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Experience from first year with wireless charging fleet in Gothenburg green city zone

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Executive summary

From beginning of March 2022, Volvo Cars, together with selected partners, started testing wireless charging in the live city environment of Gothenburg in Sweden. Over a three-year period, a fleet of twenty fully electric Volvo XC40 vehicles with integrated wireless charging technology are studied in taxi operations and charged at dedicated wireless charging stations. During the test period the project stake-holders are collecting data from vehicles and charging operations as well as performing driver and customer feedback surveys. After more than one year since the start of operation, the fleet is running as planned with twenty vehicles and have already achieved a mileage over 1 million kilometers. The overall feedback from the drivers is positive, but some of the drivers are not using this highly convenient charging opportunity since it doesn't fit to their operational needs. The wireless charging stations are so far covering for 20% of the total fleet energy supply. This number can be improved with an increased number of wireless charging stations and as a likely result more drivers will start to use this opportunity. The wireless charging fleet test is an early initiative outlined within a strategic project called Gothenburg Green City Zone, under which appointed areas within the city are used as live testbeds for the development of sustainable technologies.

Keywords: charging, wireless charging, fleet, passenger car, sustainability.

1 Background

Vehicle fleet operations are projected to become a focused area in the ongoing transformation of the automotive sector. An important way to reduce the vehicle transport related CO2 emissions will be to increase the utilization factor for the vehicles in use.

When shifting to electric driven car fleets with an expected increased utilization, it is also expected that the number of charging occasions will need to increase, and therefore the speed of charging will become more important to maintain the high accessibility to the vehicles in operation. A specific fleet operation of interest is the taxi use case, known for its high utility factor and high yearly mileage.

Wireless charging operating at competitive power levels around 50 kW provides an interesting alternative for creating an easier and more convenient journey for the taxi drivers. Access to convenient charging without additional effort is estimated to be highly appreciated. The charging environment set up for this test is consisting of two dedicated wireless charging stations with two charging points per station. The question if the setup with two charging stations will be sufficient to cover the daily travel needs for the taxi fleet is now starting to deliver some answers and studies to find more suitable charging points is continued.

Listed below are some of the interesting research topics concerning studies of the taxi test fleet operation.

- Is the switch over to vehicles with electric propulsion attractive for taxi drivers given their high milage utilization?
- How does driving habits change if the taxi drivers have access to extended charging modes, with wireless charging added, compared with the existing charging standards available in the market.
- Will the taxi drivers with their daily driving routines, feel comfortable with the charging times and station density?
- Are there any seasonal differences in the behavior of the charging needs. Gothenburg City in Sweden is an area where winter and summer climate are quite different

Already found is that communication and dialogue with the drivers is very important to create and improve understanding their needs and expectations. For most of the drivers, diesel ICE cars are the reference point, where the drivers likely have an established knowledge and long driving experience.

Any unexpected failure related to EV driving or charging might cause severe complaints and needs to be handled with care. At the same time, the project stake holders don’t want to interfere with the driver’s daily life, so to understand specific pain points and treat problems calls for sensitive and careful communication.

A deeper review of the wireless charging project scope was presented at EVS 35 Symposium [1] in Oslo. June 2022. In this publication, the author presented the integration steps of wireless charging technology together with a description of how the project stakeholders founded a collaboration within a partnership with the aim to study wireless charging over a 3-year period.

2 Project and fleet overview

2.1 Project targets

In the project formulation, following targets were defined:

- Collaboration to contribute to fossil-free transport system in Gothenburg 2030
- Measure, communicate and demonstrate the transformation of a key segment in the transport sector
- Contribute to the automotive sector's transformation to offer user friendly and convenient fossil-free transport solutions and increased business opportunities for Sweden
- Install and commission charging stations for inductive fast charging at strategic locations

Supported by this 36-month fleet study:

- Test, demonstrate and operate taxi services with inductive fast charging in a reality-based environment.
- Study taxi driver's experience of various aspects, such as:
  inductive fast charging, charging needs for taxi owners overnight, inductive charging impact of fast charging on batteries
- Investigate other applications for inductive fast charging and the possibility of a test bed environment

2.2 Launch retrospective

The launch of the test fleet took place March 3, 2022, close to the firstly built wireless charging station located near the entrance at Lindholmen Science Park, a center for automotive research and education. Echo from the official launch was spread around the world and received well over any possible expectation. See Figure1

Figure 1: Wireless Charging displayed at Lindholmen science park in Gothenburg

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After the successful project launch, finally the wireless charging test fleet went into execution. Many hours of building, tuning, and testing was over, and it was time to start looking for results. Drivers started to run their operation with their newly bought cars and the project stakeholders started to look at the resulting data streams.

Naturally, followed by launch success new questions were raised

- Will the experiment work as anticipated?
- What is the driver's reception of the new technology?
- What will the unexpected situations look like

In June 2022, Volvo Cars demonstrated two wireless charging cars for the participants visiting the Electric Vehicle Symposium, EVS 35 in Oslo. Together with the technical presentation for the interested audience at the symposium, live demonstrations were held at physical stations in the city center of Oslo. See Figure 2

Figure 2. Demonstration at Olav V's gate in Oslo

In August 2022, the second charging station was inaugurated at the location close to Sahlgrenska University hospital. This strategically well-located charging area close to places with intense people activity created opportunities for an increased level of wireless charging activity and this effort improved the taxi driver's ability to charge their cars more frequently with low distance to people pick-up areas.

Figure 3: Second Wireless Charging station at Medicinaregatan

2.3 Brief description of vehicle and wireless charging setup

Wireless charging integration into passenger cars means adaption with known vehicle technology and a supplier specific charging solution. To help the driver to start a charging session there are three key elements in wireless charging to consider:

- **Vehicle alignment.** The vehicle needs to be correctly positioned with some accuracy in relation to the ground pad location.
- **Access control**. The vehicle charging pad needs to be accepted for charging by the charging operator to start the energy transfer, start metering the charging session energy and to supply information for billing measures.
- **Charging operation**. The user is starting a charging command and system actions is executing the charging session.

Helping the driver to understand the charging process steps is communicated to the driver through displays in the car. An overview is presented in Figure 4.

A detailed description of the wireless charging technology, Integration and project setup can be found in [1]

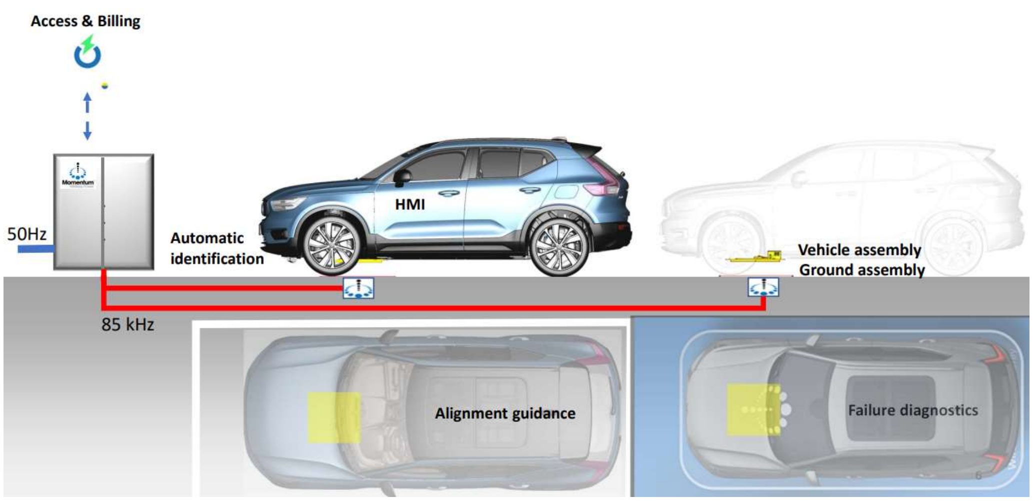

Figure 4: Wireless Charging Principle

2.4 Charging stations

Two wireless charging stations are currently in operation, first charging station, positioned at Lindholmen science park with its first operation and inaugurated in February 2022. The second charging station was built at Medicinaregatan close to Sahlgrenska University Hospital and officially inaugurated in August 2022.

Both charging stations are equipped with dual ground pads for two cars parallel charging. For detailed placement information see map showed in Figure 5.

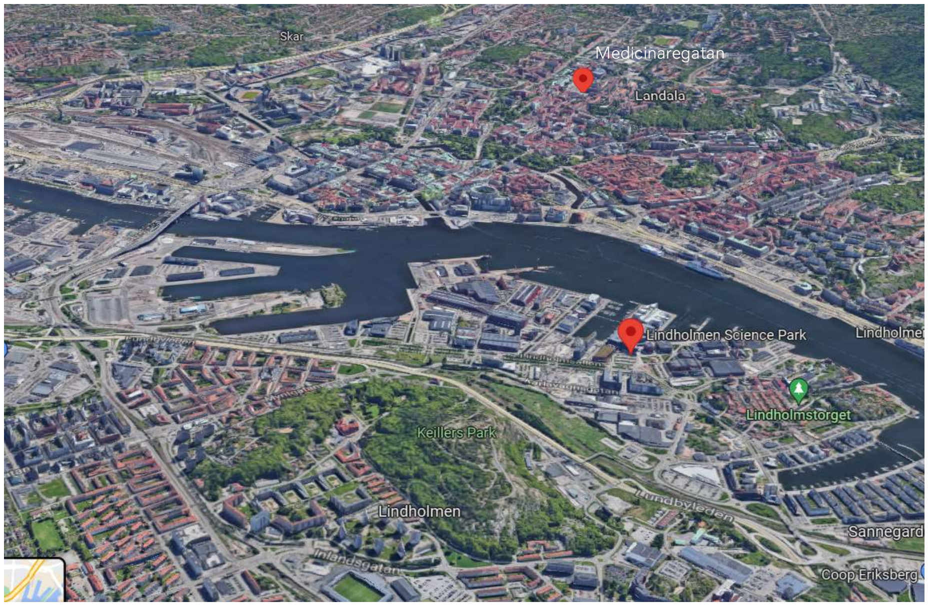

Figure 5: Gothenburg City map showing points with wireless charging stations. Source: Google maps

2.5 Organising the test fleet

The release of the fleet cars into its designated taxi operation was spread over a period of 4 months. A major reason behind a distributed rollout plan was driven by the processes to find cab drives, support the vehicle purchasing and rebuild the taxi fleet with taxi specific equipment like radio com, taxi meters and signs etc. Starting with six cars at project launch the fleet rollout reached its planned volume in beginning of July 2022. The fleet cars were also equipped with some extra capabilities to increase its attractiveness before delivery to the drivers.

For the fleet test, activities listed below was prepared in advance of the launch and evolved over time

- Setting up maintenance and service operation for the car owners/drivers.
- Starting data collection and monitoring of the fleet
- Detailed follow up of the charging performance and health status
- Interview sessions and regular communication meetings between drivers and stakeholders
- Regular project meetings within stakeholder group

One of the more important aspects when running this test fleet with business-oriented utilization is that any unnecessary disturbance to the driver's operations must be avoided since it means revenue losses. The fleet operations meant that all actions within the stakeholder group had to be made with minimal disturbance to the taxi driver's daily work. The expectations on technology and vehicle quality are high and the users have minimal tolerance for disturbances of any kind.

The drivers need high robustness and expects to get as high usability as possible and as competitive as possible with the situation they are previously experiencing with diesel fueled cars.

3 Fleet identification

To follow the fleet and the user's charging behavior over time there is a need to organize and keep track of some relevant identifiers for the unique equipment connected to each vehicle. For this project we decided to use a simple car numbering and connect the individual hardware and software related variables to the unique car number. Most of the information around the individual car details are not shared among the stakeholders.

Following principles were used for identification. See figure 6.

3.1 Car identification

Car ID number

- A Car ID was decided for each car using the wireless charging application
- Wireless charging equipment hardware and software identification. The charging pad serial number is used by the charging operator for identification and billing purpose. It also important to update the list whenever parts are changed.
- Monitoring system hardware and software identification

3.2 Charging station identification

- Charging station ID number

  The charging station number is used to identify the physical location where the vehicles are charged but is also used for looking at energy consumption, charging monitoring and fault tracing. If faults are occurring in any of the vehicles during charging events, it can be traced back to a specific time stamp of the unique operation by the charging station.

- Each charging pad at the station is identified
  The charging pad identifier is pointing to the actual ground pad the specific vehicle is charging at and is essential for the actual charging control and access. With this information we can find out charging occupancy KPI's for each charging point.

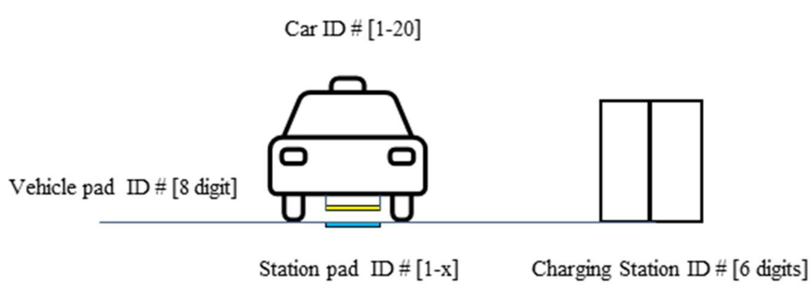

Figure 6: Principles in identification

3.2 Service and maintenance

An especially important aspect of running a fleet in a business environment is the access to regular service and maintenance. Taxi vehicles are highly utilised and in operation for larger parts of the day and warranty required maintenance occurs in a quarterly interval. To find effective ways of working, managers at Volvo Cars Retail service organisation decided to appoint dedicated personnel, called personal service technicians (PST's) for each taxi owner to achieve a smooth dialogue and find an efficient and rapid action when repairs or maintenance of any kind comes up. See Figure 8.

Figure 7: Maintenance action at Volvo Cars Retail workshop

If advanced trouble shooting is needed, it is also possible to take in cars with special analysis needs for a check at the Volvo Cars R&D test facility. This is a unique opportunity in Gothenburg where the Volvo Cars R&D headquarters is situated. To this date, very few visits have been made to the Volvo Cars R&D facilities. The rare occasions have been associated with software upgrades since the fleet cars have unique SW parts compared to the mass production vehicles.

3.3 Fleet monitoring

All cars in the taxi fleet as well as the charging stations are equipped with a data acquisition system to understand the vehicle usage patterns. By looking at the charging statistics, we can analyse aspects of the fleet usage but also look at state of health parameters. Statistics like charging energy per vehicle, driven distances per driving cycle and per day, total distance driven etc, can be read from the stored data.

Another important potential with the fleet monitoring system is that it is possible to supply extensive and easily accessible fault tracing to create service feedback when any problem arises. The third important monitoring aspect is the input and feedback from the drivers and owners. Naturally, this information comes from the dialogue with the drivers. It is important to understand if the user perspectives changes over time during the test period.

Under the sub headers below we will present more details about the data acquisition.

3.3.1 Vehicle monitoring

Through the monitoring system, vehicle live data is stored as time series based on the car usage. After each driving cycle, a package with the latest logged data uploads through a telematics link ending up into a cloud server, marked with time stamps reflecting each driving cycle. At any point in time, it is possible to perform data analytics by post processing of the acquired data points which are all time stamped.

The monitoring system is described in Figure 8 and Figure 9.

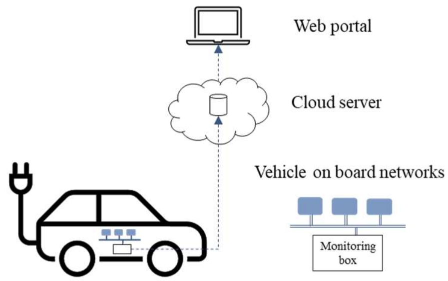

Figure 8: Vehicle monitoring system

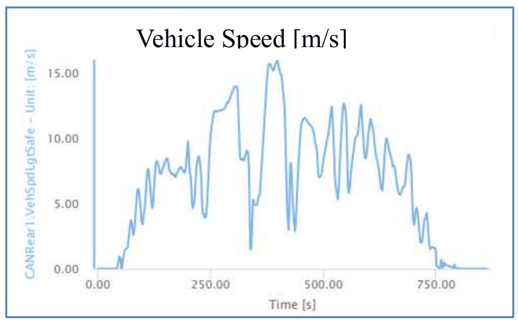

Figure 9: Example of data plots from the monitoring system

Through the monitoring system it is also possible to read out vehicle diagnostics data for an increased level of statistical vehicle usage information as well as reading of DTC's (Diagnostic Trouble Codes) to analyse if there are any issues found in the control modules in the car.

3.3.2 Charging station monitoring

Each charging station activity are continuously checked by the charging station supplier, but limited data is made available for general status review and simple fault tracing. At the charging station, the individual vehicle in the fleet that appears close to the charging point is identified through the charging pad's serial number. During the charging event, the wireless charging energy is visualized together with information about the charging session health status.

The monitored signals are captured and visualised with a web-based tool reachable over internet channels. Based on the captured data points there is a statistics portal accessible for cab drivers to understand the real time availability of the wireless station pads. This information is particularly helpful for the driver in their decision making around their charging visits. See figure 10.

Figure 10: Example showing availability of one charging pad. Graphics from Induct EV.

4 Results from first year of fleet monitoring

4.1 Vehicle Milage

Vehicle milage is expected to be high due to the taxi use case. However, we have found that individual vehicles in the fleet are used differently by drivers. In Figure 11, the driven km per vehicle is shown. The example shows the mileage profile gained up to March 15, 2023. The total mileage is equivalent of approximately twenty-three times around the world.

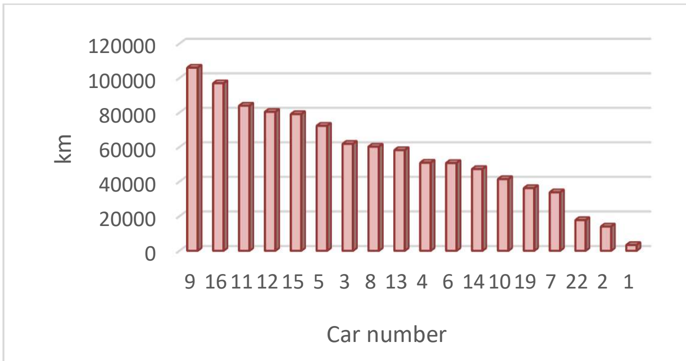

Figure 11: Summary milage, first year driving distance per vehicle

4.2 Charging usage – Wireless Charging

As expected, the use of wireless charging in the fleet depends on the different driving pattern for the taxi in mind. The difference between maximum and minimum use of wireless charging is almost 100% meaning that few drivers are using wireless charging for a high amount of charging, but others are not using wireless charging at all. See Figure 12.

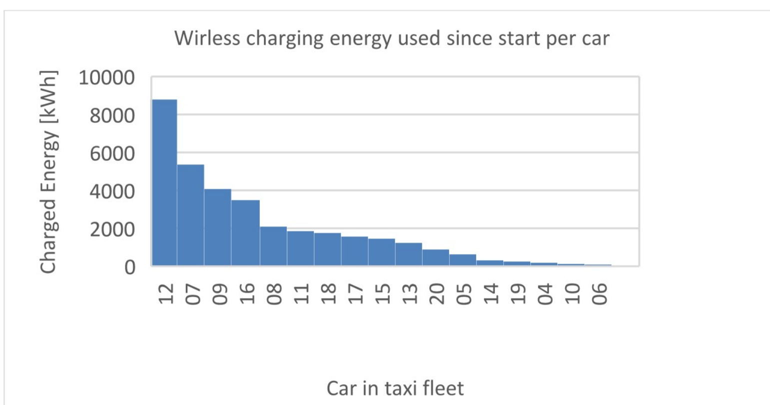

Figure 12: Wireless charging energy used per vehicle

4.3 Charging usage – comparison between the charging modes

Looking deeper into the vehicles charging usage, we can see that the charged energy per charging average level per charging occasion is in the area of 10-30 kW see Figure 13. As seen from figure, the share of the charging modes is varying but not to any extremes. 3-phase AC, the logical charging method for overnight charging has the longest duration and used energy span. DC and Wireless are closer but given the fact that there are eighty selectable DC charge points within reach but only four wireless charge points available in Gothenburg city it is difficult to draw conclusions.

Following observations can be made:

3 phase AC charging seems to be the mostly used charging type. DC fast charging adds upp to lots of the charging occations but wireless charging is not that far behind.

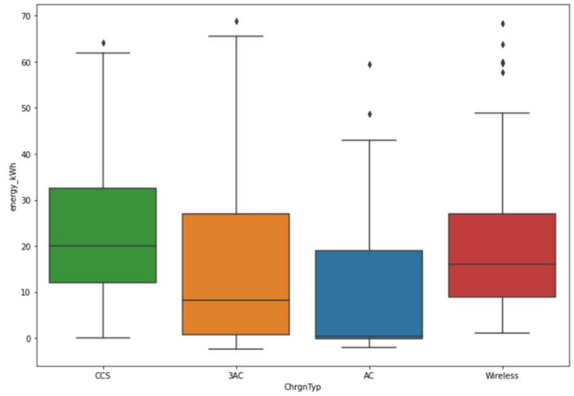

Figure 13: Charging profile per charging modes

In Figure 14, we can see that the charging speed seems to vary with the charge point capacity for the AC charging. For DC charging we can see that the charging speeds follow a more diffuse pattern. The fact that battery limits are temperature dependent and affected by climate conditions makes this spread larger

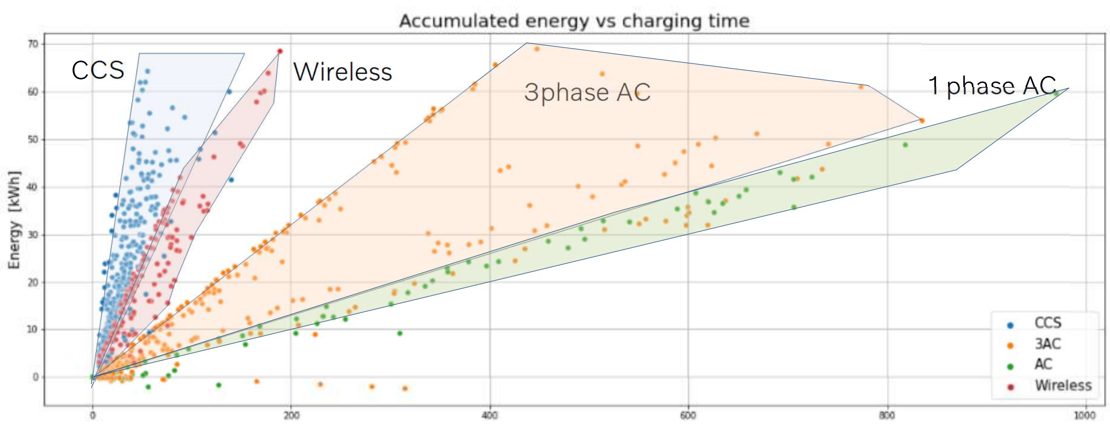

Figure 14: Wireless charging energy used per vehicle

From analysing charging behaviour, we can see that wireless charging and DC conductive charging is not so far away when it comes to practical charging speed. Even if DC fast charging is expected to charge with faster pace, spontaneous charging makes battery preheating difficult which limits the charging power accepted by the battery. More data points reflected in the figure 13y, come from winter climate charging which influences the performance of high-power charging.

5 Conclusions and learnings

5.1 Share of wireless charging

From the first year, out of the three years planned, given the limited number of four charging points, the wireless charging usage factor is found stay close to 20 % based on delivered energy and driven kilometres. Given the fact that 50-60% of the fleet users are currently using wireless charging on a weekly basis, we think that it is possible to increase the utilisation factor up to higher levels if introducing more charging stations. Parts of the remaining 40-50% of the drivers that does not use wireless charging today has also been faced with that the wireless charging functionality in a small number of the vehicles has temporarily been out of service for some of the vehicles. It is also likely that if wireless charging will improve in usage, the resulting usage factor for DC fast charging will be reduced.

5.2 Dialogue with the drivers

Even if this is a small fleet, it has already created lots of learnings around the importance of interacting and communicating with the drivers. The most crucial factor is to have open channels for smooth service and maintenance and to function as fast as possible to mitigate any problems. Another key point is to plan regular information meetings and create dialogues around issues with common nature. The internal dialogue between the drivers is as important as any given information form the project. Driving electrical vehicles in high mileage operations is a new experience to the taxi drivers.

5.3 Keeping the fleet healthy

As most projects goes through separate phases, this test fleet project is not different. From an overall view this project has been a success from start but there have been numbers of issues to deal with on the way. General checks of the fleet status are done regularly, and project meetings are needed for coordination. All cars are still running and doing the work as expected and the drivers are still committed. We are now moving forward to year two with higher expectations and hope that our learnings will give the project members even more insights.

Acknowledgements

In a project like this it is impossible to acknowledge all people involved inside and outside Volvo Cars. Without mentioning specific person, a big applause should be sent to all the enthusiastic people inside Volvo Cars that have made this project possible - Such a wonderful team!

Thanks, are also be sent for the appreciated support given by Induct EV, both locally in Sweden and from technical R&D organisation in The United States. Finally, the project team members from the stakeholder companies. The willingness to make this happen, finally got this project to a successful continuation!

References

[1] Volvo Cars to test new wireless charging technology in green city zone, EVS 35 Symposium Oslo

Presenter Biography

Robert Eriksson has a M.Sc. in Electrical Engineering from Chalmers University. Robert has more than 30 years of experience at Volvo Cars working with various electrification research and development programs and holds a role as Senior Technical Leader in the field of Electric Propulsion Architecture and Electromobility. Robert is actively leading several activities with external partners in the global arena closely related to the automotive industry transformation with a sustainable society in focus.