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System perspective for large-scale implementation of electromobility - the Swedish Electromobility Centre

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Executive Summary

Electromobility is an enabler for sustainable mobility on land, at sea and in the air. The mission of the Swedish Electromobility Centre (SEC) is to accelerate the development and implementation of electric propulsion technologies. Through a system perspective starting on the component level in the vehicle going all the way to the integration into the electric grid, the SEC project portfolio addresses the challenges for the full-scale implementation of an electric fleet into the transport ecosystem.

Electrification of transport is a subset of all electrification that is underway, including electrification of industry and digitization of society. Therefore, electrification of transport must also fit into the larger picture. The interconnection of different systems also puts high demands on reliability, robustness, and resilience.

This article aims to illustrate how SEC drives development and thereby contributes to the large-scale implementation of electromobility.

Keywords: government, strategy, mobility system, electric vehicle (EV), fuel cell vehicle

1 Introduction

The global road vehicle fleet consists of more than 1.4 billion vehicles [1] and the transport sector contributes with about 25 % of all CO2 emissions globally [2]. In addition, the transport need is growing which will put an increased strain on the energy supply of the world. This means that to have a sustainable energy system, the transport system must also become sustainable. The electrification of a large fraction of the transport vehicles, in combination with renewable or fossil free electricity production, is necessary to succeed in combating climate change and reaching sustainable mobility.

Electromobility is an enabler for sustainable mobility on land, at sea and in the air. However, the way forward is not without challenges and here the Swedish Electromobility Centre takes on a system perspective to address these challenges.

The electrification of transport is a part of the broad electrification of society that is underway, which also includes the transformation of industry and the great digitization of society and must therefore fit into the larger picture. This includes building interconnected systems that are reliable, robust, and resilient even under stress and external threats. The Centre has participated in the Swedish government´s Electrification

Commission to work together with actors in business and society to drive development and advise the government on this important task.

One example of the challenges mentioned above is the challenge of making the whole value chain sustainable, everything from the materials that goes into components onboard to the electricity that charges the battery. Another example is the connection to the electricity grid (with an increasing demand for electricity from other sectors as well), and how the need for charging of an ever-larger fleet of electric vehicles can be met.

At the same time, in parallel, new powerful technologies are emerging that could support the solution to these challenges. On the software side, big data management, blockchain and smart algorithms (AI) offers the possibility for cross-sectorial business models as well as predictive lifetime of crucial components and control of origin of materials. New hardware and manufacturing solutions such as wide-bandgap semiconductors, solid state batteries and additive manufacturing open new possibilities for increased lifetime, more compact and lighter solutions, and enhanced recyclability. However, integration of new technologies also opens opportunities for antagonists to exploit.

2 Strategic research for electromobility with system perspective

Research together with good collaboration is crucial to achieve sustainable and secure mobility. The Swedish electromobility Centre (SEC) has strategic research in five theme areas defined by academia and industry together. The theme areas have gradually developed since the founding of the centre in 2007 reflecting the growth and position of electromobility in society as whole. In 2007 the main focus was on component level and the technology onboard the vehicle whereas today focus has shifted towards system level and large-scale implementation of the technology.

Therefore, SEC theme areas today deal with the most important system mechanisms and bottlenecks that are crucial for how electrified drivelines are developed as well as the large-scale implementation of electric vehicles. They cover important technical challenges on component and subsystem level (theme 1-3) in combination with the infrastructure and environment system level (theme 4-5):

Theme 1: Intelligent vehicle and systems takes a holistic approach to the vehicle's cost and energy efficiency and develop methods for e.g., system optimization, control design and diagnosis.

Theme 2: Electrical drives and charging focuses on developing charging systems, electric drive systems and electrical components, adapted to the requirements in electrified vehicles.

Theme 3: Energy storage focuses on batteries and fuel cells, components that are central to electrification but at the same time also expensive and limiting parts of the system.

Theme 4: Environment and society studies the electrified vehicle from a societal and environmental perspective: user patterns and requirements, and solutions to achieve long-term sustainability.

Theme 5: Vehicle-grid interaction investigates the best way to integrate a comprehensive fleet of electric vehicles in an evolving power system, with a greater amount of intermittent renewable energy production and an increased electricity consumption.

Interaction between the technical themes and the system themes is important, see figure below, to ask the right research questions, keep a system perspective and avoid sub-optimization.

Many of the projects in the portfolio spans across several themes and thereby gathering the deep knowledge of researchers and experts from various fields to achieve the best results. For example, to reach system understanding for the route planning and prediction of range performed within intelligent vehicles and systems knowledge from energy storage and charging most be included and the results must then be integrated in the work of vehicle to grid.

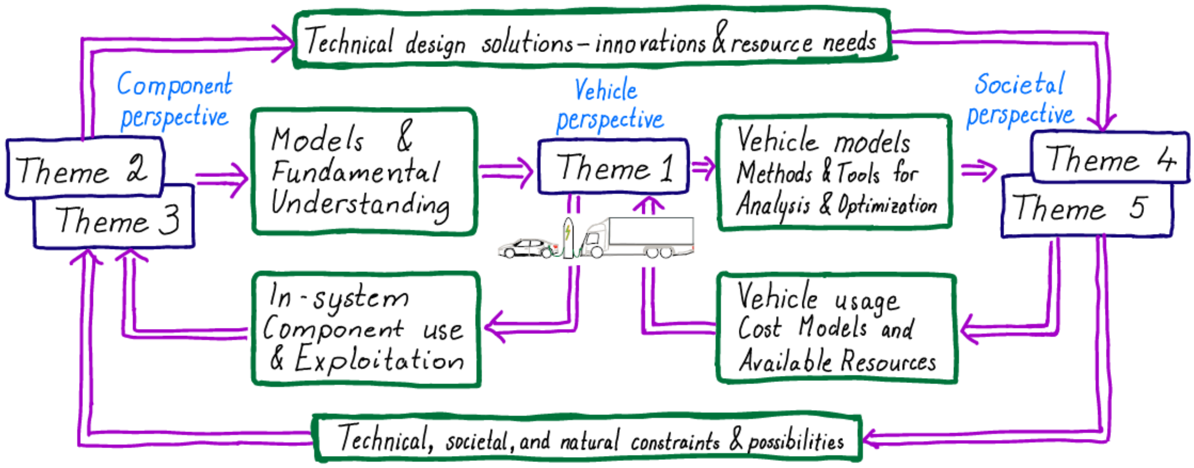

Figure 1:The theme groups of Swedish Electromobility Centre and their collaboration. Illustration: Lars Eriksson

Each theme is led by two theme leaders who ensure that the theme group serve as a platform for research collaboration and knowledge sharing within the area. The theme leaders are the scientific leaders that guarantee excellence in research, and they lead the group in the process of road map, project creation and project follow-up. Each academic and industrial partner appoints up to two experts to each theme group and the theme group have regular meetings and seminars.

3 Three examples of SEC work on system perspective

To illustrated how the centre operates and drive development, three examples of SEC activities are given here, covering three different perspectives; i) through project funding and the building of a strong project portfolio, ii) through the use of the plattform network and theme area groups to support government initiatives and iii) as a research partner to large-scale demonstration projects. All examples include cross-thematic activities and a large number of partners.

3.1 Strenthening fuel cell research at system level

This example aims to illustrate how SEC's model with a platform where small pre-studies (up to 20 000 Euro) and project funding (up to 400 000 Euro) contribute to building a research area that supports industrially important needs for knowledge on a system level.

3.1.1 Background: Fuel cell research in Sweden

Swedish fuel cell research is strong within fundamental areas, such as electrochemistry, electrode materials, membrane processes, and so forth. In transport applications, however, the fuel cell must interact with various vehicle systems and perform as intended under varying conditions. This is challenging, since vehicle applications are characterized by transient load and speed conditions, often in unpredictable duty cycles. Vehicles are also operated under extremely varying environmental conditions (e.g., varying ambient temperature, pressure, and humidity).

The fuel cell stack furthermore depends on a number of supporting systems, such as air and fuel management systems, a heat management system, and a system for controlling the intake air humidity (in PEM fuel cell systems). In vehicles, there are also hybrid systems consisting of power electronics, batteries and/or supercapacitors, electric machines, and control systems. All these systems must be developed together and matched to the specific application to give the vehicle adequate performance, reliability, and energy efficiency. The vehicle industry’s growing interest in fuel cells therefore calls for research at various system levels between the stack and the entire vehicle, an area where there is currently a lack in Swedish research.

3.1.2 Fuel Cells in Vehicle Systems - An SEC Feasibility Study

To fill the gap of fuel cell research identified above and support the vehicle industry´s need for knowledge on the system level, the SEC funded a pre-study led by Prof. Öivind Andersson at Lund University. SEC partners involved in the work was Lund University (expertise on fuel cell modelling, power electronics and electric machines, automatic control, and the thermodynamics involved in air and humidity management), the Royal Institute of Technology (expertise on fuel cell processes), Chalmers University of Technology (contributing expertise on automation, control, and cooling systems), Linköping University (expertise in vehicle modeling), PowerCell (expertise in the design and manufacturing of fuel cell systems), Scania CV (expertise electric powertrain systems heavy duty), AB Volvo (expertise electric powertrain systems heavy duty), CEVT (expertise on implementation of fuel cell systems in vehicles and electric powertrain systems light duty), and ABB (expertise on marine applications of fuel cells).

The purpose of the pre-study was to map out the research needs for fuel cell vehicles, on various system levels between the fuel cell stack level and the entire vehicle through a series of five workshops with academic reseachers and industrial experts. Invited to these workshops were representative from SEC partners from different themes, mainly theme 1, 2 and 3. In addition, also experts from other organisations were invited, for example representatives from the three centres dealing with ICE technology: CERC (Chalmers University of Technology), KCFP (Lund University), and CCGEx (Royal University of Technology).

Before each workshop, the academic researchers did preparatory work on proposals which were then discussed and processed during the workshop together with industrial parties. The project started from a general inventory of research areas during workshop 1 & 2. Examples of areas were supply of fuel and air under varying and transient conditions, hybrid system control, system safety, reliability, strategies for start-up and shutdown and energetics of refueling and on-board storage of hydrogen.

The project then moved on to be more focused on specific research needs, workshop 3 & 4. This led to a number of identified industrially relevant research questions that could form the basis of new project applications, as well as new constellations of researchers suitable for addressing the questions in interdisciplinary project teams. To further narrow the scope down a completing literature study was also performed and after that the following research questions were identified as the most relevant ones for new research projects:

- Balance of plant (i.e., systems supporting the fuel cell stack): air handling system, hydrogen supply/recirculation system, humidity control system, heat management system, power electronics and energy storage system
- Hybrid control: control strategies for vehicle efficiency and performance, control strategies for component protection and reliability, development of virtual sensors for control purposes
- Reliability: development of relevant test cycles, e.g., for lifetime prediction, stressor impact on durability and performance (inventory and development of transfer functions quantifying the impact), mechanical reliability, electric reliability, development of robust engineering methods for system design

At the fifth workshop the research questions above were discussed in detail with the industrial partners resulting in a list of ideas for potential new projects, that could form the basis for new applications. Such projects would either be financed by SEC or, if financed by another part, be coupled to the centre by association procedure. During the second half of the workshop six concrete project proposals were formulated. Each proposal with an assigned contact person responsible for taking the proposal forward to funding.

In addition to the six concrete project proposals, the pre-study also resulted directly in two approved spin-off projects within SEC:

1. "Fuel Cell Durability" (coordinated by Anneli Jedenmalm, ABB) and "A Model and Simulation Platform for Electric Vehicle Systems with Motors, Power Electronics, Batteries: The project addressed how to avoid stressors, especially during start -stop. Aim was to find methods to test cycling methods for extended life; by knowing the processes find ways to test and prevent aging.

2. “Fuel Cells and their Heating and Cooling Needs” (coordinated by Prof. Lars Eriksson, Linköping University): this project is described below under The ECCV platform: digital twin of system onboard.

From the fifth workshop, Prof. Öivind Andersson was responsible for a project proposal related to balance of plant, “Air System Modelling for Efficient FCEV (ASMEF)”, a collaboration between Lund University, Linköping University and AB Volvo. The proposal successfully received funding for a PhD-student from SEC. The aim is to model the air system to evaluate the potential of alternative concepts that could drastically improve the total cost of ownership of a FCEV, both through improved efficiency and durability. These models will then be implemented on the simulation platform, mentioned above and further described below, at Linköping University, the ECCV. More specifically the air supply will be modelled in the platform by compressors and expanders (basic models of compressors are already available but here the aim is to go more in depth, expanders are not currently available). Humidifiers will also be included since moisture is a must for the membranes to work well and improve the efficiency.

One further outcome of the pre-study was the identification of a need for academic test facilities for fuel cell systems. Research in three of the six concrete project proposals from the fifth workshop would greatly benefit from access to such test lab; balance of plant (testing of air handling, humidifiers, cooling and power electronics), hybrid control (testing of efficiency, lifetime and predictive regulation based on dynamic vehicle models) and reliability (how stressors affect lifetime). Lund University has therefore successfully applied for funding and the test lab is currently under construction.

3.1.3 The ECCV platform: digital twin of system onboard

At the same time as he was participating in the pre-study above, Lars Eriksson worked with colleagues in Linköping and SEC industrial partners on a digital twin for a commercial vehicle that is driven on an open road. The motivation for the projects was to develop metods and tools that can support engineers and researchers dealing with the complex design and research questions for future vehicles as modern vehicles becomes more and more advanced with respect to control and subsystems. In particular, there is a need to be able to evaluate new ideas and concepts at early development stages before they are mature to understand interactions and constraints, so that we can get decision support at early stages of design and development. In short, there is a great need for a system model that can be used to design, test and optimize candidate solutions. Such system model would not only serve as a useful simulation platform but also enhance research and collaboration in electro-chemical powertrains in the centre and facilitate communication between partners concerning potential solutions.

A challenge in centers that include actors competing on the same market is how to bring them together to work on important topics. The companies in SEC have inhouse simulation models and tools that often contain IPR that can’t be shared with other partners, which often causes a problem in collaboration projects. In this project the partners were involved in the modelling and gave input on the modelling work so that the model will be representative and describe phenomenas that are of relevance for them. However, the component models are built on a scientific foundation with references and documentation in papers, theses [5], and contain generic component data as starting points. Consequently, the models that are built from the platform and made available can thus be shared freely among partners enabling collaboration without the trouble of handling IPR in company models. As an example the competitors Scania and Volvo Trucks have used the platform in individual projecs [6], and [7].

The project designed interfaces for how components can be interconnected and compiled component models for the various subsystems, so they could be integrated into a system model for a complete vehicle in a driving mission. The key result is a configurable system model for a complete electric vehicle that can be powered by either a large battery or a fuel cell and be tested in various driving scenarios.

The platform enables a system developer to testdrive a conceptual vehicle in a driving mission and see how different components are used and loaded when they interact with other subsystems. For a given mission this depends strongly on the vehicle mass and other vehicle parameters, internally the energy conversions, losses, and transfers depend on both the loading and the environmental conditions. The focus in the development and research related to the platform development has been on component models and interface design which burns down to the energy conversions, losses, and transport of energy and mass in and between the components in the vehicle.

A component library with example models is now available for download on the centres file sharing platform. In the future the model will be released as open source so it will be of benefit for the whole world. A step in this direction is an open benchmark competition that has been formulated under the umbrella of the International Federation of Automatic Control and their World Congress to be held in Yokohama, Japan in the summer of ’23.

The platform has been presented in-depth to the theme groups 1, 2, & 3 in SEC. Moreover, the platform is used as a pure battery electric simulation tool in the E-Charge project, see example 3 below, as it is possible to load different road segments and profiles, so it is possible to investigate the impact of variations in driving conditions on the energy consumption.

3.1.4 Summary of example fuel cell research at system level

The pre-study “Fuel Cells in Vehicle Systems - An SEC Feasibility Study” started with the identification of a need for fuel cell research on a system level. During the course of the project six concrete research projects proposals were developed and two spin-off projects started. A digital twin and a test lab facility were constructed that will not only support the project proposals from the pre-study but also greatly strengthen the capacity to collaborate on developing new knowledge on fuel cell systems in future projects within the centre.

3.2 Strategic research areas for electric aviation

The SEC participated via the director in the Electrification Commission 2020-2022. This example describes how SEC was used as a platform to create knowledge on what research and development was needed for the electrification of aviation as part of the commission´s working group 4.

3.2.1 Background: The Electrification Commission

In the budget bill for 2020, the Swedish government announced that an Electrification Commission would be appointed to speed up work on the electrification of heavy road transport and the transport sector as a whole. The Electrification Commission would together with business and stakeholders, develop an action plan for the electrification of the most important roads in Sweden, as well as highlight other possibilities for electrification.

The Electrification Commission was given a broad mandate to accelerate the electrification of the transport sector including all types of traffic and transport as well as all technologies for electrification (battery operation with both stationary- and dynamic charging, and technologies for hydrogen operation). A special focus would be on the electrification of heavy transport in the near future, primarily regional freight transport, freight transport along industrial important routes and along the state roads.

The Electrification Commission was also to address how a number of different areas such as financing issues and digitalization could contribute to a faster implementation of the electrification of transport. In addition, consequences of electrification for defence, preparedness and the robustness and vulnerability of the infrastructure and transport system should also be addressed.

The Electrification Commission consisted of 16 members active in research, regional development, the automotive industry, and electricity network companies. The work of the commission was carried out in four working groups with various actor groups coupled to them. Members of the commission were assigned two working groups each:

WG 1: Electrification of major roads and industrially important routes

WG 2: Regional electrification pilots and construction and infrastructure projects

WG 3: Electrification of shipping

WG 4: Electrification of aviation

3.2.2 Identifying strategic research areas för electric aviation

SEC participated in the WG 1 (Electrification of major roads and industrially important routes) and WG 4 (Electrification of aviation). Right from the start, it was established a strong focus on implementation in WG 1 and that different actors would make commitments enabling the electrification of these transports to scale-up i.e. prepare for large-scale implantation by investment in for example charging infrastructure. In WG 4, on the other hand, the development of the technology was much more immature and the was a strong need for research ranging all the way from component level up to the system level including infrastructure around the airport and the energy supply. Both in the commission's WG 4 and in internal discussions within the centre, the need to map this research and development requirements emerged.

Connections to all thematic areas within the centre were identified and, together with the commission, work began on planning a workshop to begin the mapping. In order to get participants from all relevant actors, the invitation was spread both in the network of the centre but also by the members of the commission in their respective networks.

The background to the initiative given in the invitation was the dialogue in the Electrification Commission's working group for electric aviation regarding the need for research to support the electrification of aviation. The research that is already being conducted today for the electrification of other forms of transport can with great certainty also contribute to the electrification of aviation. However, there is further need for strategic research to support it´s development. The aim of the workshop was therefore to identify these strategic research areas for electric aviation.

The workshop on strategic research areas for electric aviation was then organized by the Swedish Electromobility Centre online together with the Swedish Confederation of Transport Enterprises and Region of Skåne on March 21, 2022.

A broad definition of electric aviation was used where, in addition to battery and electric drivetrain, solutions including hydrogen and fuel cells were also included. Electric aviation constitutes an important but limited subset of future solutions for increased mobility and reduced climate and environmental impact from the transport system. It was important in this context to point out that there are other aviation-related areas/techniques that from a climate perspective may have significantly greater potential in the near future, such as Sustainable Aviation Fuel (SAF) and in the long term, the burning of hydrogen may also come in as a sustainable solution for aviation.

The ambition of the workshop was to, through group work, identify the need for research from both a technical and societal perspective. Forty-six participants were divided into a total of six groups. Two groups dealt with the system and hardware on board the craft. Two groups analyzed the need from an environmental and societal perspective. One group worked with energy supply and the connection to the electricity grid. The sixth group addressed the ground infrastructure. The groups worked on a target question and were supported by a number of discussion questions, see below. Each group had a group leader and a secretary.

1. <u>Technology: systems and hardware on board:</u> Technical innovation at system and component level to strengthen develoment of electric aviation
    1. Which systems in the aircraft need to be electrified?
    2. What do the load cycles/energy demand look like for a flight mission?
    3. What special technical requirements for components, including redundancy, do electric aircraft have in comparison to electric road vehicles?
    4. What components are most critical in an electric powertrain for aviation?
    5. Where is the greatest need for research and development?
2. <u>Environment and society:</u> Sustainable implementation of electric aviation
    1. What role will the first generation of electric aircraft have in the transport system? This includes (a) which airports/locations will be of interest; (b) what travel/transportation is reimbursed; and (c) what trips and travel patterns may be added due to new opportunities?
    2. What socioeconomic analyzes should be done based on the possible scenarios of introduction that can be identified?

    3. What environmental benefit can be achieved, based on the travel patterns that occur, and which trips are replaced?
    4. What social benefit can be achieved, based on the travel patterns that occur, and which trips are replaced?
3. Electricity supply and the connection to the electricity grid: How to supply electric aircraft with energy
    1. What charging infrastructure/network capacity is needed at airports? What energy use and load profile does the first generation of electric aircraft require, how does it affect the grid and how is total energy use and stored cargo affected (given that electric aircraft replaces other forms of transport).
    2. How can charging infrastructure and load profile look like at an airport compared to other parts of an electrified transport sector such as truck terminals and ports. Are there other requirements for electricity quality compared to charging at these locations? Potential for cooperation on network capacity/infrastructure between traffic types?
    3. What are the possibilities for local electricity generation, for example from solar cells, and energy storage at the airports given requirements for electricity quality and safety etc.?
    4. What are the opportunities for collaboration and synergies with other electricity producers and electricity consumers
4. Ground infrastructure for electric aviation: Infrastructure needed for electric aviation
    1. What special technical requirements, including redundancy on infrastructure, does the handling of electric aircraft pose in comparison to electric road vehicles?
    2. Which components are most critical?
    3. Where is there therefore the greatest need for research and development?

Participant organisations (members of SEC indicated): Swedish Electromobility Centre (SEC), the Region of Skåne, the Swedish Confederation of Transport Enterprises, Lund University (SEC), Royal University of tecknology (SEC), Chalmers University of Technology (SEC), SAAB Aeronautics (SEC), Linköping University (SEC), RISE (SEC), SAAB group (SEC), Uppsala University (SEC), AirForestry AB, Scania (SEC), the Swedish National Road and Transport Research Institute (VTI) (SEC), GKN Aerospace, Skellefteå Science City, Skånetrafiken (public transport organizer Region Skåne), Umeå University, TitanX (SEC), The Swedish Transport Administration, Ängelholm municipality, Ängelholm airport, Swedavia, Skellefteå Airport, Sweden's Regional Airports.

3.2.3 Summary and utilization of report on strategic research areas för electric aviation

SEC researchers and theme leaders together with other engaged experts from the workshop finalised a report that summarized the outcome from the workshop. The report was delivered to the Government Office of the Electrification Commission. The report was discussed at the next meeting with the commission and disseminated to the relevant authorities. The Swedish Transport Administration had a government assignment in parallel on how government support for research and innovation should be organized and developed in order to speed up the introduction of electric aircraft in Sweden. The SEC report was fed into this assignment. In the final report from the assignment, in June 2022, the Swedish Transport Administration proposes increased efforts on research and innovation in the field of electric aviation.

Within SEC work is now underway to form a focus group for planning the research and development of electric aviation in our centre which take off from the results in the report, which is summarized below.

The question of how the introduction and scale-up of electric aircraft should happen is strongly dependent on how you can demonstrate social benefit and how the necessary investments can be financed. There is no end in itself with electric aviation, it must fill a need, or alternatively meet an existing need better than today's solutions. An analysis of a comprehensive introduction of electric aviation requires a good understanding of its environmental and climate impact, both in the short and long term. It is also of great importance to produce data to compare the environmental impact with other transport alternatives that will be developed and implemented in parallel.

More research is needed on business models and electricity needs. What investments must the airports take? What does the possibility of planning timetables and schedules look like from an infrastructure and needs perspective? It is desirable to have tests of how different parts of the system can work together.

Furthermore, an increased need for electricity in the aviation sector creates new and increased demand for power grid capacity. In order to meet the need, it is necessary to know how much electricity is needed for aircraft and other vehicles and buildings at airports, and how the need varies over the day and year. This research includes how different charging strategies affect the need for power grid capacity as well as the possibility of using local energy storage or local power generation. A widespread electrification of society means that many sectors need electricity. For effective utilization of society's resources, an understanding of how different sectors and the infrastructure can interact and be coordinated is also needed.

Concerning the on-board system, the electric powertrain will affect most of the system. The most prioritized issue concerns the energy density of the energy storage. High energy density of the energy storage is a requirement and in addition safety and redundancy must be guaranteed. Research on new motor topologies with even higher power density to reduce weight and increase reliability is desired. As with the energy storage, cooling the powertrain can be challenging due to low air density. Possibilities for integrated heat management for the powertrain and batteries/fuel cell are therefore most interesting and should be addressed.

3.3 SEC as research partner to large-scale demonstration projects

To learn and prepare for the large-scale implementation of electromobility Swedish industry were launching two large-scale demonstration projects: E-Charge and REEL (both financed by the FFI program in Sweden). This example aims at illustrating the role of SEC as a research partner also to projects at a much higher TRL (Technology Readiness Level) than the centre usually operates at.

3.3.1 Background: E-Charge and REEL

The aim of the E-Charge project is to accelerate the building of knowledge in the electrification of heavy long-distance transport and preparing national actors for a scale-up of the technology. The project will establish and operate a system demonstrator with four heavy trucks, in long-distance customer logistic flows, which are charged with high power in so-called Megawatt Charging System (MCS) chargers. The vehicles must be able to drive for 4.5 h and then charge for 45 minutes to then be able to drive for another 4.5 h. Three public MCS chargers will be installed with charging powers of up to 1 MW at different locations to support the flow. The operation of the system demonstrator is expected to contribute with valuable experience about the logistics system, the business cases, opportunities and risks linked to the electrified long-distance logistics system [3].

In REEL leading Swedish actors have joined forces to accelerate the transition to electrified, emission-free regional heavy transport. Within the project, 60 different regional logistics flows in varying types of driving assignments are run and evaluated. REEL brings together transport buyers, forwarders and distributors, haulage companies, terminal operators, electricity grid companies and suppliers of trucks, charging equipment and management systems. In addition, regions, national authorities and universities participate in this initiative [4].

3.3.2 Research questions on system level in projects at high TRL

The industry partners together with the project leaders of E-Charge and REEL at SEC partner Lindholmen Science Park decided to connect reasearches to the projects in order to get full exchange of learning and knowledge building from the demonstrations. The companies turned to SEC and through its network of researchers, SEC was able to match the need for experts in the respective projects to leading researchers within the centre. It was true that the projects were on a high TRL however, the SRL (System Readiness Level) of the projects was still low and through a system approach the reasearches could identify a number of important issues to address within the scope of the projects.

In E-Charge a horizontal research work package was created within the project led by the SEC. The aim was to develop models to explore the effects the electrification of long-haul trucks would have on the total system and the corresponding subsystems. These system models include the electric vehicle (the ECCV platform, described in example 1 above), different actors, traffic flow, charging infrastructure, grid, need for policy and regulation etc with the goal to achieve a cost-effective and robust system with good balance between conflicting requirements. Early results from the models may also influence the preparation and implementation of the system demonstrator or its subsystems, as modelling may be able to identify gaps, issues, or opportunities to be explored. The knowledge from the demonstrators will in turn be used to analyse how to meet the business requirements of the logistics system with the vehicles, chargers, and grid system. The models developed will further help assessing the implications of different system design considerations in an up-scaling of the demonstrator.

Five PhD students, working within individual research areas at SEC partners Chalmers University of Technology, Linköping University, Lund University and Uppsala University were funded by the project. These students were associated to the SEC program and included in the SEC doctoral student network. As a hub for research within electromobility, SEC will also be an important active part in the dissemination of the knowledge obtained in E-Charge through its network. SEC is also part of the steering group of the project.

In the REEL project SEC was asked to provide research actors concerning policy and business models. For policy the project wanted to answer the research questions like; i) which policy development favors a rapid scale-up of regional electrified logistics in Sweden, ii) recommendation what type of policy instruments should be used during a transformation period (2024-2030), iii) what regulation, codes and standards need to be developed regarding e.g. weight requirements, zero-emission zones, conditions for expansion of power grid capacity, and iv) what possible organizational innovations for public actors and business can be established in Sweden regarding e.g. cooperation, structures and procurement. The research also aims at contributing to development of international policy and standards.

Concerning business models the research questions were; i) which factors and barriers are limiting for the business model setup, ii) how can the business risk related to electrification be distributed between the actors in the value chain, iii) development of business models to provide actors in Sweden with knowledge support in the process of electrification and iv) development of financing models for how to scale up electrification based on the findings of the system demonstration.

The research within REEL is carried out by senior researchers from SEC partners at Lund University and Linköping University. Researchers from Chalmers University of Technology are also taking part of the project.

3.3.3 Summary of SEC as research partner

For the participating industrial partners of the large-scale demonstration projects it was necessary to get full exchange of learning and knowledge building from the demonstrations and therefore researchers needed to be connected to the projects. However, also for SEC the value of participating as a research partner in large demonstration projects is manifold; to learn the challenges of large-scale implementation, to develop understanding of end-user perspective and the logistic value chain, possibility to disseminate research results from the centre in the demonstration and, finally, the development of models on holistic system level that can serve also projects within the centre.

4 Conclusion

Swedish Electromobility Centre has since it was founded in 2007 developed into a great and widely appreciated platform for the research and development of electromobility in Sweden, be it the growing of a research project portfolio for an industrial important area (first example), the support of the government in research needs within a defined area (second example) or the need for a research partner in large-scale demonstration projects enabling the full-scale implementation of electromobility (third example).

It started with the technology onboard but as solutions matured the need for holistic system perspective has grown and the centre has successfully adapted. Now it contributes with knowledge and competence to the strategic work within the area supporting the government, the industry and society as a whole. At the same time keeping the larger picture in mind; electrification of transport is a subset of all electrification that is underway, it must all fit together for a sustainable future.

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Presenter Biography

Linda Olofsson is a physicist with extensive experience in leading research and coordinating industrial parties and researchers to find common solutions to complex technical challenges. After her PhD, she started a company based on her research together with Chalmers school of entrepreneurship. Then she brought the experience from these years as start-up leader to the RISE institure, where she held several leading roles before taking over the leadership of the Swedish Electromobility Centre.