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Research and innovation towards zero-emission road transport and European automotive sector competitiveness

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Contents

Abstract

This report assesses how EU-funded research and innovation supports the competitiveness of the European automotive sector during its transition towards clean, digital and resilient mobility. The analysis covers 150 projects, representing around EUR 1.99 billion in total budget and EUR 1.23 billion in EU contribution, across connected and automated mobility, software-defined vehicles, electric-vehicle batteries, zero-emission components and infrastructure, deployment, advanced materials and manufacturing, and workforce transformation. The portfolio is strongly oriented towards clean mobility, while also showing increasing attention to digitalisation, supply-chain resilience, circularity and skills. The report finds that EU R&I contributes to technology validation, demonstration and piloting, but that stronger links are needed between project results, industrial scale-up, certification, infrastructure deployment, skills development and market uptake. The findings support EU transport, research and innovation, and industrial-policy discussions on how to align future R&I programming with automotive competitiveness, decarbonisation and strategic resilience.

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Executive summary

Policy context

The EU automotive sector is central to industrial competitiveness and to the delivery of climate, energy and digital policy objectives. The sector is affected by binding decarbonisation requirements, rapid digitalisation, supply-chain dependencies and increasing global competition. This report supports EU policy work on automotive industrial competitiveness by assessing how EU research and innovation (R&I) contributes to clean mobility, digitalisation, supply-chain resilience and workforce transformation. It is relevant to the implementation of current EU transport, research, innovation and industrial policy, and to future programming priorities under the next EU Framework Programme.

Key conclusions

EU-funded research and innovation provides a substantial contribution to automotive competitiveness by supporting technologies, methods and capabilities needed for the sector's transition. The analysed portfolio shows strong alignment with the EU's clean-mobility objectives, while also addressing digitalisation, manufacturing, circularity, infrastructure and skills. The portfolio is therefore relevant not only to transport decarbonisation, but also to wider industrial policy, strategic autonomy, energy-system integration and the resilience of European value chains.

The main policy conclusion is that clean mobility and competitiveness should be addressed jointly. Electrification, batteries, zero-emission components, infrastructure and deployment remain central to regulatory compliance and market transformation. However, future competitiveness will also depend on software, automation, data, semiconductors, advanced materials, circularity and manufacturing scale-up. R&I policy should therefore avoid treating decarbonisation, digitalisation and industrial resilience as separate domains.

The analysis confirms that EU R&I is active across the innovation pipeline, including validation, demonstration and piloting. This reduces uncertainty on the technical feasibility of several zero-emission and digital automotive technologies. However, uncertainty remains higher on industrial scale-up, commercial uptake, cost reduction, supply-chain security, infrastructure availability, certification and workforce adaptation. These are not only technical issues; they require coordination between R&I funding, regulation, standards, procurement, deployment finance and industrial investment.

Future policy should place greater emphasis on the transition from project outputs to industrial capacity. Priority areas include batteries and their value chains, software-defined vehicles, connected and automated mobility, power electronics, charging and refuelling infrastructure, advanced materials, circularity, manufacturing processes and skills. Workforce transformation should receive more systematic attention, as it is a condition for industrial competitiveness and safe deployment.

The report also identifies the need for better evidence on project outcomes. More consistent reporting of technology readiness, aggregated development levels, validation environments, standards contributions, exploitation pathways and post-project uptake would strengthen policy monitoring and improve future R&I programming.

Main findings

Overview of the analysed EU R&I automotive portfolio

The project portfolio analysed in detail in the report comprises a comprehensive portfolio of 150 H2020 and Horizon Europe projects, representing around EUR 1.23 billion in EU contribution. The largest project concentration is in electric-vehicle batteries, followed by connected, cooperative and automated mobility, zero-emission vehicle infrastructure, and advanced materials and manufacturing. This distribution reflects the centrality of electrification, while showing growing attention to digitalisation and industrial capability.

Which policy priorities are most represented?

Clean mobility is the dominant orientation of the portfolio. Projects address batteries, electric powertrains, fuel-cell systems, vehicle integration, charging and refuelling infrastructure, energy management and deployment. Innovation and digitalisation form the second major trend, especially through Connected, Cooperative, and Automated Mobility (CCAM), software-defined vehicles, AI-enabled functions, data exchange, cybersecurity and validation methods. Competitiveness and supply-chain resilience are represented through batteries, materials, circularity, components and manufacturing. Workforce skills are less represented, although they are relevant to the implementation of the transition.

What development levels are covered?

The portfolio includes early research, technology validation, demonstration, piloting and deployment-oriented activities. Aggregated development levels show that EU R&I is not confined to low-readiness research. Several projects target validation in relevant environments, system integration or operational pilots. Higher maturity is visible in deployment and infrastructure-related projects, while earlier maturity remains common in advanced components, new materials, battery chemistries, fuel-cell technologies and some digital safety-assurance methods.

What are the main gaps?

The main gaps concern scale-up, supply-chain resilience, software capability, infrastructure coordination and workforce readiness. Project evidence often demonstrates technical feasibility, but the pathway to manufacturing, certification, procurement, commercial uptake and post-project deployment is not always clear. Evidence quality also varies across projects, limiting the ability to assess long-term impact and industrial uptake.

Related and future Joint Research Centre work

This report builds on JRC work through TRIMIS, the Commission Transport Research and Innovation Monitoring and Information System, which monitors transport R&I and supports evidence-based policymaking. Follow-up work can further track automotive R&I outcomes, development levels, deployment pathways and links with future EU R&I programming and industrial-policy priorities.

Quick guide

The report reviews EU-funded research and innovation relevant to automotive competitiveness. It groups projects by policy pillar, technology domain and development level. Key terms include clean mobility, connected and automated mobility, software-defined vehicles, technology readiness levels, supply-chain resilience and workforce transformation. The analysis uses project databases, public project information, automated screening and expert review. Main uncertainties concern the uneven availability of project results, ongoing projects without final outputs, and the difficulty of linking R&I results directly to market uptake.

1. Introduction

The European Union's automotive sector is undergoing a structural transition driven by decarbonisation, digitalisation, industrial competitiveness and supply-chain resilience. The sector remains a central component of Europe's industrial base, while also facing intensified international competition, rapid technological change and binding climate-policy requirements. The shift towards zero- and low-emission mobility, connected and automated vehicles, software-defined vehicle architectures, advanced batteries, resilient supply chains and workforce adaptation is therefore both a climate-policy requirement and an industrial-policy priority.

Research and innovation (R&I) is a central instrument for supporting this transition. EU-funded R&I contributes to the development, demonstration and validation of technologies, processes, methods and skills that can enable the automotive sector to meet regulatory requirements, strengthen industrial capacity and maintain technological relevance in global markets. These contributions span vehicle technologies, digital systems, battery and hydrogen value chains, charging and refuelling infrastructure, materials and manufacturing, circularity, deployment models and skills development.

This report analyses EU R&I support to automotive competitiveness, with particular attention to the contribution of projects funded under Horizon 2020 and Horizon Europe and to their alignment with the EU policy framework for the automotive sector. It assesses how the analysed project portfolio contributes to the main strategic orientations of EU automotive policy, including innovation and digitalisation, clean mobility, competitiveness and supply-chain resilience, and workforce skills. The report also identifies portfolio patterns, technology-development trends, project achievements and remaining gaps relevant to future R&I programming and policy support.

1.1. Report scope and approach

The report provides an evidence-based overview of EU-funded R&I activity relevant to the competitiveness of the European automotive sector. Its scope covers projects that address automotive technologies, industrial capabilities, enabling infrastructure and non-technological innovation directly relevant to the transition of the sector. The analysis is organised around the main thematic areas of the report: connected, cooperative and automated mobility (CCAM); software-defined vehicles; electric-vehicle batteries; zero-emission vehicle components; zero-emission vehicle infrastructure; zero-emission vehicle deployment; advanced materials and manufacturing; and workforce transformation.

The report is framed by the evolving EU policy context. During the 2019–2024 policy cycle, EU action was strongly structured by the European Green Deal and the creation of a regulatory framework for transport decarbonisation. The post-2024 agenda places greater emphasis on industrial competitiveness, strategic autonomy, supply-chain resilience and the capacity of European industry to scale the next generation of automotive technologies. The report therefore assesses R&I not only as a source of technological progress, but also as a policy instrument supporting industrial renewal, market readiness and strategic capacity.

The analytical approach combines portfolio-level quantitative assessment with thematic project review. At portfolio level, projects are classified by policy alignment, funding source, technology domain, development stage, application context and contribution to the automotive value chain. At thematic level, selected projects are reviewed to identify relevant technologies, project achievements, deployment progress, industrial relevance and remaining barriers. This dual approach is intended to provide both a systematic overview of the R&I landscape and a more detailed assessment of the contribution of specific project clusters.

The report focuses on EU R&I projects that are relevant to the automotive sector and to the four main pillars of the EU automotive policy agenda addressed in the analysis: innovation and digitalisation; clean mobility; competitiveness and supply-chain resilience; and workforce skills and social aspects. Trade-policy and external-market measures are outside the analytical scope except where they directly affect the interpretation of R&I needs or industrial competitiveness.

1.2. Data and methodology

The analysis is based primarily on the Transport Research and Innovation Monitoring and Information System (TRIMIS) database and associated project information sources. The initial project identification process used keyword-based screening across thematic categories relevant to the automotive sector, including vehicle technologies, decarbonisation and electrification, automation and digitalisation, industrial competitiveness, circularity, and workforce-related topics. This first stage generated a broad set of potentially relevant EU-funded transport R&I projects.

The initial dataset was refined through automated relevance assessment and expert verification. A structured evaluation process was used to assess the relevance of projects to the report scope and to exclude projects that only had a tangential relation to automotive competitiveness. Exclusion criteria included, for example, projects focused primarily on micromobility, general driver training, cleaner internal-combustion-engine optimisation not linked to zero-tailpipe-emission pathways, or advanced manufacturing projects without a specific automotive application. The resulting longlist was then reviewed and ranked to support the selection of projects for in-depth analysis.

The final analytical dataset used in the report comprises 150 projects for detailed review, representing around EUR 1.99 billion in total project costs and around EUR 1.23 billion in EU contribution. The largest project concentrations are found in electric-vehicle batteries, CCAM, zero-emission vehicle infrastructure, and advanced materials and manufacturing. The analysed project portfolio is **not intended to be exhaustive**. It is designed as a **representative analytical sample** of EU-funded R&I activity relevant to automotive competitiveness, with a deliberate emphasis on recent projects reflecting current policy and technology priorities. The selection also seeks to complement Research and Innovation Actions (RIA) and Innovation Actions (IA) by including, where relevant, projects from other funding sources and instruments, such as ERC, MSCA, EIC and SME-oriented support. This approach allows the report to capture both the dominant collaborative R&I portfolio and complementary innovation pathways.

Project classification uses a multi-dimensional taxonomy. Each project is assessed against strategic alignment with the automotive-policy pillars, primary focus area, detailed technology or manufacturing topic, and targeted technology readiness. This classification enables cross-cutting analysis of how EU R&I funding is distributed across themes, policy priorities and stages of technological maturity.

Project evidence was extracted from publicly available project information, including TRIMIS and CORDIS project records, project websites, public deliverables, publications, and dissemination material. For ongoing projects, the analysis focuses on objectives, expected outputs, interim achievements and intended development pathways. For completed projects, the analysis focuses on achieved results, demonstrated performance, market or deployment readiness, and implications for policy, standards, regulation and future R&I priorities.

The methodology combines automated text analysis, structured classification and manual expert judgement. Automated tools support the screening, ranking and classification of large numbers of projects, while expert review is used to verify relevance, resolve classification ambiguities and ensure consistency. This is particularly important for projects that contribute to several policy objectives at once, for example digital technologies that support clean mobility, or battery projects that simultaneously address performance, manufacturing capacity and circularity.

Certain limitations should be noted. The assessment depends on the availability and quality of public project information, which varies between projects and funding schemes. Ongoing projects may not yet have generated results, while completed projects may differ in the extent to which results are publicly documented. The classification of projects by primary policy contribution necessarily simplifies projects with multiple objectives. These limitations are mitigated through expert review, cross-checking of project sources and the use of a consistent taxonomy across the portfolio.

1.3. Document guide

The report is structured to move from policy context and portfolio overview to thematic analysis and conclusions.

Section 2 presents the European policy context for automotive R&I and competitiveness. It summarises the main decarbonisation, infrastructure, R&I and industrial-policy frameworks that shape the automotive transition, including the regulatory framework for clean vehicles, enabling infrastructure and market uptake, EU partnerships, industrial competitiveness initiatives, and the role of the JRC and TRIMIS in policy support.

Section 3 provides a quantitative overview of the EU R&I portfolio analysed in the report. It presents the distribution of projects across report themes, policy pillars, funding sources and development stages. It also identifies patterns of thematic concentration and cross-cutting contributions, including the prominence of clean mobility, the role of digitalisation across multiple technology domains, and the transversal relevance of batteries, materials and manufacturing.

Section 4 reviews the main technology and innovation areas covered by the selected projects. It is organised by thematic clusters, including CCAM, software-defined vehicles, EV batteries, zero-emission vehicle components, zero-emission infrastructure, deployment, advanced materials and manufacturing, and workforce transformation. Each subsection reviews the state of the art, relevant market and research trends, the EU R&I project portfolio, selected project achievements and remaining challenges.

Section 5 synthesises the main findings across the project portfolio. It identifies how the analysed projects contribute to EU automotive competitiveness, where the strongest R&I concentrations are located, and which gaps remain in relation to technological maturity, industrial scale-up, supply-chain resilience, interoperability, skills and deployment conditions.

Section 6 concludes the report by summarising the main implications for future R&I policy and for the alignment of EU-funded projects with automotive industrial strategy. It highlights priorities for continued research, demonstration and coordination, and points to areas where further evidence may be needed to support future policy decisions.

2. Overview of European policy

The European Union's automotive sector, a cornerstone of its industrial base and competitiveness, is navigating a profound transition towards digitalisation and decarbonisation. Two phases of EU policymaking support and structure this transition. The first, under the 2019-2024 Commission, was defined by the *European Green Deal* and the establishment of a robust regulatory framework for decarbonisation. The second, post-2024, focuses on industrial competitiveness, strategic autonomy, and securing the EU's leadership in the next generation of technologies.

EU research and innovation (R&I) is a strong driver for achieving the goals of both phases, translating regulatory ambition and strategic necessity into technological solutions, industrial processes, and a skilled workforce. This overview outlines the key policy and strategic initiatives that shape the R&I landscape for the EU automotive sector.

2.1. The transport decarbonisation framework

The regulatory framework adopted to drive the uptake of clean vehicles was underpinned by the EU's climate strategy, the European Green Deal (European Commission, 2019). This strategy set the legally binding target of climate neutrality by 2050. For the transport sector, there have been several policy and regulatory instruments towards the achievement of this ambition.

The **Sustainable and Smart Mobility Strategy** (European Commission, 2020) laid out a comprehensive roadmap with 82 initiatives to make the transport system green, digital, and resilient. It established key milestones, such as having at least 30 million zero-emission cars and 80,000 zero-emission heavy-duty vehicles (ZE-HDVs) on the road by 2030, and for nearly all new vehicles to be zero-emission by 2050. This strategy explicitly links decarbonisation with digitalisation, identifying connected and automated mobility as a key enabler.

The CO2 emission performance standards provide a direct regulatory mechanism influencing the industry's technological trajectory.

— For **light-duty vehicles (LDVs)**, following the December 2025 Automotive Package, the proposed trajectory mandates a 55% CO2 reduction for new cars and a 40% reduction for new vans by 2030 (compared to 2021 levels). The 2035 target for both vehicle categories is set at a 90% tailpipe emissions reduction (European Commission, 2025d). The framework permits the remaining 10% of emissions to be compensated through the application of low-carbon EU steel, e-fuels, or biofuels.

— For **heavy-duty vehicles (HDVs)**, the revised Regulation (EU) 2024/1610 significantly strengthens the targets, mandating emission reductions of 45% by 2030, 65% by 2035, and 90% by 2040 (compared to 2019 levels). It also mandates that all new urban buses be zero-emission by 2035.These binding targets aim towards an innovation pathway for the automotive industry, making R&I in ZEV technologies a prerequisite for market compliance. Recent developments include a public consultation[1] on the revision of the CO2 standards for cars and vans that will take place in 2026.

The adjusted targets under consultation reshape the regulatory landscape for the automotive industry. Rather than a singular focus on full electrification, the 90% target and the permitted compensation mechanisms introduce a more technology-neutral framework compared to a full phase-out scenario. This preserves the commercial relevance of plug-in hybrids, mild hybrids, and internal combustion engines adapted for alternative fuels, broadening the portfolio of technologies viable for market compliance.

2.2. Enabling infrastructure and demand stimulation

To complement the regulatory "push" of the CO2 standards, the EU has implemented "pull" measures to assist the market and remove deployment barriers, primarily through infrastructure mandates and demand stimulation.

The **Alternative Fuels Infrastructure Regulation (AFIR)** (Regulation (EU) 2023/1804) replaces the previous directive and sets mandatory, time-bound deployment targets for all Member States. This is critical as it creates a guaranteed, harmonised EU-wide market for new charging and refuelling technologies developed in R&I projects. Key targets include:

— **For LDVs:** Fast-charging pools of at least 150 kW to be installed every 60 km along the TEN-T core network by 2025.

— **For HDVs:** Charging pools starting at 1,400 kW to be deployed every 60 km on the TEN-T core network by 2030, and hydrogen refuelling stations in all urban nodes and at least every 200 km along the TEN-T core network.

Furthermore, the **Clean Vehicles Directive** (Directive (EU) 2019/1161) acts as a powerful public procurement lever, requiring public authorities to meet minimum quotas for the procurement of clean and zero-emission vehicles, thereby creating stable, large-scale lead markets for buses and municipal vehicles. Furthermore, the proposed **Regulation on clean corporate vehicles,** introduced within the December 2025 Automotive Package, establishes binding national targets for large corporate fleets to adopt zero- and low-emission vehicles (European Commission, 2025f). Given that corporate fleets account for approximately 60% of new passenger car registrations in the EU, this regulation functions as a critical demand-side instrument, bridging the gap between R&I outputs and widespread market deployment.

1 Revision of the CO2 emission standards for cars and vans, accessed 7 May 2026, https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/14765-Revision-of-the-CO2-emission-standards-for-cars-and-vans_en.

2.3. Research and innovation policy

The EU's R&I policy is the primary tool for developing the technologies needed to meet the aforementioned goals and secure competitiveness. The **Horizon Europe** Framework Programme (Regulation (EU) 2021/695) is the current main funding instrument, with much of the relevant R&I channelled through its co-programmed public-private partnerships.

These partnerships bring together the European Commission and industry to define common Strategic Research and Innovation Agendas (SRIAs) and co-invest in a portfolio of projects. The four most critical partnerships for the automotive sector are:

— **Towards Zero Emission Road Transport (2ZERO):** This partnership aims to accelerate the development and deployment of zero-emission, tailpipe-free road transport solutions. Its SRIA is focused on system-level integration, vehicle technologies, namely battery-electric vehicles (BEV) and hydrogen fuel-cell electric vehicles (FCEVs), and the crucial integration of BEVs with the energy grid, including smart charging and Megawatt Charging Systems (MCS) (2ZERO Partnership, 2024).

— **European Partnership for Batteries (BATT4EU):** The partnership's goal is to establish a world-class, sustainable, and circular European battery value chain. Its R&I addresses the full lifecycle, from next-generation battery materials and chemistries to advanced manufacturing processes and recycling (BATT4EU Partnership, 2024).

— **Cooperative, Connected and Automated Mobility (CCAM):** This partnership's objective is to strengthen European industrial competitiveness and leadership in automated mobility. It coordinates R&I on key enabling technologies (sensors, AI, connectivity), validation methodologies, and large-scale demonstrations to accelerate the safe and secure deployment of CCAM solutions (CCAM Partnership, 2023).

— **Clean Hydrogen Partnership:** This partnership is essential for developing hydrogen technologies for transport applications, focusing on reducing the cost and increasing the efficiency and durability of fuel cell systems, hydrogen storage, and refuelling infrastructure (Clean Hydrogen Partnership, 2022).

— **Chips Joint Undertaking (Chips JU):** Executing the R&I mandate of the European Chips Act, this partnership addresses the foundational hardware dependencies of the automotive sector's digitalisation. It directs funding towards advanced microcontrollers, sensors, and wide-bandgap power electronics, providing the necessary hardware prerequisites for the software-defined vehicle architectures and automated functionalities targeted by the other mobility partnerships (European ECS community, 2026).

European technology platforms (ETPs), such as ERTRAC (European Road Transport Research Advisory Council) and ALICE (Alliance for Logistics Innovation through Collaboration in Europe), are industry-led advisory bodies that play a crucial role by providing the strategic vision and feeding the detailed priorities into the SRIAs of these partnerships.

Looking ahead to the **10th Framework Programme (FP10)**, proposals from the industrial partners in the EU Partnerships are pointing towards **a more consolidated partnership model** to reduce fragmentation. The ETPs have suggested a potential single, overarching partnership for road transport, aiming to better align R&I with the strategic competitiveness and industrial policy goals articulated in the Draghi and Letta reports (2ZERO et al., 2025).

2.4. Industrial strategy and competitiveness

Road transport industrial strategy and competitiveness have been continuous concerns for the European Commission. Key initiatives reflected this dimension, including the Sustainable and Smart Mobility Strategy, the 2021 TEN-T revision, and the 2023 Green Deal Industrial Plan. The post-2024 policy focus has shifted explicitly to industrial competitiveness, security, and strategic autonomy, acknowledging the intense global competition from the US and China.

High-level advisory reports by Enrico Letta ("Much More than a Market", 2024) and Mario Draghi ("Report on the Future of European Competitiveness", 2025) have provided strategic direction for the new agenda. Both reports call for a radical strengthening of the Single Market, a reduction of regulatory burdens, and the massive mobilisation of public and private capital to finance the twin transitions and scale up European industrial champions.

This new direction is being operationalised through several instruments:

— The **Competitiveness Compass** (European Commission, 2025g) acts as a new strategic framework to ensure all EU policies contribute to competitiveness. Its core pillars include "Closing the innovation gap" and a "Joint roadmap for decarbonisation and competitiveness," directly placing R&I at the heart of industrial strategy.

— the **Clean Industrial Deal** (COM(2025) 85 final), which links decarbonisation with industrial competitiveness and provides the framework for subsequent sectoral action plans.

— The **EU Industrial Action Plan for the Automotive Sector** (European Commission, 2025b) is a dedicated strategy to ensure the sector's global competitiveness. It is built on five pillars, including (1) innovation and digitalisation (e.g., leadership in AI-powered vehicles), (2) clean mobility, (3) competitiveness and supply chain resilience, (4) skills, and (5) a global level playing field. Key actions include establishing large-scale cross-border testbeds for autonomous vehicles, launching a European Connected and Autonomous Vehicle Alliance, and developing regulations for approving autonomous vehicles (Pillar 1); a "battery booster" package involving funding (e.g., €1.8 billion for the supply chain) and legislation to support cost-competitive domestic cell production and a European supply chain for materials and components (Pillar 3). The current report will evaluate how R&I projects contribute to the achievement of the first four of these pillars, as the last one is primarily addressed through trade policy and diplomatic efforts.

— Under Pillar 3, the strategy operationalises a **battery booster strategy**, formalised in December 2025, which allocates €1.5 billion in performance-based, interest-free loans to EU battery cell producers via the Innovation fund (European Commission, 2025a). Concurrently, the proposed automotive **Omnibus regulation** seeks to alleviate administrative burdens for manufacturers, projecting an estimated €706 million in annual savings, while introducing "super credits" for small electric vehicles manufactured within the EU (European Commission, 2025e).

— This industrial plan is built on the foundations of the **Critical Raw Materials Act** (Regulation (EU) 2024/1252) and the **European Chips Act** (Regulation (EU) 2023/1781), two key regulations designed to de-risk the automotive supply chain by setting domestic capacity targets for raw material processing and semiconductor production.

2.5. Deployment, funding, and testing frameworks

Beyond R&I funding, the EU is using other financial and regulatory tools to bridge the gap from innovation to industrial deployment, a phase often referred to as the "valley of death".

- **Important Projects of Common European Interest (IPCEI):** This mechanism allows Member States to provide state aid to cross-border, high-risk R&I and industrial deployment projects that are strategic for Europe (European Commission, 2021). Two IPCEIs on batteries[2] and one on hydrogen[3] have been instrumental in channelling billions of euros into building new gigafactories and a European hydrogen ecosystem.
- **The Innovation Fund[4]:** Funded by the EU Emissions Trading System (ETS), this fund supports the demonstration of innovative, low-carbon technologies, helping to finance the first commercial-scale ZEV manufacturing plants and battery recycling facilities.
- **Regulatory Sandboxes:** To accelerate the deployment of digital technologies, particularly for CCAM, the EU is establishing new legal frameworks. The **EU AI Act** (European Parliament, 2024) mandates the creation of AI regulatory sandboxes by 2026, allowing companies to test and validate innovative AI systems (such as autonomous driving algorithms) in a controlled, real-world environment with supervisory oversight, thereby speeding up the process from R&I to certification and market entry.

2.6. Implementation and execution role of CINEA

The **European climate, infrastructure and environment executive agency (CINEA)[5]**, established in 2021, is the primary EU implementation body for R&I and infrastructure funds. CINEA's core role is to manage delegated programmes, ensuring efficient execution and effective delivery of projects funded under Horizon Europe partnerships, accelerating the industrial transition. This includes:

- **Horizon Europe (Cluster 5):** Managing the grant lifecycle for clean transport R&I projects.
- **Connecting Europe facility (CEF):** Funding the deployment of AFIR-mandated infrastructure and Intelligent Transport Systems (ITS) along the TEN-T corridors, bridging R&I with market deployment.
- **Innovation fund:** Supporting the first commercial-scale deployment of innovative, low-carbon industrial solutions.

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2 European Commission, 'Approved IPCEIs in the Batteries value chain', accessed 7 May 2026, https://competition-policy.ec.europa.eu/state-aid/ipcei/approved-ipceis/batteries-value-chain_en.

3 European Commission, 'IPCEIs on hydrogen', accessed 7 May 2026, https://single-market-economy.ec.europa.eu/industry/strategy/hydrogen/ipceis-hydrogen_en.

4 European Commission, Climate action: Innovation Fund, European Commission website, accessed 7 May 2026, https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund_en.

5 European Climate, Infrastructure and Environment Executive Agency (CINEA), 'Programmes supporting "sustainable transport"', European Commission website, accessed 7 May 2026, https://cinea.ec.europa.eu/programmes-supporting-sustainable-transport_en.

2.7. The role of the JRC and TRIMIS in policy support

The European Commission's science and knowledge service, the **Joint research centre (JRC)**, is mandated to anticipate and support the design and implementation of EU policies. This role is vital for linking R&I outputs to regulatory implementation and strategic foresight by contributing to areas such as safety, competition, standards, and decarbonisation.

The JRC's key contributions to the competitiveness of the automotive sector are framed by its **Transport and mobility** portfolio's six objectives[6], which go beyond pure R&I monitoring to actively support the policy and industrial ecosystem:

— **Scientific backing for standards and safety:** The JRC provides scientific expertise for developing and revising standards for sustainable and smart vehicles in a functional Single market and helps build a safe and competitive mobility ecosystem by supporting regulatory frameworks for advanced technologies, including connectivity, automation, and AI in transport.

— **Testing and validation facilities:** The JRC operates key testing facilities—such as the Vehicle emissions laboratories (VELA) and the EU interoperability centre for electric vehicles and smart grids—which directly support the deployment of clean mobility solutions and infrastructure standards.

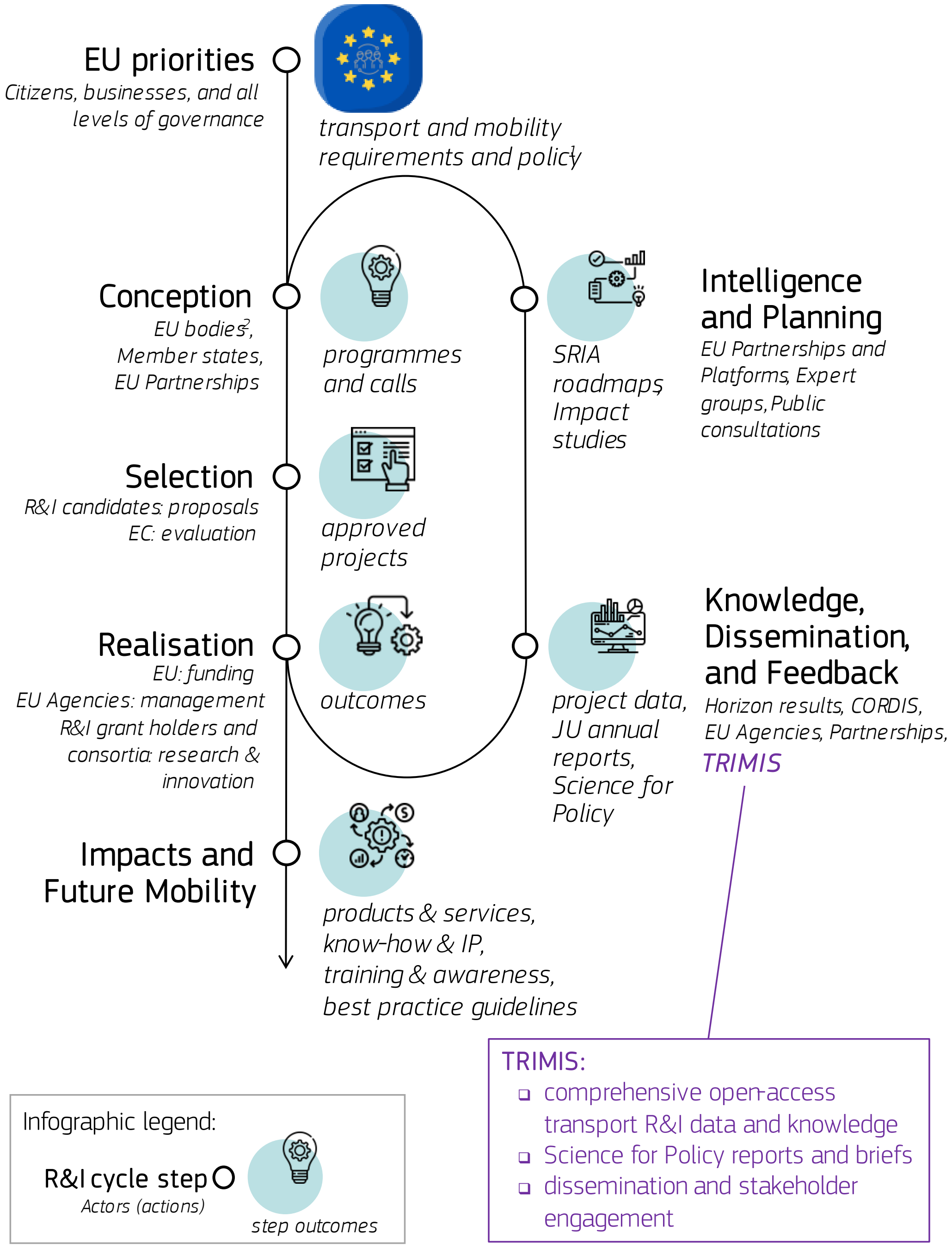
— **Regulatory tool development:** The JRC develops and maintains the Vehicle energy consumption calculation tool (VECTO), the official simulation software compulsory for the CO2 certification of heavy-duty vehicles (HDVs), which is central to implementing and monitoring the new CO2 emission performance standards.

— **R&I monitoring and foresight:** The JRC manages the Transport research and innovation monitoring and information system (TRIMIS), the R&I policy-support project that is behind this report. TRIMIS is an open-access platform[7] that collects, classifies, and analyses over 9,000 transport R&I projects in the EU and globally. It provides systematic knowledge about technology trends, R&I capacity, and progress against policy goals, offering crucial evidence and foresight that helps policymakers align future R&I priorities—including those of the European partnerships—with the EU's overall strategic objectives.

[6] European Commission: Joint Research Centre, 'Transport and mobility', JRC scientific portfolios, accessed 7 May 2026, https://joint-research-centre.ec.europa.eu/scientific-portfolios/transport-and-mobility_en.

[7] European Commission: Joint Research Centre, 'Transport Research and Innovation Monitoring and Information System (TRIMIS)', accessed 7 May 2026, https://trimis.ec.europa.eu/.

Figure 1. European transport research and innovation cycle, and the role of TRIMIS



[1] Including the interactions of transport policy with economic, environmental, climate, digital, energy, and social policy.

[2] Including the European Commission, CINEA, the European Innovation Council (EIC), the European Research Council (ERC), the European Institute of Innovation and Technology (EIT).

Source: TRIMIS, JRC, 2025

3. Quantitative overview of EU R&I innovation in support of automotive competitiveness

3.1. Projects by report section and primary EU automotive plan pillar

Table 1 presents the distribution of projects across the report sections, providing a structural portfolio overview. In total, the portfolio comprises approximately 150 projects, with the largest concentration in EV batteries (45 projects), followed by CCAM (28 projects) and both ZEV infrastructure and Advanced materials & manufacturing (19 projects each).

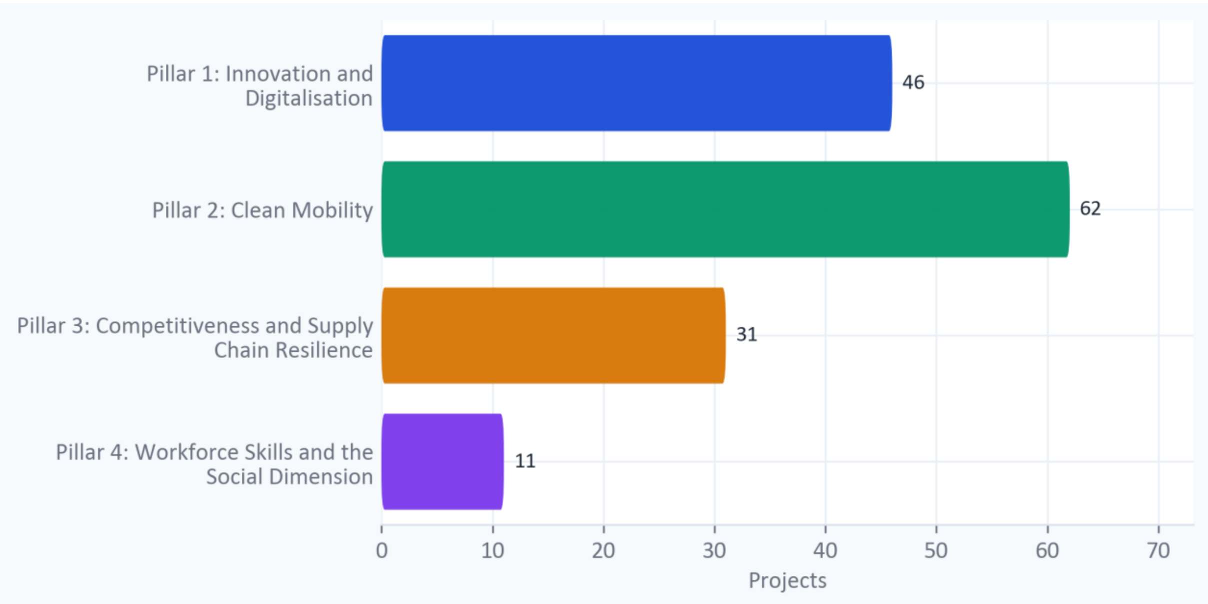
Table 1. Project overview summary table

Report subsection	Projects	Total cost	EC contribution
4.1 CCAM	28	EUR 378.0m	EUR 290.3m
4.2 Software-Defined Vehicle	7	EUR 154.0m	EUR 60.3m
4.3 EV batteries	45	EUR 295.6m	EUR 285.2m
4.4 ZEV components	14	EUR 203.1m	EUR 97.0m
4.5 ZEV infrastructure	19	EUR 438.4m	EUR 216.5m
4.6 ZEV deployment	9	EUR 267.7m	EUR 142.4m
4.7 Materials & manufacturing	19	EUR 234.4m	EUR 113.0m
4.8 Workforce transformation	9	EUR 22.0m	EUR 21.4m
Total	150	EUR 1.99bn	EUR 1.23bn

Source: TRIMIS, JRC, 2026

The projects were mapped to the pillars based on each project's primary orientation (**Figure 2**). The overall portfolio primary orientation is electrification and clean mobility, linking to Pillar 2: Clean Mobility. CCAM and Software Defined Vehicle, which associate with Pillar 1: Innovation and Digitalisation emerge as the second trend. **Pillar 3** has a moderate presence (31 projects) among the analysed projects, while **Pillar 4 is represented by 11 projects.**

Figure 2. Number of projects per Pillar of the EU Automotive Plan



Source: TRIMIS, JRC, 2026

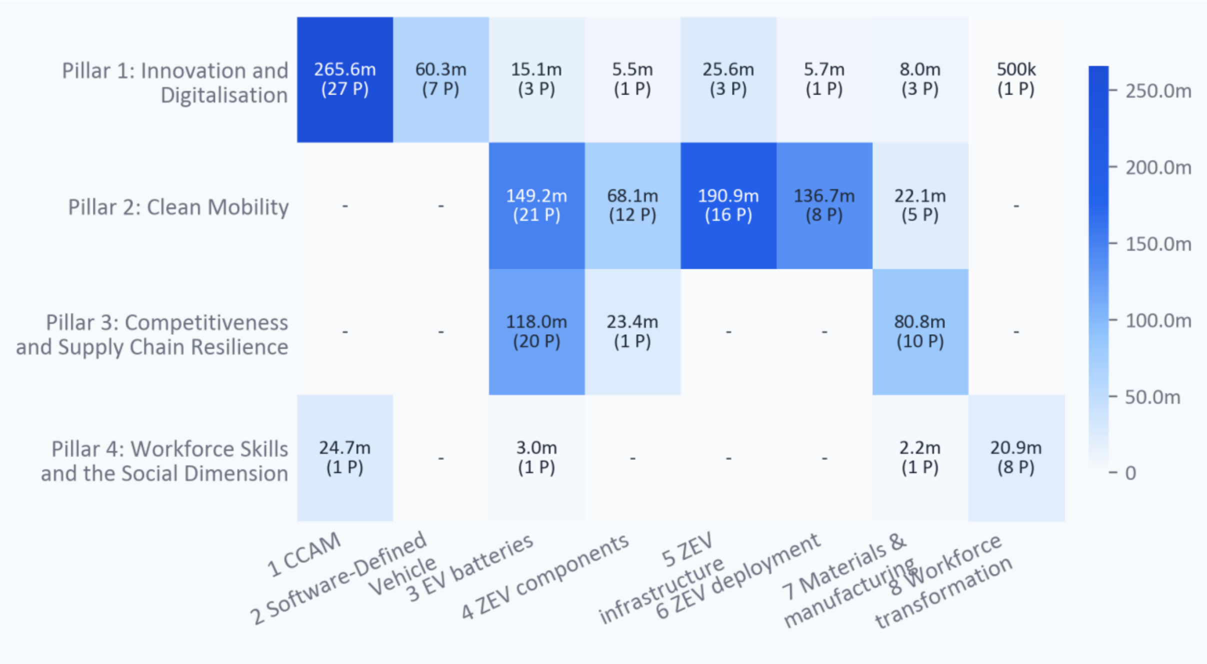
The mapping between the report sections and pillars is not a direct one-to-one correspondence but follows the projects' primary orientation based on their content, for example EV battery projects are distributed between all Pillars. The heatmap in **Figure 3** illustrates this distribution of projects across the pillars and report subsections. Each cell represents the EU funding and number of projects associated with a given combination, enabling identification of thematic concentration patterns. Observed trends include the following:

— Pillar 2 corresponds to the highest number and EU funding of projects, representing a continuing effort throughout the years towards clean mobility, and is largely concentrated in the themes of batteries, zero-emission vehicle components, infrastructure, and deployment.

— Pillar 1 innovation and digitalisation is represented by the **most diverse portfolio across all report themes**. While the link to CCAM and SDV is evident, notable is the link to battery management systems, engineering tools, energy and thermal management, fleet management, and the emergence of AI as a digital enabler across all value chains.

— With regards to report themes, EV batteries and Materials and Manufacturing emerge as the most transversal, with projects and activities covering all pillars of the EU automotive plan.

Figure 3. Funding by project cluster and primary Automotive Plan pillar addressed.



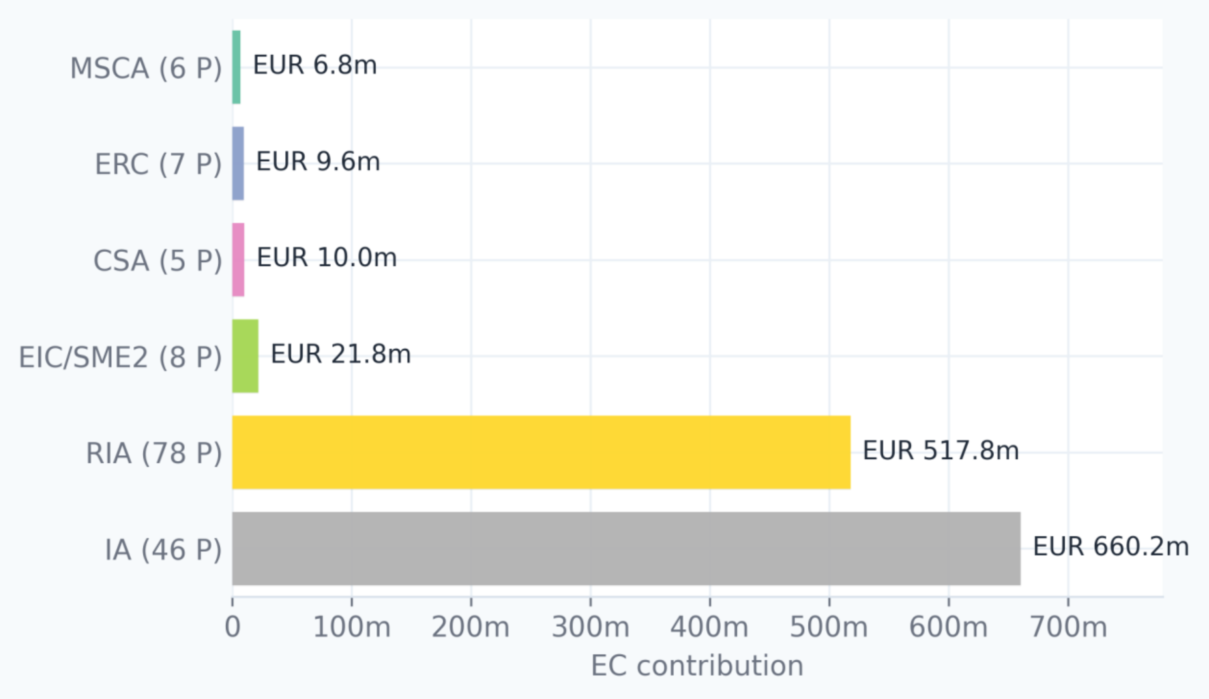
Heatmap colour shows funding; annotations show funding and project count (P).

Source: TRIMIS, JRC, 2026

3.2. Projects by targeted readiness and funding source

The TRIMIS project database contains information about the project funding actions. In the analysed project portfolio, most EU funds are invested in Innovation Actions (IA), and Research and Innovation Actions (RIA) (**Figure 4**). However, fundamental research is also represented through MSCA and the European Research Council (ERC), and support to Small and Medium Enterprises (SMEs) and startups through the SME instrument and the European Innovation Council (EIC).

Figure 4. Total EU funding of analysed project portfolio by funding scheme



Source: TRIMIS, JRC, 2026

This information can serve as a proxy of the targeted Technology Readiness Levels (TRLs), as adopted in the EU Framework Programmes (Héder, 2017). **Table 2** summarises the typical or expected target TRL depending on the funding source.

Table 2. EU funding schemes for selected automotive projects

Source	Source Type/ Programme	Receiving entities	Funding / Grant / Investment ceiling levels	Typical targeted TRL[a]
MSCA	H2020/HE Pillar I	Doctoral and postdoctoral Fellowships & Networks	Grants: ca. €170 thousand for individual fellowships	0 to 2
ERC frontier grants	H2020 / Horizon Europe Pillar I	Principal investigators and host institutions	Grants up to approximately €1.5m–€2.5m for individual grants; up to approximately €10m for Synergy Grants	0 to 2
RIA	H2020/HE Pillar II	Consortium of partners	Funding level: 100% of project costs	2 to 6
IA	H2020/HE Pillar II	Consortium of partners	Funding level: 70% of project costs	6 to 8
SME-1	H2020/HE Pillar II	SME, start-up or scale-up	Grants: €50 thousand lump sum	5 to 8
SME-2	H2020/HE Pillar II	SME, start-up or scale-up	Grants: €0.5 to €2.5 million	5 to 8
EIC	H2020/HE Pillar III	SME, start-up or scale-up	Accelerator: Grants: €0.5 to €2.5 million Direct investment: €15 million	5 to 9
CSA	H2020/HE Pillar II	Consortium of partners	Funding level: 100% of project costs	0

[a] MSCA and ERC Consolidator grants correspond to basic high-risk research, therefore the target TRL level is only an indication. SME-1 projects are desk studies on business plan development for existing innovations. CSA actions do not have a technology component.

Source: TRIMIS, JRC, 2026

Technology readiness was assessed by combining project metadata with evidence from project descriptions, deliverables, reported outcomes and stated performance targets. Each project was reviewed to identify the maturity of its main innovation, distinguishing between early-stage research, component or subsystem validation, integrated prototype development, pilot demonstration, operational testing and near-market deployment. Where projects explicitly reported TRLs, these values were retained and cross-checked against the described activities. Where TRLs were not reported, a **development stage** (Gkoumas et al., 2020) was assigned using the nature of the work performed, the validation environment, the scale of demonstration and the degree of system integration.

The development stages presented in **Table 3** represent early research, technology validation, demonstration, piloting and deployment-oriented activity. This aggregation reduces false precision in cases where project evidence is uneven, enables comparison across different technology domains, and provides a clearer view of where EU R&I investment is concentrated along the innovation pipeline. For completed projects, the assessment focused on achieved maturity and documented results, while for ongoing projects it considered both current progress and targeted end-of-project readiness.

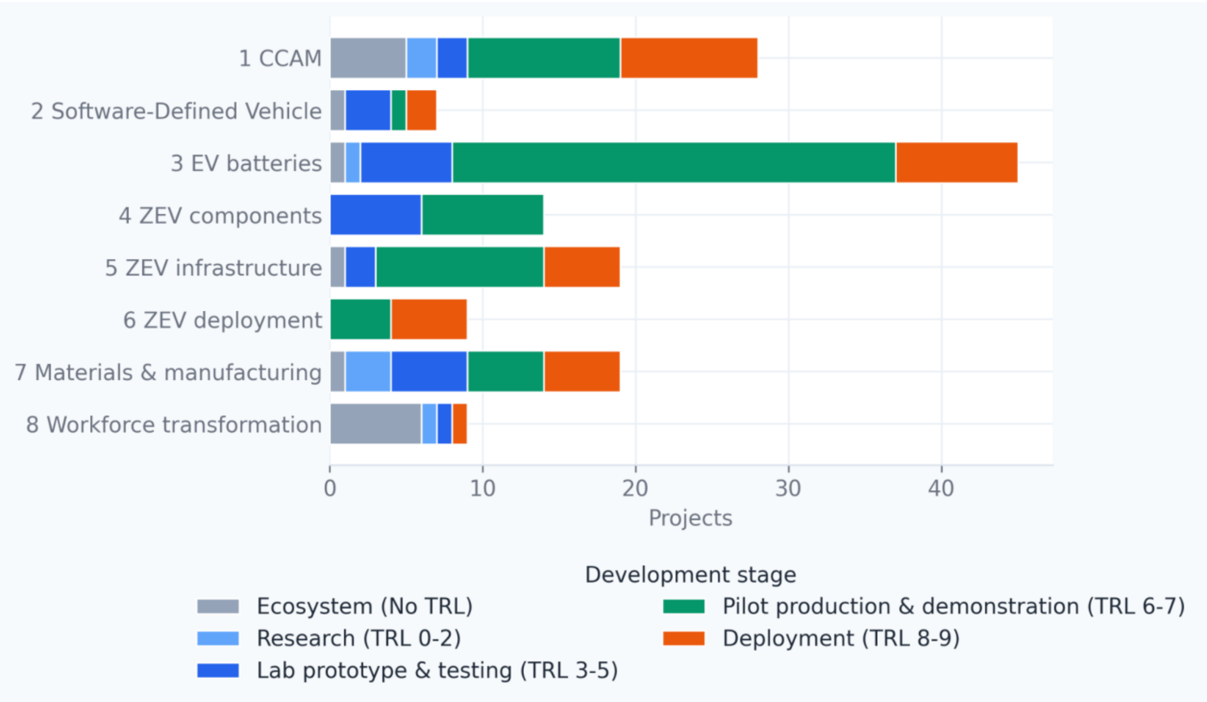
Table 3. Technology development stage and corresponding readiness levels.

Development stage	TRL range	Example project outputs
Research	0-2	Technical specifications, concepts
Prototyping and testing	3-5	Lab prototype
Pilot production and demonstration	6-7	Full vehicle prototype, Controlled environment testing
Deployment	8-9	Large scale demonstration, Product deployment

Source: TRIMIS, JRC, 2026

The following chart (**Figure 5**) shows the distribution of target or achieved technology development stage within each report section, highlighting differences in technological maturity across domains. Most sections are centred around TRL 6–7, indicating a focus on demonstration and validation. Higher maturity levels are observed in ZEV deployment (≈ TRL 8) and ZEV infrastructure (≈ TRL 7), while earlier stages appear in ZEV components (≈ TRL 5).

Figure 5. Development stage profile by report theme



Source: TRIMIS, JRC, 2026

4. Project reviews and key achievements

4.1. Connected, Cooperative and Automated Mobility

4.1.1. State of the art

The global development of connected, cooperative and automated mobility (CCAM) is defined by expanding commercial deployments in the US and China and Europe's more cautious, regulation-first trajectory. While technical maturity in controlled environments has reached high levels, the transition to scalable, commercially viable deployment remains constrained by system-level challenges: safety assurance, interoperability, regulatory readiness and the economics of industrialisation.

Market trends

The CCAM market landscape is diverging rapidly along different world regions. The figures reported from corporate and media outlets below correspond to the landscape at the end of 2025 and beginning of 2026, but the numbers may have evolved since. In the United States, the leading robotaxi operator's fleet comprised approximately 2,500 vehicles by December 2025, delivering over 450,000 paid rides per week across multiple metropolitan areas and logging 200 million fully autonomous miles by February 2026, with announced plans to expand to more than 20 additional cities, including first international markets, backed by a $16 billion funding round[8][9][10]. In China, the leading autonomous ride-hailing platform[11] was fulfilling over 250,000 fully driverless orders per week by late 2025 across approximately 20 cities, targeting per-vehicle profitability in high-density urban areas and rolling out its first international deployments (South Korea, UAE, with pilots planned in the UK and Switzerland in 2026), while several competitors are expanding domestically and internationally. Both ecosystems benefit from regulatory environments that have enabled large-scale commercial deployment at an earlier stage, substantial operational data accumulation, and aggressive capital deployment in experimental development — a phase where, as noted in recent comparative analyses of R&I funding, European public investment remains proportionally lower.

By contrast, Europe has yet to see a commercially operating fully driverless robotaxi service, reflecting a deliberate regulatory trajectory that prioritises safety assurance and legal certainty. The most advanced European initiatives - spanning OEM-led autonomous vehicle programmes, dedicated robotaxi start-ups and partnerships between European ride-hailing platforms and international technology providers - target initial deployments in selected cities from 2026 onward,

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8 CNBC, "Waymo paid rides robotaxi", accessed 7 May 2026, https://www.cnbc.com/2025/12/08/waymo-paid-rides-robotaxi-tesla.html.

9 Reuters, "Waymo defend self-driving safety record warn China competition", accessed 7 May 2026, https://www.reuters.com/world/waymo-defend-self-driving-safety-record-warn-china-competition-2026-02-03/.

10 TechCrunch, "Waymo raises $16 billion round to scale robotaxi fleet," accessed 7 May 2026, https://techcrunch.com/2026/02/02/waymo-raises-16-billion-round-to-scale-robotaxi-fleet-london-tokyo/.

11 CNBC, "China's Baidu says weekly robotaxi rides hit 250,000", accessed 7 May 2026, https://www.cnbc.com/2025/11/03/china-baidu-robotaxis-alphabet-waymo-.html.

largely with safety operators still on board[12][13]. This gap carries a tangible competitiveness risk: incumbents in the US and China are accumulating operational data, scaling supply chains and driving down unit costs at a pace that may progressively raise the barrier to entry for European players.

Trends in research

CCAM research has shifted from vehicle-level automation performance to system-level deployment challenges. The current state of the art emphasises several converging priorities:

Safety assurance and scenario-based validation: Deployment depends on robust validation across diverse operational design domains (ODDs) and compliance with emerging safety, cybersecurity and data-protection requirements. Scenario-based and virtual testing approaches are replacing conventional physical-test methods to manage the exponential growth of test scenarios.

Interoperability and connectivity: Reliable vehicle-to-infrastructure communication and cross-border operability have become decisive for industrial scalability. Trustworthy data exchange, cyber-resilience and interoperability across heterogeneous networks are now prerequisites for certification and market access.

Trustworthy AI and regulation alignment: The increasing reliance on AI-driven perception and decision-making demands explainability, traceability and alignment with emerging frameworks such as the AI Act. Safe, certifiable AI is becoming a structural requirement rather than a performance differentiator.

Within this landscape, Europe has positioned CCAM as a system-level deployment and regulatory-integration challenge rather than a race to commercialise isolated automation functions. The EU's strategy deliberately prioritises reliability, explainability, interoperability and regulatory readiness over speed-to-market.

The R&I funding gap

These challenges align with broader structural issues in EU research and innovation. According to the European Commission's comparative analysis of public R&I funding in the EU, US and China (European Commission: Directorate-General for Research and Innovation et al., 2025) , the EU allocates 40% of total R&D expenditure to experimental development — the most downstream OECD category, covering prototype and pre-commercial work — compared with 68% in the United States and 83% in China, where the EU instead places greater emphasis on research efforts (both basic and applied). This structural difference slows the translation of prototypes into market-ready solutions. The CCAM portfolio analysed in this report shows a different profile, with most projects

[12] newmobility.news, "Waymo's €16-Billion question for Europe: are robotaxis finally inevitable?," accessed 7 May 2026, https://newmobility.news/en/2026/02/04/waymos-e16-billion-question-for-europe-are-robotaxis-finally-inevitable/.

[13] Automotive World, "Uber targets robotaxi services in ten countries in 2026," accessed 7 May 2026, https://www.automotiveworld.com/news/455938/.

concentrated in TRL 6-9 (see Figure 5). Sustaining and expanding this deployment-oriented programming will be essential to convert scientific excellence into competitive advantage at scale.

Cross-cutting deployment barriers

The transition from prototypes to scalable products continues to be hindered by limited standardisation, fragmented data access and divergent national testing rules - bottlenecks that, together with user acceptance and workforce readiness, must be addressed to accelerate market uptake (CCAM Partnership, 2023).

4.1.2. EU R&I overview

For the European automotive sector, leadership in CCAM is essential for long-term competitiveness in the digital transition. Through Horizon 2020 and Horizon Europe, and particularly the establishment of the CCAM Partnership, the European Union is addressing this challenge by programming and funding a coherent portfolio of research and innovation projects.

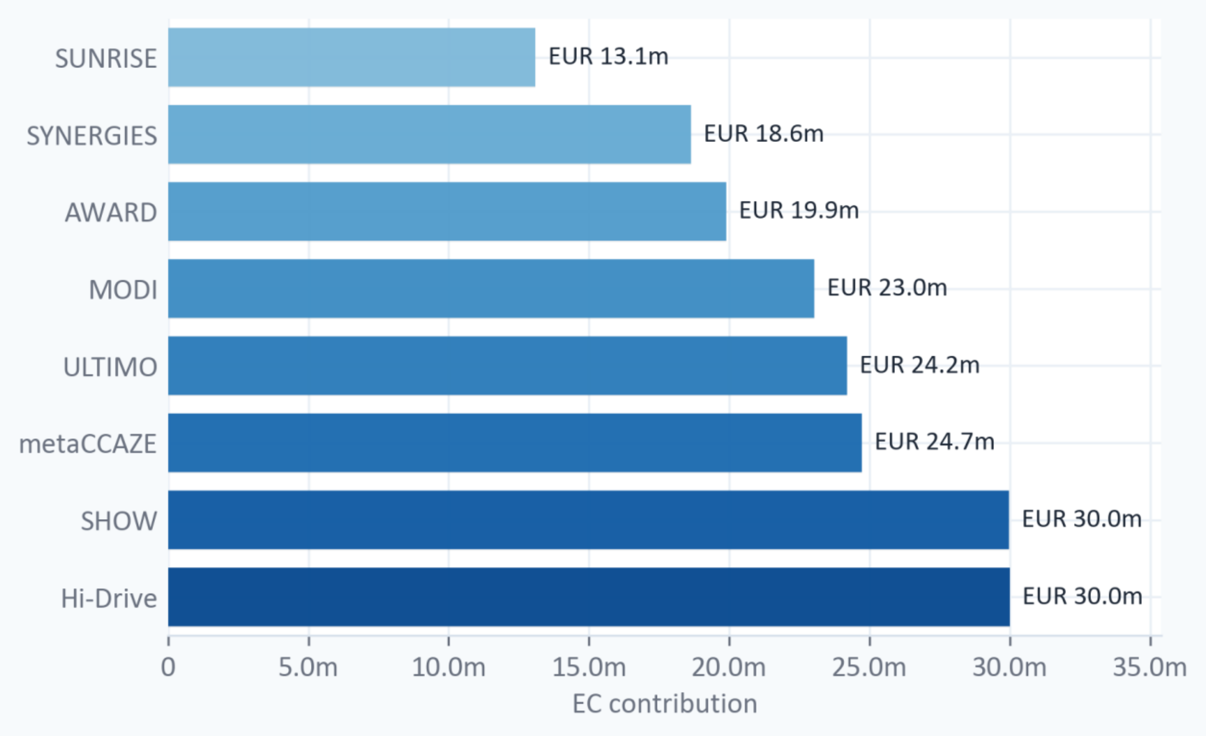
This section contains 28 projects (**Table 4**), representing EUR 378.0m in total cost and EUR 290.3m in EC contribution. The objective is to assess how this portfolio contributes, in both the short and longer term, to reinforcing Europe's position in automated and cooperative mobility and supporting the industry's technological excellence.

Table 4. CCAM project summary table

Subsection	**Projects**	**Total cost**	**EC contribution**
1 System integration & testing	12	EUR 254.8m	EUR 203.7m
2 Perception and sensing	3	EUR 11.8m	EUR 9.3m
3 Connectivity and communication	3	EUR 12.2m	EUR 12.0m
4 Control and AI decision-making	6	EUR 71.4m	EUR 41.7m
5 Traffic management	4	EUR 27.8m	EUR 23.6m
Total	28	EUR 378.0m	EUR 290.3m

Source: TRIMIS, JRC, 2026

Figure 6. Projects receiving highest funding in the CCAM theme



Source: TRIMIS, JRC, 2026

While the technological core of the portfolio is anchored in Pillar 1 (Innovation and Digitalisation), a project also contributes to Pillar 4 (Workforce skills and the social dimension), addressing skills availability, societal acceptance and organisational readiness as enabling conditions for deployment.

The strategic focus of the CCAM portfolio is structured into the five interlinked technology domains. These were derived by clustering the projects reviewed according to their primary technical contribution, following the functional architecture of CCAM systems – from sensing and decision-making at vehicle level to connectivity, network-level coordination and system-wide validation:

— **System integration and testing**: safety assurance, validation methodologies, scenario generation and operational models supporting regulation-ready deployment.

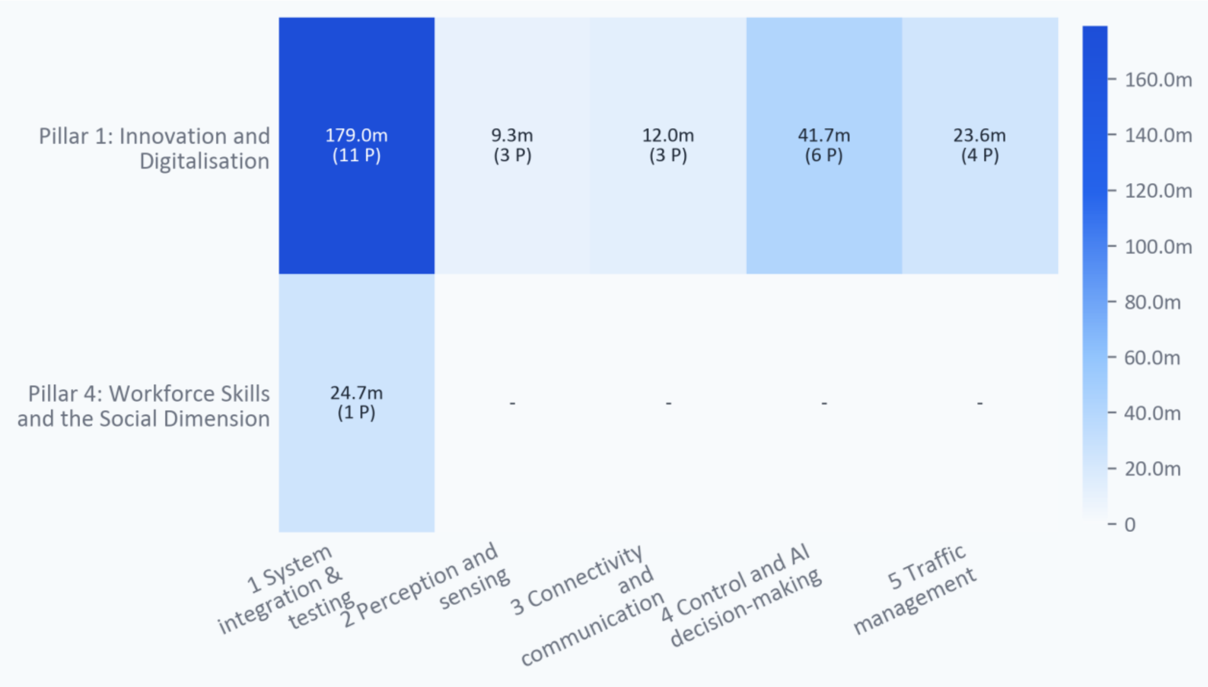
— **Perception and sensing**: advanced sensing and perception capabilities required for robust operation in complex and adverse environments.

— **Connectivity and communication (V2X)**: secure, interoperable and scalable vehicle-to-everything communication architectures enabling cooperative functions, trusted data exchange and cyber-resilient operation across vehicles, infrastructure and digital platforms.

— **Control and AI decision-making**: trustworthy, explainable and accountable AI-based control and decision-making systems aligned with emerging regulatory requirements and safety-critical deployment needs.

— **Traffic management**: system-level coordination of automated and conventional traffic to enable scalable deployment in mixed environments.

Figure 7. CCAM projects by pillar and subsection



Heatmap colour shows funding; annotations show funding and project count (P).

Source: TRIMIS, JRC, 2026

Figure 7 summarises the links between the CCAM project domains and pillars of the automotive plan. These domains are highly interdependent: robust automation requires reliable perception and AI-based decision-making; cooperative operation depends on secure and interoperable connectivity; and scalable deployment relies on integrated validation frameworks and effective traffic management. Ultimately, automotive competitiveness depends on how efficiently these elements can be validated, certified and industrialised within the EU regulatory framework.

4.1.3. Project reviews

4.1.3.1. System integration and testing

System integration and testing is the largest domain in the EU CCAM portfolio, reflecting Europe's focus on safety assurance, regulatory readiness and interoperability. Rather than concentrating solely on component-level innovation, projects in this domain validate complete CCAM systems in real-world conditions, integrating vehicles, infrastructure, digital platforms and governance models.

Early Horizon 2020 projects such as SAFE-UP (2020–2023, RIA), SHOW (2020–2024, IA) and AWARD (2021–2024, IA) established the foundations for system-level CCAM deployment. Through large-scale demonstrations in urban environments, logistics hubs and mixed-traffic conditions, they validated infrastructure-assisted safety functions, shared automation models and freight automation concepts. SHOW deployed 72 automated vehicles across more than 20 European cities, transporting over 166,000 passengers and 5,400 units of goods. SAFE-UP delivered four safety demonstrators with system sensitivity >90%, estimating a potential to prevent over 5,200 fatalities by 2050. AWARD validated all-weather autonomous logistics across five use cases including public roads and port operations.

FAME (2022–2025, RIA) addressed fragmented testing conditions across Member States by delivering a European framework: a standardised taxonomy, a Common Evaluation Methodology (EU-CEM Handbook), a CCAM Test Data Space and a cross-border legal and ethical framework. Its Connected Automated Driving Knowledge Base consolidates European and national CCAM initiatives, with half of referenced projects contributed directly by Member States.

Similarly, ARCHITECTECA2030 (2020–2023, RIA) delivered a comprehensive verification and validation (V&V) framework and a Reference Homologation Process for SAE Level 3+ vehicles, supported by 15 demonstrators across four ECS supply chains and a hierarchical four-layer in-vehicle monitoring concept for residual-risk quantification. Its methods were designed to support type-approval readiness and alignment with emerging AI and safety regulation.

Building on this, SUNRISE (2022–2025, RIA) operationalised European safety validation through a Safety Assurance Framework spanning virtual, hybrid and physical testing, accompanied by an online SAF Handbook and a Data Framework for centralised access to scenario databases. SYNERGIES (2024–2027, RIA) is building a federated European Scenario Dataspace and Marketplace, aligned with ASAM OpenSCENARIO, ISO 34503 and the AI Act, enabling large-scale generation and virtual testing of real, synthetic and AI-generated scenarios.

Large-scale operational validation was further advanced by HI-DRIVE (2021–2025, IA), which conducted over 6,000 test runs with 37 prototype vehicles across 11 European countries, covering motorway, urban, rural and parking environments. The project engaged 1,800 field participants and 20,000 users in acceptance studies, generating cross-country evidence on safety, comfort and human interaction with automated driving.

At the urban and logistics scale, MODI (2022–2026, IA) and ULTIMO (2022–2026, IA) operate at the interface between system integration, regulation and market readiness. MODI is demonstrating SAE Level 4 freight automation across cross-border logistics corridors (Rotterdam–Oslo) and ports, while ULTIMO is deploying fully automated public transport services in city environments. Both projects are generating concrete operational data on fleet performance, service reliability and interoperability with traffic-management systems — essential for moving from pilots to scalable services.

Complementing demonstration efforts, METACCAZE (2024–2027, IA) deploys six integrated smart mobility technologies — including automated charging, AI-based fleet scheduling and V2X protocols — across passenger and freight services in four trailblazer cities (Amsterdam, Munich, Limassol, Tampere). The €24.7 million programme combines technology integration with collaborative business and governance models (MetaDesign), with successful use cases to be transferred to six follower cities and monitored against SUMP/SULP targets.

In parallel, MOVE2CCAM (2022–2025, RIA) developed an Impact Assessment Modelling Tool covering 52 use cases, enabling policymakers and investors to compare scenarios and business cases. By structuring socio-economic impact evaluation, the project reduced deployment uncertainty and strengthened the investment-readiness of CCAM services.

Looking ahead, EEA4CCAM (2025–2028, RIA) addresses next-generation in-vehicle electrical and electronic (E/E) architectures as a prerequisite for scalable deployment. By developing a centralised, upgradable control architecture supporting secure data management and certification-ready integration, the project aims to underpin the transition towards software-defined vehicles.

4.1.3.2. *Perception and sensing*

Perception and sensing are foundational to CCAM performance, as reliable automated driving depends on robust environmental awareness under diverse and often adverse operating conditions. From an industrial perspective, Europe's position in this domain hinges on its ability to deliver deployable, cost-efficient, and safety-certified perception systems that perform consistently beyond controlled testing environments.

ROADVIEW (2022–2026, IA) is combining synthetic data, controlled rain/fog testing and real-world validation to develop weather-aware perception and decision systems. Early results show substantial improvements in LiDAR denoising and sensor performance under snow and fog, with reduced computational requirements. Targeting TRL 7 by project end, the project is expected to support the extension of operational design domains (ODDs) to northern and harsh-climate regions.

At the interaction level, VEVUSAFETY (2022–2024, MSCA) developed deep-learning models for mixed-traffic behaviour understanding, including trajectory prediction and interaction-aware risk assessment for vulnerable road users. The project also demonstrated an 87% reduction in communication overhead for collective perception among connected vehicles, alongside privacy-aware perception approaches using point-cloud data.

TRIPLEYE 3D PERCEPTION SYSTEM (2023–2026, EIC/SME2) focuses on camera-based 3D perception for industrial and special-purpose vehicles. Tested in real operational environments, the solution aims to reduce hardware complexity and calibration time while lowering overall system costs compared to multi-sensor alternatives. These improvements are expected to enhance deployability in safety-critical and resource-constrained ODDs, thereby contributing to Europe's industrial capacity in cost-effective perception technologies.

4.1.3.3. *Connectivity and communication*

Reliable and secure vehicle-to-everything (V2X) communication is a prerequisite for scalable cooperative CCAM deployment. Beyond raw connectivity performance, industrial competitiveness increasingly depends on trustworthy data exchange, cyber-resilience and interoperability across heterogeneous networks.

SELFY (2022–2025, RIA) strengthened the resilience of cooperative CCAM systems by delivering an open-source toolbox of 21 security tools around three domains: situational awareness, cooperative resilience and trust & data management. Demonstrated in Catalonia and Vienna, the project achieved over 95% detection of vulnerable vehicles and over 90% detection of security breaches at TRL6.

CONNECT (2022–2025, RIA) addressed trust at decision level by developing methodologies to quantify and verify trust in cooperative V2X exchanges. Integrated into vehicle-level decision algorithms and tested in real vehicles (e.g. intersection movement assist and cooperative cruise control), the project delivered the open-source Trust Assessment Framework (TAF), released under Apache 2.0 licence, enabling verifiable, trust-aware cooperative automation.

SEEDS (2021–2025, MSCA-RISE) complemented these efforts at network level, developing cross-layer V2X protection mechanisms such as blockchain-based consensus protocols, AI-driven reputation systems and privacy-preserving encryption schemes. Validated through simulations and experimental testbeds, the project demonstrated secure data dissemination architectures supporting trusted cooperative mobility.

4.1.3.4. Control and AI decision-making

Control and decision-making is a core competitiveness factor in software-defined vehicles. Europe's position in CCAM depends not only on AI performance, but on its ability to deliver trustworthy, reliable and regulation-compliant systems. Safe, explainable and certifiable AI is therefore a structural requirement for large-scale deployment.

AITHENA (2022–2025, RIA) developed a harmonised methodology for AI-based CCAM systems covering the full development chain — from data management and model design to testing and validation. By aligning AI development with emerging regulatory frameworks, including the AI Act, the project reduced compliance uncertainty and supported certifiable deployment.

AI4CCAM (2023–2026, RIA) complements this approach by developing an open interoperable digital framework for trustworthy AI in urban deployment. The project has delivered a Trustworthy AI methodology, 12 urban traffic scenarios for simulation-based validation, and explainable scene-understanding models (Qualitative Explainable Graphs) for real-time decision-making, tested across three vulnerable-road-user use cases.

Human-aware modelling is increasingly recognised as essential for mixed-traffic deployment. BERTHA (2023–2026, RIA) develops a probabilistic Driver Behavioural Model based on large-scale driver data, implemented in an open simulation platform. By enabling scalable digital validation and engaging standardisation bodies and Euro NCAP, the project aims to contribute to more predictable automated behaviour and future test protocol development.

At the industrial level, AI4CSM (2021–2025, RIA) delivered AI-enabled electronic components and integrated prototypes for electric, connected and autonomous vehicles. Combining sensor fusion, edge–cloud integration and AI-based control architectures, the project strengthened Europe's capacity to industrialise embedded AI systems and reinforced the competitiveness of the European automotive supply chain.

AWARE2ALL (2022–2025, RIA) complemented this approach by developing inclusive passive and active safety systems together with interior and exterior HMI prototypes for highly automated vehicles in mixed traffic. Through virtual, hybrid and physical demonstrators, the project validated safety performance for non-standard occupant postures and takeover situations, and tested exterior communication interfaces for interaction with vulnerable road users.

COCOS (2025–2030, ERC) explores contract-based control design for complex automated systems, developing scalable formal verification methods that could address an open industrial need: mathematically certifiable behaviour guarantees for autonomous vehicle subsystems.

4.1.3.5. Traffic management

Traffic management is a key lever for Europe's system-oriented CCAM deployment: scaling automated mobility in dense, mixed traffic requires network-level coordination, multimodal integration and governance-compatible decision support. Projects in this domain link CCAM technologies to measurable performance outcomes — such as travel time, efficiency and emissions — while strengthening the operational capability of public authorities and mobility operators.

FRONTIER (2021–2024, RIA) developed and validated AI-enabled traffic management tools across pilots in Oxfordshire, Athens and Antwerp. The project delivered the ANTME platform for real-time multimodal incident management and a Smart Infrastructure Classification Index, demonstrating how coordinated, AI-driven orchestration improves network efficiency and readiness for connected and automated vehicles.

CONDUCTOR (2022–2025, IA) integrated CCAM into traffic and fleet management systems across intermodal interfaces. Demonstrations delivered measurable gains, including reductions in passenger travel time (up to 11%), queue length (up to 15%) and heavy-duty vehicle stops (up to 30%), alongside a 71% decrease in manual interventions and associated CO_2 and NOx reductions. Designed for scalability, the solutions were validated for replication in more than 100 European cities.

IN2CCAM (2022–2025, IA) strengthened this trajectory through large-scale integration across six European living labs. By combining real-world testing with simulation and digital twin technologies, the project validated services such as Green Light Optimal Speed Advisory (GLOSA) and digital twin-based rerouting of autonomous shuttles, providing operational evidence of how automated vehicles can be embedded within intelligent infrastructure and governance frameworks.

AUGMENTED CCAM (2022–2026, IA) complements these efforts by developing a prioritised Physical and Digital Infrastructure (PDI) classification schema, an infrastructure readiness assessment tool and a digital twin framework to assess infrastructure support across operational design domains (ODDs). By linking infrastructure interventions to measurable KPIs, the project aims to reduce deployment uncertainty and support harmonised CCAM roll-out across Europe.

4.1.4. Conclusions and recommendations for CCAM competitiveness

This analysis of the EU's CCAM project portfolio illustrates an R&I strategy oriented toward system-level safety, interoperability and deployment readiness.

Identified strengths

Safety-assurance architecture as a competitive differentiator: The coordinated work of FAME, SUNRISE, SYNERGIES and ARCHITECTECA2030 is assembling a coherent European certification infrastructure — shared methodologies, common taxonomies, the European Scenario Database and a Reference Homologation Process for Level 3+ vehicles. Combined with AITHENA's alignment of AI development with the AI Act, this positions Europe to offer certifiable, regulation-ready CCAM solutions in markets where safety assurance is increasingly a market-access requirement — provided these standards demonstrably accelerate, rather than delay, time-to-market.

Simulation and virtual testing as an industrialisation accelerator: The portfolio's investment in scenario generation (SYNERGIES), open simulation platforms (BERTHA), synthetic data pipelines (ROADVIEW) and digital twins (IN2CCAM, AUGMENTED CCAM) constitutes a development toolchain that can significantly compress validation cycles and reduce time-to-certification — a direct cost and speed advantage over physical-test-dependent approaches, provided these tools are systematically adopted in industrial type-approval workflows.

Operational evidence base across deployment contexts: Through large-scale demonstrations in urban transport (ULTIMO), cross-border logistics (MODI), highway automation (HI-DRIVE) and traffic management integration (CONDUCTOR, IN2CCAM), the portfolio has generated real-world operational data on fleet performance, service reliability and system interoperability across diverse conditions and regulatory environments in Europe.

Identified gaps and possible next steps

Embed business-case validation as a mandatory programming criterion: Business-model tools such as MOVE2CCAM's Impact Assessment Modelling Tool and METACCAZE's collaborative frameworks remain isolated initiatives. Future calls should require quantified business-case assessment, cost targets and a credible path to commercial viability as eligibility conditions — not optional deliverables at project end.

Accelerate certification throughput to match deployment timelines: The safety-assurance architecture under construction is robust but risks becoming a bottleneck if approval pathways remain slow and fragmented across Member States. A concrete next step is to establish mutual recognition of test results and harmonised type-approval timelines, converting the current project-level progress (FAME, SYNERGIES) into a streamlined, predictable certification pipeline.

Create dedicated bridging instruments for post-pilot industrialisation: The portfolio repeatedly demonstrates technical viability at TRL 6–7 but lacks systematic support for the transition to commercial scale. Dedicated funding instruments — comparable in logic to the battery gigafactory support schemes — are needed to bridge the gap between successful pilots and market entry, targeting cost reduction (building on efforts like TRIPLEYE and EEA4CCAM), supply-chain readiness and first-fleet deployment financing.

4.2. Software-Defined Vehicle

4.2.1. State of the art

Growing role of software

The automotive industry is being reshaped by disruptive trends such as CCAM and electromobility. Automated vehicles feature functions such as real-time route optimisation and human-machine interaction systems often rely on computationally intense data processing techniques, such as machine learning and deep neural networks. Similarly, electric vehicles also rely heavily on computing, for example in case of battery management systems. At the same time, also a shift in customer's preferences occurs. The industry is shifting towards a more user-centric approach, with demands for personalised features, over-the-air updates, and in-vehicle infotainment.

Therefore, software is becoming increasingly important and is beginning to replace hardware as the central component of future cars. The traditional hardware-centric approach is giving way to a software-oriented model, with the average car's software containing 100 million lines of code - a number expected to triple by 2030 (Aktas, 2023). This paradigm shift is giving rise to the concept of the software-defined vehicle (SDV), which is set to revolutionise the automotive industry.

In a nutshell, a software-defined vehicle is a modern automobile in which core functions and features are controlled, updated and enhanced through software rather than fixed hardware systems. Traditionally, vehicle functions were tied to physical components and embedded systems with limited flexibility. SDVs instead rely on centralized computing platforms and modular software architectures. These systems allow over-the-air (OTA) updates, where automakers can deliver new features, updates and performance and safety enhancements through software, often remotely.

Centralised architectures

The traditional electronic and electrical architecture (EEA) of cars, with many separate Electronic Control Units (ECUs) for each function (e.g. engine monitoring, braking, safety systems, etc.), is a major obstacle. An average high-end car with advanced driver-assistance systems (ADAS) is likely to contain over 100 ECUs (Deloitte, 2021). This fragmented architecture results in low computing power, high latency, and excessive wiring, making software development and updates cumbersome. With multiple suppliers using different programming languages and standards, updates are slow and labour-intensive, constraining car manufacturers' ability to innovate.

The industry is addressing the issue by moving towards more centralised architectures. This transition is expected to occur in stages, starting with domain centralisation, where Electronic Control Units (ECUs) are reduced and grouped into functional domains (e.g. power, chassis, infotainment) controlled by Domain Control Units (DCUs) with high computing power. Further in-vehicle integration and centralisation of the domains should follow, ultimately leading to central vehicle computing.

This shift in software architecture simplifies vehicle design and production. Thanks to the organisation of the components into functional zones, the distances between them are also reduced, as well as the need for extensive wiring. Complexity of assembly lines is also reduced. Perhaps the most important advantage is that the architecture centralisation entails separation of software and hardware layers and building car software based on a common and clearly defined hardware abstraction. This will allow developers to easily build software functionalities and deliver them remotely over the air, e.g. to enable new features or provide updates, much like in the case of smartphones (European Commission, 2025c) .

This modernization allows SDVs to evolve after purchase, much like smartphones. A vehicle might gain better navigation, improved energy efficiency or even enhanced driving modes through vehicle software updates alone, without having to visit a dealership. These capabilities also allow drivers to personalize their vehicles and subscribe to features on-demand, from advanced driver assistance systems to in-car entertainment upgrades.

Industry challenges

The software-defined vehicle (SDV) model marks a major shift in how cars are designed, built and experienced. Automakers now operate more like software companies, with vehicles functioning as a dynamic, updatable platform. Tesla pioneered this model, demonstrating how software-driven upgrades can unlock new revenue streams and build brand loyalty.

Nonetheless, the traditional automotive software engineering is struggling to keep up with the transition to centralised architectures. The current approach, with independently developed ECUs and embedded software, leads to redundant effort and prevents software reuse. The traditional waterfall software development model — a linear, sequential process in which each phase (requirements, design, implementation, testing) is completed before the next begins — is too rigid, and the industry needs to adopt more agile workflows to accommodate the increasing complexity and interconnectedness of vehicle systems. Development of common implementation standards, middleware, and hardware abstraction concepts become a new necessity. Workforce shortage poses another problem, with a growing demand for IT specialists with automotive domain knowledge, a scarce resource in a field historically dominated by mechanical engineers.

The rise of SDVs has also broader impacts for the whole automotive supply chain, particularly in terms of relationships between vehicle manufacturers and suppliers. OEMs (original equipment manufacturers) are now required to shift their focus from mechanical engineering to digital innovation. This new approach reshapes expectations and unlocks business models based on software, not just hardware. Furthermore, to address the need for standardisation and flexibility, some OEMs are investing in their own software departments, while also recognizing the need for closer collaboration with suppliers to define new technological requirements.

Global competition

Apart from the purely engineering challenges, the EU also faces growing competition from non-EU manufacturers, car makers and tech companies. To remain competitive, the EU OEMs and suppliers must profoundly restructure their hardware-based business model, while some of the non-EU manufacturers have the advantage of adopting the software-driven approach from the outset. For example, Tesla benefits from a highly centralised vehicle architecture with no legacy, enabling state-of-the-art over-the-air software update capabilities.

The market is also entered by non-automotive enterprises seeing SDVs as a new growth opportunity. Some of the non-EU semiconductor companies offering integrated hardware-software platforms announced new automotive partnerships (European Commission, 2023). Large tech companies, such as Google, can take advantage of their enormous software budgets and resources, and dominate some areas of the market. Chinese OEMs such as BYD, supported by state subsidies, might transform towards software-oriented development faster, and potentially compete in the European market, after complying with the EU data privacy regulations (European Commission, 2023).

European SDV R&I ecosystem

Development of common standards and software architecture abstractions is essential for successful SDV development, making close collaboration of all automotive stakeholders a necessity. This awareness is growing in the industry, resulting in a rising number of SDV-focused partnerships and alliances. To coordinate these efforts, the European Commission established the Vehicle of the Future initiative. The initiative, involving major European automotive manufactures, R&I organisations, and SMEs, is organised into two streams. The software stream emphasises common, largely open-source building blocks, interfaces, and tools. It promotes modular software based on open-source standards with improved maintainability, portability, and faster time-to-market. The hardware stream collaborates on a RISC-V based automotive hardware platform to deliver a next generation hardware architecture, including processors with AI computing capacity[14].

[14] European Commission, 'European Digital Vehicle Ecosystem", accessed 7 May 2026, https://digital-strategy.ec.europa.eu/en/policies/digital-vehicle-ecosystem.

4.2.2. EU R&I overview

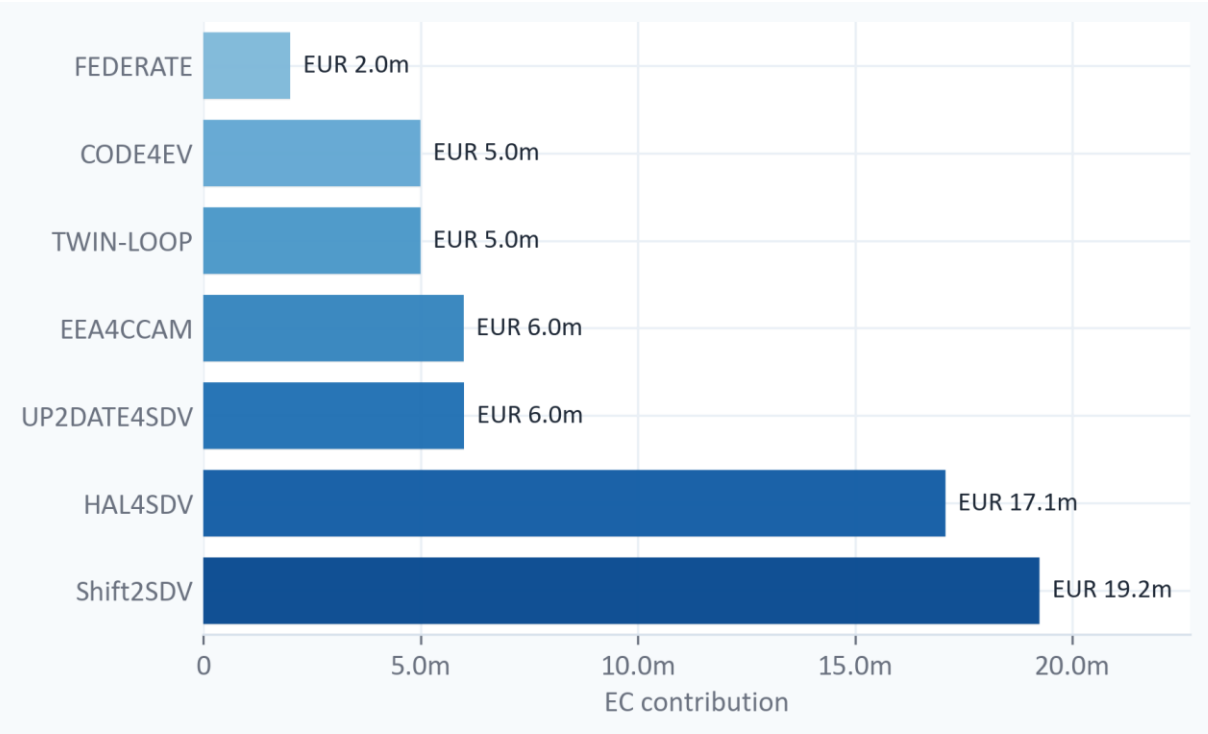
This section contains 7 projects (**Table 5**), representing EUR 154.0m in total cost and EUR 60.3m in EC contribution. The most common development stage is Lab prototype & testing (TRL 3-5); the dominant primary pillar is Pillar 1: Innovation and Digitalisation.

Table 5. Software Defined Vehicle project summary table

Subsection	Projects	Total cost	EC contribution
1 Coordination actions	1	EUR 2.0m	EUR 2.0m
2 Hardware abstraction	3	EUR 136.0m	EUR 42.3m
3 SDV for electric vehicles and CCAM	3	EUR 16.0m	EUR 16.0m
Total	7	EUR 154.0m	EUR 60.3m

Source: TRIMIS, JRC, 2026

Figure 8. Projects funding in the SDV theme



Source: TRIMIS, JRC, 2026

The projects are divided into three core domains:

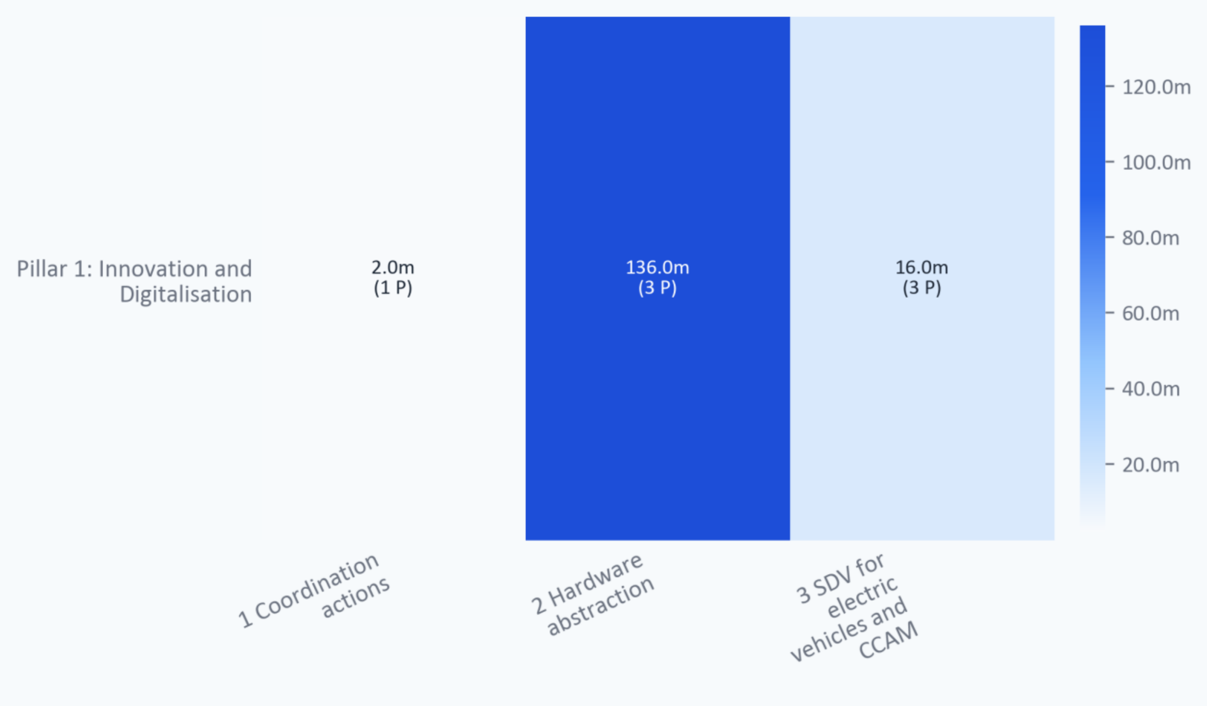
— **Coordination actions:** High-level projects focused on creation of a European SDV ecosystem, common strategy and R&I action plan.

— **Hardware abstraction:** Projects working on the technological development of SDV components related to hardware abstraction.

— **SDV for electric vehicles and CCAM:** Projects with a narrower focus on particular automotive domain, e.g. CCAM and electromobility.

All projects on SDV fall within the scope of Pillar 1: Innovation and digitalisation (**Figure 9**).

Figure 9. SDV projects by pillar and subsection



Heatmap colour shows funding; annotations show funding and project count (P).

Source: TRIMIS, JRC, 2026

4.2.3. Project reviews

4.2.3.1. Coordination actions

FEDERATE (2023 – 2026, CSA) is a strategic initiative aimed at uniting the key automotive stakeholders to create a common vision for the development of the European SDV concept. The project gathers representatives of major European OEMs, automotive tiers, semiconductor companies, relevant industry associations and industrial SDV initiatives, and is supported by a scientific board. The activities include guidance to ongoing and future projects, shaping a roadmap for accelerated SDV R&I, and creation of a common understanding (glossary) for the SDV community.

4.2.3.2. Hardware abstraction

Several projects focus on development of the hardware abstraction concept, in particular development of middleware solutions that can be integrated into existing automotive standards and would allow for flexible modifications to the software and hardware layers in the vehicle.

HAL4SDV (2024 – 2027, RIA) aims at pioneering methods, technologies, and processes for series vehicle development beyond 2030, driven by anticipated advancements in microelectronics, communication technology, software engineering, and AI. The objectives include unifying software interfaces, creating a hardware abstraction framework, enabling Over-The-Air (OTA) updates, designing platform architectures, ensuring hardware abstraction and virtualisation, offering hardware support, automating integration, supporting safety features, harnessing edge computing, implementing security measures, and providing essential development tools.

The UP2DATE4SDV (2025 – 2028, RIA) project aims to develop a comprehensive ecosystem for seamless and efficient software updates, hardware upgrades and situation-dependent reconfigurations of SDVs. The project focuses on the definition and development of three abstraction layers: the hardware abstraction layer (HAL), the OS/MW abstraction layer (OAL) for the operating system (OS) and middleware (MW), and the exploration and prototyping of a secure orchestration and reconfiguration layer (ORP) between the vehicle and the cloud.

SHIFT2SDV (2025 – 2028, IA) will create a SDV ecosystem using a middleware and API framework to enhance collaboration in the automotive sector. By developing a modular framework with microservices, the project will address the limitations of current systems, ensuring compatibility with both in-vehicle and cloud technologies. Key goals include establishing a secure architecture, simplifying application development, and integrating edge computing.

4.2.3.3. SDV for electric vehicles and CCAM

Some of the projects focused on software-defined architecture in a more specific context.

CODE4EV (2025 – 2027, RIA) aims to accelerate the development of electric SDVs by establishing a collaborative development framework. The framework will support the design, production and operational phases of electric vehicles by demonstrating its application through selected use cases relevant to emerging and future SDV architectures. The project key objective will be the elaboration of digital design tools and a trustworthy development methodology for electric SDVs.

Another project focused on electromobility is TWIN-LOOP (2025 – 2027, RIA), which leverages high-performance computing, cloud technology, and SDV architecture to create a digital twin framework for EVs. The purpose of the tool is to continuously improve energy efficiency, driver experience, and resilience of the vehicle.

EEA4CCAM (2025 – 2028, RIA) focuses on CCAM, developing in-vehicle electronic control architectures for CCAM applications, ensuring safe and cyber-secure deployment across diverse operating conditions. This will be achieved by a shift in in-vehicle electronic control architectures, developing a centralised, upgradable, and open-source design that integrates HW and SW co-design, enables smart data flows, and ensures safe and cyber-secure operation. The outcomes of the project will lay foundations for the SDV, as well as for CCAM adoption and more connected transportation system.

4.2.4. Conclusions and recommendations

This analysis of the EU's software-defined vehicle project portfolio illustrates an R&I strategy oriented toward large-scale industry collaboration, common software standards and a shared architecture vision.

Identified strengths

Strong industry collaboration: Automotive industry stakeholders joined their collective forces at large scale, which is essential for developing common SDV standards and vehicle architectures. Initiatives like Vehicle of the Future help to coordinate these efforts.

Common vision: The strong industry collaboration facilitated the development of a common long-term vision and orchestration of efforts, expressed in the Vision and Roadmap developed by the FEDERATE project.

Identified gaps and possible next steps

Difficult start and heavy global competition: The EU automotive industry must go through a deep transformation from the hardware- to software-based model. This gives competitive advantage to non-EU companies which have taken this approach from the outset, and established software-oriented companies entering the automotive market

No supply chain independence: The EU automotive industry is largely dependent on external supply chains for some critical SDVs components, such as semiconductors.

Lack of qualified workforce: Change of profile of an automotive engineer from mechanical-oriented towards IT-oriented is expected to cause workforce shortages as the industry moves towards SDV.

Regulatory barriers: Regulations do not keep pace with the quickly changing technology, contributing to delays in type approval, burdensome homologation procedures, restrictive data protection laws, and fragmented cybersecurity regulations.

4.3. Batteries for electric vehicles

4.3.1. State of the art

The global battery landscape is defined by a significant expansion in manufacturing capacity and a rapid diversification of chemistry and manufacturing pathways. While the market remains concentrated, the transition from fundamental laboratory research to applied, industrial-scale innovation is accelerating (European Commission, 2025a).

Market trends

The global battery market is experiencing significant growth. Asia Pacific continues to hold a dominant position, accounting for approximately 67% of the global market share in 2025, driven by the production scale of incumbents CATL and BYD[15]. Localisation strategies in Europe and North America aim at reducing strategic dependencies on imported processed materials (European Commission, 2025a). As part of the Battery Booster package, EUR 1.5 billion of EU funding will support European battery cell producers through interest-free loans.

For the automotive sector, lithium-ion remains the primary chemistry. The industry is facing a structural challenge of global overcapacity; in 2025, manufacturing capacity reached over 4,000 GWh while demand was below 2,000 GWh. This overcapacity is triggering intense price-driven competition, forcing European manufacturers to focus on technology-led differentiation rather than simple volume (European Commission, 2025a).

Trends in research

Current scientific literature and industrial roadmaps highlight several pathways for battery cell technology:

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[15] Fortune Business Insights, 'Battery market size, share, trends | Growth report [2034]', accessed 7 May 2026, https://www.fortunebusinessinsights.com/battery-market-105615.

— **Advanced Lithium-ion (Gen 3b):** Research is focused on pushing liquid and gel-based systems to their theoretical limits.

— **Solid-state batteries (Gen 4):** The transition from R&D to early-stage commercialisation is underway. Recent breakthroughs have demonstrated lithium-metal solid-state cells reaching energy densities of 1,070 Wh/L at the cell level[16]. Global research activity is heavily concentrated on sulphide, polymer, and halide electrolytes, with a strong focus on the stabilisation of the lithium-metal anode interface[17].

— **Alternative chemistries (Sodium-ion):** Sodium-ion has emerged as a viable, low-cost alternative for budget EVs.

The role of digitalisation and AI in R&I

A transformative trend in 2025-2026 is the systematic integration of AI and high-performance computing into the R&I lifecycle. Researchers are utilising AI foundation models to accelerate material innovation[18]. This approach has already led to the identification of new solid-state electrolytes, such as N2116, projected to reduce lithium use by up to 70%, now undergoing experimental validation (Chen et al., 2024).

Circularity and supply chain resilience

Strategic research is no longer isolated to performance but is increasingly driven by regulatory requirements for circularity. Global efforts are intensifying in "direct recycling," where cathode materials are regenerated without the energy-intensive processes of traditional smelting (Lai et al., 2025). This alignment with sustainability goals is turning "design-for-circularity" and the implementation of the "Battery Passport"[19] from administrative requirements into core competitive advantages (European Commission, 2025a).

Recent research indicates that battery innovation in transport is increasingly evaluated across the full life cycle, including second-life use, recycling, and end-of-life management, rather than solely focusing on chemistry, performance, and manufacturing. Reviews of the field particularly highlight a growing emphasis on residual-value assessment, battery diagnostics, echelon re-utilisation, and process routes for recovering critical materials (Esmaeilian et al., 2026; Xiao et al., 2025).

Literature also identifies a stronger role for operational enablers of circularity. More broadly, recent mapping of EV research underscores the increasing prominence of environmental and sustainability-oriented themes within the field, reinforcing the relevance of circularity, end-of-life management, and resource recovery in battery-related research (Haghani et al., 2025). These include collection, sorting, transportation, disassembly, robotics, artificial intelligence, digital twins,

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[16] Energy Ville, Lithium-metal battery with novel solid electrolyte achieves 1070 Wh/L through cost-effective manufacturing process, accessed 7 May 2026, https://energyville.be/en/news/lithium-metal-battery-novel-solid-electrolyte-achieves-1070-whl-through-cost-effective-manufacturing-process.

[17] IDTechEx, 2025, Solid state batteries in 2026: From hype to adoption, accessed 7 May 2026, https://www.idtechex.com/en/research-article/solid-state-batteries-in-2026-from-hype-to-adoption/33914.

[18] ANL, 2025, Building AI foundation models to accelerate the discovery of new battery materials, accessed 7 May 2026, https://www.anl.gov/article/building-ai-foundation-models-to-accelerate-the-discovery-of-new-battery-materials.

[19] EU Battery Passport Guide — Requirements, Timeline & Compliance, accessed 1August 2026, https://dpp-tool.com/en/guide/battery-passport/.

and digital product passports, which support traceability, process optimisation, and safer end-of-life handling (Esmaeilian et al., 2026).

Recent studies also introduce a spatial and policy dimension to these challenges. They reveal that end-of-life battery flows are likely to be uneven across regions, recycling capacity may not match future retirement volumes, and cross-border movements of used EVs can heighten the importance of state-of-health controls, logistics planning, and coordinated end-of-life governance (Liu et al., 2025; Parés Olguín et al., 2023).

4.3.2. EU R&I overview

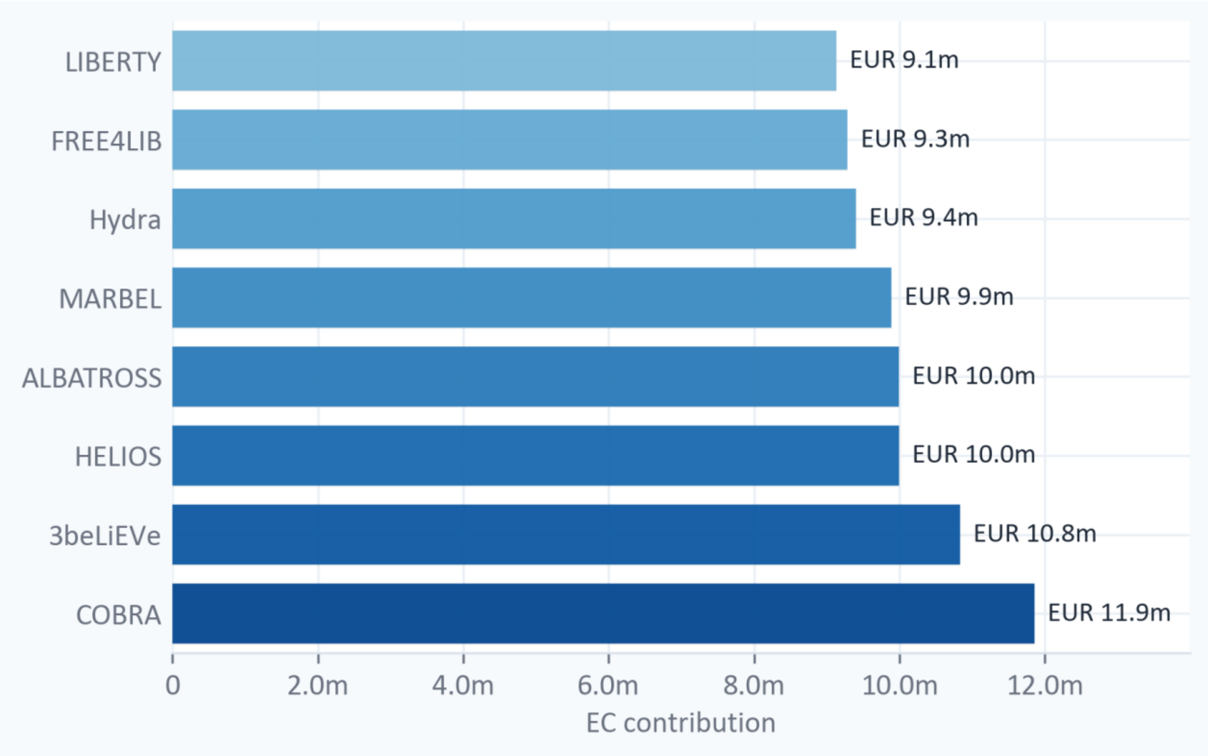
For the European automotive sector, securing a competitive, sovereign, and sustainable battery supply chain is a critical requirement. The European Union, through the framework programmes and the formation of the BATT4EU Partnership, is addressing this channel by programming and funding a broad portfolio of research and innovation projects, in addition to the support to the industry via the Innovation Fund. This section contains 45 projects, representing EUR 295.6m in total cost and EUR 285.2m in EC contribution (**Table 6**). The high average funding rate (>96%) is explained by the predominance of RIA actions in this section. The most common development stage is Pilot production & demonstration (TRL 6-7); the dominant primary pillar is Pillar 2: Clean Mobility. The objective of this analysis is to provide an overview of the multi-dimensional framework of the EU's strategy for batteries and assess its short- and longer-term impact on European automotive competitiveness.

Table 6. Batteries project summary table

Subsection	Projects	Total cost	EC contribution
1 Core cell technology	14	EUR 100.1m	EUR 100.1m
2 Manufacturing & industrialisation	8	EUR 47.0m	EUR 44.2m
3 System & pack integration	5	EUR 43.0m	EUR 37.6m
4 Digitalisation	6	EUR 33.0m	EUR 31.6m
5 Circularity & recycling	10	EUR 64.0m	EUR 64.0m
6 Ecosystem & resilience	2	EUR 8.5m	EUR 7.8m
Total	45	EUR 295.6m	EUR 285.2m

Source: TRIMIS, JRC, 2026

Figure 10. Projects receiving highest funding in the EV batteries theme



Source: TRIMIS, JRC, 2026

The EU's battery R&I portfolio follows a coherent multi-dimensional strategy. We divide the strategic focus of this portfolio into six clusters:

— **Core cell technology:** The portfolio simultaneously funds the optimisation of near-term Generation 3b liquid/gel batteries—primarily a cobalt-free lithium-nickel-manganese-oxide cathode with a silicon-graphite anode—for the 2025-2028 market. Concurrently, it places a long-term investment in Generation 4 solid-state batteries to achieve long-term technological competitiveness. This effort is supplemented by an alternative development track of sodium-ion chemistries.

— **Manufacturing and industrialisation:** The EU is investing in novel, next-generation processes: NMP-free aqueous processing, solvent-less dry-coating, 3D additive manufacturing, and Pulsed Laser Deposition, to replace current solvent-heavy manufacturing processes. This strategy aims to build a new industrial base with a potential competitive advantage in cost (lower CapEx/OpEx) and sustainability.

— **System integration and pack architecture:** The portfolio moves beyond the cell to address the pack and its full lifecycle. It funds innovation in OEM-centric areas like Cell-to-Pack (CtP) architectures and advanced thermal management.

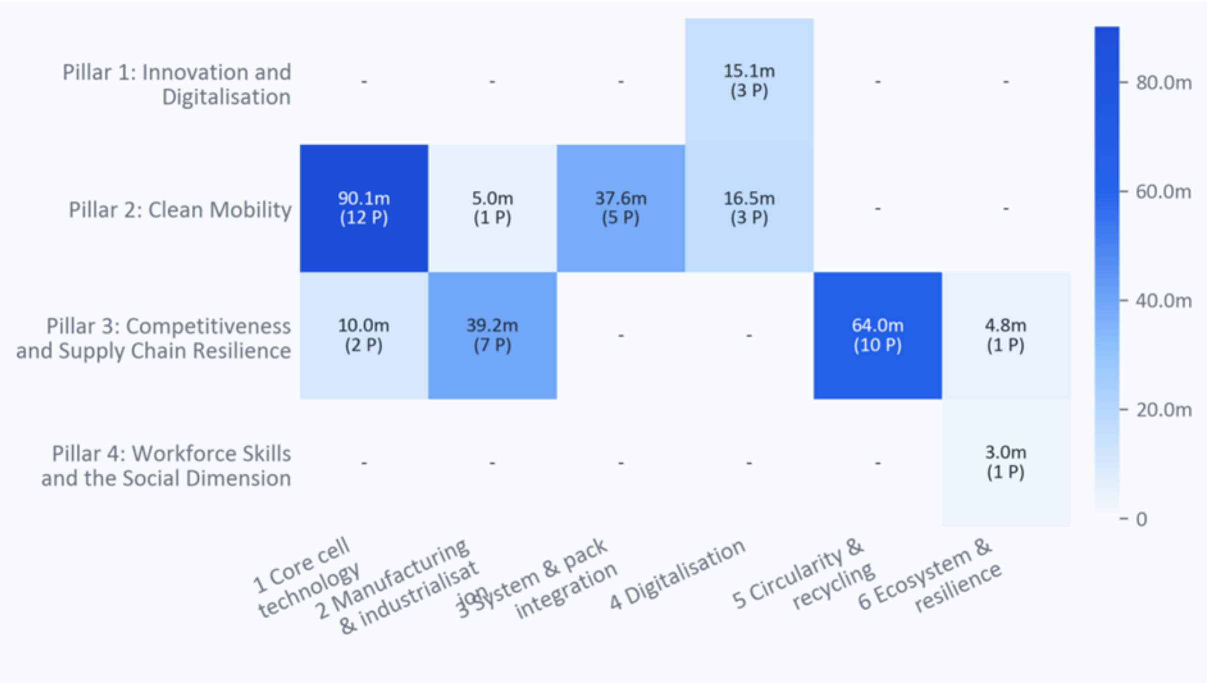
— **Digitalisation:** The projects under this cluster leverage existing EU strengths in automotive software, embedded systems, and AI. The EU battery R&I is fostering the development of a "software-defined battery" funding advanced, AI-driven Battery Management Systems, Digital Twins for R&I acceleration, and embedded in-cell sensors.

— **Circularity and recycling:** This project cluster includes projects that integrate "design-for-dismantling" and "design-for-circularity" principles, develop material recovery methods, and also consider the second life of automotive batteries.

— **Supply resilience and battery ecosystem:** The entire battery project portfolio is supported by a coordination initiative overseeing all projects and defining common KPIs. Another important project addresses raw material sovereignty, focusing on creating a resilient end-to-end European supply chain for graphite.

All projects contribute to Pillar II Clean Mobility of the Automotive Plan through the development of battery technologies for electric vehicles, nevertheless this is also achieved through actions oriented towards digitalisation, supply chain and manufacturing, therefore the link to Pillars I and III is quite prominent (**Figure 11**). Furthermore, there are interdependencies between the clusters —new chemistries are enabled by new manufacturing processes and new digital systems.

Figure 11. EV battery projects by pillar and subsection



Heatmap colour shows funding; annotations show funding and project count (P).

Source: TRIMIS, JRC, 2026

4.3.3. Project reviews

4.3.3.1. Core cell technology

The largest cluster in the portfolio, with over 15 projects, is dedicated to advancing core cell technology and chemistry. Analysis of this cluster reveals a dual-track strategy. The EU is funding (A) the optimisation of Generation 3b liquid/gel batteries for market deployment (2025-2028) and (B) a future focus into Generation 4 solid-state and lithium alternatives for long-term (2030+) strategic autonomy and competitiveness.

Gen 3b Liquid/Semi-solid battery cells

This cluster represents a pragmatic, short-term approach to provide European OEMs with competitive, next-generation cells in the 2025-2028 timeframe. The goal is to push high-performance liquid and gel-based lithium-ion (Li-ion) batteries to their theoretical limits, with a specific focus on cost, energy density, and the elimination of problematic critical raw materials.

A clear consensus has formed within this cluster around a specific "platform" chemistry: the high-voltage, **cobalt-free LNMO (Lithium-nickel-manganese-oxide) cathode** paired with a **high-capacity silicon-graphite (Si-C) anode**.

3BELIEVE (2020–2023, RIA) was a key project for this platform. Its objective was to deliver 3b generation of LNMO cells with a 10–20 wt.% Si-C anode. The performance targets were aligned with automotive EV requirements: 750 Wh/l, 300 Wh/kg, 1.4 kW/kg, and 2,000+ deep cycles. The technology is free of critical raw materials (cobalt and natural graphite), a response to both the cost volatility of cobalt and the supply risk of graphite. The project delivered two 12 kWh battery packs at TRL 6 for validation. HIGHSPIN (2022–2026, RIA) is a direct follow-on, aiming to further develop the LNMO||Si/C cell chemistry compared to the reference 3beLiEVe baseline. Its targets are higher, aiming for 390 Wh/kg and 925 Wh/l.

HYDRA (2020–2024, RIA): This project confirmed the platform consensus, also developing cobalt-free LNMO-based cathodes and "Si/graphite anodes. It also innovated on the manufacturing side by using water in place of organic solvents. The COBRA project (2020–2024, RIA) served as a diversified technology option, pursuing similar goals (cobalt-free, silicon anode) but with a "Li-rich NMC" cathode instead of LNMO.

NEXTCELL (2023–2026, RIA) acts as a bridge towards solid state batteries. It uses the same LNMO/Si-C platform but develops a novel "gellified cell concept". This "gellified" or semi-solid approach promises higher safety than fully liquid electrolytes and avoiding the electrolyte-filling step, which is a manufacturing innovation. EXTENDED (2023–2026, RIA) provides another "bridge" technology, developing a "semi-solid-state battery technology" to deliver large 35Ah cells. Like NEXTCELL's gel, this approach may offer a faster path to commercialisation by mitigating the most difficult solid-state manufacturing challenges.

Gen 4 solid-state chemistries

This cluster is large and strategically significant in the portfolio. The mature liquid Li-ion market is dominated by Asian incumbents, and the EU funds a concerted effort to develop Generation 4 solid-state batteries (SSBs) and commercialise them at scale. SSBs promise a step-change in energy density (>450 Wh/kg) and intrinsic safety by eliminating flammable liquid electrolytes. The project portfolio explores major solid-state electrolyte chemistries.

Sulphide-based: SUBLIME (2020–2024, RIA) was focused on new sulphide electrolyte based solid-state battery cells. This pathway is known for its high ionic conductivity but is sensitive to moisture, making manufacturing difficult. The project aimed to bring this high-potential technology to TRL 6.

Polymer & hybrid-based: This is a potentially scalable approach that can be more compatible with existing manufacturing. ASTRABAT (2020–2023, RIA) developed a solid hybrid electrolyte with polymer-based electrolytes and patented the method. SAFELIMOVE (2020–2023, RIA) pursued an advanced hybrid ceramic-electrolyte (polymer-ceramic).

Halide-based: HELENA (2022–2026, RIA) explores the newer, high-potential halide solid state batteries. Halides offer good conductivity and are potentially more stable against high-voltage cathodes, making them a key target for application in electric vehicles.

Hybrid (oxide/sulphide): ADVAGEN (2022–2026, RIA) takes a pragmatic approach by developing a new lithium metal (LiM) battery cell technology based on a hybrid solid-state electrolyte, attempting to combine the stability of oxides with the high conductivity of sulphides. The project produced two patents.

Additive manufacturing: AM4BAT (2022–2026, RIA) aims to develop innovative component materials and assemble an anode-free all-solid-state battery manufactured by a cost-competitive and sustainable photopolymerisation 3D printing to reach each a high-performance battery the energy density of 400 Wh/kg and 1000 Wh/L.

Sodium-Ion (Na-ion): HYSOBATT (2023–2025, MSCA) and 4SBATT (2022–2027, ERC) investigate rechargeable solid-state Na batteries as an alternative to lithium-based technology. The objective is to secure resource independence by developing viable battery chemistries for automotive applications that do not rely on critical raw materials, most notably lithium, cobalt, and graphite.

4.3.3.2. Manufacturing and industrialisation

Further analysis of the battery project portfolio reveals a focus on competitive industrial manufacturing, funding R&I on novel manufacturing processes that, if successful, could become more competitive than incumbent, capital-intensive processes. This strategy aims to alter the manufacturing landscape targeting a potential competitive advantage in cost, sustainability, and flexibility.

Solvent-free processing

A key target of this sub-cluster is the elimination of N-Methyl-2-pyrrolidone (NMP), which is a toxic, environmentally harmful, and expensive solvent used in conventional electrode coating. As noted in the NoVOC project, its elimination reduces the capital costs associated to the solvent recovery system, which can account for a significant portion of a gigafactory's CapEx and OpEx (energy).

The portfolio is addressing this problem on two parallel tracks:

1. **Aqueous (water-based) processing:** This approach replaces NMP with water. It is a TRL 6 route as it is a "drop-in" modification for existing "wet coating systems".
2. **Dry-coating processing:** This process is targeting a TRL of 5. It eliminates solvents entirely, mixing active material and binder as a dry powder and extruding it onto the foil. This process is faster, cheaper, and has a fraction of the energy footprint.

GIGAGREEN (2022–2026, RIA) illustrates this dual-track strategy, explicitly investigating two alternative R&I trajectories, one based on NMP-free wet processing and a second based on dry processing. The NOVOC (2022–2026, RIA) project follows the same approach aiming to design and demonstrate two competitive cell manufacturing technologies, aqueous and dry. Finally, SOLID (2022–2026, RIA) focuses on roll-to-roll (R2R) dry extrusion coating.

Novel manufacturing

This is the exploratory cluster aiming to offer alternatives to conventional roll-to-roll manufacturing, as the viability of *Gen 4 chemistry* (Li-metal) investigated in the projects above is highly dependent on the viability of a *new manufacturing process* such as Pulsed Laser Deposition (PLD).

Additive manufacturing: VERSAPRINT (2023–2026, RIA) uses 2D/3D printing directly on battery components to integrate thermal and safety-oriented functionalities. This integration of manufacturing and pack design creates "smart" components.

Pulsed laser deposition: The Gen 4 solid-state batteries that use a lithium-metal (LiM) anode have a significant challenge: Li-metal is difficult to produce as a stable, ultra-thin foil, therefore there is a synergy between novel manufacturing techniques and the development of cells. PULSELION (2022–2026, RIA) develops a novel pulsed laser deposition technique for manufacturing of anode components composed of lithium metal, with participant PULSEDEON holding a patent on the roll-to-roll PLD technology. SOLID (2022–2026, RIA) is also developing cost-efficient R2R pulsed laser deposition, which enables minimising the Li thickness down to 5 μm.

Nanostructured fabrics: ELECTROFLOAT (2023–2024, ERC) proposed a new method to produce high capacity nanostructured silicon fabrics to manufacture high silicon (Si) content anodes for the next generation LIBs (3b and 4a).

Industrial TRL 6+ pilot lines

Several of the projects equally aim to bridge the gap between a lab-scale cell and an industrially relevant, mass-producible prototype.

GIGABAT (2023–2026, IA) focuses on sustainable and digitalised gigafactory production utilising made-in-Europe machinery. It targets the development of energy-efficient manufacturing equipment for GEN3b lithium-ion batteries, pilot plant validation in real environments, improved energy and carbon management, and more integrated plant design, including logistics and recyclability considerations.

The SPINMATE (2022–2026, RIA) objective is to demonstrate a scalable and sustainable proof-of-concept pilot line, at a TRL6 level for the large-scale manufacturing of generation 4b SSB cells. The project integrates Industry 4.0/5.0 tools – IIoT, machine-learning algorithms, digital twins and giga-factory simulation – to digitalise the pilot line and manufacturing processes. The **PULSELiON** project aims to be upscaled to a pilot line proof-of-concept (TRL 6), with partner ABEE preparing a 0.5 GW solid-state cell factory in Belgium. ADVAGEN has a pragmatic approach of adapting an existing liquid-state line for solid-state cell assembly, aiming to reduce the CapEx cost of re-tooling for European manufacturers.

4.3.3.3. System integration and pack architecture

This section focuses on the pack-level system integration—the traditional domain of European OEMs.

Pack architecture: This project cluster demonstrates a focus on areas where European OEMs and Tier 1 suppliers add value. Innovation here is focused on lightweighting, modularity, safety, and performance at the pack level. A clear trend is the move toward **Cell-to-Pack** (CtP) or **module-free** designs, which reduce weight, cost, and complexity. BATSS (2024–2026, RIA) develops a new cell-to-pack modular concept for heavy-duty transport applications, while TEMPEST (2023–2026, RIA) develops module-free battery systems.

LIBERTY (2021–2024, IA) and ALBATROSS (2021–2025, IA) were OEM-led vehicle integration projects, both targeting a lightweight battery system for a 500 km range. These projects include key innovations such as immersion-cooling (LIBERTY) and robotic tools for sustainable dismantling (ALBATROSS).

4.3.3.4. Digitalisation

The projects in this section are aiming for a “software-defined battery” that is safer, longer-lasting, and more performant than a conventional one. Digitalisation is also a key enabler for the advanced chemistries and manufacturing lines. The digital and chemical R&I streams are therefore co-dependent.

Advanced BMS & state estimation: NEMO (2023–2026, RIA) and ENERGETIC (2023–2026, RIA) are advancing battery management systems by engaging advanced physics-based and data-driven battery models, developing both software and hardware to perform BMS functions with edge and cloud computing. ALBATROSS and MARBEL pack integration projects confirm the trend. Both are developing a cloud-connected Battery Management System. This shows the digital integration is moving from the cell to the pack to the vehicle and finally to the cloud, turning the entire battery into a full-scale IoT device for fleet management, predictive maintenance, and V2G (Vehicle-to-Grid) applications.

Digital twins & R&I modelling: The DEFACTO project (2020–2023, RIA) has developed an open-source battery modelling and design optimisation tool, targeting the reduction of development time and cost for battery cells by up to 30%. HELIOS (2021–2025, IA) was a pack integration project that included a digital twin to optimise performance and process circularity. The SPINMATE project includes digital twins for giga-factory line simulation.

Embedded sensors & self-healing: The PHOENIX project’s (2023–2027, RIA) objective is to develop battery cells with integrated sensors (mechanical, enhanced impedance spectroscopy, temperature, gas, reference electrode) and self-healing functionalities. First-generation sensors have been built and integrated into cells for validation. INFRALYTICS (2025–2030, ERC) is an ERC project that aims to integrate infrared wave spectroscopy (IR-FEWS) into battery cells for "real-time monitoring of battery chemistry dynamics.

4.3.3.5. Circularity and recycling

A substantial share of the European battery research portfolio is dedicated to circularity, end-of-life management and closed-loop resource use. Across these projects, batteries are treated not only as waste streams, but also as assets that can be diagnosed, repurposed, dismantled and reintegrated into production. The portfolio therefore addresses three interrelated priorities: extending battery lifetime through second-life applications, recovering critical raw materials through advanced recycling, and linking battery manufacturing with circular material flows.

Design-for-circularity: This is a forward-looking group of projects that aligns R&I with forthcoming EU regulations, such as the EU Battery Passport's requirements for recycling and recycled content. The objective is to turn this regulatory requirement into a design advantage. The key trend is shifting from a focus on recycling (a chemical/metallurgical process) to a design-led focus on design-for-dismantling, re-manufacturing, and re-use.

MARBEL (2021–2025, IA) was a key H2020 project for this concept. It designed, developed and demonstrated modular battery packs that are easy to pack together and to disassemble to ease the manufacture and dismantling. This is circularity-by-design, creating a pack that is valuable at its end-of-life for second-life applications or material recovery. The VERSAPRINT project, included in the manufacturing section, has also circularity elements. Its 3D-printed busbars are a key enabler easy and safe dismantling and re-manufacturing. SAFELOOP (2024–2027, RIA) aims to develop the world's first EV-rated lithium-ion battery using up to 25% recycled and fully rejuvenated battery-active materials. GIGABAT (2023–2026, IA) targets among other production objectives an integrated plant design, including logistics and recyclability considerations.

Diagnostics, dismantling, and second life: Another group of identified projects addresses diagnostics, automated dismantling, safe logistics and second-life reuse. RECIRCULATE (2023–2026, RIA) develops an integrated circular approach. It combines AI-driven dismantling, rapid SoX characterisation, smart logistics, and a blockchain-based battery passport and marketplace. Its objective is to support repair, reuse, remanufacturing and recycling across the battery value chain. REINFORCE (2023–2027, RIA) develops a standardised, automated and safe value chain for end-of-life batteries from electric-vehicle and stationary applications. It integrates collection and reverse logistics, diagnostics, robotic dismantling and traceability tools. The system will be validated at pilot scale, reaching a TRL 6 level. REBELION (2023–2026, RIA) addresses similar challenges through fast battery testing, autonomous pack and module disassembly, improved labelling supported by digital tools, and enhanced safety systems. It also develops smart storage and transport concepts, including thermal monitoring and container-based safety solutions, to support both second-life use and recycling. REBORN (2025–2028, IA) focuses specifically on second-life battery packs and battery management solutions. It introduces solderless mechanical interconnections, wireless RF communication between cells and the BMS, cloud-based data transfer, physics-based AI algorithms and semi-automated robotic dismantling. The project is intended to accelerate post-characterisation, screening and sorting for mobility and stationary applications.

Recovery of critical raw materials: The final group of projects targets advanced recycling and the recovery of critical raw materials. RELIEF (2022–2025, RIA) focused on lithium recovery from secondary raw material sources beyond conventional battery scrap. It targeted to reduce unrecovered lithium waste by more than 70% through an integrated continuous-processing route that produces battery-grade materials. The integrated process up to battery precursor recovery was developed to TRL 5, while the battery active-material closed-loop process reached TRL 4. FREE4LIB (2022–2026, RIA) develops six sustainable and efficient recycling processes for end-of-life lithium-ion batteries. These cover dismantling, pre-treatment and material recovery, and are complemented by reuse routes for metals and polymers, electrode synthesis for remanufacturing, a battery-passport methodology and digital optimisation tools. The project targets TRL 5–6. RESPECT (2022–2026, RIA) develops a flexible closed-loop recycling chain that can treat different lithium-ion chemistries, applications and battery states. It combines two main recycling routes, full hydrometallurgy and direct recycling, and includes life-cycle assessment, safety and sustainability considerations, with validation planned up to pilot scale. RHINOCEROS (2022–2026, RIA) develops and demonstrates economically and environmentally viable routes for reusing, repurposing, reconditioning and recycling end-of-life electric-vehicle and stationary batteries. It combines smart sorting and dismantling, reassembly of working modules into repurposed batteries, and circular recycling routes for cathodic, anodic and other raw materials. RENOVATE (2024–2026, RIA) develops a circular and chemistry-neutral approach for recycling and recovery of battery waste feeds. It aims to recycle and reuse battery components and industrial side streams, while reducing virgin material demand, supplier dependence and waste generation.

Taken together, these projects demonstrate that circularity is not considered as confined only to end-of-life treatment, but part of a holistic value chain, including battery diagnosis, second-life use, material recovery, and reintegration into manufacturing.

4.3.3.6. Supply resilience and battery ecosystem

This cluster contains two different yet strategically important projects in the overall portfolio, as they address the entire value chain. GR4FITE3 (2023–2027, IA) aims to achieve graphite resilience through a sustainable European end-to-end supply chain. Progress includes high-purity graphite purification, pilot-scale spheronisation, electrode fabrication, recycling, and stakeholder outreach, with further scale-up planned. BEST project (2022–2025, CSA): As the "Batteries Europe Secretariat", its function is to coordinate the other 29+ projects. It develops the strategic R&I agenda and updated roadmaps and establishes KPIs for each application including transport.

4.3.4. Conclusions and recommendations for battery value chain competitiveness

This analysis of the EU's automotive battery project portfolio illustrates an R&I strategy oriented toward next-generation cell chemistries, software-defined battery intelligence and sustainable, circularity-driven manufacturing.

Identified strengths

R&I focus in next-generation chemistry: The EU is investing in solid-state with a diversified portfolio in Gen 4 SSBs, and by funding sulphide (SUBLIME), polymer (ASTRABAT), halide (HELENA), and hybrid (ADVAGEN) tracks simultaneously, the EU is increasing its chances of a manufacturable breakthrough.

Smart batteries: The integration of advanced digital technologies is a European strength, leveraging existing automotive software expertise to create a "software-defined battery" (via NEMO, ENERGETIC, DEFACTO) to create a value proposition for its OEMs.

Sustainable manufacturing: The focus on NMP-free and solvent-less (dry-coating) processes (e.g., GIGAGREEN, NOVOC) is an both an environmental and economic strategy. It aims to create a new generation of gigafactories with lower CapEx, lower OpEx (energy), and a smaller physical and environmental footprint, potentially competing with the capital-intensive NMP-based process.

Policy-driven innovation: The focus on "design-for-dismantling" (MARBEL) and "design-for-recycling" (VERSAPRINT) is an example of turning EU policy (e.g., the Battery Passport) into a design advantage, targeting the reduction of long-term lifecycle costs and securing a future supply of recycled materials.

Identified gaps and possible next steps

Higher TRL manufacturing pilots and bridge to mass production: The analysed projects target TRL 6 pilot lines. Further research and innovation but equally also funding and investment in larger scale pilot lines will be necessary to bring the developed innovations towards the scaling and commercialisation of solutions.

Assess and consolidate technology and manufacturing pathways: Several technology tracks are investigated for SSB chemistries and manufacturing. Continuous techno-economic assessment should provide an effective and flexible management of R&I programming and execution timelines, and consolidate funding on the most promising initiatives, considering the lead times for entering and scaling manufacturing and equally the pressure from international competition.

Smart Batteries interoperability and standardisation: To capitalise on smart developments in the R&I projects, reuse of current developments should be encouraged in future programming and awarded projects, and best practices should be integrated into project- and eventually industry-wide standards.

4.4. Electric powertrain components

4.4.1. State of the art

The global powertrain landscape is undergoing a profound transformation driven by rapid **electrification**, advances in **semiconductor technologies** and increasing pressure to reduce **dependency on critical raw materials** and Europe is acting in both fronts with regulations (EU) 2023/1781 (Chips Act), and (EU) 2024/1252 (Critical Raw Materials Act). While the market remains highly competitive, the shift from incremental improvements to disruptive innovation is accelerating, supported by strong industrial investment and coordinated public R&I programmes.

Market trends

The global market for electric powertrains continues to expand, with Asia maintaining a dominant position across electric machines, power electronics and drivetrain integration. China accounts for the largest share of global production capacity, supported by vertically integrated supply chains and strong domestic demand. Europe and North America are pursuing localisation strategies to reduce reliance on imported components, particularly Silicon Carbide (SiC) devices, permanent magnets and high-voltage inverters, while strengthening their own manufacturing ecosystems.

Electrification is now the primary technological trajectory for LDVs. For HDVs, battery-electric solutions are gaining ground in urban logistics, but the long-haul segment remains contested by hydrogen fuel cells and low-carbon fuels. However, the sector faces structural challenges linked to **cost pressures, supply-chain vulnerabilities and the need for higher efficiency** at system level. Competition is intensifying around wide-bandgap (WBG) power electronics, high-speed electric machines and integrated drive units, with global manufacturers seeking differentiation through performance, compactness and functional integration rather than production volume alone.

Trends in research

Current scientific literature and industrial roadmaps highlight several converging pathways for next-generation powertrain technologies:

— **Wide-bandgap power electronics (SiC and Gallium Nitride - GaN)**: Research focuses on higher switching frequencies, improved thermal management and advanced packaging concepts. SiC is becoming the reference for traction inverters, while GaN is gaining traction in low-voltage and auxiliary systems.

— **High-efficiency electric machines**: Global R&I efforts target axial-flux topologies, high-speed motors, direct-cooling concepts and magnet-reduced or magnet-free designs. Rare-earth substitution and recycling are emerging as strategic priorities.

— **Integrated drive units**: The combination of motor, inverter and gearbox into compact modules is accelerating, supported by multiphysics optimisation and advanced control strategies.

— **Digital engineering**: Digital twins, virtual sensing and AI-assisted optimisation are increasingly embedded in design workflows, enabling faster iteration cycles and more accurate prediction of lifetime behaviour.

A defining trend is the integration of AI, high-performance computing and data-driven modelling into the powertrain R&I lifecycle. **AI-assisted optimisation** is being applied to inverter topologies, electromagnetic design, thermal behaviour and control strategies. Digital twins are becoming central tools for predictive maintenance, virtual validation and system-level optimisation, reducing development time and improving reliability. These approaches are also enabling new functionalities, such as real-time health monitoring and adaptive control of electric drive systems.

Circularity and supply- chain resilience

Circularity is emerging as a core driver of global research, particularly for permanent magnets and semiconductor materials. Efforts are intensifying in magnet **recycling**, short-route manufacturing and rare-earth substitution, aligned with regulatory requirements and industrial strategies for supply-chain resilience. "Design-for-circularity" principles, once peripheral, are now embedded in early-stage R&I, influencing material selection, cooling concepts, and end-of-life strategies. In parallel, global initiatives aim to strengthen **regional value chains** for SiC substrates, power modules and electric-machine components, reflecting the strategic importance of secure and sustainable access to critical materials.

4.4.2. EU R&I overview

Europe's transition to climate-neutral mobility increasingly depends on the development of high-efficiency, reliable and sustainable **electric powertrains** capable of supporting large-scale electrification across all vehicle segments. As the automotive sector undergoes profound technological change, powertrain systems are evolving from isolated hardware components into **integrated, software-defined and digitally optimised subsystems**. EU-funded research and innovation (R&I) projects are central to this transformation, advancing next-generation electric machines, wide-bandgap (WBG) power electronics, digital-twin-enabled control strategies and circular approaches to materials and manufacturing.

The European R&I landscape for electric powertrains is expanding rapidly, driven by accelerating EV deployment, increasing performance requirements and the need to strengthen industrial competitiveness in a global market dominated by Asian manufacturers. As powertrain technologies become more complex and interdependent, Europe **maintains a robust R&I pipeline in high-efficiency components** through a coordinated portfolio of research, demonstration and industrial-readiness actions.

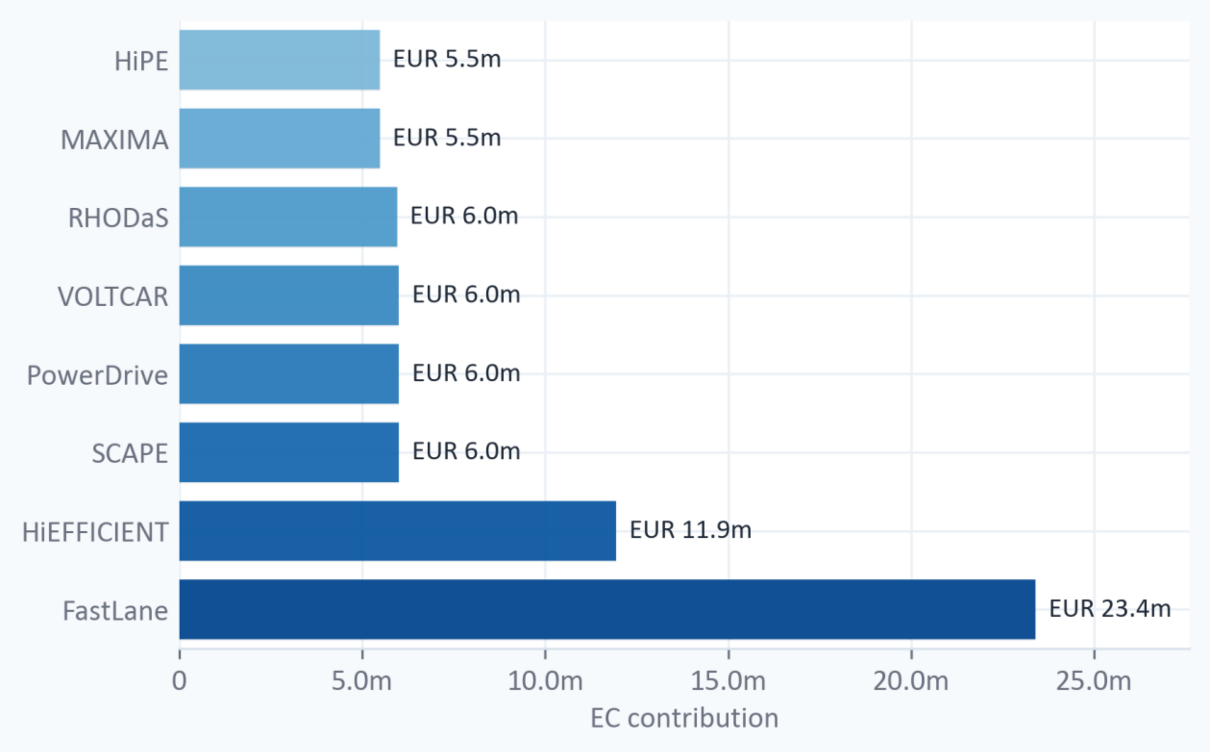
This section contains 14 projects, representing EUR 203.1m in total cost and EUR 97.0m in EC contribution (**Table 7**). The most common development stage is Pilot production & demonstration (TRL 6-7); the dominant primary pillar is Pillar 2: Clean Mobility. The portfolio covers initiatives ranging from high-efficiency electric machines and rare-earth-reduced magnet technologies to advanced SiC/GaN power electronics, integrated drive units and digital-engineering methodologies.

Table 7. Electric powertrain components project summary table

Subsection	Projects	Total cost	EC contribution
1 Wide-bandgap power electronics	9	EUR 179.4m	EUR 73.5m
2 Electric machines	5	EUR 23.7m	EUR 23.5m
Total	14	EUR 203.1m	EUR 97.0m

Source: TRIMIS, JRC, 2026

Figure 12. Projects receiving highest funding in the electric powertrain components theme



Source: TRIMIS, JRC, 2026

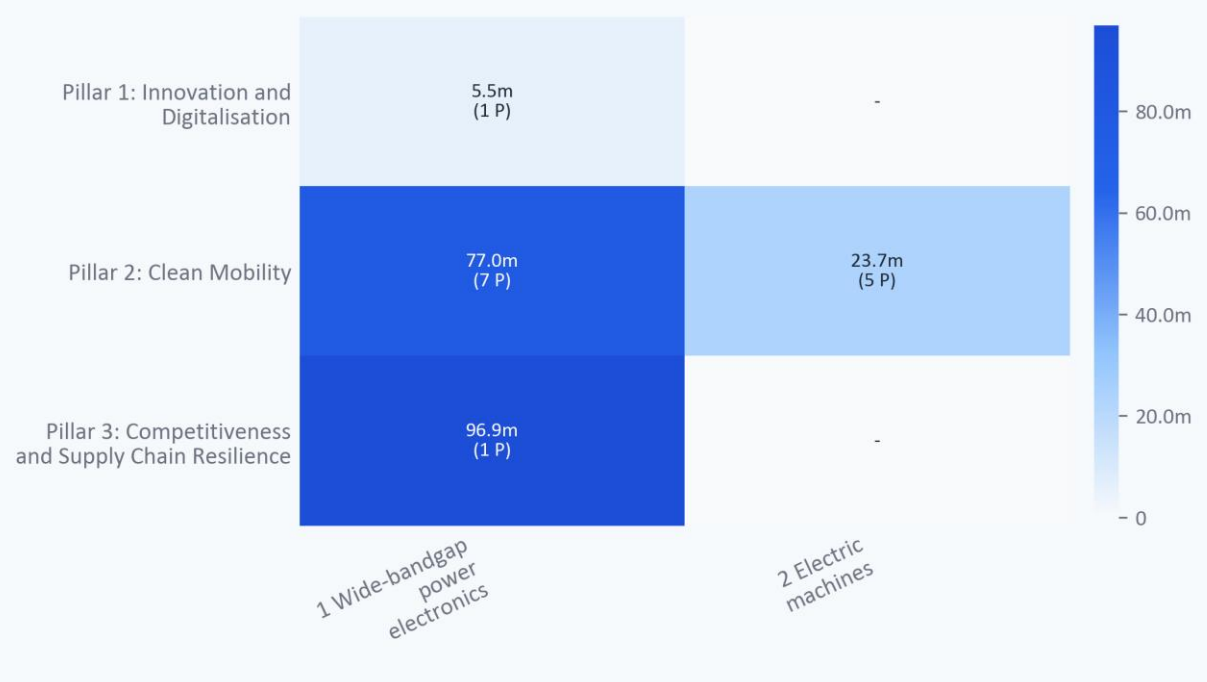
The analysed projects are divided in the following clusters:

— The first cluster focuses on **wide-bandgap** power electronics and converter technologies, where projects develop high-efficiency SiC and GaN devices, advanced packaging concepts, multi-level converter architectures and integrated thermal-management solutions. These initiatives demonstrate how WBG technologies can significantly improve inverter efficiency, reduce system volume and enhance reliability, strengthening Europe's position in strategic semiconductor value chains.

— A second cluster concentrates on **electric machines, rare-earth reduction and circularity**, reflecting the growing need to reduce dependency on imported critical materials while improving performance and manufacturability.

While the technological core of the portfolio is anchored in **Pillar 2** (Clean Mobility) of the Automotive Action Plan (**Figure 13**), projects also contribute significantly to **Pillar 1** (Innovation and Digitalisation) by advancing smart-charging intelligence and digital-twin environments.

Figure 13. Electric powertrain component projects by pillar and subsection



Source: TRIMIS, JRC, 2026

4.4.3. Project reviews

4.4.3.1. Wide-bandgap power electronics and converter innovation

The evolution of Europe's next-generation power electronics begins with projects that laid the foundations for high efficiency, compact and reliable WBG based systems. HIEFFICIENT (2021–2024, RIA) advanced in GaN and SiC technologies, achieving over 98 % efficiency, 40 % volume reduction and significant lifetime improvements. Through six industrial use cases, the project delivered innovative packaging, advanced cooling and multi-level converter concepts.

Building on this foundation, RHODAS (2022–2026, RIA) expanded the scope toward heavy-duty applications, developing advanced converter topologies and integrated motor drive technologies tailored to long-haul vehicles. The project advances WBG devices, thermal management strategies, digital twins and AI-based fault tolerant control, progressing toward validation of high-power converters and integrated drive systems.

In parallel, HIPE (2022–2026, RIA) broadened the technological landscape by designing a new family of modular, compact and highly efficient WBG-based power electronics for BEVs. Its digital-twin modelling, EMI mitigation and advanced cooling solutions support improved power density and predictive control across interoperable inverter, charger and DC/DC architectures.

POWERDRIVE (2022–2026, RIA) strengthens this cluster by developing next-generation, ultra-compact and cost-effective SiC- and GaN-based power electronics for BEVs. The project advances integrated inverter and OBC solutions, improved passive components, innovative cooling and interconnection concepts, and digital-twin-supported modelling. The project targets a 28% cost reduction, 35% loss reduction and power-density levels above 26 kW/kg and 50 kW/l.

Complementing these system level advances, SCAPE (2022–2026, RIA) introduces a standardisable and scalable approach to EV power conversion systems. By developing multilevel converter technologies and chip embedded switching cells, early results demonstrate reduced parasitic inductance, improved thermal behaviour and integrated inverter–charger concepts that meet or exceed key performance indicators. The project also makes use of digital twins of the powertrain and advanced control strategies to enhance predictive maintenance and condition monitoring.

FITGEN (2019–2022, IA) delivered a fully integrated e-axle, combining a high-speed PM motor, SiC inverter, high-speed transmission, DC/DC for 400/800 V operation and superfast charging, plus an AC/DC OBC, validated at TRL7 on a FIAT 500e. It achieved up to 6 kW/kg motor power density, 35 kW/l inverter density and 10–15% efficiency gains, setting a benchmark for market ready third generation EV power electronics.

EVC1000 (2019–2022, RIA) developed mass-production-ready in-wheel powertrains with SiC dual inverters, brake-by-wire and electro-magnetic suspension to improve efficiency, dynamics and comfort. Scalable in-wheel motors, predictive health monitoring and integrated controllers were validated on two EV demonstrators, enabling long-distance daily trips up to 1000 km and strengthening Europe's capability to industrialise WBG-enabled propulsion and chassis systems.

HIGHSCAPE (2023–2026, RIA) further accelerates this trajectory by exploring WBG-based BEV architectures through deep integration of SiC/GaN inverters, OBC and DC/DC converters, including in-wheel powertrains with zero-footprint traction drives. It delivers reconfigurable winding topologies, predictive thermal management and intelligent health monitoring, achieving higher power density, efficiency and reliability while reducing costs through modularity and dual-use components.

Finally, FASTLANE (2024–2027, IA) strengthens the upstream value chain by advancing European SiC substrate quality, reuse and manufacturing. Early achievements include first-generation SiC test samples, prototype MOSFETs, integrated sensing concepts and initial automotive power-module variants, reinforcing Europe's strategic autonomy in semiconductor materials.

4.4.3.2. Electric motors, rare-earth reduction and circularity

Europe's progress in electric machine innovation follows a similar pattern, beginning with projects that address fundamental material and design challenges before moving toward advanced architectures and circularity driven manufacturing. HEFT (2022–2026, RIA) develops high efficiency permanent magnet motors with reduced rare-earth content, supported by recycled magnets and Ce-based alternatives. The project advances 800 V architectures, composite housings and EU wide magnet recycling scenarios.

Building on this, EM-TECH (2023–2025, RIA) developed direct cooling, virtual sensing and digital twin optimisation. The project delivered high torque and power density while reducing rare-earth use and production costs, supported by validated LCA/LCC methodologies and circular design strategies.

A complementary pathway emerges with VOLTCAR (2023–2026, RIA), which develops high-speed permanent-magnet-assisted synchronous-reluctance motors. Through multiphysics optimisation, direct-liquid cooling and early prototype development, the project improves efficiency, recyclability and cost performance while reducing dependency on critical materials.

CLIMAFLUX (2024–2026, RIA) advances axial flux motors targeting over 35 % loss reduction and 60 % rare-earth savings. Digital twins and AI-based predictive control support system level optimisation and TRL7 validation across multiple vehicle types, demonstrating the maturity of axial flux concepts.

Completing this cluster, MAXIMA (2023–2027, RIA) integrates design, manufacturing and recycling considerations into a unified methodology for low-cost axial-flux motors. The project optimises motor geometries, thermal management and magnet-recycling strategies, supported by operational LCA to guide sustainable design choices.

4.4.4. Conclusions and recommendations for EV component competitiveness

This analysis of the EU's power-electronics project portfolio illustrates an R&I strategy oriented toward wide-bandgap devices, integrated and modular drive systems, and digital-twin-based design.

Identified strengths

R&I specialisation in wide-bandgap power electronics

Europe is investing heavily in SiC and GaN-based power electronics, with projects such as HIEFFICIENT, HIPE, RHODAS and SCAPE delivering breakthroughs in device integration, advanced packaging, thermal management and multilevel converter architectures. These initiatives strengthen the EU position in high efficiency, high power density inverter and converter technologies, enabling significant cost reductions through smaller, lighter and more efficient power stages, as well as increased driving range thanks to lower switching losses and improved energy utilisation.

Strong innovation capacity in integrated and modular powertrain systems

Projects demonstrate Europe's ability to design modular, scalable and interoperable power-electronics platforms. HIPE and SCAPE, for example, advance integrated inverter–charger concepts and digital-twin-enabled system optimisation, supporting flexible architectures that can be adapted across vehicle segments and manufacturers.

Advanced digitalisation and predictive control

Digital-engineering capabilities are a clear European strength. RHODAS, HIPE and SCAPE integrate AI-based control, virtual sensing and real-time digital twins into power-electronics development. These tools enable predictive maintenance, faster design cycles and improved reliability, reinforcing Europe's competitive advantage in software-defined powertrains. HIGHSCAPE contributes with predictive thermal-management strategies, intelligent health-monitoring algorithms and a shared simulation toolchain, strengthening Europe's ability to design and validate advanced WBG-based BEV architectures.

Progress in upstream value-chain resilience

FASTLANE demonstrates Europe's growing capacity to strengthen its semiconductor value chain by advancing SiC substrate quality, reuse and manufacturing. Combined with packaging and reliability innovations across the portfolio, this contributes to reducing strategic dependencies and improving long-term competitiveness.

Identified gaps and possible next steps

Need for higher-TRL demonstrators and industrial-scale pilots

Many projects operate at TRL 5–7. To accelerate market uptake, Europe will need larger-scale pilots for WBG-based inverters, integrated drive units and digital-twin-enabled control systems. Demonstration factories and regulatory sandboxes could support faster industrial deployment.

Consolidation of technology pathways and cost-competitiveness strategies

Multiple converter topologies, packaging approaches and thermal-management concepts are being explored. Continuous techno-economic assessment is needed to identify the most viable pathways, streamline investment and ensure alignment with automotive cost structures. Reducing the cost of SiC devices remains essential for mass-market penetration.

Interoperability, standardisation and cross-project reuse

To capitalise on digital-engineering advances, Europe should strengthen standardisation efforts for modelling frameworks, data formats and validation protocols. Reuse of software components, shared simulation environments and harmonised reliability methodologies would accelerate industrial adoption and reduce duplication.

4.5. Zero-emission vehicle infrastructure

4.5.1. State of the art

The global transition toward climate-neutral mobility is reshaping how vehicles are powered, charged and refuelled. While BEVs and FCEVs follow different technological pathways, both rely on infrastructure ecosystems that are increasingly **intelligent, interoperable and integrated with the wider energy system**. The evolution of these infrastructures is no longer separate: both are converging toward shared principles of **digitalisation, safety, flexibility, user-centricity and regulatory harmonisation**.

Market trends

Worldwide, **EV charging infrastructure** is expanding at double-digit annual rates, with China leading in absolute numbers of installed chargers (International Energy Agency, 2025). Europe has developed a strong ecosystem around smart charging, interoperability and V2X-ready infrastructure, supported by regulatory frameworks such as the Alternative Fuels Infrastructure Regulation (AFIR) (Regulation (EU) 2023/1804) and the Renewable Energy Directive (RED III). Despite this progress, the distribution of charging points remains uneven across Member States as demonstrated at the European Alternative Fuels Observatory (EAFO)[20] and grid constraints are emerging as a structural bottleneck for further deployment. As EV penetration increases, the need for intelligent charging coordination, particularly at low-voltage levels, becomes critical to avoid congestion, voltage deviations and costly grid reinforcements.

In parallel, hydrogen mobility is emerging as a targeted solution for heavy-duty, long-range and high-utilisation segments. EAFO shows an ongoing EU deployment of **hydrogen refuelling stations (HRS**), with Europe playing a leading role in safety engineering, protocol development and permitting harmonisation. High-flow refuelling for trucks, buses and trains is becoming a strategic priority, supported by advances in high-pressure systems and fuel-quality assurance.

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[20] European Alternative Fuels Observatory, 'European Alternative Fuels Observatory', accessed 7 May 2026, https://alternative-fuels-observatory.ec.europa.eu/.

Trends in research

Current scientific and industrial roadmaps highlight three major R&I pathways shaping the future of **EV charging:**

- **User-centric and advanced charging solutions:** Research is focused on ultra-fast charging, dynamic wireless charging, mobile charging services and improved human–machine interfaces. These innovations aim to reduce charging time, increase convenience and support seamless integration into daily mobility patterns.
- **V2X flexibility and energy-system integration:** V2X flexibility refers to the ability of electric vehicles to modulate charging and provide bidirectional energy services to the grid, acting as distributed energy resources. Research is increasingly directed toward bidirectional chargers, flexibility markets, local energy communities and the orchestration of EV fleets as distributed energy resources. Digital twins, co-simulation platforms and advanced control algorithms are becoming essential tools to assess system impacts and optimise charging strategies across households, buildings, microgrids and cities.
- **Digitalisation and AI-enabled grid management:** Real-time analytics, predictive algorithms, integrated data layers and grid-aware operating systems are enabling more efficient use of existing infrastructure. These developments mirror broader trends in the energy sector, where digital twins, edge-cloud architectures and AI-driven forecasting are becoming standard components of operational planning.

In parallel to EV charging, Europe is advancing a complementary R&I agenda focused on **hydrogen refuelling infrastructure**, which plays a critical role in decarbonising heavy-duty transport, long-distance mobility and high-utilisation fleets. Hydrogen refuelling requires high-pressure systems, rigorous safety engineering, harmonised permitting and consistent fuel-quality assurance, areas where EU-funded projects are delivering significant progress.

The European R&I landscape for hydrogen refuelling is shaped by three strategic priorities:

First, **high-capacity and reliable refuelling stations**, enabling fast turnaround times and operational efficiency comparable to diesel.

Second, **standards, regulations and fuel-quality assurance**, essential for safe, interoperable and scalable deployment.

Third, **liquid hydrogen storage and refuelling**, an emerging area addressing the needs of long-range heavy-duty applications, rail and maritime sectors.

Circularity, resilience and regulatory alignment

Both infrastructures are shaped by EU priorities on **sustainability, cybersecurity, supply-chain resilience and consumer protection**. Interoperability, open standards, data governance and harmonised permitting are essential to ensure that recharging and refuelling infrastructures evolve coherently within Europe's mobility and energy systems.

4.5.2. EU R&I overview

Europe's transition to climate-neutral mobility increasingly depends on the development of smart, flexible and interoperable charging solutions capable of integrating millions of electric vehicles into the energy system.

As EV uptake accelerates, charging infrastructure must evolve from a static, hardware-based asset into a **dynamic, intelligent and user-responsive** component of the wider energy ecosystem. EU-funded R&I projects address several aspects of this transition, advancing technologies that improve user experience, enable vehicle-to-everything (V2X) flexibility, and support real-time coordination between mobility and energy systems.

The European R&I landscape for smart EV charging is expanding rapidly, driven by EV uptake, increasing pressure on electricity grids and the need for intelligent, interoperable and energy-integrated charging solutions. As charging infrastructure evolves from static hardware to dynamic, software-defined systems, Europe is engaging in this transition through a coordinated portfolio of research, demonstration and innovation actions.

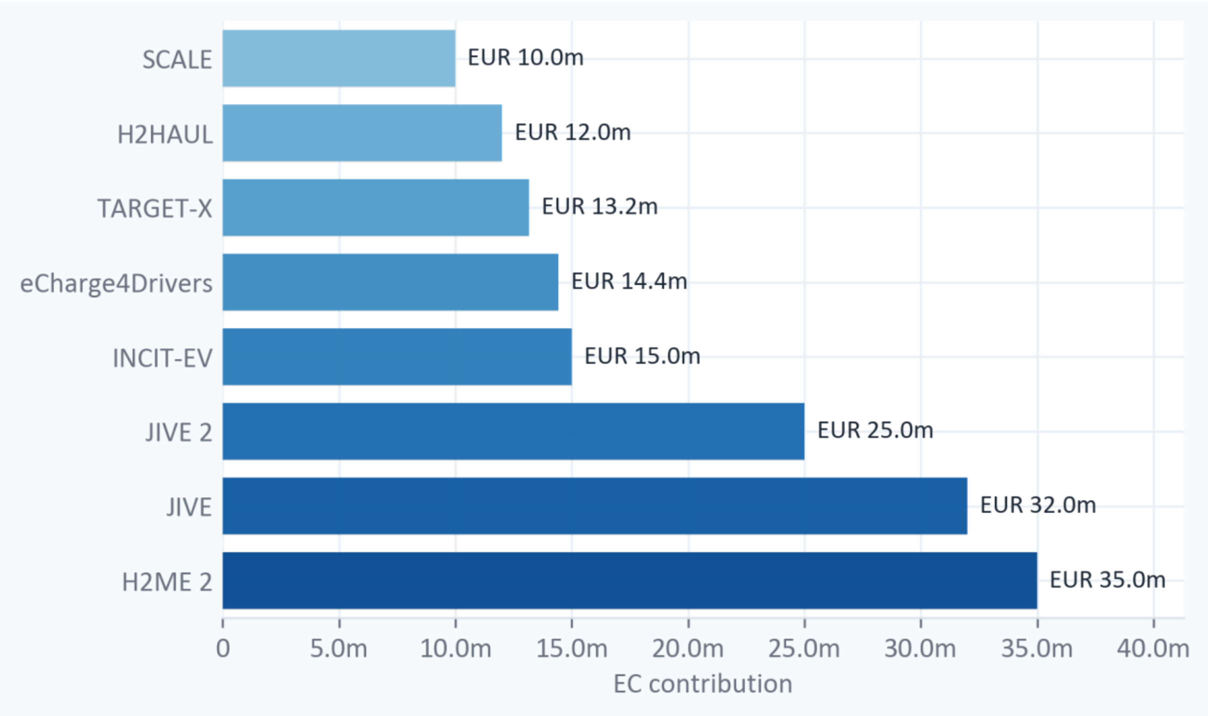
This section contains 19 projects, representing EUR 438.0m in total cost and EUR 216.5m in EC contribution (**Table 8**). The most common development stage is Pilot production & demonstration (TRL 6-7) and the dominant primary pillar is Pillar 2: Clean Mobility. The section covers initiatives ranging from user-centric charging solutions, V2X flexibility and digitalised grid-aware management systems.

Table 8. ZE vehicle infrastructure project summary table

Subsection	Projects	Total cost	EC contribution
1 User-centric charging	2	EUR 36.1m	EUR 29.4m
2 Grid integration	6	EUR 55.9m	EUR 54.4m
3 Digitalisation	3	EUR 18.4m	EUR 16.0m
4 Hydrogen refuelling stations	6	EUR 320.0m	EUR 111.1m
5 Refuelling standards	2	EUR 7.9m	EUR 5.5m
Total	19	EUR 438.4m	EUR 216.5m

Source: TRIMIS, JRC, 2026

Figure 14. Projects receiving highest funding in the ZE infrastructure theme



Source: TRIMIS, JRC, 2026

While the technological core of the portfolio is anchored in **Pillar 1** (Innovation and Digitalisation) of the Automotive action plan, most of the projects also contribute substantially to **Pillar 2** (Clean Mobility) by advancing smart charging, V2X integration and energy-system optimisation as essential enablers of large-scale EV deployment. At the same time, several initiatives address elements of **Pillar 4**, particularly through user-centric design, behavioural research and the development of new organisational capabilities for cities, operators and energy communities.

The current R&I landscape reveals three major and complementary clusters:

— The first focuses on **user-centric and advanced charging infrastructure**, where projects develop more accessible, predictable and convenient charging solutions. These initiatives demonstrate how improved service design, interoperability and innovative charging concepts, such as dynamic wireless charging, superfast systems or mobile charging, can reduce barriers to EV adoption and enhance the daily experience of drivers. They also provide tools and business models that help cities and operators plan charging networks more efficiently.

— A second cluster concentrates on **V2X flexibility, energy integration and system-level optimisation**, reflecting the growing recognition that EVs can act as distributed energy resources. These projects explore how EVs can support grid stability, enable renewable integration and participate in emerging flexibility markets. Their work spans user-centric V2X strategies, open architectures for smart charging, digital-twin-enabled optimisation, and real-world deployment of bidirectional technologies across diverse environments. Together, they illustrate a clear progression from conceptual frameworks to advanced control systems and operational demonstrations, highlighting the central role of V2X in future energy systems.

— The third cluster addresses **digitalisation and grid-aware charging management**, where AI, data analytics and real-time communication are used to optimise charging processes and grid operation. These projects develop digital twins, prediction algorithms, integrated data layers and real-time operating systems for distribution networks. Their work shows how digitalisation can reduce grid stress, improve demand-side management and provide cost-effective alternatives to traditional grid reinforcement, enabling the large-scale integration of EVs and distributed energy resources.

Concerning hydrogen refuelling, this section analyses a portfolio of 10 EU-funded R&I projects, representing around 120 million in EU funding, that advance the technological, organisational and regulatory foundations for next-generation hydrogen refuelling ecosystems. These initiatives represent a significant investment in Europe's hydrogen mobility innovation landscape and cover developments ranging from high-capacity refuelling stations to harmonised safety standards, non-proprietary refuelling protocols, and fuel-quality assurance frameworks.

While the technological core of this portfolio aligns closely with **Pillar 2** (Clean Mobility) of the Automotive Action Plan, many of the projects also contribute substantially to **Pillar 1** (Innovation and Digitalisation). At the same time, several initiatives support **Pillar 4**, particularly through the development of user-oriented refuelling protocols, risk-informed station design, and new organisational capabilities for operators, regulators and infrastructure planners.

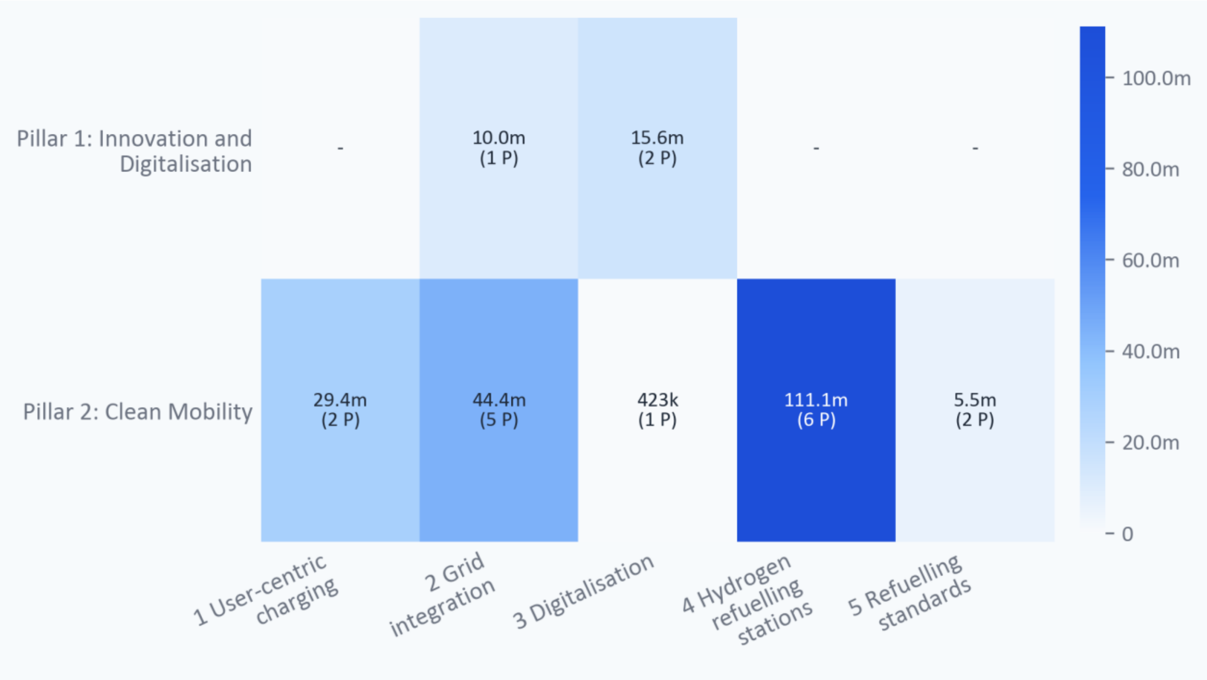
The current R&I landscape reveals three major and complementary clusters:

— **High-capacity and reliability hydrogen refuelling stations**, where projects develop advanced refuelling lines, high-flow dispensing technologies and validated safety protocols. These initiatives demonstrate how standardised procedures, such as SAE J2601 can ensure safe and predictable operation under diverse conditions, while next-generation systems aim to deliver up to 100 kg of hydrogen in 10 minutes for heavy-duty trucks (Crouslé et al., 2025).

— **Hydrogen refuelling standards, regulations and fuel quality**, reflecting the need for harmonised permitting, consistent safety zoning and robust impurity monitoring. Projects in this cluster produce non-proprietary refuelling protocols, harmonised rules for HRS co-located with other fuels, and open-source databases on hydrogen purity based on samples collected across Europe.

— **Liquid fuel storage and refuelling**, an emerging area addressing the requirements of long-range heavy-duty transport, rail and maritime applications. Work in this cluster focuses on cryogenic storage, high-density energy carriers and the operational frameworks needed to integrate liquid hydrogen into the broader refuelling ecosystem.

Figure 15. ZE infrastructure projects by pillar and subsection



Source: TRIMIS, JRC, 2026

4.5.3. Project reviews

4.5.3.1. User centric and advanced charging infrastructure

The evolution of user centric charging solutions in Europe begins with projects that sought to directly improve the charging experience and reduce barriers to EV adoption. INCIT-EV (2020–2024, IA) demonstrated various charging technologies, from dynamic wireless charging to superfast systems and V2G-enabled hubs, across diverse environments. Using neuroscience-based mobile sensing to capture user preferences, the project informed new charging concepts and delivered TRL-8 tools enabling large-scale deployment of advanced solutions. In parallel, ECHARGE4DRIVERS (2020–2024, IA) expanded the focus on user needs by developing more accessible and predictable charging services, including mobile charging, lamppost solutions and battery swapping for light EVs. Through ten demonstration areas, the project validated interoperable high and low power charging systems, Plug & Charge functionality and enhanced route planning and booking services.

4.5.3.2. V2X flexibility and energy integration

The cluster of projects addressing V2X flexibility and system level optimisation move from conceptual frameworks to advanced digital twin-enabled control and real-world deployment of bidirectional technologies. EV4EU (2022–2026, RIA) provides bottom-up, user-centric V2X strategies, tested across different European demonstrators. Its work spans households, SMEs, fleets, parking lots and energy communities, supported by an Open V2X Management Platform and co-simulation tools that assess the impacts of mass EV deployment on power systems and urban planning. SCALE (2022–2025, RIA) complemented this approach by addressing the ecosystem conditions required for V2X uptake, developing an open architecture informed by user behaviour and city needs, and demonstrating how coordinated charging can reduce grid load. Its SCALE

Blueprint and joint procurement activities helped cities prepare for integrated mobility and energy planning.

FLOW (2022–2026, RIA) advances EV flexibility via smart charging and V2X solutions.

Demonstrations in five countries validate V1G–V2G services in diverse contexts, showing how EV flexibility can ease grid congestion, boost renewable use and reduce system costs while enabling scalable, harmonised business and interoperability frameworks.

Concerning system-level optimisation, XL-CONNECT (2023–2026, RIA) advances analytical and technological capabilities by combining V1G, V2G and V2X technologies with a comprehensive digital twin of the charging chain. The project enables detailed simulation, upscaling and validation of advanced charging strategies. Demonstrations in Belgium, Germany, Italy and Portugal test interoperability, sector coupling and bidirectional hardware, while standardisation work supports future alignment. In parallel, DRIVE2X (2023–2026, RIA) deepens both the technical and socio-technical understanding of V2X by developing next-generation bidirectional chargers progressing from TRL 3 to TRL 7 and deploying them across eight diverse environments. Its AI-based flexibility estimation, exploration of local V2X marketplaces and socio-technical modelling highlight the importance of user perceptions and behavioural drivers in V2X adoption. Extending the scope further, EPOWERMOVE (2025–2028, IA) integrates charging-infrastructure design with grid-energy control, emphasising social innovation, affordability and user acceptance. Demonstrations in Helsinki, Klagenfurt and Nicosia explore interoperable slow-charging solutions and new business and usage models, showing how communities can participate in power-system optimisation while maintaining accessibility and cost-effectiveness.

4.5.3.3. Digitalisation and grid aware charging management

Digitalisation plays an increasingly central role in enabling smart and flexible EV charging, with projects progressively integrating AI, data analytics and real time communication into charging and grid management systems. This cluster focuses on how the energy system adapts to large-scale EV integration, through AI-enabled grid management, real-time optimisation and digital-twin-based grid operation.

EVOLVE (2023–2026, MSCA) develops AI driven prediction algorithms, digital twins and integrated data layers that support more efficient charging, improved demand side management and enhanced grid stability. Progressing toward five proof-of-concept demonstrations, the project establishes unified communication frameworks and scheduling software while strengthening academia-industry collaboration.

Complementing this approach, PLEXIGRID (2024–2026, EIC) develops a real-time operating system for electricity distribution networks. The project combines real-time visibility, analytics and forecasting, and flexibility management to support advanced grid operations. Its AI-powered digital twin enables optimisation without detailed grid models, showing how digitalisation can reduce reinforcement needs and support large-scale EV and distributed energy resources integration through a secure and scalable architecture.

Extending the digitalisation landscape further, TARGET-X (2023–2025, IA) accelerated industrial digitalisation through large-scale 5G and emerging 6G trials across energy, automotive, construction and manufacturing. It validated real-time communication, localisation, digital twinning and sensor-fusion technologies in realistic environments, assessed sustainability and performance through a KPI/KVI framework, and strengthened Europe's 5G/6G ecosystem by engaging SMEs, IT/OT partners and numerous third-party innovators.

4.5.3.4. High-capacity and reliability hydrogen refuelling stations

EU projects are advancing the performance, safety and throughput of hydrogen refuelling stations (HRS), particularly for heavy-duty applications.

H2ME2 (2016-2023, IA) delivered Europe's largest real-world validation of hydrogen mobility, deploying 20 HRS and over 1,100 FCEVs in nine countries. Stations operated under high utilisation, 20% on average, over 50% in some sites, enabling 361,000 refuellings and 917 tonnes dispensed without incidents. The project also demonstrated MW-scale electrolyser-HRS integration and generated extensive operational and business-model insights.

H2REF-DEMO (2023-2026, IA) scales up hydrogen compression for heavy-duty applications, enabling bus-depot and truck refuelling. Its TRL 7 demonstrator targets 150 kg/h peak dispensing and 1 200 kg/day capacity. The project also develops a digital twin of the scaled-up process to simulate and optimise a full year of 350-bar truck refuelling operations.

The recently finished JIVE (2017-2024, IA) and JIVE 2 (2018-2025, IA) are large scale demonstration projects, deploying hydrogen FCE buses and their associated infrastructure. JIVE project deployed large hydrogen refuelling stations (200-400 kg/day) with high reliability and availability. The successor JIVE 2 expanded Europe's fuel-cell bus deployment, installing new or upgraded HRS in 14 regions. The project built on JIVE's results, improving station performance, operational readiness and fleet integration, and supporting the transition toward commercially viable hydrogen bus networks.

The ongoing H2HAUL (2019-2026, IA) installs publicly accessible high-capacity HRS at four demonstration sites to support heavy-duty fuel-cell trucks. The project monitors infrastructure performance throughout operation and develops a best-practice guide for HRS installation, covering availability, efficiency and environmental benefits.

As a complementary solution to fixed HRS, MOBHYLE (2021-2024, SME-2) developed a mobile hydrogen refuelling station using cascade dispensing technology and high-pressure storage in 6- or 12-metre containers. The project demonstrated 350-bar HDV refuelling, proving the technical and economic viability of mobile HRS solutions for flexible deployment and road-assistance applications.

H2ACCELERATE TRUCKS (2023–2030, IA) deploys 125 fuel-cell heavy-duty trucks across several European countries, supported by a new generation of truck-specific hydrogen refuelling stations delivering over 1,000 kg/day. The stations will progressively expand along major transport corridors. The project produces a public dataset on technical, economic, environmental and attitudinal performance to validate large-scale hydrogen trucking and prepare the market for series production from 2027.

4.5.3.5. Hydrogen refuelling standards, regulations and fuel quality

Regulatory harmonisation, safety zoning and fuel-quality assurance are essential for the large-scale deployment of hydrogen mobility.

New refuelling protocols are being developed within the ongoing RHEADHY (2023–2027, RIA) develops next-generation high-flow refuelling protocols and the associated technical requirements for heavy-duty 700-bar trucks. To validate these protocols, the project is designing a new high-flow refuelling line capable of delivering 100 kg H_2 in 10 minutes for 700-bar trucks, addressing the needs of long-haul logistics and high-utilisation fleets.

MULTHYFUEL (2021–2024, RIA) developed a comprehensive knowledge base for safety rules on hydrogen dispensing, HRS layout recommendations, hazardous-area zoning and harmonised permitting requirements, including for stations co-located with other fuels.

HQE (2023–2026, RIA) is conducting the first large-scale assessment of hydrogen fuel quality across Europe, collecting samples from at least 100 HRS in 13 countries and publishing an open-source database on impurities to support compliance and protect fuel-cell systems.

4.5.4. Conclusions and recommendations for ZEV infrastructure competitiveness

This analysis of the EU's charging and hydrogen-refuelling project portfolio illustrates an R&I strategy oriented toward user-centric charging, V2X flexibility, grid-aware digitalisation and cryogenic hydrogen refuelling.

Identified strengths

Strong R&I focus on V2X and flexibility services

Europe is investing heavily in V2X-enabled charging, with projects such as EV4EU, SCALE, XL-CONNECT and DRIVE2X developing interoperable architectures, digital-twin-based optimisation tools and real-world bidirectional charging demonstrations. This positions the EU as a frontrunner in flexibility markets and energy-system integration.

Their combined insights highlight the central role of V2X in enabling a resilient, renewable-based energy system and reinforce Europe’s competitive position in smart electromobility.

R&I specialisation in user-centric charging innovation

Projects like INCIT-EV and ECHARGE4DRIVERS demonstrate Europe’s strength in designing charging solutions around user needs, behavioural insights and service innovation. This user-centric orientation enhances acceptance, improves charging convenience and supports large-scale EV uptake.

Advanced digitalisation and grid-aware management

EVOLVE and PLEXIGRID show a clear European advantage in integrating AI, real-time analytics and digital twins into charging and grid-management systems. FLOW complements these advances with forecasting, optimisation and orchestration tools that support coordinated flexibility services across different stakeholders. These capabilities enable more efficient use of existing infrastructure, reduce grid stress and support scalable deployment of distributed energy resources.

System-level integration across mobility and energy

The portfolio demonstrates strong cross-sectoral integration, linking charging infrastructure with power-system planning, flexibility markets and city-level mobility strategies. This systemic approach aligns with EU policy priorities on decarbonisation, energy efficiency and digital transformation.

Growing innovation capacity in liquid hydrogen and high-density energy carriers

A complementary set of hydrogen-focused projects shows Europe’s strategic investment in liquid hydrogen storage, cryogenic refuelling, and high-density carriers for long-range and heavy-duty applications. These projects collectively strengthen Europe's position in sectors where battery-electric solutions face limitations.

Identified gaps and possible next steps

Need for higher-TRL demonstrations and pre-commercial pilots

Many projects operate at TRL 5–7. To accelerate market uptake, Europe will need larger-scale, real-world pilots for V2X services, digital-twin-enabled grid management and interoperable charging architectures, supported by targeted funding and regulatory sandboxes. Continued investigation of battery impacts should be encouraged.

Consolidation of V2X technology pathways and business models

Multiple V2X strategies, architectures and market concepts are being explored. Continuous techno-economic assessment is needed to identify the most viable pathways, streamline investment and ensure alignment with evolving electricity-market reforms and grid-service frameworks. For V2X to scale, participation must be economically attractive and beneficial for end users. Avoiding an uneven distribution of costs and benefits among stakeholders (e.g. drivers, manufacturers and operators) is essential.

Interoperability, standardisation and cross-project reuse

To capitalise on the digital and V2X innovations emerging from the portfolio, Europe should strengthen standardisation efforts, including harmonisation of its implementation, promote reuse of software components and ensure that best practices from R&I projects feed into industry-wide standards and certification schemes.

Strengthening organisational readiness and skills

As highlighted in several projects, the deployment of smart charging and V2X solutions requires new skills for operators, municipalities and energy communities. Future programmes should support capacity-building, training and organisational innovation to ensure effective implementation. Collaboration among EU projects and mutual learning should continue to be promoted to optimise efforts and enhance effectiveness.

Need for integrated safety, certification and operational frameworks

While projects like ELVHYS advance safety science, Europe still lacks harmonised certification pathways, refuelling protocols, and operational guidelines for liquid hydrogen in heavy-duty transport. The rapid emergence of LH_2 technologies and high-flow refuelling concepts increases the urgency for common safety barriers, validated test procedures and cross-sector alignment. Coordinated work across R&I, regulators and industry is needed to accelerate safe deployment and ensure that innovations can progress from pilot demonstrations to scalable, certifiable infrastructure.

Techno-economic assessment of hydrogen carriers

Innovations require further cost, efficiency and lifecycle assessments to determine their competitiveness relative to compressed or liquid hydrogen.

Current evidence suggests promising safety and storage advantages, but economic viability depends on conversion efficiency, regeneration pathways and supply-chain integration. Clearer market pathways will help guide investment and industrial uptake and support informed decisions on which carrier technologies can scale in parallel with conventional gaseous and liquid hydrogen solutions.

4.6. Vehicle integration and deployment

4.6.1. State of the art

The transition toward climate-neutral mobility is in a complex consolidation phase across all vehicle segments, driven by advances in electrification, digitalisation, and intelligent energy-system integration. BEVs and FCEVs are evolving along complementary pathways, each addressing specific operational needs while increasingly converging around shared principles of modularity, interoperability, safety, and lifecycle sustainability. European R&I projects are playing a central role in shaping this evolution, demonstrating next-generation technologies in real-world conditions and informing future regulatory and industrial strategies.

Market trends

BEV deployment continues to grow worldwide, supported by falling battery prices, improved vehicle efficiency and the rollout of smart charging infrastructure, although the pace of expansion varies significantly across regions. China leads in absolute BEV sales in 2024 (International Energy Agency, 2025b), while Europe remains at the forefront of regulatory harmonisation, interoperability and grid-integrated charging. The emergence of megawatt-scale charging for heavy-duty vehicles provides a technical pathway for long-haul freight strategies, enabling operational patterns previously dominated by diesel (Schneider et al., 2023). Despite this progress, structural challenges persist. High upfront battery costs remain a barrier to cost parity for heavy-duty BEVs, as highlighted by recent European demonstrations. Grid constraints, particularly at low-voltage levels, are becoming increasingly visible, reinforcing the need for coordinated charging management, digital twins, and predictive control systems to avoid congestion and costly reinforcements.

In parallel, hydrogen mobility is gaining momentum in heavy-duty segments where extended range, high utilisation and rapid refuelling are critical. Europe has emerged as a global leader in hydrogen refuelling station deployment[21], safety engineering and permitting harmonisation. Large-scale demonstrations of fuel-cell buses and trucks show that hydrogen can deliver operational performance comparable to diesel, though cost barriers remain significant (UITP, 2024). Fuel prices, station design and local hydrogen production pathways strongly influence total cost of ownership (TCO), underscoring the need for coordinated infrastructure planning and economies of scale.

Trends in research

Current scientific, industrial and policy roadmaps highlight a set of converging R&I trajectories that are reshaping the future of zero-emission road transport across both BEV and FCEV technologies:

— **New vehicle architectures:** Research combines studies on lightweight design, modular powertrains and scalable components. Digital-twin engineering, virtual validation and model-based design are becoming standard tools to accelerate development cycles, reduce

[21] Clean Hydrogen Partnership, H2-Stations – Europe's central access point for reliable, free and up to date hydrogen refuelling station data, accessed 28 August 2026, https://h2-stations.eu/.

testing costs and optimise performance across diverse mission profiles. This trend spans passenger cars, vans, buses and heavy-duty vehicles, enabling more flexible configurations and facilitating the integration of next-generation batteries, fuel-cell systems and power electronics.

— **Battery and fuel-cell efficiency, durability and cost:** For BEVs, research focuses on high-energy-density batteries, advanced thermal management, improved recuperation strategies and high-efficiency inverters and converters. For FCEVs, innovation targets more durable stacks, optimised hydrogen storage systems and hybridised powertrains that combine batteries and fuel cells for long-range, high-utilisation applications. Across both technologies, the objective is to reduce energy consumption, extend range and improve overall vehicle efficiency.

— **Digital technologies:** AI-enabled predictive maintenance, connected fleet management platforms and mission-optimisation algorithms are becoming central to improving reliability and reducing operational costs. These tools support real-time decision-making, optimise charging or refuelling schedules, and enhance the utilisation of vehicles in both passenger and freight transport. Increasingly, vehicles are conceived as nodes within a wider digital ecosystem, interacting with infrastructure, energy networks and logistics platforms.

Circularity, resilience and regulatory alignment

Global R&I agendas place growing emphasis on lifecycle sustainability, from raw-material sourcing to end-of-life management. Research focuses on battery recycling, second-life applications, resource-efficient design and the integration of LCA methodologies into vehicle and infrastructure development. For hydrogen systems, attention is directed toward reducing the environmental footprint of production pathways and improving the circularity of key components such as stacks and storage tanks.

4.6.2. EU R&I overview

Europe’s transition to climate-neutral mobility increasingly depends on the development of advanced zero-emission vehicle technologies and the supporting ecosystems that enable their large-scale deployment. As both battery-electric vehicles (BEVs) and fuel-cell electric vehicles (FCEVs) gain traction across passenger, urban and heavy-duty segments, the focus of innovation is shifting from conventional vehicle electrification toward smart, modular and interoperable powertrains capable of meeting diverse operational needs.

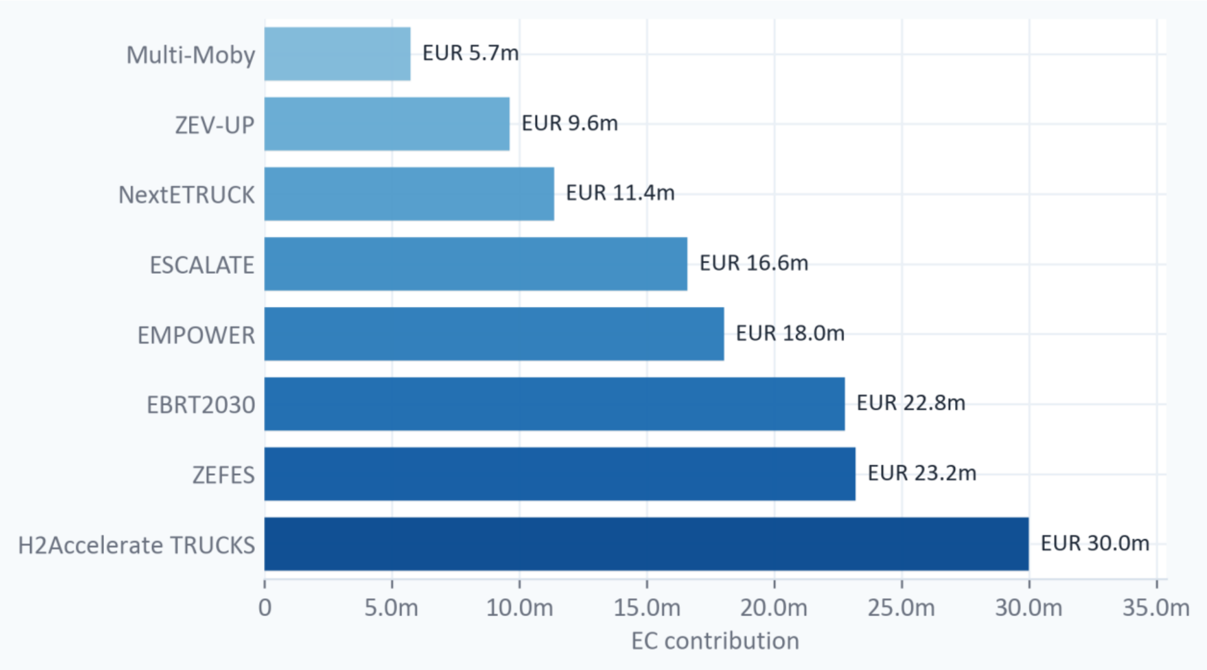
This section contains 9 projects, representing EUR 267.7m in total cost and EUR 142.4m in EC contribution (**Table 9**). The most common development stage is Deployment (TRL 8-9); the dominant primary pillar is Pillar 2: Clean Mobility. This portfolio covers initiatives ranging from lightweight and modular vehicle architectures, digital-twin-based development, high-efficiency powertrains, predictive maintenance, fleet-level optimisation and lifecycle sustainability.

Table 9. Vehicle integration and deployment project summary table

Subsection	Projects	Total cost	EC contribution
1 Advanced vehicle architectures	3	EUR 26.8m	EUR 20.5m
2 Heavy-duty applications	6	EUR 240.9m	EUR 122.0m
Total	9	EUR 267.7m	EUR 142.4m

Source: TRIMIS, JRC, 2026

Figure 16. Projects receiving highest funding in the vehicle integration and deployment theme



Source: TRIMIS, JRC, 2026

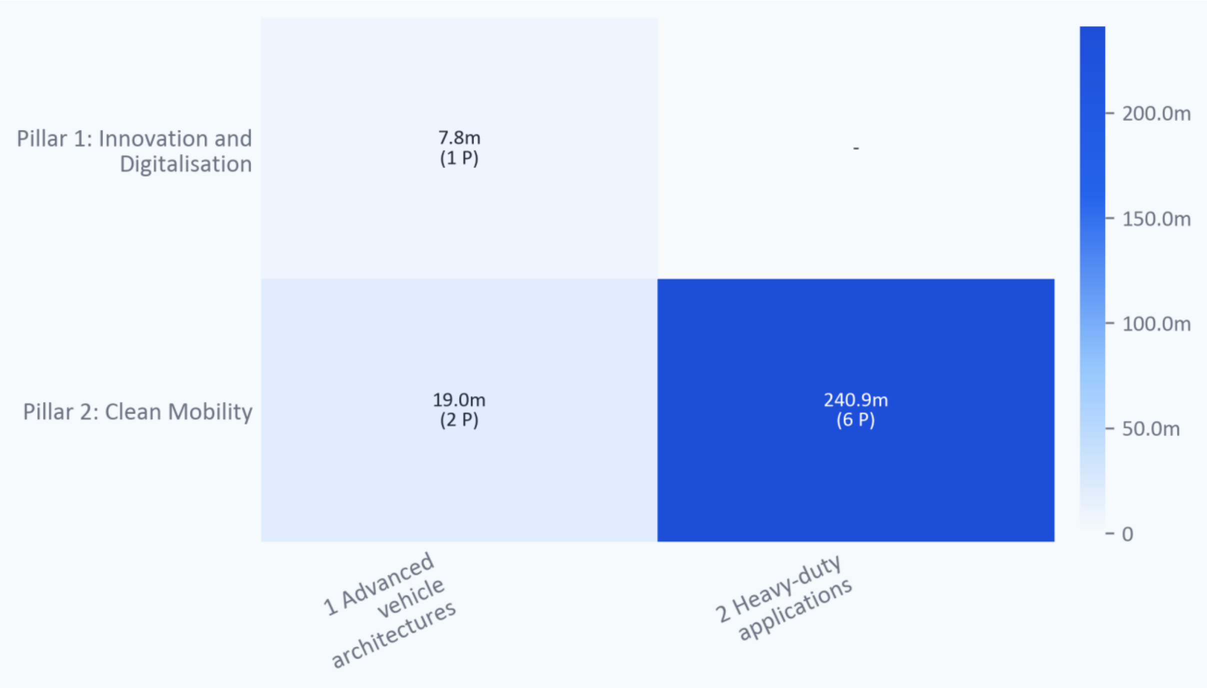
While the technological core of this portfolio is firmly anchored in **Pillar 2** (Clean mobility) of the Automotive Action Plan, most of the initiatives also contribute substantially to **Pillar 1** (Innovation and digitalisation). At the same time, several activities address elements of **Pillar 4**, particularly through user-centric design and behavioural insights for fleet adoption.

The current R&I landscape for zero-emission vehicles reveals three major and complementary clusters that collectively advance the performance, efficiency and operational readiness of next-generation BEVs and FCEVs:

— **Advanced vehicle architectures, modular powertrains and digital engineering**. These initiatives focus on the development of new vehicle architectures that are lighter, more efficient and easier to scale across multiple use cases. Research efforts are converging on modular battery and fuel-cell powertrains that can be configured for different mission profiles, digital-twin-enabled design and validation, reducing development time and improving component optimisation, lightweight structures and improved aerodynamics to reduce energy consumption, enhanced safety systems and automation-ready platforms for buses, vans and trucks.

— **High-efficiency electric and hydrogen powertrains** for long-range and heavy-duty applications. These initiatives concentrate on improving the efficiency, durability and operational performance of BEV and FCEV powertrains, particularly for long-haul and high-utilisation segments. Research in this area targets high-efficiency inverters, converters and thermal management systems, hybridised battery–fuel-cell architectures for extended range and optimised energy use, energy-efficient driving strategies, including maximised recuperation and predictive control and mission-specific optimisation for heavy-duty vehicles operating at high gross vehicle weights.

Figure 17. Vehicle integration and deployment projects by pillar and subsection



Source: TRIMIS, JRC, 2026

4.6.3. Project reviews

4.6.3.1. Advanced vehicle architectures and modular powertrains

Research and innovation efforts in this cluster focus on developing next-generation vehicle architectures that are lighter, more modular and easier to scale across multiple use cases. These initiatives converge on digital-twin engineering, modular battery and fuel-cell powertrains, lightweight structures and automation-ready platforms to accelerate development cycles and improve component optimisation.

MULTI-MOBY (2020–2023, IA) advanced multi-purpose electric mobility through the development of commercial vans that combined enhanced safety features, autonomous-ready sensing systems and robust hybrid battery packs. By integrating low-cost charging solutions and flexible powertrain configurations, the project demonstrated how modular EV architectures can support a wide range of urban and peri-urban transport needs.

URBANIZED (2021–2024, IA) strengthened this cluster by demonstrating a modular, all-electric N1 platform for urban logistics. By integrating high-efficiency e-powertrain components, interchangeable cargo modules and advanced energy-management strategies, the project validated scalable 48 V e-axles and improved drivetrain components through real-world demonstrations, illustrating how modular architectures can support diverse operational needs.

ZEV-UP (2024–2027, IA) complements this approach by focusing on cost-effective and user-centric vehicle design. Through extensive use of digital-twin engineering, the project optimises structural components, reduces material use and accelerates validation processes. Its modular L7e platform, designed for both passenger and goods transport, is expected to illustrate how lightweight architectures and innovative business models such as Battery-as-a-Service can enhance affordability and market uptake.

4.6.3.2. Electric and hydrogen deployment for long-range and heavy-duty applications

This cluster targets the improvement of efficiency, durability and operational performance in long-haul and high-utilisation segments. Projects focus on high-efficiency inverters and converters, advanced thermal management, hybridised battery–fuel-cell architectures and mission-specific optimisation for vehicles operating at high gross vehicle weights. Digital-twin tools, fleet-level optimisation models and lifecycle-aware assessments are increasingly embedded to support real-world deployment and cost-reduction strategies.

NEXTETRUCK (2022–2026, IA) develops energy-efficient BEV trucks designed to increase energy efficiency by at least 10%. The project combines modular battery systems, advanced power electronics and predictive maintenance with smart charging strategies and mission-specific optimisation, demonstrating the potential of high-efficiency BEV powertrains for demanding logistics operations.

EBRT2030 (2023–2026, IA) extends architectural innovation to the public transport domain. The project is developing next-generation electric Bus Rapid Transit systems that integrate full electrification, automation and connectivity. Demonstrations in seven European cities will showcase predictive maintenance, smart charging coordination and IoT-enabled fleet management, highlighting the potential of automation-ready bus platforms to transform urban mobility.

ESCALATE (2023–2026, IA) brings modularity and digital engineering to heavy-duty vehicles. It develops scalable BEV/FCEV powertrains supported by digital-twin mission management, AI-based predictive maintenance and resource-efficient component design. Cross-border pilots validate architectures capable of delivering up to 800 km of range, demonstrating the feasibility of modular platforms for long-distance freight.

ZEFES (2023–2026, IA) advances both BEV and FCEV powertrains for long-haul freight. It focuses on high-efficiency inverters, improved HVAC systems, enhanced recuperation and interoperable megawatt charging. Demonstrations across 15 use cases aim to validate ranges up to 750 km at 40-ton GVW, supported by digital-twin design tools, fleet-level optimisation models and TCO analysis.

EMPOWER (2023–2026, IA) develops high-efficiency BEV/FCEV heavy-duty powertrains with advanced thermal management and high-efficiency e-axles. The project targets demonstrators capable of 400 km (BEV) and 750 km (FCEV) ranges at TRL 8, supported by real-world trials with logistics operators. Integrated LCA and TCO assessments will highlight the need for significant battery and fuel-cell cost reductions by 2030 to reach parity with diesel HDVs.

H2ACCELERATE TRUCKS (2023–2030) focuses on industrialising hydrogen long-haul trucks through coordinated production scaling by major European manufacturers. The project aims to deliver 150 fuel-cell trucks by 2029 and achieve full industrialisation by 2030, targeting articulated trucks in the 41–44 tonne segment with ranges above 600 km.

4.6.4. Conclusions and recommendations for ZE vehicle competitiveness

The analysis of the EU's vehicle integration and deployment project portfolio illustrates an R&I strategy oriented toward modular ZEV architectures, long-haul heavy-duty demonstration and fleet-level digital optimisation. The projects advance modular vehicle architectures, digital-twin-enabled optimisation, high-efficiency powertrains and automation-ready platforms, forming a complementary set of capabilities that strengthen Europe's position in next-generation electric mobility. Together, they demonstrate that ZEVs are rapidly maturing across light-duty, urban and long-haul segments, with digitalisation and modularity emerging as key competitiveness drivers.

Identified strengths

Strong R&I focus on modular, scalable and mission-optimised powertrains is identified both for BEV and FCEV.

Across ZEV-UP, MULTI-MOBY, NEXTETRUCK, ZEFES, ESCALATE and EMPOWER, Europe is investing heavily in modular BEV and FCEV powertrains, digital-twin-based optimisation and mission-specific configurations. These projects demonstrate how scalable architectures can reduce development costs, improve efficiency and support diverse operational needs from urban vans to 40-ton long-haul trucks. Their combined insights highlight modularity as a central pillar of future ZEV competitiveness.

Leadership in long-haul zero-emission heavy-duty vehicle development

Projects such as ZEFES, ESCALATE and EMPOWER validate ranges of 400–800 km under real-world conditions, confirming the technical feasibility of long-haul BEV and FCEV trucks. Demonstrations across TEN-T corridors, cross-border pilots and industrial-scale programmes (H2ACCELERATE TRUCKS) position Europe as a frontrunner in zero-emission freight transport. These initiatives show that ZE-HDVs can match diesel performance in payload, reliability and mission duration.

Advanced digitalisation and fleet-level optimisation

Digital-twin engineering, AI-based predictive maintenance and integrated fleet-management tools are central strengths of the portfolio. Projects such as NEXTETRUCK, EBRT2030, ZEFES and ESCALATE demonstrate how digital tools enhance reliability, reduce downtime and optimise energy use across complex missions. These capabilities are essential for scaling BEV and FCEV fleets in logistics, public transport and cross-border operations.

Growing industrial capacity for hydrogen trucks and buses

Large-scale deployment initiatives such as H2ACCELERATE TRUCKS show Europe's strategic investment in fuel-cell buses and long-haul trucks. These projects collectively strengthen Europe's industrial base, demonstrating high-utilisation performance and preparing supply chains for commercialisation. They also highlight the importance of coordinated procurement and economies of scale to reduce vehicle and fuel costs.

Integration of lifecycle sustainability and TCO analysis

ESCALATE and EMPOWER embed LCA and TCO methodologies into vehicle development, supporting resource-efficient design and transparent cost assessment. This strengthens Europe's ability to align ZEV technologies with regulatory expectations on sustainability, circularity and environmental performance.

Identified gaps and possible next steps

Need for accelerated cost-reduction pathways for batteries and fuel-cell systems

Across all heavy-duty projects, high upfront costs remain the main barrier to competitiveness. Batteries for BEVs and stacks/storage for FCEVs require significant cost reductions to reach diesel parity. Europe should prioritise industrial scaling, next-generation chemistries and coordinated procurement to reduce capital expenditure.

Scaling up industrial deployment for hydrogen trucks and buses

FCEV competitiveness depends on large-volume production. While early industrial programmes are promising, Europe needs sustained support for scaling manufacturing, harmonising specifications and coordinating deployment with hydrogen supply chains. Without this, FCEVs will remain more expensive than diesel alternatives.

Consolidation of modular powertrain standards and architectures

Multiple modularity strategies are being explored across projects. Europe should encourage standardisation of interfaces, components and digital-twin frameworks to reduce fragmentation, accelerate development cycles and support cross-manufacturer interoperability.

Strengthening digital and organisational readiness for fleet-level optimisation

Digital tools require new skills for operators, logistics companies and public transport authorities. Future programmes should support capacity-building, training and organisational innovation to ensure effective adoption of AI-based maintenance, mission planning and fleet-management systems.

4.7. Advanced materials and manufacturing

4.7.1. State of the art

Advanced materials and manufacturing for the automotive sector are evolving from a specialised engineering domain into a strategic enabler of industrial competitiveness, supporting vehicle performance, production efficiency and innovation capacity across the value chain.

Market trends

The market for advanced automotive materials and manufacturing is being reshaped by electrification, cost pressure and industrial restructuring. As electric-vehicle markets grow, competition is moving beyond propulsion systems alone It increasingly depends on the materials and manufacturing solutions that determine weight, efficiency, durability and production cost. This is strengthening demand for lightweight multi-material structures, advanced aluminium and composite solutions, and more efficient processing routes. It also increases the need for scalable manufacturing systems that can reduce industrialisation time and lower environmental impacts. At the same time, more value in future vehicles is concentrated in batteries, semiconductors, software and AI-enabled functions. This makes advanced materials strategically important not only for vehicle structures, but also for magnets, electronics and other next-generation components (Tazi, Nacef et al., 2025).

A second market trend is the growing importance of supply security and material resilience. The rapid expansion of electric mobility and other clean-energy technologies is driving demand for lithium, nickel, cobalt, graphite and rare-earth metals. At the same time, refining and processing remain highly concentrated geographically. According to the IEA, lithium demand increased by almost 30% in 2024. While volume demand for nickel, cobalt, and lithium continues to rise, extreme price volatility in 2024–2025 has shifted the industrial focus from simple substitution to long-term price-hedging and supply-chain vertical integration. In the automotive sector, this is pushing companies towards lower material dependency, substitution of critical raw materials, stronger recycling systems and more circular product design. As a result, advanced materials are no longer only an engineering issue. They are becoming a core competitiveness issue that links vehicle performance, affordability, circularity and supply-chain resilience (International Energy Agency, 2025a).

Trends in research

Current research trends show a shift from isolated material substitution to more integrated design approaches. The literature increasingly suggests that no single material family can meet future vehicle requirements on its own. Research is therefore moving towards combinations of advanced high-strength steels, aluminium alloys, polymer composites and hybrid structures. These are supported by improved joining methods, modelling tools and lifecycle-oriented design. In this context, lightweighting is no longer seen only to reduce mass. It is treated as a broader systems challenge that connects structural performance, durability, recyclability and manufacturability (Zhang et Xu, 2022).

A second trend concerns materials and processes that reduce dependence on critical raw materials while improving circularity and safety. For instance, in magnet materials, recent review literature highlights the growing interest in rare-earth-free or rare-earth-reduced alternatives, including manganese-based systems. These still face major performance and industrialisation challenges, but they are strategically important. In parallel, research is increasingly shaped by safe-and-sustainable-by-design principles. These approaches aim to integrate hazard, exposure and lifecycle considerations from the earliest stages of innovation. This is especially relevant in automotive value chains, where new materials must combine performance with regulatory robustness and circularity (Apel et al., 2024; Keller et al., 2022).

A third trend is the convergence of advanced materials, manufacturing, electronics and digital intelligence. Research roadmaps increasingly stress the role of silicon photonics, programmable photonic circuits and energy-efficient embedded systems for future sensing, communication and computing. In automotive terms, this means that competitiveness in advanced materials is no longer limited to structural materials. It increasingly includes functional materials and semiconductor platforms that support edge AI, autonomous functions and stronger European electronics capability (Shekhar et al., 2024; Tazi, Nacef et al., 2025).

Circularity and supply-chain resilience

A further trend is the growing integration of circularity into advanced materials strategies. This is no longer only an environmental objective. It is also becoming an industrial resilience priority. In the automotive sector, this is reflected in efforts to reduce dependence on primary critical raw materials, increase the use of secondary materials, and improve design for disassembly, recyclability and material recovery. This is particularly important for lightweight alloys, composites, battery materials and permanent magnets. In all these areas, future competitiveness will depend not only on performance, but also on the ability to secure material supply and retain value within European industrial ecosystems (European Commission, 2025b; International Energy Agency, 2024).

4.7.2. EU R&I overview

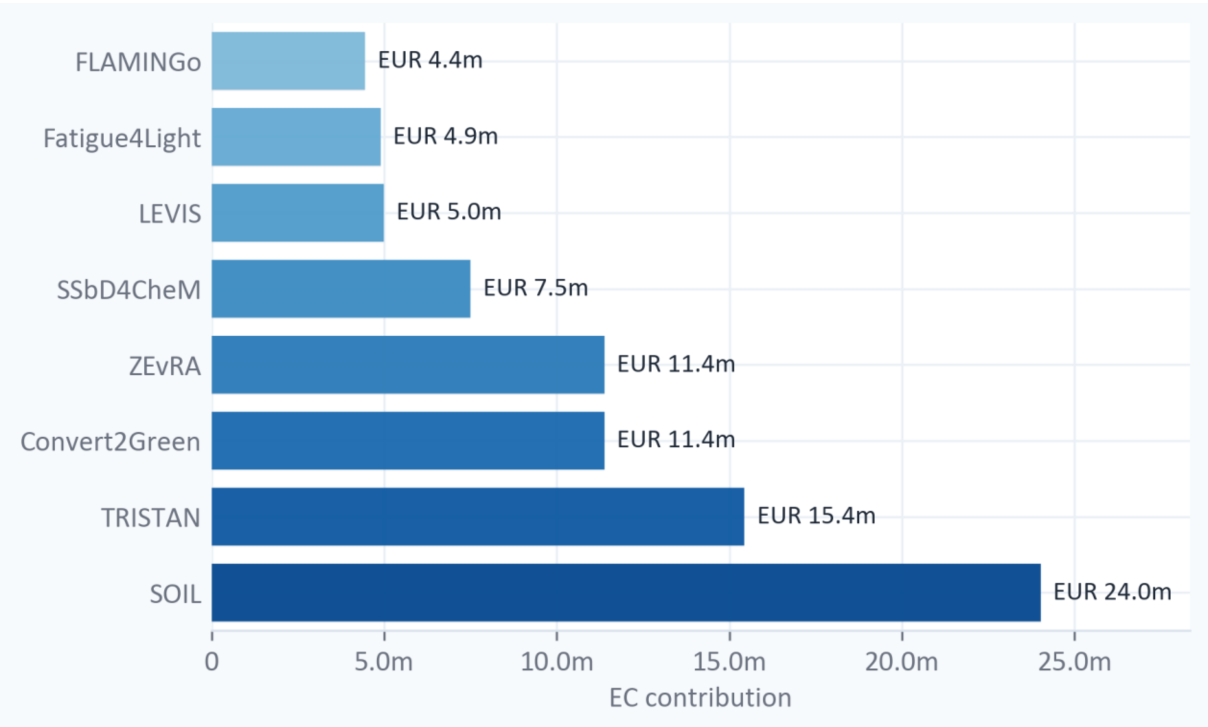
EU research and innovation in advanced materials and manufacturing is increasingly shaped by the need to combine decarbonisation, industrial competitiveness and strategic autonomy. Across Horizon Europe and related innovation instruments, the portfolio of analysed projects moves beyond isolated material breakthroughs towards integrated solutions that link vehicle performance, circularity, manufacturing scale-up and secure access to critical technologies. This reflects a broader industrial logic - Europe's automotive transition depends not only on cleaner propulsion, but also on stronger capabilities in materials engineering, production processes and strategic components. This section contains 19 projects, representing EUR 232.1m in total cost and EUR 113.0m in EC contribution (**Table 10**). The most common development stage is Pilot production & demonstration (TRL 6-7); the dominant primary pillar is Pillar 3: Competitiveness and Supply Chain Resilience.

Table 10. Advanced materials and manufacturing project summary table

Subsection	Projects	Total cost	EC contribution
1 Lightweight materials & structural innovation	5	EUR 25.4m	EUR 22.6m
2 Circularity & safe-and-sustainable materials	5	EUR 36.5m	EUR 35.4m
3 Manufacturing & material processing	4	EUR 7.6m	EUR 7.6m
4 Semiconductors & digital intelligence	5	EUR 164.9m	EUR 47.4m
Total	19	EUR 234.4m	EUR 113.0m

Source: TRIMIS, JRC, 2026

Figure 18. Projects receiving highest funding in the advanced materials and manufacturing theme



Source: TRIMIS, JRC, 2026

While the portfolio is anchored primarily in Pillar 3 (Competitiveness and Supply Chain Resilience), reflecting the strategic importance of advanced materials, manufacturing capability and supply security for the European automotive industry, a substantial part of the analysed projects also contributes to Pillar 2 (Clean Mobility) through lightweighting, vehicle efficiency and circular design for electric vehicles. In addition, a smaller but strategically important set of projects aligns with Pillar 1 (Innovation and Digitalisation), particularly where semiconductor technologies, advanced computing architectures and embedded intelligence support future automotive competitiveness.

The projects can be organised into four complementary groups:

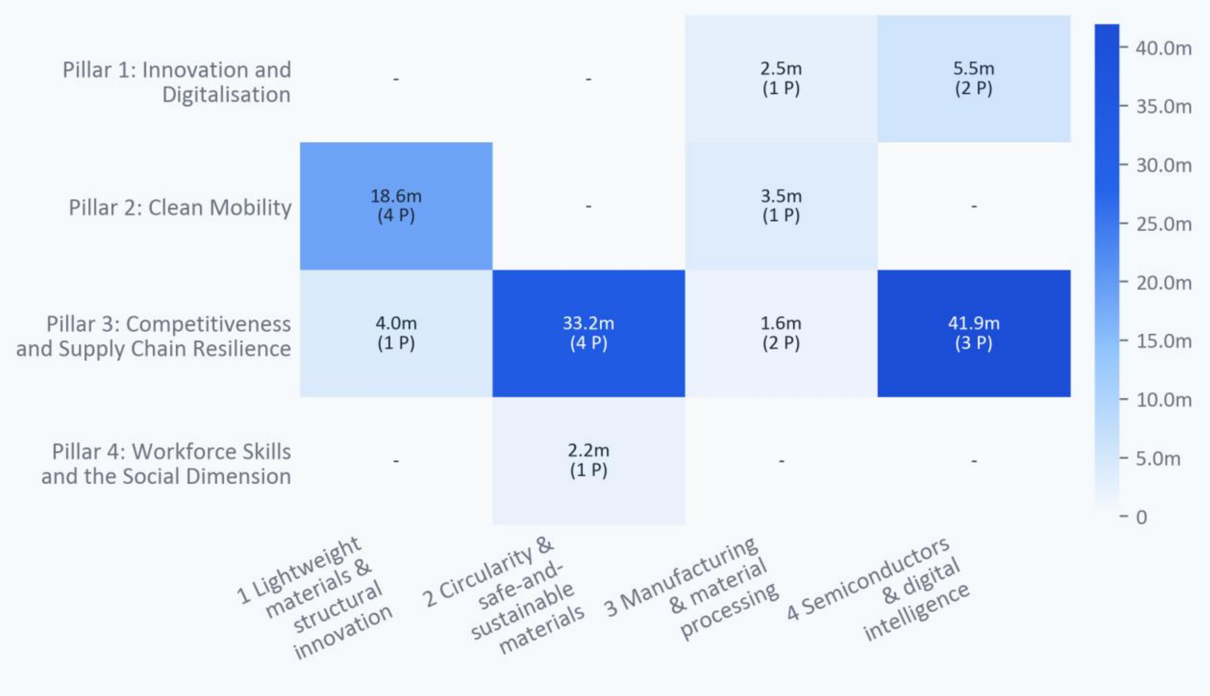
— The first focuses on **lightweight materials and structural innovation**, where new multi-material concepts, aluminium solutions and fatigue-aware design approaches aim to reduce vehicle mass while preserving safety and durability.

— The second group addresses **circularity, recycling and safe-and-sustainable materials**, showing how design-for-circularity, recovery technologies and safer chemistry are becoming central to future automotive value chains.

— A third group covers **manufacturing and advanced material processing**, highlighting the importance of scalable production routes, magnetic-material innovation and reduced dependence on critical raw materials.

— Finally, a strategically important set of projects targets **semiconductors and electronics**, and digital intelligence, underlining that automotive competitiveness increasingly depends on European capability in semiconductors, computing architectures and embedded intelligence alongside advances in materials and manufacturing.

Figure 19. Advance materials and manufacturing projects by pillar and subsection



Source: TRIMIS, JRC, 2026

4.7.3. Project reviews

4.7.3.1. Lightweight materials and structural innovation

This group covers projects that improve vehicle efficiency and competitiveness through lighter structures, better fatigue performance and more advanced integration of structural materials into future electric-vehicle platforms.

ALMA (2021-2024, IA) developed a multi-material battery-electric vehicle structure built around eco-design, circularity and lightweighting. By combining advanced high-strength steels, sheet moulding compounds and hybrid materials, it demonstrated a 160 kg lighter body-in-white, lower life-cycle emissions, detachable assembly solutions and integrated structural health monitoring.

FATIGUE4LIGHT (2021-2024, IA) addressed one of the key barriers to lightweight chassis deployment - proving long-term durability quickly and reliably. It combined advanced steels, aluminium alloys and hybrid composites with new fatigue-modelling and fast-testing methods, helping reduce validation time while supporting lighter, safer chassis parts for electric vehicles.

LEVIS (2021-2024, IA) extended the lightweighting agenda through thermoplastic-based carbon-fibre reinforced plastics, metal hybrids and integrated structural health monitoring. Its demonstrators achieved major weight and global-warming-potential reductions while showing that eco-design, circularity and end-of-life recycling can be built into high-performance structural components from the start. FLAMINGO (2021-2025, IA) focused on lightweight aluminium metal-matrix composites for electric-vehicle applications. By combining metallurgical innovation with forming technologies, it sought to substitute heavier steel parts with higher-strength, higher-stiffness aluminium solutions, thereby reducing vehicle mass while creating a more industrially viable manufacturing route for advanced components.

FLEXCRASH (2022-2026, RIA) complements this cluster by targeting crash-tolerant aluminium structures through flexible and hybrid manufacturing. Its approach uses additive manufacturing to create tailored surface patterns on preformed parts, enabling local property optimisation, improved crash energy absorption and more adaptive lightweight structures suited to increasingly complex vehicle requirements.

4.7.3.2. Circularity, recycling and safe-and-sustainable materials

This group addresses circularity as a design and industrial strategy, linking material selection, end-of-life recovery, traceability and safer chemistry to more sustainable automotive value chains.

ICIRCULAR3 (2023-2026, MSCA) strengthens circular-economy capabilities through doctoral training and digital methods focused on electric vehicles, industrial robots and outdoor power products. Its relevance lies in reverse logistics, circular supply-chain design and battery remaining-useful-life estimation, all of which support more intelligent second-life, remanufacturing and recovery strategies. CONVERT2GREEN (2023 - 2026, IA) built a distributed innovation ecosystem for climate-neutral materials, connecting testing, validation, scale-up and business support. For automotive applications, its relevance lies in helping firms move sustainable material solutions beyond early development by improving access to pilot infrastructure, technical services and collaborative industrial uptake pathways.

TRIFLUORIUM (2025-2029, EIC/SME2) develops a tribolysis-based recycling route for organofluorides and fluoropolymers, materials that are relevant to semiconductors, hydrogen technologies and electric vehicles. By converting difficult, fluorinated waste streams into stable inorganic fluorides, it addresses both circularity and Europe's dependence on imported critical fluorine resources. SSBD4CHEM (2024-2027, RIA) develops a Safe and Sustainable by Design framework for next-generation chemicals and materials. For the automotive sector, this includes renewable composites and PFAS-free alternatives, supported by hazard screening, advanced life-cycle methods, characterisation tools and stakeholder-oriented validation designed to improve regulatory and industrial acceptance.

ZEVRA (2024-2026, RIA) aims to harmonise circularity across the full light-duty electric-vehicle value chain. It combines design-for-circularity methods, digital product passports, logistics concepts, business-model innovation and workforce upskilling, with the goal of reducing life-cycle emissions and embedding circular practices across a large share of EV material content.

4.7.3.3. Manufacturing, magnets and advanced material processing

This group combines projects that reinforce industrial capability through advanced processing routes, magnetic-material innovation and manufacturing methods that can reduce material dependency while enabling more efficient electric-powertrain and component production.

AM2SOFTMAG (2022-2026, EIC/SME2) develops additive manufacturing routes for amorphous soft-magnetic materials used in electric machines and passive electrical systems. By designing metallic-glass alloys, powders and process chains for 3D-printed components, it supports higher-efficiency motors and opens new manufacturing possibilities for next-generation electric mobility systems. REFMAG (2022-2023, ERC) explored bulk rare-earth-free permanent magnets based on MnBi as an alternative to critical-material-intensive magnet systems. Its importance for automotive lay in the search for lower-risk magnetic materials for electric-mobility applications, supported by a novel processing route that could create anisotropic bulk magnets without conventional sintering.

MAG-TOOL (2025-2030, ERC) targets sustainable Fe-rich magnets that could replace Nd-Fe-B systems dependent on heavy rare earths. By combining machine learning, experimental alloy design and additive manufacturing, it seeks to reduce trial-and-error development and deliver magnet solutions relevant to electric vehicles and other clean-energy applications. 3DMULTIFERRO (2024-2029, ERC) investigates three-dimensional multiferroic architectures combining ferroelectric and magnetic functionalities in curved microstructures. Although as the ERC project it is more exploratory, the project contributes to Europe's knowledge base in advanced functional materials for future low-power memory and logic devices, with possible longer-term relevance for computing systems used in AI-enabled and autonomous technologies.

4.7.3.4. Semiconductors, electronics and digital intelligence

This group highlights a smaller but strategically important part of the portfolio, showing that automotive competitiveness increasingly depends on semiconductor capability, computing architectures and embedded intelligence alongside advances in materials and manufacturing.

SOIL (2024-2027, IA) seeks to strengthen the European FDSOI (Fully Depleted Silicon On Insulator) ecosystem as a strategic semiconductor platform for automotive, space, IoT and edge-AI applications. By expanding manufacturing, design IP and digital-analogue-RF integration capability, it supports supply resilience and a more autonomous European chip base for key industrial markets. VIVID project (2023-2025, EIC/SME2) developed a European 5 nm processing-platform architecture intended to support applications from the edge to high-performance computing. It linked to future ADAS and autonomous-driving processors, where computing performance, energy efficiency and reduced dependence on non-European semiconductor architectures are likely to become increasingly important.

TRISTAN (2022-2025, IA) supported the transition to RISC-V (Reduced Instruction Set Computing) as an open, competitive and strategically important chip architecture for Europe. By strengthening the ecosystem for open hardware and software, it lowered barriers to integrated-circuit innovation and helped to build the design autonomy needed for future embedded and automotive computing applications.

NEUROPIC (2023-2027, EIC/SME2) develops programmable photonic integrated circuits using silicon photonics, nanofabrication and neuromorphic concepts. The project targets ultra-low-power, scalable optical processing for data centres, autonomous vehicles and quantum information systems. It supports flexible, high-bandwidth architectures for sensing, interconnects and AI applications.

EKKONO FLIIOT (2023-2025, EIC/SME2) broadened this sub-theme from hardware to edge intelligence. It developed edge intelligence for industrial IoT, with learning performed directly on very small devices. Instead of relying on cloud-based models, the approach trained local models on each unit. This supported distributed optimisation, lower data transfer needs and stronger control over sensitive industrial data.

4.7.4. Conclusions and recommendations for Advanced Materials and Manufacturing for the Automotive Sector

This analysis of the EU's advanced-materials project portfolio illustrates an R&I strategy oriented toward multi-material lightweighting, lifecycle and circularity integration, and critical-raw-material resilience.

Identified strengths

Lightweighting

The analysed portfolio points to a strong concentration of European R&I activity in lightweight materials and multi-material solutions for automotive applications. Projects such as ALMA, FATIGUE4LIGHT, LEVIS and FLAMINGO show progress in reducing component or vehicle weight while addressing structural performance, durability and manufacturability. Taken together, these projects suggest a solid foundation in advanced lightweighting approaches with clear relevance for future vehicle development.

Lifecycle integration

A second observable strength is the extent to which sustainability-related considerations are integrated into project activities from relatively early stages. Several projects include lifecycle assessment, lifecycle costing, recyclability, design-for-circularity or safe-and-sustainable-by-design approaches alongside technical development. This is particularly visible in ALMA, FATIGUE4LIGHT, ZEVRA and SSBD4CHEM, that are focused not solely on the performance improvement, but also on broader environmental and circularity objectives.

Circularity and traceability

The analysed projects also indicate growing activity in circularity-related innovation for advanced automotive materials and associated value chains. Across projects addressing recyclability, end-of-life recovery, fluorinated waste treatment, circular business models and digital product passport approaches, there is evidence of increasing attention to materials management beyond the use phase. This is particularly visible in ALMA, TRIFLUORIUM and ZEVRA, which together cover recyclability and recovery, difficult waste streams, traceability and circular value-chain design. While the EU portfolio demonstrates technical progress in recyclability, the industrial challenge remains the 'green premium' cost, which must be mitigated to maintain global competitiveness.

Supply-chain resilience

Finally, the project portfolio shows growing attention to supply-chain resilience in areas of increasing strategic relevance for the automotive sector. Projects such as REFMAG, TRIFLUORIUM and SOIL address issues linked to critical raw materials, rare-earth-free alternatives, semiconductor-related materials and related industrial capabilities.

Identified gaps and possible next steps

Industrial scale-up

Several projects demonstrate promising technical results at laboratory or pilot level, while the path toward industrial-scale manufacturing remains less clearly developed. This is particularly relevant for advanced lightweight materials, magnetic materials and novel processing routes, where further work may be needed to demonstrate production consistency, integration into existing manufacturing systems and cost-competitive scaling. A possible next step would be to strengthen support for higher-TRL pilot lines, industrial demonstrators and scale-up activities more explicitly linked to manufacturing readiness.

Validation and prioritisation

The analysed projects cover a broad and valuable range of materials, processing routes and circularity concepts – however it is not always evident which approaches are most likely to prove viable at industrial scale. In several areas, projects advance along parallel pathways with different maturity levels and with limited directly comparable evidence on cost, manufacturability or likely market uptake. A useful next step would therefore be to combine stronger techno-economic assessment with more systematic cross-project comparison to help identify the most promising routes for continued support.

Standards and uptake

Although the projects generate technically promising results, the wider uptake is likely to depend not only on further R&I, but also on the availability of common testing approaches, validation procedures, design rules and integration guidance. This appears particularly relevant for areas such as fatigue modelling and rapid testing, circularity and traceability tools, and safe-and-sustainable-by-design methods. A possible next step would therefore be to complement project-based innovation support with stronger pre-normative work, common methodologies and closer alignment with industrial qualification and regulatory requirements.

4.8. Workforce transformation

4.8.1. State of the art

Employment in the EU automotive sector

The crucial role of the automotive sector for Europe's economy is reflected in its impact on the EU job market. The automotive sector provides direct and indirect employment to 13.8 million Europeans, amounting to 6.1% of total EU employment[22]. This number includes 2.6 million employees involved in direct manufacturing of motor vehicles, which represents 8.5% of total EU manufacturing employment. The automotive sector has also stimulating effect on other industries, such as steel, chemicals, textiles, as well as ICT, repair and mobility services. The automotive sector is currently being affected by several trends, most notably electrification, automation, and digitalisation.

Impact of electrification

Shift to electric cars is undoubtedly one of the most profound transformations in the history of the automotive sector. Driven by the EU climate ambitions, fast technological progress and fierce competition from other global players like China, it requires remodelling of the whole industry value chain. Manufacturing of many traditional car components, like combustion engines, gearboxes, or exhaust systems will be replaced by electric motors, batteries, charging systems, etc. This will inevitably lead to major shift in employment, with disappearance of certain professions, emergence of new job profiles, and redefinition of required skillset (Eurofound, 2025).

The distribution of these impacts is likely to be unequal. The challenge will be more significant for the manufacturers specialized in products that will become less relevant, such as ICEs parts. Suppliers higher up the value chain are expected to be more affected than the assembly plants, since the automotive industry outsources around 75% of its components production (Çınar, 2020). This might also translate into regional differences in terms of employment impacts, with Central and Eastern European countries playing more important role in the components manufacturing than the Western Europe, where most of high-end assembly lines, headquarters, and R&D departments are located (European Parliament, 2021).

Another feature of EV manufacturing is that their production is far less complex than ICE vehicles. Labour intensity of a battery electric vehicle is estimated to be 61% of that of a diesel car (Galgóczi, 2023). Also, vehicle maintenance complexity is reduced. This fact might contribute to loss of jobs and force some workers to switch jobs or change tasks in their current positions.

Batteries manufacturing plays a key role in stabilizing employment in the EV transition, as it constitutes 40% of EV value (ACEA, 2025), and 40% of the total labour input into manufacturing of a car (Galgóczi, 2023). The EU has set a target of reaching 25% of global production capacity by 2030 (BEPA, 2025). In 2023 the EU accounted for 7% of global battery production, second to China, the world's biggest producer controlling 83% of the market. However, these ambitions face shortage of qualified employees in several areas, such as high-quality, high-volume, highly digital and technically complex production processes, chemical engineering and mass production expertise (Eurofound, 2025) .

Automation and digitalisation

The automotive industry has historically been a major point of interest for automation and remains one of the key beneficiaries of industrial automation and robotics. In 2023, 36% of automotive manufacturing enterprises used robots, compared to the average of 6% of all EU enterprises.

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[22] European Commission, 'Automotive Industry - Internal Market, Industry, Entrepreneurship and SMEs', accessed 28 August 2026, https://single-market-economy.ec.europa.eu/sectors/automotive-industry_en.

However, the robotisation rate might differ substantially between countries, e.g. the indicator for Poland being 6 times lower than for Germany (Eurofound, 2025). Although the widespread use of robots in the industry is not new, it is currently a subject to radical expansion and acceleration due to advancing digitalisation and new technologies such as collaborative robots, connected logistics, automated forklifts, Internet of Things, additive manufacturing and others. Also, the use of AI is more widespread in automotive than in other sectors, with 15% of workforce using generative AI and cobots (collaborative robots) (Eurofound, 2025) . In addition to manufacturing, also sales and maintenance operations become increasingly digitalized, with the online operations becoming more widespread (Broughton et al., 2024). The exact effect of these trends on employment is difficult to predict. While many analyses point at decline of manual labour and low-skill, repetitive white-collar jobs, there are many professions that are still difficult to fully automate, e.g. vehicle assembly and quality inspection.

In addition to automation and digitalisation of the manufacturing process, also the cars themselves are being affected by these trends. The concepts of connected, shared, and automated mobility, as well as software-defined vehicles are a drastic departure from the conventional car concept. These new paradigms shift the traditional focus on mechanical engineering towards software engineering and data. Some predictions estimate the value of software to constitute 50% of total car value by 2030 (Deloitte, 2021). Due to the increasing demand for IT skills, automotive OEMs are becoming the major employers of software engineers. Closer collaboration will also be required between the industry and academia, to satisfy the growing demand for highly qualified researchers in domain such as AI, cybersecurity, and development of common architectures and standards for the industry (EARPA, 2025).

Initiatives for workforce adaptation

In response to the above challenges, the Automotive Industrial Action Plan provides for several EU wide measures. The plan proposes legal amendments to the European Social Fund Plus (ESF+) and the European Globalisation Fund (EGF). The changes should extend the scope of funding to support companies in restructuring processes to protect employees against the risk of unemployment. The plan also assumes more active engagement with relevant actors and Member States to draw attention to the available support options. The plan also aims to create a European Fair Transition Observatory to develop and collate relevant data, including projecting employment trends across the European automotive value chain and at sectoral and regional levels. These actions will complement the already existing initiatives, such as Pact for Skills and the Automotive Skills Alliance (European Commission, 2025b).

These initiatives often work in parallel with programmes on regional and state level. Still, the most important source of reskilling will likely be the OEMs, and the success of workforce transformation will depend on their training departments, and partnerships with universities and vocational training providers (Eurofound, 2025).

4.8.2. EU R&I overview

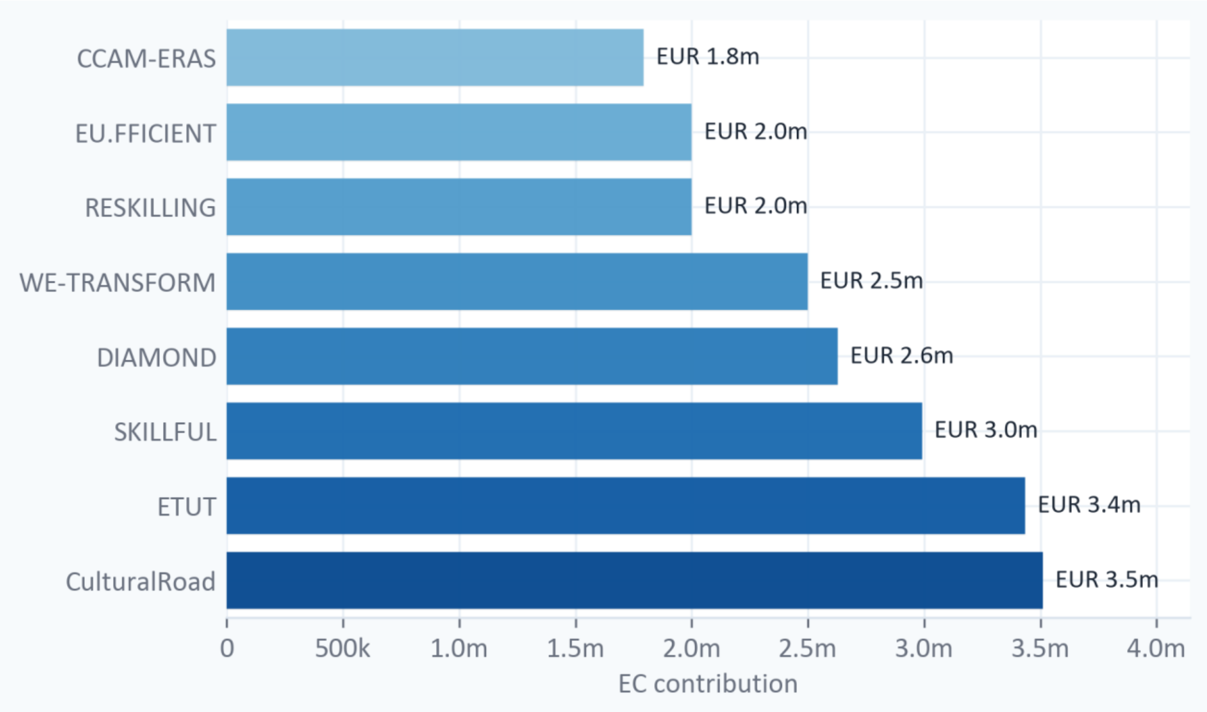
The selection of projects presented in this report consists of 9 projects with total 21.4m EUR of EU contribution (**Table 11**). The projects constitute a representative sample to provide an overview of research activities in the domain of workforce transformation.

Table 11. Workforce transformation project summary table

Subsection	Projects	Total cost	EC contribution
1 Technological impact	2	EUR 6.1m	EUR 5.5m
2 Impact of CCAM	3	EUR 7.3m	EUR 7.3m
3 Women in transport workforce	2	EUR 3.1m	EUR 3.1m
4 Other initiatives	2	EUR 5.5m	EUR 5.4m
Total	9	EUR 22.0m	EUR 21.4m

Source: TRIMIS, JRC, 2026

Figure 20. Project funding in the workforce transformation theme



Source: TRIMIS, JRC, 2026

The following thematic clusters can be distinguished:

— **Comprehensive analysis of technological impact**: Projects characterized by broad scope, examining workforce impacts of multiple trends and technologies, e.g. automation, electrification, digitalisation, decarbonisation, etc.

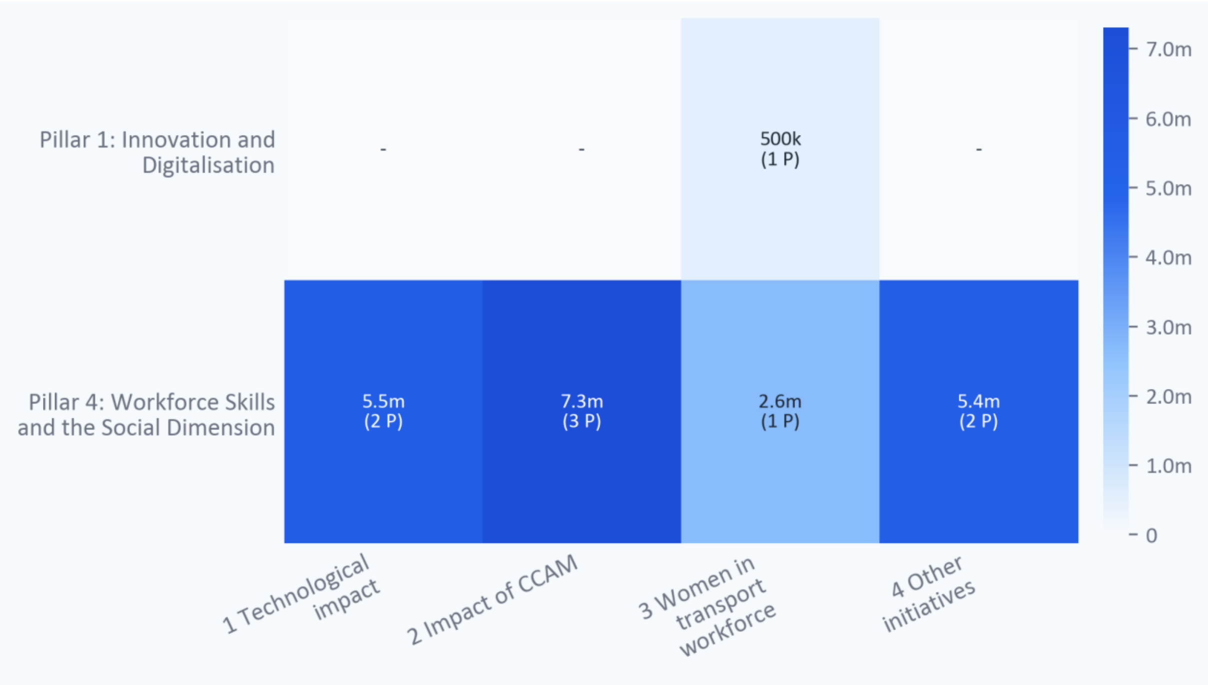
— **Impact of CCAM**: Several projects address the impacts of cooperative, connected, and automated mobility

— **Women in transport workforce**: Initiatives aiming at understanding and stimulating women participation in the transport workforce

— **Other initiatives**: Other workforce-related projects not fitting in the remaining categories

The topics covered by these projects are essential for the Pillar 4: Workforce skills and the social dimension.

Figure 21. Workforce transformation projects by pillar and subsection



Source: TRIMIS, JRC, 2026

4.8.3. Project reviews

4.8.3.1. Comprehensive analysis of technological impact

SKILLFUL (2016–2019, RIA) performed a review and critical analysis of the existing, emerging, and future knowledge and skills requirements in the sector in the view of changing technological landscape, e.g. automation, electrification etc. Future job requirements were investigated given the identified trends, for all transport modes and multimodal chains, and for various types of employees (blue/white collar, managers, operators, researchers, etc.). The project identified and benchmarked the existing and novel training and education approaches and tools, and developed novel curricula and training schemes for the future transport sector.

WE-TRANSFORM (2020–2024, CSA) applied a participatory approach to explore the impact of automation and digitalisation on transport workforce, with the end goal of generating an evidence-based agenda to research, formulate and prioritise the arising challenges. This was realized through creation of a Living Hub and discussions among workers, passengers, unions, public authorities, and policymakers. The results include a policy agenda including 11 policies, related to four thematic areas (Public governance and regulation, Industrial governance, Training and reskilling, Minimisation of labour exclusion and exploitation).

4.8.3.2. Impact of CCAM

In addition to system integration and large-scale demonstrations, the EU CCAM portfolio includes targeted projects on workforce skills and societal acceptance as critical enablers of deployment. CCAM scaling depends not only on technical maturity but also on workforce transformation and public acceptance — dimensions that directly influence market uptake. These actions play a decisive role in reducing deployment risks and skills-related bottlenecks. They align with Pillar 4 of the EU

Automotive Industrial Action Plan, supporting a just and inclusive transition of the automotive ecosystem.

The RESKILLING (2025–2027, RIA) examines how transport workforce should evolve in the future to respond to the CCAM innovations. The project looks closely at all professions linked to CCAM services for both people and goods, accounting for different social contexts and regional specificities. The key element of the process is the RESKILLING co-innovation framework, which facilitates co-creation between professionals, industry actors, policymakers, and beneficiaries, ensuring thereby the technical viability of the solutions and their fitness to real-world needs.

CCAM-ERAS (2024–2026, RIA) focuses on the workforce dimension of CCAM deployment, addressing reskilling and upskilling across the automotive and mobility value chain. The project aims to support the anticipation of skills gaps, labour-market impact analysis and the alignment of training pathways with emerging CCAM technologies, thereby strengthening workforce adaptability and reducing constraints on industrial scale-up.

CULTURALROAD (2024–2027, RIA) addresses societal acceptance and inclusiveness as preconditions for market uptake of CCAM. The project has developed a Five-Pointed Star Rating System — assessing inclusivity, network optimisation, safety, acceptance and psychological factors — and is currently applying it through participatory workshops at five demonstration sites across Europe (Barcelona, Karlsruhe, Eilat, Ljubljana and the West Midlands/Oxfordshire regions). It targets integration of its guidance into SUMPs/NUMPs and large-scale demonstrations, with demonstrators focusing on CO_2 reduction and road safety improvements.

4.8.3.3. Women in transport workforce

The DIAMOND project (2018-2022, RIA) looked at innovations that could contribute to a more fair and inclusive transport system, with the focus on women. Through the collection and analysis of disaggregated data, analytics, and management techniques, the consortium delivered a toolbox with recommendations on female inclusiveness. The project delivered a transport system model allowing to define behavioural patterns, gaps, opportunities, and provided recommendations for a fair and inclusive transport system. Moreover, a toolbox, curriculum guidelines, a white paper, corporate social responsibility protocols and guidelines for the autonomous automotive sector were produced.

INFIMO (2023-2025, CSA) was a project focused on strategic collaboration between clusters and diverse innovation actors from Estonia, Portugal, and Georgia. Two collaboration models were developed: one to support digitalisation and sustainability across sectors, and another to enhance competitiveness in the mobility sector through joint research, development, and innovation pilots and an open innovation competition. One of the central goals of the project was facilitating stronger involvement of women innovators and increasing gender-responsiveness of services offered by the partners.

4.8.3.4. Other initiatives

ETUT (2021–2025, MSCA) established a doctoral training network dedicated to electrical transport. The project developed competencies in power electronics, EMC, battery management and wireless power transfer, ensuring that Europe’s technological progress in electromobility is matched by a highly qualified engineering workforce.

EU.FFICIENT (2024-2026, CSA) is a project centred around the concept of co-creation: a collaborative, open innovation process where companies work directly with customers, stakeholders, or employees. The project is working to create a dedicated platform and methodology to streamline access to co-creation resources, as well as training and networking opportunities across diverse sectors, including mobility, advanced manufacturing, and artificial intelligence.

4.8.4. Conclusions and recommendations

This overview of the EU's workforce project portfolio illustrates an R&I strategy oriented toward the employment effects of automation, digitalisation and electrification, with an emerging focus on connected and automated mobility.

Identified strengths

Broad coverage of workforce impacts research topics: The identified projects investigate a variety of relevant trends, including automation, digitalisation, and electrification, providing an exhaustive analysis of their possible impacts.

Current focus on CCAM impacts on workforce: Two ongoing projects are investigated topic so far underrepresented in the other R&I initiatives – cooperative, connected, and automated mobility.

Identified gaps and possible next steps

More research needed on the impact of artificial intelligence: past initiatives on the broad technological impacts were initiated before the AI revolution, therefore the question of its impacts on transport workforce requires further investigation.

Ageing of the workforce: While technological change is a key factor for workforce transformation, demographic situation will also play an important role. The aspect of workforce aging is not sufficiently covered by the described projects, which focus mainly on the technological aspect.

5. Competitiveness contribution analysis

5.1. Motivation and approach

An AI-assisted competitiveness assessment workflow was developed to perform an expert-judgement task in a way that remained reproducible, evidence-based, and suitable for the project portfolio-level analysis. The workflow assesses whether project actions as described in CORDIS contribute to different dimensions of competitiveness, without those dimensions being named explicitly in the source text. It also requires distinguishing between project objectives, implemented actions, broader context, and expected impacts.

The use of this workflow allowed to assess the projects included in this report on their contribution towards the competitiveness of the European automotive sector. For this purpose, several relevant competitiveness dimensions were identified, including consumer price, user features, societal readiness, interoperability, operational efficiency, technical novelty, EU leadership, production scaling, raw materials, circularity, and skills development.

The dimensions were grouped into five broader analytical clusters:

— **Market adoption:** consumer price, user features, societal readiness

— **Systems and operations:** interoperability, operational efficiency

— **Technology and industry:** technical novelty, EU leadership, production scaling

— **Resources and circularity:** raw materials, circularity

— **Skills and capabilities:** skills development

Projects were assessed using the following scoring scale:

— **0 = No admissible evidence:** No relevant project action or objective was described in the source data, or only background / motivation / expected impact is present.

— **1 = Objective or early/planned action:** The text describes a relevant objective or planned action, but with limited procedural or implementation detail. No clear validation, demonstrator, industrialisation, manufacturing scale-up, or concrete mechanism is described.

— **2 = Concrete action or validated approach:** The text describes a concrete method, implementation, demonstrator, pilot, prototype, validation activity, industrialisation action, manufacturing scale-up pathway, standardisation mechanism, user trial, or similarly specific action directly linked to the criterion.

The text evidence, which is a direct quote from the input data, is preserved for each project. Then the results were aggregated over the competitiveness dimensions and clusters, allowing to extract both quantitative trends and qualitative insights on how R&I contributes towards competitiveness.

5.2. Outcome

5.2.1. Overview

This section synthesises the main findings of the competitiveness assessment of the selected automotive R&I projects. The analysis combines the scoring framework with evidence extraction. The following **Table 12** summarises the competitiveness analysis dimensions, their role for competitiveness, as well as the assessment criteria, and finally extracted evidence.

Table 12. Competitiveness clusters, dimensions, assessment criteria and extracted evidence

Cluster	Dimension	Role for competitiveness	How it is assessed	Extracted evidence of supporting actions
Market adoption	Consumer price	Captures whether a project can improve affordability or reduce total cost of ownership, thereby supporting market uptake and economic attractiveness.	Assessed through explicit evidence of actions or objectives linked to manufacturing cost, operating cost, maintenance cost, lifecycle cost, or total cost of ownership. Generic cost awareness is not sufficient.	Cost-reduction targets for power electronics, lower bus purchase price through procurement and ownership models, or reduced refuelling time and cost.
Market adoption	User features	Captures whether a project improves the attractiveness of products or services for end users through convenience, usability, comfort, accessibility, or user-facing safety.	Assessed through explicit user-facing functionalities or safety benefits for drivers, passengers, road users, or end users of mobility services.	Super-fast charging capability, automated emergency braking and steering, or safe and reliable fuelling under user conditions.
Market adoption	Societal readiness	Captures whether a project supports public acceptance, trust, adoption, and real-user interaction, all of which affect the practical uptake of new transport solutions.	Assessed through evidence of public or user acceptance measures, co-creation, real-user testing, user perception,	Large-scale market tests in real customer applications, roadshows and demonstration trials, surveys, focus groups,

			behavioural uptake, or adoption mechanisms.	and stakeholder workshops.
Systems and operations	Interoperability	Captures whether a project reduces integration barriers and enables system compatibility across actors, infrastructures, and digital environments, which is central to scalable transport innovation.	Assessed through evidence of compatibility, interfaces, APIs, protocols, data exchange, digital or physical interoperability, or standards that directly enable interaction or integration.	C-ITS/ETSI protocol implementation, open interfaces for Plug and Charge, brand-independent solutions across vehicle segments, or platform-level data exchange.
Systems and operations	Operational efficiency	Captures whether a project improves efficiency during use or operation, for example through better utilisation, lower downtime, improved routing, in-use energy efficiency, or fleet management.	Assessed through explicit evidence of operational or in-use efficiency gains.	Advanced energy management, lower fuel consumption, higher e-axle efficiency, or higher infrastructure utilisation.
Technology and industry	Technical novelty	Captures whether a project introduces technically or methodologically specific advances that go beyond current practice and may strengthen the innovation base of the sector.	Assessed only where the text explicitly states what goes beyond the state of the art, existing approaches, current practice, or a defined technical limitation. Generic claims of innovation are not sufficient.	Novel reliability concepts in power electronics, first-of-a-kind methodological toolboxes, new battery chemistries, or explicit advances beyond previous deployments.

Technology and industry	EU leadership	Captures whether a project strengthens first-of-a-kind European capability, strategic autonomy, dependency reduction, or the global industrial position of EU actors.	Assessed conservatively and only when the text explicitly states first-of-a-kind EU capability, strategic autonomy, reduced dependency on non-EU capability, or stronger EU industrial competitiveness in global markets.	First-of-a-kind European capability in hydrogen deployment, Plug and Charge market readiness, or European analytical capability for gender-aware transport policy support.
Technology and industry	Production scaling	Captures whether a project supports industrial uptake through manufacturing readiness, industrialisation, pilot-line development, or production-process scale-up.	Assessed through evidence of manufacturing-related scaling or industrial readiness.	Kilogram-scale synthesis of battery materials, scalable production know-how for solid-state batteries, pilot-line activity, or manufacturing documentation for battery packs.
Resources and circularity	Raw materials	Captures whether a project reduces dependence on scarce or critical raw materials, thereby supporting resilience and long-term industrial sustainability.	Assessed through explicit evidence of substitution, recovery, efficiency, diversification, or dependency reduction related to critical or scarce materials.	Low-cobalt or cobalt-free batteries, reduced rare-earth use, abundant-material substitution, or lower graphite dependence.

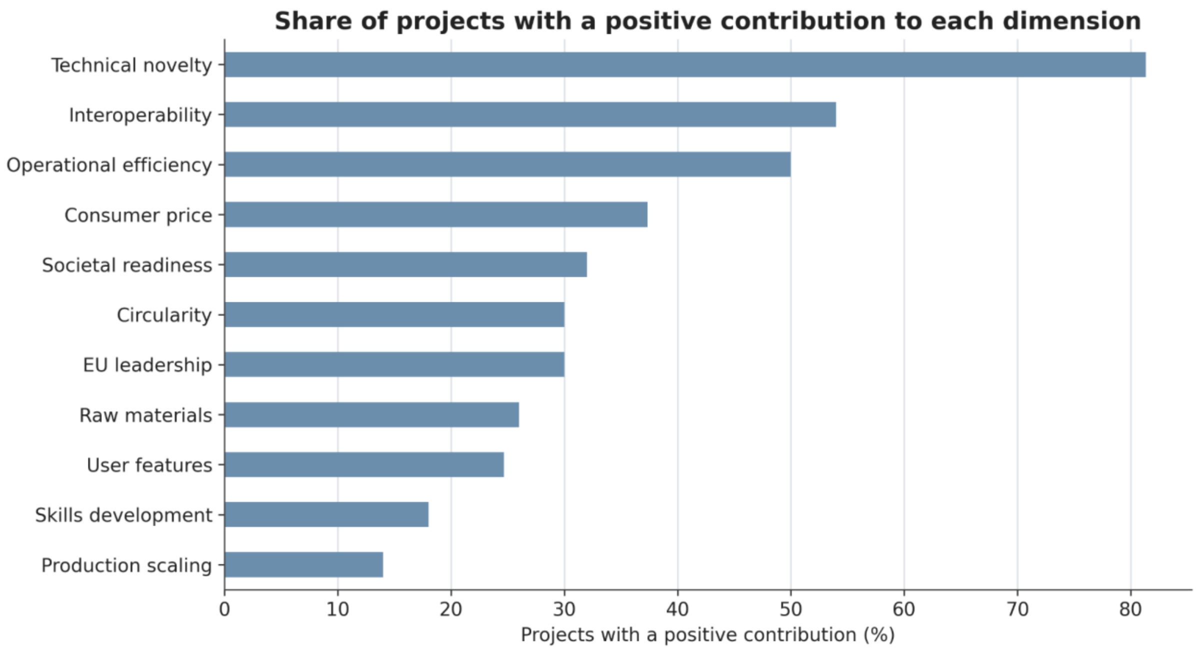
Resources and circularity	Circularity	Captures whether a project strengthens circular use of resources through reuse, recycling, remanufacturing, repairability, second life, or end-of-life strategies.	Assessed through explicit circular mechanisms rather than generic sustainability language.	High material recovery rates, recycling tests, second-life ageing protocols, or battery-swapping and reuse-oriented service concepts.
Skills and capabilities	Skills development	Captures whether a project contributes to workforce capability, training, upskilling, or reskilling that can support industrial transition and implementation capacity.	Assessed through evidence of training, workshops, courses, hackathons, upskilling, reskilling, or other organised learning and capacity-building actions.	New curricula, trainer profiles, business roles, training material collections, hackathons, or structured knowledge-transfer schemes.

Source: TRIMIS, 2026

5.2.2. Main quantitative trends across themes

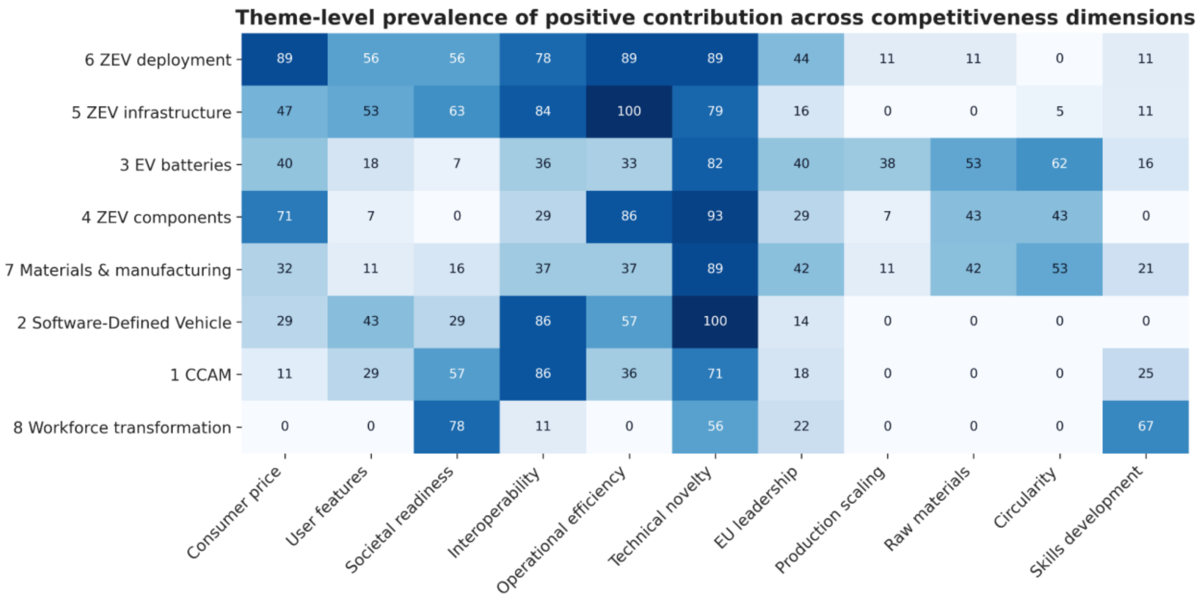
Figures 22 and **23** show that competitiveness contributions are distributed across thematic areas and that the portfolio is characterised by differentiated profiles rather than a single dominant model of competitiveness.

Figure 22. Share of projects with a positive contribution to competitiveness dimensions



Source: TRIMIS, JRC, 2026

Figure 23. Share of projects with specific actions targeting competitiveness dimensions across the automotive project themes. The number annotations in the boxes represent the percentage of projects in each report section (rows) where evidence of contribution towards the competitiveness dimension in each column were found.

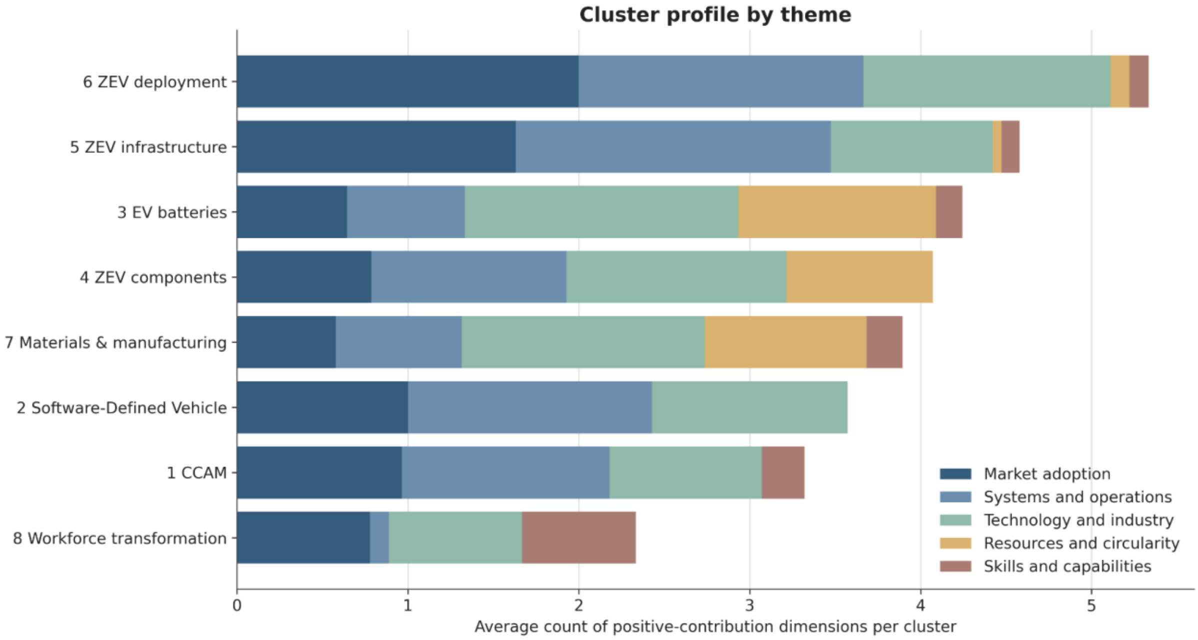


Source: TRIMIS, JRC, 2026

A robust pattern is the prominence of technical novelty across much of the portfolio. It is particularly strong in software-defined vehicle, EV components, advanced materials and manufacturing, and batteries for electric vehicles. This suggests that many projects contribute through technically specific advances that are explicitly framed as going beyond current practice. At the same time, these high novelty scores are not mirrored equally by production scaling, which remains low across almost all themes. This indicates that the portfolio is rich in technical innovation, but that explicit manufacturing-scale evidence is much rarer.

A second pattern is the concentration of interoperability and operational efficiency in infrastructure and deployment-related themes. Charging infrastructure, ZEV infrastructure, vehicle deployment, and connected, cooperative and automated mobility show especially strong scores in these dimensions. This is consistent with projects focused on interfaces, communication protocols, energy management, traffic integration, operational performance, and complex multi-actor system environments.

Figure 24. Competitiveness contributions across dimensions and automotive project themes

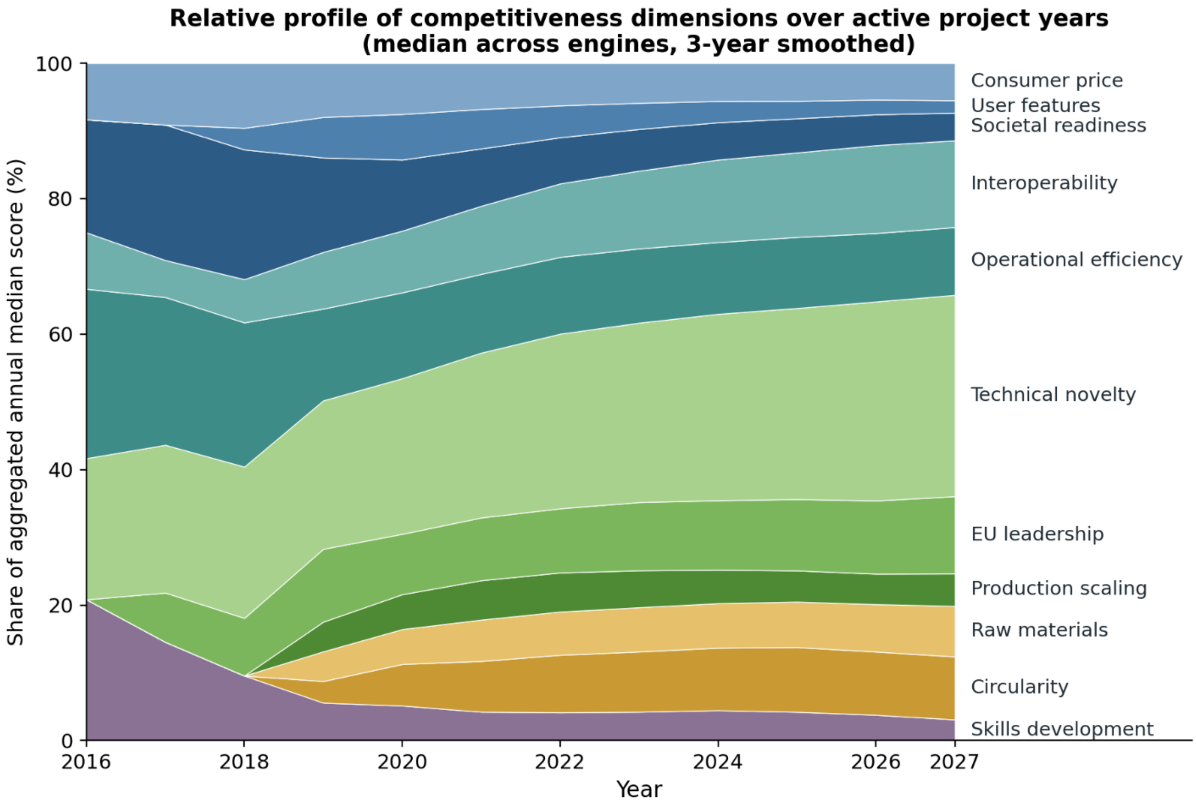


Source: TRIMIS, JRC, 2026

Evolution over time

The normalised time chart (**Figure 25**) shows how the relative composition of competitiveness contributions changes overactive project years. The chart is normalised, and it should be read as a change in portfolio profile over time rather than as a change in raw output volume.

Figure 25. Normalised competitiveness dimensions across project over the years



Source: TRIMIS, JRC, 2026

The clearest trends are:

— the increasing weight of technical novelty and interoperability,

— the introduction of manufacturing, raw materials, and circularity starting from 2020 onwards,

— the decreasing weight of operational efficiency, skills development, and societal readiness-oriented actions,

— and a relatively constant trend with regards to consumer price and features-oriented actions, which however are main enablers of competitiveness.

The time-based profile therefore adds an important dynamic reading to the thematic analysis as the project portfolio does not only vary across themes but also changes in composition over time.

5.2.3. Main qualitative trends from the extracted evidence

The qualitative evidence confirms that the quantitative patterns correspond to distinct families of project action.

A first major trend is the importance of **technical novelty** in batteries, EV components, advanced materials, and software-defined vehicle themes. Here the evidence refers to new cell chemistries, novel reliability concepts, improved power-electronics architectures, digital toolchains, and methodological advances explicitly framed as improvements over current practice.

A second trend is the concentration of **interoperability** and **operational efficiency** in infrastructure, CCAM, and deployment themes. The supporting actions are often system-level: interfaces, protocols, real-time communication, platform integration, energy management, maintenance optimisation, routing, and operational performance in real or semi-real deployment contexts.

A third trend is the concentration of **raw materials** and **circularity** in batteries and advanced materials. Here the main supporting actions include reducing cobalt or rare-earth dependence, using lower-criticality materials, improving recyclability, enabling second life, and integrating recovery or recycling pathways into the innovation process.

Consumer price is most often supported through cost-reduction actions, lower operating costs, lower total cost of ownership, or reduced refuelling and charging time. **User features** appear more selectively, mainly where projects describe explicit end-user convenience or safety functions, such as fast charging, safe fuelling, automated emergency braking, or similar user-facing benefits. **Societal readiness** is especially visible in CCAM, workforce, and infrastructure projects through real-user trials, public demonstrations, surveys, co-creation processes, roadshows, and stakeholder workshops.

Production scaling remains comparatively rare and is concentrated in batteries and manufacturing-oriented projects, where evidence refers to kilogram-scale material production, pilot-line activity, scalable production know-how, manufacturing documentation, or industrial-readiness work. **Skills development** appears through curricula, training materials, workshops, hackathons, business-role design, and other structured learning or knowledge-transfer schemes. **EU leadership** remains selective and is usually supported only where the text explicitly refers to first-of-a-kind European capability, strategic autonomy, dependency reduction, or stronger European positioning.

7. Overall synthesis

Taken together, the quantitative and qualitative evidence suggests that the portfolio contributes to competitiveness primarily through three broad channels:

- technically specific innovation (Technical novelty dimension),
- systems integration and operational performance (Interoperability and Operational efficiency dimensions),
- and resource and circularity-related improvements in selected technological domains (Raw materials and Circularity dimensions for batteries, ZEV components, and manufacturing).

The analysis shows that the retrieved competitiveness evidence is theme-dependent. Batteries, EV components, and advanced materials contribute through technical novelty, materials resilience, circularity, and, in some cases, manufacturing-related readiness. Infrastructure, CCAM, and deployment themes contribute more through interoperability, operational efficiency, and societal readiness. Workforce-oriented projects contribute mainly through skills and capability formation.

The heatmap in **Figure 23** demonstrates why a multidimensional framework is necessary. A single overall competitiveness label would hide major differences in the way themes contribute. Some dimensions, such as technical novelty, interoperability, or operational efficiency, are relatively visible in standard project summaries. Others, such as production scaling or EU leadership, remain more selective because they require stronger and more explicit forms of textual evidence.

This suggests that project-level AI-assisted competitiveness analysis is most useful when it is treated not as a proxy for a single industrial-performance score, but as a structured mapping of distinct contribution pathways. In that sense, the method helps reveal not only whether projects contribute to competitiveness, but how they do so, in which thematic areas, and with what balance between technological, operational, societal, resource-related, and skills-related mechanisms.

6. Conclusions

6.1. Summary

This report analysed how EU-funded research and innovation (R&I) supports the competitiveness of the European automotive sector in the context of decarbonisation, digitalisation, industrial transformation and intensified global competition. The analysis covered a portfolio of approximately 150 projects, with a total cost of around EUR 1.99 billion and an EU contribution of around EUR 1.23 billion, organised across eight thematic areas: connected, cooperative and automated mobility; software-defined vehicles; electric-vehicle batteries; zero-emission vehicle components; zero-emission vehicle infrastructure; zero-emission vehicle deployment; advanced materials and manufacturing; and workforce transformation.

The project portfolio shows that EU R&I is **strongly aligned with the clean-mobility transition**, while also contributing to the wider competitiveness agenda. The largest concentration of projects is found in electric-vehicle batteries, followed by CCAM, zero-emission infrastructure, and advanced materials and manufacturing. This distribution reflects the continuing centrality of electrification and zero-emission mobility but also shows that EU R&I increasingly addresses the industrial and digital capabilities required to support the automotive transition.

The main findings of the report are as follows:

— **EU R&I contributes directly to the four automotive-policy pillars analysed in this report.** Projects support innovation and digitalisation through automation, connectivity, software-defined vehicle architectures, artificial intelligence, validation tools and cyber-resilience. They support clean mobility through batteries, electric powertrains, fuel-cell systems, charging and refuelling infrastructure, energy management and zero-emission deployment. They contribute to competitiveness and supply-chain resilience through materials, manufacturing technologies, circularity, battery value chains, components and industrial process innovation. They also address workforce skills and social aspects, although this remains a comparatively smaller part of the portfolio.

— **Clean mobility remains the dominant orientation of the portfolio.** This is consistent with the EU regulatory framework for vehicle emissions and with the role of electrification in the transition of the automotive sector. Batteries, zero-emission components, charging and refuelling infrastructure, and deployment projects form the core of this effort. These projects contribute to cost reduction, performance improvement, system integration, operational validation and preparation for market uptake.

— **Digitalisation is becoming a cross-cutting competitiveness domain.** CCAM, software-defined vehicles, artificial intelligence, data exchange, cybersecurity and digital validation methods are no longer peripheral technology areas. They increasingly define vehicle value, industrial positioning and the capacity of European firms to compete in global automotive markets. The portfolio shows relevant activity in these areas, but also points to the need for stronger links between R&I, operational data, certification, software engineering capacity and scalable digital platforms.

— **The portfolio contains a broad range of development levels.** EU-funded projects are not limited to early-stage research. A significant share of the analysed activity is oriented towards validation, demonstration and piloting. Infrastructure, deployment and some vehicle-integration projects reach higher aggregated development levels, while several advanced components, new battery chemistries, fuel-cell materials, manufacturing processes and digital safety-assurance methods remain at earlier stages. This confirms the need for differentiated support according to technology maturity, industrial readiness and market conditions.

— **System-level integration is a recurrent strength of the EU R&I portfolio.** Many projects address interoperability, standardisation, validation methods, infrastructure interfaces, safety, user acceptance and deployment conditions. These dimensions are essential for a regulated European market and can become a source of competitive advantage where safety, trustworthiness, interoperability and regulatory compliance are market requirements.

— **The transition from demonstration to industrial deployment remains a central bottleneck.** Projects often establish technical feasibility under defined conditions, but the path from project output to industrial production and commercial uptake is not always explicit. Wider deployment depends on manufacturing scale, infrastructure availability, supply-chain security, certification, standardisation, energy-system integration, access to finance and regulatory implementation.

The report therefore confirms that EU R&I provides a substantial contribution to automotive competitiveness by reducing technological uncertainty, supporting strategic capabilities and aligning innovation activity with EU policy objectives. Its contribution is most visible where projects combine technological progress with system integration, validation and relevance to market or regulatory needs.

6.2. Discussion and outlook

The competitiveness of the European automotive sector will increasingly depend on the interaction between multiple technology domains rather than on progress in isolated areas. Electrification, automation, software, batteries, semiconductors, materials, manufacturing, infrastructure, circularity and skills form an interdependent industrial system. This means that the value of EU R&I should be assessed not only by individual project outputs, but also by the extent to which projects strengthen the wider innovation and industrial ecosystem.

A first implication is that **decarbonisation and competitiveness should be treated as mutually dependent objectives**. Clean-mobility technologies are necessary for compliance with climate and vehicle-emission objectives, but they are also central to industrial positioning. Battery innovation, for example, affects vehicle cost and performance, but also raw-material dependence, manufacturing capacity, recycling, energy-system integration and investment decisions. Similarly, charging and refuelling infrastructure is not only an enabling condition for vehicle uptake, but also a market-shaping factor for new services, grid integration and industrial deployment.

A second implication is that **digital capability is becoming a strategic industrial asset**. In CCAM and software-defined vehicles, competitiveness depends on safety assurance, validation environments, data governance, cybersecurity, vehicle software architectures, artificial intelligence and operational learning. Europe's regulatory and system-integration approach can support trustworthy and interoperable deployment. However, this strength must be matched by sufficient speed, scale and continuity in experimental development. Competitors in other regions are accumulating operational data, scaling autonomous-mobility services, expanding battery production and reducing costs rapidly. EU R&I therefore needs to support not only research excellence, but also faster routes towards industrialisation and deployment.

A third implication is that **scale-up requires strong continuity across funding and policy instruments**. Many R&I projects produce prototypes, demonstrators, models, methods and technical evidence, but these outputs do not automatically translate into industrial capacity. Future programming would benefit from clearer links between R&I projects and downstream instruments, including manufacturing investment, standardisation, certification, public procurement, deployment funding, regulatory sandboxes and infrastructure programmes. This is particularly relevant for batteries, power electronics, advanced materials, charging infrastructure, autonomous-vehicle testing, circularity and manufacturing process innovation.

Several priorities emerge for future R&I policy:

— **Strengthen clean-mobility technology development and deployment.** Continued support is needed for batteries, electric powertrains, fuel-cell systems, energy management, charging and refuelling infrastructure, vehicle integration and operational deployment. Priority should be given to cost reduction, durability, performance, energy efficiency, circularity and interoperability.

— **Treat software and digitalisation as core competitiveness domains.** R&I should further address software-defined vehicle architectures, AI-enabled functions, CCAM validation, cybersecurity, data spaces, digital twins, simulation environments and certification-ready safety assurance. These areas should be linked more explicitly to industrial strategy and not treated only as enabling technologies.

— **Reinforce manufacturing, materials and supply-chain resilience.** Future projects should place stronger emphasis on battery value chains, power electronics, semiconductors, advanced materials, recycling, process innovation and scale-up of European manufacturing capabilities. This is necessary to reduce strategic dependencies and to convert technology development into industrial capacity.

— **Improve the pathway from demonstration to market uptake.** Deployment-oriented R&I should be more closely connected with regulation, standardisation, procurement and infrastructure planning. Demonstration projects should produce evidence that can support certification, interoperability, business models and investment decisions.

— **Increase attention to skills and workforce transformation.** Workforce-related projects are comparatively limited in the analysed portfolio, although the automotive transition will affect engineering, manufacturing, maintenance, repair, software development, battery handling, safety procedures and organisational models. Skills should be treated as a condition for industrial competitiveness, not only as a social accompanying measure.

— **Improve evidence quality and post-project traceability.** Public project information varies considerably across projects and funding schemes. More consistent reporting of TRL progression, aggregated development levels, validation environments, use cases, standards contributions, exploitation pathways and post-project outcomes would improve portfolio monitoring and policy learning.

The outlook for EU automotive R&I is therefore defined by a dual requirement. On the one hand, continued research is needed in emerging areas such as advanced battery chemistries, fuel-cell materials, AI-enabled mobility, software-defined vehicle systems, circular materials and advanced manufacturing. On the other hand, a larger share of effort needs to support demonstration, scale-up, certification, deployment and skills formation. The central challenge is not only to generate innovations, but to ensure that they can be absorbed by European industry and deployed in European and global markets.

References

2ZERO, ERTRAC, CCAM and EAPRA (2025), 'Proposal for an Automotive Partnership in the next European budget', https://www.ertrac.org/wp-content/uploads/2025/06/Automotive_Partnership_Proposal_June2025.pdf.

2ZERO Partnership (2024), '2ZERO strategic research and innovation agenda (SRIA) 2021–2027: updated version', https://www.2zeroemission.eu/wp-content/uploads/2024/03/SRIA-2024-webversion_compressed.pdf.

ACEA (2025), 'EU battery supply chain and import reliance', https://www.acea.auto/files/ACEA_Fact_sheet-EU_battery_supply_chain_and_import_reliance_.pdf.

Aktas, I. (2023), 'Trends towards Software-defined Vehicles', ETAS.

Apel, C., Kümmerer, K., Sudheshwar, A., Nowack, B., Som, C. et al. (2024), 'Safe-and-sustainable-by-design: State of the art approaches and lessons learned from value chain perspectives', *Current Opinion in Green and Sustainable Chemistry*, Vol. 45, p. 100876, https://doi.org/10.1016/j.cogsc.2023.100876.

BATT4EU Partnership (2024), 'BATT4EU strategic research and innovation agenda (SRIA) 2024', The Batteries European Partnership Association, https://bepassociation.eu/our-work/sria/.

Broughton, A., Tanis, J., Brambilla, M., Voss, E. and Vitols, K. (2024), 'Research for TRAN Committee: Trends, challenges and opportunities in the EU transport labour market'.

CCAM Partnership (2023), 'CCAM strategic research and innovation agenda (SRIA): update 2023'.

Chen, C., Nguyen, D. T., Lee, S. J., Baker, N. A., Karakoti, A. S. et al. (2024), 'Accelerating computational materials discovery with artificial intelligence and cloud high-performance computing: from large-scale screening to experimental validation', *Journal of the American Chemical Society*, Vol. 146, Issue 29, pp. 20009–20018, https://doi.org/10.1021/jacs.4c03849.

Çınar, G. (2020), 'The Green Deal and the Automotive Industry in the EU – Transforming the Automotive Industry: Impact on EU Region', Renew Europe, https://reneweurope-cor.eu/wp-content/uploads/2020/06/The-Green-Deal-and-the-Automotive-Industry-in-the-EU.pdf.

Clean Hydrogen Partnership (2022), 'Clean hydrogen strategic research and innovation agenda (SRIA) 2021–2027'.

Crouslé, D., Guewouo, T., Nouvelot, Q. and Bellahcene, R. (2025), 'RHEADY - Deliverable D6.6 Recommendations for standardization', https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e51957af80&appId=PPGMS.

Deloitte (2021), 'Software-Defined Vehicles A forthcoming industrial evolution'.

Draghi, M. (2025), 'The future of European competitiveness', Luxembourg: Publications Office of the European Union, https://doi.org/doi:10.2872/1823372.

EARPA (2025), 'EARPA Position Paper: The Role of Researchers in Advancing Software-Defined Vehicles (SDVs)'.

Esmaeilian, B., Xiao, Y., Goyal, G. K., Zuo, L., Chen, L. et al. (2026), 'Electric Vehicle Batteries Recycling: A Review', *Waste Management*, Vol. 212, New York, N.Y., p. 115302, https://doi.org/10.1016/j.wasman.2025.115302.

Eurofound (2025), 'Crisis in the EU automotive industry: Remaining competitive amid the twin transitions', Publications Office of the European Union, Luxembourg, https://doi.org/https://data.europa.eu/doi/10.2806/6339859.

European Commission (2019), 'The European Green Deal, COM (2019) 640 final', European Commission, Brussels, Belgium, https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN.

European Commission (2020), 'Sustainable and Smart Mobility Strategy – putting European transport on track for the future', https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:789:FIN.

European Commission (2021), 'Communication from the Commission Criteria for the analysis of the compatibility with the internal market of State aid to promote the execution of important projects of common European interest 2021/C 528/02, OJ C 528, 30.12.2021, pp. 10–18', https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.C_.2021.528.01.0010.01.ENG.

European Commission (2023), 'Concept Paper on an open European software-defined vehicle platform | Shaping Europe's digital future', https://digital-strategy.ec.europa.eu/en/library/concept-paper-open-european-software-defined-vehicle-platform.

European Commission (2025a), 'Battery Booster Strategy', https://webgate.ec.europa.eu/circabc-ewpp/d/d/workspace/SpacesStore/c1e2c753-e327-4d9f-b060-56ab4af2a754/download.

European Commission (2025b), 'Boosting the European car sector: industrial action plan for the automotive sector, COM(2025) 95 final', https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52025DC0095.

European Commission (2025c), 'Does the Transition to Battery Electric, Software-Defined Vehicles Create Opportunities for Europe? - Internal Market, Industry, Entrepreneurship and SMEs', Luxembourg: Publications Office of the European Union, https://single-market-economy.ec.europa.eu/publications/does-transition-battery-electric-software-defined-vehicles-create-opportunities-europe_en.

European Commission (2025d), 'Proposal for a Regulation of the European Parliament and of the Council amending Regulation (EU) 2019/631 as regards CO2 emission performance standards for new light duty vehicles and vehicle labelling and repealing Directive 1999/94/EC', https://climate.ec.europa.eu/eu-action/transport-decarbonisation/road-transport/cars-and-vans_en.

European Commission (2025e), 'Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Regulations (EC) No 561/2006, (EU) 2018/858, (EU) 2019/2144 and (EU) 2024/1257 of the European Parliament and of the Council as regards the simplification of technical requirements and testing procedures for motor vehicles and repealing Council Directive 70/157/EEC and Regulation No 540/2014 of the European Parliament and of the Council', https://webgate.ec.europa.eu/circabc-ewpp/d/d/workspace/SpacesStore/c2bfb611-2cbf-42c7-8043-a68b8ecec1e2/download.

European Commission (2025f), 'Proposal for a Regulation of the European Parliament and of the Council on clean corporate vehicles', https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2025%3A994%3AFIN.

European Commission (2025g), 'The competitiveness compass: a new roadmap for Europe's dynamism and economic growth, COM(2025) 30 final', https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52025DC0030.

European Commission: Directorate-General for Research and Innovation, Steeman, J.-T., Peiffer-Smadja, O. and Ravet, J. (2025), 'A comparative analysis of public R&I funding in the EU, US, and China', Publications Office, LU, https://doi.org/10.2777/3869663.

European ECS community (2026), 'Electronic Components and Systems strategic research and innovation agenda 2026', https://ecssria.eu/ECS-SRIA-2026.pdf.

European Parliament (2021), 'The Future of the EU automotive sector', Luxembourg, https://doi.org/https://data.europa.eu/doi/10.2861/680215.

European Parliament (2024), 'Artificial Intelligence Act: legislative resolution of 13 March 2024, P9_TA(2024)0138', https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=ep:P9_TA%282024%290138.

Galgóczi, B. (2023), 'On the Way to Electromobility – a Green(Er) but More Unequal Future?'.

Gkoumas, K., Marques dos Santos, F., Tsakalidis, A., Balen, M. van, Ortega Hortelano, A. et al. (2020), *New and emerging transport technologies and trends (NETT) in European research and innovation projects*, Publications Office of the European Union, Luxembourg, KJ-NA-30360-EN-N, https://data.europa.eu/doi/10.2760/977404.

Héder, M. (2017), 'From NASA to EU: the evolution of the TRL scale in Public Sector Innovation', Vol. 22.

International Energy Agency (2024), 'Recycling of Critical Minerals'.

International Energy Agency (2025a), 'Global Critical Minerals Outlook 2025', https://www.iea.org/reports/global-critical-minerals-outlook-2025.

International Energy Agency (2025b), 'Global EV Outlook 2025'.

Keller, T. and Baker, I. (2022), 'Manganese-based permanent magnet materials', *Progress in Materials Science*, Vol. 124, p. 100872, https://doi.org/10.1016/j.pmatsci.2021.100872.

Lai, Z., Long, J., Lu, Y., Luo, F., Zeng, L. et al. (2025), 'Direct Recycling of Retired Lithium-Ion Batteries: Emerging Methods for Sustainable Reuse', *Advanced Energy Materials*, Vol. 15, Issue 21, p. 2501009, https://doi.org/10.1002/aenm.202501009.

Letta, E. (2024), 'Much more than a market: report to the European Council', Council of the European Union, https://www.consilium.europa.eu/media/ny3j24sm/much-more-than-a-market-report-by-enrico-letta.pdf.

Liu, B., Chen, J., Gao, Y., Zhang, X. and Zhao, S. (2025), 'Regional differences in the recycling capacity of retired batteries for new energy vehicles in China: A perspective of sales volume forecasting', *Transport Policy*, Vol. 172, p. 103764, https://doi.org/10.1016/j.tranpol.2025.103764.

Parés Olguín, F., Iskakov, G. and Kendall, A. (2023), 'US-Mexico second-hand electric vehicle trade: Battery circularity and end-of-life policy implications', *Transportation Research Part D: Transport and Environment*, Vol. 125, p. 103934, https://doi.org/10.1016/j.trd.2023.103934.

Schneider, J., Teichert, O., Zähringer, M., Balke, G. and Lienkamp, M. (2023), 'The novel Megawatt Charging System standard: Impact on battery size and cell requirements for battery-electric long-haul trucks', *eTransportation*, Vol. 17, p. 100253, https://doi.org/10.1016/j.etran.2023.100253.

Shekhar, S., Bogaerts, W., Chrostowski, L., Bowers, J. E., Hochberg, M. et al. (2024), 'Roadmapping the next generation of silicon photonics', *Nature Communications*, Vol. 15, Issue 1, Nature Publishing Group, p. 751, https://doi.org/10.1038/s41467-024-44750-0.

Tazi, Nacef, Orefice, Martina, Candelaresi, Daniele, Martinini, Samuel, Marchetto, Alberto et al. (2025), *Circularity measures on critical raw materials and e-drive motors in vehicles*, Publications Office of the European Union, KJ-01-25-071-EN-N, https://data.europa.eu/doi/10.2760/6053264.

UITP (2024), 'Fuel cell buses in your fleet: a case study guide to best practice implementation, Knowledge Brief', https://www.fuelcellbuses.eu/sites/default/files/documents/2410_Best_Practice_Final_Report2024_UITP_Knowledge_Brief_October.pdf.

Xiao, J., Jiang, C., Terzi, S., Zheng, C. and Macchi, M. (2025), 'A sustainable echelon re-utilization and recycling for dynamic end-of-life electric vehicle battery packs', *Journal of Cleaner Production*, Vol. 535, p. 147120, https://doi.org/10.1016/j.jclepro.2025.147120.

Zhang, W. and Xu, J. (2022), 'Advanced lightweight materials for Automobiles: A review', *Materials & Design*, Vol. 221, p. 110994, https://doi.org/10.1016/j.matdes.2022.110994.

List of abbreviations and definitions

Abbreviations	Definitions
ΑΒΓ	Alpha Beta Gamma
ΔΕΖ	Delta Epsilon Zeta
ΗΘΙ	Eta Theta Iota
2ZERO	Towards Zero Emission Road Transport Partnership
ACARE	Advisory Council for Aviation Research and Innovation in Europe
ADAS	Advanced Driver Assistance Systems
AFIR	Alternative Fuels Infrastructure Regulation
AI	Artificial Intelligence
ALICE	Alliance for Logistics Innovation through Collaboration in Europe
BATT4EU	European Partnership for Batteries
BEPA	Batteries European Partnership Association
BEV	Battery Electric Vehicle
BMS	Battery Management System
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CCAM	Connected, Cooperative and Automated Mobility
CCS	Combined Charging System
CEF	Connecting Europe Facility
CHJU	Clean Hydrogen Joint Undertaking
Chips JU	Chips Joint Undertaking

Abbreviations	Definitions
CINEA	European Climate, Infrastructure and Environment Executive Agency
CO2	Carbon Dioxide
CSA	Coordination and Support Action
CtP	Cell-to-Pack
DC	Direct Current
DG MOVE	Directorate-General for Mobility and Transport
DG RTD	Directorate-General for Research and Innovation
EC	European Commission
ECU	Electronic Control Unit
EEA	European Environment Agency
EIC	European Innovation Council
EIB	European Investment Bank
EIT	European Institute of Innovation and Technology
ERC	European Research Council
ERRAC	European Rail Research Advisory Council
ERS	Electric Road System
ERTRAC	European Road Transport Research Advisory Council
ETP	European Technology Platform
EU	European Union
EV	Electric Vehicle
FCEV	Fuel-Cell Electric Vehicle

Abbreviations	Definitions
FCET	Fuel-Cell Electric Truck
FP7	Seventh Framework Programme for Research and Technological Development
FP9	Ninth Framework Programme; Horizon Europe
FP10	Tenth Framework Programme for Research and Innovation
GaN	Gallium Nitride
GHG	Greenhouse Gas
GWh	Gigawatt-hour
H2	Hydrogen
HDV	Heavy-Duty Vehicle
HE	Horizon Europe
HEV	Hybrid Electric Vehicle
HRS	Hydrogen Refuelling Station
H2020	Horizon 2020
IA	Innovation Action
ICE	Internal Combustion Engine
ICE-H2	Hydrogen Combustion Engine
IEA	International Energy Agency
IGBT	Insulated-Gate Bipolar Transistor
IoT	Internet of Things
IPCEI	Important Project of Common European Interest
ITS	Intelligent Transport Systems

Abbreviations	Definitions
JRC	Joint Research Centre
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCV	Light Commercial Vehicle
LDV	Light-Duty Vehicle
LEV	Light Electric Vehicle
LFP	Lithium Iron Phosphate
LiM	Lithium Metal
LLM	Large Language Model
LNMO	Lithium Nickel Manganese Oxide
MCS	Megawatt Charging System
MSCA	Marie Skłodowska-Curie Actions
NMC	Nickel Manganese Cobalt
NOx	Nitrogen Oxides
OBC	On-Board Charger
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
OJ	Official Journal of the European Union
OpEx	Operational Expenditure
PEM	Proton Exchange Membrane
PHEV	Plug-in Hybrid Electric Vehicle
PoC	Proof of Concept

Abbreviations	Definitions
R&D	Research and Development
R&I	Research and Innovation
R2R	Roll-to-Roll
RF	Radio Frequency
RIA	Research and Innovation Action
SAE	SAE International, formerly the Society of Automotive Engineers
SDV	Software-Defined Vehicle
SiC	Silicon Carbide
SME	Small and Medium-sized Enterprise
SOC	State of Charge
SOE	State of Energy
SOH	State of Health
SRIA	Strategic Research and Innovation Agenda
SSB	Solid-State Battery
TCO	Total Cost of Ownership
TEN-T	Trans-European Transport Network
TRIMIS	Transport Research and Innovation Monitoring and Information System
TRL	Technology Readiness Level
UNECE	United Nations Economic Commission for Europe
V2G	Vehicle-to-Grid
V2X	Vehicle-to-Everything

Abbreviations	Definitions
VECTO	Vehicle Energy Consumption Calculation Tool
VELA	Vehicle Emissions Laboratories
WBG	Wide-Bandgap
ZE-HDV	Zero-Emission Heavy-Duty Vehicle
ZEV	Zero-Emission Vehicle

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