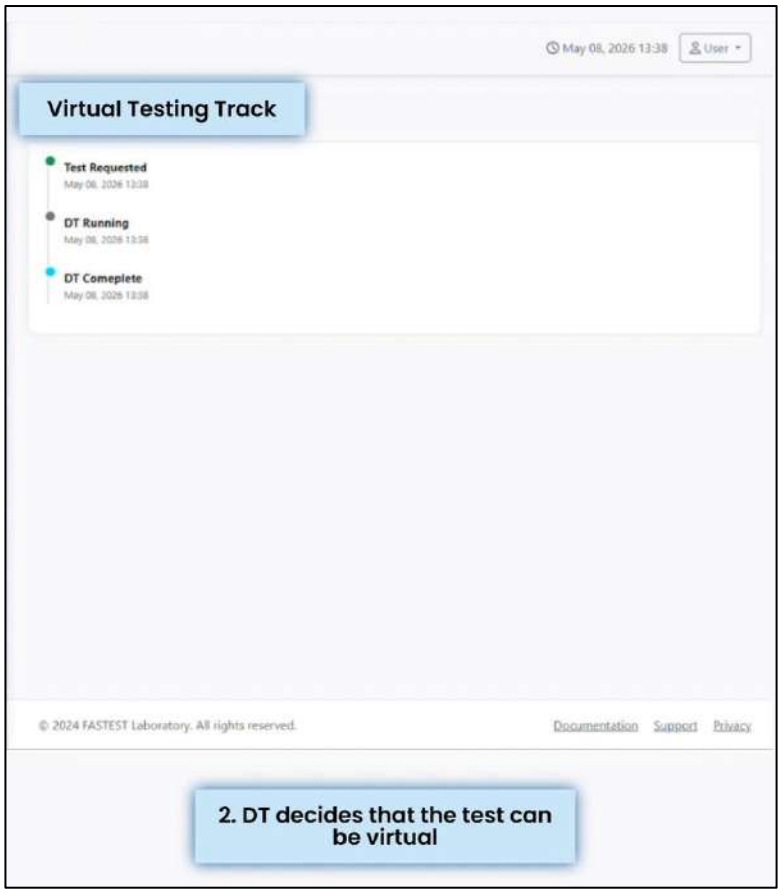

```
{
    "test_UUID": "TR-20260508-59440A58",
    "test_name": "Aging and Performance - Capacity Test",
    "test_date": "2026-05-11T14:30:00.0000000Z",
    "test_UUT": "Gen3b - Cell",
    "use_case": "Stationary",
    "test_bench": "Physical - Flanders Make",
    "variables": {
        "test_procedure": [ ···
        ],
        "FMU_signal_connections": [
            {
                "InSignalReference": "/FMU_02/Initial_SoC_In/Initial_SoC_In",
                "OutSignalReference": "/FMU_01/Initial_SoC_Out/Initial_SoC_Out"
            },
            {
                "InSignalReference": "/FMU_02/Ambient_Temp_In/Ambient_Temp_In",
                "OutSignalReference": "/FMU_01/Ambient_Temp_Out/Ambient_Temp_Out"
            }
        ]
    },
    "status": {
        "value": "Test Requested",
        "last_update": "2026-05-08T13:38:12.132578Z"
    }
}
```


Virtual Test

#Step 1

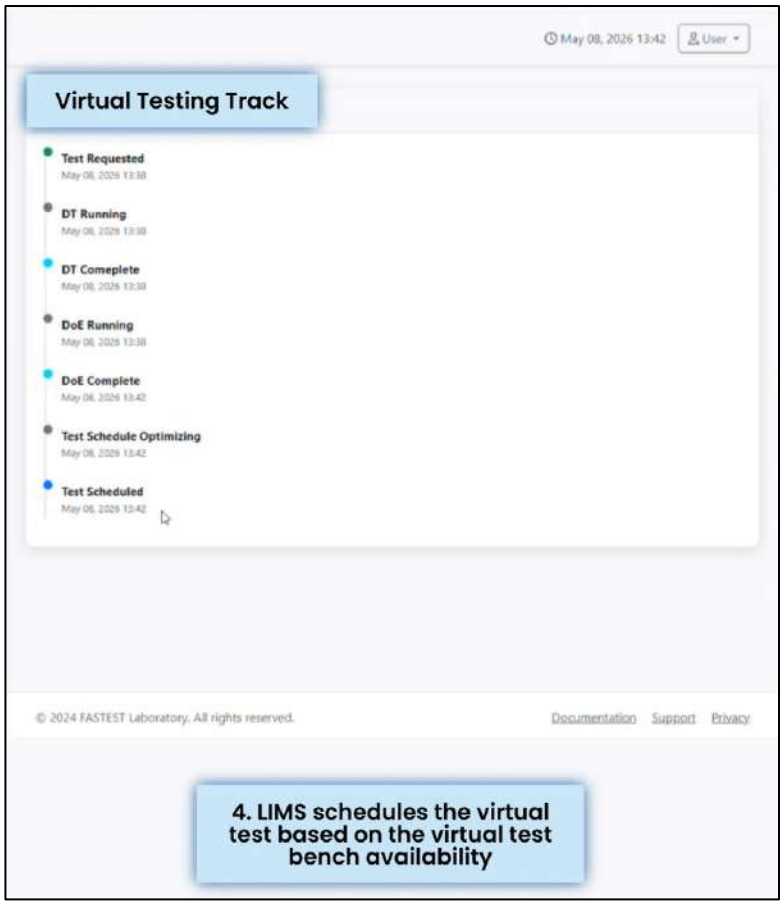


#Step 2

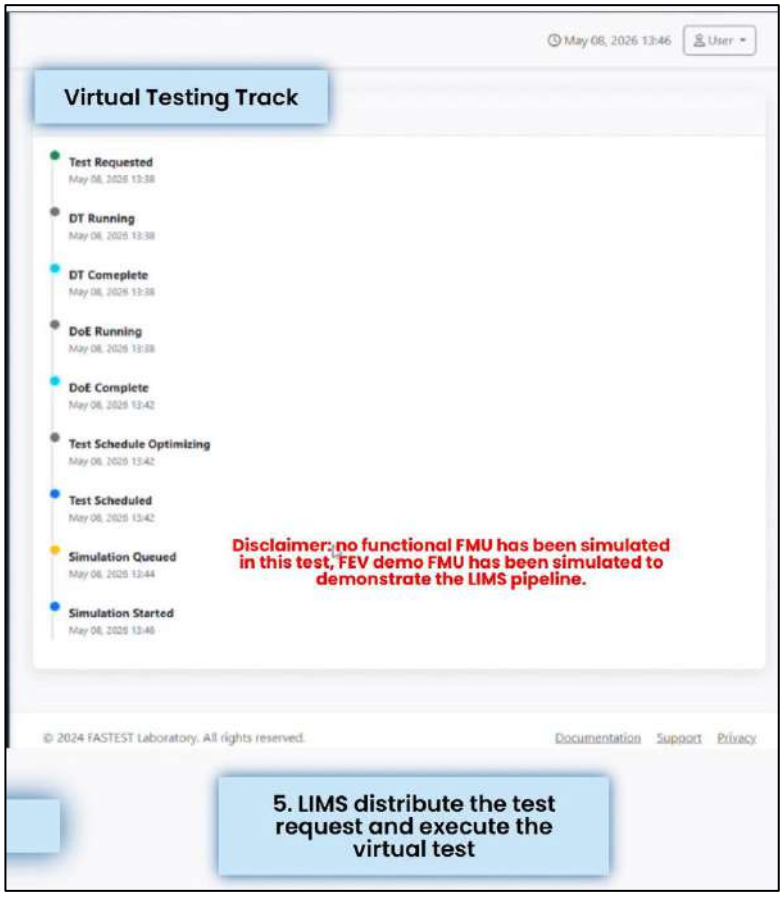


#Step 3

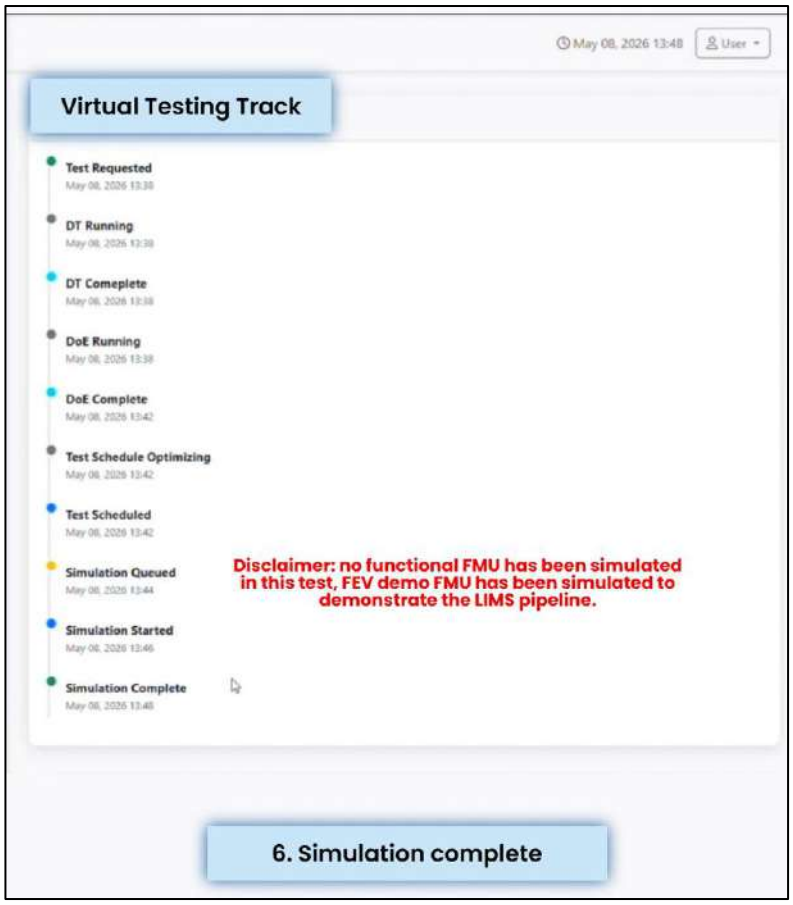
#Step 4



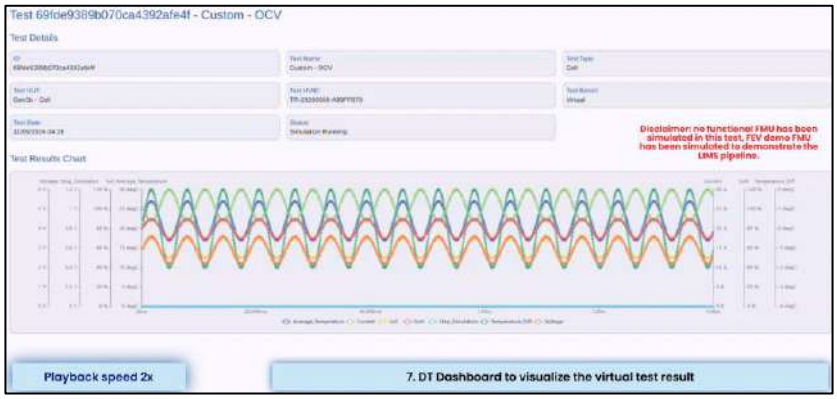
#Step 5



#Step 6



#Step 7



DoE output virtual


```
"test_UUID": "TR-20260508-A99FF873",
"test_name": "Custom - OCV",
"test_date": "2026-05-11T14:28:00.000000Z",
"test_UUT": "Gen3b - Cell",
"use_case": "Automotive",
"test_bench": "Virtual",
"variables": {
    "test_procedure": [...
    ],
    "FMU_signal_connections": [
        {
            "InSignalReference": "/FMU_Output_Handler/Stop_Simulation_In/Stop_Simulation_In",
            "OutSignalReference": "/FMU_Battery_Model/Stop_Simulation_Out/Stop_Simulation_Out"
        },
        {
            "InSignalReference": "/FMU_Output_Handler/Current_In/Current_In",
            "OutSignalReference": "/FMU_Battery_Model/Current_Out/Current_Out"
        },
        {
            "InSignalReference": "/FMU_Output_Handler/Voltage_In/Voltage_In",
            "OutSignalReference": "/FMU_Battery_Model/Voltage_Out/Voltage_Out"
        },
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        },
        {
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            "OutSignalReference": "/FMU_Battery_Model/SoC_Out/SoC_Out"
        },
        {
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            "OutSignalReference": "/FMU_Battery_Model/SoH_Out/SoH_Out"
        },
        {
            "InSignalReference": "/FMU_Output_Handler/Temperature_Diff_In/Temperature_Diff_In",
            "OutSignalReference": "/FMU_Battery_Model/Temperature_Diff_Out/Temperature_Diff_Out"
        },
        {
            "InSignalReference": "/FMU_Battery_Model/Test_Procedure_In/Test_Procedure_In",
            "OutSignalReference": "/FMU_Input_Handler/Test_Procedure_Out/Test_Procedure_Out"
        },
        {
            "InSignalReference": "/FMU_Battery_Model/Initial_SoC_In/Initial_SoC_In",
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        },
        {
            "InSignalReference": "/FMU_Battery_Model/Initial_Temperature_In/Initial_Temperature_In",
            "OutSignalReference": "/FMU_Input_Handler/Initial_Temperature_Out/Initial_Temperature_Out"
        }
    ],
    "optimized_cell_temperature": 298.15
},
"status": {
    "value": "Test Requested",
    "last_update": "2026-05-08T13:38:42.73977312"
}
```


Additional Results

Bridge connection success with DT

MQTT – Outbound Publish Messages

4.3 Pipeline Integration with FMU from WP3

This test aims to prove the compatibility of the FASTEST virtual testing platform and FASTEST FMUs.

In this test, the FMU provided by WP3 named "Gen3b_cell_level_SPM_THERMAL_cyclerV3_FMI3.fmu" has been integrated into the Virtual Test Bench.

Following log from the VEOS software shows that the FMU model has been loaded and simulated.

```
$ python ../utils/fmu_launcher.py --simulation-sub-folder simulation_folder_3 --simulation-
stop-time 100 --no-wait
INFO:root:Found 3 FMU file(s) after 1 attempt(s): ['FMU_Input_Handler.fmu',
'Gen3b_cell_level_SPM_THERMAL_cyclerV3_FMI3.fmu', 'FMU_Output_Handler.fmu']
INFO:root:Executing: /opt/dspace/veos2024b/bin/veos build fmu /home/cosim-
admin/tmp/simulation_folder_3/fastest-models_fmus/FMU_Input_Handler.fmu -o /home/cosim-
admin/tmp/simulation_folder_3/fastest-models_fmus/build/FMU_Input_Handler.osa
2026-05-13T10:30:15.409+00:00    [Info]       [veos]                          Starting build
of /home/cosim-admin/tmp/simulation_folder_3/fastest-models_fmus/FMU_Input_Handler.fmu into
the offline simulation application /home/cosim-admin/tmp/simulation_folder_3/fastest-
models_fmus/build/FMU_Input_Handler.osa.
…
================================================================================
2026-05-13T10:30:20.006+00:00    [Info]       [veos]                          BUILD OF
SIMULATION SYSTEM FINISHED WITH STATE VALID
2026-05-13T10:30:20.006+00:00    [Info]       [veos]
================================================================================
…
[Info]    Preloading the simulation...
[Info]    Extracting the simulation system from the following file: /tmp/veos-
3m5szqnh/simulation.osa.
[Info]    Extracted the following simulation system: FMU_Input_Handler.
[Info]    License was acquired: VEOS - Base, Network license: The license is permanent.
[Info]    Simulation preloaded.
[Info]    Loading the simulation...
[Info]    Application /tmp/veos-3m5szqnh/ModelController/o5114qmb/FMU_Input_Handler.vap loaded
at 7fd72650d000-7fd72651bfff
[Info]    DSRTT Version 24.2
[Info]    DSRTT Build Date: Apr 11 2025, Time 09:45:30
[Info]    Application /tmp/veos-
3m5szqnh/ModelController/n4qzmfww/Gen3b_cell_level_SPM_THERMAL_cycler.vap loaded at
7d51892ea000-7d5189302fff
[Info]    Message from the FMU_Input_Handler VPU: Resources folder set to '/tmp/veos-
3m5szqnh/ModelController/o5114qmb/resources/'.
[Info]    Additional module /tmp/veos-3m5szqnh/ModelController/o5114qmb/binaries/x86_64-
linux/FMU_Input_Handler.so loaded at 7fd726124000-7fd7261fffff
[Info]    DSRTT Version 24.2
[Info]    DSRTT Build Date: Apr 11 2025, Time 09:45:30
[Info]    Application /tmp/veos-3m5szqnh/ModelController/f3szyvf0/FMU_Output_Handler.vap
loaded at 72be53fb8000-72be53fc5fff
[Info]    Message from the Gen3b_cell_level_SPM_THERMAL_cycler VPU: Resources folder set to
'/tmp/veos-3m5szqnh/ModelController/n4qzmfww/resources/'.
[Info]    Additional module /tmp/veos-3m5szqnh/ModelController/n4qzmfww/binaries/x86_64-
linux/Gen3b_cell_level_SPM_THERMAL_cycler.so loaded at 7d5188e83000-7d5188ffffff
[Info]    DSRTT Version 24.2
[Info]    DSRTT Build Date: Apr 11 2025, Time 09:45:30
[Info]    Message from the FMU_Output_Handler VPU: Resources folder set to '/tmp/veos-
3m5szqnh/ModelController/f3szyvf0/resources/'.
[Info]    Additional module /tmp/veos-3m5szqnh/ModelController/f3szyvf0/binaries/x86_64-
linux/FMU_Output_Handler.so loaded at 72be53e39000-72be53f29fff
[Info]    Simulation loaded.
INFO:root:Executing: /opt/dspace/veos2024b/bin/veos sim start 100
Connected to the following VEOS Simulator on 127.0.0.1: 24.2.1.2491448.
[Info]    Starting the simulation...
[Info]    Message from the FMU_Input_Handler VPU: Starting application process with runtime
revision 24.2.0.1291 of module VEOS frame.
[Info]    Message from the Gen3b_cell_level_SPM_THERMAL_cycler VPU: Starting application
process with runtime revision 24.2.0.1291 of module VEOS frame.
[Info]    Message from the FMU_Output_Handler VPU: Starting application process with runtime
revision 24.2.0.1291 of module VEOS frame.
[Info]    Simulation step will end at 100 s.
[Info]    Simulation started.
```

At the same time, after the simulation has been started, following MQTT message has been received by LIMS, proving that the integration has been successful and all communication has been validated.

```
Received message: {
    "test_name": "Custom - OCV",
    "test_UUID": "c2b2b6c7-6f5d-4c7a-9d1a-2f0a6c9d7b31",
    "test_UUT": "Gen3b - Cell",
    "test_bench": "Virtual",
    "use_case": "Automotive",
    "variables": {
        "test_result" : [
            {
            "name": "Stop_Simulation",
            "type": "Input",
            "unit": "1",
            "values": [ { "timestamp" : 200, "value" : 0.000 } ]
            },
            {
            "name": "Current",
            "type": "Input",
            "unit": "A",
            "values": [ { "timestamp" : 200, "value" : 0.000 } ]
            },
            {
            "name": "Voltage",
            "type": "Input",
            "unit": "V",
            "values": [ { "timestamp" : 200, "value" : 2.023 } ]
            },
            {
            "name": "Average_Temperature",
            "type": "Input",
            "unit": "degC",
            "values": [ { "timestamp" : 200, "value" : -0.000 } ]
            },
            {
            "name": "SoC",
            "type": "Input",
            "unit": "%",
            "values": [ { "timestamp" : 200, "value" : 0.066 } ]
            },
            {
            "name": "SoH",
            "type": "Input",
            "unit": "%",
            "values": [ { "timestamp" : 200, "value" : 1.000 } ]
            },
            {
            "name": "Temperature_Diff",
            "type": "Input",
            "unit": "degC",
            "values": [ { "timestamp" : 200, "value" : 0.000 } ]
            }
        ]
    },
    "test_date": "2026-01-29T09:00:00Z",
    "status": { "value" : "Simulation Running", "last_update" : "2026-05-
13T10:30:47.890448Z" }
} on topic LIMS/metrics/veos/simulation_metrics
```


4.4 Integration of HiL Test Bench – Ikerlan

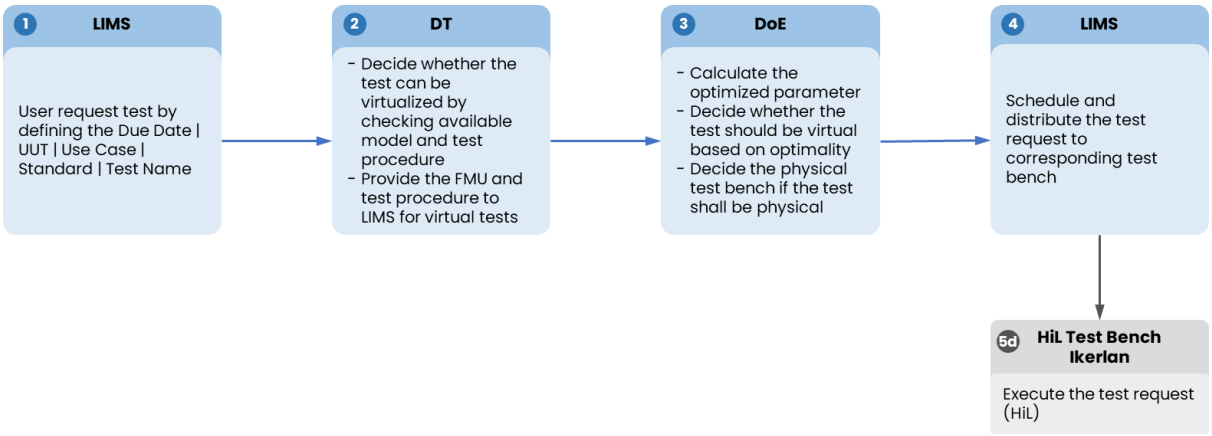
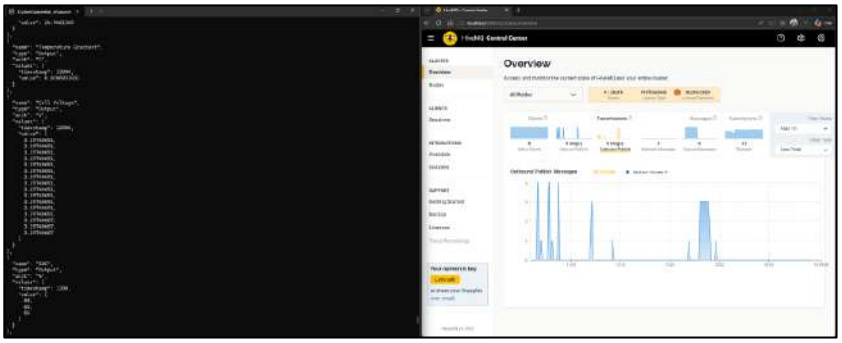


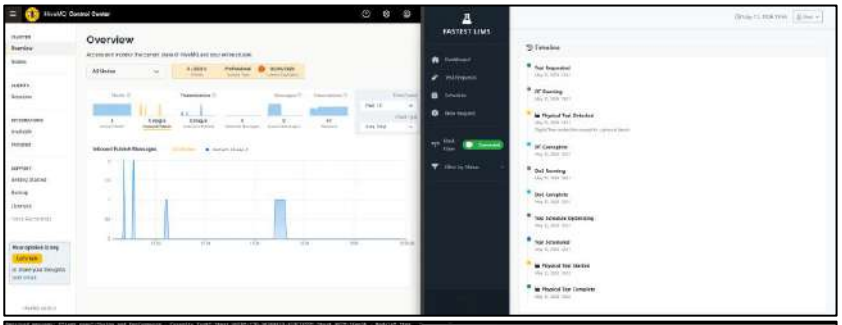
Figure 4 Integration test with HiL Test Bench - Ikerlan.

Testing results

The out-bounding MQTT Message logged by the LIMS HiveMQ MQTT broker indicating successful connection with HiL Test Bench – Ikerlan.

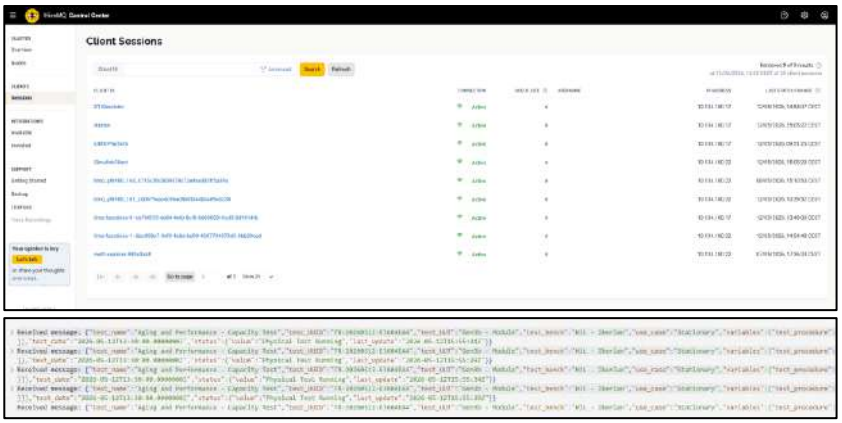


LIMS Status shows all processes has been running and the requested test is completed.



The in-bounding MQTT message logged by the LIMS HiveMQ broker, indicating the testing results are successfully transferred from the HiL Test Bench – Ikerlan to LIMS.

Screenshot shows the FASTEST components that were active during the test.



4.5 Integration of Physical Test Bench – Flash Battery

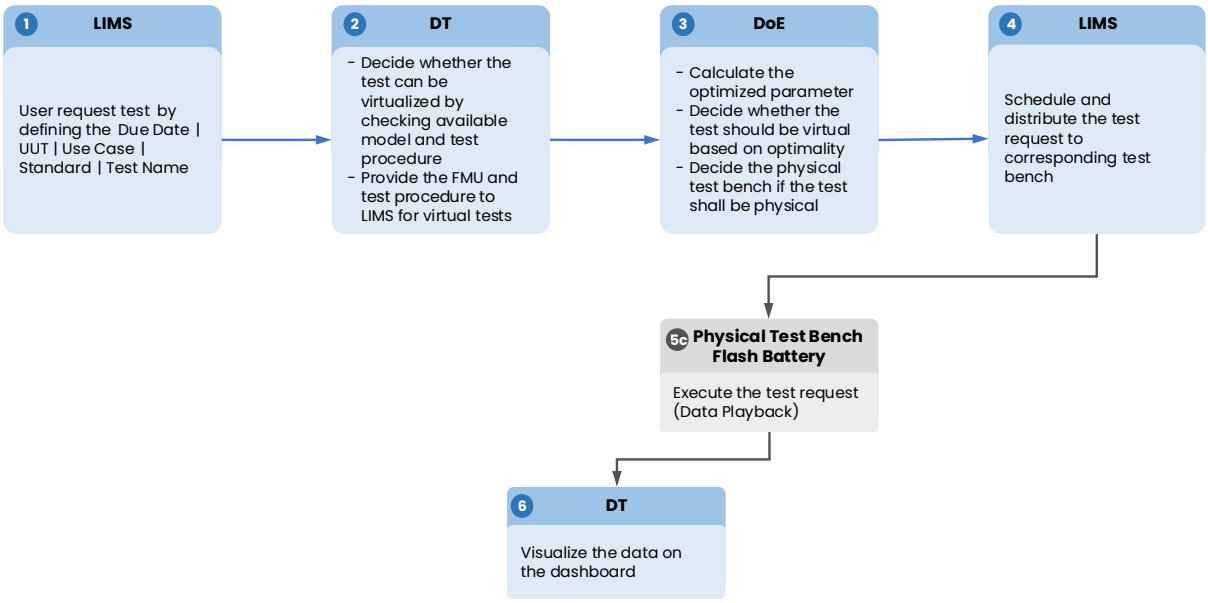
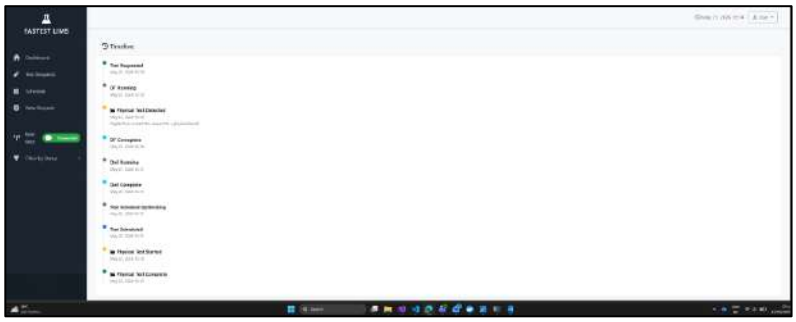
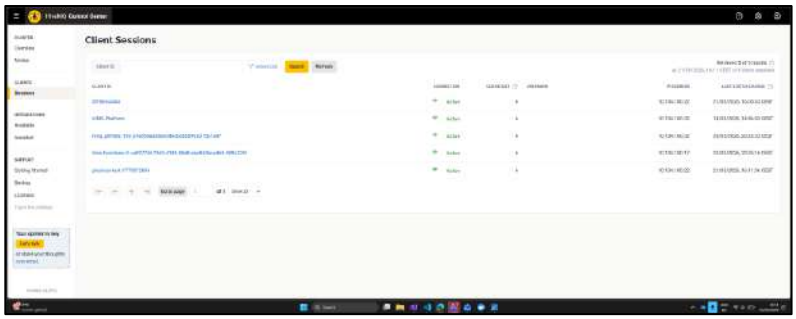


Figure 5 Integration test with Physical Test Bench – Flash Battery.

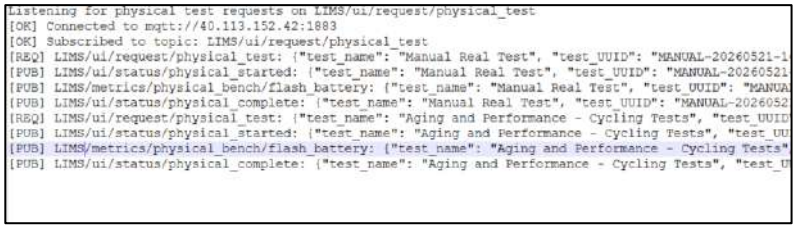
LIMS Status shows all processes has been running and the requested test is completed.



Screenshot shows the FASTEST components that were active during the test.



Screenshot from Flash Battery – Test Bench showing that the communication has been successfully established.



5. Conclusion

Deliverable D6.6 validates the FASTEST hybrid testing platform in an exemplary environment and demonstrates the functional integration of the main WP6 developments. The validation activities show that LIMS can serve as the central orchestration component for hybrid battery testing by receiving user-defined test requests, interacting with DT and DoE services, triggering scheduling logic, distributing test requests to the corresponding execution resource, and forwarding test results for visualization.

The first validation step confirmed the internal readiness of the LIMS pipeline and the virtual test bench by using simulated DT and DoE components. This test verified the basic workflow from user request creation to FMU upload, DoE and scheduling execution, virtual test start, MQTT result publication, and test completion. This provided a controlled baseline before testing the platform with partner components.

The second validation step extended the scope to an end-to-end integration workshop. In this test, the FASTEST workflow was demonstrated with concurrent virtual and physical test requests. The virtual path covered DT-based provision of FMU files and test procedure data, DoE-based processing, scheduling, virtual test execution, and result forwarding to the DT. In parallel, the physical path covered a capacity test request, DoE-based selection of Flanders Make as the physical test bench, LIMS-based distribution of the request, physical test result return, and result forwarding to the DT dashboard. This demonstrated that the FASTEST platform can process virtual and physical test workflows concurrently.

The third validation step confirmed that the virtual test bench is not limited to demonstration models. By integrating the WP3 FMU, the platform verified compatibility with project-developed FASTEST FMUs. The VEOS logs confirmed that the FMU was built, loaded, and simulated successfully, while the received MQTT

message confirmed that simulation results were published back to LIMS through the agreed topic structure.

Additional integration activities with the Ikerlan HiL test bench and the Flash Battery physical test bench complete the validation coverage of the physical testing interfaces.

In summary, the validation activities confirm that the FASTEST platform can coordinate hybrid virtual–physical battery testing across multiple execution resources. The demonstrated end-to-end workflows, concurrent test handling, FMU compatibility, and MQTT-based result exchange provide the technical basis for the final TRL 6 validation of the FASTEST hybrid testing platform.