BATTERY SWAPPING IN CHINA

Report from an exploratory trip, 20-24 November 2023

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Sweden-China Bridge
Collaborative Academic Platform for the Electrification of Transportation Systems

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Summary

"Of the 10 largest manufacturers of electric heavy trucks, nine are Chinese! China is leading the electrification in the transportation sector, with Battery swapping for heavy trucks now becoming the dominant recharging infrastructure solution, expected to reach 70% in a few years' time" (Liu & Danilovic, 2021).

This study tour was arranged to give a unique insight into Chinese electrification with a specific interest in Battery swapping. The study trip was conducted 18-25 November 2023. It was made possible due to extensive long-lasting collaboration between the Sweden-China Bridge project (SCB), financed by Trafikverket (Swedish Transportation Administration) led by Professor Mike Danilovic and Dr. Jasmine Lihua Liu, Halmstad and Lund University, and the Shanghai Dianji University.

The SCB project has studied Chinese renewable energy since 2013 and the electrification of transportation since 2018, including Battery Swapping. This has led to vast knowledge, a broad industrial, business, and academic network of collaborative contacts, and a unique possibility for on-site observation and exchange of experience. SCB, in collaboration with the regional logistics cluster Logistikia and VTI (Swedish National Road and Transport Research Institute) has worked to increase Sweden's knowledge of battery-swapping as a complementary solution to cable charging. We advocate battery-swapping because it has a potential to be an important enabler in scaling up the electrification of heavy transports, responding to major obstacles identified for transportation companies and challenges regarding power capacity in local grids. From a Swedish perspective, we consider it remarkable that battery swapping is unknown and not discussed on the national Swedish scene and that public financing is biased towards cable charging as the only solution!

The explorative study program in China covered several electrifications of transportation hot spots. It gave participants a broad and deep understanding of the electrification of transport in China and particularly about the status of battery swapping as a concept and how it is organized and developed in the Chinese context.

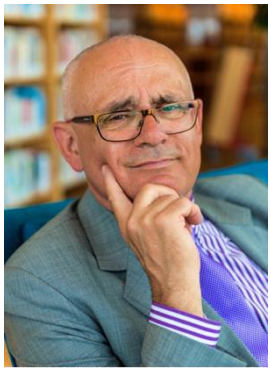
In short, we conclude the following experience from the trip:

- Chinese electrification, regarding technological development and implementation in the real life, is many years ahead of Europe in all fields of electrification of transport.
- The technology development and implementation speed is very fast, and the speed to full-scale implementation is remarkably fast.
- China's official climate goals set the direction, but in practice, the electrification, including the battery swapping, is business-driven. What is not business-wise successful is not moving to large-scale implementation.
- There is a close, almost seamless cooperation between academia/research and companies, enabling high speed in development, implementation, and innovation.
- Battery swapping is an essential solution for electrifying heavy electric trucks, dominating sales of heavy trucks in China since 2022.
- The technical development is extremely fast, with several (three) generations of battery swapping on the market.
- There are battery-swapping solutions for all types of vehicles and trucks, with the dominating areas seemingly being mining, construction/dumpster trucks, and trailer transportation
- The dominating battery-swapping solution for heavy trucks is by placing the battery on top of the chassis, behind the cabin.
- Several companies are developing solutions where batteries are swapped from the side or below, mounted under the chassis, between front and rear axles (as with fixed batteries).
- Grid power capacity is not an issue; companies do not consider battery swapping as an enabler in that perspective. Instead, the business value is the number one issue, and physical space utilization is also considered necessary, as well as the time for "recharging" the truck, i.e., swapping the battery.
- The efficiency and effectiveness of operations are two major concerns for Chinese transportation companies when they choose solutions for the electrification of transportation solutions.

About Sweden-China Bridge

Sweden-China Bridge started researching the electrification of transportation systems in China in 2017-2018. In 2018, a VIP team from the Swedish Transport Administration (Trafikverket, TRV) visited China and explored its development.

Researchers on the development of electrification of transport in China



Professor Mike Danilovic.

Professor at Halmstad University, Industrial Management focusing on Innovation and Technology Management. Distinguished overseas professor at Shanghai DianJi University since 2011. Project leader Sweden-China Bridge.

Dr. Jasmine Lihua Liu.

Lund University, Affiliated with Jönköping International Business School. Has been working as a researcher in Sweden since 2012. Received Ph-D. in Innovation Sciences in 2019 on extensive action-based research in business model innovation of the wind power industry. Jasmine is the key researcher in Sweden-China Bridge.

Other Swedish researchers in the projects are: Tech. lic., Arne Nåbo (VTI), Dr. Harrison John (VTI), and Dr. Philip Almestrand Linné (VTI).

Sweden-China Bridge 1.0, 2020-2023

In 2020, we started the Sweden-China Bridge 1.0 project, focusing on a deeper exploration of the development of electrification of transportation in China. Battery swapping was discovered as an exciting and rapidly growing solution for all transportation systems.

Sweden-China Bridge 2.0, 2023-2026

In 2023, SDCB started a three-year project, Sweden-China Bridge 2.0 focusing on the system approach to electrification and the Inteligentization of transportation systems. SCB intend to explore and understand how different technologies are developed and integrated on different system levels to achieve larger-scale electrification of electrified vehicles integrated with intelligent roads, and smart cities, all the way along the value chain and across system levels.

The SCB have three perspectives on exploring electrification in China:

- the holistic system approach,
- the symbiotic collaboration between decision makers, institutions, regulatory, and industry, and
- the experimental approach in developing electrification of transport.

All those three characterize the Chinese way of approaching renewable energy and the electrification of transportation.

SCB project is exploratory and includes a step-by-step approach to knowledge development. The project spans different areas of knowledge, technology, business, and society, where we will shed light on what technologies

are being developed for the electrification of the transport system, from critical technologies such as minerals and batteries to complete intelligent vehicle systems, to integration with intelligent roads and smart cities.

The 2023 battery-swapping explorative trip-delegation

17 people constituted the delegation, broadly representing the Swedish transport and heavy-truck industry, transportation companies, transportation buyers, industrial networks, and research and innovation clusters from Sweden and Finland. Competencies in the group stretched from truck operation to battery expertise, truck engineering, business and market, and others. The different profiles and experiences in the group contributed to interesting discussions and different perspectives being put forward

Program and visits

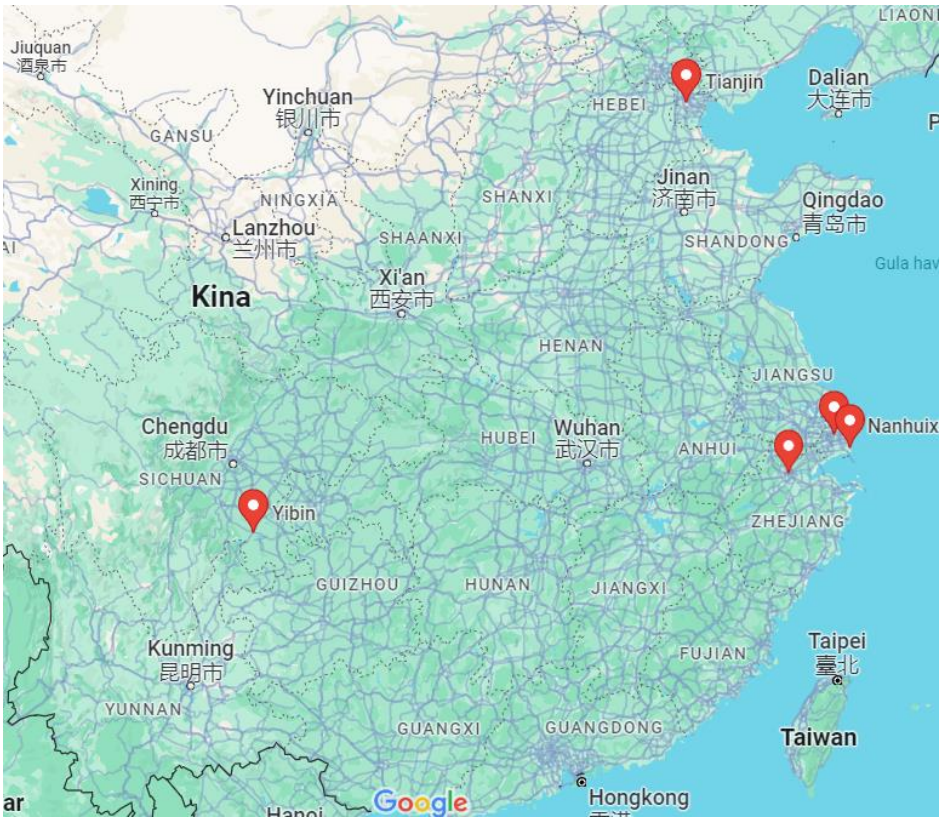
The study week featured an intensive program covering major hotspots in Chinese electrification, looking at battery swapping in practice, vehicles, swapping stations, research and development of artificial intelligence and autonomous technologies, full-scale test road capabilities, and manufacturing. The program also covered a lot of meetings with presentations, discussions, and mutual Q&As. Our hosts received the delegation well at all stops, for which we are very grateful! We are impressed by the openness and willingness to share experiences and practice in all those areas we explored.

The trip was made possible thanks to massive and thorough preparation by Dr. Jasmine Lihua Liu and prof Mike Danilovic

Exploring many places

During the week we explored Shanghai, Lingang as one of the major development areas in China, Hangzhou, Yibin, Beijing and Tianjin.

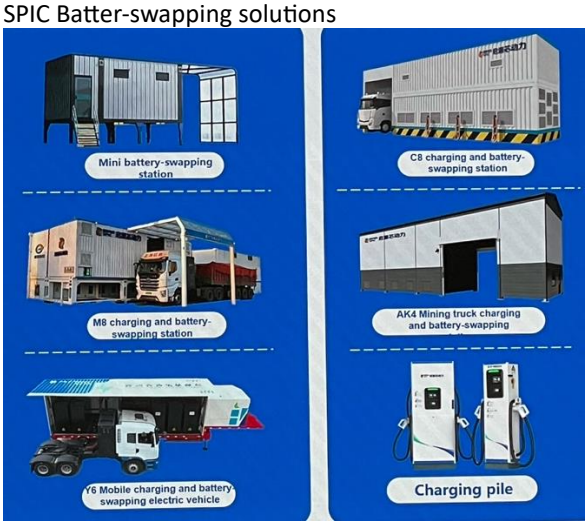
We visited University, research centers, test drive facilities, vehicle manufacturers, battery manufacturers, battery-swapping system developers and manufacturers, and got close experiences of intelligent heavy trucks.



Explorative schedule of the week

Sunday November 19, Shanghai City Walking tour in Shanghai	An appreciated first glance of Shanghai and introduction to China. Stunning experience with close to 100% electrified 2-wheelers and taxis.	Shanghai, Bund in the night 
Monday November 20, Lingang (Shanghai) Shanghai Dianji University (SDJU) & Lingang municipality. President SDJU Siyi Gong, Director Yimin Bian. Visit Artificial Intelligent Center Visit Autonomous Driving Center	Opening conference at SDJU, Chinese counterpart in the SCB project, enabling contacts with research centers and companies in China. Presentation and visit to Lingang, 800 km2 development area with intense activities, new companies moving in, including Teslas new factory. We visited 3 development nodes – Centers **Innovation Center**	Shanghai DianJi University (SDJU) welcoming ceremony President Professor Gong   Innovation Center – Future Vehicle 

Visit Test Center for autonomous driving and battery swapping	**AI Center** (planned to house 30-50,000 people working with AI)	Intelligent chassis 
	Autonomous driving center, Test-range for autonomous driving and battery swapping.	
	Battery swapping practice, test site and autonomous driving to port of Shanghai	
Visit Aulton, 3rd party battery-swapping system developer	Visiting Aulton test and development for swapping from side (battery between axles)	

Seminar from SPIC, world's largest producer of green power	Presentation from SPIC, developed the first swapping systems. Today 500 operational stations, average of 40 vehicles/station	SPIC Batter-swapping solutions 
Tuesday November 21, Hangzhou Geely, Farizon, meet and study BS station in operations Test driving	Visit swapping station developed and operated by Geely. This station supports 20+ concrete trucks at a concrete industry. Station supplied with 2,5MW performs max. 168 swaps/24h with 7 batteries. Station can be relocated in 48 hrs. Footprint 60m2. Time for swapping 3 min. Meeting with Geely discussing technical development, marketing strategies and differences in the Chinese and Swedish transportation market. Presentation of the Farizon Homtruck (brand owned by Geely) for long haul transports with convoying features, L4 autonomous ability, build.in battery-swapping as standard solution, and a fully equipped "home like" cabin. Farizon also develops a cables truck for closed environment operations. The Homtruck is set to be on the market by 2025.	  

Wednesday 22 November, Yibin We started with exploring the Prof Ouyang Minggao Academician Workstation, Sichuan New Energy Vehicle innovation center. First visit Zhi Li Wu Lian. We also visited CATL battery manufacturing in Yibin.	Visit exhibition area. Integration research and technical development including battery research. “in 2022 CATL was ranked n:o 1 globally in EV battery consumption for 6 consecutive years” https://www.catl.com/en/about/profile/ The stand-alone EV-platform in the picture is a product of Zhi Li Wu Lian and CATL. Zhi Li Wu Lian conduct research and develops batteries, vehicle mounting fixture, swapping robots and two generations of swapping stations.	 
Thursday 23 November Zhi Li Wu Lian, factory, swapping test sites, swapping operational site, test driving	Visit Zhi Li Wu Lian manufacturing and test site. We explored the new generation with a linear robot that swaps a battery in a few minutes. Visit Zhi Li Wu Lian operational swapping station	

Friday 25 November, Tianjin (Beijing area) Deepway trucks and battery swapping station, development, test drive area	Study and test drive the DeepWay newly developed Intelligent truck. The truck is already on the market. As of December 2023 DeepWay will start real traffic tests with autonomous L4 (vehicle performs all driving tasks, with only human monitoring). Battery swapping as standard solution, placement between axles, swap from below	

Reflections on the Chinese electrification

From 2-wheelers to taxis and trucks

In Shanghai, all mopeds and scooters are electric, as well as most taxis. Hence, traffic is silent and almost emission-free. Heavy trucks spotted in the city and on highways are still normally fossil-based. Several electric trucks, especially in construction, are electric in areas visited during the trip. Most electric trucks spotted were with battery swapping. The impression is that the electrification of heavy trucks emerges out of clusters with large concentrations of electric trucks rather than equally distributed throughout the country

Autonomous driving

Electrification in China is closely related to digitalization and the development of autonomous driving. Even in low-salary developing economies, the cost of the truck driver is significant. In addition, the Chinese market, as well as the European, suffers from a lack of drivers, especially for long-haul transport. Modern trucks for long-haul are equipped comfortably, some even with showers, washing machines, and toilets. Autonomous driving L4 is anticipated to be an important selling feature of modern trucks, already from 2024.

Speed in innovation and application

Companies visited showed an impressive speed in their development. DeepWay, as mentioned above, was founded in December 2020, and already has several hundreds of new intelligent electric trucks on the market. New prototypes have been developed and tested with only months apart, indicating a different, seamless, approach to the traditional sequential process. Speed may often be prioritized above perfection, “put new products on the market and correct faults as you go!”.

Integration between research and companies

As a foreigner it is not easy to understand all different relations between state, companies and academia, but a frequent, fast and close cooperation, many times symbiotic, is evident. The Sichuan New Energy Vehicle innovation center and Zhi li Wu Lian that we visited, was one example of this. Led by professor Minggao (PhD from Denmark) the institution has incubated many companies, that cooperates and stay connected to the center. The close cooperation between actors seems to be an important factor to explain the speed of which Chinese electrification is moving forward

Vehicle standard

Compared to premium brands as Scania and Volvo, Chinese trucks are plain and from a Swedish driver perspective of lower standards (suspension, quality of materials etc). This version of trucks would not be accepted by Swedish drivers. However, this should not be interpreted as a lack of quality, Chinese manufacturers may supply also higher quality if asked for, it is a matter of cost.

Battery development and battery swapping, lessons learned

Battery development

There are numerous manufacturers of electric vehicles, passenger cars and trucks. Battery suppliers are fewer and more dominating. World leading CATL is said to represent about one fifth of all vehicle batteries presently on the market, heavy trucks and passenger cars, including VW and Tesla. Research is intense and focused towards several areas such as energy density (kWh/kg), capacity (kW), battery management, cost and safety. The bulk of 1st generation batteries are based on Silicon which has a theoretical maximum energy density around 400Wh/kg. Next generation batteries may be NA-based (lower energy density) or Fe-based, significantly higher energy density, around 600Wh/kg. Seemingly battery manufacturers may take a pole position in the electrification, controlling the most strategic component!

Battery swapping

Battery swapping is rather new (about 5 years on the market) but well established on the Chinese markets with thousands of vehicles in operation and several generations and different solutions for swapping stations. Battery swapping has become one crucial complementary technology for recharging heavy trucks. Battery-swapping based trucks have about 50% of the electric heavy truck market in China. Today, it is a proven and robust technology, scalable and flexible with very little footprint compared with cable charging. SPIC who started the development, has 21 000+ vehicles with BS on the market and 500+ swapping stations of different design.

By November 2023, 3,394 battery-swapping stations have been installed in China (source: EVCIPA). Among the 3,394 battery-swapping stations, about 400 are for heavy trucks. The acceleration is rapid, and almost all heavy truck OEMs offer vehicles with battery-swapping solutions.

The first and most popular solution for battery swapping is a battery mounted on the frame behind the cabin. The benefit is a simple technical solution for mounting vehicles and swapping stations. It is also a verified and robust solution for challenging environments, bad roads, etc. The downside is the space occupied by the battery intruding on load (length). The high mounting could be a disadvantage regarding the point of gravity, but no such effects have been reported and could not be confirmed during our discussions. Currently there are several manufacturers of heavy trucks that are developing a solution where batteries are mounted under the frame, as with traditional cable-charged vehicles. For swapping the three manufacturers we visited have chosen different solutions, two swapping from below and one from the side. Currently, the placement of the battery behind the cabin, swapping upwards is the dominant solution.

Applications

There is battery swapping for two-wheelers, passenger cars, boats, and all sorts of heavy machinery. Heavy trucks have a lot of different applications. However, the main applications are in construction (dump trucks, concrete trucks) and mining with short distances and high frequency.

The development of swapping stations has gone through three phases, the last is presently being rolled out:

1. Stand-alone - One swapping station provides several local trucks with service. Trucks operating in the area use the same station. This model can "stand-alone" without a general market penetration. With some 20 trucks using the station, the utilization rate is at break-even
2. Local grid – Several swapping stations in one area where trucks can use one or the other to swap batteries
3. Connecting cities – Swapping stations along highways enabling trucks to go a longer distance between remote destinations

Picture: Swapping station DeepWay trucks, swapping from below

We also witnessed several battery-swapping trucks parked and charging by cable at charging stations, which is always possible.

The Chinese business case versus a Swedish/European perspective

China has set out national goals about CO2 emissions, which sets the direction towards electrification. From there, the development is totally business-driven; transportation companies buy

BS trucks when they get better revenue (also compared to diesel). Swapping station operators' primary earnings come from energy sold.

The grid-capacity problems in Sweden with insufficient power, emerging as a bottleneck in Swedish electrification, seem irrelevant in China! We discussed this with several companies, and no one could relate to limitations in power for charging. Still, “vehicle 2 grid”-function is under development in China, also for battery swapping stations.

Standardization
Standardization in electrification is a prioritized subject in China, as in Europe. There is a national Battery swapping organization promoting this. Companies may choose to join a standard or stay outside; there is no mandatory regulations regarding standards. Chinese organizations have a long tradition of dialogue, which seems to enable the process of standardization

Today, there are two standards regarding frame-mounted batteries, one of which is an accepted national standard. The main manufacturer of this is Zhi Li Wu Lian, which company also manufactures an “adapter” for when the battery and vehicle are of different standards

Regarding batteries mounted between axles, there is not yet any one standard accepted, and companies developing this concept have chosen to go with their individual solutions.

Final words

Remarkably, the awareness of battery swapping in Sweden and in Europe still is very low, despite it being the dominating solution in Chinese electrification, being many years ahead of Europe. The main reason for this, we argue, is the reluctance of European manufacturers to discuss and test the concept on the European market. Also, the public funding promoting electrification is biased towards cable charging, further obstructing a test of the BS concept. To our knowledge, there is not one BS station or truck in Europe, making it challenging to evaluate the solution under our market conditions.

Hence, it is not a lack of interest from transportation companies and transportation buyers that holds the process back; on the contrary, transportation companies line up to try a solution as soon as it is available.

The consortium behind the trip (Sweden China Bridge, VTI, and Logistikia) intends to continue work to place battery swapping on the national agenda, spreading knowledge and interest. The main immediate target is to get a battery-swapping system tested on the Swedish market

Suggested continued reading

We have collected some information of battery swapping on Logistikias homepage, https://logistikia.se/battery-swapping/. The page will be updated with further documentation from the trip as well as other news on the topic.

The SCB project is housed by Halmstad University where you can find project information and all reports: https://www.hh.se/forskning/var-forskning/forskning-vid-akademin-for-foretagande-innovation-och-hallbarhet/forskningsprojekt-vid-akademin-for-foretagande-innovation-och-hallbarhet/sweden-china-bridge.html

Several new reports from the project will be published in the beginning of 2024.

VTI together with LiU, Logistikia, Scandinavian Executive Education and Research (SEER), and Intuizio has during 2023 conducted a feasibility study on implementing battery swapping in Sweden. The report will be available as of Q1-24.

Further information

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