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FASTEST

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

Deliverable D7.7 Update Exploitation Plan and IP Management Strategy 2

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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 generalised 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 to 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, virtualised benches, and 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 physic-based and data driven models able to substitute physical characterisation experiments; and the overarching Digital Twin architecture managing the information flows, and the TRL6 proven and integrated prototype of the hybrid testing platform.

LIST OF ABBREVIATIONS, ACRONYMS AND DEFINITIONS

Acronym	Name
BPS	Battery Packs & Systems
CINEA	European Climate Infrastructure and Environment Executive Agency
CMEM	Cell manufacturing & equipment manufacturers
DC	Dissemination and Communication
DoE	Design of Experiments
DT	Digital Twin
FTO	Freedom to Operate
GP	General Public
HE	Horizon Europe
HIL	Hardware-in-the-Loop
IP	Intellectual Property
KER	Key Exploitable Result
KPI	Key Performance Indicators
LIB	Lithium-ion battery
M	Month
MoU	Memorandum of Understanding
OEM	Original Equipment Manufacturer
OS	Open science
PM	Policymakers
R&I	Research and Innovation
ROL	Results Ownership List
RSL	Recycling / Second Life
SC	Scientific community
SIE	Sustainable innovations
STC	Standardisation Technical Committees
TM	Trade Media
TTO	Technology Transfer Offices
WP	Work Package

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EXECUTIVE SUMMARY

This document presents the third and final version of the Exploitation Plan and IP Management Strategy as deliverable D7.7, due at month 36, customised for the FASTEST project under Grant Agreement (GA) No. 101103755.

Building on the foundations established in D7.5 (M6) and D7.6 (M18), the Key Exploitable Results (KER) list has been finalised in accordance with the full project outcomes, the consolidated results of all technical work packages, and the exploitation ambitions of the consortium partners. This report represents the definitive approach to the tangible and intangible outcomes of the project and the pathways through which they will continue to generate impact beyond the funded period. It considers the evolving market landscape for the battery value chain, as well as the updated strategies and resources of each consortium member.

All exploitation and IP management objectives for the full project duration have been achieved, including the finalisation of the Key Exploitable Results, the consolidation of exploitation routes and IP ownership allocations, and the completion of the Results Ownership List (ROL) as required by the Grant Agreement.

This final report has been developed through a continuous engagement process with all partners, including exploitation workshops, questionnaires, and bilateral follow-up activities conducted between M18 and M36. It updates D7.6 and constitutes the **definitive Exploitation Plan and IP Management Strategy of the FASTEST project**.

1. INTRODUCTION

The main aim of WP7 is to identify and define the KERs, ensure KER exploitation through adequate IPR measures, disseminate project results to targeted audiences in support of the exploitation plan, and communicate the main project messages to wider audiences.

This deliverable is part of WP7 and is related specifically to **Task 7.3. Exploitation plan and IPR management**. The objectives of this task include the following points:

- To identify intangible and tangible project KERs and prepare exploitation plans for them
- To outline strategies for exploitation of project results in close collaboration with project partners after the project period
- To establish an IPR Management framework to ensure that valuable knowledge generated is protected
- To ensure that adequate dissemination and exploitation measures are put in place

In this document, the roadmap and methodology for exploiting the main outcomes of the FASTEST project have been finalised. The process built upon the market analysis and KER definitions established in D7.5 (M6) and D7.6 (M18), further refining and consolidating these elements based on the complete project results and updated partner inputs gathered between M18 and M36. The KERs have been confirmed, described in full detail, and analysed with information provided by all partners through questionnaires, exploitation workshops, and continuous bilateral follow-up throughout the second half of the project.

The project encompasses a total of **six KERs**, now fully developed and validated as of M36:

1. Hybrid testing platform
2. Knowledge-based DoE methodology toolbox
3. Physics-based modelling tools
4. Data-driven modelling tools
5. Safety and reliability AI toolchain
6. Digital Twin Model

A notable development during this final reporting period has been the expansion and granularisation of **KER3. Physics-based modelling tools**, which has evolved into seven distinct sub-KERs, each reflecting the depth and specificity of the modelling results achieved by the consortium:

- **KER3.1.** Simulink/FMUs for performance/thermal/ageing (cell + module + pack). Led by MGEP

- **KER3.2.** Ageing model (C-code), including degradation mechanisms. Led by UL
- **KER3.3.** Parameter characterisation for Gen3b and Gen4/SSB. Led by ABEE
- **KER3.4.** Definition and execution of cell/module testing. Led by ABEE
- **KER3.5.** Physics-based equivalent circuit model (cell level). Led by VTT
- **KER3.6.** Vibrational fatigue and mechanical reliability (module). Led by IKERLAN
- **KER3.7.** Virtual cycler (simulation environment). Led by IKERLAN

This granularisation reflects the maturity reached by the physics-based modelling activities and allows for more precise exploitation strategies and IP ownership definitions at the sub-result level. The full project KER portfolio as of M36 therefore comprises **6 main KERs** encompassing **12 distinct exploitable results** (including the 7 sub-KERs within KER3).

The internal and external factors influencing the exploitation of these outcomes have been **updated and finalised** in accordance with the most recent market landscape. The IP strategy has been consolidated, including the **final IP ownership allocations** for each KER and sub-KER, the completion of the **Results Ownership List (ROL)**, and the definitive IP protection approaches agreed upon by the consortium. The IP risk matrix has been reviewed and updated to reflect the current status of each result.

The partners have maximised, as much as possible, the openness of results and the interaction with sectoral stakeholders, in a balanced way with IP protection measures established where necessary to ensure the proper exploitation of the project's KERs. The Consortium has contributed to common information and dissemination activities to increase the visibility and synergies with other Horizon Europe supported actions.

2. EXPLOITATION PLAN METHODOLOGY

Given the costs and time involved in developing an innovative technology, product, or service, entering the market can be difficult. In this line, a product or service's chance of success can be increased by developing a well-thought-out exploitation plan and having a thorough understanding of the market this innovation is intended to target. Through Task 7.3 (Exploitation plan and IPR management), an exploitation and IP management plan has been continuously developed throughout the project's lifetime. This plan has outlined the framework for making the most of the results attained after the project's conclusion and has worked to avoid any potential disputes between partners regarding ownership and exploitation of those results after the project's completion.

2.1. Exploitable Innovations and Ambitions

This section aims to describe the novelty value of FASTEST's innovations, as well as their advantages and disadvantages compared to similar existing technologies in the market. It will include the description of all technical information of these innovations, such as features, development stages, etc. Also, it will further describe the value proposition of the project, explaining the core values of these innovations, what problems they will solve, what unfulfilled needs will they meet, or what added value will they provide compared to existing technologies that target the same user segments.

The potential barriers or limitations will also be listed and will be targeted by carrying out a risk analysis throughout the project, addressing the main limitations that could be encountered through the project and that could endanger the implementation of FASTEST's KERs.

2.2. Market Overview

This analysis will use Kothari's "ex-post facto" research methodology (Kothari, 1985). In order to create a complete and accurate image of the industry, it will concentrate on the analysis of the existing situation and the forecasts available for industrial trends. The analysis will mostly be based on secondary data (gathered through scientific papers, news stories, other European Union (EU) reports, and market studies) and primary data (gathered through facilitated interviews and questionnaires with consortium partners).

- **Target market identification:** Main customer and geographic segments.
- **Market Quantitative Analysis:** Main related market growth identification and geographical segments if available.

2.3. Exploitation Plan

The exploitation strategy will lead the way to how the innovations of the FASTEST project can be exploited and delivered onto the market. This section will include the measures to put this strategy in place during the project's lifetime and after its end.

The exploitation plan will develop guidelines to reach the targets, depicting a roadmap on how to achieve the exploitation objectives in the following years after the end of the project. It will also describe the parties who will be responsible for

the exploitation, and the external partners or experts to be involved to exploit the results.

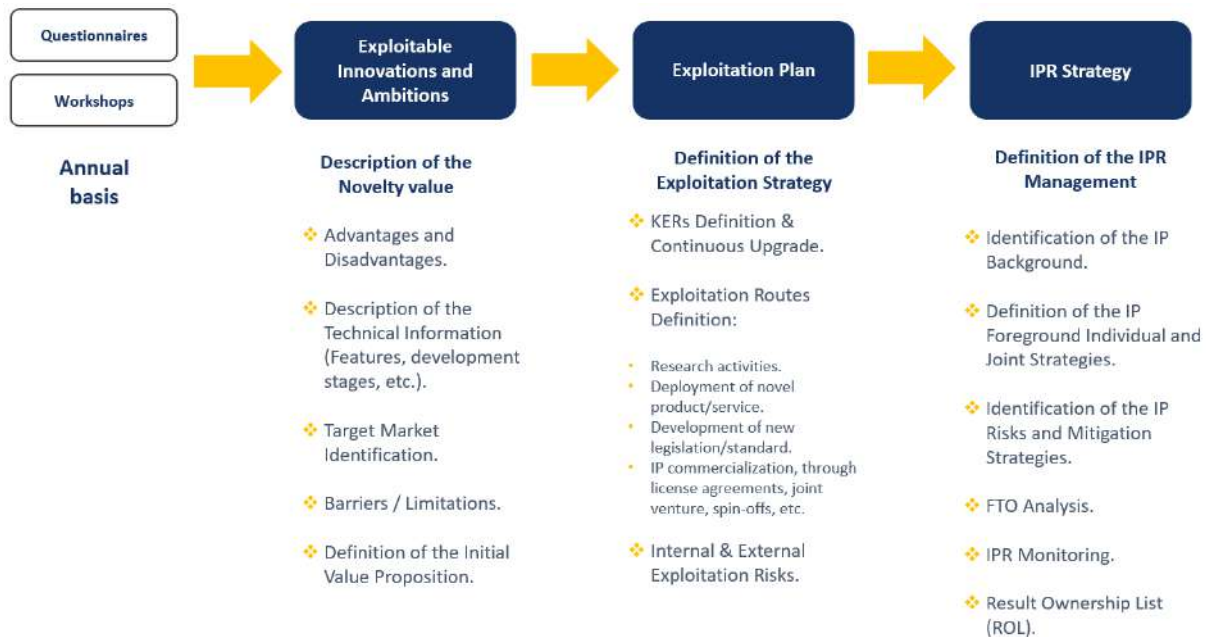


Figure 1: FASTEST Exploitation Roadmap.

Considering the FASTEST results and their expected TRLs, the exploitation route and the timeline for its execution will be further refined through this and the following reports. Listed below are the possible exploitation routes to be considered, either for individual or group exploitation:

- ✓ Research activities
- ✓ Deployment of novel product/service
- ✓ Development of new legislation/standard
- ✓ Commercialization (through IP commercialization, license agreements, joint venture, spin-offs or other possible collaborations with the value chain's stakeholders).

Business models and plans for the project innovations will be part of the work performed in T7.4 (COMAU), this task will evaluate the feasibility of the business model, the quantification of revenues and cost-structure, the market and regulatory compliance, among other.

2.4. Internal Exploitation Risks

Depending on where they are in the value chain, newcomers to the battery industry can face substantial risks. The battery market is relatively slow to grow and has long development cycles at each stage, which results in long payback times. Additionally, there are other battery technologies available in the market to compete. This also applies to the entire battery periphery, including test procedures and platforms.

This version of the Exploitation Plan, as well as any subsequent iterations, will analyse the challenges the partners could encounter while attempting to exploit

the results. Table 1 shows the format the consortium will follow to report internal exploitation risks.

Table 1: Exploitation Risk Table Format.

Risk Number	Risk Description	Risk Level	Risk Mitigation Measures
#1			
#2			
#3			
...#N			

This table will be completed as the exploitation risks are identified and will be updated accordingly through this report’s later versions.

2.5. External Exploitation Drivers and Barriers

Like every project, there are always external exploitation limitations that can be identified from the market trends and the general evolution of any market and can often be considered as barriers for the penetration and market uptake of the project results.

This section will include the barriers identified for the battery testing procedures and platforms, considering external factors such as political, societal, economic, legislative, and technological developments that can affect the adoption of certain technologies and hinder market growth.

3. IP MANAGEMENT METHODOLOGY

The procedures to draft FASTEST’s IP strategy are described in the sections below. This report includes a first approach to the protection of the project results. In future versions of this report, the strategy will be further refined in accordance with the project development.



Figure 2: FASTEST IP Management Methodology.

3.1. Management of Knowledge

IP management is an important topic to consider in project management, since it ensures that the project outcomes are protected most practically, while ensuring freedom to operate in potentially lucrative market areas. The background knowledge brought by each partner will be used to accomplish the project's goals, which is one of the keys to the project's success.

The management of the exploitation and intellectual property rights (IPR) strategy falls under the supervision of the Innovation & Exploitation Manager (in this case, SIE). The manager's job is to monitor and guide the partner's IP decisions and effectively manage the IP background to provide a debate forum inside the consortium and to ease decision-making regarding these topics.

3.2. Foreground IP

The consortium agreement provides comprehensive instructions on how to manage and preserve all the project collaborators' foreground IP. The partner who developed a specific result or outcome shall be the owner of the IPR of said result after the project's lifetime. However, knowledge needed for the completion of the project must be shared among partners to ensure smooth collaboration between all parties.

Results like publications, procedures and tools produced throughout the project will remain with their developing owners for exploitation. In the case of joint ownership, a notified agreement is strongly recommended.

As stated in Annex 5 of the Grant Agreement under Protection of results:
"Beneficiaries which have received funding under the grant must adequately protect their results — for an appropriate period and with appropriate territorial coverage — if protection is possible and justified, taking into account all relevant considerations, including the prospects for commercial exploitation, the legitimate interests of the other beneficiaries and any other legitimate interests."

3.3. Background IP

Before the Consortium Agreement, all partners' prior (background) knowledge was determined. Each partner will hold their background IP and will be responsible for updating it for the length of the project, to identify the ownership that each partner holds and differentiate between background and foreground IP. All knowledge required to carry out the project goals will be accessible without charge for the duration of that project, but after that, access will need to be granted by the owning partner under their terms.

3.4. Ownership Allocations

The basic rules to allocate the ownership of the project results have been set out in Article 16 in the Grant Agreement and in Section 8 in the Consortium Agreement, which have been signed by all the partners participating in the project.

First, the **partner that generates a result will be considered the owner of it and its related IP.**

In the case of two or more partners who are considered as “generators” or “developers” of the result, first, it must be determined if their specific contributions can be separated into sub-results or sub-parts. If this is the case, then they will own the IP related to the corresponding sub-results or sub-parts. **If it is impossible to separate/differentiate the contributions, then the involved partners will have joint ownership over the results.**

In this case, a separate ownership agreement between the involved partners is recommended to determine the allocation and terms of ownership, as well as any other pertinent matters, like the application, obtainment, or maintenance of the chosen protection strategy.

Without the need for the approval of the other parties, **each of the joint owners can use (and sublicense to their respective businesses under the same control) the jointly owned results for non-commercial research and teaching activities.** If the other joint owners are given both (a) at least 45 calendar days' prior notice; and (b) fair and reasonable compensation, **each of the joint owners may exploit their jointly owned results and even grant non-exclusive licenses to third parties** (without the right to sublicense). All protection measures and the allocation of associated costs must be pre-agreed upon by the joint owners.

3.5. Transfer and Licensing of Results

Each party is free to transfer ownership of its results, including their share of a jointly owned result, in accordance with the procedures outlined in Grant Agreement Article 16.4 if it does not affect any of the partners' obligations under the grant agreement contract. In this case, the beneficiary must ensure that the new owner is subject to the obligations they have under the agreement (such as the duty to exploit such result after the project, among other things) to ensure compliance with its stipulations. The transferring party must, unless otherwise agreed, give the other beneficiaries with access rights at least 45 days' notice of the transfer.

As was previously noted, the beneficiary is free to grant non-exclusive licenses to their products as long as doing so has no bearing on their capacity to fulfil their obligations. Only if all beneficiaries have relinquished their access rights may exclusive-access licenses be taken into consideration. Both for the transfer of ownership or to grant an exclusive license, both interested beneficiaries must give the granting authority (EC-CINEA) advance written notice. For this, they must:

- ✓ Identify the specific results concerned.
- ✓ Describe in detail the new owner/licensee and the potential exploitation of the results.
- ✓ Include an assessment of the impact of this transfer/license.

The granting authority can object to the transfer/license within 60 days of receiving the notification.

No transfer/licensing may take place in the following cases:

- ✓ Pending the granting authority's decision.

- ✓ If the granting authority objects.
- ✓ Until the conditions are complied with (if the authority’s objection comes with conditions).

3.6. IP Risks

It is crucial to guarantee the results' freedom to operate for the consortium partners to successfully and freely exploit them once the FASTEST project has ended.

During the next months, the IPR management will be overseen in order to assess any potential conflicts that could arise between partners regarding ownership of the results. A matrix will be used to determine whether there is any disagreement between the partners regarding IP ownership and exploitation rights, including any potential conflicts between background IP and foreground IP holders.

Any risks resulting from partners' present activities or interests in a specific asset's protection will be assessed and managed using the IPR Risk Matrix shown below.

Table 2: Structure of the IP Risk Matrix.

KER	PARTNERS (IP BACKGROUND)	PARTNERS (IP FOREGROUND)	RISK LEVEL
KER 1	Partner 1	Partner 1	The same partner owns the foreground and background. (LOW RISK / INEXISTENT)
KER 2	Partner 1 Partner 2 Partner 3	Partner 1 Partner 4	Different partners own foreground and background, or the IP foreground ownership is not clear. (MODERATE)
KER 3...	Partner 1 Partner 2 Partner 3	Partner 1 Partner 2 Partner 3 Partner 4 Partner 5	Different partners own foreground and background individually, or the foreground is distributed among several partners. (HIGH RISK)

3.7. Freedom-to-Operate

Freedom to Operate (FTO) refers to the ability to develop, produce, and market a product without infringing on the intellectual property (IP) rights of others. Conducting an FTO analysis involves a review of the proposed IP strategy (Patent) and searching existing patents to ensure that the product or process does not infringe on any existing patents. This helps mitigate the risk of costly litigation and allows companies to proceed with their commercial plans confidently.

As mentioned above, FTO analysis involves a patent mapping exercise in the relevant sector for all the innovations (KERs) that are intended to be protected by patents.

By mapping the patent landscape, white spaces and potential areas for innovation are identified, providing partners with the necessary insights to make informed decisions regarding research and development investments, patent filing

strategies, and licensing opportunities. The patent mapping includes three main criteria if available according to the innovation analysed: Geographic criterion, which displays the geographic distribution of patents, including the number of patents and percentages, Temporal criterion, which shows the evolution of patents over time, showing the number of patents filed per year and the Competitive criterion, which displays the most important applicants in terms of the number of patents were available.

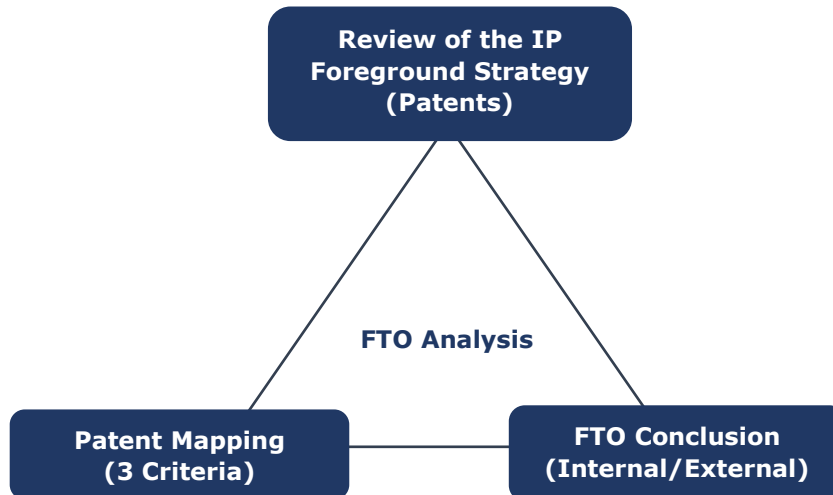


Figure 3: FTO Methodology.

4. EXPLOITATION PLAN FOR FASTEST

The following section describes the exploitation plan for each of FASTEST's KER, analysing in detail each of the innovations developed in the project, with their corresponding state-of-the-art overview and other relevant technical information.

4.1. FASTEST's Innovation and Ambition

The FASTEST project aims to develop and validate up to TRL 6 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.

In general, the consortium aims to develop and integrate into the fast-track testing platform:

- **Optimal DoE strategies** according to three different use cases (automotive, stationary, and off-road).
- A complete set of **physics-based and data-driven models** able to substitute physical characterisation experiments.
- The overarching **Digital Twin (DT) architecture** manages the information flows.

FASTEST will provide a significant impact in improving the R&D phase of the battery development, thus accelerating the development cycle, reducing R&D costs, and improving the overall innovation process. The expected results will be the contribution to an improved design of the partners' batteries, aiming at longer life, increased knowledge, better reliability and enhanced safety (both in the testing environment and in relation to the application). The platform will also contribute to a safer and more reliable testing environment, ultimately optimising the whole battery development and testing strategy. The results aim to accelerate the design phase and reduce the time from concept to market.

The introduction of the above-mentioned platform will directly impact the R&D cost benchmark: esteemed R&D cost reduction is by 35% (Automotive) and 34% (Stationary and off-road), while esteemed R&D time reduction is by 42% (Automotive) and 41% (Stationary and off-road).

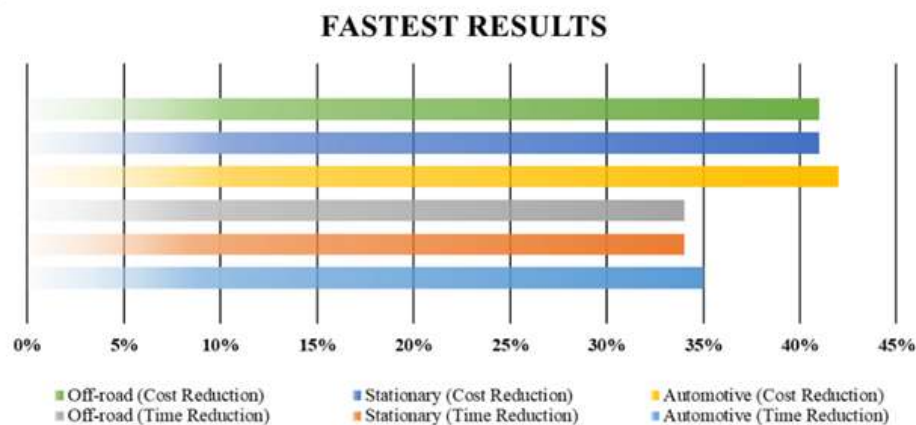


Figure 4: FASTEST overall results for cost and time reductions.

Finally, knowledge transfer activities such as scientific, research publications, and model-added-value demonstrations to the community are among the ambitions of the consortium in order to collaborate with the batteries R&D environment.

4.2. FASTEST's Key Exploitable Results

The KERs are the outputs generated during the project, which can create impact during and after the funded activity is finished, either by the project partners or by other stakeholders. The KER list was first drafted during the proposal stage and has been progressively refined throughout the project lifetime, with formal updates reflected in D7.5 (M6) and D7.6 (M18). The methodology and process followed during the early stages of the project are fully documented in those preceding deliverables.

For the preparation of this final deliverable D7.7, SIE coordinated a dedicated exploitation and IP management engagement process with all partners covering the period from M18 to M36. This process included:

- A **final exploitation questionnaire** circulated to all partners, gathering updated individual and collective views on exploitation ambitions, IP ownership, and protection strategies for each KER and sub-KER
- An **exploitation workshop held at M30**, during which the KERs, exploitation routes, and IP strategies were discussed, refined, and aligned across the consortium
- A **continuous bilateral follow-up** with partners throughout the final reporting period to ensure completeness and accuracy of the information collected

A key outcome of this final engagement process has been the granularisation of KER3. Physics-based modelling tools into seven distinct sub-KERs (KER3.1 through KER3.7), reflecting the depth and maturity of results achieved across the physics-based modelling activities by M36. The insights gathered through the questionnaire and workshop have been embedded directly into the corresponding KER entries of the summary table below.

As a result, the **final KER portfolio of the FASTEST project** as of M36 comprises **6 main KERs**, with KER3 structured into 7 sub-KERs, yielding a total of **12 distinct exploitable results**. These are summarised in Table 3 below, introducing the lead and participating partners, the current and expected TRL, a description of each result, the state of the art, the specific partner contributions, and the finalised exploitation and IP strategies.

Table 3: Key Exploitable Results – M36(Summarised).

#	KER name	Partners / TRL	KER description	State-of-the-art	Partners Contributions
1	Hybrid testing platform	<p>Lead Partners : FEV, IKERLAN, ABEE, INEGI & FHG.</p> <p>Participating partners : FLASH BATTERY, BMZ, FLANDERS MAKE, SURREY & COMAU</p> <p>TRL</p> <p>Initial: 3</p> <p>Current: 3</p> <p>Expected: 6</p>	<p>The Hybrid Testing Platform (HTP) is an integrated cyber-physical battery testing ecosystem that orchestrates physical test benches, virtual models, Digital Twin components, and scheduling services into a unified operational framework for battery validation.</p> <p>The platform dynamically optimises battery test campaigns by:</p> <ul style="list-style-type: none"> Integrating Design of Experiments (DoE) logic Combining physical and virtual testing workflows Enabling quasi-Hardware-in-the-Loop (HIL) BMS validation Managing real-time data exchange between Digital Twin, LIMS, and test benches Reducing redundant physical testing Embedding safety and reliability modelling into operational decision-making <p>HTP transforms conventional battery test centres into intelligent, decision-driven validation environments capable of accelerating R&D while reducing cost and resource consumption.</p>	<p>Current battery testing environments are fragmented:</p> <ul style="list-style-type: none"> Physical and digital tests are conducted separately. Scheduling is often manual. Models are not dynamically reused. HIL validation is limited to isolated subsystems. <p>HTP introduces:</p> <ul style="list-style-type: none"> Integrated test orchestration logic Decision-driven switching between physical and virtual validation Embedded Digital Twin synchronisation Full data lifecycle management 	<p>As the final compound outcome of the project, all contributions are merged.</p> <ul style="list-style-type: none"> FEV.io: System architecture, scheduling services, integration framework, final validation coordination. ABEE: Quasi-HIL BMS demonstrator, physical validation datasets, multiscale modelling integration, Gen3b & Gen4 cells supply. IKERLAN: HIL integration, validation environment setup. FLASH BATTERY: Industrial use case integration, test bench-LIMS interfacing, off-road validation scenario. INEGI & COMAU: Digital Twin integration and data management platform. FHG: DoE integration logic. <p>BMZ, FLANDERS MAKE, SURREY: Use case definition and validation input.</p>

2	Knowledge-based DoE methodology toolbox	<p>Lead Partners :</p> <p>FHG</p> <p>Participating partners :</p> <p>UL</p> <p>TRL</p> <p>Initial: 3-4</p> <p>Current: 3-4</p> <p>Expected: 5-6</p>	<p>The Knowledge-Based DoE Methodology Toolbox is a software-supported methodological framework for optimising battery testing campaigns and parameter identification processes. It combines machine-learning-based surrogate modelling and statistical identifiability analysis to design experiments that maximise the information extracted from physical tests.</p> <p>The toolbox enables the efficient selection of measurement protocols and operating conditions for battery characterisation, allowing researchers and engineers to obtain accurate model parameters while significantly reducing the number of experiments required.</p>	<p>Design of Experiments methodologies are widely used in engineering and scientific research; however, current applications in battery research remain largely manual and rely on simplified sensitivity analyses. Existing approaches often lack the ability to evaluate parameter identifiability and correlations systematically, resulting in inefficient experimental campaigns and redundant testing.</p> <p>The FASTEST toolbox advances the state of the art by integrating physics-informed surrogate modelling with statistical identifiability analysis, enabling automated and data-driven experimental design strategies tailored to battery modelling applications.</p>	<p>FHG</p> <p>Lead developer of the Physics-Informed Neural Network framework and parametrised surrogate modelling methods enabling efficient application of Design of Experiments strategies.</p> <p>UL</p> <p>Developer of the parameter identifiability assessment methodology based on Fisher Information Matrices, enabling the evaluation of measurement configurations and the determination of uniquely identifiable model parameters.</p>
3.1	Simulink/FMUs for performance/thermal/ageing (cell + module + pack)	<p>Lead: MGEP</p> <p>TRL: Expected TRL5</p>	<p>Physics-based reduced-order model accounting for electrochemical and ageing processes is linked to thermal model at cell, module and pack level, which allows fast and accurate computation. Moreover, the model is exported into FMU format, extending the applicability of the models into the fast-track hybrid platform.</p>	<p>Some models are being proposed in the literature; partners should demonstrate the viability of those models in terms of accuracy and safe substitution of physical experiments (reducing cost and time).</p> <p>Degradation modelling tools: simplified models of degradation based on Tafel equations, not accounting for stress/strain contributions and active material cracking.</p> <p>Some models already exist in the literature, but they have not been validated in a relevant environment.</p>	<p>MGEP</p> <p>The model is reduced in order, and different levels (cell, module, pack) and chemistries (LFP, NMC) are accounted for. The FMU exportation is also done. • In MGEP, the models will be further developed to better account for the ageing, performance and thermal behaviour of actual and new cells. After the FASTEST project, the models will be complete. The extensions will be more focused on reducing the error and/or adding new formats/chemistries of cells</p>

3.2	Ageing model (C-code), including degradation mechanism	Lead: UL TRL: Expected TRL4	A validated ageing model implemented in C-code, describing the electrochemical behaviour of a single electrode particle coupled with multiple degradation mechanisms, including SEI growth, reversible lithium plating, and particle cracking. While the core model is developed and implemented, further development is expected to improve computational speed, numerical robustness and upscaling to the electrode level. An estimated 2 years and 30000 € to reach full commercialisation.		UL: Lead partner is UL, where full model development was performed. Participating partner is MGEP. MGEP provided model parameters and performed integration of the model into the full electrochemical model of an elementary electrochemical cell.
3.3	Parameter characterisation for Gen3b and Gen4/SSB	Lead: ABEE TRL: Expected TRL5	The core innovation of Sub-KER is the comprehensive electrochemical, thermal, and ageing parameter characterisation of the Gen3b (LFP/Si-C) and Gen4 solid-state cells. This includes: <ul style="list-style-type: none"> o Determining OCV curves, HPPC profiles, thermal behaviour, ionic/electronic conductivities, solid-phase diffusivities, transference numbers, and ageing-related parameters. o Providing validated, high-quality datasets necessary for the calibration of physics-based and reduced-order models developed in WP3. ABEE performs BoL, cycling, EoL and post-mortem tests, generating the full dataset used in modelling activities.		Lead Partner: ABEE <ul style="list-style-type: none"> • Performs the full experimental test campaign (BoL, cycling, EoL, post-mortem) for Gen3b and Gen4 cells. • Provides raw labelled datasets for parameter identification and validation. • Defines test procedures, reference conditions and supports DoE integration. Participating Partners: <ul style="list-style-type: none"> •UL: Contributes ageing-mechanism modelling (e.g., SEI, Li-plating). •VTT, MGEP, IKERLAN: Use ABEE datasets for ROM, PBM and hybrid models. •INEGI/Fraunhofer: Support advanced testing protocols and analysis (e.g., EIS, thermal characterisation)

3.4	Definition + execution of cell/module testing	Lead: ABEE TRL: Expected TRL5	Designing and executing the complete experimental testing matrix at the cell and module levels, providing validation datasets for the hybrid testing platform		<p>Lead Partner: ABEE</p> <ul style="list-style-type: none"> Executes all physical testing of Gen3b/Gen4 cells and the reference module. Generates ground-truth datasets for validation of ROM, PBM, ageing models and Digital Twins. Provides test specification input to WP1 and WP2. Supports integration with LIMS and DT interfaces. <p>Participating Partners:</p> <ul style="list-style-type: none"> INEGI: Module-level thermal & mechanical modelling validation. IKERLAN: Structural reliability and vibration fatigue analysis (validation using ABEE datasets). MGEP/VTT: Use ABEE experimental results for validating reduced-order models.
3.5	Physics-based equivalent circuit model (cell level)	Lead: VTT TRL: Expected TRL5	The core innovation of this model is to reduce the order of the physics-based model by bridging the the equivalent circuit model (ECM)		VTT: Develop physics-based equivalent circuit models at the cell and module level to bridge the gap between physics-based models and equivalent-circuit models by using circuit models that have real physical meaning for each circuit element (Development Shared with ABEE).
3.6	Vibrational fatigue and mechanical reliability (module)	Lead: IKERLAN TRL: Expected TRL4	Development of a novel methodology for predicting failures in laser welds under vibrational fatigue loads. Advanced methods (SoA) for evaluating joint integrity under vibrational fatigue loads.		
3.7	Virtual cycler (simulation environment)	Lead: IKERLAN TRL: Expected TRL5	Implementation of a Parametrizable Virtual Cycler model, enabling the standardised cycling of a battery model in a simulated environment in the form of an FMU, ensuring the interface between the test sequence generator and the battery model.		IKERLAN: Structural reliability and fatigue loading conditions at module level (Proprietary model by Ikerlan).

4	Data-driven modelling tools	<p>Lead Partners VTT</p> <p>Participating Partners : FHG, BMZ, MGEP & SURREY</p> <p>TRL Initial: 3 Current: 3-4 Expected: 5</p>	<p>The Data-Driven Modelling Tools consist of predictive algorithms capable of estimating battery degradation and operational state functions using operational and historical data from battery systems. The tools process large volumes of battery data collected from sensors and monitoring systems and use machine learning techniques to build predictive models that estimate battery ageing and remaining useful life. These models enable online monitoring of battery condition and provide early indications of degradation, allowing battery operators to optimise operation strategies, improve reliability, and plan maintenance actions more effectively.</p>	<p>Data-driven approaches for battery ageing estimation are increasingly studied in scientific literature; however, many existing models remain limited to laboratory datasets and have not been validated in real-world battery operation environments. FASTEST advances the state of the art by validating data-driven ageing models using real operational datasets and integrating them with hybrid testing platforms and digital twin environments. This integration improves the robustness and applicability of predictive models for industrial battery Applications.</p>	<p>VTT – Lead developer: Development of the core data-driven modelling framework for battery ageing estimation and prediction, including algorithms capable of processing operational data and generating predictive insights on battery performance and degradation.</p> <p>BMZ: Provision of operational battery usage data and insights on cell behaviour during operation and ageing, supporting the development and calibration of predictive models.</p> <p>Fraunhofer IISB (FHG): Contribution to ageing modelling methodologies and support in model validation and performance optimisation.</p> <p>MGEP: Contribution to model validation and interaction with physics-based modelling tools developed within FASTEST.</p> <p>University of Surrey: Contribution to algorithm development and application of predictive modelling methods for battery applications.</p>
5	Safety and reliability AI toolchain	<p>Lead Partners RSTER</p> <p>Participating Partners ABEE, UL, INEGI, IKERLAN, SURREY & VTT</p> <p>TRL Initial: 3</p>	<p>The Safety and Reliability AI Toolchain is a software-based analytical framework that applies artificial intelligence and machine learning methods to monitor, analyse, and predict the safety and reliability of battery systems. The toolchain processes operational data from battery systems, digital twins, and modelling environments to identify degradation trends, detect anomalies, and assess potential safety risks. It enables both real-time monitoring and predictive analysis, supporting safer and more efficient battery operation.</p>	<p>The current state of the art in AI-powered tool chains for battery systems leverages advanced machine learning, digital twin technology, and multi-physics simulations to enhance battery safety, reliability, and performance. AI models are used for accurate predictions of battery degradation, remaining useful life, and failure modes, while digital twins enable real-time virtual simulations under various conditions. Multi-physics tools integrate electrical, thermal, and electrochemical simulations for comprehensive insights. Real-time monitoring systems improve failure detection, and alignment with safety standards streamlines certification processes, reducing time and costs.</p>	<p>RSTER – Lead partner Development of the AI-based toolchain architecture and overall framework for safety and reliability analysis, including integration of monitoring, simulation, and predictive analysis capabilities.</p> <p>ABEE Development of interfaces between the AI toolchain and battery subsystems and implementation of machine learning techniques based on failure tree analysis (FTA), degradation modes, and risk management approaches.</p> <p>University of Ljubljana (UL) Integration of ageing modelling functionalities developed in WP3 into the AI</p>

		<p>Current: 3</p> <p>Expected: 5</p>	<p>By combining predictive algorithms with safety-oriented system architecture design, the toolchain helps optimise battery system development, testing, and operational strategies.</p>		<p>toolchain to support degradation prediction and reliability analysis.</p> <p>INEGI Definition of input and output structures for the toolchain within the digital twin environment, enabling data exchange between simulation and monitoring components.</p> <p>IKERLAN Design of safety and reliability-oriented system architecture aligned with applicable safety standards throughout the development lifecycle.</p> <p>University of Surrey Development of AI-based predictive algorithms applicable to automotive battery systems and other battery-based applications.</p> <p>VTT Support in modelling integration and system-level validation.</p>
6	Digital Twin Model	<p>Lead Partners :</p> <p>INEGI & COMAU</p> <p>Participating Partners :</p> <p>RSTER</p> <p>TRL</p> <p>Initial: 3</p> <p>Current: 3</p>	<p>The Digital Twin Model is a conceptual and technical framework that enables the virtual representation of battery systems by modelling the relationships between battery components, operational parameters, and performance behaviour.</p> <p>The model integrates simulation tools, real-time operational data, and structured data management to create a digital environment capable of replicating the behaviour of battery cells, modules, and packs. This virtual representation allows engineers to analyse system behaviour, perform predictive simulations, and optimise battery design and operation strategies.</p>	<p>Modelling and simulation have long been used in battery development; however, most existing solutions focus on specific modelling tasks such as charge-discharge simulation or performance analysis under predefined conditions.</p> <p>Digital twin technologies represent a more advanced approach by synchronising virtual models with real operational data to replicate the behaviour of physical systems in real time. Despite growing interest in digital twins for industrial systems, applications in battery development remain limited and often address isolated components rather than the entire battery system.</p> <p>The FASTEST Digital Twin Model advances the state of the art by integrating models representing different battery system levels into a unified platform capable of</p>	<p>INEGI – Co-lead developer Development of the conceptual digital twin framework, including ontology definition, information modelling, and the representation of battery components and their relationships. INEGI also defines the semantic structure of the digital twin in accordance with FAIR data principles and battery asset characterisation developed in other FASTEST work packages.</p> <p>COMAU – Co-lead developer Development of the digital twin platform architecture and implementation of the supporting infrastructure for data ingestion, storage, monitoring, and visualisation. COMAU contributes its proprietary industrial IoT platform (In.Grid) to enable cloud-based deployment, communication protocols, and user interface dashboards.</p>

		Expected: 6	The Digital Twin Model serves as the foundation for the development of operational digital twin platforms capable of supporting testing, validation, and monitoring of battery systems.	orchestrating simulations, monitoring operational data, and supporting virtual testing workflows.	RSTER Contribution to the definition of ontology structures and mapping of asset data required for the development of the digital twin framework
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4.3. Exploitation Routes

The Exploitation Routes are how the outcomes of the FASTEST project can be used for further purposes. Exploitation can be commercial, societal, or scientific in nature, and may be pursued by the project partners individually, jointly, or through engagement with third parties.

Table 4 presents the finalised exploitation routes for each KER and sub-KER of the FASTEST project as of M36, as defined through the engagement process conducted between M18 and M36, including the final exploitation questionnaire and the M30 workshop. For each result, the table introduces the identified exploitation routes, the main business applications and the added value of the innovation, and the expected end users and target markets. These have been updated and consolidated to reflect the full maturity of the project results and the confirmed exploitation ambitions of the responsible partners.

Table 4: Exploitation Routes, Applications and End Users.

#	KER name	Partners / TRL	Exploitation Routes	Business Applications and Added Value	End / Target Users
1	Hybrid testing platform	<p>Lead Partners: FEV, IKERLAN, ABEE, INEGI & FHG.</p> <p>Participating partners: FLASH BATTERY, BMZ, FLANDERS MAKE, SURREY & COMAU.</p> <p>TRL Initial: 3 Current: 3 Expected: 6</p>	<p>Primary commercialization routes:</p> <ol style="list-style-type: none"> 1. Full system integration and deployment (engineering service model) 2. Licensing of integration architecture 3. Consultancy-based deployment <p>Exploitation leader: FEV.io Industrial internal adopters: ABEE, FLASH BATTERY.</p>	<p>The Hybrid Testing Platform has varied business applications with significant added value across multiple industries:</p> <ul style="list-style-type: none"> • Automotive Industry: For electric vehicles, it enhances battery safety and performance, speeding up development and market entry. • Energy Storage and Renewable Energy: Improves efficiency and lifespan of batteries in renewable energy systems, aiding in stable energy integration. • Consumer Electronics: Ensures longer battery life and safety in devices like smartphones and laptops, accelerating innovation. • Industrial Applications: Increases battery durability and efficiency in industrial equipment, supporting tailored battery solutions. • Research and Development: Facilitates rapid battery research and innovation, providing comprehensive data for new battery technologies. <p>Overall, the platform offers significant efficiency, safety, and performance benefits, making it valuable for sectors focused on advanced battery technologies and energy management.</p> <ul style="list-style-type: none"> • Battery Quality Assurance, Battery development, manufacturing and R&D - including highly tailored battery solutions, as in the case of Flash Battery. <p>Added value: The Hybrid Testing Platform delivers measurable industrial impact:</p> <ul style="list-style-type: none"> • Up to 41–42% reduction in R&D time • 20–35% reduction in testing costs • Increased bench utilisation rates • Reduced manual scheduling effort • Improved reproducibility and traceability • Enhanced safety integration in validation cycles <p>Its key differentiator is the real-time orchestration of physical and virtual testing, rather than isolated simulation or hardware validation.</p>	<p>The Hybrid Testing Platform primarily targets automotive manufacturers, particularly in the electric vehicle sector, due to their need for efficient and reliable battery systems. Renewable energy companies, which require advanced storage solutions for integrating solar and wind power, also form a significant customer base. Industrial equipment manufacturers who require robust batteries for machinery and backup systems, and research institutions engaged in advanced battery development and testing, are also interested.</p> <p>All the battery value chain would be impacted by the adoption of the fast-track hybrid testing platform, since this outcome aims to reduce cost and time related to R&D, thus impacting the competitiveness of the end user.</p>
2	Knowledge-based DoE methodol	<p>Lead Partners: FHG</p> <p>Participating partners:</p>	<p>The toolbox will primarily be exploited through:</p> <ul style="list-style-type: none"> • Integration into existing software platforms such as FoxBMS 	<p>The Knowledge-Based DoE Toolbox can support several industrial and research activities:</p> <ul style="list-style-type: none"> • Battery model calibration and parameter identification • Optimisation of battery characterisation testing • Accelerated development of battery management systems 	<ul style="list-style-type: none"> • Battery manufacturers • Battery software developers • Battery management system developers

	ogy toolbox	<p>UL</p> <hr/> <p>TRL</p> <p>Initial: 3-4</p> <p>Current: 3-4</p> <p>Expected: 5-6</p>	<ul style="list-style-type: none"> • Engineering consultancy and modelling services • Research collaborations and follow-up projects • Scientific dissemination through publications and training activities <p>The result is expected to support further R&D activities and methodological development rather than direct product commercialisation.</p>	<ul style="list-style-type: none"> • Support for hybrid testing environments combining simulation and experiments • Training and education in battery modelling methodologies <p>Added value: The toolbox provides several advantages for battery R&D and modelling activities:</p> <ul style="list-style-type: none"> • Reduction of experimental testing requirements • Faster parameter calibration for battery models • Improved reliability of model identification • Lower R&D costs in battery development • More efficient integration of virtual and physical testing <p>By ensuring that each experiment maximises the information gained about system parameters, the toolbox significantly improves the efficiency of battery development workflows</p>	<ul style="list-style-type: none"> • Research institutions • Engineering consultancies specialised in battery modelling.
3.1	Simulink/FMUs for performance/thermal/ageing (cell + module + pack)	<p>Lead: MGEP</p> <p>TRL: Expected TRL5</p>	<ul style="list-style-type: none"> •Internal exploitation by MGEP for R&D and service offerings •Scientific and research publications to demonstrate the model's added value •Potential service commercialisation to industry partners post-project 	<p>Business Application: Development and optimisation of battery cells and packs for stationary and mobility applications. Integration into HiL and virtual testing environments</p> <p>Added value: Enables fast and accurate computational substitution of physical experiments, accelerating the battery design phase and reducing time-to-market. Multi-level (cell/module/pack) and multi-chemistry coverage provides versatility for industrial applications.</p>	<p>HiL developers, battery cell manufacturers, battery pack integrators, automotive and off-road OEMs.</p>
3.2	Ageing model (C-code), including degradation mechanism	<p>Lead: UL</p> <p>TRL: Expected TRL4</p>	<ul style="list-style-type: none"> •Internal research use and enhancement of UL's modelling capabilities •Scientific publications in peer-reviewed open-access journals •Networking and future collaboration with industry and research partners 	<p>Business Application: Industrial simulation environments, embedded applications, and integration into commercial battery modelling platforms</p> <p>Added value: Improved prediction capabilities for ageing phenomena in cells with composite Si/Graphite anodes. Suitable for offline SoH observer applications and integration into commercial BMS and simulation platforms</p>	<p>Battery manufacturers and cell developers are assessing ageing behaviour. BMS developers are integrating ageing models into state-of-health estimation</p>

3.3	Parameter characterisation for Gen3b and Gen4/SSB	Lead: ABEE TRL: Expected TRL5	<ul style="list-style-type: none"> •Internal: Enhancement of ABEE's battery validation workflow and cell design activities •Commercial: Contract testing and parameterisation services to OEMs and integrators •Licensing of datasets or validated parameter sets •High-level methodology publications; raw datasets kept confidential 	<p>Business Application: Contract parameterisation and characterisation services. Provision of validated datasets for model developers and digital twin providers</p> <p>Added value: Unique validated parameter datasets for next-generation cell chemistries (Gen3b, Gen4 SSB), foundational for model accuracy across the entire FASTEST modelling chain and Digital Twin</p>	Automotive OEMs, industrial/off-road system integrators, battery manufacturers and research institutes, Digital Twin and virtual testing software providers
3.4	Definition + execution of cell/module testing	Lead: ABEE TRL: Expected TRL5	<ul style="list-style-type: none"> •Internal: Improvement of ABEE testing facilities, workflows, and data management •Commercial: Advanced test campaign and validation services to industry •Integration of validated methods into consultancy and service offerings •Publication of high-level testing methodologies 	<p>Business Application: High-fidelity test services, consultancy integration, and data-driven battery pack development</p> <p>Added value: Standardised, interoperable test datasets that directly feed into virtual testing workflows, reducing redundant physical testing and accelerating validation cycles across the battery value chain</p>	Cell and module manufacturers, automotive and off-road OEMs, stationary storage integrators, certification bodies (indirectly, via validated methods).
3.5	Physics-based equivalent circuit model (cell level)	Lead: VTT TRL: Expected TRL5	<ul style="list-style-type: none"> •Individual internal exploitation by VTT •Scientific dissemination via conference paper (planned) •No commercial exploitation planned at this stage 	<p>Business Application: R&D environments and battery industry applications requiring fast, physically interpretable cell models</p> <p>Added value: Provides a computationally efficient yet physically grounded modelling alternative, suitable for embedding in BMS and real-time simulation environments where full physics-based models are computationally prohibitive.</p>	Battery R&D teams, BMS developers, battery system integrators
3.6	Vibrational fatigue and mechanical reliability (module)	Lead: IKERLAN TRL: Expected TRL4	<ul style="list-style-type: none"> • Internal exploitation through R&D projects with industry companies • Scientific conference paper already published/presented • Full methodology manuscript in preparation 	<p>Business Application: Software/DT and simulation service provision for structural calculation in battery and electronic component manufacturing</p> <p>Added value: Reduction in time and resources required for structural validation. Enables simplified numerical model validation and optimisation of battery module structures without extensive physical testing</p>	Battery and electronic component developers (CAF P&A, Cegasa, Artech, Amopack), laser welding designers and users (Mercedes-Benz, Gestamp, Fagor Electrónica).

3.7	Virtual cycler (simulation environment)	<p>Lead: IKERLAN TRL: ExpectedTRL5</p>	<p>•Internal exploitation by IKERLAN for standardising and optimising BMS XIL testing, validation and verification scenario inputs •No commercial exploitation planned at this stage</p>	<p>Business Application: BMS validation (simulation or HIL), virtualised battery model execution, Digital Twin integration Added value: Standardises and accelerates BMS validation and verification workflows through virtualisation, reducing the need for physical cycling campaigns and enabling flexible scenario-based testing.</p>	BMS HIL developers, battery system Digital Twin developers
4	Data-driven modelling tools	<p>Lead Partners: VTT Participating Partners: FHG, BMZ, MGEP & SURREY TRL Initial: 3 Current: 3-4 Expected: 5</p>	<p>The result will be exploited through multiple channels:</p> <ul style="list-style-type: none"> • Development of new modelling services for battery system analysis • Integration into digital twin platforms and battery management systems • Collaboration with industrial partners and technology developers • Generation of datasets and modelling knowledge for future projects • Scientific publications and knowledge transfer activities <p>The tools may also support new commercial products or services related to battery monitoring and predictive maintenance.</p>	<p>Business Application: The Data-Driven Modelling Tools enable several high-value applications in the battery industry:</p> <ul style="list-style-type: none"> • Predictive maintenance for battery systems • Performance monitoring of battery packs • Optimisation of battery operation strategies • Improved lifecycle management of battery systems • Support for digital twin implementations in battery systems • Enhanced decision support for battery operators <p>Added value: The Data-Driven Modelling Tools provide several advantages compared to existing battery monitoring solutions:</p> <ul style="list-style-type: none"> • Accurate prediction of battery ageing and degradation trends • Reduced need for extensive ageing tests • Continuous model calibration using operational data • Improved predictive maintenance capabilities • Enhanced reliability of battery systems <p>These capabilities enable battery operators and manufacturers to make more informed decisions regarding system operation, maintenance, and lifecycle management.</p>	<ul style="list-style-type: none"> • Battery manufacturers • Battery energy storage system (BESS) operators • Battery management system developers • Engineering consultancies • Industrial companies deploying large battery systems
5	Safety and reliability AI toolchain	<p>Lead Partners: RSTER Participating Partners: ABEE, UL, INEGI, IKERLAN, SURREY & VTT</p>	<p>The result will be exploited through several pathways:</p> <ul style="list-style-type: none"> • Technology transfer and collaborative development with industrial partners • Licensing of AI-based safety algorithms 	<p>Business Application: The Safety and Reliability AI Toolchain supports several industrial applications:</p> <ul style="list-style-type: none"> • Predictive maintenance for battery systems • Early fault detection in battery packs • Safety monitoring for electric mobility and energy storage systems • Optimisation of battery design and operational strategies • Support for battery certification and safety validation 	<p>Primary users include:</p> <ul style="list-style-type: none"> • Battery manufacturers • Battery pack integrators • Electric vehicle manufacturers • Stationary energy storage system providers

		<p>TRL</p> <p>Initial: 3</p> <p>Current: 3</p> <p>Expected: 5</p>	<ul style="list-style-type: none"> Joint ventures or cooperation agreements with battery manufacturers Integration into battery monitoring platforms and digital twin systems Scientific publications and knowledge dissemination 	<ul style="list-style-type: none"> Integration with digital twin environments for virtual safety testing <p>Added value: The Safety and Reliability AI Toolchain provides significant advantages compared to existing monitoring solutions:</p> <ul style="list-style-type: none"> Real-time monitoring of battery safety and reliability parameters Early detection of battery faults and abnormal behaviour Predictive analysis of degradation trends and remaining useful life Reduced certification time through virtual validation methods Improved decision-making through advanced data analysis <p>These capabilities help reduce operational risks, lower maintenance costs, and improve the reliability of battery systems across multiple applications.</p>	<ul style="list-style-type: none"> Industrial equipment manufacturers Battery testing laboratories Research organisations and universities.
6	<p>Digital Twin Model</p>	<p>Lead Partners:</p> <p>INEGI & COMAU</p> <p>Participating Partners:</p> <p>RSTER</p> <p>TRL</p> <p>Initial: 3</p> <p>Current: 3</p> <p>Expected: 6</p>	<p>The Digital Twin Model will be exploited through several pathways:</p> <ul style="list-style-type: none"> Development and provision of digital twin-based engineering services Collaboration agreements with industrial partners for further platform development Integration into existing industrial digital platforms such as COMAU's In.Grid system Knowledge transfer through scientific publications and research collaborations Participation in future research and innovation projects focused on battery modelling and digital twins 	<p>Business Application: The Digital Twin Model supports several industrial applications:</p> <ul style="list-style-type: none"> Accelerated battery product development Virtual testing of battery performance, safety, and reliability Optimisation of battery system design and manufacturing processes Monitoring and analysis of battery behaviour during operation Support for hybrid testing environments combining simulation and physical experiments <p>These capabilities allow battery manufacturers and technology developers to reduce development costs and testing time while improving the reliability of battery systems.</p> <p>Added value: The Digital Twin Model supports several industrial applications:</p> <ul style="list-style-type: none"> Accelerated battery product development Virtual testing of battery performance, safety, and reliability Optimisation of battery system design and manufacturing processes Monitoring and analysis of battery behaviour during operation Support for hybrid testing environments combining simulation and physical experiments <p>These capabilities allow battery manufacturers and technology developers to reduce development costs and testing time while improving the reliability of battery systems</p>	<p>The main target users include:</p> <ul style="list-style-type: none"> Battery manufacturers and battery pack integrators Battery testing laboratories and consultancies Technology developers working on battery systems Research organisations and universities <p>Industrial companies are developing digital twin platforms for battery manufacturing and testing</p>

4.4. Market Advantages

The integration of cutting-edge tools and platforms in battery development offers significant market advantages by enhancing efficiency, reducing costs, and accelerating time-to-market. These innovations streamline the battery development process, improving safety, reliability, and overall performance. Table 5 presents the finalised market advantages of each KER and sub-KER of the FASTEST project as of M36.

Table 5: Market Advantages.

#	KER Name	Market Advantages
1	Hybrid testing platform	The Hybrid Testing Platform offers significant advantages by integrating digital and physical testing, enhancing efficiency and adaptability across the battery development process. Its ability to reduce testing time by up to 40% while cutting costs by 20–30% makes it highly attractive to industries such as automotive and energy storage, where speed, accuracy, and safety are top priorities. The platform integrates advanced safety and reliability modelling, optimising the battery testing process end-to-end. For off-road applications, the platform is expected to reduce R&D costs by 34% and R&D time by 41%. By accelerating verification, validation, and testing phases, the HTP significantly shortens the concept-to-market timeline while improving the safety and reliability of testing environments.
2	Knowledge-based DoE methodology toolbox	The toolbox provides a valuable solution for lowering both costs and time in the R&D process of battery systems. By combining virtual and physical testing intelligently, it enhances efficiency and streamlines the battery development lifecycle. The integrated parameter identifiability methodology maximises the information extracted from experimental measurements while minimising the number of tests required, enabling better optimisation of testing resources and reducing overall R&D expenditure.
3	Physics-based modelling tools	Collectively, the KER3 sub-KERs offer a comprehensive, modular physics-based modelling ecosystem covering electrochemical, thermal, ageing, structural, and circuit-level battery behaviour. Together, they accelerate the design phase, reduce time-to-market, lower testing costs through virtual substitution of physical experiments, and enhance accuracy in predicting degradation phenomena across different cell chemistries and system levels.
3.1	Simulink/FMUs for Performance/Thermal/Ageing	Enables fast and accurate computational substitution of physical experiments at cell, module, and pack levels across multiple chemistries (LFP, NMC). FMU exportation extends applicability into HIL and virtual testing environments, making this tool directly integrable into industrial development workflows. Accelerates battery design and reduces time-to-market for cell and pack developers targeting stationary and mobility applications.
3.2	Ageing Model (C-code), Including Degradation Mechanisms	Delivers improved modelling capabilities for predicting ageing phenomena in cells with composite Si/Graphite anodes. Written in C-code, the model is directly embeddable in industrial simulation environments and BMS platforms, enabling advanced offline SoH

		estimation and reducing reliance on long-duration physical degradation testing. The estimated commercialisation path of 2 years positions this as a near-term industrial asset.
3.3	Parameter Characterisation for Gen3b and Gen4/SSB	Provides uniquely validated, high-quality parameter datasets for next-generation cell chemistries (Gen3b LFP/Si-C and Gen4 solid-state), which are scarce in the open literature. These datasets are foundational for calibrating the entire FASTEST modelling chain and Digital Twin, creating a significant competitive advantage for partners and potential commercial clients requiring accurate models for advanced chemistries.
3.4	Definition + Execution of Cell/Module Testing	Delivers standardised, interoperable test datasets that directly feed into virtual testing workflows, reducing redundant physical testing and accelerating validation cycles. The integration with LIMS and Digital Twin interfaces provides a validated bridge between physical test data and virtual environments, supporting faster and more cost-effective battery development across the value chain.
3.5	Physics-Based Equivalent Circuit Model (Cell Level)	Fills a critical modelling gap by providing a computationally efficient yet physically interpretable cell model, bridging full physics-based models and standard ECMs. Suitable for embedding in BMS and real-time simulation environments where computational resources are limited, offering a practical intermediate modelling option for R&D and industrial applications.
3.6	Vibrational Fatigue and Mechanical Reliability (Module)	Reduces the time and resources required for structural validation of battery modules by providing a simplified, validated methodology for predicting laser weld failures under vibrational fatigue loads. Enables optimisation of battery module structures without extensive physical testing, providing a competitive advantage for manufacturers focused on mechanical reliability and structural certification.
3.7	Virtual Cyclers (Simulation Environment)	Standardises and accelerates BMS validation and verification workflows through a parametrisable FMU-based virtual cycling environment. Reduces the need for physical cycling campaigns and enables flexible, scenario-based testing for BMS HIL developers and Digital Twin integrators, contributing to faster and more cost-efficient battery system validation.
4	Data-driven modelling tools	The data-driven modelling tools enhance decision-making by offering predictive insights on battery degradation and remaining useful life with high accuracy. By integrating operational data from real battery systems, these tools empower engineers to make informed decisions during design and testing phases, further optimising efficiency and accuracy across battery development processes. Their validation with real-world operational data — a key advance over literature models — strengthens industrial applicability.
5	Safety and reliability AI toolchain	Provides an advanced solution for ensuring the safety and reliability of battery systems through real-time monitoring and virtual simulations across multiple domains. The toolchain enables early failure detection, degradation trend prediction, and battery lifespan optimisation. It also reduces certification time and costs by integrating applicable safety standards into the testing process, streamlining compliance efforts and enabling more informed decision-making.

6	Digital Twin Model	Facilitates the creation of digital replicas of physical battery systems, enabling simulation, predictive analysis, and real-time monitoring. A single centralised platform orchestrating all models allows battery developers and manufacturers to access a complete, interoperable system supporting their development workflows. Key advantages include remote data accessibility, backup capability, comparison of simulated and real values, differentiated user authorisation, and seamless interoperability with the wider FASTEST platform ecosystem.
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4.5. Internal Exploitation Risks

Internal exploitation risks within an innovation and development project encompass various threats originating from within the project consortium, potentially compromising the project's integrity, innovation, and overall success. Therefore, early identification of these risks is crucial, followed by the implementation of suitable mitigation strategies. During the initial 18 months of the project, only one internal exploitation risk was identified, primarily concerning delays in providing essential information for Exploitation and IP Management activities.

- **Internal Exploitation Risk:** Delayed provision of KERs information.
- **Risk Description:** Challenges arose in identifying the lead and participating partners for each KER, exacerbated by a lack of comprehension of certain exploitation and IP management concepts.
- **Mitigation Measures:** A rigorous follow-up process was instituted to ensure timely compliance, addressing all partners' inquiries effectively. Additionally, at the First Exploitation and IP Management Workshop, specific commitments and deadlines were established with designated individuals from each partner organization.

4.6. External Exploitation Drivers and Barriers.

The exploitation potential of the FASTEST project results is shaped by a dynamic market landscape characterised by strong structural growth drivers and a set of persistent barriers that partners must navigate in their post-project commercialisation strategies. This section presents an updated overview of the most relevant external factors as of M36, covering the battery development, testing, modelling, and digital twin markets that are directly relevant to the FASTEST KER portfolio.

4.6.1. Drivers

Energy transition and EV market growth. The accelerating global transition towards electromobility and renewable energy storage continues to be the primary structural driver for the entire battery value chain. Government mandates, emissions regulations, and industrial decarbonisation targets across the EU, US, and Asia are sustaining strong investment in battery development, manufacturing, and testing infrastructure. This directly expands the addressable market for FASTEST tools across all KERs.

Rising complexity of next-generation battery chemistries. The industry shift towards advanced chemistries — including high-silicon anodes (Gen3b) and solid-state batteries (Gen4) — is increasing the demand for sophisticated modelling, characterisation, and testing tools. Standard physical testing approaches are insufficient to handle the complexity and cost of validating these chemistries at scale, creating a strong pull for the physics-based modelling tools (KER3), parameter characterisation datasets (KER3.3), and the hybrid testing platform (KER1) developed within FASTEST.

Cost and time pressure on battery R&D. Battery developers face intense competitive pressure to reduce development cycles and R&D costs. The substitution of physical experiments with validated virtual testing — the core value proposition of the FASTEST platform — is increasingly recognised as a strategic necessity rather than an optional enhancement. Industry benchmarks indicate potential R&D cost reductions of 20–40% through hybrid testing approaches, directly validating the market relevance of KER1, KER2, KER3, and KER4.

Growth of battery testing equipment and simulation software markets. The global battery testing equipment market and battery simulation software market are both experiencing sustained growth, driven by increasing production volumes, stricter safety and certification requirements, and the adoption of HIL testing methodologies. These trends directly support the commercial prospects of the Hybrid Testing Platform (KER1), the DoE toolbox (KER2), and the Safety and Reliability AI Toolchain (KER5).

Digital Twin adoption in industrial manufacturing. Digital twin technologies are rapidly gaining traction across industrial sectors, supported by the proliferation of Industrial IoT, cloud computing, and advanced analytics. The battery sector is increasingly investing in digital twin capabilities for product development, quality assurance, and operational monitoring. This trend directly supports the exploitation of KER6 and reinforces the value of the integrated FASTEST platform as a whole.

EU regulatory and standardisation framework. The EU Battery Regulation (2023/1542) introduces mandatory requirements for battery passports, lifecycle data management, carbon footprints, and performance standards for EV and industrial batteries. Compliance with these requirements will drive demand for advanced testing, modelling, and digital twin tools — positioning FASTEST results favourably within the evolving regulatory landscape.

4.6.2. Barriers

High upfront investment and integration complexity. The adoption of advanced battery testing and modelling platforms requires significant initial investment in infrastructure, software integration, and workforce training. For smaller battery developers and SMEs, this represents a meaningful barrier to entry that partners must address through service-based business models, phased deployment approaches, and clear demonstration of return on investment.

Data interoperability and standardisation gaps. The battery development ecosystem remains fragmented, with limited standardisation of data formats, model interfaces, and testing protocols across organisations and platforms. While FASTEST has made progress through FMU-based interoperability and LIMS integration, broader adoption of FASTEST tools will depend on continued alignment with emerging industry standards and data exchange frameworks.

Validation confidence and industrial trust. Replacing physical tests with virtual alternatives requires a high degree of confidence in model accuracy and reliability. Building this trust with industrial end users — particularly in safety-critical automotive applications — is a gradual process that demands robust validation evidence, traceable datasets, and compliance with applicable certification standards. Partners should anticipate extended technology transfer timelines for safety-critical use cases.

IP complexity in collaborative results. Several FASTEST KERs involve contributions from multiple partners, creating joint IP ownership situations that require careful management through consortium and collaboration agreements. Without clear and timely IP agreements, the commercial exploitation of jointly owned results may be delayed or complicated, particularly as partners pursue individual commercialisation pathways after project closure.

Talent and skills scarcity. The deployment of advanced battery modelling, AI toolchains, and digital twin technologies requires specialised expertise that remains scarce in the market. This limits both the speed of internal exploitation by partners and the rate of customer adoption, particularly in industrial sectors with less mature digital capabilities.

5. IP STRATEGY FOR FASTEST

This chapter presents the finalised IP Strategy for the FASTEST project, consolidating the intellectual property background and foreground definitions reached by the end of the project at M36. The IP strategy has been progressively developed throughout the project lifetime, with preliminary versions documented in D7.5 (M6) and D7.6 (M18). This final version reflects the consolidated positions of all partners following the engagement process conducted between M18 and M36, including the final exploitation questionnaire and the M30 exploitation workshop.

5.1. IP Background and Foreground

The IP background refers to all pre-existing knowledge, tools, data, expertise, patents, and other intellectual assets brought into the project by the partners, upon which the FASTEST exploitable results have been built. The IP foreground refers to all knowledge and results generated during the project, including the KERs and sub-KERs described in the preceding sections.

Throughout the project, the IP management strategy has been governed by the principles established in the Grant Agreement and the Consortium Agreement. The progressive refinement of IP ownership definitions — from the preliminary positions stated at the proposal stage through to the consolidated agreements reached at M36 — has been a continuous process involving all partners.

A notable evolution in this final reporting period has been the granularisation of KER3 into seven sub-KERs, each with individually defined IP ownership and protection strategies. This level of specificity in IP definition reflects the maturity of the project results and ensures clarity on ownership responsibilities as the project concludes and exploitation activities begin.

The Results Ownership List (ROL), as required by the Grant Agreement, has been finalised and is reflected in the IP foreground table below. Table 6 presents the finalised IP background contributions of each partner alongside the confirmed IP foreground protection strategies for each KER and sub-KER as of M36.

Table 6: IP Management.

#	KER name	Lead partner	Participating partners	Expected IP owners	Background IP	IP Protection Strategy
1	Hybrid testing platform	FEV, IKERLAN, ABEE, INEGI & FHG	FLASH BATTERY, BMZ, FLANDERS MAKE, SURREY & COMAU	FEV, IKERLAN, ABEE, INEGI, FHG, FLASH BATTERY, BMZ, FLANDERS MAKE, SURREY & COMAU	<p>ABEE</p> <ul style="list-style-type: none"> Battery Cells: Advanced battery cell technologies that are fundamental to the testing processes. Multiscale Models: Sophisticated modelling techniques that span different scales, essential for accurate battery analysis and testing. State Functions (SoC and SoH): Intellectual property related to State of Charge (SoC) and State of Health (SoH) functions, critical for battery performance assessment. Identification Techniques: Techniques used for identifying and characterizing battery parameters and behaviours. Copyright. Utility model. Know-how in the field of research and development, particularly in the areas of Battery Management Systems (BMS). The company's know-how was built on their extensive experience in cell production and battery pack systems. <p>IKERLAN</p> <ul style="list-style-type: none"> Background on HIL development and different safety standard compliance by IKERLAN. 	<p>• Trade secret: architecture and integration logic (all lead partners)</p> <ul style="list-style-type: none"> Patent: FEV (DE102023133703A1 and follow-on DE102024131323.4) Consortium Agreement governs IP ownership, access rights and confidentiality obligations across all partners FEV granted access rights to all partner-owned building blocks for integration, deployment and commercialisation of the full platform <p>Open elements per partner:</p> <ul style="list-style-type: none"> FEV: high-level architecture descriptions, interface definitions, interoperability guidelines FHG: high-level DoE methodology (publications, deliverables) IKERLAN: high-level architecture descriptions, dissemination material ABEE: interfaces, APIs, selected methodological approaches <p>✓ IP governance resolved (agreed May 2026): no JOA required. Platform building blocks are individually owned by each contributing partner. FEV exploits the full integrated platform under a mutually agreed access rights scheme, enabling commercialisation without joint ownership complexity. ROL to be finalised at M36 closure.</p>
2	Knowledge-based methodology toolbox	DoE FHG	UL	FHG & UL	<p>FHG</p> <ul style="list-style-type: none"> There is no IP background other than technical expertise. <p>UL</p> <ul style="list-style-type: none"> Methodology for assessing uniqueness of parameter identification: KER rely on the existing methodology applied to the fuel cells and is owned by UL. Trade Secret. 	<p>Individual protection per component. No patent planned. FHG: Trade secret (institutional know-how) + open-source integration into foxBMS platform + open-access scientific publications (1 published, 1 pending). UL: Trade secret (FIM methodology) + open-access scientific publications. No joint ownership arrangement required — each partner</p>

						independently owns and exploits their respective component.
3	Physics-based modelling tools	MGEP	ABEE, IKERLAN, VTT, UL & BMZ	MGEP, ABEE, IKERLAN, VTT, UL & BMZ	<p>MGEP</p> <ul style="list-style-type: none"> Background on modelling by MGEP on reduce order modelling and electrochemical parameter measurement and estimation. Know-how on battery physics-based modelling and characterization. Know-how on battery physics-based reduced order modelling techniques. Know-how battery thermal modelling, both in 3D and reduced order thermal modelling and battery thermal characterization. <p>UL</p> <ul style="list-style-type: none"> Degradation modelling tools: no existing IP. Proprietary multi-domain and multi-scale battery modelling suite. <p>IKERLAN</p> <ul style="list-style-type: none"> Background on modelling and testing by IKERLAN on structural reliability and vibrational fatigue loading conditions. 	<ul style="list-style-type: none"> Copyright for publications. Trade secret between lead and participating partners. The protection will cover the entire KER's concept and all participating partners will share the IP ownership. For this end a joint ownership agreement must be concluded after completion of the project.
3.1	Simulink/FMUs for Performance/Thermal/Ageing	Lead: MGEP	NA	MGEP	<p>MGEP extensive background IP:</p> <ul style="list-style-type: none"> Electrochemical models (P2D, SPM, SPMe, full & reduced order) Thermal models (1D-3D) + characterisation know-how Ageing equations (SEI, Li deposition, cracking, LAM) SoX estimators (SPKF, UKF, EKF) MODEST tool (registered), ECM parameterisation tool Neural network, PINN & hybrid models 	<p>Multi-level ROMs (cell/module/pack) in Simulink & FMU format for LFP and NMC chemistries</p> <ul style="list-style-type: none"> <input checked="" type="checkbox"/> Trade Secret <input checked="" type="checkbox"/> Open Source / Public
3.2	Ageing Model (C-code), Including Degradation Mechanisms	Lead: UL	NA	UL	No background IP contributed	<p>C-code ageing model: single-particle electrochemical model + SEI growth, Li-plating, particle cracking</p> <ul style="list-style-type: none"> <input checked="" type="checkbox"/> Trade Secret Scientific publications planned (open-access)
3.3	Parameter Characterisation for Gen3b and Gen4/SSB	Lead: ABEE	NA	ABEE	<ul style="list-style-type: none"> <input checked="" type="checkbox"/> ABEE background IP: Proprietary test methodologies & protocols (Li-ion, SSB) Data labelling, reliability screening, cycling know-how <p>Protection: Trade Secret + Copyright</p>	<p>Validated parameter datasets for Gen3b/Gen4 cells (OCV, HPPC, thermal, conductivities, ageing params)</p> <ul style="list-style-type: none"> <input checked="" type="checkbox"/> Trade Secret <input checked="" type="checkbox"/> Copyright Raw datasets: confidential; methodologies: may publish

3.4	Definition + Execution of Cell/Module Testing	Lead: ABEE	NA	ABEE	<input checked="" type="checkbox"/> ABEE background IP: <ul style="list-style-type: none"> Proprietary test protocols, fixtures, measurement procedures Internal data formatting & traceability systems Protection: Trade Secret + Copyright	Test execution procedures + validated datasets (electrical/thermal/mechanical) interoperable with DT, DoE and modelling toolchains <ul style="list-style-type: none"> <input checked="" type="checkbox"/> Trade Secret <input checked="" type="checkbox"/> Copyright
3.5	Physics-Based Equivalent Circuit Model (Cell Level)	Lead: VTT	NA	VTT	No background IP contributed	Physics-based ECM bridging full PBM and standard ECM <ul style="list-style-type: none"> ⚠ No protection option selected by VTT Conference paper planned
3.6	Vibrational Fatigue and Mechanical Reliability (Module)	Lead: IKERLAN	NA	IKERLAN	<input checked="" type="checkbox"/> IKERLAN background IP: <ul style="list-style-type: none"> Structural reliability modelling know-how Vibrational fatigue loading conditions expertise 	Methodology manuscript + calculation spreadsheets + know-how for laser weld failure prediction under vibrational fatigue loads <ul style="list-style-type: none"> <input checked="" type="checkbox"/> Copyright Conference paper already published
3.7	Virtual Cypher (Simulation Environment)	Lead: IKERLAN	NA	IKERLAN	No background IP contributed	Parametrisable FMU-based Virtual Cypher for standardised battery model cycling <ul style="list-style-type: none"> <input checked="" type="checkbox"/> Copyright Internal use only (BMS XIL testing)
4	Data-driven modelling tools	VTT	FHG, BMZ, MGEP & SURREY	VTT	VTT <ul style="list-style-type: none"> Background on data-driven model development by VTT (Know-how / not protected) 	<ul style="list-style-type: none"> VTT Trade secret: The protection will cover the entire KER. An IP transferring agreement should be signed between participating partners and VTT, to establish VTT as the IP owner. FLASHBATTERY Collaboration agreement with FLASHBATTERY: To participate in the exploitation of this KER.
5	Safety and reliability AI toolchain	RSTER	ABEE, UL, INEGI, IKERLAN, SURREY & VTT	RSTER ABEE, UL, INEGI, IKERLAN, SURREY & VTT	<ul style="list-style-type: none"> No pre-existing protected background IP declared by any attending partner (ABEE, RSTER, IKERLAN, SURREY). All contributions based on knowledge and skills (know-how). UL, INEGI, VTT background IP not confirmed — to be aligned separately. 	<ul style="list-style-type: none"> Patent: planned for the integrated AI toolchain concept and overall architecture. ABEE leads and manages patent filing process once JOA is signed. Copyright: software components and scientific publications (all partners). JOA to be drafted by SIE and signed by all 7 partners before patent filing is initiated. Open items: ownership split (equal vs. contribution-weighted — TBD) and governance model (unanimous vs. qualified majority — TBD).

6	Digital Twin Model	INEGI & COMAU	RSTER	INEGI, COMAU & RSTER	<p>INEGI</p> <ul style="list-style-type: none"> • Know-how on semantic-based data modelling for the virtual representation of physical objects, involving the definition of components, properties and relationships that need to be captured in the digital twin. • Know-how on data ingestion for building data pipelines ingesting real-time data from sensors and other sources from physical objects. • Know-how on simulation of behavioural models of the physical entity or system, enabling "what-if" analysis and predictive modelling. • Knowledge on battery engineering and manufacturing domains for applying the previous know-hows to the unique challenges and requirements of the battery industry. • Trade Secret. • Copyright. • Non-exclusive, non-transferable, non-sublicensable and royalty-free access rights for the Project consortium on a need-to-know-basis and in the context of the implementation of the Project. Information is confidential outside the Project consortium. <p>COMAU</p> <ul style="list-style-type: none"> • Know-how on automation systems and specifically on technical solutions for battery and cell manufacturing, material handling, battery assembly and joining technologies. Know-how on digital technologies related to manufacturing systems including proprietary IoT platform (In.Grid). • Trade secret. • Copyright. • Trademark. 	<ul style="list-style-type: none"> • INEGI: Copyright for scientific publications (CC BY-NC-ND 4.0 — confirmed, Marques et al. DOI: 10.5220/0013082300003838). No trade secret enforced post-project. No patent. Open licensing — third parties may build on ontology and DT know-how. • COMAU: Copyright for software integrated into In.Grid (primary IP asset) and scientific publications. In.Grid trademark maintained as background IP. No patent filing planned. • JOA considered and confirmed not required — clear separation of roles eliminates need for joint governance. COMAU independently exploits KER6 commercially through In.Grid; GA/CA framework sufficient for INEGI's non-commercial use.
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5.2 IP Risks

In order to assess the potential risks regarding IP ownership of each of the project results, an IP risk matrix was developed and customised for the FASTEST project following the first exploitation and IP management workshop and the initial refinement of IP strategies at M18. This matrix has been reviewed and finalised during the M18–M36 period, incorporating the updated IP ownership definitions and protection strategies confirmed by all partners through the final exploitation questionnaire and the M30 workshop.

The matrix summarises the IP risks associated with each KER and sub-KER of the project, evaluating each result in terms of its IP background, foreground strategy, and ownership allocation, and highlighting potential risks that could impact the exploitation of the project outcomes. Unlike the preliminary version presented in D7.6, this final IP risk assessment reflects the consolidated and agreed IP positions of all partners at project closure, including the individually defined IP strategies for each of the seven sub-KERs within KER3.

Table 7 presents the finalised IP protection strategies and the corresponding IP risk assessment for each KER and sub-KER as of M36.

Table 7: FASTEST IP Risk Matrix.

#	KER name	Partners	Background IP	IP Protection Strategy	Expected IP owners	IP Risk
1	Hybrid testing platform	<p>Lead Partners:</p> <p>FEV, IKERLAN, ABEE, INEGI & FHG.</p> <p>Participating partners:</p> <p>FLASH BATTERY, BMZ, FLANDERS MAKE, SURREY & COMAU</p>	<p>ABEE</p> <ul style="list-style-type: none"> Copyright. Utility model. Know-how (Stated in CA). <p>IKERLAN</p> <ul style="list-style-type: none"> Know-how (Declared specific know-how). <p>FEV</p> <ul style="list-style-type: none"> Patent DE102023133703A1 + follow-on DE102024131323.4 (scheduling and orchestration logic) <p>ALL PARTNERS PARTICIPATING IN THE KER</p> <ul style="list-style-type: none"> Know-how. 	<ul style="list-style-type: none"> Trade secret: (architecture and integration logic). Patent protection (FEV).. Consortium Agreement governing access rights. FEV exploits full platform under access rights scheme – no JOA required. 	<p>Individual ownership per building block: FEV (~35%), ABEE (~15–20%), IKERLAN (~10%), FHG (DoE component), INEGI, FLASH BATTERY, COMAU, BMZ, FLANDERS MAKE, SURREY – per their respective technical contributions. FEV granted access rights to all building blocks for platform commercialisation.</p>	<p>LOW</p> <p>Platform building blocks are clearly separable and individually owned. JOA not required – resolved May 2026. FEV access rights scheme agreed. ROL to be finalised at M36 closure. Risk reduced from MODERATE (M18) to LOW.</p>
2	Knowledge-based DoE methodology toolbox	<p>Lead Partners:</p> <p>FHG</p> <p>Participating partners:</p> <p>UL</p>	<p>FHG</p> <ul style="list-style-type: none"> Know-how and technical expertise. <p>UL</p> <ul style="list-style-type: none"> Trade Secret. 	<ul style="list-style-type: none"> Trade secret (institutional know-how per partner). Copyright (scientific publications – open access). No patent planned. FHG: integration into open-source foxBMS platform. UL: exploitation through secured national project. 	<p>FHG & UL. Individual ownership per component: FHG owns PINN-based surrogate modelling component. UL owns FIM identifiability methodology. No joint ownership.</p>	<p>LOW</p> <p>Each partner owns their individual component. No overlap or conflict identified. Open-access publication route for scientific outputs reduces risk of IP dispute. Risk reduced from MODERATE (M18) to LOW.</p>
3	Physics-Based Modelling Tools (KER3 – 7 sub-KERs)	<p>Sub-leads:</p> <p>MGEP (3.1), UL (3.2), ABEE (3.3, 3.4), VTT (3.5), IKERLAN (3.6, 3.7)</p>	<p>MGEP</p> <ul style="list-style-type: none"> Know-how and technical expertise (Stated in CA). <p>UL</p> <ul style="list-style-type: none"> Know-how and technical expertise (Stated in CA). <p>IKERLAN</p> <ul style="list-style-type: none"> Know-how and technical expertise. 	<ul style="list-style-type: none"> Copyright for publications. Trade secret: This IP strategy will cover the entire KER’s concept. Collaboration agreement. 	<p>MGEP, ABEE, IKERLAN, VTT, UL & BMZ</p>	<p>LOW</p> <p>Granularisation into 7 sub-KERs with individual ownership per partner significantly reduces IP conflict risk vs. M18.</p>

			<p>ABEE</p> <ul style="list-style-type: none"> ABEE: Proprietary test protocols and datasets (trade secret, copyright). 			
4	Data-driven modelling tools	<p>Lead Partners:</p> <p>VTT</p> <p>Participating Partners:</p> <p>FHG, BMZ, MGEP & SURREY</p>	<p>VTT</p> <ul style="list-style-type: none"> Know-how and technical expertise. 	<p>VTT</p> <ul style="list-style-type: none"> Trade secret: The protection will cover the entire KER. <p>FLASHBATTERY</p> <ul style="list-style-type: none"> Collaboration agreement with FLASHBATTERY: To participate in the exploitation of this KER. 	<p>VTT</p> <p>VTT – individual ownership as lead developer. IP transfer agreements to consolidate foreground ownership under VTT..</p>	<p>LOW RISK / INEXISTENT</p> <p>None, as the IP foreground strategy will encompass an IP transferring agreement to set VTT as the IP owner.</p>
5	Safety and reliability AI toolchain	<p>Lead Partners:</p> <p>RSTER</p> <p>Participating Partners:</p> <p>ABEE, UL, INEGI, IKERLAN, SURREY & VTT</p>	<ul style="list-style-type: none"> No IP background except knowledge and skills. 	<ul style="list-style-type: none"> Patent planned for integrated AI toolchain architecture – ABEE leads filing post-JOA. Copyright for software and publications (all partners). JOA to be signed by all 7 partners before patent filing. 	<p>Joint ownership – 7 partners per foreground contributions. Confirmed: RSTER (toolchain architecture), IKERLAN (safety architecture design – ISO 26262/IEC 61508), ABEE (BMS interfaces, ML/FTA techniques), SURREY (AI predictive algorithms for automotive – new confirmed commercial route). UL, INEGI, VTT foreground scope pending.</p>	<p>MODERATE</p> <p>No protected background IP declared. Patent + copyright strategy agreed. Open items: JOA ownership split and governance model (TBD); UL, INEGI, VTT foreground alignment pending.</p>
6	Digital Twin Model	<p>Lead Partners:</p> <p>INEGI & COMAU</p> <p>Participating Partners:</p> <p>RSTER</p>	<p>INEGI</p> <ul style="list-style-type: none"> Know-how and technical expertise. Trade Secret. Copyright. <p>COMAU</p> <ul style="list-style-type: none"> Know-how and technical expertise (Stated in CA). Trade secret. Copyright. Trademark. 	<ul style="list-style-type: none"> Trade secret (core DT framework components). Copyright (publications, software, documentation). COMAU: trademark protection for In.Grid platform maintained. Collaboration agreement between INEGI, COMAU and RSTER. INEGI open to IP licensing/transfer to consortium partners or external organisations. 	<p>INEGI: ontology framework and FAIR data modelling. COMAU: DT platform architecture and In.Grid-integrated software. RSTER: no foreground ownership claim. JOA not required – INEGI (RTO/science) and COMAU (commercial via In.Grid) have complementary non-competing roles. INEGI publication confirmed: Marques et al., DOI 10.5220/0013082300003838</p>	<p>LOW</p> <p>Revised from MODERATE (M18). All three previously open risks resolved. Grid boundary (COMAU sole commercial exploiter), INEGI background scope (no competing commercial interest), RSTER role (minor, no claim). JOA considered and confirmed not required.</p>

5.3 Results Ownership List (ROL)

The **Results Ownership List** allows beneficiaries to provide information on the owner(s) of the results in the reporting periods. This includes whether the ownership is single or joint, the name of the owner(s), the country of establishment of the owner(s) and whether the results will be exploited by the owner(s). Failure to do so will block both the submission of the final periodic report and the final payment. Horizon Europe has a specific objective: to strengthen the exploitation of research results. This calls for clarity as to the results ownership. This final version of the ROL reflects the confirmed IP ownership positions of all partners as of M36, incorporating the outputs of the partner exploitation questionnaires, the KER5 and KER6 IP ownership meetings, the Booster go-to-market process for KER1, and the granularisation of KER3 into seven sub-KERs each with individual ownership. The ownership structure has evolved significantly since the preliminary M18 version: KER1 has moved from joint ownership to individual building block ownership with FEV granted access rights for platform commercialisation; KER3 has been disaggregated into seven individually owned sub-KERs; KER5 has confirmed ABEE as Lead Partner with a JOA and patent filing process underway; and KER6 has confirmed that no JOA is required given the complementary and non-competing roles of INEGI and COMAU.

Table 8: FASTEST Preliminary (M36) ROL.

Project Result	Single or joint ownership of results?	Result owners	Owner country of establishment	Will the owners exploit the result?	In which form will the result be made available to other consortium members and/or third parties?	Does the exploitation of the results require access to background of one or several consortium members?	Does the exploitation of the results require access to third-party IPR?
Hybrid testing platform	Individual ownership per building block. FEV granted access rights for full platform exploitation. No JOA required.	FEV, IKERLAN, ABEE, INEGI, FHG, FLASH BATTERY, BMZ, FLANDERS MAKE, SURREY & COMAU	FEV (DE), IKERLAN (ES), ABEE (BE), INEGI (PT), FHG (DE), FLASH BATTERY (IT), BMZ (DE), FLANDERS MAKE (BE), SURREY (UK) & COMAU (IT)	YES	Licensing (FEV access rights scheme). Non-disclosure agreement for confidential components.	YES — FEV requires access to all partner-owned building blocks under the agreed access rights scheme.	NO
Knowledge-based DoE methodology toolbox	Individual ownership per component. No JOA required.	FHG (PINN surrogate modelling component). UL (FIM identifiability methodology).	FHG (DE) & UL (SI).	YES — FHG (internal R&D, foxBMS integration, training). UL (internal R&D, national project exploitation, training).	Open access (scientific publications). foxBMS open-source integration (FHG).	NO	NO
Simulink/FMUs for Performance, Thermal & Ageing	Single ownership	MGEP	MGEP (ES)	YES — internal R&D and service offering	Trade secret (internal) or open access (publications)	NO	NO
Ageing Model (C-code)	Single ownership	UL	UL (SI)	YES — UL (internal R&D, publications).	Scientific publications (open access). Trade secret (C-code).	NO	NO
Parameter Characterisation for Gen3b and Gen4/SSB	Single ownership	ABEE	ABEE (BE)	YES — internal use and commercial contract characterisation services	Trade secret (raw datasets). Open access (high-level methodologies). Licensing of datasets.	NO	NO

Definition + of Execution Cell/Module Testing	Single ownership	ABEE	ABEE (BE)	YES — ABEE (internal use and commercial test campaign services)	Trade secret (procedures). Open access (high-level methodologies).	NO	NO
Physics-Based Equivalent Circuit Model	Single ownership	VTT	VTT (FI)	YES — internal R&D use.	Scientific publications (conference paper planned)	NO	NO
Vibrational Fatigue & Mechanical Reliability	Single ownership	IKERLAN	IKERLAN (ES)	YES — internal exploitation via industrial R&D projects	Copyright	NO	NO
Virtual Cyber (Simulation Environment)	Single ownership	IKERLAN	IKERLAN (ES)	YES — internal use only (BMS XIL testing)	Copyright	NO	NO
Data-driven modelling tools	Single Ownership	VTT	VTT (FI).	YES	[Secret/nondisclosure agreement] [Licensing]	NO	NO
Safety and reliability AI toolchain	Joint Ownership (7)	RSTER ABEE, UL, INEGI, IKERLAN, SURREY & VTT	RSTER (BE), ABEE (BE), UL (SI), INEGI (PT), IKERLAN (ES), SURREY (UK) & VTT (FI)	YES	[Licensing]	NO	NO
Digital Twin Model	Joint Ownership (3)	INEGI, COMAU & RSTER	INEGI (PT), COMAU (IT) & RSTER (BE)	YES	[Secret/nondisclosure agreement] [Licensing]	NO	NO

6 Horizon Result Booster for FASTEST Hybrid Testing Platform

6.1 Overview

As part of the FASTEST project's exploitation activities during the final reporting period (M18–M36), the Hybrid Testing Platform (KER1) was selected to participate in the **Horizon Results Booster (HRB)**, a European Commission service supporting research consortia in accelerating the market uptake of their most promising results. The Booster process for KER1 was coordinated by SIE (WP7 Lead) and engaged the lead exploitation partner FEV together with key contributing partners across a series of structured workshops and bilateral sessions held between M30 and M36.

The Booster activities covered four analytical workstreams: Market Definition Canvas (MDC), Value Proposition Canvas (VPC), Exploitation Strategy Session (ESS), and a Go-to-Market (G2M) risk assessment and prioritisation exercise. The outputs of these workstreams have directly informed and significantly enriched the KER1 exploitation factsheet, the IP strategy, and the post-project commercialisation roadmap presented in this deliverable.

6.2 Market Definition and Value Proposition Canvas

The **Market Definition Canvas (MDC)** established the priority customer segment for KER1 as R&D managers and validation engineers at **automotive OEMs and Tier-1 battery suppliers**, with a staged market opening sequence prioritising: (1) automotive OEM and Tier-1 R&D centres, (2) stationary BESS developers, (3) heavy-duty and off-road manufacturers, and (4) gigafactory R&D centres.

The **Value Proposition Canvas (VPC)** identified the core customer job-to-be-done as qualifying battery systems efficiently while ensuring safety, model accuracy, and regulatory compliance across physical and virtual validation workflows. The top customer pains identified were: excessive time and cost of physical-only testing campaigns; manual and fragmented scheduling workflows; lack of integration between physical test data, simulation models and LIMS; and difficulty demonstrating regulatory compliance (ISO 26262, EU Battery Regulation) through conventional testing alone.

The HTP's key gain creators confirmed through the VPC process include: up to 41% reduction in R&D time and up to 35% reduction in testing costs; automated heuristic scheduling replacing manual workflows; real-time DT–LIMS integration providing full data traceability; and embedded safety and reliability modelling supporting regulatory compliance evidence generation.

A competitive benchmarking exercise conducted as part of the MDC confirmed that no existing commercial platform integrates DoE, HIL, Digital Twin and LIMS into a real-time, decision-driven orchestration layer at the battery test-centre level. Competing publicly funded projects (Axlebots, Digibet, TOR) each address isolated aspects of this challenge, but none provides the integrated orchestration layer delivered by FASTEST.

KER1. Hybrid Testing Platform (HTP) - FASTEST

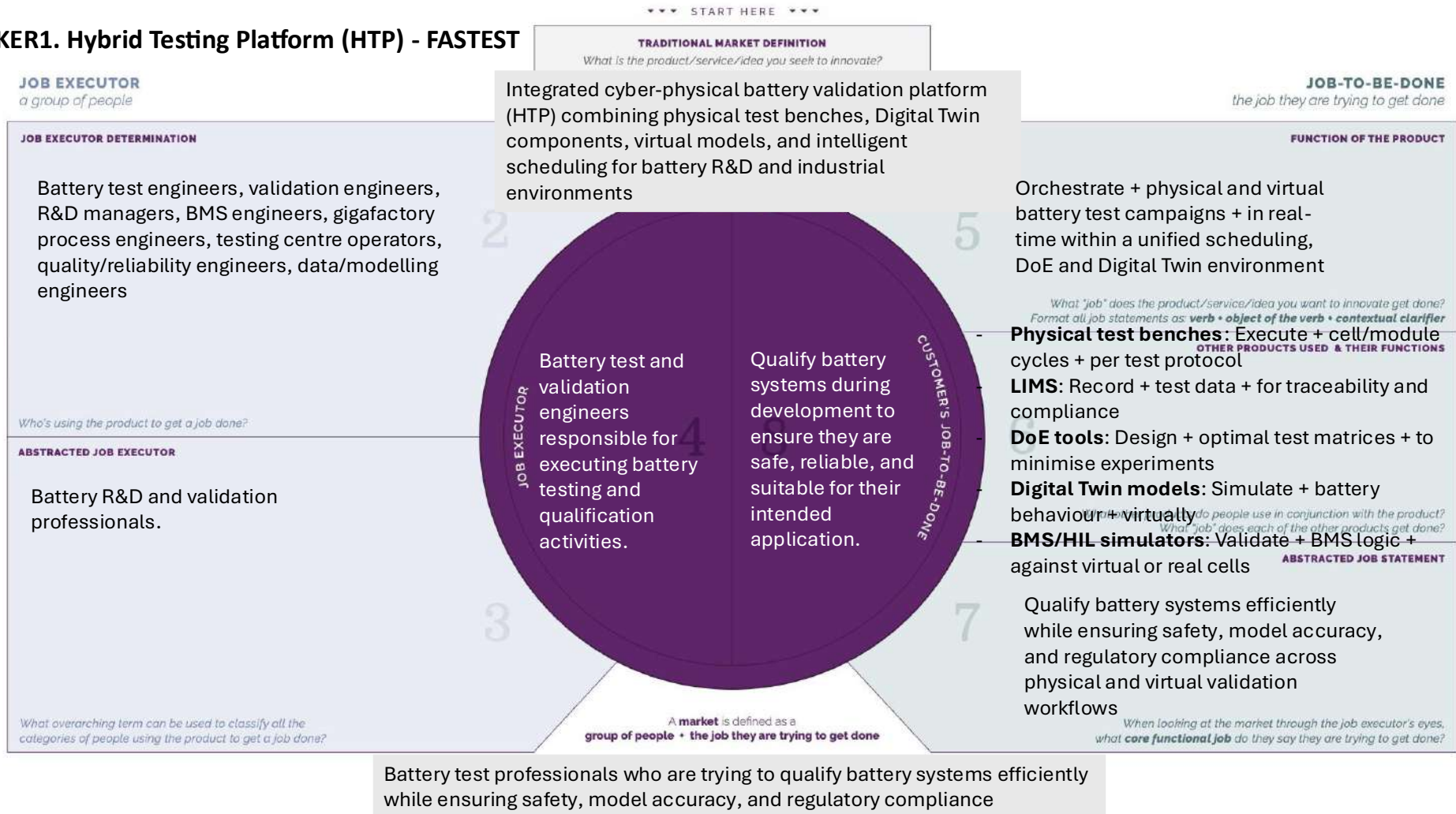


Figure 5 MARKET DEFINITION CANVAS - FASTEST

The Value Proposition Canvas

KER1. Hybrid Testing Platform (HTP) - FASTEST

Customer Segment: Battery test professionals at EV/BESS battery test centres — R&D teams at OEMs, Tier-1 suppliers, gigafactories, and specialised testing labs (early adopters: ABEE, Flash Battery, BMZ)

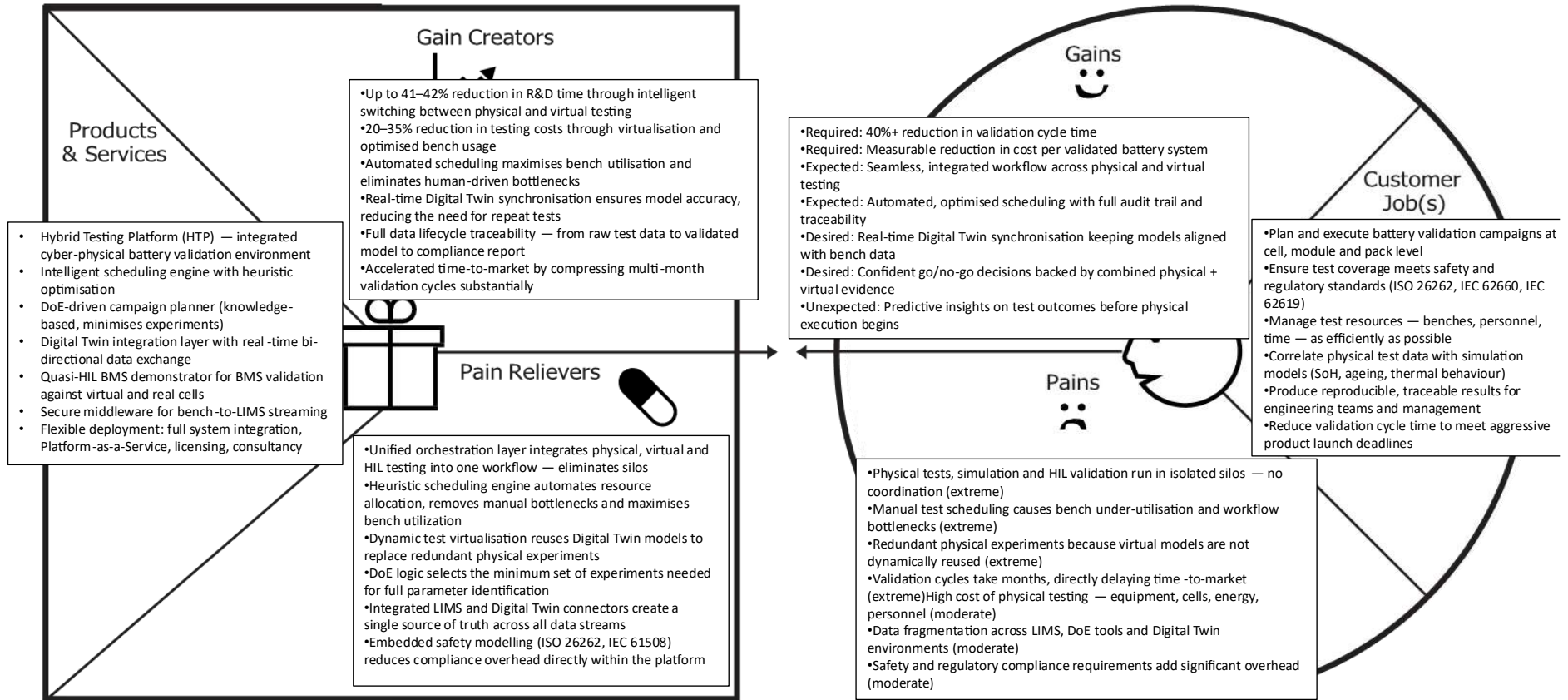


Figure 6 VALUE PROPOSITION CANVAS - FASTEST

6.3 Exploitation strategy

The Exploitation Strategy Session (ESS) confirmed and refined the exploitation hierarchy for KER1 as follows:

- **Full system integration and deployment as an engineering service** — primary commercial route, led by FEV.io. This involves FEV deploying, integrating and operating the HTP for industrial customers on a service basis, leveraging the modular platform architecture.
- **Licensing of the integration architecture** — secondary route, enabling third parties to access and deploy specific platform components under bilateral licence agreements with the relevant contributing partner.
- **Consultancy-based deployment** — conditional route for customers requiring bespoke adaptation.
- **Platform-as-a-Service (PaaS) model** — deprioritised at M36 pending TRL advancement; target reassessment in 2027.

Internal industrial adoption by consortium partners runs as a parallel track: ABEE will deploy the quasi-HIL BMS demonstrator internally from 2026 for Gen3b/Gen4 cell validation; FLASH BATTERY will integrate the HTP with its MES and LIMS for off-road validation use cases. A spin-off or joint venture model was considered and removed as not viable at the current stage.

The **Go-to-Market risk assessment** identified the following priority risks requiring immediate action: (1) conservative adoption by industrial users with entrenched conventional testing workflows; (2) long integration and qualification cycles at customer sites; (3) absence of external early adopters outside the consortium at M36; and (4) the need to validate — through customer interviews — the cycle-time reduction threshold that justifies switching from conventional to hybrid testing approaches. Partnership risks around IP governance and commercialisation decision-making have been substantially reduced following the IP framework agreement described in Section 6.4 below.

6.4 IP framework – Access Rights Scheme

A key output of the Booster process was the clarification and formal agreement of the **IP governance framework for KER1**, reached at the Booster seminar held in May 2026, with the participation of the Booster legal expert.

The central question addressed was whether KER1 requires a Joint Ownership Agreement (JOA) given the multi-partner contribution structure. The Booster legal expert confirmed that the platform is **technically separable**: the core is developed and hosted on the FEV cloud, and contributions from other partners are integrated through interfaces and remain separable. The legal precondition for joint ownership under the Grant Agreement — namely that the contributions cannot be separated — is therefore not met for KER1. Joint ownership is not the appropriate IP regime.

The confirmed framework for KER1 is therefore an **access rights scheme**, consistent with the Horizon Europe Grant Agreement and Consortium Agreement baseline:

- During the project, access rights between partners are automatic and royalty-free.
- After the project ends, any partner wishing to use another partner's contribution for exploitation purposes must request access rights **within one year** of project closure, on fair and reasonable conditions.
- Access rights granted under this regime **do not permit sub-licensing**. Where FEV (or any other partner) needs to pass a component to a customer or third party, a **bilateral licence agreement** with the contributing partner is required.
- Conversely, contributing partners wishing to use the integrated KER1 platform for their own internal purposes may do so through a non-exclusive licence from FEV, without sub-licensing rights.

To bridge the gap between the one-year contractual window and the time realistically needed by partners to negotiate and sign bilateral licences, the Booster recommends the conclusion of a **Memorandum of Understanding (MoU)** among all KER1 partners. The MoU serves two purposes: it designates a named decision-maker and contact point per partner to ensure that commercial conversations can continue two to three years after project closure; and it extends the effective access-rights window accordingly. Commercial partners are advised to process the MoU through their legal departments; research and technology partners through their Technology Transfer Offices (TTOs).

The MoU template has been provided to the FASTEST consortium through the Booster deliverables package and will be circulated by SIE to all KER1 partners following project closure.

6.5 Post-project roadmap

The combined outputs of the Booster workstreams confirm the following post-project roadmap for KER1:

- **2026 H2:** Industrial hardening phase (cybersecurity, authentication, scalability). Internal reference deployments at ABEE and FLASH BATTERY. Finalisation of ROL and bilateral MoU/licence agreements. Definition of engineering services commercial offer and pricing. Identification of 3–5 external early adopter candidates.
- **2027:** Beta commercial deployments with first external customers. Licensing agreements initiated. PaaS model re-evaluation.
- **2028 (TRL 9 target):** Full commercial deployment in gigafactories and commercial battery test centres. Active licensing agreements operational.

Post-project investment requirements identified through the Booster process: ABEE estimates EUR 15–20M for industrial integration and large-scale deployment; FLASH BATTERY estimates EUR 250–300K for MES integration; FEV will pursue follow-on Horizon Europe funding and internal R&D investment to support TRL advancement.

7. CONCLUSION

This document constitutes the third and final version of the Exploitation Plan and IP Management Strategy of the FASTEST project, submitted as deliverable D7.7 at month 36. It supersedes D7.5 (M6) and D7.6 (M18), incorporating the full outcomes of exploitation and IP management activities conducted during the final reporting period.

All exploitation and IP management objectives planned for the full project duration have been successfully achieved. The KER portfolio has been finalised at **six main KERs encompassing twelve distinct exploitable results** (TRL 4–6), with the most notable development being the granularisation of KER3 into seven individually owned sub-KERs, each with its own exploitation strategy, IP protection approach and post-project roadmap.

A key evolution during this final period has been the move from generic joint ownership arrangements towards precise, partner-specific IP frameworks. KER1 operates under an access rights scheme with FEV as the designated exploitation partner and a supporting MoU recommended by the Horizon Results Booster. KER2 and KER3 sub-KERs are individually owned by their respective lead partners. KER6 requires no JOA, given the complementary roles of INEGI and COMAU. KER5 remains the most complex situation, with a seven-partner JOA and patent filing process underway led by ABEE, continuing beyond project closure. IP risk has improved across the portfolio, with five of six KERs rated **LOW** at M36.

The participation of KER1 in the **Horizon Results Booster** programme delivered a structured go-to-market analysis — Market Definition Canvas, Value Proposition Canvas, Exploitation Strategy Session and Risk Priority Map — confirming automotive OEM and Tier-1 R&D centres as the priority customer segment and establishing a clear 2026–2028 commercialisation roadmap.

The FASTEST consortium is committed to maximising exploitation through commercial services, internal industrial adoption, licensing, and scientific dissemination, supported by follow-on national and European funding. The strong regulatory and market drivers shaping the European battery sector position the consortium well to translate the technical achievements of FASTEST into lasting scientific, industrial and societal impact.

REFERENCES

- BIS Research. (2020). *Global Digital Twin Market*. BIS Research, data from Statista. Retrieved October 26, 2023, from https://bisresearch.com/industry-report/digital-twin-market.html?utm_source=Statista
- Emergen Research. (2023). *Lithium-ion Battery Market*. Retrieved from <https://www.emergenresearch.com/industry-report/lithium-ion-battery-market>
- European Central Bank. (2024). *European Central Bank - Reference Euro Exchange Rates from 19 April 2023 to 19 April 2024*. Retrieved from https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html
- European Patent Office. (2022). *European Patent Guide*. Retrieved from [https://documents.epo.org/projects/babylon/eponet.nsf/0/8266ED0366190630C12575E10051F40E/\\$File/how_to_get_a_european_patent_2022_en.pdf](https://documents.epo.org/projects/babylon/eponet.nsf/0/8266ED0366190630C12575E10051F40E/$File/how_to_get_a_european_patent_2022_en.pdf)
- European Patent Office. (2022). *European Patent Guide*.
[exchange-rates.org](https://www.exchange-rates.org). (2023). *US Dollar (USD) To Euro (EUR) Exchange Rate History for 2023*. Exchanges-Rates.org. Retrieved October 26, 2023, from <https://www.exchange-rates.org/exchange-rate-history/usd-eur-2023>
- GMI- Global Market Insights. (2024). *Battery Design & Manufacturing Software Market*. Retrieved from <https://www.gminsights.com/industry-analysis/battery-design-and-manufacturing-software-market>
- Grand View Research. (2024). *Lithium-ion Battery Market*. Grand View Research. Retrieved from <https://www.grandviewresearch.com/industry-analysis/lithium-ion-battery-market>
- Inkwood Research. (2022). *GLOBAL BATTERY MARKET FORECAST 2022-2030*. Inkwood Research. Retrieved October 26, 2023, from <https://inkwoodresearch.com/reports/battery-market/>
- IPCEI Batteries (Accompanying Research: Battery Cell Production). (2023). *European Battery Cell Production (Market Analysis Q2-2023)*. VDI/VDE Innovation + Technik GmbH.
- IPCEI Batteries (Accompanying Research: Battery Cell Production). (2023). *European Battery Cell Production (Market analysis Q4 2022)*. Berlin: VDI/VDE Innovation + Technik GmbH.
- Kothari, C. (1985). *Research Methodology: Methods and Techniques*.
- Market Research Future. (2024). *Global Gel Polymer Electrolyte Market Overview*. Retrieved from <https://www.marketresearchfuture.com/reports/gel-polymer-electrolyte-market-25537>

- MarketWide Research. (2024). *Gel Polymer Electrolyte Market Analysis*. MarketWide Research. Retrieved from <https://markwideresearch.com/gel-polymer-electrolytes-market/>
- McKinsey & Company. (2017). *Technology Deep Dive: Digital Twins*. McKinsey & Company. Retrieved October 30, 2023, from <https://www.mckinsey.com/~media/mckinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/The%20top%20trends%20in%20tech%20final/Tech%20Trends%20slides%208%209%2010#:~:text=Missing%20mindset%20for%20continuous%20optimization%20and%20ongoing%20data,>
- Precedence Research. (2023). *Lithium Iron Phosphate Battery Market Size, Share, and Trends 2024 to 2034*. Retrieved from <https://www.precedenceresearch.com/lithium-iron-phosphate-battery-market>
- Straits Research. (2023). *Battery Testing Equipment Market*. Straits Research. Retrieved October 30, 2023, from <https://straitsresearch.com/report/battery-testing-equipment-market/>
- The Insight Partners. (2022). *Battery Testing Equipment Market Size and Analysis by 2028*. The Insight Partners. Retrieved October 26, 2023, from <https://www.theinsightpartners.com/reports/battery-testing-equipment-market>
- VMR - Verified Market Report. (2024). *Global Battery Simulator Market*. Retrieved from <https://www.verifiedmarketreports.com/product/battery-simulator-market/>
- World Intellectual Property Organisation. (2023). *Trade Secrets*. Retrieved October 11, 2023, from World Intellectual Property Organisation: <https://www.wipo.int/tradesecrets/en/>
- World Intellectual Property Organisation. (2023). *World Intellectual Property Organisation*. Retrieved October 12, 2023, from Copyrights: <https://www.wipo.int/copyright/en/>

Annex I – KERs factsheets (M36)

The following fact sheets provide a comprehensive and structured description of each Key Exploitable Result of the FASTEST project as of M36. They have been developed by SIE (WP7 Lead) through a continuous engagement process with all responsible partners during the final reporting period, incorporating inputs gathered through the final exploitation questionnaire, the KER5 and KER6 IP ownership meetings, and the Horizon Results Booster go-to-market process for KER1. Each fact sheet consolidates the technical definition, partner contributions, market advantages, state of the art, business applications, target users, exploitation strategy, IP strategy and post-project roadmap for the corresponding result.

For KER3 – Physics-Based Modelling Tools, individual fact sheets are provided for each of the seven sub-KERs (KER3.1 through KER3.7), reflecting the granularisation of this result confirmed during the final reporting period. Each sub-KER factsheet has been validated with the respective lead partner and reflects their confirmed exploitation and IP positions at project closure.

The fact sheets presented in this Annex constitute the primary supporting documentation for the exploitation routes, IP strategies and Results Ownership List presented in the main body of this deliverable, and are intended to serve as living reference documents for each partner's post-project exploitation activities.

Table 9 KER1 – Hybrid Testing Platform

Type	KER1 – Hybrid Testing Platform
Definition and technical scope	
Definition	<p>The Hybrid Testing Platform (HTP) is an integrated cyber-physical battery testing ecosystem that orchestrates physical test benches, virtual models, Digital Twin components, and scheduling services into a unified operational framework for battery validation.</p> <p>The platform dynamically optimises battery test campaigns by:</p> <ul style="list-style-type: none"> • Integrating Design of Experiments (DoE) logic • Combining physical and virtual testing workflows • Enabling quasi-Hardware-in-the-Loop (HIL) BMS validation • Managing real-time data exchange between Digital Twin, LIMS, and test benches • Reducing redundant physical testing • Embedding safety and reliability modelling into operational decision-making <p>HTP transforms conventional battery test centres into intelligent, decision-driven validation environments capable of accelerating R&D while reducing cost and resource consumption.</p>
Technical Scope	<p>The Hybrid Testing Platform includes:</p> <ul style="list-style-type: none"> • Scheduling engine with heuristic optimisation • DoE-driven campaign planner • Digital Twin integration layer • Secure middleware for real-time bi-directional streaming • Quasi-HIL BMS demonstrator • LIMS integration adapters • Modular architecture for future scalability <p>TRL at M36: TRL 6 (validated in relevant industrial environment) Target post-project: TRL 9 (commercial deployment by 2028)</p>
Partner contribution	

<p>Partner contributions</p>	<ul style="list-style-type: none"> • FEV.io: System architecture, scheduling concept and software solution, LIMS orchestration framework, DT-LIMS integration layer, real-time communication middleware, final system integration and validation coordination. • ABEE: Quasi-HIL BMS demonstrator, physical validation datasets, multiscale modelling integration, Gen3b & Gen4 cells supply. • IKERLAN: HIL environment emulating physical system functionality for validation, executing battery models in real time. • FLASH BATTERY: Industrial use case integration, test bench-LIMS interfacing, off-road validation scenario. • INEGI & COMAU: Digital Twin integration and data management platform. • FHG: DoE integration logic. Implementation of an intelligent model-based DoE approach for a smart combination of physical and virtual testing. • BMZ, FLANDERS MAKE, SURREY: Use case definition and validation input. BMZ is listed as an integrator with industrial adoption interest.
<p>Market advantage and State-of-the-Art</p>	
<p>Market advantage</p>	<p>The Hybrid Testing Platform delivers measurable industrial impact:</p> <ul style="list-style-type: none"> • Up to 41-42% reduction in R&D time • 20-35% reduction in testing costs • Increased bench utilisation rates • Reduced manual scheduling effort • Improved reproducibility and traceability • Enhanced safety integration in validation cycles <p>Its key differentiator is the real-time orchestration of physical and virtual testing, rather than isolated simulation or hardware validation.</p>
<p>SoTA</p>	<p>Current battery testing environments are fragmented:</p> <ul style="list-style-type: none"> • Physical and digital tests are conducted separately. • Scheduling is often manual. • Models are not dynamically reused. • HIL validation is limited to isolated subsystems. <p>HTP introduces:</p> <ul style="list-style-type: none"> • Integrated test orchestration logic • Decision-driven switching between physical and virtual validation • Embedded Digital Twin synchronisation • Full data lifecycle management
<p>Business Applications</p>	<p>HTP applies across:</p> <ul style="list-style-type: none"> • Automotive battery validation (EV packs) – priority primary segment. • Stationary energy storage (BESS) • Off-road and industrial battery systems • Gigafactory R&D centres • Battery testing consultancies • Advanced research laboratories <p>Primary value proposition: Accelerated concept-to-market timelines with embedded safety and reduced validation costs.</p>
<p>Exploitation and IP strategy</p>	
<p>Exploitation Strategy</p>	<p>Priority exploitation routes:</p> <ol style="list-style-type: none"> 1. Full system integration and deployment – engineering service model (FEV.io lead). PRIMARY ROUTE. 2. Licensing of integration architecture – second priority route. 3. Consultancy-based deployment – conditional route. 4. PaaS model – deprioritised pending TRL advancement. 2027 launch date under review. <p>Internal industrial adoption (parallel track):</p> <ul style="list-style-type: none"> • ABEE: internal deployment of quasi-HIL BMS demonstrator for Gen3b/Gen4 validation from 2026 • FLASH BATTERY: HTP integration with MES and LIMS for off-road validation from 2026

	<ul style="list-style-type: none"> • BMZ: industrial adoption interest <p>Spin-off / JV model: removed — not viable at this stage.</p>
Commercial readiness	<p>Key actions required before first external commercial deployment:</p> <ul style="list-style-type: none"> • Finalise ROL, confirming individual building block ownership per partner and FEV access rights scope • Define engineering-services commercial offer (scope, pricing, contractual baseline) • Run internal pilots at ABEE and FLASH BATTERY as reference deployments • Identify 3–5 external early adopter candidates outside consortium • Conduct customer interviews to validate top pain, top job and cycle-time threshold justifying the switch • Map commercial competitors in battery test orchestration, LIMS and DT-integration markets
IP Strategy	<p>Individual ownership per building block — each platform component is individually owned by the partner that developed it. No Joint Ownership Agreement (JOA) required.</p> <p>The platform building blocks are clearly separable and attributed to individual partners. FEV, as lead exploitation partner, will exploit the full platform under an access rights scheme — granting FEV the right to integrate, deploy and commercialise all building blocks without requiring a JOA. ROL to be finalised at M36.</p> <p>Confirmed foreground ownership claims:</p> <ul style="list-style-type: none"> • FEV: ~35% — scheduling concept, LIMS orchestration, DT-LIMS integration, middleware, system architecture • ABEE: ~15–20% — quasi-HIL BMS demonstrator, validation datasets • IKERLAN: ~10% — HIL environment and real-time model execution • FHG: intelligent DoE integration component (% TBC)
Protection strategy	<ul style="list-style-type: none"> • Trade secret: architecture and integration logic (all lead partners) • Patent: FEV (DE102023133703A1 and follow-on DE102024131323.4) • Consortium Agreement governs IP ownership, access rights and confidentiality obligations across all partners • FEV granted access rights to all partner-owned building blocks for integration, deployment and commercialisation of the full platform <p>Open elements per partner:</p> <ul style="list-style-type: none"> • FEV: high-level architecture descriptions, interface definitions, interoperability guidelines • FHG: high-level DoE methodology (publications, deliverables) • IKERLAN: high-level architecture descriptions, dissemination material • ABEE: interfaces, APIs, selected methodological approaches <p>✅ IP governance resolved (agreed May 2026): no JOA required. Platform building blocks are individually owned by each contributing partner. FEV exploits the full integrated platform under a mutually agreed access rights scheme, enabling commercialisation without joint ownership complexity. ROL to be finalised at M36 closure.</p>
Regulatory and compliance framework	<p>HTP must align with:</p> <ul style="list-style-type: none"> • CE compliance • ISO 26262 (automotive functional safety) • IEC 62660 / IEC 62619 • IEC 61508 • GDPR (data management) • Emerging EU AI Act (if AI-based decision logic is embedded)
Post-project roadmap	<p>2026 H1: TRL 6 validation complete (project end, May 2026)</p> <p>2026 H2:</p> <ul style="list-style-type: none"> • Industrial hardening phase: cybersecurity, authentication, scalability upgrades • Internal pilots at ABEE and FLASH BATTERY as reference deployments

	<ul style="list-style-type: none"> • Finalise ROL, confirming individual building block ownership and FEV access rights • Define engineering services commercial offer and pricing • Identify 3–5 external early adopter candidates • Secure follow-up funding (Horizon Europe + FEV/ABEE internal R&D) <p>2027:</p> <ul style="list-style-type: none"> • Beta commercial deployments with first external customers • Licensing agreements initiated • PaaS model re-evaluation pending TRL advancement <p>2028 (TRL 9 target):</p> <ul style="list-style-type: none"> • Full commercial deployment in gigafactories and commercial battery test centres • Active licensing agreements <p>Post-project investment (indicative):</p> <ul style="list-style-type: none"> • ABEE: EUR 15–20M (industrial integration and large-scale deployment) • FLASH BATTERY: EUR 250–300K (MES integration) • FEV: follow-up EU Horizon funding + internal R&D investment
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Table 10 KER2 – Knowledge-Based DoE Methodology Toolbox

KER2 – Knowledge-Based DoE Methodology Toolbox	
Technical description	
Definition	<p>The Knowledge-Based Design of Experiments (DoE) Methodology Toolbox is a computational framework designed to optimise battery testing and modelling campaigns through intelligent experiment planning and parameter identification. The toolbox integrates advanced surrogate modelling techniques and statistical identifiability analysis to determine the most informative test configurations while minimising the number of required physical experiments.</p> <p>By combining Physics-Informed Neural Networks (PINNs) with Fisher-Information-Matrix-based identifiability analysis, the toolbox enables researchers and engineers to identify optimal measurement protocols and test conditions that maximise information gain on key battery parameters. This significantly reduces experimental time, lowers development costs, and improves the reliability of model calibration.</p> <p>Within FASTEST, the toolbox functions as a methodological enabler supporting hybrid testing environments and model development activities. It contributes to the overall project objective of accelerating battery validation workflows by ensuring that physical testing campaigns generate the highest possible information content for model development and parameter estimation.</p>
Technical Scope	<p>The toolbox integrates two complementary methodological components:</p> <p>A) Physics-Informed Neural Networks (PINNs) [FHG]</p> <ul style="list-style-type: none"> • Parametrised surrogate models representing electrochemical and thermal battery behaviour while respecting physical constraints • Provide fast approximations of system responses across a wide range of parameter combinations • Enable efficient exploration of experimental design spaces for DoE strategy application <p>B) Parameter Identifiability Analysis [UL]</p> <ul style="list-style-type: none"> • Methodology based on Fisher Information Matrices to assess how uniquely model parameters can be identified from experimental data • Quantifies parameter sensitivity, interdependence, and measurement information content • Guides selection of optimal experimental configurations

	Together, these methods support: efficient parameter estimation; reduced experimental testing campaigns; improved reliability of battery models; faster model calibration workflows		
TRL at M36	<p>TRL 5 overall toolbox</p> <ul style="list-style-type: none"> • FHG (PINN component): TRL 3–4 — proof-of-concept for PINN integration demonstrated through 1 published and 1 pending open-source publication • UL (FIM identifiability tool): TRL 4 — general tool for parameter identifiability assessment based on FIM approach, operationally mature <p>The original target TRL of 5–6 has not been reached. FHG confirmed during the workshop that technical limitations encountered during the project constrained the achievable maturity level of the PINN-based surrogate modelling component within the project timeline. The methodology remains valid and functional at the achieved TRL; integration into foxBMS is not affected.</p>		
SoTA	<p>Design of Experiments methodologies are widely used in engineering and scientific research; however, current applications in battery research remain largely manual and rely on simplified sensitivity analyses. Existing approaches often lack the ability to evaluate parameter identifiability and correlations systematically, resulting in inefficient experimental campaigns and redundant testing.</p> <p>The FASTEST toolbox advances the state of the art by integrating physics-informed surrogate modelling with statistical identifiability analysis, enabling automated and data-driven experimental design strategies tailored to battery modelling applications.</p>		
Partner contribution			
Partner contributions	<table border="0"> <tr> <td style="vertical-align: top;"> <p>FHG – Fraunhofer IISB</p> <ul style="list-style-type: none"> • Lead development of the Physics-Informed Neural Network (PINN) framework • Parametrised surrogate modelling methods enabling efficient application of DoE strategies • Responsible for integration into the foxBMS open-source platform (Apache License 2.0) as the primary dissemination vehicle • Technical restrictions prevented reaching TRL 5–6; revised TRL to be confirmed </td> <td style="vertical-align: top;"> <p>UL – University of Ljubljana</p> <ul style="list-style-type: none"> • Development of the parameter identifiability assessment methodology based on Fisher Information Matrices • Adaptation of pre-existing fuel-cell FIM methodology (UL Background) to lithium-ion battery applications within FASTEST • Evaluation of measurement configurations and determination of uniquely identifiable model parameters • No TRL issues flagged for the FIM contribution </td> </tr> </table>	<p>FHG – Fraunhofer IISB</p> <ul style="list-style-type: none"> • Lead development of the Physics-Informed Neural Network (PINN) framework • Parametrised surrogate modelling methods enabling efficient application of DoE strategies • Responsible for integration into the foxBMS open-source platform (Apache License 2.0) as the primary dissemination vehicle • Technical restrictions prevented reaching TRL 5–6; revised TRL to be confirmed 	<p>UL – University of Ljubljana</p> <ul style="list-style-type: none"> • Development of the parameter identifiability assessment methodology based on Fisher Information Matrices • Adaptation of pre-existing fuel-cell FIM methodology (UL Background) to lithium-ion battery applications within FASTEST • Evaluation of measurement configurations and determination of uniquely identifiable model parameters • No TRL issues flagged for the FIM contribution
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Market and business applications			
Market advantage	<ul style="list-style-type: none"> • Reduction of experimental testing requirements through intelligent DoE • Faster parameter calibration for battery models • Improved reliability and uniqueness of model parameter identification • Lower R&D costs in battery development • More efficient integration of virtual and physical testing • Ensures each experiment maximises information gained about system parameters 		
Business Applications	<ul style="list-style-type: none"> • Battery model calibration and parameter identification 		

	<ul style="list-style-type: none"> • Optimisation of battery characterisation testing campaigns • Accelerated development of battery management systems • Support for hybrid testing environments combining simulation and experiments • Training and education in battery modelling methodologies 				
Target users	<ul style="list-style-type: none"> • Battery manufacturers • Battery software companies and OEMs • Battery management system developers • Research institutions • Engineering consultancies specialised in battery modelling • Fuel cell developers and other electrochemical system R&D organisations 				
Exploitation strategy					
Exploitation Strategy (M36)	<p>Both FHG and UL confirm the following exploitation approach:</p> <ul style="list-style-type: none"> • Internal R&D use by both partners • Integration into existing platforms: FHG will integrate parts of the results into the open-source foxBMS platform (Fraunhofer IISB). UL integration into external platforms is not planned at M36, but not excluded in the future. • Training and educational activities by both partners • Scientific dissemination through open-access publications (FHG: 1 published, 1 pending; UL: publications planned) • UL: active exploitation confirmed through a secured national project leveraging the FIM identifiability tool • Licensing to third parties: FHG, yes, if further PINN developments are successful; UL currently no, not excluded for future. • <u>Confidential components:</u> DoE-specific results related to FASTEST-specific cells (e.g. testing campaign insights) will remain protected. UL: components relying on existing fuel-cell methodology kept confidential. <p>Both partners confirmed that KER2 is positioned as a research and engineering enabler rather than a commercial product. Neither FHG nor UL has commercial exploitation ambitions for this result at this stage. The toolbox will support R&D activities, open-source dissemination, and methodology transfer.</p>				
Exploitation routes	<table border="0" style="width: 100%;"> <tr> <td style="vertical-align: top; width: 50%;">FHG</td> <td style="vertical-align: top; width: 50%;">UL</td> </tr> <tr> <td> <ul style="list-style-type: none"> • Integration of KER2 components into the foxBMS open-source platform (Apache License 2.0) as the primary dissemination route • Scientific publications and conference presentations • Internal R&D use within FHG battery and fuel-cell research projects • Engineering consultancy and modelling services • Training and educational activities in battery modelling </td> <td> <ul style="list-style-type: none"> • Slovenian national research project (awarded): the FIM-based identifiability methodology will be further developed and applied within a nationally funded project — confirmed post-project exploitation pathway • Further R&D activities and research collaborations building on the FIM methodology • Scientific publications and conference presentations • Potential knowledge transfer to research institutions seeking to adopt identifiability analysis methods </td> </tr> </table>	FHG	UL	<ul style="list-style-type: none"> • Integration of KER2 components into the foxBMS open-source platform (Apache License 2.0) as the primary dissemination route • Scientific publications and conference presentations • Internal R&D use within FHG battery and fuel-cell research projects • Engineering consultancy and modelling services • Training and educational activities in battery modelling 	<ul style="list-style-type: none"> • Slovenian national research project (awarded): the FIM-based identifiability methodology will be further developed and applied within a nationally funded project — confirmed post-project exploitation pathway • Further R&D activities and research collaborations building on the FIM methodology • Scientific publications and conference presentations • Potential knowledge transfer to research institutions seeking to adopt identifiability analysis methods
FHG	UL				
<ul style="list-style-type: none"> • Integration of KER2 components into the foxBMS open-source platform (Apache License 2.0) as the primary dissemination route • Scientific publications and conference presentations • Internal R&D use within FHG battery and fuel-cell research projects • Engineering consultancy and modelling services • Training and educational activities in battery modelling 	<ul style="list-style-type: none"> • Slovenian national research project (awarded): the FIM-based identifiability methodology will be further developed and applied within a nationally funded project — confirmed post-project exploitation pathway • Further R&D activities and research collaborations building on the FIM methodology • Scientific publications and conference presentations • Potential knowledge transfer to research institutions seeking to adopt identifiability analysis methods 				
foxBMS	FHG, as maintainer of the foxBMS open-source Battery Management System platform, will integrate KER2 modules into foxBMS under the Apache License				

	<p>2.0. This constitutes the primary public dissemination route for KER2 and will make the toolbox accessible to the global battery R&D community.</p> <p>Components integrated into foxBMS will be publicly available; core algorithmic implementations will remain protected as trade secrets.</p>		
IP strategy			
IP Ownership	<p>Fraunhofer IISB (FHG) and University of Ljubljana (UL)</p> <ul style="list-style-type: none"> FHG claims foreground ownership of the PINN-based surrogate modelling component UL: KER relies on the existing UL methodology originally developed for fuel cells. UL background IP underpins the FIM identifiability tool and remains owned by UL. 		
IP strategy per partner	<table border="0" style="width: 100%;"> <tr> <td style="width: 50%; vertical-align: top;"> <p>FHG – IP Strategy</p> <ul style="list-style-type: none"> Trade secret (source code): Key PINN algorithmic implementations will remain protected as FHG trade secret and will not be fully publicly released Open-source modules: Components integrated into foxBMS released under the Apache License 2.0 Copyright: Scientific publications arising from KER2 development No patent filing planned Background: PINN-based surrogate modelling expertise (know-how, pre-project). Boundary with FASTEST foreground considered clear. </td> <td style="width: 50%; vertical-align: top;"> <p>UL – IP Strategy</p> <ul style="list-style-type: none"> Trade secret (source code): Key FIM algorithmic implementations will remain protected as UL trade secret Open-source modules: Applicable components contributed to foxBMS under the Apache License 2.0 Copyright: Scientific publications arising from KER2 development No patent filing planned Background: Original FIM methodology developed for fuel-cell applications (UL Trade Secret). FASTEST foreground = adaptation to Li-ion battery applications. Boundary considered clear; no further documentation required. </td> </tr> </table>	<p>FHG – IP Strategy</p> <ul style="list-style-type: none"> Trade secret (source code): Key PINN algorithmic implementations will remain protected as FHG trade secret and will not be fully publicly released Open-source modules: Components integrated into foxBMS released under the Apache License 2.0 Copyright: Scientific publications arising from KER2 development No patent filing planned Background: PINN-based surrogate modelling expertise (know-how, pre-project). Boundary with FASTEST foreground considered clear. 	<p>UL – IP Strategy</p> <ul style="list-style-type: none"> Trade secret (source code): Key FIM algorithmic implementations will remain protected as UL trade secret Open-source modules: Applicable components contributed to foxBMS under the Apache License 2.0 Copyright: Scientific publications arising from KER2 development No patent filing planned Background: Original FIM methodology developed for fuel-cell applications (UL Trade Secret). FASTEST foreground = adaptation to Li-ion battery applications. Boundary considered clear; no further documentation required.
<p>FHG – IP Strategy</p> <ul style="list-style-type: none"> Trade secret (source code): Key PINN algorithmic implementations will remain protected as FHG trade secret and will not be fully publicly released Open-source modules: Components integrated into foxBMS released under the Apache License 2.0 Copyright: Scientific publications arising from KER2 development No patent filing planned Background: PINN-based surrogate modelling expertise (know-how, pre-project). Boundary with FASTEST foreground considered clear. 	<p>UL – IP Strategy</p> <ul style="list-style-type: none"> Trade secret (source code): Key FIM algorithmic implementations will remain protected as UL trade secret Open-source modules: Applicable components contributed to foxBMS under the Apache License 2.0 Copyright: Scientific publications arising from KER2 development No patent filing planned Background: Original FIM methodology developed for fuel-cell applications (UL Trade Secret). FASTEST foreground = adaptation to Li-ion battery applications. Boundary considered clear; no further documentation required. 		
Background IP	<ul style="list-style-type: none"> UL: Existing methodology for parameter identifiability based on FIM, originally developed for fuel cells – owned by UL. No access to external partner background IP is required by UL. FHG: Expertise in PINN-based surrogate modelling. No access to external partner background IP required at M36. 		
IP risk assessment	<p>LOW – confirmed at M36 IP Ownership Workshop</p> <p>UL confirmed the IP risk for KER2 is LOW. The primary basis is the use of open-source libraries throughout the toolbox implementation. No third-party proprietary dependencies were identified that would restrict exploitation or create Freedom-to-Operate issues.</p> <p>All open-source libraries used are compatible (or expected to be compatible) with the Apache License 2.0 requirements for foxBMS integration. FHG to confirm compatibility before final foxBMS contribution.</p>		
Joint Ownership Agreement	<p>LOW – confirmed at M36 IP Ownership Workshop</p> <p>UL confirmed the IP risk for KER2 is LOW. The primary basis is the use of open-source libraries throughout the toolbox implementation. No third-party</p>		

	<p>proprietary dependencies were identified that would restrict exploitation or create Freedom-to-Operate issues.</p> <p>All open-source libraries used are compatible (or expected to be compatible) with the Apache License 2.0 requirements for foxBMS integration. FHG to confirm compatibility before final foxBMS contribution.</p>	
Post-project roadmap		
Post-project roadmap	FHG	UL
	<ul style="list-style-type: none"> Finalise and confirm revised TRL at M36 (pending) Complete integration of KER2 modules into foxBMS under Apache License 2.0 Internal R&D use within FHG battery and fuel-cell research programmes Engineering consultancy and training activities in battery modelling Scientific publications arising from KER2 methodology development 	<ul style="list-style-type: none"> Slovenian national project: Further development and application of the FIM-based identifiability methodology in a nationally funded R&D programme Continued research activities building on the FASTEST FIM battery-specific developments Scientific publications and conference dissemination Potential knowledge transfer to research institutions
Technical risks	<ul style="list-style-type: none"> TRL constraint: PINN component did not reach TRL 5–6; additional development may be needed post-project for full operational maturity Scalability of the PINN surrogate models to more complex battery chemistries and operating conditions <p>Industrial adoption may require validation in specific industrial test environments beyond the FASTEST context</p>	
Barriers to adoption	<ul style="list-style-type: none"> Lack of awareness of advanced DoE and parameter identifiability methods in industry Need for user-friendly tools and documentation for non-specialist users <p>Dependency on the foxBMS ecosystem for the primary dissemination channel</p>	

Table 11 Sub-KER 3.1: Simulink/FMUs for Performance/Thermal/Ageing

Sub-KER 3.1: Simulink/FMUs for Performance/Thermal/Ageing	
Lead Partner: MGEP TRL at M36: TRL 5–6	
DEFINITION & TECHNICAL SCOPE	
Definition	Physics-based reduced-order model (ROM) covering electrochemical and ageing processes, coupled with a thermal model at cell, module, and pack level, exported in FMU format for integration into the FASTEST hybrid testing platform.
Technical Scope	<ul style="list-style-type: none"> Electrochemical models: P2D, SPM, SPMe (full-order and reduced-order via orthogonal collocation)

	<ul style="list-style-type: none"> • Thermal model: 1D to 3D, at cell, module and pack level • Ageing equations: SEI growth, lithium deposition, mechanical cracking, loss of active material • Cell chemistries: LFP, NMC • FMU exportation for platform interoperability • SoX estimators with ECM, physics-based and hybrid models (SPKF, UKF, EKF)
PARTNER CONTRIBUTION	
MGEP (Lead)	Full development of the reduced-order physics-based model at cell, module and pack levels. FMU exportation. Post-project extensions focused on reducing errors and adding new cell formats and chemistries.
MARKET ADVANTAGE & STATE OF THE ART	
Market Advantage	Enables fast and accurate computational substitution of physical experiments, accelerating the battery design phase and reducing time-to-market. Multi-level (cell/module/pack) and multi-chemistry coverage provides versatility for industrial applications.
State of the Art	Existing models in literature address individual aspects (electrochemical or thermal) but lack integrated multi-level, multi-chemistry ROM frameworks with FMU export capability validated for industrial substitution of physical testing.
BUSINESS APPLICATION & TARGET USERS	
Business Application	Development and optimisation of battery cells and packs for stationary and mobility applications. Integration into HiL and virtual testing environments.
Target Users	HiL developers, battery cell manufacturers, battery pack integrators, automotive and off-road OEMs.
EXPLOITATION STRATEGY	
Exploitation Strategy	<ul style="list-style-type: none"> • Internal exploitation by MGEP for R&D and service offerings • Scientific and research publications to demonstrate the model's added value • Potential service commercialisation to industry partners post-project
IP STRATEGY	
Background IP	Extensive MGEP background: physics-based models (P2D, SPM, SPMe), thermal models, ageing equations, SoX estimators, MODEST degradation analysis tool. Available at the MGEP research portal.
Foreground IP	Trade Secret (internal exploitation) and/or Open/Public (scientific publications). Individual ownership by MGEP.

POST-PROJECT ROADMAP

Post-Project Roadmap	Further development to improve model accuracy for ageing, performance and thermal behaviour of new cell formats and chemistries. Extensions focused on reducing prediction error and broadening chemistry coverage beyond LFP/NMC.
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Table 12 Sub-KER 3.2: Ageing Model (C-code), Including Degradation Mechanisms

Sub-KER 3.2: Ageing Model (C-code), Including Degradation Mechanisms	
Lead Partner: UL TRL at M36: TRL 4	
DEFINITION & TECHNICAL SCOPE	
Definition	A validated ageing model implemented in C-code, describing the electrochemical behaviour of a single electrode particle coupled with multiple degradation mechanisms.
Technical Scope	<ul style="list-style-type: none"> • SEI layer growth modelling • Reversible lithium plating • Active material particle cracking • Single-particle electrochemical model in C language • Integration capability with full electrochemical cell models
PARTNER CONTRIBUTION	
UL (Lead)	Full development of the C-code ageing model, including the electrochemical particle model and all degradation mechanisms.
MGEP (Participating)	Provision of model parameters and integration of the ageing model into the full electrochemical model of an elementary electrochemical cell.
MARKET ADVANTAGE & STATE OF THE ART	
Market Advantage	Improved prediction capabilities for ageing phenomena in cells with composite Si/Graphite anodes. Suitable for offline SoH observer applications and integration into commercial BMS and simulation platforms.
State of the Art	Existing degradation models rely on simplified Tafel equations and do not account for stress/strain contributions or active material cracking. This model advances accuracy and physical fidelity.
BUSINESS APPLICATION & TARGET USERS	
Business Application	Industrial simulation environments, embedded applications, and integration into commercial battery modelling platforms.
Target Users	Battery manufacturers and cell developers are assessing ageing behaviour. BMS developers integrating ageing models into state-of-health estimation.

EXPLOITATION STRATEGY	
Exploitation Strategy	<ul style="list-style-type: none"> • Internal research use and enhancement of UL's modelling capabilities • Scientific publications in peer-reviewed open-access journals • Networking and future collaboration with industry and research partners
IP STRATEGY	
Background IP	No background IP contributed for this sub-KER.
Foreground IP	Trade Secret. Both joint or individual ownership possible between UL and MGEP, to be agreed post-project.
POST-PROJECT ROADMAP	
Post-Project Roadmap	Further development required to improve computational speed, numerical robustness, and upscaling to electrode level. Estimated 2 years and €30,000 to reach full commercialisation.

Table 13 Sub-KER 3.3: Parameter Characterisation for Gen3b and Gen4/SSB

Sub-KER 3.3: Parameter Characterisation for Gen3b and Gen4/SSB	
Lead Partner: ABEE TRL at M36: TRL 5–6	
DEFINITION & TECHNICAL SCOPE	
Definition	Comprehensive electrochemical, thermal, and ageing parameter characterisation of Gen3b (LFP/Si-C) and Gen4 solid-state cells, providing validated datasets for physics-based and reduced-order model calibration.
Technical Scope	<ul style="list-style-type: none"> • OCV curves, HPPC profiles, thermal behaviour characterisation • Ionic/electronic conductivities, solid-phase diffusivities, transference numbers • Ageing-related parameters from BoL, cycling, EoL and post-mortem tests • High-quality labelled datasets for WP3 model calibration and validation • Applicable standards: IEC 62660, UL1973, IEC 62619
PARTNER CONTRIBUTION	
ABEE (Lead)	Full experimental test campaign design and execution. Provision of raw labelled datasets. Test procedure definition and DoE integration support.
Participating Partners	<ul style="list-style-type: none"> • UL: Ageing-mechanism modelling (SEI, Li-plating) • VTT, MGEP, IKERLAN: Use of ABEE datasets for ROM, PBM and hybrid models

	<ul style="list-style-type: none"> • INEGI/Fraunhofer: Advanced testing protocols and EIS/thermal characterisation
MARKET ADVANTAGE & STATE OF THE ART	
Market Advantage	Unique validated parameter datasets for next-generation cell chemistries (Gen3b, Gen4 SSB), foundational for model accuracy across the entire FASTEST modelling chain and Digital Twin.
State of the Art	Parameter characterisation datasets for Gen4 solid-state cells are scarce in literature. Most publicly available datasets are limited to standard NMC/LFP chemistries without SSB-specific ageing parameters.
BUSINESS APPLICATION & TARGET USERS	
Business Application	Contract parameterisation and characterisation services. Provision of validated datasets for model developers and digital twin providers.
Target Users	Automotive OEMs, industrial/off-road system integrators, battery manufacturers and research institutes, Digital Twin and virtual testing software providers.
EXPLOITATION STRATEGY	
Exploitation Strategy	<ul style="list-style-type: none"> • Internal: Enhancement of ABEE's battery validation workflow and cell design activities • Commercial: Contract testing and parameterisation services to OEMs and integrators • Licensing of datasets or validated parameter sets • High-level methodology publications; raw datasets kept confidential
IP STRATEGY	
Background IP	ABEE proprietary test methodologies, protocols for Li-ion and SSB cell evaluation, data labelling know-how. Protected as trade secret and copyright.
Foreground IP	Trade Secret and Copyright. Selective joint ownership where dataset generation is co-dependent on partner methodologies (e.g., shared EIS analysis).
POST-PROJECT ROADMAP	
Post-Project Roadmap	Extension of methodologies to next-generation solid-state chemistries. Additional cycling campaigns to strengthen long-term ageing models. Scalable automation of parameter extraction. Estimated 12–18 months of additional effort.

Table 14 Sub-KER 3.4: Definition + Execution of Cell/Module Testing

Sub-KER 3.4: Definition + Execution of Cell/Module Testing

Lead Partner: ABEE | TRL at M36: TRL 6

DEFINITION & TECHNICAL SCOPE

Definition	Design and execution of the complete experimental testing matrix at cell and module levels, generating ground-truth validation datasets for the FASTEST hybrid testing platform and all modelling activities.
Technical Scope	<ul style="list-style-type: none"> • Full test execution procedures for Gen3b/Gen4 cells and reference module • Electrical, thermal, and mechanical behaviour datasets • Standardised test formats interoperable with DT, DoE and modelling toolchains • LIMS and Digital Twin interface integration • Applicable standards: IEC 62660-1/2, IEC 62619, UL1973

PARTNER CONTRIBUTION

ABEE (Lead)	All physical testing of Gen3b/Gen4 cells and reference module. Ground-truth dataset generation. Test specification input to WP1 and WP2. LIMS and DT interface support.
Participating Partners	<ul style="list-style-type: none"> • INEGI: Module-level thermal and mechanical modelling validation • IKERLAN: Structural reliability and vibration fatigue analysis • MGEP/VTT: Validation of reduced-order models using ABEE experimental results

MARKET ADVANTAGE & STATE OF THE ART

Market Advantage	Standardised, interoperable test datasets that directly feed into virtual testing workflows, reducing redundant physical testing and accelerating validation cycles across the battery value chain.
State of the Art	Most industry testing remains siloed with limited interoperability between physical test data and virtual model environments. FASTEST's integrated approach provides a validated bridge between physical testing and digital tools.

BUSINESS APPLICATION & TARGET USERS

Business Application	High-fidelity test services, consultancy integration, and data-driven battery pack development.
Target Users	Cell and module manufacturers, automotive and off-road OEMs, stationary storage integrators, certification bodies (indirectly, via validated methods).

EXPLOITATION STRATEGY

Exploitation Strategy	<ul style="list-style-type: none"> • Internal: Improvement of ABEE testing facilities, workflows, and data management
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	<ul style="list-style-type: none"> • Commercial: Advanced test campaign and validation services to industry • Integration of validated methods into consultancy and service offerings • Publication of high-level testing methodologies
IP STRATEGY	
Background IP	ABEE proprietary cell/module test protocols, fixtures, measurement procedures, and internal data formatting and traceability systems. Protected as trade secret and copyright.
Foreground IP	Trade Secret and Copyright. Joint ownership where workflows and data are co-developed with partners.
POST-PROJECT ROADMAP	
Post-Project Roadmap	Extension of testing capabilities to next-generation SSB modules. Automation of complex thermal and mechanical testing. Integration with future DoE and AI-driven optimisation workflows. Estimated 12–24 months of additional development.

Table 15 Sub-KER 3.5: Physics-Based Equivalent Circuit Model (Cell Level)

Sub-KER 3.5: Physics-Based Equivalent Circuit Model (Cell Level)	
Lead Partner: VTT TRL at M36: TRL 5	
DEFINITION & TECHNICAL SCOPE	
Definition	A physics-based equivalent circuit model (ECM) that bridges the gap between high-fidelity physics-based models and computationally efficient equivalent circuit representations, by assigning real physical meaning to each circuit element.
Technical Scope	<ul style="list-style-type: none"> • Reduced-order physics-based modelling at cell level • ECM with physically meaningful circuit elements derived from electrochemical principles • Bridging link between full physics-based models (KER3.1) and data-driven approaches (KER4) • Market application: R&D and battery industry
PARTNER CONTRIBUTION	
VTT (Lead)	Development of the physics-based ECM, including model derivation, parameterisation, and validation at cell level. Shared development aspects with ABEE.
MARKET ADVANTAGE & STATE OF THE ART	
Market Advantage	Provides a computationally efficient yet physically grounded modelling alternative, suitable for embedding in BMS and real-time simulation

State of the Art	environments where full physics-based models are computationally prohibitive. Standard ECMs lack physical interpretability; full physics-based models (P2D) are computationally expensive. This sub-KER fills the gap with a physically-informed reduced model at cell level.
BUSINESS APPLICATION & TARGET USERS	
Business Application	R&D environments and battery industry applications requiring fast, physically interpretable cell models.
Target Users	Battery R&D teams, BMS developers, battery system integrators.
EXPLOITATION STRATEGY	
Exploitation Strategy	<ul style="list-style-type: none"> • Individual internal exploitation by VTT • Scientific dissemination via conference paper (planned) • No commercial exploitation planned at this stage
IP STRATEGY	
Background IP	No background IP contributed for this sub-KER.
Foreground IP	Copyright. Individual ownership by VTT.
POST-PROJECT ROADMAP	
Post-Project Roadmap	No further technical development planned beyond M36. Scientific publication of the modelling approach planned as the primary post-project output.

Table 16 Sub-KER 3.6: Vibrational Fatigue and Mechanical Reliability (Module)

Sub-KER 3.6: Vibrational Fatigue and Mechanical Reliability (Module)	
Lead Partner: IKERLAN TRL at M36: TRL 4	
DEFINITION & TECHNICAL SCOPE	
Definition	A novel methodology for predicting structural failures in laser welds under vibrational fatigue loads, providing advanced tools for evaluating joint integrity and optimising battery module structural reliability.
Technical Scope	<ul style="list-style-type: none"> • Failure prediction in laser welds under vibrational fatigue loads • Simplified validation method for numerical structural models • Structural optimisation and improvement of battery module components • Advanced SoA methods for joint integrity evaluation

	<ul style="list-style-type: none"> Market application: software/DT and simulation service providers for structural calculation
PARTNER CONTRIBUTION	
IKERLAN (Lead)	Sole developer of the methodology. Full model development covering structural reliability and fatigue loading conditions at module level. Scientific conference dissemination already been completed.
MARKET ADVANTAGE & STATE OF THE ART	
Market Advantage	Reduction in time and resources required for structural validation. Enables simplified numerical model validation and optimisation of battery module structures without extensive physical testing.
State of the Art	Advanced methods for evaluating vibrational fatigue in laser welds exist, but have not been specifically validated and simplified for battery module manufacturing environments.
BUSINESS APPLICATION & TARGET USERS	
Business Application	Software/DT and simulation service provision for structural calculation in battery and electronic component manufacturing.
Target Users	Battery and electronic component developers (CAF P&A, Cegasa, Arteche, Amopack), laser welding designers and users (Mercedes-Benz, Gestamp, Fagor Electrónica).
EXPLOITATION STRATEGY	
Exploitation Strategy	<ul style="list-style-type: none"> Internal exploitation through R&D projects with industry companies Scientific conference paper already published/presented Full methodology manuscript in preparation
IP STRATEGY	
Background IP	IKERLAN background on modelling and testing for structural reliability and vibrational fatigue loading conditions.
Foreground IP	Copyright (methodology manuscript, calculation spreadsheets, know-how). Individual ownership by IKERLAN.
POST-PROJECT ROADMAP	
Post-Project Roadmap	Core methodology complete at M36. Future scope expansion possible through follow-on projects: increased standardisation, sub-model and surrogate model development, TRL advancement. Estimated ~12 person-months for further development.

Table 17 Sub-KER 3.7: Virtual Cyclor (Simulation Environment)

Sub-KER 3.7: Virtual Cyclor (Simulation Environment)	
Lead Partner: IKERLAN TRL at M36: TRL 5	
DEFINITION & TECHNICAL SCOPE	
Definition	A parametrisable Virtual Cyclor model enabling standardised cycling of battery models in a simulated environment, exported as an FMU to ensure the interface between the test sequence generator and the battery model within the FASTEST platform.
Technical Scope	<ul style="list-style-type: none"> • FMU-based parametrisable virtual cycling environment • Interface between test sequence generator and battery model • BMS validation in simulation or HIL environments • Virtualised battery model execution for Digital Twin integration • Market application: BMS validation (simulation/HIL), DT
PARTNER CONTRIBUTION	
IKERLAN (Lead)	Sole developer. Full implementation of the parametrisable Virtual Cyclor model and FMU integration within the FASTEST platform.
MARKET ADVANTAGE & STATE OF THE ART	
Market Advantage	Standardises and accelerates BMS validation and verification workflows through virtualisation, reducing the need for physical cycling campaigns and enabling flexible scenario-based testing.
State of the Art	Virtual cycling environments exist in commercial tools but lack the parametrisability and standardised FMU-based interface with test sequence generators required for seamless HIL and DT integration.
BUSINESS APPLICATION & TARGET USERS	
Business Application	BMS validation (simulation or HIL), virtualised battery model execution, and Digital Twin integration.
Target Users	BMS HIL developers, battery system Digital Twin developers.
EXPLOITATION STRATEGY	
Exploitation Strategy	<ul style="list-style-type: none"> • Internal exploitation by IKERLAN for standardising and optimising BMS XIL testing, validation, and verification scenario inputs • No commercial exploitation planned at this stage
IP STRATEGY	
Background IP	No background IP contributed to this sub-KER.

Foreground IP	Copyright. Individual ownership by IKERLAN.
POST-PROJECT ROADMAP	
Post-Project Roadmap	No further development required beyond M36 for core functionality. Potential extension in future projects to increase standardisation and flexibility of the virtual cycling environment.

Table 18 KER4 – Data-Driven Modelling Tools

Type	KER4 – Data-Driven Modelling Tools
Definition	<p>The Data-Driven Modelling Tools consist of predictive algorithms capable of estimating battery degradation and operational state functions using operational and historical data from battery systems.</p> <p>The tools process large volumes of battery data collected from sensors and monitoring systems and use machine learning techniques to build predictive models that estimate battery ageing and remaining useful life.</p> <p>These models enable online monitoring of battery condition and provide early indications of degradation, allowing battery operators to optimise operation strategies, improve reliability, and plan maintenance actions more effectively.</p>
Technical Scope	<p>The modelling framework integrates several components:</p> <ul style="list-style-type: none"> Data ingestion and processing from battery operation and testing Machine learning algorithms for degradation prediction Data-driven estimation of battery state variables (SoH, SoC, SoP, RUL) Continuous model calibration using operational datasets Integration with battery management systems and digital twin platforms <p>The models are designed to operate with reduced experimental datasets compared to traditional ageing characterisation approaches, making them suitable for industrial environments where extensive testing campaigns are costly.</p> <p>Expected TRL at M36: TRL 5</p>
Partner contributions	<p>VTT – Lead developer: Development of the core data-driven modelling framework for battery ageing estimation and prediction, including algorithms capable of processing operational data and generating predictive insights on battery performance and degradation.</p> <p>BMZ: Provision of operational battery usage data and insights on cell behaviour during operation and ageing, supporting the development and calibration of predictive models.</p> <p>Fraunhofer IISB (FHG): Contribution to ageing modelling methodologies and support in model validation and performance optimisation.</p> <p>MGEP: Contribution to model validation and interaction with physics-based modelling tools developed within FASTEST.</p> <p>University of Surrey: Contribution to algorithm development and application of predictive modelling methods for battery applications.</p>
Market advantage	<p>The Data-Driven Modelling Tools provide several advantages compared to existing battery monitoring solutions:</p> <ul style="list-style-type: none"> Accurate prediction of battery ageing and degradation trends Reduced need for extensive ageing tests Continuous model calibration using operational data Improved predictive maintenance capabilities Enhanced reliability of battery systems <p>These capabilities enable battery operators and manufacturers to make more informed decisions regarding system operation, maintenance, and lifecycle management.</p>

SoTA	<p>Data-driven approaches for battery ageing estimation are increasingly studied in scientific literature; however, many existing models remain limited to laboratory datasets and have not been validated in real-world battery operation environments.</p> <p>FASTEST advances the state of the art by validating data-driven ageing models using real operational datasets and integrating them with hybrid testing platforms and digital twin environments.</p> <p>This integration improves the robustness and applicability of predictive models for industrial battery Applications.</p>
Business Applications	<p>The Data-Driven Modelling Tools enable several high-value applications in the battery industry:</p> <ul style="list-style-type: none"> • Predictive maintenance for battery systems • Performance monitoring of battery packs • Optimisation of battery operation strategies • Improved lifecycle management of battery systems • Support for digital twin implementations in battery systems • Enhanced decision support for battery operators
Target users	<ul style="list-style-type: none"> • Battery energy storage system (BESS) operators • Automotive battery system developers and OEMs • Battery manufacturers • Battery management system developers <ul style="list-style-type: none"> • Engineering consultancies and industrial companies deploying large battery systems
Exploitation Strategy (M34)	<p>VTT confirmed the following exploitation intentions:</p> <ul style="list-style-type: none"> • Internal R&D use ✓ • Training and knowledge transfer ✓ <p>Integration confirmed for:</p> <ul style="list-style-type: none"> • Battery Management Systems (BMS) ✓ • Digital Twin Platforms ✓ • Hybrid testing environments ✓
IP Strategy	<p>IP owner: VTT</p> <p>Background IP includes internal know-how related to data-driven model development.</p> <p>The protection strategy foresees:</p> <ul style="list-style-type: none"> • Protection of algorithms and modelling methodologies as trade secrets • Establishment of IP transfer agreements between contributing partners • Consolidation of foreground IP ownership under VTT <p>This strategy aims to enable future commercial exploitation while preserving collaborative development within the consortium.</p>

Table 19 KER5 – Safety and reliability AI toolchain

Type	KER5 – Safety and reliability AI toolchain
Definition	<p>The Safety and Reliability AI Toolchain is a software-based analytical framework that applies artificial intelligence and machine learning methods to monitor, analyse, and predict the safety and reliability of battery systems.</p> <p>The toolchain processes operational data from battery systems, digital twins, and modelling environments to identify degradation trends, detect anomalies, and assess potential safety risks. It enables both real-time monitoring and predictive analysis, supporting safer and more efficient battery operation.</p> <p>By combining predictive algorithms with safety-oriented system architecture design, the toolchain helps optimise battery system development, testing, and operational strategies.</p>

<p>Technical Scope</p>	<p>The Safety and Reliability AI Toolchain integrates multiple components supporting safety assessment and predictive diagnostics:</p> <ul style="list-style-type: none"> • Data ingestion from battery operation and testing environments • Machine learning algorithms for degradation and failure prediction • Integration of ageing models developed within FASTEST • Safety-oriented system architecture design • Data evaluation across multiple battery operation scenarios • Digital twin integration for virtual testing and system analysis • Early fault detection and anomaly identification <p>The system enables comprehensive monitoring of battery state variables and provides predictive insights that support operational decision-making and safety assessment. Expected TRL at M36: TRL 5</p>
<p>Partner contributions</p>	<p>RSTER – Lead partner Development of the AI-based toolchain architecture and overall framework for safety and reliability analysis, including integration of monitoring, simulation, and predictive analysis capabilities.</p> <p>ABEE Development of interfaces between the AI toolchain and battery subsystems and implementation of machine learning techniques based on failure tree analysis (FTA), degradation modes, and risk management approaches.</p> <p>University of Ljubljana (UL) Integration of ageing modelling functionalities developed in WP3 into the AI toolchain to support degradation prediction and reliability analysis.</p> <p>INEGI Definition of input and output structures for the toolchain within the digital twin environment, enabling data exchange between simulation and monitoring components.</p> <p>IKERLAN Design of safety and reliability-oriented system architecture aligned with applicable safety standards throughout the development lifecycle.</p> <p>University of Surrey Development of AI-based predictive algorithms applicable to automotive battery systems and other battery-based applications.</p> <p>VTT Support in modelling integration and system-level validation.</p>
<p>Market advantage</p>	<p>The Safety and Reliability AI Toolchain provides significant advantages compared to existing monitoring solutions:</p> <ul style="list-style-type: none"> • Real-time monitoring of battery safety and reliability parameters • Early detection of battery faults and abnormal behaviour • Predictive analysis of degradation trends and remaining useful life • Reduced certification time through virtual validation methods • Improved decision-making through advanced data analysis <p>These capabilities help reduce operational risks, lower maintenance costs, and improve the reliability of battery systems across multiple applications.</p>
<p>SoTA</p>	<p>Current AI-powered solutions for battery monitoring combine machine learning techniques, digital twin simulations, and multi-physics modelling approaches to improve battery safety and performance.</p> <p>However, many existing tools focus on isolated aspects such as degradation prediction or failure detection without providing integrated safety assessment frameworks that combine operational data, predictive modelling, and system-level architecture considerations.</p> <p>The FASTEST Safety and Reliability AI Toolchain advances the state of the art by integrating these capabilities into a single analytical framework, enabling comprehensive monitoring, prediction, and safety-oriented design optimisation.</p>
<p>Business Applications</p>	<p>The Safety and Reliability AI Toolchain supports several industrial applications:</p> <ul style="list-style-type: none"> • Predictive maintenance for battery systems • Early fault detection in battery packs

	<ul style="list-style-type: none"> • Safety monitoring for electric mobility and energy storage systems • Optimisation of battery design and operational strategies • Support for battery certification and safety validation • Integration with digital twin environments for virtual safety testing
Target users	<p>Primary users include:</p> <ul style="list-style-type: none"> • Battery manufacturers • Battery pack integrators • Electric vehicle manufacturers • Stationary energy storage system providers • Industrial equipment manufacturers • Battery testing laboratories • Research organisations and universities
Exploitation Strategy (M34)	<p>The result will be exploited through several pathways:</p> <ul style="list-style-type: none"> • Technology transfer and collaborative development with industrial partners • Licensing of AI-based safety algorithms • Joint ventures or cooperation agreements with battery manufacturers • Integration into battery monitoring platforms and digital twin systems • Scientific publications and knowledge dissemination
IP Strategy	<p>IP ownership: Joint ownership between participating partners (RSTER, ABEE, UL, INEGI, IKERLAN, SURREY, VTT).</p> <p>The IP protection strategy includes:</p> <ul style="list-style-type: none"> • Patent protection covering the AI toolchain concept and architecture • Copyright protection for publications and software components • Joint ownership agreement between partners after project completion <p>This strategy ensures that the partners contributing to the development of the toolchain retain ownership rights while enabling collaborative exploitation of the technology.</p>

Table 20 KER6 – Digital twin model

KER6 – Digital twin model	
Technical description	
Definition	<p>The Digital Twin Model developed in FASTEST provides a comprehensive virtual representation of battery systems, enabling the monitoring, simulation, and analysis of battery behaviour across multiple levels – cells, modules, and packs. The model establishes a structured framework that captures the relationships between battery components and operational parameters, allowing the creation of a digital environment capable of replicating the behaviour of physical battery systems.</p> <p>By combining structured data management, modelling tools, and simulation capabilities, the Digital Twin Model allows engineers and researchers to analyse battery performance, optimise system design, and support testing and validation processes. The digital twin integrates information from modelling tools, experimental data, and operational monitoring systems, enabling real-time comparison between simulated and physical system behaviour.</p> <p>Within FASTEST, the Digital Twin Model acts as a central integration layer connecting modelling tools, hybrid testing platforms, and AI-based diagnostic systems. This enables a comprehensive virtual testing environment capable of accelerating battery development, improving reliability assessment, and supporting more efficient product design processes.</p>

<p>Technical Scope</p>	<p>The Digital Twin Model framework integrates the following functional components:</p> <ul style="list-style-type: none"> • Model management and storage for battery simulation models • Data collection and storage from sensors, testing systems, and operational environments • Data monitoring, aggregation, filtering, and visualisation tools • Interfaces for data exchange with external systems, including a Model Exchange Interface (INEGI) • Communication protocols supporting interoperability: MQTT and REST APIs • Integration with testing platforms and modelling tools developed within FASTEST • Integration with Laboratory Information Management Systems (LIMS) – demonstrated at M36 <p>The platform architecture enables the orchestration of multiple battery models representing different product levels and operating conditions. Algorithms allow the selection and execution of appropriate models depending on simulation or testing requirements.</p>						
<p>TRL at M36</p>	<p>TRL 6 – Confirmed at M36</p> <p>TRL 6 confirmed by COMAU following successful demonstration of the integrated Digital Twin platform, including DT-LIMS interactions and the effective incorporation of INEGI's ontology components. INEGI also confirmed TRL 6 for its contribution, with the platform validated in a relevant industrial environment.</p> <p><i>Post-project target: TRL 9 – commercial deployment through integration into COMAU's In.Grid platform.</i></p>						
<p>Partner contributions</p>							
<p>Partner contributions</p>	<table border="0"> <thead> <tr> <th data-bbox="464 1081 901 1108">INEGI</th> <th data-bbox="906 1081 1404 1108">COMAU</th> </tr> <tr> <th data-bbox="464 1115 901 1142">Co-lead developer</th> <th data-bbox="906 1115 1404 1142">Co-lead developer</th> </tr> </thead> <tbody> <tr> <td data-bbox="464 1149 901 2033"> <ul style="list-style-type: none"> • Development of the conceptual digital twin framework: ontology definition, information modelling, and representation of battery components and their relationships • Semantic structure of the digital twin in accordance with FAIR data principles • Battery asset characterisation integrated from other FASTEST work packages • Model Exchange Interface: enabling interoperability between modelling tools and the DT platform • Demonstrated DT-LIMS integration and incorporation of INEGI components into the COMAU platform </td> <td data-bbox="906 1149 1404 2033"> <ul style="list-style-type: none"> • Development of the digital twin platform architecture and supporting infrastructure for data ingestion, storage, monitoring, and visualisation • Proprietary industrial IoT platform (In.Grid): cloud-based deployment, communication protocols (MQTT, REST), and user interface dashboards • System architecture, platform integration, and user interface/visualisation tools • LIMS integration and validation of the full platform at TRL 6 • In.Grid constitutes COMAU Background IP; foreground = platform components built on top of In.Grid </td> </tr> </tbody> </table>	INEGI	COMAU	Co-lead developer	Co-lead developer	<ul style="list-style-type: none"> • Development of the conceptual digital twin framework: ontology definition, information modelling, and representation of battery components and their relationships • Semantic structure of the digital twin in accordance with FAIR data principles • Battery asset characterisation integrated from other FASTEST work packages • Model Exchange Interface: enabling interoperability between modelling tools and the DT platform • Demonstrated DT-LIMS integration and incorporation of INEGI components into the COMAU platform 	<ul style="list-style-type: none"> • Development of the digital twin platform architecture and supporting infrastructure for data ingestion, storage, monitoring, and visualisation • Proprietary industrial IoT platform (In.Grid): cloud-based deployment, communication protocols (MQTT, REST), and user interface dashboards • System architecture, platform integration, and user interface/visualisation tools • LIMS integration and validation of the full platform at TRL 6 • In.Grid constitutes COMAU Background IP; foreground = platform components built on top of In.Grid
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	<p>RSTER Contribution to the definition of ontology structures and mapping of asset data required for the development of the digital twin framework.</p>
Market and business applications	
Market advantage	<ul style="list-style-type: none"> • Centralised platform for integrating battery models and testing data • Improved ability to analyse and simulate battery behaviour across different system levels • Real-time comparison between simulated and physical system behaviour • Improved accessibility and traceability of testing data and simulation results • Support for remote monitoring and collaborative engineering environments • High-fidelity virtual testing directly synchronised with LIMS, enabling earlier identification of performance issues and reducing reliance on expensive physical tests (COMAU)
SoTA	<p>Modelling and simulation have long been used in battery development; however, most existing solutions focus on specific modelling tasks such as charge-discharge simulation or performance analysis under predefined conditions.</p> <p>Digital twin technologies represent a more advanced approach by synchronising virtual models with real operational data to replicate the behaviour of physical systems in real time. Despite growing interest in digital twins for industrial systems, applications in battery development remain limited and often address isolated components rather than the entire battery system.</p> <p>The FASTEST Digital Twin Model advances the state of the art by integrating models representing different battery system levels into a unified platform capable of orchestrating simulations, monitoring operational data, and supporting virtual testing workflows.</p>
Business Applications	<ul style="list-style-type: none"> • Accelerated battery product development • Virtual testing of battery performance, safety, and reliability • Optimisation of battery system design and manufacturing processes • Monitoring and analysis of battery behaviour during operation • Support for hybrid testing environments combining simulation and physical experiments
Target users	<ul style="list-style-type: none"> • Battery manufacturers and battery pack integrators • Battery testing laboratories and consultancies • Technology developers working on battery systems • Research organisations and universities • Industrial companies developing digital twin platforms for battery manufacturing and testing
Relevant market sectors	<ul style="list-style-type: none"> • Battery manufacturing • Battery testing services • Digital manufacturing platforms • Energy storage systems
Exploitation Strategy	
Organisational roles	<p>A clear and complementary split between two types of organisation was confirmed at the M36 IP Ownership Workshop:</p> <p>INEGI (RTO): Research and Technology Organisation. The primary objective is scientific knowledge generation and R&D service delivery. INEGI does not pursue commercial exploitation of KER6.</p> <p>COMAU (Industry): Commercial company and designated exploitation leader for KER6. COMAU will drive commercial uptake through the enhanced In. Grid platform, once the result is ready for industrial deployment.</p>

<p>Exploitation routes</p>	<p>INEGI</p> <ul style="list-style-type: none"> • Engineering services and R&D projects addressing specific technical challenges (e.g. digital twin integration for battery testing) • Licensing or IP transfer to third parties seeking to adopt and build on the digital twin know-how • Open knowledge dissemination: INEGI's primary route is the scientific publication of results • Participation in future national and European R&D projects leveraging KER6 outcomes <p>COMAU</p> <ul style="list-style-type: none"> • Integration of the KER6 Digital Twin Model into the In.Grid commercial platform as the primary exploitation vehicle — resulting in an enhanced In.Grid product for the battery market • Engineering services and collaborative development with industrial partners • COMAU is currently identifying potential industrial players for the commercialisation of the enhanced In. Grid platform incorporating KER6 • Exploitation expected to unfold over a 1–3 year post-project timeline, starting with internal refinement and stabilisation of the integrated platform
<p>Scientific dissemination</p>	<p>INEGI has published the following scientific paper arising directly from KER6 FASTEST foreground work:</p> <p><i>Marques, N., Rodrigues, M., Himanshu, M. and Gandoman, F. "Towards Developing an Ontology for a Digital Twin in Battery Testing." DOI: 10.5220/0013082300003838</i></p> <p><i>Published under Creative Commons Licence CC BY-NC-ND 4.0 (Attribution – Non-Commercial – No Derivatives)</i></p> <p>This publication is registered in the FASTEST dissemination records. Further scientific publications from both INEGI and COMAU are expected post-M36.</p>
<p>Market status</p>	<p>COMAU is currently in the process of identifying potential industrial players and customers for the enhanced In. Grid platform incorporating KER6. No external industrial partners or customers have been formally committed beyond the existing project consortium at M36.</p> <p>Main barriers to industrial adoption identified by COMAU:</p> <ul style="list-style-type: none"> • Interoperability challenges between different industrial systems and data formats • Need to build industry trust in virtual testing over traditional physical testing
<p>IP Strategy and Ownership</p>	
<p>IP Owners</p>	<p>INEGI and COMAU</p>
<p>IP strategy per partner</p>	<p>INEGI – IP Strategy</p> <ul style="list-style-type: none"> • Copyright: Scientific publications, including the CC BY-NC-ND 4.0 paper already published • No trade secret: INEGI's mission is to publish and disseminate scientific <p>COMAU – IP Strategy</p> <ul style="list-style-type: none"> • Copyright (software): Primary IP asset — the KER6 software developed and integrated into In. Grid is protected by copyright • Copyright (publications): Scientific

	<p>knowledge, not to protect it commercially</p> <ul style="list-style-type: none"> • Open licensing: Open to allowing third parties to build on the ontology and digital twin know-how • No patent filing planned 	<p>and technical publications related to KER6</p> <ul style="list-style-type: none"> • In.Grid® trademark: COMAU Background IP; governs commercial deployment; not subject to joint ownership • No patent filing planned
Background IP	<p>INEGI:</p> <ul style="list-style-type: none"> • Know-how on semantic data modelling and digital twin ontology development • Expertise in real-time data ingestion pipelines • Simulation modelling and predictive analysis capabilities for industrial systems <p>COMAU:</p> <ul style="list-style-type: none"> • Expertise in automation systems and battery manufacturing technologies • Proprietary industrial IoT platform In.Grid® (Trade Secret + Trademark) • Digital manufacturing system architectures and integration technologies 	
IP risk assessment	<p>LOW</p> <p>The IP risk has been revised to LOW. The clear separation of organisational roles (INEGI as RTO pursuing scientific dissemination; COMAU as commercial company pursuing market deployment through In.Grid) eliminates the main sources of IP conflict previously identified:</p> <ul style="list-style-type: none"> • In.Grid boundary risk: resolved — COMAU is the sole commercial exploiter and controls In.Grid; INEGI does not seek post-project commercial access to In.Grid • INEGI background scope risk: resolved — no competing commercial ownership claims requiring formal delineation <p>RSTER role risk: resolved — minor contribution confirmed; no ownership claim</p>	
Joint Ownership Agreement	<p>Not required – agreed by both INEGI and COMAU at the M36 IP Ownership Workshop</p> <p>Both INEGI and COMAU confirmed that a Joint Ownership Agreement is not necessary or useful for KER6. The fundamental reason is the clear complementarity of organisational types and objectives: INEGI pursues scientific knowledge and R&D (no commercial interest); COMAU independently pursues commercial exploitation through In.Grid (no joint commercial revenues to govern). There are no competing exploitation routes, no shared licensing decisions, and no scenario requiring joint consent</p>	
Post-project roadmap		
Post-project plans	<p>INEGI</p> <ul style="list-style-type: none"> • Further engineering R&D services addressing battery digital twin challenges • Open dissemination of ontology framework results through scientific publications • Participation in future Horizon Europe and 	<p>COMAU</p> <ul style="list-style-type: none"> • 1–3 year post-project timeline: internal refinement and stabilisation of the integrated In.Grid + KER6 platform • Gradual market implementation for industrial applications

	<p>national projects building on KER6 know-how</p> <ul style="list-style-type: none"> • Openness to licensing the ontology framework to third parties seeking to build operational digital twin platforms 	<p>once platform is commercially ready</p> <ul style="list-style-type: none"> • Active identification of industrial players and customers for the enhanced In.Grid platform • Potential further collaborative R&D projects leveraging validated DT-LIMS and platform interfaces
Technical risks	<ul style="list-style-type: none"> • Interoperability between modelling tools across different industrial platforms • Scalability of the digital twin platform to larger industrial deployments • Integration with heterogeneous industrial data systems and formats 	
Regulatory considerations	<ul style="list-style-type: none"> • Functional safety standards (relevant to battery testing environments) • AI regulation (EU AI Act — may apply to AI-based monitoring and diagnostic functions) • Battery safety certification requirements in target markets 	