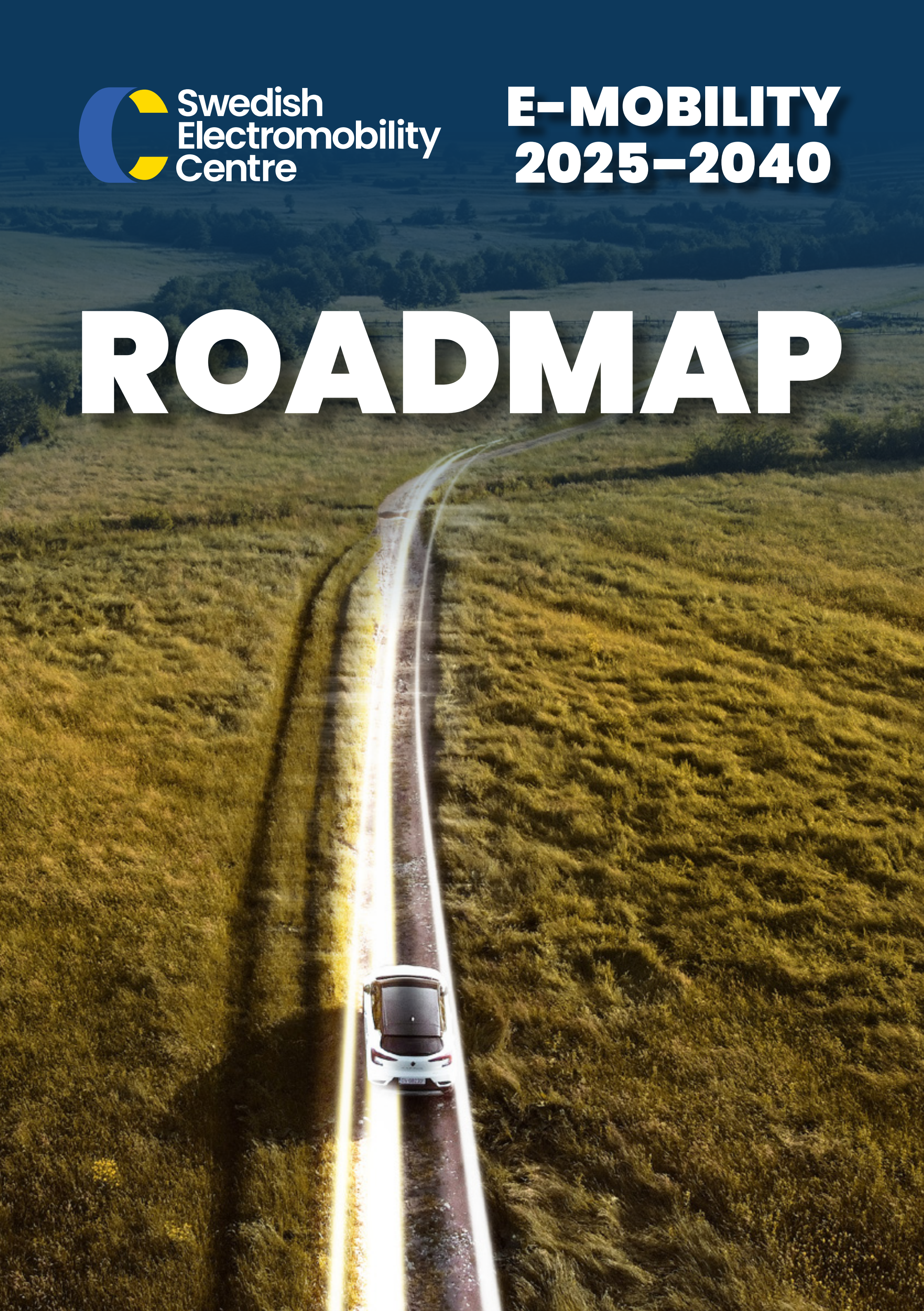
Swedish
Electromobility
Centre

E-MOBILITY 2025–2040

ROADMAP



The road towards
ELECTROMOBILITY

Swedish Electromobility Centre (SEC) envisions a good future, where electromobility, together with renewable electricity generation, reaches its full potential for serving as a building block of a society based on the United Nations' Sustainable Development Goals.

In this future mobility solutions meet people's needs and most vehicles are electrified. The share of renewable electricity is significantly increased from today's levels to cover the electrification of the industry and transport sectors, as well as the rest of society's needs. We manage the climate transition and we use the earth's resources sustainably.

Electromobility, or e-mobility, is defined as a transport system based on vehicles that are fully or partly electrically driven, equipped with on-board energy storage, and obtaining their energy either directly or indirectly from the power grid. Electromobility also includes fuel cell solutions with the use of hydrogen to produce electricity for propulsion. Electromobility has mainly been land-based but is now reaching the maritime and aviation sector as well.

Electrical motors have zero tail-pipe emissions and generate very little noise. This significantly reduces greenhouse gas emissions, air and noise pollution caused by transportation. However, to make electrified vehicles truly sustainable we also need to include production costs and societal aspects.

Electromobility has grown substantially in recent years but there are still many technical challenges to be addressed. It will require large investments, political will and cooperation between different sectors and actors such as the automotive industry, the energy industry, urban planners, and political decision makers. A combination of innovative business models, new policies and regulations, and an acceptance of the new electrified vehicles will most probably be vital. The intense development driven by sustainability requirements, autonomous driving, digitalisation, and artificial intelligence, makes it highly likely that other forms of transport solutions, than those we are used to today, will be the most dominant ones in the future.

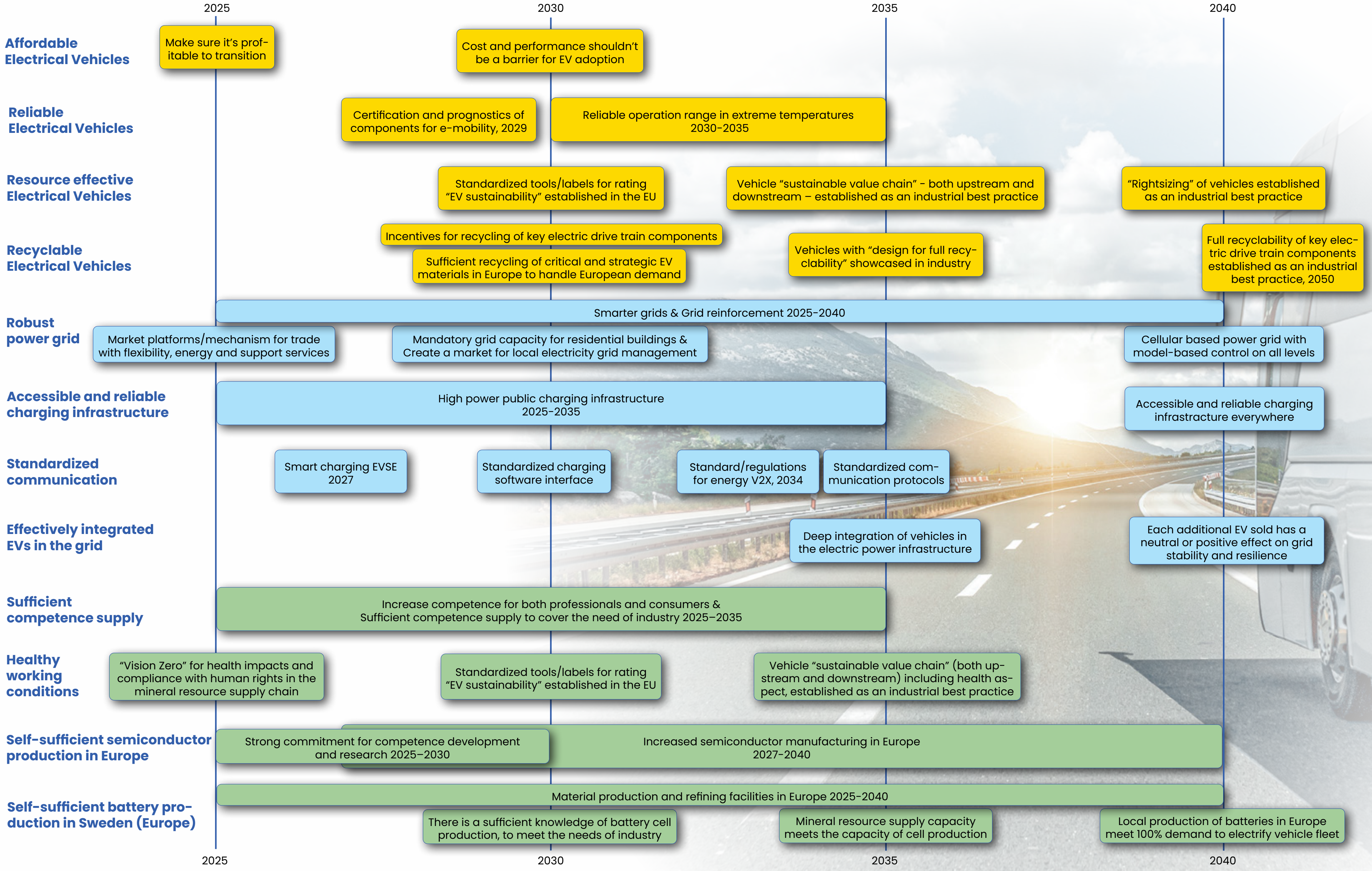
SEC activities have strong connections to several of the UN Sustainable Development Goals. These goals have acted as a north star for businesses, governments, and organizations, as well as for the Swedish Electromobility Centre, guiding our way to a sustainable future. The contribution in solving the transport part of the climate goals, is one of the centre's strongest motives. We believe that this can be achieved by, developing innovative and affordable technologies that enable the widespread adoption of electric vehicles (EVs) and improve the efficiency and reliability of our transportation infrastructure.

E-MOBILITY MILESTONES

To reach the full potential and implementation of e-mobility, SEC has identified a number of important milestones and work needed.

E-mobility milestones

Swedish Electromobility Centre



Affordable Electrical Vehicles
- Make sure it's profitable to transition
- Cost and performance shouldn't be a barrier for EV adoption

Reliable Electrical Vehicles
- Certification and prognostics of components for e-mobility, 2029
- Reliable operation range in extreme temperatures 2030-2035

Resource effective Electrical Vehicles
- Standardized tools/labels for rating "EV sustainability" established in the EU
- Vehicle "sustainable value chain" - both upstream and downstream – established as an industrial best practice
- "Rightsizing" of vehicles established as an industrial best practice

Recyclable Electrical Vehicles
- Incentives for recycling of key electric drive train components
- Sufficient recycling of critical and strategic EV materials in Europe to handle European demand
- Vehicles with "design for full recyclability" showcased in industry
- Full recyclability of key electric drive train components established as an industrial best practice, 2050

Robust power grid
- Smarter grids & Grid reinforcement 2025-2040
- Market platforms/mechanism for trade with flexibility, energy and support services
- Mandatory grid capacity for residential buildings & Create a market for local electricity grid management
- Cellular based power grid with model-based control on all levels

Accessible and reliable charging infrastructure
- High power public charging infrastructure 2025-2035
- Accessible and reliable charging infrastructure everywhere

Standardized communication
- Smart charging EVSE 2027
- Standardized charging software interface
- Standard/regulations for energy V2X, 2034
- Standardized communication protocols

Effectively integrated EVs in the grid
- Deep integration of vehicles in the electric power infrastructure
- Each additional EV sold has a neutral or positive effect on grid stability and resilience

Sufficient competence supply
- Increase competence for both professionals and consumers & Sufficient competence supply to cover the need of industry 2025–2035

Healthy working conditions
- "Vision Zero" for health impacts and compliance with human rights in the mineral resource supply chain
- Standardized tools/labels for rating "EV sustainability" established in the EU
- Vehicle "sustainable value chain" (both upstream and downstream) including health aspect, established as an industrial best practice

Self-sufficient semiconductor production in Europe
- Strong commitment for competence development and research 2025–2030
- Increased semiconductor manufacturing in Europe 2027–2040

Self-sufficient battery production in Sweden (Europe)
- Material production and refining facilities in Europe 2025-2040
- There is a sufficient knowledge of battery cell production, to meet the needs of industry
- Mineral resource supply capacity meets the capacity of cell production
- Local production of batteries in Europe meet 100% demand to electrify vehicle fleet

Swedish Electromobility Centre's role

The mission of SEC is to accelerate the development and implementation of electric propulsion technologies into the transport ecosystem by maximising their applicability, versatility, and efficiency, while minimising their overall impacts on the environment, human health, and natural resources, and strengthen the Swedish industry's competitiveness.

SEC supports Swedish industry in developing long-term sustainable solutions at a pace that enables the highest possible efficiency and functionality from a system perspective. SEC contributes by rigorously evaluating activities and reported progress, and develop a skilled workforce through science-based education.

SEC as research centre

SEC was established in 2007 and the centre's research scope has followed the development in the field of electromobility ever since. During this period some questions have matured and diminished in importance and new have emerged. SEC continuously needs to identify and prioritize the most relevant challenges that remain to be solved.

The main research focus is on solving the identified challenges for all transport modes. This in many cases requires conducting disruptive research, rather than gradual improvements. Both the structure and the processes in the centre should be flexible enough to facilitate this by adopting agile working methods and organizational models. For example, if the identified challenges are mostly cross-disciplinary and of a system perspective, the definition and scope need to be adjusted accordingly.

SEC should manage competence, ideas, resources, and financing to conduct research in the field of electromobility in the most effective way within Sweden. At the same time, SEC is responsible for making this knowledge and competences available to other societal actors.

SEC as network, platform, and arena

Electromobility requires a systemic and broad perspective. Studying electromobility from different systems perspectives can help to resolve complex issues related to energy efficiency, safety, environmental issues, resource scarcity, driving patterns, new business models, and governmental policy support.

Co-creative approaches are encouraged to facilitate research and innovation at technological, societal, and economical levels. SEC aims to be the reference point for all relevant actors in the transition to an electrified transport system, coordinating activities and projects with universities, research institutes, industry, governmental agencies, and users. Moreover, SEC promotes collaboration with other centre formations in adjacent areas.

SEC is a platform and trustful network with a unique culture of collaboration encouraging competitors to share their experiences and challenges with each other as well as the researchers in universities and institutes. This is supported by a working method that is very effective for collaboration. Roadmaps, project creation and research findings provide the foundation for constructive and creative discussions, ultimately shaping the development of research areas.

SEC should be a neutral and transparent arena for the exchange of ideas between different actors, even across industries and sectors. To scale up electromobility, an increased and deepened cooperation is needed between different industries and societal actors when traditional business models and operations are changing. Cost and revenues need to be distributed fair and understandable for all actors to speed up the process from ideas and concepts to market products.

SEC in relation to other actors

Policy and decision makers

SEC provides competence and knowledge to policymakers to support them with long-term relevant science-based insights for decision making. SEC also serves as a platform for policy makers and decision makers to connect with the e-mobility community.

Research funders

SEC identifies research gaps and needs that are not covered by the scope and funding possibilities within the centre. Furthermore, SEC provides a platform to create new project ideas for the main research funders.

Educational institutions

Well-educated people will be a limiting factor in the transformation that the transport sector is undergoing. The universities have the important role of offering education based on current research. SEC is active in attracting talents and intranational researchers to supporting Sweden's capabilities to achieve its sustainability goals.

International actors

All the above have an international aspect as well. Most of the work have historically been conducted by the partners themselves but there is crosstalk between the theme groups and a dedicated group will soon be formed within SEC to gain strength in our common international voice.

Users & Society

The change that the transport sector undergoes to reach the sustainability goals does not only involve new technical solutions, but also changes in behaviour and attitudes. A close interaction with other disciplines and the surrounding society is therefore important. SEC supports the public awareness about the opportunities a behavioural changes needed to implement an electrified transport sector.

Areas of limitations

Electromobility has begun to make an impact in society, and through this the challenges and research questions have developed and affect increasingly large parts of society. It thus becomes impossible for a single centre to handle all these issues without losing depth and focus. Because there are already programs and centres that deal with these related issues, SEC should seek collaborations rather than conducting its own research in these areas.

Product development

The centre's role is to focus on knowledge building and competence provision, rather than product development. In cases where research projects may lead to new products, the possibilities of productization and patents must of course be investigated.

Electricity generation

Understanding how electromobility affects the electricity grid and vice versa is an important area for the centre. However, electricity generation is not part of the activities that the centre generally support.

Combustion engines

Combustion engines based on biofuels and electro-fuels could also be viewed as a part of a sustainable transport system, but activities linked to combustion processes are outside the centre's scope.

Laws and regulations

SEC investigates and analyzes how policies, laws, and regulations may hinder, support, or facilitate e-mobility. While potential beneficial areas and measures for the transition are addressed, SEC does not actively advocate for any specific policies, laws, or regulations.

Swedish Electromobility Centre's research

SEC wants to identify relevant stakeholders, drivers, and barriers, and solve key issues that might limit the transition towards sustainable transport.

To do so, the centre focuses on five theme areas, each one of them developing a road map to identify knowledge gaps and encourage strategic research in the field.

Theme 1: Intelligent Vehicles & Systems
Theme 2: Electric Drives & Charging
Theme 3: Energy Storage
Theme 4: Environment & Society
Theme 5: Vehicle–Grid Interaction

Challenges that guide SEC

Each theme area focusses on various research challenges ranging from the performance of specific technical components to the overall system design as well as policy instruments required for the practical implementation of electromobility solutions. These research challenges, which the theme areas can address from different perspectives, are described on the following pages.

Vehicle optimization

To maximize the benefits of electromobility, it is essential to optimize the design and operation of electric vehicles. This involves addressing various challenges, such as:

- Lightweight design
- Aerodynamics
- Energy efficiency
- Vehicle lifespan

Electric vehicles can be optimized for specific applications, such as passenger cars, heavy-duty trucks, buses, and two-wheelers, each requiring a tailored approach.

One of the challenges is the optimization of electric vehicle components, including electric motors, power electronics, and energy storage systems. Innovations in material science, manufacturing processes, and thermal management are crucial to improving the efficiency, performance, and durability of these components.
In addition to technological optimization, the development of intelligent transport systems (ITS) is essential. An intelligent transport systems enhance the planning and management of transportation networks, optimize traffic flow, and improve the overall efficiency of the transport system. This includes the integration of electric vehicles into existing transportation infrastructure and the development of smart charging solutions.

Energy storage

Batteries are a fundamental component of electromobility, serving as onboard energy storage for vehicles. Batteries can also provide an energy storage solution for stabilizing the grid when integrating renewable energy and managing loads.

Advancements in battery cell technologies are directly impacting the range, performance, and cost of electric vehicles. New cell technologies pose challenges at the system level in terms of application and design, including Battery Management Systems (BMS). Questions concerning raw material bases, manufacturing, and recycling must also be considered. Sustainable battery technology therefore involves multiple dimensions, such as:

- Energy density
- Power density
- Charging speed and efficiency
- Cost and affordability
- Safety
- Lifespan and degradation
- Environmental impact
- Scalability, and production capacity

Fuel cells and hydrogen complement batteries for applications where energy output and energy density requirements are high, such as long-distance heavy transport and aviation. Hydrogen can be used as an energy buffer, a transport medium for renewable energy, and a means to reduce carbon emissions beyond the transport sector. To make fuel cells more suitable for vehicle applications, improvements are needed in:

- Power density
- Lifespan
- Increased operating temperature.

This requires a focus on new materials and efficient hybridization for maximum synergy between the fuel cell and the battery.

Charging infrastructure and hydrogen refueling

Electromobility does not work without an efficient, reliable, stable, and resilient charging infrastructure. The research questions have a wide scope:

- What will the charging infrastructure look like?
- What type of investments should be made, and who bears responsibility at what level?
- What kind of standardization will be introduced?
- Which charging technology will eventually be chosen, and why?

All the infrastructure-related issues mentioned above are intertwined with vehicle-related charging issues, such as the technology used for onboard charging, the type and size of energy storage, the ability to have bidirectional energy flow to use the vehicle as an integrated part of the grid, changes to drivetrain components (such as electric motors) for both propulsion and charging purposes, among others. These questions also relate to the actors involved and those currently absent, such as authorities that may need to take on new responsibilities.

Hydrogen is an excellent way to store and transport energy from intermittent electricity production. Hydrogen produced with renewable electricity is also expected to play a significant role in transitioning other sectors, such as the steel and chemical industries. Key questions include how hydrogen for other applications can interact with the transport sector, relieve the electricity system, and facilitate the electrification of heavier vehicles and other modes of transportation.

It is crucial to generate comprehensive knowledge to support the development of policies and regulations, as they can significantly impact the type of charging and hydrogen infrastructure built in the future.

Sustainable value chain and circular solutions

The main goal of electrifying transportation is to decouple vehicles from direct use of fossil fuels. However, to achieve fully sustainable transportation, the entire value chain must be considered. This also include the demand for scarce metal resources, and toxic emissions related to metal extraction and processing risking polluting drinking water and harm human health. It is essential to gather knowledge about and monitor the development of various supply chains for electromobility, considering their life cycle.

Reducing emissions in the production of primary materials and maximizing the use of existing products are crucial. The forecasted high demand for certain materials in electromobility, such as lithium, copper, cobalt, nickel, and rare earth metals, raises concerns. Long-term demand and availability of various metals depend on factors like scarcity in the earth's crust, supply chain control, and technological developments.

Extending the lifespan of lithium-ion batteries through cell reuse and refurbishment is known as second life. However, achieving full circularity involves maximizing the value of already produced products through sharing, maintenance, and closed material loops, including high-efficiency recycling. Challenges include logistics inefficiencies and the fact that cell and battery pack designs are often not suitable for disassembly. Similar issues arise for electric motors, where the use of copper and rare earth metals may face long-term supply problems.

Actors and behavior

The electrification of the transport sector will require significant investments in vehicles, especially in battery and fuel cell manufacturing and usage, as well as in charging and hydrogen refueling infrastructure. Understanding how the transport system changes concerning its ability to meet the demand for freight transport and mobility services, and how these changes interact with changes in the electricity and other energy systems, is crucial.

It is fundamental to comprehend the involved actors, as they can either drive or hinder changes. Evaluating the impact of various policies introduced to expedite the transition is also crucial. For example, charging behavior of different operators and users, infrastructure requirements for charging and hydrogen refueling, vehicle design, and the size of battery packs and fuel cells are factors to consider.

Specifically, long-distance freight transport poses a significant challenge due to long routes combined with high energy consumption. The need to cover typical distances of over 400 kilometers, spanning several days between regions and countries, makes this application particularly demanding.

Policy and regulation

The successful transition to electromobility requires a supportive policy and regulatory framework that should address various aspects including:

- Development of standards for charging infrastructure
- Incentives for electric vehicle adoption
- Emissions reduction targets
- Regulations for grid integration.

Standardization is crucial for interoperability and the widespread adoption of electric vehicles. Common standards for charging interfaces, communication protocols, and safety features enable seamless integration into existing infrastructure and facilitate the development of a competitive market for electric vehicle technologies.

Incentives play a vital role in accelerating the adoption of electric vehicles. Financial incentives, such as tax credits and subsidies, can make electric vehicles more attractive to consumers and businesses. Additionally, regulatory measures, such as emissions standards and zero-emission zones, can drive the demand for electric vehicles and encourage the development of cleaner technologies.

Emissions reduction targets are essential for achieving environmental sustainability. Ambitious targets for the reduction of greenhouse gas emissions from the transport sector can drive innovation and investment in cleaner technologies.

Regulations are needed to ensure the efficient and reliable integration of electric vehicles into the power grid. This includes measures to manage peak demand, encourage smart charging practices, and support the development of Vehicle-to-Grid (V2G) technologies.

In conclusion, a comprehensive and forward-looking policy and regulatory framework is essential to facilitate the large-scale implementation of electromobility and ensure its sustainability. This framework should consider the diverse challenges and opportunities associated with electrifying different modes of transport, address the needs of various stakeholders, and provide a clear roadmap for the transition to a sustainable and electrified transport system.

Grid integration

The introduction of electric vehicles will change how, where, and when we use electricity. Successful electrification of the transport sector requires that the power grid can handle additional loads from electric vehicle charging at both high and low power levels. From a socio-economic perspective, it is essential to utilize the existing grid as efficiently as possible without compromising its stability and reliability over time. This must be ensured under normal operating conditions as well as more challenging scenarios, such as crises and wars. This can be achieved through:

- Smart charging
- Load management strategies
- Local energy storage
- Local renewable energy production
- Vehicle-to-Grid (V2G) solutions

In some areas, it will also be necessary to increase grid capacity and reinforce both distribution and transmission systems efficiently in terms of time and resources. This requires an in-depth understanding of opportunities and challenges for both the power grid and the electric vehicle sector.

Furthermore, the transition itself is dynamic, with multiple pathways that involve a range of time scales. Electric vehicle adoption can be gradual, increasing gradually over time, or it can be rapid with uptake leading to significant market penetration within a short period. The development of advanced simulations and models is essential to understanding these dynamics and predicting the impacts on the grid.

Resilience and cybersecurity

SEC recognize the importance of resilience and cybersecurity as the transport sector becomes increasingly reliant on digital technologies and connectivity. Ensuring the resilience and cybersecurity of the entire system is paramount. However, to take full responsibility for this SEC must work togehter with other expertise. Resilience refers to the ability of the system to withstand and recover from disruptions caused by:

- Natural disasters
- Accidents
- Intentional attacks

Cybersecurity is a critical aspect, as digital technologies are vulnerable to cyber threats that can compromise the safety and functionality of electric vehicles and charging infrastructure. Cybersecurity measures need to be implemented throughout the entire ecosystem, from vehicle components to communication networks and central control systems.

Additionally, resilience planning should consider potential disruptions to the transport system, such as extreme weather events, accidents, and cyberattacks. This includes developing strategies to mitigate the impact of disruptions, rapidly restore functionality, and ensure the safety of passengers and cargo.

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