Novel Power Infra

A modular, accreditation-ready framework for testing, validation and system-level innovation in modern power system technologies

Executive summary

Novel Power Infra addresses a recognised gap by creating a coherent pathway across Finland's power- and energy-system validation capabilities — connecting existing facilities, enabling new shared capabilities and, where justified by demand and investment, supporting the establishment of new testing infrastructure. Within this pathway, hardware, software, interoperability, market-facing behaviour and cyber security can be examined together across connected laboratory environments and dedicated facilities, with accredited services where recognised schemes exist. Strong capabilities already exist; what is missing is a coherent route through them — and a mechanism for adding the capabilities that are still needed. Integration is therefore the concept's defining feature: shared criteria and a continuous chain of evidence between stages — not necessarily co-location.

By linking technical validation with market, service and business-model development, Novel Power Infra also creates a basis for business model innovation, shared infrastructure use and new value propositions across the energy ecosystem. This white paper sets out the concept's purpose, value proposition and indicative direction, and invites stakeholders to define the rest.

Europe's energy transition is moving faster than the systems that verify it. Electrification, inverter-based resources, digitalised grid operation and market-driven flexibility have made system-level assurance necessary alongside traditional device-level testing — evidence that an interconnected system behaves as intended under realistic conditions, where the system includes the physical network, control software, market signals and the cyber layer at once. Regulation has followed: interoperability, cyber resilience and data handling are increasingly subject to explicit regulatory and standards-based requirements rather than being treated solely as competitive choices.

Many of the capabilities needed already exist. Europe hosts world-class specialised laboratories, and initiatives such as ERIGrid and DERlab have established methods and collaborative practices on which to build. What is missing is a coherent route through existing capabilities — together with a mechanism for adding the capabilities that are still needed. In Finland, simulation, CHIL/PHIL testing, MW-scale physical testing, cyber-security assessment and accredited testing and certification capabilities are distributed across different organisations and facilities, without a common pathway that carries evidence consistently from one stage to the next. Cyber-security assessment and physical performance validation also remain largely separate, even though failures and vulnerabilities can propagate across both domains.

This is primarily a gap in coordination, not competence. Many capabilities have developed through separate organisational and project-based initiatives, each strong within its own scope. The coordination gap becomes increasingly consequential as product development accelerates and regulators, customers and system operators require evidence that spans technologies, domains and validation stages.

Novel Power Infra is a proposal to close this gap: a national, neutral and accreditation-ready validation framework that connects existing capabilities, enables the development of new shared capabilities and leaves room for new dedicated testing infrastructure where demand and investment justify it. These capabilities are brought together through a coherent verification, validation and certification (VVC) pathway. The infrastructure is layered — physical, digital and virtual — with cyber security, data governance, market modelling and interoperability running across the layers. It is modular, so that capabilities can be developed and expanded as needs, partnerships and investments evolve. Its distinguishing feature is not any single laboratory or platform, but the pathway between them: shared methods and interfaces, agreed criteria for moving between stages, and an evidence chain that can survive the transition from simulation through laboratory validation to accredited testing and certification.

The concept was developed and tested through two EnergyVaasa co-design workshops, on 7 November 2025 with approximately 50 participants from 18 organisations, and on 8 December 2025 with approximately 30 participants from 15 organisations. Participants identified the need for scalable multi-megawatt testing capability, with requirements ranging from at least 5 MW for system-level applications to approximately 8–10 MW for demanding industrial testing, alongside HIL/PHIL integration and high short-circuit testing capability. They also identified the need for services spanning research, simulation and validation through to accredited testing and certification, with clearly distinguished roles for infrastructure operation, development and independent testing or certification. The second workshop defined value propositions and requirements for six stakeholder segments. The convergence of needs across actors with different technical and commercial perspectives indicates that the gap is structural rather than specific to any single organisation.

Development is envisaged through a definition phase followed by three broad development phases — foundation and core, growth and ecosystem, and scale and European alignment. European collaboration runs throughout the process, while Novel Power Infra's role in European networks strengthens as its distinctive capabilities mature.

What is not decided

The architecture is a blueprint, not a specification. Equipment, power ratings, the balance between existing and newly established facilities, ownership structure, governance model, operating model and funding mix remain open. The broad development direction and three-phase roadmap structure were discussed with stakeholders in the 2025 workshops, but the roadmap remains an early-stage, living hypothesis rather than an investment plan.

Call to action

The definition is being produced now through VECTORIA, a publicly funded definition project led by the University of Vaasa and scheduled to deliver by Q2/2027. VECTORIA will develop two or three development options — each with its own capability sequence, investment profile, ownership and operating arrangement, and funding path. The alternatives have not been predetermined; they will be shaped through stakeholder interviews, surveys, workshops and international benchmarking. Organisations joining now are therefore not choosing between prepared alternatives. They are helping determine what those alternatives will be.

We invite manufacturers and system integrators, DSOs and TSOs, testing and certification bodies, research organisations, authorities and funders to take part while the definition remains open. Each group contributes information, capabilities or decision criteria that cannot be defined credibly by the project team alone. Where a stakeholder perspective is missing, the corresponding part of the definition remains generic — and a generic definition provides a weak basis for investment decisions.

What we ask

We ask organisations to nominate one or two experts to the requirements work and to bring forward the priority use cases, operational questions or validation needs that matter most to them. Confidentiality arrangements are agreed before sensitive information is shared. The commitment at this stage is primarily expert time, not investment: no funding decision is required, and none is made during the definition phase.

Detailed requests by stakeholder group are set out in *Call to action* -chapter, together with what each contribution unlocks.

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Background and strategic context

The global energy transition requires technologies that enable decarbonisation and reduce dependence on fossil fuels. In Europe, research infrastructures (RIs) are increasingly treated as strategic assets for the green and digital transitions, expected to supply FAIR-compliant data, interoperable services and environments for cross-border collaboration.

Finland is a credible location for an integrated energy-systems infrastructure of this kind: it combines a strong technology base with close cooperation between industry and research organisations [1]. Within Finland, the Vaasa region brings together a significant concentration of energy-technology companies, universities and research actors. Research on collaborative innovation communities suggests that proximity and interaction between complementary actors can support innovation [2], [3].

European research infrastructures are becoming integrated

Across Europe, RIs are increasingly being developed not as stand-alone installations but as parts of a broader research and innovation ecosystem. ESFRI calls for a healthy, sustainable and integrated European RI ecosystem in which infrastructures support scientific excellence, innovation and wider societal objectives. Research infrastructures are increasingly expected to bridge disciplinary boundaries, provide interoperable and FAIR research data, enable transnational access and collaboration, and develop services around the needs of their users [4].

For energy-system research and innovation, this broader policy direction translates into a need for environments capable of studying increasingly interconnected cyber-physical systems, including interactions between power technologies, digital control, data and system operation. Such environments need to combine physical and digital capabilities while allowing data, methods and services to be connected across organisational and disciplinary boundaries. This is consistent with ESFRI's direction towards more integrated, interoperable and user-oriented RIs that support both scientific research and innovation [4].

Novel Power Infra is conceived as a national capability that can connect with this evolving European landscape while developing distinctive testing and validation capabilities of its own.

Finland’s research infrastructure landscape

Finland's national RI roadmap for 2025–2028 illustrates a diverse infrastructure landscape that includes both major individual facilities and distributed, multi-organisational infrastructures [5]. Several roadmap infrastructures connect capabilities across universities, research institutes and other organisations, while many also operate as Finnish nodes in wider European RI networks.

Open access, services for research and industry, international connectivity and shared use of specialised capabilities are recurring features across the roadmap [5].

This landscape is relevant to Novel Power Infra in two ways. First, it demonstrates that a nationally significant RI does not need to follow a single organisational or physical model: it may combine distributed capabilities, dedicated facilities and international connections. Second, national relevance depends on the capabilities and services provided, not simply on the ownership or location of individual assets. Novel Power Infra is therefore conceived as a potential next-generation national capability whose final configuration — including the balance between existing distributed resources and new dedicated infrastructure — remains to be defined.

Why system-level validation is now necessary

Electrification, increasingly inverter-based power systems, EV charging clusters, energy storage and digitalised distribution operations introduce non-linear and highly dynamic behaviour that depends on interactions across power, ICT and market layers.

Component-centric testbeds remain essential for product-level verification, including type testing and certification, but they are not sufficient on their own to capture these system-level interactions, particularly where cyber security, data exchange, control systems and flexibility mechanisms interact with the physical power system. At the same time, European regulation and standards are introducing increasingly explicit requirements for cyber resilience, interoperability and data handling, extending validation needs beyond the electrical performance of individual products.

The consequence is a clear rationale for infrastructures that complement product-level testing with integrated system-level verification and validation across the development and deployment pathway. Such environments allow secure-by-design and interoperable-by-design principles to be considered during development and subsequently demonstrated at system level before deployment in real energy systems.

Regulation does more than constrain validation; it is also an important source of demand for it. As standards and regulatory requirements become applicable to new technologies and system functions, they create recurring needs for conformity assessment, testing and documented evidence alongside development-driven validation. Validation demand therefore reflects both product-development cycles and the evolution of standards and regulation.

This relationship works in both directions. Where regulatory requirements and available testing approaches align, an integrated validation pathway can reduce duplication and shorten the route to conformity assessment and certification. Where requirements evolve faster than established testing practice — including in areas such as interoperability, cyber resilience and inverter-based system behaviour — research and validation infrastructures can generate evidence that supports the development of test methods, standards and regulatory practice. Producing such evidence can therefore be one of the infrastructure's functions, alongside testing individual technologies.

Building on the European testing framework

European initiatives have already established a strong methodological foundation for energy-system testing. ERIGrid and ERIGrid 2.0 developed methods for system-level validation of cyber-physical energy systems, including holistic test description, co-simulation, and controller-, power- and power-system-in-the-loop methodologies (CHIL, PHIL and PSIL) [6], [7]. Their work treats modern power systems as multi-domain cyber-physical systems, where device-level testing alone is not sufficient to capture emergent behaviour, cross-domain coupling and failure propagation. It has also demonstrated how geographically distributed laboratories can be connected for coordinated and virtual experimentation.

Europe hosts world-class specialised laboratories and collaborative initiatives, among them DERlab and ERIGrid. Novel Power Infra builds on this foundation and is intended to remain compatible with ERIGrid 2.0 methods and procedures. Its primary contribution is continuity across a coherent national VVC pathway.

Regional commitment and the evidence base

The concept described in this paper was developed through two EnergyVaasa co-design workshops. The first, on 7 November 2025, brought together approximately 50 participants from 18 organisations, working in four thematic groups: technical architecture and testing methods; service concepts and user groups; certification and regulation; and ecosystem and collaboration models. The second, on 8 December 2025, brought together approximately 30 participants from 15 organisations and developed the concept further through segment-specific value-proposition work.

The first workshop produced a shared preliminary concept. Its results were subsequently synthesised into four main findings. First, participants identified the need for scalable high-power testing together with HIL/PHIL capability. Requirements ranged from at least 5 MW for system-level applications to approximately 8–10 MW for demanding industrial testing, combined with wide AC/DC operating ranges, high short-circuit capability, secure communication interfaces and a layered virtual–digital–physical architecture. Second, services should cover the pathway from research and simulation through verification and validation to accredited testing and certification, with modular service packages supporting both company-specific needs and system-level multi-actor testing. Third, participants highlighted growing regulatory and standards-related demands, including the Cyber Resilience Act, AI-related requirements and evolving DC standards and regulation. Accreditation readiness under ISO/IEC 17025, CE/IEC/UL-related conformity assessment and witness-testing capability, and robust documentation practices were treated as important requirements. Fourth, participants called for a shared and independent test environment capable of accredited testing, with type-testing capability, simulation interoperability and clearly distinguished roles for infrastructure operation, development and independent testing or certification.

The second workshop examined these needs from the perspective of six stakeholder segments: manufacturing industry, system integrators, control-device manufacturers, research, distribution system operators and test execution. The convergence of requirements across actors with different technical, institutional and, in some cases, competing commercial interests suggests that the identified gaps are structural rather than specific to any single organisation. At the same time, the workshops did not determine a final technical configuration, ownership structure, governance model or funding solution. Those choices remain deliberately open.

The concept was subsequently exposed to international expert feedback. Version 0.2 of this paper was presented to the General Assembly of DERlab, the European association of distributed energy laboratories, on 21 April 2026, and members were invited to comment. Feedback received following the General Assembly reinforced the importance of treating regulation and standards not only as constraints on validation but also as drivers of recurring testing and evidence needs. This perspective is reflected in *Why system-level validation is now necessary* -section.

Problem statement and gap analysis

Two framing points apply throughout. First, the gaps identified here are primarily gaps in coordination and continuity. Finland has strong expertise and specialised validation capabilities, many of which have developed through individual projects, organisations and facilities. What is still missing is a coherent pathway between them and, in some areas, additional capability that does not yet exist at the required scale. Second, several of these gaps have become more consequential as power-system behaviour, product development and regulatory requirements have evolved.

System-level assurance, used repeatedly below, means evidence that an interconnected system behaves as intended under realistic operating conditions, where the system includes the physical network, control software, market signals and the cyber layer at the same time. This is distinct from device-level verification, which establishes that a component meets its specification in isolation.

Limited domestic testing capacity

Finland has limited access to domestically coordinated MW-scale electrical testing, including demanding short-circuit and arc testing and accredited type-testing capabilities.

This has become more consequential as product cycles in power electronics, EV charging infrastructure, battery systems and switchgear have shortened while testing, conformity-assessment and certification requirements have expanded. The EnergyVaasa workshops identified both the increasing urgency of market entry and the need for more flexible domestic testing capability.

The result is continued dependence on specialised facilities outside Finland for some demanding test campaigns, which can introduce logistics costs, lead times and limited opportunities for iterative testing. Existing national capabilities also do not yet form a scalable pathway covering emerging needs such as real-time grid emulation, digital-twin-based validation, HIL/PHIL integration and coordinated cyber-physical assessment. For smaller companies in particular, access to suitable high-power infrastructure can become a significant development constraint.

No unified environment for multi-vendor interoperability and IT/OT integration

Finland does not currently have a dedicated, neutral and repeatable environment in which complex interactions between devices, software and control systems from different vendors can be validated together at system level.

Interoperability requirements are becoming increasingly important as communication standards such as IEC 61850, open protocols for EV charging, API-based control and multi-vendor device stacks become embedded in modern energy systems. Cyber-security requirements add another dimension by extending evidence needs from physical and functional behaviour to software, communication interfaces, data handling and lifecycle practices.

What is missing is threefold: an end-to-end environment linking controller- and power-hardware-in-the-loop testing (CHIL and PHIL), digital twins and physical grid components; a neutral setting in which interface behaviour, timing, cyber resilience and protocol compliance can be validated across vendors; and a pathway through which relevant test evidence can support accredited testing, conformity assessment and certification where recognised schemes exist. The absence of such a pathway increases integration risk and makes late-stage troubleshooting more likely.

No integrated system-level validation for flexibility, markets and distribution operations

Finland lacks a dedicated integrated environment in which interactions between flexibility resources, market signals and distribution-grid operation can be examined before deployment.

This gap has become more important as price-responsive loads, EVs, storage and other flexible resources increasingly influence distribution-network behaviour. At the same time, DSOs need to assess how tariff structures, flexible connections, demand-response mechanisms and new control strategies may affect network loading, operational risk and future dimensioning. The second EnergyVaasa workshop identified market–flexibility–grid scenarios, ADMS development and testing, tariff effects, flexible connections and future network-dimensioning questions as important system-level needs.

In this context, DSOs would not typically operate the research and testing infrastructure themselves. Their role is primarily to contribute operational data, network models, requirements, constraints, representative scenarios and research questions. These inputs can then be examined together with researchers and specialised testing experts using simulation, ADMS-related studies, protection-interaction analysis and other system-level validation methods.

What is currently missing is an integrated market–flexibility–grid environment combining market signals, demand response and power-flow effects with realistic grid and control-system behaviour; a common setting in which ADMS logic, protection interactions and cyber-to-grid effects can be studied before live deployment; and sufficient capability for examining IT/OT failures, communication delays and data-quality problems together with physical network behaviour. This increases uncertainty in grid planning and makes it more difficult to evaluate new operating approaches before they are introduced into real networks.

Transmission-level requirements and distribution-level phenomena

There is no validated pathway that credibly links device- and distribution-level behaviour to transmission-level studies.

From a transmission system operator (TSO) perspective, an increasingly important challenge is the aggregate and emergent behaviour of large numbers of inverter-based resources connected within distribution networks. Individual device compliance remains necessary, but it does not alone establish how large populations of such resources will behave at system level. Many system-level requirements, grid codes and modelling practices are defined from the transmission-system perspective, while important dynamic phenomena may originate at distribution and even low-voltage levels.

This creates a structural challenge in connecting requirements defined at one system level with behaviour emerging at another. In some studies, simplified aggregate models are sufficient; in others, detailed control-level or electromagnetic transient representations are required. The gap is not simply an absence of models, but the lack of validated, context-aware pathways for determining which representation is appropriate for a given study and demonstrating that the chosen representation reproduces the relevant behaviour.

Synthesis: the absence of a coordinated national VVC pathway

Taken together, these observations point to one underlying issue: Finland does not currently have a coordinated verification, validation and certification (VVC) pathway connecting simulation, CHIL/PHIL testing, MW-scale physical testing, cyber-security assessment and accredited testing and certification.

Relevant capabilities are distributed across specialised organisations and facilities, but they do not yet operate through a common end-to-end evidence pathway. Cyber-security assessment and physical performance validation are also often addressed through separate processes, although cyber and physical behaviour increasingly interact in modern power systems. Evidence generated at one stage therefore does not necessarily transfer directly to the next, limiting the ability to build a continuous and traceable evidence base from early development through system-level validation and, where applicable, conformity assessment and certification.

The consequences include duplicated work, discontinuities in evidence between stages and missed opportunities to reuse test results for model improvement, subsequent validation, conformity assessment and standardisation. A more coherent pathway would also make it easier to generate systematic evidence that can contribute to the development of testing practices, standards and conformity-assessment approaches.

The VVC pathway

The VVC pathway was introduced publicly in the session “Building the Control System of the Future” at the IEEE PES ISGT Europe conference in Valletta, Malta, in October 2025 [8].

The pathway connects three related but distinct functions. *Verification* establishes whether a product, model or system implementation satisfies specified design and technical requirements. *Validation* establishes whether the resulting solution is suitable for its intended use and behaves as required in the relevant system context. *Certification*, where applicable, provides formal third-party confirmation of conformity with specified requirements on the basis of evidence generated through recognised conformity-assessment procedures.

What integration means here is precise. It does not require these activities to take place in the same building or even within the same organisation. It means compatible methods, interfaces and evidence requirements between stages, together with a continuous evidence chain that allows results generated in one stage to inform and support the next. Evidence established through modelling and simulation should be usable in subsequent HIL/PHIL and physical validation, while evidence generated through validation should, where relevant and accepted, support accredited testing, conformity assessment and certification without unnecessary reconstruction at each boundary.

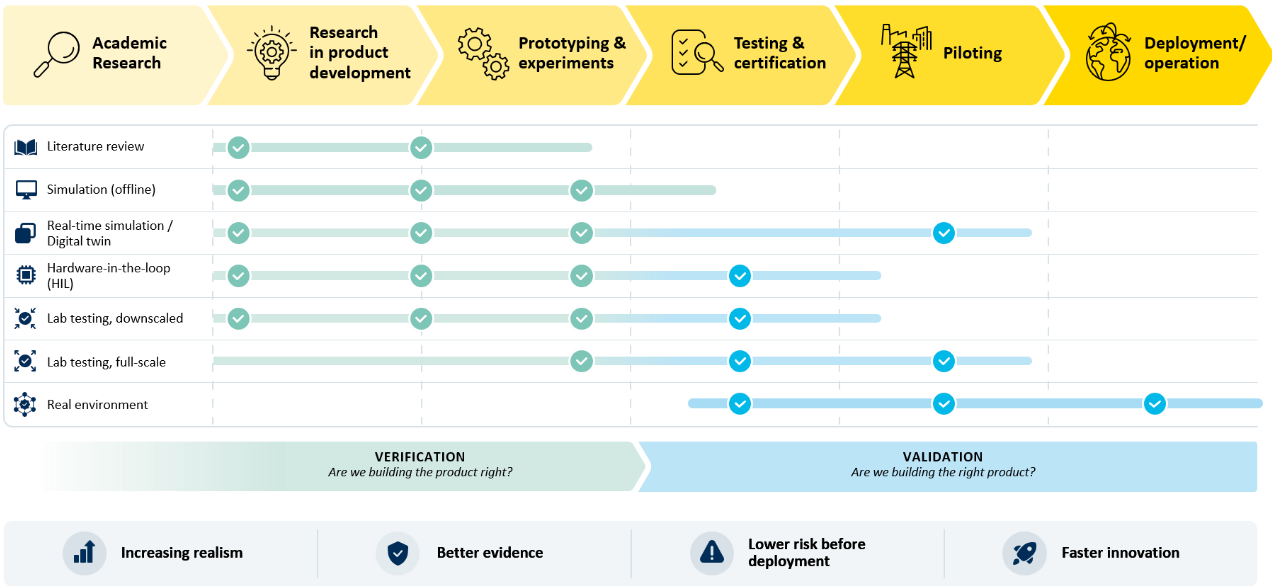

Figure 1. The gap: an integrated verification, validation and certification pathway [8].

Novel Power Infra is proposed as a direct response: an integrated, neutral and accreditation-ready validation framework designed to create continuity across the VVC pathway while leaving the eventual physical and organisational configuration open.

Infrastructure lens: what Novel Power Infra consists of

Novel Power Infra is conceived as more than a laboratory: it is a layered socio-technical infrastructure. What makes joint validation of devices, systems, markets and cyber security possible is not equipment alone, but the combination of physical capabilities, models, data, interfaces, governance and working practices. The value lies in how these elements are connected across the validation pathway.

This chapter describes the architecture at concept level. Equipment choices, layouts, power ratings and investment decisions are not fixed here; they will be assessed and specified through the definition phase described in *Call to action* -chapter.

Design principles

Four principles guide the architecture.

Evidence continuity. The infrastructure is intended to support progression from early-stage modelling and simulation through hardware-in-the-loop experiments and system-level validation to physical testing, field trials and, where applicable, conformity assessment and certification. Evidence generated at one stage should be structured so that it can inform and support the next.

Multi-actor participation and neutrality. Manufacturers, system operators, integrators, testing bodies and researchers contribute to and use the infrastructure according to their respective roles. DSOs and TSOs primarily contribute system requirements, operational data, models, scenarios and research questions, while specialised research and testing actors carry out the corresponding studies and validation activities. Neutrality, confidentiality and accreditation readiness must be reflected in access arrangements, data separation, test execution and reporting.

Cyber security and interoperability by design. Both are embedded as core architectural considerations rather than treated only as separate late-stage test activities, because cyber, communication, interoperability and physical-system behaviour increasingly interact.

European compatibility. Architectures, interfaces and test-description frameworks should remain compatible with relevant European RI and testing practices, enabling federated experiments, shared methods and cross-laboratory collaboration where useful.

The three layers

Physical layer. Electrical test environments for validating real hardware under controlled conditions: high-voltage and high-power testing, converter and drive validation, storage and EV-charging experiments, and system-level tests involving switchgear, protection and automation equipment. It is intended to accommodate a range of power levels, from low-power R&D set-ups to demanding MW-scale testing. Sizing, location and equipment portfolio remain open questions for the definition phase.

Digital layer. Real-time simulation of power-system and device-level behaviour, with interfaces for controller- and power-hardware-in-the-loop experiments (CHIL and PHIL). Coupling real devices and control systems to high-fidelity real-time models makes it possible to examine closed-loop interactions, implementation effects, communication and timing behaviour, and other phenomena that are difficult to assess through simulation alone. This layer supports studies of protection schemes, grid-forming behaviour, EV-cluster dynamics, storage operation and distribution-automation concepts.

Virtual layer. Digital-twin and scenario capabilities for assets, networks and systems, linked to the digital and physical layers so that studies can move from model to laboratory and back. Scenario capability here covers three broad technical categories: *planning scenarios*, such as long-horizon what-if assessments; *operational scenarios*, including contingency, stability and dynamic-response studies; and *stress and robustness scenarios*, which examine system behaviour under adverse or boundary conditions. ERIGrid and ERIGrid 2.0 provide structured test-description approaches that can be used to specify objectives, system configurations, test cases and evaluation criteria across such studies [6], [7]. These technical scenarios are distinct from strategic scenarios used, for example, in investment planning.

Together, the three layers support a stepwise and iterative validation route across virtual exploration, real-time simulation and physical testing. Results can move both forward and back between the layers, using compatible test descriptions, models and evidence so that learning accumulates across the pathway.

Two cross-cutting layers

Data and cyber security. This layer determines whether the evidence produced can be trusted and reused. It covers secure data handling and logging and may include support for software bill-of-materials, vulnerability-assessment practices and cyber-resilience testing in connection with physical and digital experiments. The architecture should also allow controlled remote access and, where appropriate, remote-witness arrangements without compromising confidentiality or security. Over time, and subject to agreed governance and confidentiality arrangements, trusted aggregation of selected test data across projects could support anomaly detection, benchmarking, model improvement and root-cause analysis.

Market and interoperability. This layer connects technical performance to operational and commercial contexts. On the market side, it supports examination of tariff structures, flexibility products, demand-response schemes and connection concepts in combination with physical and simulated networks. Market modelling may involve different purposes, including market design, market simulation, participation models and market–grid interaction models; these should not be treated as interchangeable because they impose different data, modelling and validation requirements. On the interoperability side, standards-based interfaces, protocols and APIs can be exercised in multi-vendor settings, including cross-domain interactions between power, ICT and market systems.

The market models, interface specifications and interoperability profiles to be prioritised will be defined with relevant stakeholders during the definition phase. DSOs and other system operators contribute operational questions, constraints, data and scenarios, while the detailed modelling and validation methods are developed and applied with the relevant research and testing expertise.

Modularity and staged development

The architecture is modular so that capabilities can be developed, connected and expanded as needs, partnerships and investment opportunities evolve. This reduces the need to commit to the entire long-term configuration at once and allows individual investment decisions to be tied to demonstrated requirements and value.

Modularity does not mean that every capability must be built in small increments. Where the demand, technical requirements and investment case justify it, a major dedicated facility can form one of the infrastructure's core modules. The architecture therefore accommodates both distributed capabilities and substantial new physical investments.

The same architecture supports safe experimentation with demanding conditions — for example large changes in market-driven operating conditions, protection misoperation, communication failures or cyber incidents — without exposing an operational power system to the corresponding risk.

The architecture remains an initial blueprint. It defines structure and intent while deliberately leaving detailed technical specifications, locations, investment choices and organisational models open. Recent work on grid-code certification using simulation and hardware-in-the-loop for EN 50549 illustrates how simulation and HIL methods can contribute to conformity-assessment and certification processes for inverter-based resources [9].

Ecosystem lens: who does what, and on what terms

Novel Power Infra is conceived as a multi-actor innovation and validation ecosystem in which complementary capabilities, expertise and responsibilities are brought together around a shared VVC pathway. The ecosystem challenge is both organisational and infrastructural: coordination determines how the pieces work together, while investment determines which capabilities ultimately exist and where [10].

Complementary roles

Each stakeholder group contributes a different part of the capability.

- **Manufacturers and technology providers** bring products, control solutions and cyber-physical systems for validation, and articulate requirements — power levels, interfaces, procedures and evidence needs — that help determine what the infrastructure must be able to do.
- **DSOs and TSOs** define system-level requirements, constraints and priority questions, and contribute operational data, grid models and representative scenarios where appropriate. These are examined together with specialised research and testing actors, and the resulting evidence supports planning, procurement and deployment decisions.
- **Testing and certification bodies** contribute conformity-assessment expertise, standards, methods and processes that help translate experimental capability into accredited testing and, where applicable, certification.
- **Universities and research institutes** act as conveners and method developers, maintaining and developing simulation environments, digital twins and co-simulation frameworks, and anchoring long-term research, education and standardisation.
- **Public authorities and funders** provide strategic and regulatory perspectives and the financial framework, connecting the infrastructure to national research-infrastructure development, energy policy and European initiatives.

Neutrality is what makes these roles compatible. It requires credible arrangements for access, confidentiality, independence and evidence quality regardless of who owns or operates individual capabilities.

Governance and ownership

In the initial phase, the University of Vaasa, together with industrial, system-operator, research and testing partners, coordinates the definition process: clarifying requirements and roles and developing alternative operating, governance, ownership and investment models.

Governance will need to cover strategic steering, investment prioritisation, access, quality responsibilities, data governance and the relationship between infrastructure operation and independent testing or certification. Ownership may take different forms; the operating model must support neutrality, efficient use, investment and long-term viability.

Experience from Finnish multi-actor ecosystems shows why governance deserves explicit attention. Multi-actor collaboration can generate new partnerships, services and knowledge, while recurring challenges include funding and cross-organisational data management [11]. Although not directly equivalent to research and testing infrastructures, these findings are relevant to shared resources and multi-actor value creation.

Governance and ownership remain open. Both are key outputs of the definition phase, in which alternatives will be assessed and a reasoned recommendation developed.

Development process

The Novel Power Infra development process, illustrated in Figure 2, consists of a definition phase followed by three broad development phases aligned with the roadmap presented in *Roadmap 2026–2035* -section.

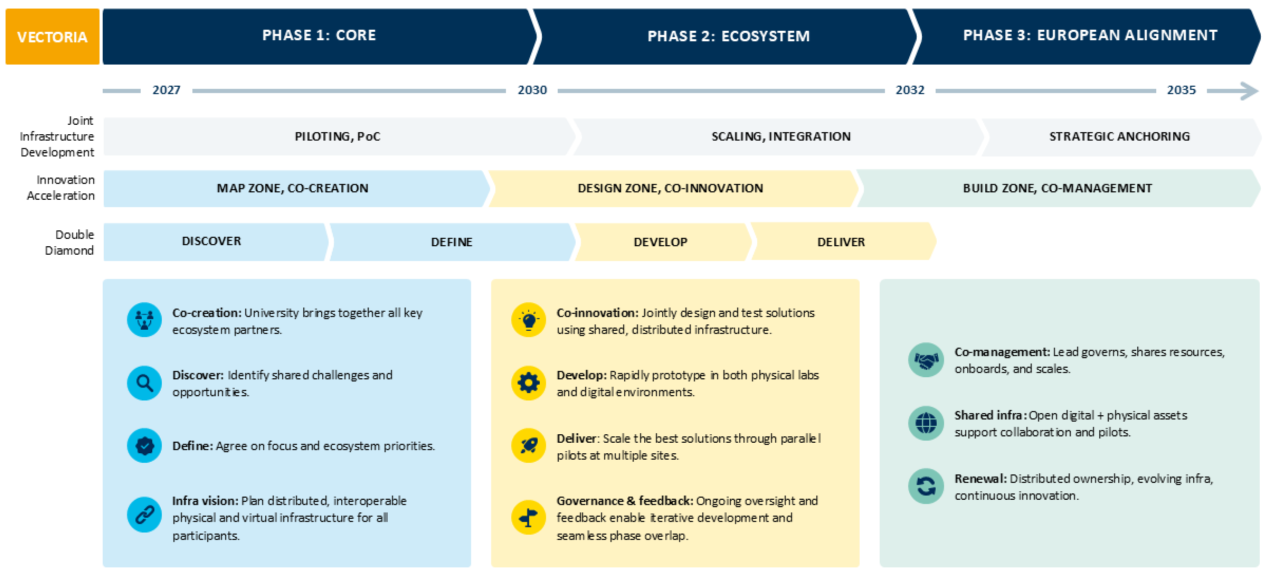

Figure 2. Novel Power Infra development process: a definition phase followed by three development phases aligned with the indicative 2026–2035 roadmap.

Definition and decision preparation — 2026–Q2/2027. VECTORIA consolidates requirements and use cases and develops alternative technical, operating, ownership, investment and funding models.

Phase 1 — Foundation and core — 2027–2030. Subject to decisions and funding, the first integrated capabilities are developed and implemented.

Phase 2 — Growth and ecosystem — 2030–2032. Capabilities, services and partnerships expand, and physical, digital and virtual elements become increasingly integrated.

Phase 3 — Scale and European alignment — 2032–2035. Novel Power Infra develops into a mature national capability with a sustainable operating model and strong European connections.

Learning, stakeholder engagement and European collaboration continue throughout the process, and experience from implementation feeds back into subsequent development decisions.

Regional foundation and European positioning

The concept is anchored in the EnergyVaasa cluster, where energy-technology companies, system integrators, service providers, universities and research organisations have long collaborated in close physical proximity. As discussed in *Background and strategic context* -section, interaction between complementary actors can support collaborative innovation [2], [3]. The cluster provides a practical starting point for co-definition, early use cases and capability development, while Novel Power Infra is intended as a national capability open to partners across Finland.

Internationally, Novel Power Infra builds on the methods and collaborative practices developed through DERlab, ERIGrid and related European initiatives. The objective is compatibility with European networks while developing distinctive Finnish testing and validation capabilities of its own. As system-level validation becomes increasingly multi-domain, both dedicated facilities and federated arrangements can contribute to the pathway, depending on the capability concerned.

Figure 3 illustrates the federated concept: physical, digital and virtual environments in different organisations and regions can participate in a distributed validation chain through compatible methods and interfaces. It does not prescribe a specific physical or ownership configuration for Novel Power Infra.

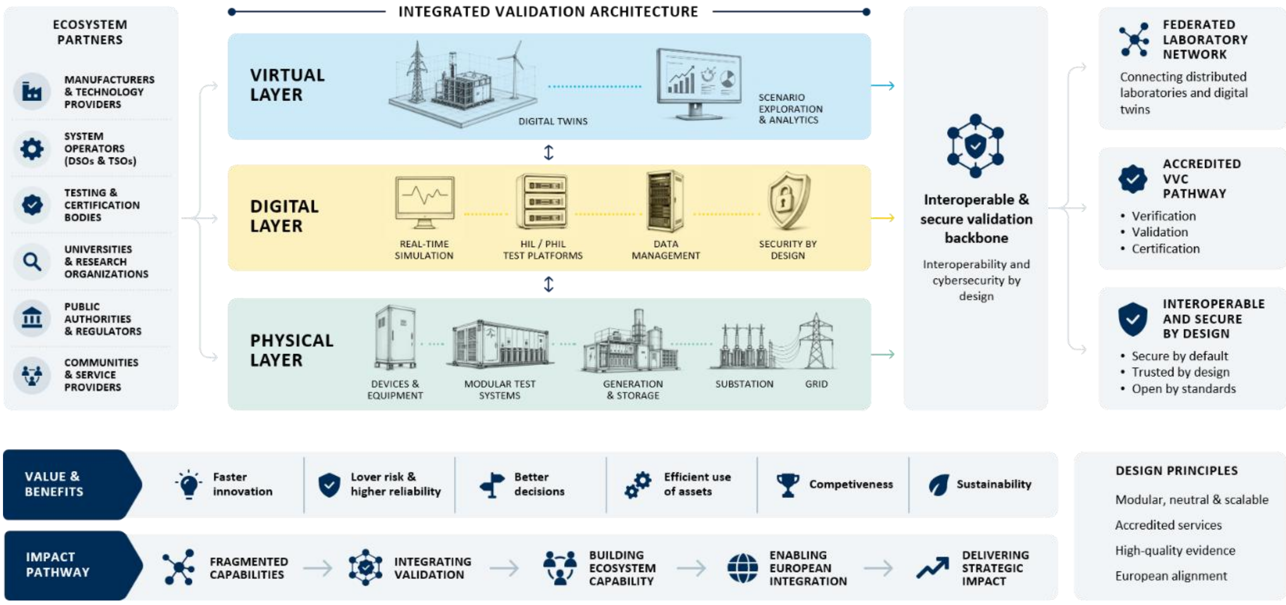

Figure 3. Federated multilayer architecture for integrated energy-system research [8].

Alignment with European architectures, methods and test-description frameworks enables cross-laboratory experiments, exchange of models and access to specialised capabilities. The relationship works in both directions: Finnish actors can access European capabilities, while Novel Power Infra can contribute distinctive capabilities to European partners.

Value lens: who benefits, and how

Value is not only a list of benefits. Participation also requires expert time, coordination and, in some cases, contribution of data, models or use cases. The relevant question for each stakeholder group is whether the value received justifies that contribution. The contributions requested during the definition phase are set out in *Call to action* -section; this section describes the corresponding value.

Value by stakeholder group

The six groups below build on the stakeholder segments used in the 8 December 2025 workshop. The value propositions combine the workshop results with their subsequent synthesis in the Novel Power Infra concept.

Manufacturers *(power electronics, EV charging, energy storage, drives, motors, switchgear)* gain a route through an integrated VVC pathway linking pre-compliance work, real-time simulation, HIL and PHIL validation, physical type testing, cyber-security and interoperability assessment, and accredited reporting where applicable. The expected benefits are shorter lead times, earlier identification of design and integration risks, and more flexible use of domestic and European testing capabilities.

System integrators *(switchgear, substations)* gain access to coordinated device- and system-level electrical testing with real-time simulation support for complex assemblies. Earlier system-level validation can reduce delivery risk and help avoid late-stage surprises in customer projects.

Protection, control and IT/OT vendors gain a realistic multi-vendor environment for validating standards-based interfaces, APIs, novel control concepts, grid-code behaviour and cyber resilience in closed-loop conditions — allowing behaviour under disturbances and mixed-vendor operation to be examined before live deployment.

DSOs gain an environment for examining interactions between markets, flexibility and grid operation. DSOs contribute operational data, requirements, models and research questions rather than operating the infrastructure; these can be examined with specialised researchers and testing experts through simulation, ADMS-related studies, protection-interaction analysis and cyber-to-grid scenarios. The value lies in better-informed planning and investment decisions and stronger system-level risk management.

Testing and certification bodies gain opportunities to develop more automated, system-level and cyber-aware services. Integrated evidence generation and possible remote-witness arrangements can support efficient testing and alignment with evolving accreditation and conformity-assessment requirements.

Universities, research organisations and the talent base gain access to a shared infrastructure combining advanced testing, digital twins and real-time simulation with research and education — supporting joint research, standardisation contributions, thesis work and workforce development.

Research on cross-sector and university–industry collaboration indicates that coordinated action can create benefits beyond those achieved by organisations acting separately [12], [13, [14].

Four use-case categories

These define strategic scope. They are not a service catalogue; which services are built first is decided in the definition phase.

Product-level validation. A pathway linking model-based design, real-time simulation, HIL/PHIL validation and physical testing, including accredited testing where applicable. The aim is to identify problems earlier, reduce late-stage redesign and support credible evidence on performance, safety, interoperability and cyber resilience.

System-level validation. Interoperability across standards and vendors, behaviour of automation and protection schemes under realistic grid conditions, and interactions between IT/OT systems and the physical network. Representative cases can include hybrid power plants, advanced control applications and aggregated inverter-based resources relevant to transmission-system analysis, such as EV fleets, distributed storage and grid-forming converters.

Market and business design. Co-design and assessment of tariffs, flexibility products, service concepts and value-sharing mechanisms in a realistic system context. Relevant cases include demand response, EV clusters, storage and new connection concepts, together with their effects on grid loading, protection, voltage quality, investment needs and resilience.

Research, standardisation and long-term capability. Research on cyber-physical energy systems, development of digital-twin and co-simulation methods, contributions to international standards and conformity-assessment practice, and professional development in real-time simulation, HIL/PHIL, cyber security and interoperability.

What makes this different

The distinguishing feature is not any single laboratory, simulation platform or testbed. Strong specialised capabilities already exist in Finland and elsewhere. Novel Power Infra aims to create continuity between existing and future capabilities through compatible methods, interfaces and evidence requirements, so that results can move more effectively from modelling and simulation through laboratory and system-level validation to accredited testing and certification where applicable.

Integration is therefore the central value proposition, but it does not exclude construction. The pathway may combine existing facilities, expanded capabilities and new dedicated infrastructure where demand and investment justify it. What makes Novel Power Infra distinctive is the ability to connect these elements into a coherent national VVC pathway rather than prescribing one physical implementation.

Roadmap 2026–2035

Novel Power Infra is envisaged to develop in three phases. The phases indicate sequence and emphasis; they do not fix the final technical configuration, ownership model or investment path.

2026–Q2/2027 — Definition and decision preparation. VECTORIA defines priority use cases and requirements, develops alternative technical and operating concepts, and assesses ownership, investment and funding options. Existing capabilities can already be used in selected pilots and joint activities while requirements for future capabilities are specified.

2027–2030 — Foundation and core. A first integrated capability is established, combining high-power testing with real-time simulation and HIL/PHIL, with cyber security and secure data handling considered from the outset. Early services can include pre-compliance work, interoperability pilots and joint research campaigns, while accreditation pathways are defined alongside the relevant processes. In parallel, the concept is positioned within the national research-infrastructure landscape and requirements for further investment are specified.

2030–2032 — Growth and ecosystem. Capabilities expand as demand and investment justify them, potentially including additional voltage and power levels, storage, e-mobility, industrial loads and other dedicated modules. Physical, digital and virtual capabilities become more tightly integrated. Services develop into defined offerings, potentially including regulatory and market sandboxes, while accredited testing capabilities are extended where recognised schemes and demand support them.

2032–2035 — Scale and European alignment. Novel Power Infra operates as a mature national capability, potentially combining major dedicated facilities with distributed and federated resources. Secure remote access and digital-twin arrangements support cross-laboratory and international test campaigns. The infrastructure contributes to standardisation and European collaboration, supported by a sustainable funding model combining appropriate forms of core funding, competitive projects, investment and service income.

This phasing remains an early hypothesis. Its broad direction has been discussed in the two stakeholder workshops, but it is not sufficiently defined to support an investment decision. Workshop participants nevertheless identified a shared, accredited test environment as a four-to-five-year ambition, providing an important reference point for the roadmap.

The detailed alternatives are being developed through VECTORIA. The project will define a small number of development options — likely two or three — with different capability sequences, investment profiles, ownership and operating arrangements, and funding paths. These options are not predetermined: interviews, surveys, workshops and benchmarking will shape both their content and their assessment. The eventual implementation path is therefore not decided in this paper or by the project team alone.

Strategic impact

Whichever option is chosen, the concept is expected to deliver impact in four areas.

First, connecting digital twins, real-time simulation, HIL/PHIL and physical testing can reduce discontinuities between development stages, support earlier identification of problems and reduce dependence on foreign laboratories for capabilities that can be provided competitively in Finland.

Second, integrated multi-vendor testing can strengthen interoperability, IT/OT reliability and cyber resilience, and generate more coherent and traceable evidence for customers, conformity assessment and regulatory needs.

Third, DSOs gain a structured route for contributing operational data, requirements, models and research questions related to flexibility, tariffs, EV and storage clusters, ADMS logic and market-driven load dynamics. These questions can be examined with specialised research and testing expertise before deployment, supporting better-informed planning, investment and operational decisions.

Fourth, as a nationally significant research and validation infrastructure, Novel Power Infra can support high-impact research and innovation projects, standardisation, talent development and international partnerships.

What success looks like

Within roughly a decade, success would mean that Novel Power Infra provides internationally competitive high-power and system-level validation capability integrated with PHIL, real-time simulation and digital twins. Depending on the development path chosen, this could combine major dedicated facilities with specialised capabilities distributed across partner organisations.

Success would also mean that relevant services can provide accredited and internationally credible test evidence for power electronics, EV charging, storage, automation and other energy-system technologies; that system operators can bring demanding system-level questions into a controlled research and validation environment; and that the infrastructure contributes evidence to international standards, conformity-assessment practice and European research and innovation.

Ultimately, success means that Finland can offer not only advanced energy technologies, but also credible capability to demonstrate how those technologies operate safely, interoperably and securely as part of future energy systems.

Call to action

Novel Power Infra is being defined now, and the definition is open.

The concept described in this paper is deliberately unfinished. Its architecture, service portfolio, governance, ownership and funding model are not yet fixed, and this white paper does not fix them. They are being specified during 2026 and the first half of 2027 in VECTORIA, a publicly funded definition project led by the University of Vaasa. We invite manufacturers, system integrators, DSOs and TSOs, testing and certification bodies, research organisations, authorities and funders to take part while the alternatives are still being shaped.

What we are defining together

VECTORIA will produce a decision-ready definition of Novel Power Infra by Q2/2027, based on alternative development paths. The work covers the layered virtual–digital–physical architecture and its interfaces; the verification, validation and certification pathway and related service concepts; user groups and priority use cases; alternative ownership, governance and operating models; investment estimates and funding options; and a phased implementation roadmap for each development option.

The definition is built through surveys, interviews, workshops and benchmarking. Participants therefore help determine what the alternatives contain and how they are assessed. The resulting options will provide an evidence base for later investment, funding and implementation decisions.

Who we need, what we ask, and what it unlocks

The definition depends on input from groups that bring different requirements, knowledge and evidence.

Manufacturers and system integrators *(power electronics, EV charging, energy storage, drives, motors, switchgear, substations)*

Nominate the products and use cases whose validation is most difficult today. Contribute one or two experts to help define test requirements, interfaces and evidence need. Where relevant, indicate what conditions would make future use or investment attractive.

Without this input, capability priorities cannot be grounded in real industrial demand.

DSOs and TSOs

Identify priority system-level questions that are difficult to examine before deployment — for example flexibility and tariff interactions, ADMS logic, protection coordination, aggregate inverter-based behaviour or cyber-to-grid interactions. Contribute requirements, representative scenarios and, where feasible, models or data under agreed confidentiality arrangements.

Without this input, system-level capabilities cannot be designed around the actual questions and constraints of system operators.

Testing and certification bodies

Outline what ISO/IEC 17025-compatible processes, remote-witness arrangements and reporting would require of the infrastructure. Indicate which accreditation pathways are plausible for interoperability, cyber and grid-edge devices. Advise on how pilot-phase methods must be designed to be auditable later.

Without this, "accredited" remains an aspiration rather than a specification.

Universities and research organisations

Contribute expertise on modelling, digital twins, HIL/PHIL methods, test descriptions, data and evaluation criteria. Connect the concept to Finnish and European RI development and identify which models, methods, test descriptions or non-sensitive datasets could be shared.

Without this input, the infrastructure loses methodological continuity and RI alignment.

Authorities and funders

Provide guidance on relevant policy, regulatory and funding requirements and on the evidence future validation services may need to produce, including in areas such as cyber security. Help identify realistic funding instruments and conditions for subsequent design and investment phases.

Without this input, development options cannot be assessed against realistic regulatory and funding conditions.

Participation at this stage primarily requires expert time and the effort of articulating requirements and use cases. **No investment commitment is requested in the VECTORIA definition phase.** Confidentiality arrangements are agreed where sensitive information is needed. The return is the opportunity to ensure that the resulting alternatives reflect real requirements before later investment decisions are made.

How to engage

The requirements work combines a company survey, interviews, joint workshops and international benchmarking of comparable facilities. Organisations can participate through these activities and can also nominate reference facilities, contribute relevant models or use cases, or provide written input on technical, operational, regulatory and market needs.

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Involvement during 2026 and early 2027 shapes the architecture, service concepts and development alternatives directly. Involvement after Q2/2027 means commenting on alternatives that have already been defined.

Why it matters now

Finland already has strong testing, simulation and research capabilities, but they do not yet form the coherent VVC pathway described in this paper. The definition phase makes the remaining needs, alternatives and investment choices explicit. By taking part now, stakeholders can help ensure that later decisions are based on shared priorities, realistic requirements and credible operating models.

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