Sweden-China Bridge

Collaborative Academic Platform for the
Electrification of Transportation Systems

March 2021

ELECTRIFICATION OF THE TRANSPORTATION SYSTEM IN CHINA

EXPLORING BATTERY-SWAPPING FOR ELECTRIC VEHICLES IN CHINA 1.0

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Funded by: The Swedish Transport Administration (Trafikverket, TRV).

ISBN: 978-91-987011-0-4
Report number: 2010-1
Edition: Only available in pdf for individual printing.

ABOUT THE SWEDEN-CHINA BRIDGE PROJECT

Exploratory approach

This project is exploratory in nature and includes a step-by-step approach to knowledge development in both the Swedish and Chinese contexts. The project spans different areas of knowledge in which we will highlight what technologies and systems are prioritized in China, Sweden and Europe, what drivers and motives exist, which players are involved in the transition to electrified, intelligent and integrated transportation systems, and what the conditions and business models will look like for achieving this conversion to electrified and integrated transportation systems in an intelligent and smart society.

The purposes of the Sweden-China Bridge Project

1. The project aims to establish and develop a platform for academic knowledge sharing and knowledge transfer between Sweden and China for collaboration between universities and research institutes in the two countries. Its purpose is to contribute to increased understanding and information and knowledge sharing on the technical and commercial development of electrified vehicle systems, integrated transportation system solutions, and energy supply infrastructure as a fully integrated system for intelligent and smart cities.

2. From this perspective, the project will explore the development and implementation of relevant technology for the electrification of vehicles, such as fuel cells, bioenergy, battery storage, combinations of energy systems for hybrid vehicles, energy supply for integrated electrified vehicles, integrated electric road technology, associated charging infrastructure, and static and dynamic technology.

3. We also intend to explore the management of renewable energy supply systems, from the production of renewable electricity to its distribution to consumers of electrified transportation systems, which is needed to power electrified vehicles and transportation systems.

Expected value creation

This project is expected to create value for the key stakeholders and players involved in the electrification of transportation systems in the following general ways.

1. To create insights into the current and future status of electrification of transportation systems in Sweden and in China from technical, social, societal and economic perspectives.

2. To learn and mutually develop insights into how new knowledge, technology, system-based solutions, logistics and transportation systems can be developed, commercialized and operated according to a life cycle perspective in both Sweden and China.

3. To create a long-term learning context in which Sweden and China exchange experience for the benefit of both countries and their industries.

4. To develop a deeper understanding of how Sweden and China are managing the large-scale electrification of the road network using different technologies, including electric charging, energy production (fuel cells, hybrid vehicles, battery storage and electric roads): what do the short- and long-term potentials look like? How are they using long-term industry policy instruments to develop technology and implement it in society? How are they outlining business models for the large-scale roll-out of electrified transportation systems?

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ACKNOWLEDGMENT

First of all, we would like to express our appreciation to the Swedish Transport Administration (Trafikverket, TRV) for their financial support of this project. Without funds the research underlying this paper would not be possible. Without the TRV support we would know less of the global development of the electrification of transport.

We are also very happy of the support from our Chinese academic colleagues that supported establishing this project and supported the work of the research team in the Chinese context, for sharing their experiences of the Chinese achievements of electrification and opening up their hearts for laowai from Sweden (in English “foreigners”) and our understanding of what and how this very complex and important societal transformation in electrification is being conducted in China. Together we can learn from each other, with each other and together we can change the world to a better place to live and for our kids to grow-up.

As project leader of this project, I am very happy with the work of the Swedish research team, our Chinese partners and our steering group. Some of us went to China to grasp the context and explore the development in the real life of electrification in China. This project was conducted during the most difficult conditions possible, during the global lock-down due to covid-19, with all the restrictions it created.

We will be always grateful for the support of the Scania Innovation Team in Beijing for their support and their opening of doors for us, sharing of connections to industry in this area, and joint efforts in Shenzhen study.

Finally, we are grateful to all people in academia, institutes and industry that spend their time in reading this paper about electrification of transport in the Chinese context, and particularly the development of battery-swapping in China. As researchers we are interested in knowledge development and the prosperity of humankind and our environment, the good life for all people of the world, and the future for our kids.

As researchers we want to share our knowledge the best we can, for mutual learning and mutual benefits. As researchers we leave politics outside our mission. Outside our work and hope that this knowledge we develop can be seen as assets that we share with all of the others that want to contribute to the development of our world, our life’s and our joint human prosperity.

We hope that other stake holders such as decision makers, industry and other researchers find this paper of interest and continue where we end. Our results is only the beginning of the work of others. Hopefully we contribute to the better understanding of the conditions for the development of our environment and the world.

Thank you all

Magnus Lindgren (TRV)
Jonas Jansson (VTI)
Arne Nåbo (VTI)
Philip Almestrand Linné (VTI)
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OUTLINE OF THE PAPER

This paper consists of three main parts and appendix:

Abstract

This provides the reader with a brief summary of the work and main conclusions.

Part one
Electrification of transportation in China

This part demonstrates and considers the fast development and diffusion of new energy vehicles (NEV) and pure electric vehicles (EV). The purpose is to place the development of EVs in the larger development context as this is a new and fast emerging industry.

Part two
Exploring battery-swapping in China

This part demonstrates the establishment and diffusion of battery-swapping technology by some early companies and demonstrates with numbers the diffusion of swapping system solutions.

Part three
Consideration and analysis of battery-swapping development in China

This part provides the reader with a broader analysis of battery-swapping development and some thoughts on the development of electrification and battery-swapping with particular reference to China.

This part is based on the extensive descriptions and analysis of the information presented in the sections below and the appendix, which contains the historical overview, as well as some recent perspectives of the development.

To understand the development and implementation of battery-swapping, we need to place it in the specific Chinese context and societal approach to work - the interplay between politics, institutions, industry and main stakeholders aimed at developing, establishing and spreading battery-swapping systems.

We call this the symbiotic business model where the politics, institutions and industry together develop the new eco-system. Based on the eco-system actors develop the business models for commercialization of battery-swapping systems. This new business model for battery-swapping is based on the decomposition of the vehicle as a system, the separation of cars, batteries and charging into three separate but integrated business components providing customers with a high level of customized solutions.

Appendix
The history of battery-swapping in China

This part presents a history of battery-swapping in China. It provides a brief historical overview of battery-swapping development from the modern invention to inception in Germany, China, Israel and USA prior to development and scale-up in the Chinese context. This part outlines different approaches taken in China by different players and shows how the new business model is emerging, enabling exploitation and large-scale diffusion of battery-swapping in China.

Finally, this part illustrates the latest attempts to expand battery-swapping in India, Italy, Germany, Sweden and Finland, and Japanese attempts to exploit battery-swapping in global markets.

RESEARCH METHODOLOGY

This research is conducted based on primary data and through the collection of secondary data in English and in Chinese. One senior research team member, Dr. Jasmine Lihua Liu, is of Chinese origin and thus we were able to cover this area from Chinese perspectives, both in respect of a literature search and from the point of view of a deeper understanding of the societal, cultural and contextual environment in the process of electrification of transportation and the development of battery-swapping in China. We followed discussions in different webinars, conferences and discussions among experts to deepen our understanding.

Dr. Liu is an experienced researcher both in the Swedish and Chinese context of transformation towards renewable energy. She received her PhD in Innovation Sciences from Halmstad University in 2019 and thus is well oriented in the Swedish context. In October – December 2020 part of the research team travelled to China where they visited both corporate organizations and academic institutes in Beijing, Shanghai and Shenzhen, and carried out personal interviews with people on the research area of the electrification of transportation systems in China. Also discussed was the status of battery-swapping as a means of providing a reliable electricity supply to battery based vehicles.

During December 2020, in one intensive week, we conducted company visits, discussions and formal interviews with key players in the electrification of Shenzhen city in southern China. This working week was a joint collaborative venture with the Scania China Innovation Team in Beijing.

The information collected during this intensive period in China is due to be elaborated in forthcoming papers on electrification technology development and research into the electrification of Shenzhen as the only city in the world that has succeeded in achieving 100% electric taxis, buses and the majority of intra-city based logistics and working vehicles, as well as also being covered in this paper on battery-swapping in China.

BATTERY-SWAPPING FOR ELECTRIC VEHICLES IN CHINA

ABSTRACT

Thus far, the global electrification of transportation has been conducted mainly by the use of battery-powered vehicles. Over the years, the number of electric vehicles (EV) has grown substantially in number, the batteries have become larger in size providing vehicles with longer ranges, the efficiency of batteries has improved, and the prices have decreased substantially, etc. However, all batteries need to be charged with electricity. Several solutions to battery charging have been introduced, static and dynamic conductive and inductive technologies as well as cable charging. The most common, almost the dominant global solution, is stationary charging using cables, whether normal or fast charging.

There is, however, another battery charging technology, that of battery-swapping, i.e. replacement of the discharged battery in the vehicle with a charged battery from outside the vehicle. This modern battery-swapping technology was used by the German company Mercedes-Benz in the 1970s, the Israeli company Better Place in 2007 and also by US company Tesla in 2013. Tesla originally designed their car in a modular way that embraced battery-swapping but then opted for their own proprietary cable-based charging system and a business model that integrates cars and charging.

During the 2010s, when the country started the substantial development of new energy vehicles, Chinese grid operators and entrepreneurial OEMs tried to put the swapping technology into practice in collaboration with Better Place. However, the early exploitation of battery-swapping failed due to the high cost of battery-swapping systems and batteries, lack of standards, lack of openness and divergent technical and economic interests among key stakeholders and objections from car manufacturers to opening up their vehicle structure. Additionally, one fire accident on a pilot project car raised safety questions that needed to be solved. Lastly, political support was lacking because the Chinese government did not promote battery-swapping technology in the countries' first strategic development plan for a new energy vehicle 2012 to 2020.

From 2012 to 2016, battery-swapping charging stations underwent large-scale development as the major complementary energy solution in China. BAIC, Lifan, NIO and some other Chinese OEM brands together with third-party battery-swap station operators, such as Aulton, insisted on exploring the battery-swapping option and made substantial progress. Market scale reached a certain volume and the technology became more mature. When cable-based charging solutions became insufficient, forming the bottleneck of the rapidly growing EV market, Lifan again proposed battery-swapping as a complementary solution to the national congress in 2016. This time, the attitude of the various players was more positive. In 2020, after a discussion meeting with delegations from major stakeholders related to EV development, Chinese central government included battery-swapping technology in the National New Energy Vehicle Development Strategy 2021 to 2035 and included battery-swapping in the list of the New Infrastructure Construction campaign.

Since 2020, there has been fast growth in battery-swapping infrastructure in Chinese cities and along the main highways. Modularly designed cars with fully integrated automated fast battery-swapping system solutions are available. There are also other emerging application areas for battery-swapping such as buses, trucks, heavy-duty vehicles etc.

The new emerging business model for commercialization of battery-swapping is based on the idea of separating the price of the electric car from its cost liest part, the battery. Batteries can be chosen flexibly based on their size and can either be purchased or rented on a monthly basis to reduce anxiety and uncertainty among customers. Also, the charging of batteries can be cable-based or based on a monthly subscription according to the required amount of energy, resulting in great flexibility for the customer.

Thus, the investment cost for customers is based on their purchasing power, risk taking attitude, level of uncertainty and driving habits. The swapping time is reduced down to 1 minute. This system enables great flexibility because the customer can choose and, if necessary, subsequently change the battery size depending on their needs as well as choosing the charging system and payment methods.

At the end of January 2021, there were 562 battery-swap stations operative in China, providing a service to taxis, online car-hailing vehicles, private passenger vehicles and business operation vehicles. More than 100,000 cars have been sold with batery-swapping systems. Battery-swapping's status as an important complementary solution to EV energy supply has been recognized by various parties. The feasibility of developing battery-swapping for taxis, online car-hailing vehicles, logistic vehicles and other business operation vehicles has been preliminarily verified.

The major challenges faced by players include the large investment required for battery-swapping station construction, operation and maintenance requests, the high financial cost of batteries in the swapping stations, and battery depreciation, difficulty in achieving unified standards, overlap of the division of responsibilities, limited space for station construction and safety issues. Accordingly, solutions are being intensely worked on by various players.

A multi-player, new ecosystem is investing jointly in battery-swap stations and battery asset companies are also starting up. Third-party operator Aulton is initiating the exploration of battery standardization by unifying the interfaces of the battery outer package and the vehicles, leaving the content of the battery to OEMs. Government agencies are also driving a discussion on the standardization issue. Innovative collaborations on space sharing is providing space for battery-swap stations. Active and passive safety technologies are being developed that address the safety issue.

A combination of local provincial governments, the automotive industry, IT-developers, entrepreneurs, state grid system operators, swapping system operators, electricity suppliers, institutes and universities are developing a new ecosystem and placing large-scale systems in operation.

We call this the Chinese approach, the Symbiotic Business Model, the collective exploration and experimenting of industrial, institutional and political players, leading all the way from technology development through to the establishment of local market solutions for the development and commercialization of battery-swapping systems, and the simultaneous construction and reshaping of a new ecosystem.

The placement of battery-swapping on the national strategic list demonstrates the systematic approach to the electrification of transportation that needs to be seen and understood starting from energy production, distribution, charging, and the creation of a balancing component in overall energy sourcing and energy storage. Thus, the new ecosystem comprises the major part of the main players in the energy and electrification system. Battery-swapping must not be seen as just one technology that is only a business target for some players, but rather as strategic solution to the entire energy system transformation and part of the ongoing energy and transportation transformation.

The battery-swapping system when operated on a large-scale has significant strategic importance as decentralized, distributed and localized energy storage helping to balance energy production and distribution in the national grid system. Substantial rapid developmental growth in battery-swapping is expected in China from 2021. It is still not possible to predict the long-term development of this technology approach, but it is only in trying it, that it will be possible to discover the outcome.

Implementation of the battery-swapping system can only be successful when all the main players in the energy-transportation system and along the value chain collaborate in the development and commercialization, implementation and large-scale diffusion.

PART ONE

ELECTRIFICATION OF TRANSPORTATION IN CHINA

We are at the early stage in electrification of transportation and a new energy revolution

The traditional transportation system has been subject to change for several centuries, since the introduction of the first steam-powered car by Verbiest, a member of a Jesuit mission in China, in around 1672.

The starting point for electric vehicles is difficult to establish clearly because there were many different construction attempts in several parts of the world, nevertheless, there was a series of breakthroughs from the battery to the electric motor in the 1800s that led to the first electric vehicle. In 1828, Ányos Jedlik invented a type of small electric car. Rechargeable batteries that provided a viable means for storing electricity on board a vehicle did not come into being until 1859. The first electric vehicle with its own power source was demonstrated in Paris in 1881. New York City had a fleet of more than 60 electric taxis at the end of 1890s.

In 1870 a new liquid-fueled internal combustion engine was developed that used gasoline, the technology still in use today. However, it was probably Ford's Model T mass-produced in the USA that killed off the electric car. Introduced in 1908, the Model T made gasoline-powered cars widely available and affordable.

By 1912, a gasoline car in the USA cost only $650, while an electric car cost $1,750, almost three times more. This was the turning point when vehicle technology switched from electrical to oil-derived energy. At that point in time, nobody could foresee the consequences of gasoline-powered cars on health and the environment, and global warming was a still undiscovered concept.

Oil became all conquering. During several oil crises in the 1970s and 1980s, many car manufacturers tested electric cars as prototypes, but none ever went into mass production. Aside from the awareness of environmental issues and, more recently, the issue of global warming, three modern industrial initiatives in Japan, China and the US are worthy of note in that they contributed to a change in the prevailing situation and later helped to initiate the transformation of the transportation system.

- It was the Toyota Prius, released in Japan in 1997, and worldwide in 2000, that became the world's first mass-produced hybrid electric vehicle, combining a combustion engine with a battery-powered electric drive. Toyota started the new energy vehicle (NEV) revolution, although few really saw it in that way at the time. Toyota foresaw societal challenges, they invented solutions, they developed the markets and they created the innovation of hybrids. At that time, it was a revolutionary approach.

- Chinese also recognized the environmental challenges and wanted solutions. The electrification of China started at the end of 1990s. In 2001 China launched its "863 EV Project". The National Development and Reform Commission followed that initiative with the Auto Industry Development Policy in 2004. China started to move down the path of the electrification of transportation.

- Tesla Motors was established in 2003 and announced in 2006 that they were to develop an electric car before launching production of a luxury car in 2010.

  Two young entrepreneurs saw the future that they wanted to create, Elon Musk lent his support and Tesla took off. It was another revolutionary approach that subsequently pushed the world towards the electrification of vehicles.

Both the Toyota Prius hybrid energy car and the Tesla electric car are now legendary in their creation of what is now the new revolution in the energy and transportation system. At that time, few could see where the vision of those early pioneers would lead. Now there are many more followers.

Today in 2021, a majority of vehicle manufacturers offer hybrid solutions - following the course set by Toyota in 1997. Today, whilst many NEV manufacturers are launching their first hybrids, Toyota is delivering the 5th generation of their own technology, which demonstrates the importance of a visionary approach to problem recognition, invention and creation on innovation, technology and market development and exploitation.

For years Toyota has been identified as the most innovative automaker in the world followed closely by Tesla.

The rest is history. Now we are living through dynamic change, witnessing transformations from fossil fuels to renewable energy, from ICE vehicles to electric vehicles. Hybrids are merely a mitigating solution on the way to new technologies.

The development of NEVs is both fast and slow, depending on the perspective chosen.

Considering large scale manufacturing of NEVs, the transformation is complex, and many different areas need to be changed: renewable energy production and distribution, energy storage in vehicles, large scale and widespread charging of batteries, development of new logistics systems, reeducation of people to handle emerging technologies, etc. Viewed globally, the transformation is huge and dramatic, as all revolutions are.

Thus far, the achievements in electrification and the introduction of electric vehicles can be summarized as follows:

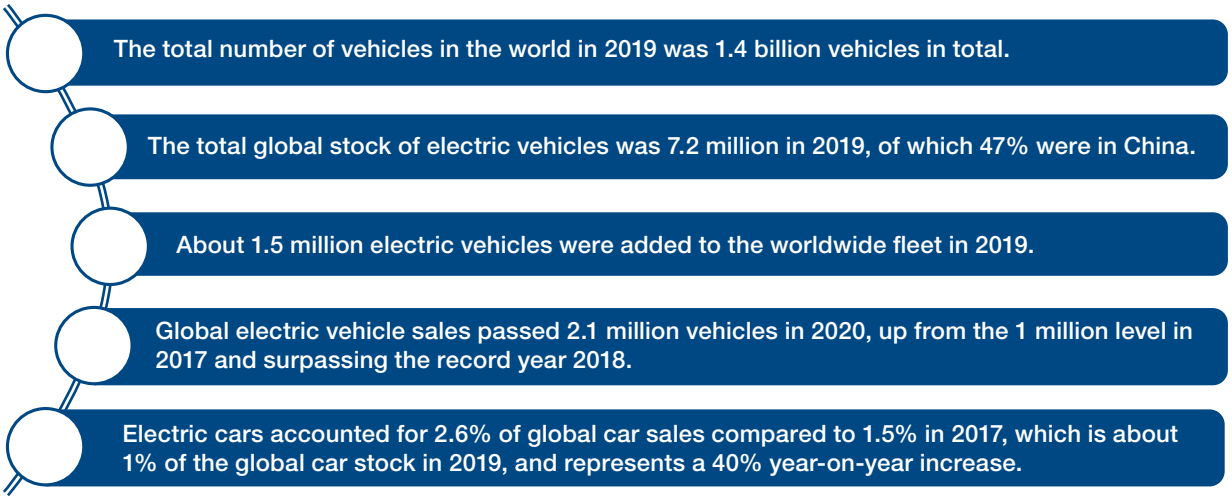


Figure 1: Key numbers of electric vehicle exploitation on the global basis (Global EV Outlook, 2019).

The total transformation to NEVs based on electrification and the use of hydrogen as energy storage is just ahead of us. It will still take many years before the major part of the transportation system is based on 100% renewable energy. It might not happen until the second half of this century.

"In 2025 our target is to have 50% sales of new cars based on pure electric cars. I am ready to discuss the time for when all of our cars shall be pure electrical. Around 2030 might be possible that we only produce pure electric cars."

"Batteries and battery cells are the new vital part of the car value chain - and a country's employment. But despite the fact that Sweden has one of the very few European battery manufacturers, the Northvolt, Volvo buys batteries from Asian battery manufacturers."

Håkan Samuelsson, CEO of the Swedish Volvo in Dagens Nyheter, 25th February 2021

What Håkan Samuelsson is stressing is that the transformation to electric cars takes time and that the battery system is one of the most vital systems in the car.

Batteries need to be charged, the entire value chain is global, and China has taken a strong position in the electrification of transportation and battery manufacturing. This is not a minor development issue.

What we are facing is an enormous transformation of transportation systems from fossil to renewable. This is an energy revolution that we are right at the beginning off. It is not only the vehicles that need to be developed; also the entire supply chain of renewable energy is facing giant transformation. Gasoline and diesel are being replaced and new infrastructure has to be introduced. However, that is not enough. Where will the amount of renewable energy that will be needed to power the global fleet of renewable energy vehicles come from? How will we connect the grid system to the millions of EVs that are going to be produced? How do we ensure the power used by EVs is renewable and green? Vehicles, energy production and supply system have to exist hand in hand. This is challenging and in combination will create an energy revolution, from production to distribution and consumption based on renewable energy systems.

The impact on society will be huge as a result of the transformation of technology towards electrification. Electric vehicles are simpler and contain fewer components while the electric systems themselves are much cheaper than the old mechanical systems such as engine, gearbox, powertrain etc. Many people within the contemporary automotive industry will lose their jobs, while other industrial segments will grow such as IT, electrical engineering and electronics, charging systems and energy production and distribution. The old sales, service and maintenance industries will have to transform to electrical maintenance that will be quite different.

One German government report predicts that about 80,000 jobs might be lost by 2030 in the Swedish automotive industry as a consequence of the electrification of vehicles. However, new jobs will be created in the new segments. Across the world, politicians, decision makers, energy producers, industry leaders and ordinary people are thinking of how this transformation will take place and how it will impact them. Globally, countries are targeting 100% renewable solutions, although the chosen technologies, solutions, technological and business paths to achieving targets, and the way the transformation is being conducted varies from country to country. The context and conditions differ between countries. A major question is whether the jobs lost or gained will occur at the same place in the world or whether jobs will be transferred from one place to another in the world. Who will lose and who will win in this energy revolution is the “million-dollar question”?

In the early days of this transformation, it was almost impossible to imagine and estimate what the situation would look like in 10 or 20 years. The speed of development is fast. The speed of technological evolvements is high. We see different solutions being developed by different countries and industry, and utilized by different customers and operators. We are living through the early stages of the divergence in the development of new solutions, before we will be able to see the convergence to some mainstream solutions. Some estimates indicate that 2025 might be the year when electric cars achieve a similar price level to ICE cars. 2025 may well be the turning point in the establishment of EVs.

Thus far, battery-based technology has become a key solution although it is still impossible to say whether it will become the dominant solution in the future.

Hydrogen is progressing through the laboratory phase and entering the market penetration phase. Nevertheless, the hydrogen fuel cell technology path chosen by Toyota has been criticized by Tesla CEO Elon Musk who stated:

> *“mind-bogglingly stupid” … “fool cells” … “load of rubbish” … “success is simply not possible”.*
>
> Makichuk in Asia Times, 1st March 2021

However, Toyota might repeat their success of 1997 by launching the first mass-produced hydrogen car and hydrogen trucks in 2021. While a major part of the automotive industry is stuck in the hybrid stage, Toyota is moving on to the next generation of vehicle technology, hydrogen-based energy. Toyota is setting-up a new hydrogen energy based experimental city outside Tokyo, The Woven City, in order to develop large-scale hydrogen technology in a city-type infrastructure and create a true-to-life transportation experimental area for hydrogen technology development alongside autonomous vehicle and interconnectivity development.

Alongside Toyota, Hyundai of South Korea is also launching a hydrogen-based vehicle in 2021. We see hydrogen-based solutions being introduced in Japan, South Korea, USA and also in China.

Other technological progress includes development of high-density battery and charging technologies.

Currently, the dominant battery charging solutions are stationary cable-based charging or battery-swapping. Other conductive or inductive technologies will provide competing solutions in the future.

However, we currently have to use the technology that is developed, known, practical and usable, and is economically affordable. In the short term, there are few options.

Our research purpose

The choice of China as the target of our research is because China has become the largest market for the electrification of transportation and because there is little knowledge and understanding of the processes of establishing electrification in China outside China.

The purpose of our research is to explore and understand the electrification of the transportation systems in China. To achieve this target, our intention is to use a number of research activities, targeting different areas such as battery storage technologies, hydrogen energy development, inductive charging and battery-swapping technology. We will be looking at large scale implementation projects to deepen our understanding of Chinese approaches to the ongoing transformation of the transportation system. Our intention is that we will gradually develop new knowledge to share and learn from.

The purpose of this report is to explore the situation vis-à-vis battery-swapping in China to give an understanding of which solutions are being developed and put into practice and to discuss the possible direction of this technology for electrification of the transportation system in general.

Our research is not intended

- To argue which is the best transportation electrification solution from any particular perspective or any point of view.

- To argue which battery charging solution is preferable whether cable based or battery-swapping, conductive or inductive, from any particular perspective or any point of view.

In this report we explore the situation in China vis-à-vis battery-swapping technology, its history, the current level of achievements, direction of the technology and its implications for society.

We have chosen to explore battery-swapping solutions because they are complementary to stationary charging piles, and because their introduction in China has been ongoing since 2010.

We want to understand the motivation, drives and barriers to this development and explore the underlying technical as well as the business aspects of establishing and expanding these new solutions. As researchers, it is our ambition to explore and understand the underling aspects, motives and drivers as well as conditions, challenges and consequences, in this case, the introduction of battery-swapping systems.

Battery-swapping is not new. It was explored in Europe, Israel and the USA before China took the initiative to develop large scale swapping systems. This is explored in the Appendix to provide a historical and context-based understanding of its origin and global status in order to better understand the Chinese situation.

Our focus is initially on new energy vehicles (NEV), more specific the segment of small electric cars. We are aware that there are also buses, trucks, heavy duty vehicles, small sized two- and three wheelers etc. that use battery-swapping technology, however, they are not focused upon in this paper.

Our intention is to subsequently expand this exploration to other related areas such as battery-swapping for buses and heavy-duty trucks, the status of battery technology, inductive charging and hydrogen technology in China, and then also to explore large-scale electrification such as that taking place in Shenzhen city and others.

Electric vehicle sales are taking off

The focus of this paper is on electric vehicles, although new energy vehicles (NEV) also include hybrid technology, hydrogen and bio energy-based solutions.

Figure 2 shows the increase in sales volumes of electric vehicles between 2010 and 2019.

Global electric car stock, 2010-2019

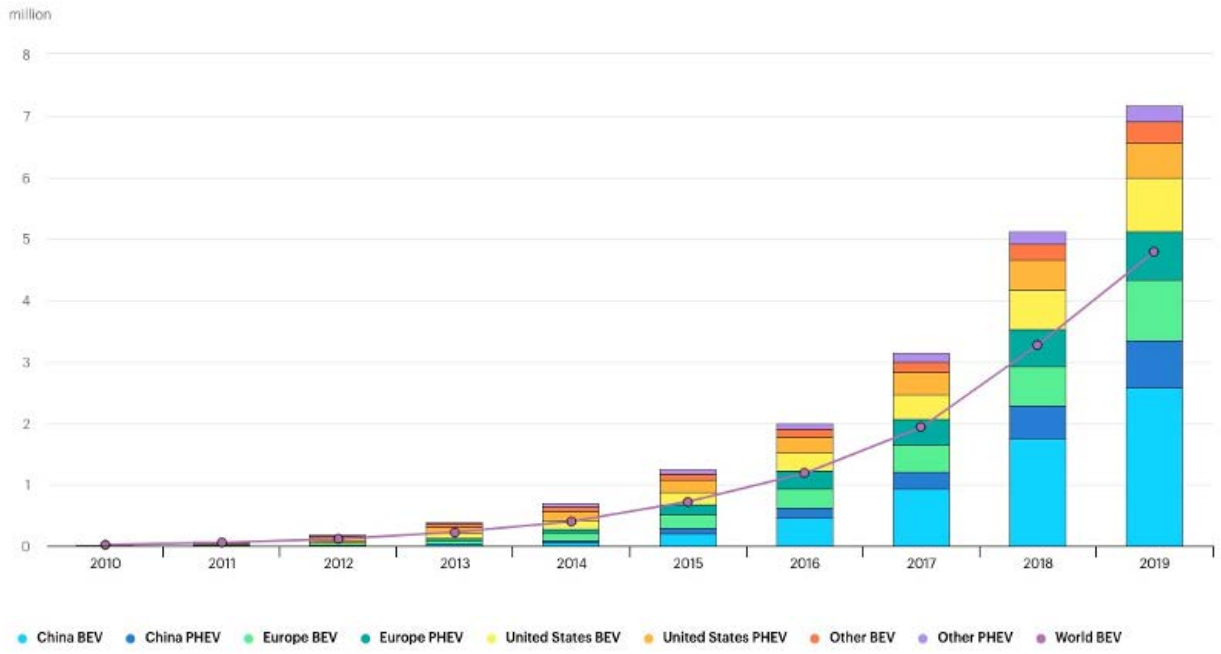


Figure 2: Global sales of electric vehicles 2010-2019 (Source: IEA, 2020).

Figure 2 illustrates the fast diffusion of electric cars from very low levels in 2010 to the 7+ million level in 2019, and rapidly increase in the pace of sales.

Figure 3 shows the estimated expansion from 2018 to 2030, the anticipated development and exponential growth of electric vehicles from 7+ million in 2019 to an estimated 250 million by 2030.

If this is really to happen, we face step changes both in the transformation and in establishing the revolutionary energy changeover to renewable energy that is required if we are to ensure that this growth in EVs is based on renewable energy.

Global electric vehicle stock in the Sustainable Development Scenario, 2019-2030

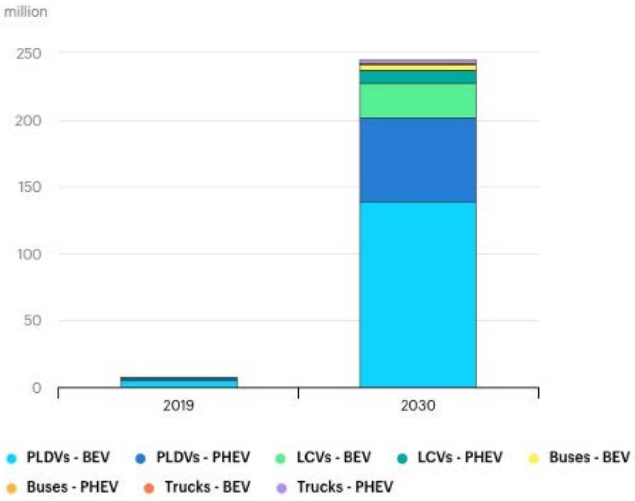
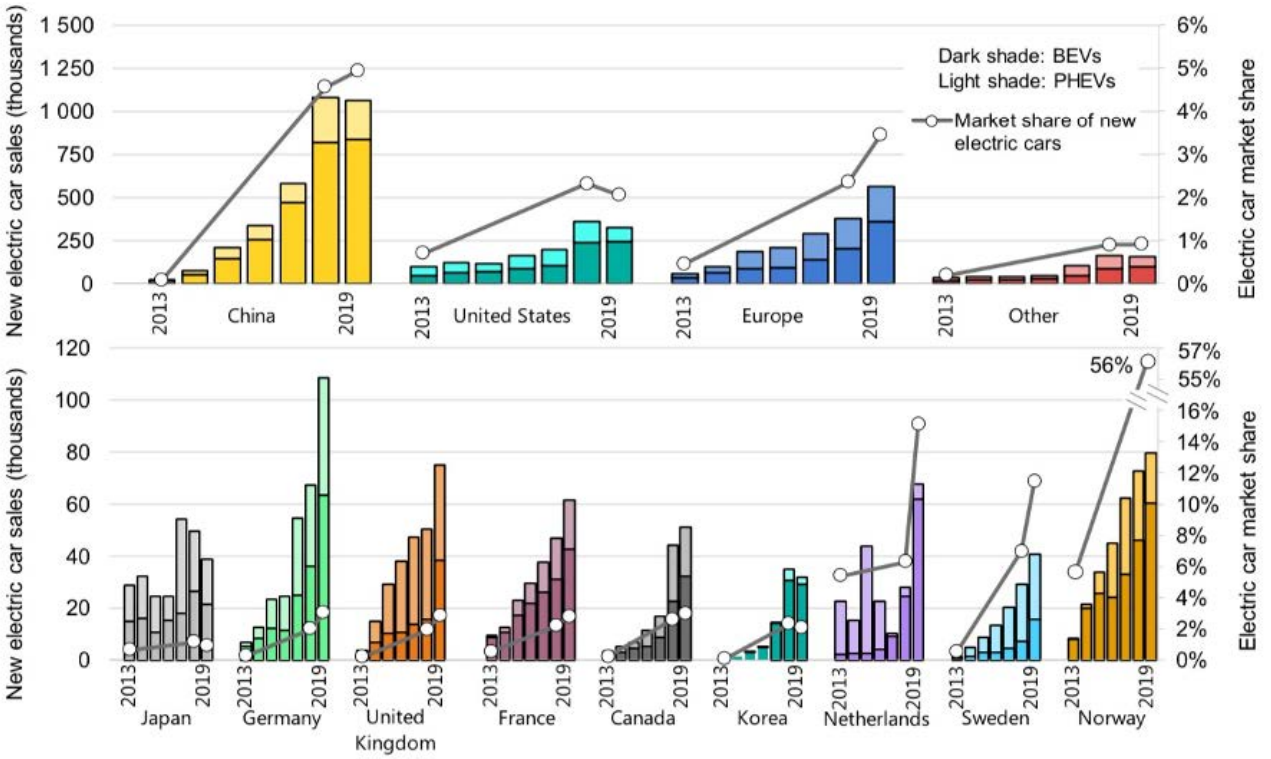


Figure 3: Anticipated growth of electric vehicles from 2019 to 2030. (Source: IEA, 2020).

Otherwise it might end in a zero sum game. What is gained on vehicles is lost on the energy production side.

If this estimate is reasonable it will have severe implications for the charging infrastructure. For this reason, our research will explore if, how and under what conditions battery-swapping will help to support this development.



Note: Regions and countries in this figure represent the largest electric vehicle markets and are ordered by size of their conventional car market.

Sources: IEA analysis based on country submissions, complemented by ACEA (2020); EAFO (2020c); EV-Volumes (2020); Marklines (2020); OICA (2020); CAAM (2020).

Figure 4: Growth of electric vehicles between 2013-2019, in the main countries adopting electric vehicles.

We can see that in Europe, Germany is the biggest market followed by Norway, Netherlands, France, UK and Sweden. (Source: IEA, 2020).

We are now facing a situation in which electric vehicles are achieving rapid market penetration in many countries. It is clear that the supply of electricity to vehicles, the renewable energy supply and distribution and charging capacity for electric vehicles, may soon become key bottlenecks.

China takes the lead in developing electric vehicles

In 2020 there were more than 200 electric NEV brands in China. Not all of those brands have their own manufacturing capabilities. They are using a few large-scale manufacturers to produce their own specific design and technology.

The rapidly developing Chinese NEV market has become a source of innovation as conditions, markets, customers and rapidly growing numbers and transformation to NEVs create a dynamic for change. It is no wonder that manufacturers are now starting to innovate new solutions and in this way create new business opportunities.

In 2020 around 1.37 million new energy vehicles (NEV) were sold in China compared to 360,000 NEVs sold in the USA and about 60,000 NEVs in the UK. In 2021 this number is expected to grow to 1.6 million NEVs.

Figure 5 shows that sales of NEVs are surging in many countries, and that Europe is catching up with China. As the total number of NEVs is growing rapidly across the globe, the charging infrastructure must also grow rapidly. The more NEVs, the more new energy supplies, in particular electricity, and the more charging points are needed.

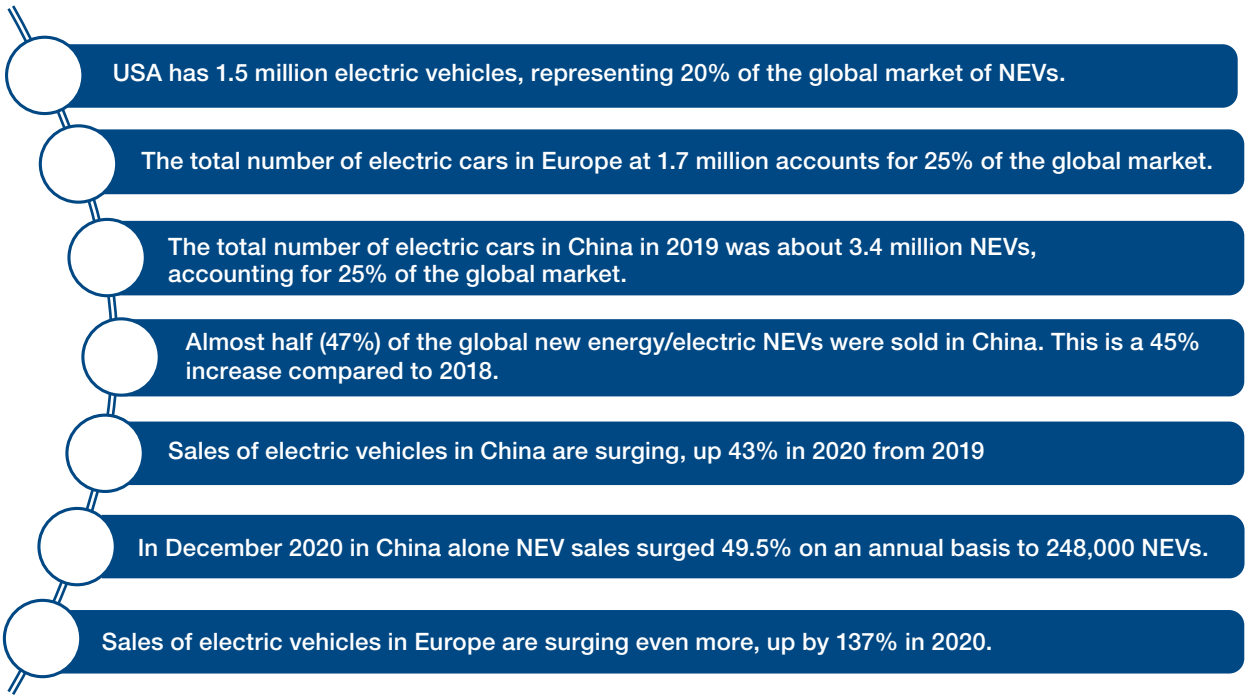


Figure 5: Key numbers in the development of NEVs (IEA, 20202 b).

China starts to export electric vehicles

China has rapidly become one of the largest and most important markets for vehicles in general, and new electric vehicles (NEV) in particular. This is due to the rapid economic growth of China, the size of the population, increased awareness of impacts on the environment and pollution, increased consumer demands and purchasing capabilities and the fast growth of the automotive market.

Another key driver of the technological development towards new energy vehicles (NEV) is the need to reduce the negative environmental impact of pollution.

We have seen witnessed the successful diffusion of Japanese cars in the 1970-1980s and South Korean cars in the 1990-2000s. In 2019, China accounted for nearly 30 percent of global vehicle production while only some 3% of passenger cars produced in China were exported. China has been a large importer of vehicles over a long period.

However, China is gradually moving from being an importer of cars, both fossil-fueled and electric, to becoming an exporter.

The following figure shows the export of passenger cars and commercial vehicles from China between 2010 and 2020.

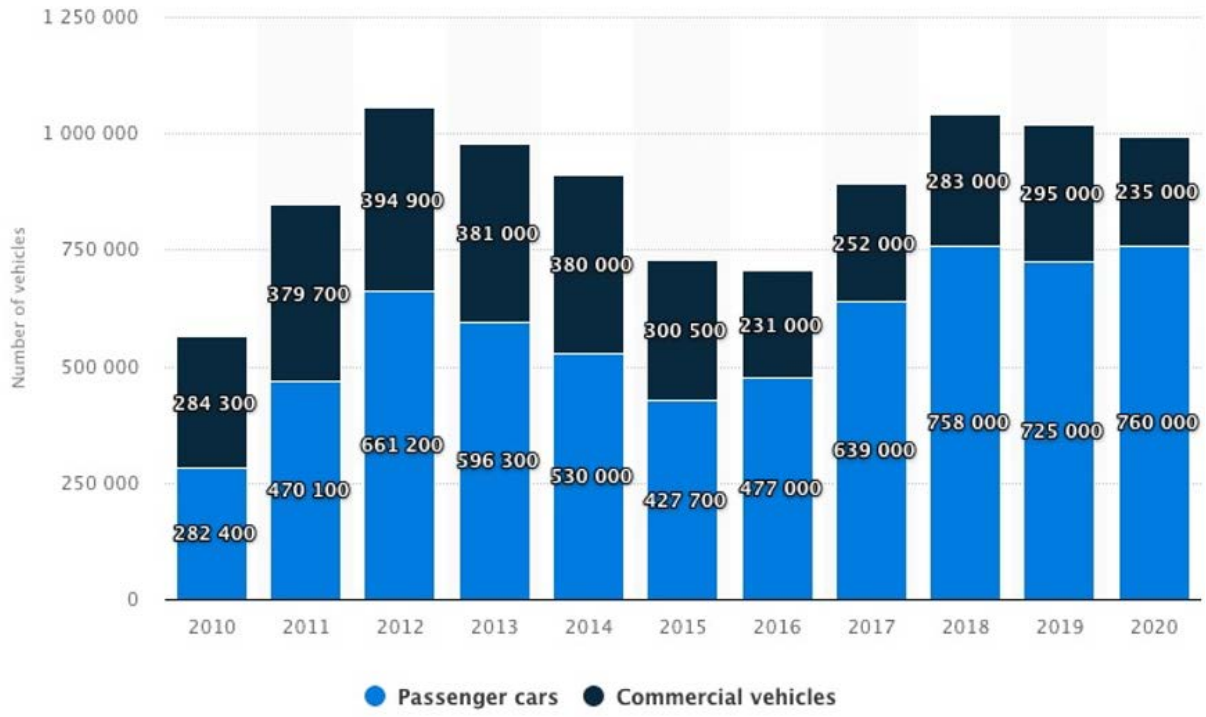


Figure 6: Export of passenger cars and commercial vehicles from China 2010-2020. (Source: Statista, 2020).

In 2010 the total number of exported vehicles was 566,700 increasing to 995,000 in 2020. To a large extend this relates to exports of traditional fossil-fueled cars. The export of electric vehicles is just about to start.

A growing number of carmakers are looking to China for the production of electric vehicles that are to be sold in Europe and other western markets, including Tesla, BMW and Renault (Automotive Logistics, 2020).

According to Automotive Logistics:

- Tesla will start exporting the Shanghai-manufactured Tesla Model 3 in November 2020. The plan is to export 250,000 cars annually.

- BMW is planning to export its first fully electric SUV, the iX3, from China to Europe.
- The Renault-Nissan-Mitsubishi Alliance is also planning to export the Dacia Spring electric SUV from China to Europe.
- Daimler is also planning to export its Smart city car from Hangzhou as part of the joint venture it signed with Geely last year. Polestar, the performance EV joint venture between Volvo and its parent Geely, is already exporting its Polestar 1 and 2 to Europe from China
- Chinese start-up carmaker Xiaopeng Motors (XPeng) has started exports of its G3i electric SUV to Europe, with the first models expected to be on the road in November of this year.

Source: Statista, 2020

The total number of electric buses in the world is expected to undergo a 300% increase from 386,000 in 2017 to about 1.2 million in 2025, with China accounting for a major share of the global electric bus market. In 2020 China had 410,000 electric buses in operations.

Batteries are one of the most critical components of NEVs. Sales of batteries in China to power new energy vehicles (NEVs) rose by 56.9% in 2020 compared to 2019 and battery prices are falling.

Those numbers indicate that China is moving towards being a major manufacturer of electric vehicles as well as beginning to emerge as a new exporter of electric vehicles to many parts of the world on behalf of multiple players.

Top automakers in China in 2020

The following table shows the market share of the main EV automakers in China in 2020. Tesla is the market leader with almost 100,000 sold cars. It should be noted that Tesla has established a factory in Shanghai in collaboration with Shanghai Automobile and the establishment of a Gigafactory for battery manufacturing in China is underway.

In Europe in 2019, Tesla had a market share of 31%. In 2020, the three most popular electric models have been the Renault Zoe with 63,000 units sold, followed by the Tesla Model 3, with 57,000 units sold, and the Volkswagen e-Golf, with 27,000 units sold. In January of 2021 Tesla delivered 1,619 vehicles which is 3.5% of the monthly sales of electric vehicles and compares to 1,977 in January 2019.

On an annual basis this indicates a large loss in market share for Tesla from a 31% to a 13% total market share of the European electric vehicle market. Cheaper competitors are changing the competitive situation. Currently, it is impossible to say how the future situation will look in Europe once Chinese manufacturers of electric vehicles and Toyota´s hybrid vehicles enter the European market.

Until now, the production of conventional vehicles has been carried out by a few large-scale automotive manufacturers with a long history and tradition of mechanical engineering and perfection in manufacturing. Now, with the entry of electric vehicles into the market, traditional manufacturing is being pushed out and a new manufacturing approach is starting to emerge. We are on the verge of an automotive and transport revolution.

This is a period of innovation, and history has shown that at such times, many old players will be outpaced by faster moving new more visionary players who can grasp the new technology, rearrange and recombine and instigate new value creation solutions. This was apparent in the transformation to digital photography, the smartphone industry and now it is occurring in the automotive industry.

By 2020 there were about 200 domestic Chinese car brands in China. Most do not have their own manufacturing capacity. They are technology developers and designers, business developers, marketing and system integrators. They represent the beginning of the new vehicle industry, the beginning of a decade of integrating energy, information and interconnectivity into a new electric vehicle design.

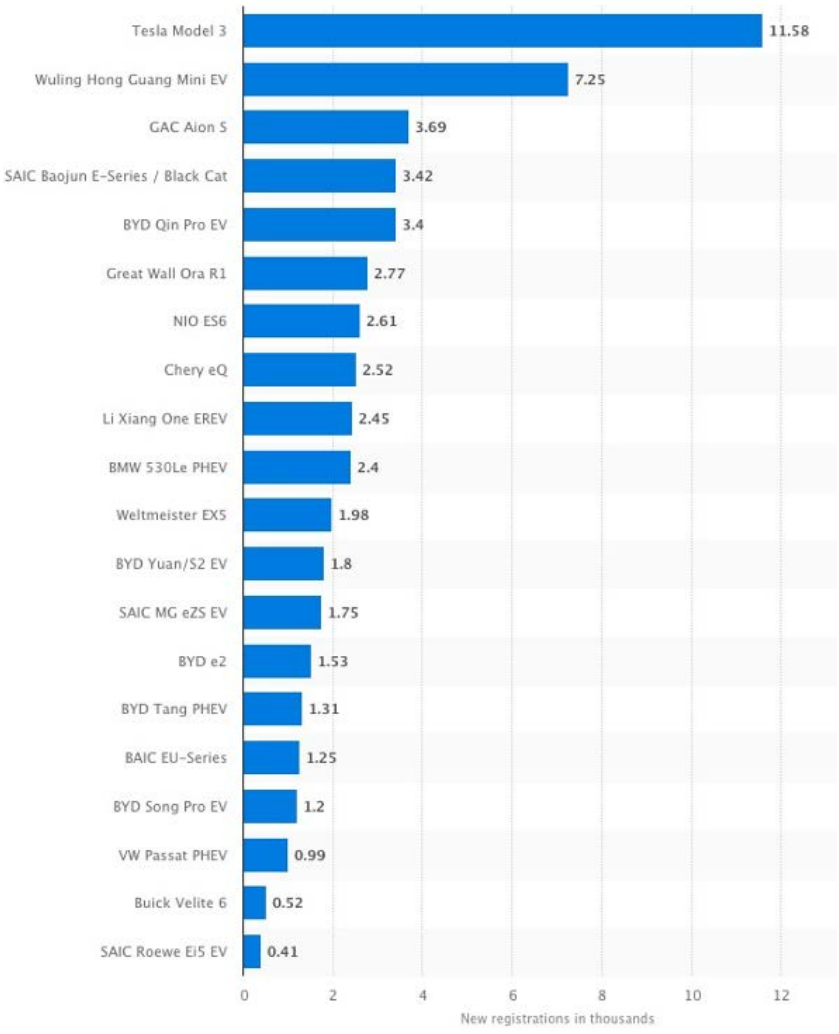


Figure 7: Top ranked suppliers of electric cars in China in 2020 (Statista, 2021).

Tesla has become the premium brand of the rapidly growing Chinese middle class. However, the second car is a much cheaper Chinese brand, Wuidling followed by GAC, SAIC, BYD and Great Wall. The overall Chinese market for electric cars is shifting away from targeting the top premium markets in big cities to the lower end of the average middle class and is also targeting new markets in rural China as well as the coming boom in the western part of China.

Of the top 20 brands sold in 2020, 15 were Chinese brands and 5 were western brands.

According to figure 7, Tesla is the excelling top brand with more than 120 thousand sold cars in 2020, followed by major domestic EV brands.

Some indicators show it is possible that Chinese EV sales will reach 1.8 million units in 2021.

What we see in China is that the growing number of brands of electric cars is achieved by separation of car design, development and manufacturing. Not all new Chinese EV brands manufacture their own cars. This issue is elaborated upon at the end of this paper.

This is a new way of creating economies of scale while simultaneously managing a large variety. A wide variety on the customer side and economies of scale on the production side means all brands have an opportunity to be flexible in adopting new technologies, adjusting to match customer demands and to rapidly change deliveries to customers.

China takes the lead in developing the charging infrastructure

After the entire automotive industry switched to fossil-fuels (gasoline and diesel) the first electric cars were largely relegated to museums with some limited exceptions. Later, due to the emissions of energy systems based on fossil fuels, environmental issues (especially relating to CO2 emissions), and the political desire to switchover from oil to renewable energy, the electrification of vehicles began a renaissance. Now, electric cars use batteries for energy storage. Energy distribution to vehicles occurs in three major ways as shown in the picture:

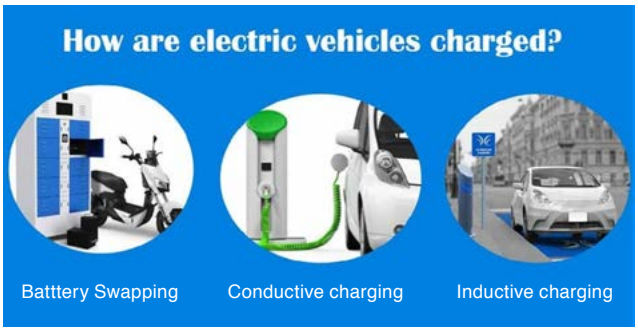


Figure 8: Basic charging solutions: battery-swapping, conductive and inductive charging.

Figure 8 illustrates the three basic principles used in charging electric vehicles: battery-swapping, static charging via cable charging or other conductive charging (via cable or rails in the ground), and dynamic charging via wireless inductive charging (by magnetic energy transfer, or cable in the air or rails while driving). Conductive charging is available with different charging speeds and uses different standards of cables. Inductive charging too is associated with a variation in energy transfer and speed of charging. At this stage, however, inductive charging is yet to progress beyond the experimental phase.

The most widely accepted and globally distributed charging systems are based on a plug-in cable from a charging station to the vehicle. Inductive wireless charging can occur either with the car stationary or via dynamic charging while the car is moving. The third energy supply method is the swapping over of discharged batteries from the vehicle for charged batteries from a supply point.

Vehicle electrification started more than 20 years ago in China. Until now, the dominant solution has been a wide variety of plug-in charging units, with different cabling standards and charging speeds. Lack of standardization is an obvious barrier to the rollout of a single harmonized solution. The wireless charging system is still in the development phase with some of the issues preventing its release into the market including the fact that generic standards do not exist, the speed of electricity transfer is still too low for both practical static use and also for dynamic use, and that the radiation from inductive magnetic technology is perceived to be too high or is associated with uncertainties. Inductive technology is being developed at several sites with the USA, Europe, China, Israel, Japan and South Korea among the dominant players. The third solution, battery-swapping, is an old solution but a growing interest in this system-oriented approach and applied solutions is now apparent.

Charging electric vehicles “filling the batteries” with electricity is crucial operating EVs. A charging system is a system for distribution of electricity to a pile that has one or more charging outlets that provide electricity to the electric vehicle via a cable. The charging piles need to have a certain level of intelligence so that they can charge at the right level, intensity and dynamics in order to adapt to the different capabilities of batteries to receive charge thus protecting the batteries against overheating, catching fire and destruction. Charging technology is critical, and it is important that the charging system, vehicle and battery management system communicate intelligently with each other.

Charging of vehicles can be done via cable at normal speed in the convention manner, or via fast charging which enables a shorter charging time but is associated with a higher risk of battery wear and higher risk in general. To charge a modern car by fast charging can take about one hour compared to slow charging that can take 6-8 hours. Electric vehicle owners can choose to charge their vehicles at home, at the office or other private places or in public places, at public charging stations etc. Thus, vehicle charging vehicles depends on the available technology and charging location.

For home charging, slow charging is the dominant solution while for public charging fast charging at different speeds is the dominant solution. Battery-swapping is primarily available via public charging or special private charging for businesses such as taxi services. All other alternatives such as static or dynamic inductive charging, or solar charging remain possible future solutions.

The China Electric Vehicle Charging Infrastructure Promotion Alliance recorded that by the end of June 2020 there were more than 1.68 million charging piles in operation, with 807,000 public charging piles and 874,000 private ones operating across the country. According to the alliance, China added 462,000 new public charging piles in 2020, with an average annual growth rate of 37.9%.

As a comparison to the growth in charging stations in China, 144,000 charging points were available across the European Union in 2019, over 26% being located in the Netherlands (37,037 in 2019 increasing to 60,000 stations in 2020), with another 19% in Germany (27,459), 17% in France (24,850) and 13% in the United Kingdom (19,076). These four countries combined account for 76% of all ECV charging points in the EU while covering only 27% of the EU’s total surface area. At the other end of the scale is Romania, roughly six times larger than the Netherlands with 125 charging points in 2019 and 70 new charging stations installed in 2020 to give a total of 195 installed charging stations in 2020, or 0.1% of the EU total.

Considering the absolute number of NEVs and the total population in China, both are very large, so that if the charging pile density per NEV or per capita is considered, China is actually lagging behind Europe. Also of note is that the installation of charging stations occurs mainly in the large cities and eastern provinces with the majority of the Chinese population. As mentioned, there are different charging solutions for cable-based charging in respect of charging speed. The technology is developing rapidly and new solutions are being introduced by different technology providers. Also, different terminology is used in different countries to label different charging speeds.

Here we refer to three common charging speeds:

a. The traditional slow/normal charging that can be conducted in private homes using 220 V standard supplies. Normal charging energy is 2-4 kW and the charging time is usually 5-8 hours.

b. With semi-fast charging at 11-22 kW the charging time is usually 1-3 hours.

c. With fast charging at 40-50kW the charging time is usually 20-40 minutes.

There are also some proprietary superfast charging technologies developed solely for certain car brands. In the Global EV Outlook 2020 these three standards are presented as two main groups, one representing slow/normal charging while semi-fast and fast are integrated into the group of fast chargers.

To make an international comparison we use the presented summary derived from The Global EV Outlook 2020.

Figures 9-11: Global distribution of charging piles (Source: The Global EV Outlook 2020).

Figure 9: 598 thousand publicly accesible-slow charges

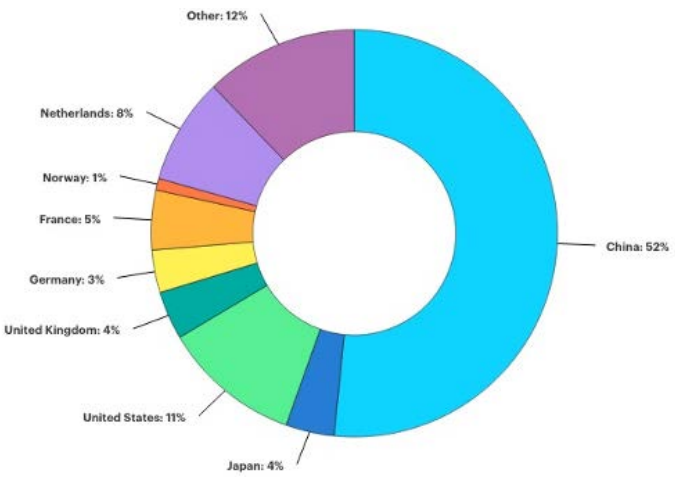


Figure 9: The figure shows the distribution of the slow/normal charging technology suitable for over-night charging, home charging or when there is time available for several hours of charging.

Figure 9 shows the available charging piles for public charging. From Figure 9 we can see that about 52% of the slow/normal charging piles were installed in China in 2019.

Figure 10: 6.5 million private chargers

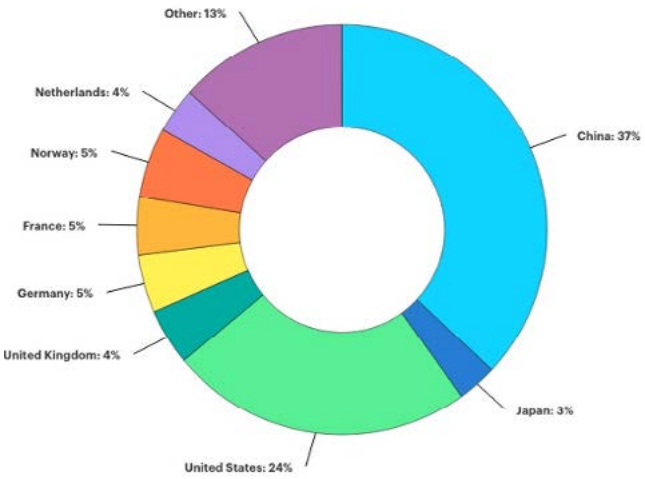


Figure 10: Global distribution of slow charging piles in private charging places.

Here China's domination is lower, 37% of the world's slow/normal charging piles are located in China. The low number can be understood in the light of the density of Chinese cities and the lack of opportunities for people to setup their private charging piles with the distribution of electric vehicles being largely concentrated in large city areas.

Figure 11: 264 thousand publicly accessible fast chargers

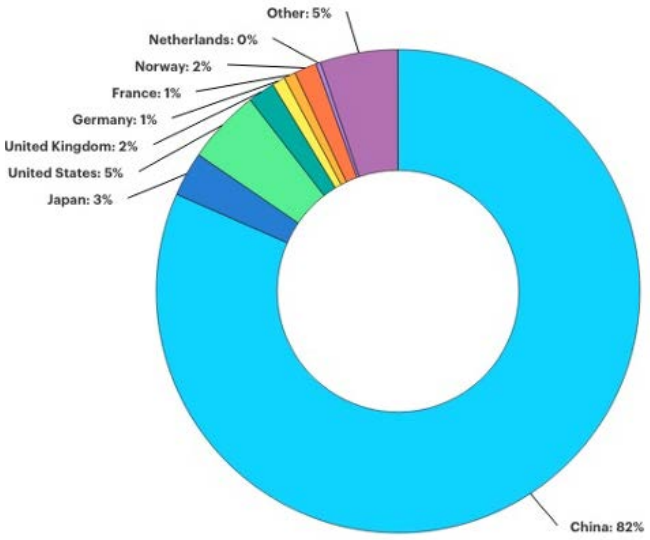


Figure 11: The figure shows the global distribution of semi-fast and fast publicly available charging piles. Here we see that China is in a leading position with 82% of charging piles. Here too, the situation can be understood as above because access to charging infrastructure is limited and thus the solution is constrained towards charging.

Nevertheless, irrespective of the leading position, there are insufficient charging piles to catch up with the rate of growth of electric vehicles.

This is one of the motives in searching for other efficient publicly available solutions, and explains why battery-swapping has gained high attention now that the technology has improved, battery-swapping time is reduced, and total system solutions are in place combined with suitable vehicle solutions; i.e. the ecosystem is ready and the timing is right.

Battery-based NEVs need to be charged with electricity in order to operate whether it be using conductive technology such as cables from stationary charging piles, by swapping over the vehicle's battery or by dynamic charging while driving via conducting overhead wires similar to trams or via conducting rails in the ground. Research and development is also ongoing into turning the entire car into a solar energy recipient and storage entity.

PART TWO

EXPLORING BATTERY-SWAPPING DEVELOPMENT IN CHINA

Battery-swapping progress in China by 2020

By the end of January 2021, different players had installed a total of 562 battery-swapping stations, primarily and largely located in the eastern part of China (Source: China Electric Vehicle Charging Infrastructure Promotion Alliance).

Below is a summary of the results in establishing battery-swapping in China up until the end of 2020. As battery-swapping was only placed on the Chinese strategic technology list in 2020, we believe that the establishment of battery-swapping as a practice will grow, new players will enter the market and diffusion increase.

This listing is based on the main business players' battery-swapping installations, comprising the OEMs BAIC and NIO, and the third party swapping station operators Aulton, as well as the newly announced OEM Geely.

Details of the entry of SKI into the market and its joint venture with BAIC remain unknown, so what this will mean for the swapping industry, battery technology development or the increased diffusion of complete systems also remains unknown.

BAIC

- BAIC started R&D on battery-swapping in collaboration with Better Place as early as 2009.
- As long ago as 2010 BAIC and Better Place established a pilot swapping station in Shenzhen.
- The strategic business focus for BAIC battery-swapping started based on the b2b market targeting taxis in Shenzhen.
- By November 2020, BAIC had developed and established 225 battery-swap stations in 19 cities in China and launched 22,000 battery-swapping vehicles on the market. 6.8 million battery-swapping services have been realized. The total mileage of battery-swapping vehicles has now reached 950 million kilometers.
- BAIC plans to build 100 new battery-swap stations in 2021 to provide a service for 10,000 vehicles.
- Beijing authorities decided to add 6,000 battery-swapping electric vehicles to its taxi fleet in 2019 and another 20,000 in 2020.
- BAIC will replace 50,000 existing taxis with EVs equipped with swapping batteries for the 2022 Winter Olympic Games in Beijing and Zhangjiakou.
- The 4th generation of battery-swapping vehicles and swapping stations entered the market in 2020.

  Now it only takes 30 seconds for a single power change, and the whole process has been further shortened from 3 minutes to 90 seconds. The station occupies 75 square meters and can hold 60 batteries; the designed service capacity is up to 400-500 swaps per day.
- In 2020 all BAIC vehicle models introduced the same battery design and same battery-swapping system.
- BAIC has had a strategic collaboration with the State Grid since 2011. In July 2020, the two parties further strengthened their collaboration.

  For the first time in China, the two parties are to launch a large-scale business model of naked (battery-less) vehicle sales and battery leasing for business vehicles.

  The separation of vehicle and battery, is an attempt to reduce the purchase cost of new energy vehicles to the same level as internal-combustion-engine (ICE) vehicles, and to provide users with a fast service similar to refueling.

  Due to the battery storage/reservation ratio of 1:1.12, charging, battery-swapping and energy storage can be integrated in one station.

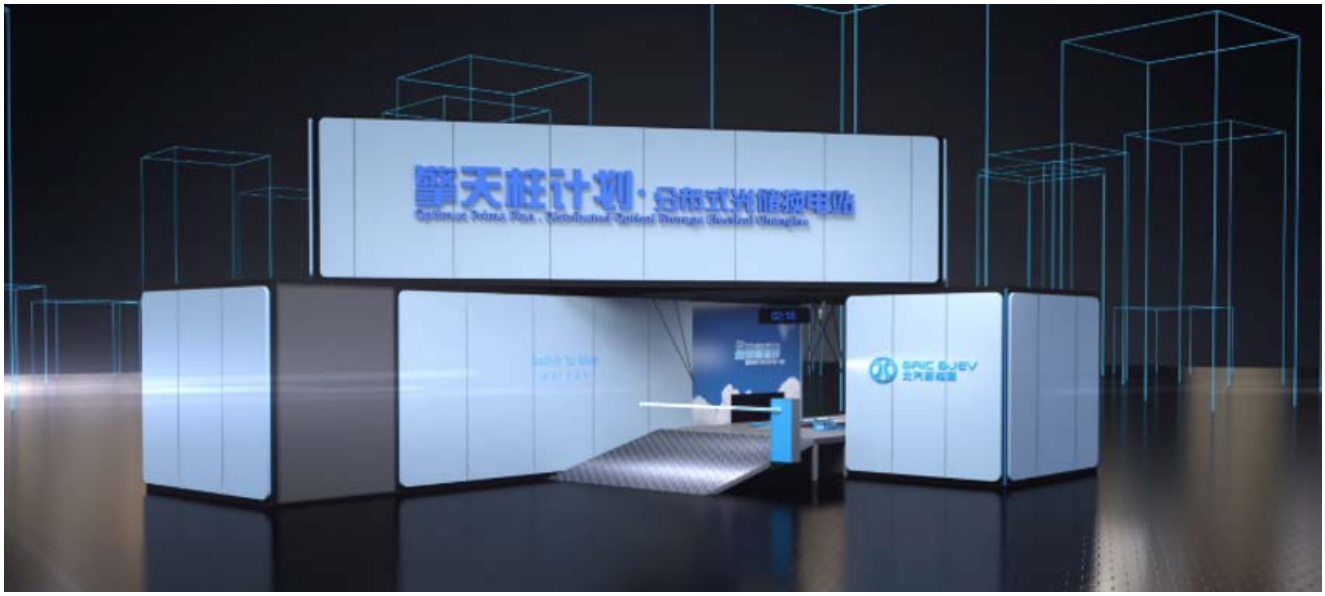


Figure 12: Demonstration video of the battery-swapping process in a 4th generation station.

Source: New infrastructure, new power – the sustainable development of new energy vehicle Salon 2020 hosted by BAIC. BAIC official website.

Link: https://www.bjev.com.cn/html/charge-transfer.html

At the same time, the battery load can be flexibly mobilized to participate in power grid operation by optimizing peak load reduction and valley filling of the power grid, as well as clean energy consumption.

- BAIC/BJEV plan to invest more than 10 billion yuan ($1.4 billion) to build 3,000 battery-swap stations capable of serving 500,000 electric vehicles by the end of 2022.

- BAIC has had a strategic collaboration with Huawei extending over many years. BAIC and Huawei are cooperating in developing the first mass-producible autonomously driving passenger vehicle with lidar as a perception tool.

The new car will be officially launched in November 2021 at the Shanghai auto show.

- On January 21, 2021, BAIC received more than $47 million of financing jointly invested by SKI new energy, CATL and the Langfang Anpeng fund.

- BAIC holds a 30% stake in Aulton, the largest third-party battery-swapping service provider in China.

- The 4th generation of a BAIC battery-swap station is demonstrated in following picture and video:

SKI & BAIC joint venture

- Although it is more than likely that the new joint venture will probably impact the development and diffusion of battery-swapping solutions, just how remains unknown, although, SKI is indeed one of the leading battery manufacturers in the world.

- SKI, BAIC, and Beijing Electric Control jointly established a battery production factory named BEST in China in 2019. The completed factory is SKI's first global battery cell production base.

NIO

- NIO delivered 20,565 vehicles in 2019 and 43,728 vehicles in 2020.
- NIO is targeting the 100,000 vehicle level in 2021.
- NIO's battery-swapping technology has been available since 2014.
- NIO built its first battery-swap station in May 2018.
- NIO has applied for more than 1,200 patents for its battery exchange station.
- From the start, the strategic business focus for NIO has been the business to consumer (b2c) market targeting private car owners.
- By 2020, NIO had established 178 battery-swap stations across the country in 64 different cities in the eastern part of China. The stations cover two major highways between Beijing-Guangzhou and Beijing-Shanghai.
- Their plan is to reach 500 battery-swap stations by the end of 2021.
- By June 2020, NIO had completed more than 700,000 battery swaps.
- By the end of 2020, NIO had installed 53,000 NIO slow charging piles and 100 supercharge stations.
- NIO is the process of setting up its "NIO's Power Mobile team" which offers an impressive 40-60 kW mobile charging service wherever an electric vehicle might be.
- On August 20, 2020, NIO officially launched its Battery as a Service (BaaS). BaaS is a break-through innovation both in terms of technology and business model, which allows consumers to buy a car without a battery, and provides battery rental together with recharge, replace and upgrade services and options.
- Users who choose BaaS when buying an NIO car do not need to buy a battery pack when they buy the car. BaaS users can choose to rent battery packs with different capacities according to their actual needs and pay a monthly service fee.
- As with battery buyers, BaaS users enjoy NIO's battery-swapping service and flexible battery upgrade service and can benefit from the national new energy vehicle purchase subsidy and purchase tax exemption policy.

Picture and video of NIO battery-swap station

Figure 13: Demonstration video of NIO battery-swapping.

Link: https://www.bilibili.com/video/BV15z411q7qw?p=2

Source: NIO president and vice president speeches at China EV100 forum 2021. NIO official website.

- When consumers use BaaS to buy any NIO model, the vehicle price will be reduced by $10,852 (relative to a vehicle with a 70 kWh battery pack) and by about $20,000 (relative to a vehicle with a 100 kWh battery pack). The idea behind BaaS is that consumers feel that their electric car is a little cheaper than an ICE car irrespective of when they buy or use the car.

- For a 70 kWh battery pack, the monthly rental fee is $152. For a 100 kWh battery pack, the monthly rental fee is $229. With the above renting package, consumers receive six free swaps per month. Beyond six swaps, users have to pay for the swap. The battery-swapping fee equals the quantify of electricity in kWh * (electricity unit price + service fee).

- Taking a 45kWh battery exchange as an example, the battery swap fee in 2020 was 45 kWh* (electricity price of $0.21/kWh + service fee of $0.06/kWh) = $12,14.

- Powered by a 100-kWh battery, the range of NIO models can reach up to 615 km (382 miles).

- The new battery pack boosts energy density to 360 Wh/kg due to a hybrid electrolyte, an inorganic Si/C composite anode, and a nano-coated high-nickel cathode. This battery increase the range of the new ES8 to 850 km, the ES6 to 900 km, the EC6 to 910 km, and the ET7 to 1,000 plus km.

- In 2021 a new 150 kWh battery pack will be introduced enabling NIO cars to run for 1000 km on one charge.

- NIO's second-generation battery-swapping station can accommodate 13 batteries, allowing for up to 312 swap services per day.

- NIO had about 9,000 employees in 2020.

- Together with CATL and two other investors, NIO Battery Asset Co., Ltd., was registered on August 18 2020 with $124 million registered capital. The battery asset company will purchase battery packs while NIO will provide consumers with battery rental and operation services.

- NIO's new NEV is the ES6, all-wheel-drive, available with either a 70 or 100 kWh battery delivering 536 PS (529 HP) and acceleration of 0–100 km/h in 4.6 seconds.

- NIO signed a strategic collaboration agreement with the Norwegian Electric Vehicle Association in October 2018. NIO's "Marco Polo Project" is aimed at entry into the European market, and the first overseas NIO dealership may well launch in Copenhagen.

Geely

- Geely (owner of the Swedish Volvo Cars group) was founded in January 1986.
- In 2020 Geely announced its entry into the battery-swapping business by establishing operations in Chongqing.
- On February 2 2021, Geely completed and put into service its first 10 smart battery-swap stations in the Chongqing Expressway Service area. Each new energy vehicle requires just 60 seconds to complete battery-swapping. Announcement of rental battery prices for these stations is expected around the Chinese New Year. The battery-swap stations will not only provide battery rental for Geely new energy vehicles, but also provide battery-swapping interfaces for other makes of new energy vehicle.
- The new battery-swapping station occupies 126 square meters and has 39 battery charging positions. The station can support nearly 1000 battery swaps per day. It takes 60 seconds to complete a battery swap.
- Geely is planning to build 35 battery-swap stations in Chongqing alone, rapidly expanding by an additional 100 in 2021 and 200 in 2023.
- Geely is developing a new business model based on a membership model including insurance and maintenance, differentiating Geely from the more common purchasing or leasing models.
- Geely owns the new electric vehicle brand Polestar as well as Volvo.

Photograph of Geely battery-swap station

Figure 14: Geely battery-swap station.
Source: Geely official website

Aulton New Energy Automotive Technology

(largest third-party battery-swapping operator in China)

- Aulton began to explore the battery-swapping technology in 2000. In 2005, the world's first experimental charging and swapping station was set up in Lanzhou. In 2008, the world's first electric bus with a battery-swapping mode was used successfully during the Olympic Games. The world's largest battery-swap station was established at the 2010 Shanghai World Expo. In the same year, a battery-swap station was operated commercially for the first time at the Guangzhou Asian Games.
- The 2020 fourth generation Aulton battery-swapping service can change a battery in 20 seconds, the whole process takes only 1 minute. It is currently the world's fastest swapping speed. The service capacity of a single battery-swap station is 500-1000 vehicles.
- The battery-swap station has a modular design and can be built within a day. The station holds 28 batteries (third generation station) and each battery costs about CNY 50,000 (about $7,728). Adding the overheads, such as land rental etc., each station costs about CNY 5 million (about $770,000).
- Aulton has more than 1200 international and domestic patents.
- By the end of 2020, more than 300 battery-swap stations had been set up in China, equal to 50% of the total number of battery-swap stations in China. The total service capacity exceeds 50,000 vehicles spread across 20 cities.
- More than 7.5 million battery-swapping operations have been carried out; the total mileage equivalent of this battery-swapping exceeds one billion km, the maximum mileage travelled by a single vehicle has exceeded 930,000 kilometers.
- Aulton battery-swapping is a sharing platform for vehicle services. Thus far, they have shared their service with 9 vehicle models manufactured by 7 mainstream OEMs. Aulton has developed a standardized interface and electromechanical connectivity model.
- In 2021, Aulton will build 500 battery-swap stations covering more than 50 cities, increasing the battery-swapping capacity to 320,000 commercial vehicles or 3.2 million passenger vehicles.
- By 2025, the company plans to build 5,000 battery-swap stations in 100 cities across China, serving 2 million battery-swapping enabled NEVs.
- One third will target private consumers and two thirds will target commercial customers and operators.
- To promote standardization, Aulton plans to provide standard exterior packaging for batteries.

  "It's like Aulton provides bottles for bottled water. As for the content inside the bottles, it's the OEM's business. "

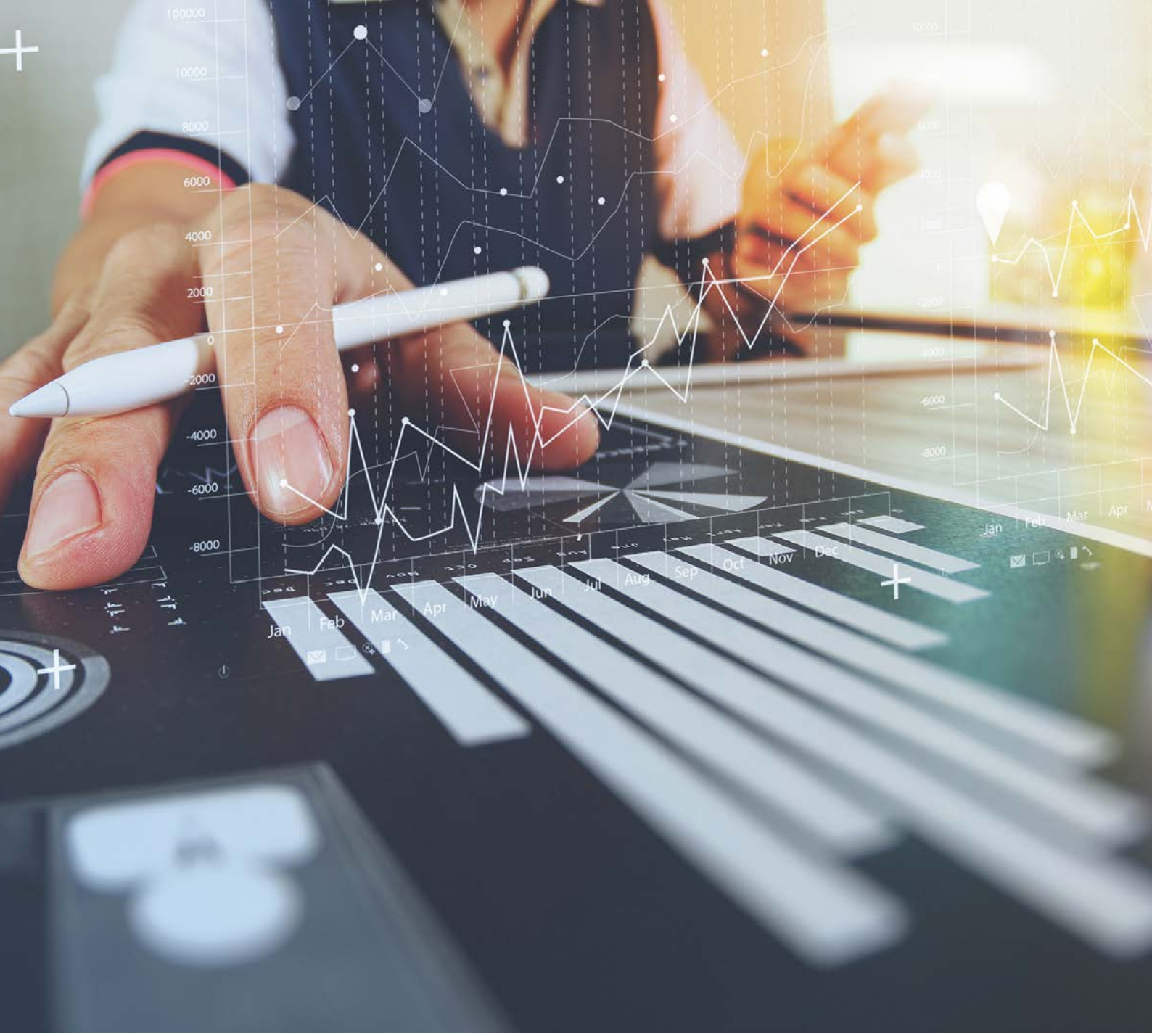
  President of Aulton

- BAIC holds a 30% share in Aulton.
- NIO is also a shareholder in Aulton.

Aulton 4.0 generation battery-swap station is demonstrated in following picture and video

Figure 15: Aulton battery-swapping video available at: https://v.qq.com/x/page/x3205o5nnoz.html

Source: Aulton president and vice president speeches at China EV100 forum 2021. Aulton official website.



PART THREE

ANALYSIS AND REFLECTIONS OF BATTERY-SWAPPING DEVELOPMENT IN CHINA

From cable charging to battery-swapping

The idea of battery-swapping was initiated by Chinese transmission system operators (TSOs) already as early as the 2000s. However, the timing was not right for exploitation, neither was the technology ready nor were industry and business ready. Technology and industry readiness came almost ten years later when the technology had been developed and several local auto manufacturers together with the national grid company supported by political players, TSOs and swapping-station operators set about creating a new large-scale battery-swapping ecosystem.

To begin with, the cost of battery-swapping systems was much higher than the cost of cable-based charging systems. The NEV as a whole was much more expensive, and the additional battery-swapping cost was unacceptable from the industry perspective. This changed a few years later when prices of NEVs went down as sales volumes went up and economies of scales made NEVs cheaper, and the industry started to find new competitive solutions and new business models to attract new customers. Nevertheless, the big picture of what electrification means, was still missing in those early days. Something which is now changing.

The modern idea of battery-swapping was first promoted by an Israeli entrepreneur who founded the business Better Place. Although the original idea appeared brilliant, the idea failed in its exploitation and commercialization phase due to a lack of customers and market focus, lack of integration with new electric vehicle (NEV) manufacturers, lack of standardization of the NEV swapping system, lack of entire value chain collaboration in joint exploitation of the basic idea, lack of political and institutional support and lack of an appropriate business model supporting commercialization of the battery-swapping idea. Battery-swapping is a radical approach to battery-powered electrical vehicles and as such requires radical exploitation solutions.

Tesla initially adopted the idea of battery-swapping when developing its new Tesla electric car. The new Tesla was innovative in many different aspects, far ahead of competitors. Moreover, it was a beautiful car that appealed to customers' feelings and expectations as a premium car. Comparisons with Apple are not inappropriate. Tesla's cars are, like Apple phones, a combination of break-through technology in an advanced state-of-the-art design, a beautiful product appealing to feelings.

Initially, Tesla cars were designed to be modular, enabling battery-swapping solutions, and Tesla also developed practical swapping systems.

Tesla developed fully automated and fully integrated swapping technology solutions but failed to develop an appropriate business model that supported the idea. Tesla's focus was on premium car design for premium customers who could not see the benefits of swapping when there was a lack of established battery-swap station infrastructure to visualize and demonstrate the power of the solution. Customers rejected the idea during the concept phase.

Chinese entrepreneurs were then inspired by the Better Place and Tesla solutions and developed new fully automated and fully integrated battery-swapping solutions that were appropriate for the Chinese context. In the Chinese solution, the core players were NEV manufacturers, third party battery-swapping operators and TSOs who created a value-chain-inclusive collaborative network that was supported by the political, institutional and regulatory players in China in developing and commercializing the basic idea. Beijing was the focus for the establishment of BAIC swapping solutions focusing on city taxis while NIO established swapping stations in cities and along highways.

There were about 1,400,000 taxis in China and about 72,000 taxis in the capital Beijing in 2019.

From exploration to exploitation, from technology to business

However, the global introduction of battery-swapping is subject to a harsh environment both technically but especially from a business point of view. Battery-swapping requires that the NEV is designed for the modular use and battery-swapping in the early concept and design phases. It is almost impossible for swapping technology to be applied retrospectively to an NEV, after its design. The implications are severe for those companies that decide to implement swapping systems. It might take 5-10 years after the decision is taken before the corresponding infrastructure is available in the real world.

However, due to the size and design of buses and heavy trucks, here the implementation of swapping technology is substantially easier during the vehicle design phase. Some trucks and buses already have a substantially modular design and can be adapted to battery-swapping much more easily and quickly than small cars.

Whether the majority of automakers will adopt battery-swapping or not, does not come down to the technology. Technology is the easy thing, and it is already available and established. The technology is already there, available for large scale exploitation for those that see opportunities and want to adopt it. The technology is already proven to be mature enough for global exploitation.

We need to recognize the importance and size of the Chinese domestic market. There is a large variety in the needs and expectations of Chinese consumers. A national experimental approach allows industry to establish different large-scale experimental solutions that can be tried-out and compared competitively with each other. It is also possible that the size of China supports development of parallel solutions in different parts of China as they are not competing with each other simultaneously at the same place and time.

The main players in battery-swapping in China

Battery-swapping development in China needs to be viewed in the light of the specific Chinese context of history, economic development, technological development, transformation to renewable energies and establishment of NEVs at the end of 1990s. Several simultaneously developing processes came together.

The rapid economic development post 1978, and early attempts to develop a domestic automotive industry, demonstrated that the technological advantage held by western countries was complicated, difficult to handle and hard to catch-up with.

Increasing environmental challenges, the energy needed for economic growth and their deep belief in technological opportunities meant Chinese leaders saw an opportunity in transforming the economy towards renewable energy and electrification of the transportation system.

Early in the 2010s, an evaluation of different possible routes for electrification of transportation started. Two routes were quickly identified as possible and complementary to each other, cable-based charging and battery-swapping. Cable-charging was technically less complicated, cheaper, and essentially used old established technologies.

Hence cable-charging quickly came to dominate the market. Nevertheless, battery-swapping was also explored by different players. See the Appendix for a historical overview of battery-swapping development.

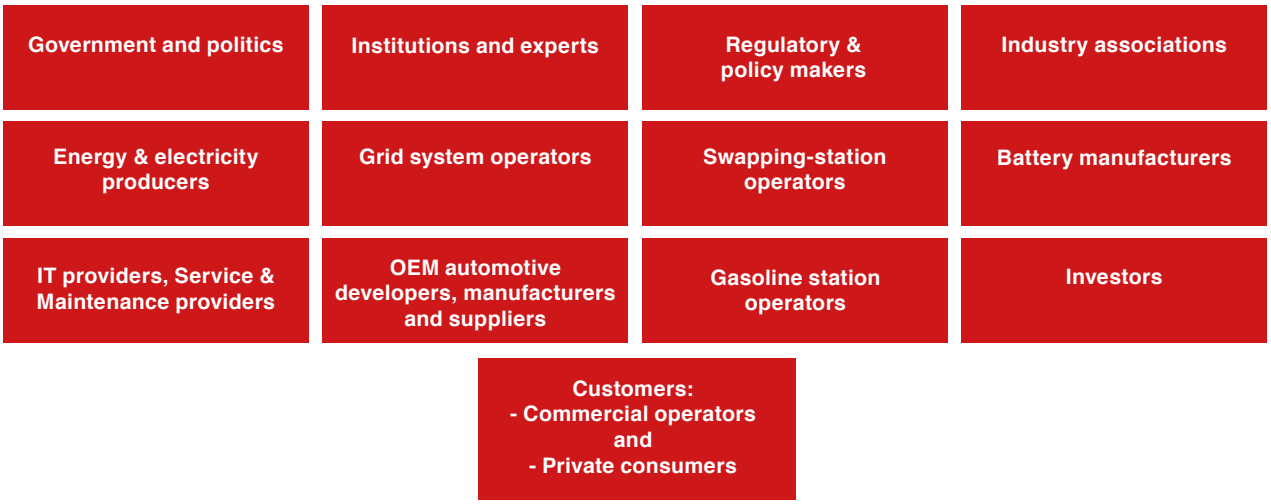


Figure 16: Main players in the transformation to transportation electrification in China (Own construct).

All these players interacted in different ways during the period from the beginning of the 2010s to 2020.

The Chinese transformation to electrification of transportation using battery-swapping technology can be divided into six main phases, with each of the main players acting in different ways. Here we intend to briefly summarize the process to understand why the process looked the way it did until it reached its tipping point in 2020.

Six main development phases

In the following section we will briefly describe and reflect on the process and the interplay between the main players which led to battery-swapping being made a complementary solution to stationary cable-based technology in the national strategy for electrification. This section "Six main development phases" is primarily based on information from China Automotive Research.

In our analysis we have divided the development into six phases that are not clearly separated but rather overlapping. Some players, activities and actions were initiated or started to become important in one phase but only had a significant impact in the next phase.

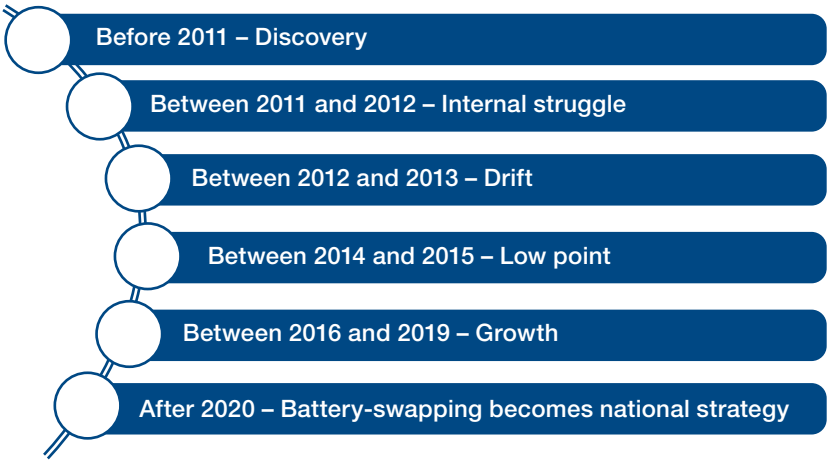


Figure 17: Key phases in the development of battery swapping technology and systems in China.

Source: Forecast report on the development and investment prospects of China's new energy vehicle charging infrastructure market in the 14th five year plan from 2021 to 2025, China Automobile Research.

Before 2011 – Discovery

As evidenced in Appendix 1, battery-swapping was initially investigated in Germany, Israel and the US. In the early phase of electrification of vehicles and charging infrastructure in China, it was difficult to see the future technological path.

Initially the main stakeholders entering the market were those with physical and financial resources and financial investment strength, such as the large state-owned enterprises State Grid, China Southern Power Grid, and China National Offshore Oil Corporation. Their investment choices determined the development direction of the entire early NEV market.

In July 2010, the Ministry of Finance, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, and the Development and Reform Commission jointly developed the ”National Private New Energy Vehicle Pilot Work Conference” in Shenzhen, Guangdong province.

From the political perspective, standardization of the specifications and sizes of batteries used in electric vehicles determined the feasibility and opportunities for replacing batteries. The recommended charging method, and the one that was politically adopted, was slow cable-based changing and a decentralized charging system. At that time, it was not considered appropriate to build centralized fast charging equipment on a large scale, especially not for private cars. The suggestion was to use ”slow charge + battery-swapping” as the energy supply method for pure electric vehicles and high-hybrid vehicles.

However, the State Grid and China Southern Grid proposed a development model based on battery-swapping, which is easier for TSOs to manage.

The State Grid established an operating model of “mainly battery-swapping, complemented by cable-based charging”. The predecessor of the electric bus demonstrated battery-swapping with electric buses in Lanzhou in 2006.

In 2005, the world’s first experimental charging and swapping station for buses was set up in Lanzhou. In 2008, the world’s first electric bus with battery-swapping was used successfully at the Beijing Olympic Games. The world’s largest battery-swap station was established at the 2010 Shanghai World Expo. In the same year a battery-swap station was operated commercially for the first time at Guangzhou Asian Games.

The State Grid established the first battery-swap station in Hangzhou. BAIC New Energy set-up a demonstration station in the city of Guangzhou in collaboration with the Israeli company Better Place and China Southern Grid.

At this point in time the driving force promoting battery-swapping came mainly from the transmission system operators who would be responsible for supplying electricity and ensuring that the decentralized system would be capable of charging the emerging fleet of NEVs.

Between 2011 and 2012 – Internal struggle

However, the vehicle manufacturers were afraid that once the model was fully rolled out, the State Grid would monopolize battery procurement, and they, the manufacturers, would lose business. The vehicle manufacturerxs’ position at that time was very clear, they would never give up their rights to control vehicle design and control their business including battery procurement. The TSOs continued to promote their choice of a battery-swapping solution and announced their strategic development plan in that direction.

This dispute, based on a lack of trust and mutual understanding, was not only between the business players but also between different ministries with different perceptions of where the development was taking China. It led to a delay in the national strategy for new energy vehicle development of almost two years. Further to that, an incident in which one taxi caught fire in Hangzhou in 2011 shed doubts on battery-swapping as a future route for charging NEVs. Also the main players involved had different visions of the future: transmission system operators saw the development from the perspective of electrical power, the political decision makers hesitated about which route to take believing the technology was not mature enough for large-scale operations, the OEMs of NEVs were unwilling to open up their vehicle architecture and separate the car from the battery and thus rejected proposals for battery-swapping that would be outside their full control, and the battery manufacturers wanted to achieve more influence in the development of NEVs.

Between 2012 and 2013 – Drift

Transmission system operators and OEM manufacturers were in dispute with each other about different solutions, market share etc. Various stakeholders were competing with each other over the construction of charging infrastructure and the choice between cable charging mode and battery-swapping mode was always not far from the focus of any disputes.

In 2012, the State Council deliberated and approved the "energy saving and new energy vehicle industry development plan (2012-2020)". The plan did not elaborate on battery-swapping explicitly It focused on the construction of slow charging piles and public fast charging piles. Battery-swapping systems were left to be developed by local actors.

The main reasons for not including battery-swapping in the national plan were:

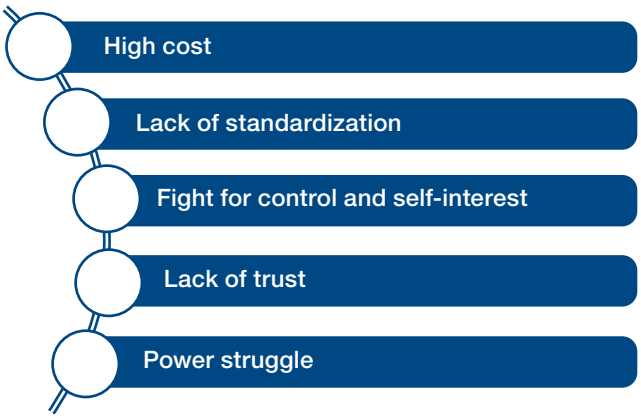


Figure 18: Main reasons for hesitation in adopting a battery-swapping system at an early stage. (Own construct)

High cost

The construction cost and the investment needed to develop battery-swapping stations is too high compared to a charging cable based approach.

Lack of standardization

The electric vehicle technical standards of different companies are different, and the battery standards are also very different; moreover, the automobile manufacturers did not want to adopt one unifying standard solution.

Fight for control and self-interest

The OEMs felt they needed to keep control of their proprietary system design. OEMs followed the traditional way of thinking in wanting to retain full control over their products.

Lack of trust

The OEMs were generally unwilling to share technical standards as technical information was and remains viewed as proprietary and business-sensitive. The OEMs did not trust the transmission system operators.

Power struggle

Transmission system operators had opposing views concerning the establishment of swapping system solutions when compared with those of the OEMs. The TSOs saw themselves as the drivers behind this development. The OEMs did not agree.

Better Place went bankrupt in 2013 and Tesla also gave up on the battery-swapping approach in the same year. Gradually, Chinese transmission system operators refocused on cable-based system solutions to support the needed transformation and aimed at providing electricity to the growing cable-based systems. They almost gave up the struggle for swapping systems.

Some Chinese players continued developing the swapping system on their own, while some third party players initiated minor experiments and some business OEM pioneers such as DongFeng, Zhongtai, Kangdi and Nanjing Automobile continued to launch a series of battery-swapping commercial vehicles for business markets. However, they failed at that time because both the technology and market were still not mature enough.

Between 2014 and 2015 – Low point

The fast establishment of cable-charging as the charging solution although quick was not sufficient to keep up with the development of the entire NEV market and was not sufficient to charge all NEVs.

The lack of charging capacity acted as a bottleneck on the quick introduction of NEVs. Even though the battery-swapping model was going through its low point, several OEMs continued to invest in establishing battery-swap stations, namely, BAIC, NIO and Lifan. Gradually, the main players gained in experience, learning and insight, leading to the conclusion that the focus should be on the commercial market and not the private consumer market.

Between 2016 and 2019 – Growth

Even a large-scale expansion of cable-based systems could not keep up with the growth in NEVs. New solutions were needed. The main players in the battery-swapping ecosystem concluded that the time was right to discuss the swapping system as a joint solution.

Every year a National Congress is held in China that is a very important arena for discussions and decision making in respect of the county's annual working plan. In 2016, Lifan as an OEM delegation put forward the proposal of "Inclusion of the new energy vehicle battery-swapping mode in the national top-level planning", and proposed to solve the "bottleneck" in new energy vehicle battery charging by use of the battery-swapping mode of charging. The Government listened to the suggestion. Lifan was an OEM that explored a battery-swapping solution for buses at an early stage in the development process; they were recently taken over by Geely.

Also, in 2016, an industry association held a seminar on this issue to discuss swapping as a solution to support the transformation of transportation to renewable energy. The industry association decided to support battery-swapping.

With the start of power transformation and the improvement of battery-swapping technology, the battery exchange model finally found its own position in the market after several twists and turns. Lifan Automobile and BAIC New Energy began to establish their business in the field; Shanghai Automobile, Guangzhou Bus and Zhongtai Automobile discussed cooperation with companies operating battery-swapping infrastructure.

Some key players, third party swapping system developers and operators such as Aulton, had been working in this direction for several years gaining in experience, and the swapping technology had matured, so that the OEMs started to seriously discuss the swapping system as a strategy.

- In 2016 Linfang focused on buses as a business market segment.
- In 2017 BAIC focused on taxis as a business market segment.
- In 2018 NIO focused on the consumer market.

On July 31, 2019, the Equipment Industry Department of the Ministry of Industry and Information Technology visited the Zhejiang SKIO Motors company premises to investigate the situation in new energy vehicle battery-swapping technology. Thy organized a symposium to listen to the opinions of industrial enterprises.

The meeting analyzed the development and actual operation of different battery-swapping technologies in detail, swapped experience and know-how in battery-swapping solutions and business model innovation, and discussed the existing system, standards and other problems as well as the future direction of work. Representatives from State Grid, Botann Technology, SKIO, BAIC New Energy, NIO Automobile and other related enterprises took part in the research and discussion event.

After 2020 – Battery-swapping becomes national strategy

In 2020, battery-swapping could not be overlooked. In 2020 the Government put battery-swapping system technology on the national strategic list and thus restarted battery-swapping technology development. Now, battery-swapping technology is on the list of the New Infrastructure Construction campaign and is clearly promoted in the National New Energy Vehicle Development Plan 2021 to 2035.

The Chinese Government is gradually decreasing subsidies to consumer passenger vehicles. However, according to the latest subsidy policy, users buying battery-swapping models of NEVs priced at more than 300,000 CNY can still receive the subsidy.

This new subsidy policy established in 2020 boosted interest in battery-swapping to a higher level. In 2020 new players entered the Chinese battery-swapping market. South Korean investors and battery suppliers have also entered the battery-swapping market in China.

In 2011, the China State Grid company's 12th Five Year Plan for electric vehicle charging service network development, proposed the mode of centralized charging and unified distribution based on battery-swapping, supplemented by plug-in charging.

The plan failed due to a lack of support from the main stakeholders and the dominant usage of large-scale charging solutions. In 2020 the situation is different, the technology is more mature, and the stakeholders can see that cable charging on its own will not be sufficient to satisfy the demand for rapid development of the EV market.

Successful large-scale battery-swapping solutions have been established in Beijing by BAIC focusing on b2b solutions, and newcomer NIO has demonstrated new ecosystems to enable commercialization of battery-swapping systems focusing on private consumers in the b2c sector.

The current strategic position of the battery-swapping solution in China

Battery-swapping is a supportive solution that complements cable-based charging solutions. It should not be viewed as an alternative solution seeking to out-compete cable-based systems.

The development path of the battery-swapping solution in China

Now, more stakeholders are following the direction set by this battery-swapping policy decision. Where development of the direction is concerned, different Chinese experts in the field agree that:

- **The business vehicle market**, or a company's own vehicles, **is the first scenario in which the battery-swapping mode can be used.**

  BAIC and several other participants' actions in this field have demonstrated that the business is feasible. In particular, buses, logistics centers, loading and unloading forklifts, small transport vehicles, luggage vehicles at airports etc.. For commercial passenger cars, such as shared cars and taxis, battery-swapping is a good business model in principle. However, **the best scenario for battery-swapping is probably the electric medium and heavy truck.**

- **Experts and participants are very cautious in respect of the consumer passenger vehicle market.** TELD, China's largest EV charging service provider has decided against entering the battery-swapping field for the time being.

  Experts also perceive that **many challenges exist in battery-swapping for the consumer vehicle market.** Namely:

- **Cost problem.** A battery-swap station is expensive to construct, operate and maintain, and the depreciation costs of equipment and batteries are high.

  According to data from NIO, the cost of a battery-swap station including battery-swapping equipment, batteries, labor, site leasing, etc. is about 5 million yuan (about $772,800), which is much higher than the construction cost of a charging station of about 2 million yuan (about $309,112). Equipment depreciation is calculated over ten years, and the annual depreciation cost of the station is some 500,000 yuan (about $77,280). In addition, batteries are expensive; each one can cost tens of thousands of yuan/dollars. NIO first generation stations keep 5 to 6 batteries in storage.

Second generation station can keep up to 13 batteries. Aulton third generation stations keep 28 batteries. This means a high level of tied-up capital and thus a high total cost of investments. When a new generation of batteries is launched on the market, it will depreciate the value of the old batteries belonging to operators quite substantially.

- For new energy car owners, the battery-swapping model is **more expensive to run.** The lowest cost mode is slow charging, with an average cost of about 50 cents/km ($ 7.8 cents/km), while the average price of fast charging is 1 yuan/km ($ 15.5 cents/km) without including parking fees. At present, the price of battery-swapping mileage works out at about 1-2 yuan ($ 15.5-31 cents/km) in China.

- **Non-unified standards.** Compared to electric commercial vehicles, electric passenger vehicles have many more varieties in respect of brand image and vehicle design. All OEMs are very reluctant to share their core standards, standards relating to batteries and battery management systems.

- **Limited available space for station construction.** Location selection for battery-swap stations is very demanding. Easy physical accessibility, high voltage electricity resource availability, and high environmental safety requirements all have to be considered simultaneously. To be convenient enough for consumers, the density of stations needs to reach a certain level. However, in busy mega cities, spaces that can satisfy the above requirements are limited.

- **Safety problem and difficulty in determining responsibility when a safety incident occurs**. Under the battery-swapping model, batteries will be swapped many times during their life cycle. If the battery is not fixed firmly, it may be shaken loose. If the power line is plugged in and out multiple times and sand or foreign matter gets into the connection, it may conduct electricity and result in a fire. If a safety incident occurs, who is liable/responsible? The car manufacturer, the battery manufacturer, or the battery-swapping service provider? It is not an easy question to answer.

Source: China EV100 forum 2021, keynote speeches; TELD president interview on topic of battery-swapping and charging solutions for EV, EV Observer

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To conclude, some experts are not currently suggesting fast development of the battery-swapping model in the consumer vehicle market. The alternative suggestion is that battery-swapping should “expand from city to city, not expand everywhere simultaneously”. Economies of scale, rate of diffusion, localized positioning and gradual changes in consumer behavior are some of the underling arguments.

What Chinese players did in developing the battery-swapping model was a fast rollout in the b2b segment first such as taxi in cities. In this way they gained experience, developed know-how, further developed technology, reduced prices and increased volumes to make the model more attractive to users and investors.

Business vehicles do not require such a density of stations, do not have such a wide range of battery standards, and the driving behavior of drivers is more easily catered for with simpler swapping solutions in the early days. If a certain scale of battery-swapping business vehicles can support the survival of a given number of battery-swap stations, the total number of battery-swap stations will gradually increase to reach a scale that is sufficient to also support consumer passenger vehicles. We are not there yet.

Advantages of the battery-swapping model

There are reasons for participants to insist on exploiting the battery-swapping model. The following are the specific advantages the battery-swapping model can deliver to key stakeholders.

To EV users:

1. Separation of vehicle and battery, **reduces the cost of EV purchase**, enhances the competitiveness of the EV market and facilitates the maturity of the whole industry.

2. It can **improve the safety and prolong the life of the battery** by correct charging.

3. **Users don't need to worry about the attenuation and residual value of the battery**, and car owners can continue to enjoy the dividends brought about by improvements in battery technology, and they can choose batteries on demand by renting them.

4. It can **redesign the value of second-hand EVs.** If the whole electric car is sold as a second-hand car, the value of the battery is not clear. There is a large battery value both in echelon utilization and in recycling of the battery. However, if the battery assets belong to scattered users, the information transparency is low and the transaction cost is huge, which is not conducive to large-scale recycling and utilization.

5. With **centralized management of batteries,** including echelon utilization of the whole battery and physical disassembly, closed-loop management of the whole industrial chain can be achieved, effectively **reducing the user cost of the whole new energy vehicle.**

To transmission system operators and energy producers:

1. **Easier management**. With the battery-swapping model, batteries are centrally charged; the power of a centralized charging station is large, but the power can be centrally controlled, which is beneficial to the special planning of power grid lines. Individual connection to a grid of mass-distributed cable-charging systems is more complicated than when swapping system providers connect to the grid using systematic standardized solutions; it is also easier to negotiate with fewer players.

2. It can **support the transformation of the whole energy structure** so that it can absorb and store more renewable energy. Centralized orderly charging means forecasting power demand is more accurate, making it easier for the TSO to manage and participate in peak shaving and trough filling.

For instance, when all the cars in Beijing have been replaced by electric cars, their daily storage capacity will be equivalent to the daily power requirement of the city. This means that if EVs charge during the valley time, they will make a significant contribution to peak shaving and valley filling, but if EVs charge during the peak time, it could easily bring about the failure of the whole transmission system.

Through the use of battery-swapping the charging can be anticipated, predicted and adopted to the supply and demand side in a generally better way.

To industry in general:

1. **Battery-swapping is a platform for battery resource sharing.** Separation and unified management of vehicle and battery can realize the maximum value of the whole life cycle of the battery. Private cars and commercial vehicles share the calendar life, improving the efficiency of battery use, allowing the batteries to be recharged, replaced, upgraded, and harshly used over a longer calendar life, effectively reducing the cost of the battery sharing operation.

2. **Life cycle perspective**. Calendar life has an important impact on the attenuation of the battery's performance. As the battery ages, not only does the performance of the battery decline, but also the failure rate of the wiring harness, structural parts and controller in the battery pack increase significantly. As most batteries have to be retired on reaching the battery calendar life of 10 years, when the battery has only used less than 50% of its useful cycle life, this represents a huge waste of social resources. Commercial organizations can fully adjust the battery demand through the distributed battery-swapping network, so that the battery assets are systematically used to maximally exploit their cycle life.

3. **Key nodes of energy flow network.** The battery-swap station provides a platform for battery transfer and scheduling among OEMs, users, maintenance sites and recycling. New models of batteries can be quickly distributed to the battery circulation system, which enables convenient upgrading for users; faulty batteries can be quickly transferred to the maintenance site without affecting the car owners; users can choose battery models according to their needs; retired batteries can be smoothly removed from the circulation system.

Source: New infrastructure, new power – the sustainable development of new energy vehicle Salon 2020 hosted by BAIC; NIO president speech at China EV100 forum 2021; EV infrastructure salon at China EV100 forum 202

Solutions to challenges faced by the battery-swapping model

To address the above mentioned challenges faced by the battery-swapping model, system participants are working towards solutions.

- **To meet the high cost and high investment challenge, more players are joining the sector to share both cost and risk.** Multiple players are establishing consortiums to jointly operate battery-swapping business, or co-own a battery asset company.

  For example,
  - In January 2020, BAIC received investment from SKI, CALT, and investment funds.
  - In July 2020, BAIC signed a strategic cooperation agreement with the State Grid to collaborate on battery-swapping and related business fields.
  - In August 2020, NIO established the NIO Battery Asset Company in conjunction with CALT and other investors.

- With national policy support, investing in the EV industry and battery-swapping sector is currently a very attractive proposition in China.

- The majority of commercial operators such as taxi companies, bus companies and transport companies were public organizations and have taken a socially responsible approach by taking actions to support this transformation. **Both demand side and supply side have collaborated.**

- **To tackle the challenge of standardization, various players are making efforts to provide unified solutions.**
  - OEM brands have unified their own internal standards across different vehicle models. Unfortunately, unifying each brands' internal standards is not enough, however, it is at least a first step.
  - **Third party operator** Aulton has demonstrated an approach to developing technology that makes it easier for OEM-developers and manufacturers to utilize swapping without scarifying their individual designs. Aulton can currently swap across up to seven brands and up to 9 different battery solutions. Aulton is proposing a solution in which the outer packaging of batteries is standardized leaving the content inside the battery to be designed freely by the OEM.
  - Other parties' reactions to this have yet to be revealed. Nevertheless, it shows that swapping technology has room for standardized development.
  - **Government ministries** are developing related standards, and a batch of standards might be ready for release in the middle of 2021. Nevertheless, it is very difficult to standardize battery-swapping solutions because there is also an influence on vehicles, batteries and swapping technology. However, actions in these directions are just starting.

- **To tackle the limited space issue**, in February this year, NIO signed a strategic collaboration agreement with the Red Star Macalline company (RSM), a Chinese furniture department store similar to IKEA, to build 60 battery-swap stations on RSM's sites. More similar collaborations are anticipated. Through innovative space sharing, it should always be possible to find a solution to the space issue.

- **To tackle the safety issue, technical solutions are being worked on to ensure safety.** For instance, active prevention, flexible connection of the battery pack to the vehicle, and data-driven lifetime safety management of the battery are being implemented.

In 2020, NIO sold 43,728 vehicles and their total revenue was 16,258 billion yuan, double that of 2019.

The net loss in 2020 was 5,117 billion yuan, which is 53,3% lower than that in 2019 when the loss exceeded 10 billion yuan. According to NIO's financial report for February 2021, consumers choosing the battery renting model account for 55% of all their buyers.

This shows that the acceptance level of the NIO business model is increasing among private users.

From idea to innovation

The innovation process is not a straight line from identification of a problem or requirement through the discovery of solutions requiring the development of inventions and on to the creation of a successful solution which can be brought to market, creating value and profits. Rather it is a dynamic process of intertwined interest and struggle of many stakeholders, people and ideas, dreams and capabilities.

As we can see from the description above, this process of identifying problems, realizing solutions and coming together for the exploitation of the product was a process that took more than 20 years. Many challenges and problems needed to be solved and many solutions needed to be put in place before the whole ecosystem of battery-swapping was synchronized for large-scale exploitation. Timing is a complex process involving people, activities and events as well as technology and business synchronization.

2020 was the tipping point in China for battery-swapping. However, it must be borne in mind that every country has its own context and conditions for development, as well as variation among key stakeholders with many differing perspectives. What was characteristic of the Chinese development cannot easily be transferred to other countries and different contexts.

The following is a summary of the main drivers and barriers to diffusion of electric vehicle and battery-swapping technology:

There are four major drivers of battery-swapping diffusion:

- **Government decisiveness**, policies and subsidiary policy: governments are trying to achieve their emission goals set in various global agreements and have devised various incentive schemes to promote electric vehicle sales.
- **Tesla effects:** while electric vehicles are a major step in advancing environmental goals, Tesla managed to add the high performance aspect together with aesthetic appeal, thereby playing a pivotal role in changing the industry's overall appeal.
- **Lower battery costs:** the drastic fall in the price of battery packs is also driving mass adoption of these vehicles.
- **Lower operational cost:** following the initially more expensive purchase of NEVs, frequently operating costs can be cheaper than ICE vehicles if charging is conducted at home. However, some private charging stations are extremely expensive, making e-driving more expensive than gasoline-based driving.

Five main challenges hindering the adoption of battery-swapping for electric vehicles:

- **Lack of infrastructure, e.g., charging piles and swapping stations:** not only are charging stations still very few and far between, they are also frequently belong to different suppliers without a standardized charging and payment system which acts as a barrier to acceptance.

- **Limited range of NEVs:** the most common mileage on one battery charge is 200-400 km on one battery charge. This is suitable for city use but inconvenient for inter-city or long-distance driving.

- **High up-front costs:** NEVs are between 30-60% more expensive than similar gasoline-based vehicles. Estimates indicate that by 2025 NEVs and gasoline-based vehicles will cost about the same. After 2025, NEVs will start to become cheaper. In the long run, electric vehicles will probably be much cheaper because of their simpler design and lower system and component costs. High up-front costs make electric vehicles less attractive than traditional ICE cars, mainly due to high battery costs, which often account for as much as 50% of the total vehicle cost.

- **Lack of consumer knowledge and trust:** consumers still do not know enough about the technology behind NEVs, or have concerns regarding electric vehicles' quality, reliability and the availability of charging points. Oil companies and OEMs are lobbying against the fast adoption of electric vehicles.

- **Unstable governmental policy and subsidy systems:** the introduction of NEVs is dependent on stable and predictable government support and predictable subsidy systems to ensure people believe that their new investment makes sense in the long term.

Electrification of vehicles is a challenge to traditional vehicle makers and energy system operators

Traditional car makers have been developing their brands since the start of the automotive industry in the 1800s and the beginning of the 1900s. Old prestigious brands like Mercedes-Benz, BMW, Jaguar etc. are still premium brands, although there are now many other brands that also claim premium status. Few have succeeded in moving from bottom to top of the branding scale quite as well as AUDI. VW tried and failed with its Phaeton model, just like many others. The automotive market and industry are still very conservative and slow-to-change when it comes to branding and technological transformations.

The rapidly emerging electrification of transportation and emergence of NEVs promises to change this global situation both dramatically and quickly. The transformation may be too fast for some of the established brands to handle. When innovation brings about a technological transformation, then many old companies fail to make the transition and cease to exist.

Equally, with the technology shifts driven by electrification and entry of new players into the market with new solutions, it is also not impossible that the logic behind old brand status might change. Moving from electro-mechanical technology to electrical technology could change the business logic fundamentally. While car manufacturers continue to argue for integrated solutions and their own batteries as forming the quality aspect of vehicles, customers might view batteries and electricity as a commodity. In other words, customers might see new opportunities.

In addition, it is also apparent that the rapid growth in the number of electric vehicles with a large volume of batteries is creating new challenges for the transmission system and overall energy production. First and foremost the must be an adequate amount of electricity to meet society's requirements, then there must be enough electricity to meet the requirements of modernization and the rapidly increasing demands of electric vehicles. We need to investigate and consider how to handle the balancing challenges between normal production, variable production and the demand side. Global battery storage needs to be integrated in the energy supply and distribution system and enable balancing of the demand and supply sides.

THE CHINESE DEVELOPMENT APPROACH FOR THE BATTERY-SWAPPING SYSTEM

Conditions for establishing battery-swapping in China

We have identified the following eight aspects of the development of battery-swapping in China and present them in a logical sequential way so that the development path is recognizable, even though there is a substantial forth and back dynamic.

Figure 19: Illustration of the main eight aspects of the Chinese process of adopting battery-swapping technology and systems. (Own construct).

1. Chinese traditional experimental approach

For a long time, China has behaved in an experimental manner. The time period after the civil war and establishment of the People's Republic of China (PRC) in 1949 can be characterized as a period of "trial & error", an experiment in finding the best path to the revitalization of China and overcoming the most important problem, the poverty of hundreds of millions of people.

After the economic reforms initiated in 1978, China was trying to merge western and Chinese ideas in order to achieve what was perceived as most suitable in a Chinese historical, social and societal context. The main goal was to fight poverty, and industrialization and technological development were the best means of doing so. However, the resultant rapid industrialization needed a huge amount of energy and created pollution problems and an energy shortage. This energy shortage was met by exploiting coal as an energy source, although the price included severe environmental problems. The rapid economic development and the establishment of a fossil-fuel-based transportation system only made the pollution problems even worse. Electrification was seen as one possible way of improving conditions for the population and combatting pollution and the CO2 emissions that from the end of the 1990s had started to be viewed as an issue. "Try and learn" was the approach used in the economic transformation after 1978, and the southern province of Guangdong played the leading role.

At the focal point was electrification of the modern upstart city of Shenzhen, now the Silicon Velley of China with 14 million citizens. Here 100% of taxis and 100% of buses and almost all local transport are electrical. The process was initiated in the start of the 2010s and completed by the end of the decade. Battery-powered vehicles were already available then and the technology available for charging was cable-based, which, at that time, was the most mature available solution.

When battery-swapping become possible, a large-scale demonstration was implemented in Beijing and along the long-distance main highways connecting Beijing with Shanghai and Shenzhen. This was another example of trial-and-error experiments. There was no direct competition with solutions established in Shenzhen; rather new complementary solutions were developed.

Fuel cell and inductive charging solutions are also being explored. Two illustrations of the experimental approach to the electrification of transport:

- A new large-scale hydrogen operation is currently being set up in the city of Foshan in the south of China.

- In Jinan in the eastern part of China, solar roads have been set-up, to explore the possibility of solar cells on the roads for the production of electricity and developing static and dynamic inductive charging.

As mentioned earlier, the entire transformation of the transportation system is still in its early stages, technology is developing rapidly, and new solutions are still to be released. Thus, China has chosen to set-up large-scale trials with several promising solutions, to see the outcome, to learn from it and then explore new opportunities "learning by doing".

However, those experimental solutions require that the main stakeholders along each path combine together and cooperate in working out solutions from idea to implementation.

This takes time and effort. Not all ideas are worth the effort involved.

2. Insights showing that existing cable charging needs complementary solutions.

Different stakeholders see different aspects, benefits and challenges where the electrification of transportation is concerned. Early solutions focused on cable-based charging and it took some time for stakeholders to see that this solution would not be enough on its own, that there were different segments of society, customers, operators and users that needed different solutions because of the technological limitations of the cable-based solutions.

Different stakeholders have different but intertwined interests, different targets and ambitions. Gradually they have come to a joint understanding of the limitations of cables and the possibilities of swapping solutions. However, it took some time.

3. Maturing battery-swapping technology

It took some time for battery-swapping technology to mature. The speed of battery development, lack of standardized solutions and the lack of standards for batteries and swapping represented large barriers. Gradually these barriers were overcome, and demonstration projects convinced many stakeholders that the latest swapping solutions were mature enough for large-scale exploitation.

4. New business players seeing opportunities & new solutions

One of the main barriers to diffusion of battery-swapping was that the OEM developers and manufacturers did not want to lose control of their propriety technology nor lose control of the new core technology, i.e., batteries.

BAIC focused on redesigning their vehicles for adopting swapping solutions focusing on commercial markets while one newcomer (NIO) to the industry saw the swapping solution as their differentiation and competitive advantage for targeting private customers with s new strategy.

They were strongly supported by energy producers, transmission system operators and third-party swapping system providers. The new ecosystem started to emerge.

Now the main stakeholders started to see the light at the end of the tunnel.

5. Timing of politics, policy, & joint insights for collaboration

Gradually the industry associations, local politics and policy makers also realized that the early ideas of battery-swapping were possible, although the path looked far from straightforward at the beginning. The early arguments among stakeholders and the divergent approaches started to converge into a basic understanding of possible solutions, although the majority of vehicle OEMs had still to come on board.

Now too, national politics, institutions and regulatory players started to revise their old knowledge and experience.

6. Ecosystem development

When major stakeholders, politics and institutional players came to the joint understanding that battery-swapping was technically, practically and commercially feasible and supported the overall development of the renewable energy-based transformation of transportation, and that the societal benefits were positive, the decision makers were ready to act.

7. Symbiotic business model creation at the national level

The new political decision to put battery-swapping technology on the strategic list of the Chinese government was the ultimate evidence of the success of the demonstration projects, technological development and that the new ecosystem was in place guided by the industrial associations. It also meant that the political players were ready to support the nationwide diffusion of swapping system solutions.

Now new players such as Geely and Koran SKI joined the market, new business relationships were formed, joint ownership agreements between players were made, merging of business interests with new joint ventures was initiated, and new large-scale investments took off at the end of 2020 and the beginning of 2021.

Battery-swapping technology and system solutions was launched as the new complementary solution to cable-based systems.

8. New business model design based on new business logic

However, without an appropriate business model at the company level and inclusion of the main stakeholders it was probable that this situation would not occur.

BAIC and NIO targeted different market segments. Both of them have different swapping technologies but share a common business model that separates the car from the battery and charging according to the customer's interests, needs and expectations, and, most importantly of all, decrease the purchasing price of EVs.

The separation of the car from the battery which then can either be bought or rented and charging based on a single use or subscription model, led to a reduction of the cost of cars and in this way reduced the threshold for entering the electric car market for many people and opened the door to brand commercialization of NEVs.

It is interesting to note that to achieve the exploitation of this new technology-based battery-swapping opportunity and create a new business logic based on the design, the integration of technology, products, services and businesses, via very new solutions, it required new entrants to enter the market, new entrants who thought outside the box.

A major question remains, will the new players survive? Players such as NIO, a technology development company without its own manufacturing capability, or is that in fact NIO's competitive advantage?

Tesla struggled for years before achieving profitability. A big challenge for Tesla was moving away from being a technology developer and being able to scale-up its manufacturing and improve efficiency. Will NIO make it? The first to market is not always the company that is left standing at the end.

Symbiotic relationships for developing battery-swapping

Our analysis of the battery-swapping solutions developed and introduced in China shows that success depends on:

- The branding of the system solution and development of the system in close collaboration with the main stakeholders.

- The symbiotic relationship between decision makers, politics, institutions, supportive regulations, regulatory players and policies, and the collaboration of industry along the value chain, electricity producers, transmission system and electricity distribution players and swapping station operators together with vehicle developers and manufacturers, altogether creating a new ecosystem.

- Very probably the most important factor is the business model of unbundling cost for car, battery and charging, that was used to exploit the battery-swapping concept.

- This requires deep understanding of the context, markets, customers and economy of buyers and operators of NEVs such as taxi companies in order to understand how to develop battery-swapping opportunities.

For the battery-swapping model, the existing value chain of NEVs using stationary charging systems was insufficient.

New companies had to be brought on board, new technology had to be developed to make the entire system usable and competitive vis-à-vis existing cable-based charging systems.

Figure 20: Symbiotic relationships between the main players in the new battery-swapping ecosystem. Dynamics of establishing battery-swapping in China. (Own construct).

Our analysis shows a "swarm approach" of different independent players that come together in the development and exploitation of the new ecosystem and its opportunities. It is crucial that all the industries along the value chain have a collaborative attitude, willingness and capabilities in the process from initial exploration to final exploitation.

This process represents a business and industry cluster initiative initiated by the key stakeholders during the 2010s when the government first decided to promote battery-swapping. However, the initiative had to mature to enable the "swarm" to collaborate, develop and exploit the at-the-time immature swapping technology and early period of the new business models for swapping systems.

The industrial cluster initiative made key-stakeholders aware of directions and opportunities but they lacked successful results showing how swapping could be implemented on a large-scale. However, elements in the industrial cluster initiative gradually continued the process in different combinations and gradually the initiative demonstrated results showing that the entire new ecosystem was obviously in place.

Finally, in 2020, the political decision makers realized that the timing was right for the industrial cluster initiative to receive full political support to implement the swapping system in practice. The swarm approach made this situation possible, through the industrial cluster initiative, collaboration and joint efforts as well as new entrants broadening the boundaries and

paving the way for new solutions. BAIC and NIO as OEMs, and third party swapping system developers such as Aulton demonstrated that it was possible to move to a large-scale implementation.

Aulton's solutions show that standard solutions for swapping are possible, and that in this way it is possible to adapt to the variation between brands and range of customer requirements. Whether the OEMs will follow this route, remains to be seen. Figure 20 show the main stakeholders in the new ecosystem for developing and exploiting battery-swapping systems. This symbiotic relationship among the main stakeholders in the Chinese context is very probably one of the main factors behind the development and exploitation of battery-swapping system solutions and thus the growth of a new industry.

In our research on the Chinese wind power industry between 2012 and 2019, we noticed a similar approach. China started from nothing and, by cooperation between the main domestic stakeholders and international partners developed the first-generation of wind power in China. They went from learning from western solutions, to learning with collaborative partners in developing the technology to indigenous development of new technology and systems. Today China is one of the largest and foremost countries in both wind and solar power.

The example of the wind power industry helps us see and understand how Chinese players have combined to develop and exploit battery-swapping solutions. Similarities include the determination, experimental approaches taken, swarm-oriented ecosystem design and symbiotic business model development.

Developing technology and establishing home markets for battery-swapping

However, it should be borne in mind that one of the most successful development areas in the world, Silicon Valley in California, was developed in a symbiotic relationship between politics, industry and academia in the USA and that the success of Swedish industrial companies such as Ericsson, Asea, Volvo and Saab were also based on symbiotic relationships between Swedish politics, industry and academia. From a historical perspective, this is a reasonable well-trodden approach to technology development and business-based exploitation.

The symbiotic relationship, mutual understanding, and joint efforts between politics and business are clear. The first establishment of a swapping system was in Beijing. The main player was a Beijing based NEV company, BAIC, that together with many value chain industries and players developed large scale system solutions to create a system for use as the official taxi system. The choice of taxis was a purposeful and deliberate choice between business and consumer segments. BAIC chose a business-to-business approach (b2b). With this approach, politics supported the technology development, establishing a complete new ecosystem along the value chain with complementary resources, and supported establishment of the home market for the BAIC-driven solution in the Beijing area. We refer to this approach as the *"Symbiotic business model driven swarm driven approach"*.

In contrast to the normal western, fragmented, piecemeal approach, China seems to operate a more integrated, goal-driven, large-scale experimental approach with different solutions and fast-adoption of new systems in large scale experimental situations.

Later a newcomer in the fast-growing Chinese NEV market took the idea to the next level by developing a new NEV based on the radical idea of fully automated and fully integrated battery-swapping aimed at the private car segment. The new company NIO developed a complementary business model to support their market choice, a new business model allowing customers to choose the car design and battery charging functions. A new business model for NEVs is emerging, the decomposition of the traditional integrated approach comprising vehicles with batteries into a model in which the electromechanical vehicle is separate from the energy storage batteries. Until this point, all manufacturers had viewed vehicles and batteries as an integrated system. NIO changed the logic to a new business logic that decouples the vehicle from battery.

Often, the cost of the battery is about 50% of the cost of the entire car. Also, batteries create a lot of concerns for customers because of their perception of batteries as a new system, the depreciation of batteries, the second-hand value of the car, future investments in a new battery, quality issues, safety, reliability, charging points when driving long distances etc.

The transformation from dominant ICE vehicles to NEVs creates many new challenges for customers.

This disintegrated, unbundling business model, separating the car from the battery and charging, decoupling ownership of the car from ownership of the battery system and the charging function became a game changer. Also, the technology for the operating the swapping system was fully developed and automated. Now the time was right to implement the technology and business solutions, for large-scale battery-swapping systems.

The new option for car owners was to buy the car, buy or rent the battery according to their needs, and do their own charging via cable charging, or subscribe to a charging plan/swapping batteries.

This is the core of the disintegrated NIO business model. The focus of NIO was towards private customers in medium and high level customer groups. They established automated swapping stations in the populous eastern Chinese cities and along two main highways.

In 2021 NIO is going international.

Government policies support battery-swapping solutions

In May 2020, China included battery-swapping technology into its "New Infrastructure" strategy specifically focused on the whole life cycle value of the battery. This is a national strategic development project.

The battery installed in the battery-swap stations will very probably grow substantially in the future and become a strategic source for the global energy storage system (ESS). This solution might include building-up a power distribution infrastructure which also enables grid balancing in regional or local contexts.

In June 2020, the Chinese MIIT (Ministry of Industry and Information Technology) Minister, Mr. Wei Miao argued, during the Annual National Congress, that the government supports battery-swapping.

At the end of 2020, battery-swapping was clearly supported in the New Energy Vehicle Development Plan 2021 to 2035, which is the most important national strategy guiding industrial development.

Battery-swapping solutions become Chinese strategic positioning

Estimates have been made about the growth of battery-swapping in China over the next 5 years. The barriers to this growth are high costs and a lack of standardization.

"In the next 5-10 years, the number of commercial vehicles with potential demand for battery-swapping will reach 4 million.

We believe that by 2025, the number of battery-swapping NEVs will reach 1.24 million, with 12,370 battery-swap stations needed."

Zhang Feng, deputy general manager of Blue Park Smart Energy (Beijing) Technology at 2020 China International Battery Switching Mode Industry Summit Forum, held in late December 2020 in Shanghai.

"In 2021, Blue Park Smart Energy (Beijing) Technology will build no less than an additional 100 battery-swap stations across China to reached 2,500 in total, covering at least 120 cities in China by 2025".

Source: ibid.

Shanghai-based Aulton New Energy Automotive Technology is claiming that by 2025, the company will build 5,000 battery-swap stations in 100 cities in China, serving 2 million swapping-enabled NEVs.

"One-third of them (the 2 million NEVs) will be commercial vehicles, and the rest will be private,"

Huang Chunhua, general manager of marketing at the Shanghai-based Aulton New Energy Automotive Technology.

This indicates that battery-swapping technology and system solutions might very well be reaching a tipping point where battery-swapping solutions might be the bridge to cross the innovation chasm, a means for moving from small-sized segments to large-scale deployment and capture of the mass market.

Battery-swapping is becoming big business

Information indicates that the construction cost of a battery-swap station is around $460,000-$1.53 million depending on the size, swapping volume and location.

Based on assumptions that each station needs to have a store of 20 batteries, and each battery is valued at $10,000 to $15,000, the cost of batteries for each station will be up to $300,000 exclusive of the real estate costs, 4-5-person labor staff and electricity. The cost of labor is pushing the developers of swapping systems towards fully automated solutions.

> *"If complete automation can be achieved, the revenue of each battery-swap station can be increased by at least 12 percentage points"*
>
> Zhang as above

The complexity of the NEVs, with their variation in vehicle design and shape, battery sizes and formats, different connections, different materials and energy density is one of the main challenges to diffusion of battery-swapping systems rather than the investment and operating costs.

Developing and establishing a large-scale infrastructure for nationwide battery-swapping system is very big business.

- BAIC: establishing 3,000 stations by 2022 might cost as much as $2,318 million.
- NIO: establishing 500 stations by 2021 might cost as much as $386 million.
- Geely: establishing 200 stations by 2023 might cost as much as $155 million.
- Aulton New Energy Automotive Technology: establishing 5,000 stations by 2025 might cost as much as $3,850 million.

Those figures indicate that battery-swapping is becoming a significant economic issue in respect of investments in infrastructure alone. This is based on estimates that the market will grow and that the demand for swapping solutions will increase.

The business model of separating the cost of the vehicle from the cost of the battery, and a subscription-model based payment system for charging and swapping might be the factors that make customers choose vehicles enabling battery-swapping and NEV developers redesign their NEVs to embrace swapping solutions.

Chinese regulatory support for battery-swapping

China's first safety standard on EV battery swapping approved by the national standard authority was published in 2020, *"The Safety Requirements of Battery Swap for Electric Vehicles".* This is a national voluntary standard developed by industries and institutions such as BAIC BJEV, NIO and China Automotive Technology & Research Center (CATARC) that has been approved by the National Technical Committee of Auto Standardization (NTCAS).

This new regulation will serve as safety guidance for development of battery-swapping technology and businesses.

This regulation regulates key elements such as the vehicle as a whole, battery-swapping system, swappable battery pack and battery-swapping interface. Its purpose is to minimize potential failure in battery-swapping and a vehicle's running processes, safety systems and the security aspects of the complete vehicle, systems and parts.

Reduction of Chinese subsidies for NEV

China has started to reduce the subsidies for NEVs which were set in 2016.

These actions contributed to a significant drop in NEV sales in China in the 2019. The reduction of subsidies led to a much higher price for customers and the consequences of course were greater for middle-class citizens with lower financial resources.

The future will see further reduced subsidies and in a few years' time they will be removed completely, as people are already noticing. The consequences of this dynamic in the Chinese market are also having a strong influence on the global market because China represents a major part of the global NEV market.

Considering that prices for NEVs are likely to decrease, that the competition in the NEV market is increasing as more players enter the market, that the number of Chinese producers is large and that new solution are being introduced, and also considering that although battery prices are going down substantially the capacity of batteries is going up, and that we are only just at the beginning of a very fast electrification growth cycle etc., the outcome is that the proportion of the battery cost in those new NEVs is probably increasing. Currently the battery proportion of the total NEV price may be as high as 60% + of the NEV price. For all these reasons, the new business models are becoming more interesting from the customers' point of view. If a supplier can separate the cost for purchasing the NEV from the ownership and investment in the battery pack, and adapt the cost to actual use of the car as a whole this will make the average consumer feel safer and more comfortable about buying an NEV that they might otherwise consider to be outside their price range.

For those reasons we can envisage increasing success for BAIC, NEO and possibly also Geely with their new technical solutions for fast battery-swapping integrated into new business models.

Battery-swapping is now a growing industry in China

Although BAIC and NIO were two of the first players in the Chinese battery-swapping industry with complete system solutions including vehicle and swapping station, Geely and the South Korean SKI are now entering the market. The state grid company, Southern Power Grid Electric Vehicle Service, has signed a strategic collaboration agreement with DiDi (Chinese version of Uber), and one of the largest manufacturers of NEVs, BYD, to explore battery swapping and smart vehicle business.

Aulton New Energy Technology, the oldest and largest third-party battery-swapping company in China, sees a solution to fast battery swapping as one of their strategic targets.

"To achieve the capacity of swapping a battery within 20 seconds we have been exploring for 20 years. In 2000, we began to explore the battery-swapping technology. In 2005, the world's first charging and swapping experimental station was set up in Lanzhou. In 2008, the world's first electric bus with the battery-swapping mode successfully served the Olympic Games.

The world's largest battery-swap station was established in 2010 Shanghai World Expo. In the same year, battery-swap station was operated in a commercial mode for the first time at Guangzhou Asian Games. In 2016, the Aulton brand was established and implemented the "100 stations" plan in Beijing. In 2018, the plan of "one thousand stations in one hundred cities" was launched, and the nationwide large-scale business expansion was carried out. In 2019, strategic cooperation was established with a number of domestic mainstream OEMs to jointly research and develop new vehicle models based on battery-swapping.

In 2020, the fourth generation of Aulton battery-swapping service can change the battery in 20 seconds, the whole process is only 1 minute. We operate nearly 300 battery-swap stations in 20 cities in China".

Zhang Jianping, CO chairman of Aulton New Energy Technology Co., Ltd, speech at EV100 conference in 2021.

This indicates the commitment of one of the largest operators in China to expanding their battery-swapping systems.

Aulton is striving to be the system integrator and provider of generic battery-swapping technology solutions to all OEMs that wish to follow this path. They intend to be the global provider and developer of new swapping technology for small NEVs as well as for trucks and buses.

Their newest swapping station can change a battery in 20 seconds, which is currently the fastest in the world (2021).

The arguments for battery-swapping from Aulton's perspective are as follows:

- **Efficient use of land.** The fourth generation battery-swap station can change the battery of 3,000 cars within an area of 150 square meters, which means that each car covers just 0.5-0.05 square meters. By contrast, a private charging pile uses 12 square meters. As the area-equivalent of the car occupied at a battery-swap station is 0.5-0.05 square meters, the occupation of land resources is reduced by at least 20 times.
- **Battery-swapping** is also a platform for **battery resource sharing**. The separation and unified management of vehicle and battery can realize the maximum value of the whole life cycle of the battery.
- **Battery-swapping** is becoming a **commodity**, a **sharing platform** for vehicle services, shared with 9 vehicle models of 7 mainstream OEMs in China. This creates an opportunity for unification of the physical interface and electromechanical connection mode, which could go on to be the standard solution for battery-swapping in the future.
- **Battery-swapping enables continuous quality checking** and ensures that no faulty battery is returned to a NEV that might cause a malfunction and in the worst-case scenario, a fire. Statistics show that about 75% of fire accidents involving models from brands such as Tesla occur when the vehicles are being charged.

Battery-swapping requires large-scale infrastructure solutions

Estimates in China suggest that if all 300 million Chinese passenger cars were converted to pure electric vehicles, and each car has an average 65 kWh battery, then the on-board energy storage capacity would be about 20 billion kWh, which is equivalent to the total electricity consumption in China every day. Thus, the energy storage in vehicle batteries
becomes a balance between production and usage in the transportation system. When they are not being used, they can be placed back in the energy/electricity supply system to supply electricity to other users. The battery-swapping systems could work as a huge energy storage and balancing system for the national energy production and transmission system.

Seen from this perspective, battery-swapping could have a strategic impact on the national energy system.

However, to exploit this opportunity, the entire system has to be much more advanced and with a high level of interconnectivity within the local-provincial-national energy production and distribution system.

Battery-swapping creates a huge strategic energy reserve

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Battery-swapping may help EVs to cross the innovation chasm

There is currently a huge level of overstatement about the electrification of transport. It is easy to believe that the just-started electrification is already transforming the entire world and that it will dramatically change the climate problems we are facing. It is worth remembering that the large effects are still to come.

- The growth of the automotive industry has been fast, from around 342 million vehicles in 1976 to 670 million vehicles in 1996.

- The total number of vehicles was estimated to be about 1.4 billion in 2019.

- The world could have 2.8 billion vehicles by 2036 and 8 billion by 2100 (WardsAuto, 2020).

Cars (or automobiles) make up approximately 74% of the total global annual production of motor vehicles. The remaining 26% is made up by light commercial vehicles and heavy trucks (motor vehicles with at least four wheels, used for the carriage of goods), buses, coaches and minibuses (comprising more than eight seats in addition to the driver's seat).

Therefore, the global number of vehicles is huge, and almost all of them are run on fossil fuels, i.e. products derived from oil.

Although the transformation of transportation systems from ICE vehicles to NEVs and the electrification of transportation was launched by Toyota in Japan and Tesla in the USA, and the entire automotive industry is now rapidly developing NEVs, the entire NEV sector is still very much in a new and immature phase of development, quite apart from the very low actual numbers of vehicles when seen from a global point of view. Although the numbers of NEVs entering the market looks large in absolute numbers and the pace of development is fast, it is only the start of the growth phase.

- The total number of electric vehicles in the world in 2019 was almost 4.8 million. Compare that to the total number of 1.4 billion vehicles in total.

- About 1.5 million new battery electric vehicles were added to the global fleet in 2019.

- In 2019 global electric vehicle sales surpassed the two million mark, almost doubling the sales of 2017.

However, the stock of plug-in electric cars represented almost 1 in every 200 motor vehicles (0.48%) on the world's roads by the end of 2019. Although the numbers are growing rapidly, it will take some time before the number of NEVs surpasses the number of ICE vehicles in the world. Considering the average life-cycle of vehicles, which for private cars is about 15 years, the transformation to NEVs will take some time.

Those numbers show that the proportion of electric vehicles both at the global and EU level is very low, irrespective of the rapid growth, due to the relatively low growth of NEVs in general and because the total number of vehicles in the world is huge. Based on these numbers it is clear that currently the electrification of transportation is being wildly overstated and consequently that the work involved in large-scale transformation is still ahead of us.

It is important to keep this in mind when trying to understand the development of NEV technology, business and markets. The most important point is that everything we know and everything that is in place at the moment related to NEVs is immature and still undergoing rapid development and redevelopment, and that we have yet to see the long-term directions of the development, particularly the technological development.

The total penetration of NEVs is less than 1% of the total volume of vehicles as of 2020. This means that the operators, users, owners and customers of NEV OEMs are pioneers, ideologists, technology freaks, and those dreaming of a better world tomorrow. The long-term impact of the transformation to NEVs is huge, but it will take some time before NEVs become the dominant technology, and which technology will be the dominant solution has yet to be decided, and currently no one can be certain which it will be.

"Volvo Car Corporation urges the EU to coordinate incentives whilst supporting research and development. The European automotive industry risks losing the present technological leadership if this doesn't happen. In the long-term, this jeopardizes our industry's competitiveness and European jobs.

Stefan Jacoby, CEO Volvo, Volvo Press 2012.

The European Commission study of 2010 "A European strategy for clean and energy efficient vehicles", estimated that the market share in the EU would be 3-4% for NEVs as a percentage of the total vehicle market (hybrids and electric vehicles) in 2020 growing to 30% by 2030.

"Both predictions are unrealistic. Considering the lack of coordinated governmental incentives and the high battery system costs, the market share for electrified vehicles will struggle to pass the one percent mark by 2020.

Stefan Jacoby, CEO Volvo, Volvo Press 2012.

Looking at the EU market situation in 2020/2021 some key figures indicate the following:

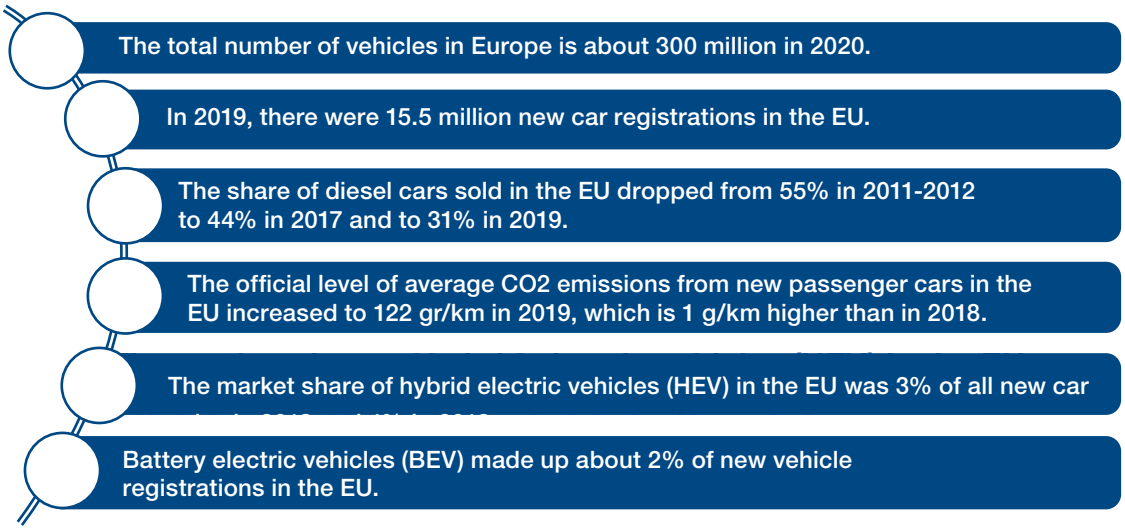


Figure 21: Some basic statistics of NEVs development in EU. (ICCT European vehicle market statistics 2020/21).

According to Statista, customers in Europe purchased between 1.4 and 1.5 million plug-in electric vehicles in 2020 – more than double the number sold in 2019, an increase of about 240 percent year-on-year.

Statistics from ACEA indicate the following outcome in the EU in 2019:

- 3.0% of all new cars being sold in 2019 were electrically chargeable (+2.4 percentage points since 2014).
- 5.9% of all new cars being sold in the EU were hybrid electric last year (+4.5% percentage points over six years).

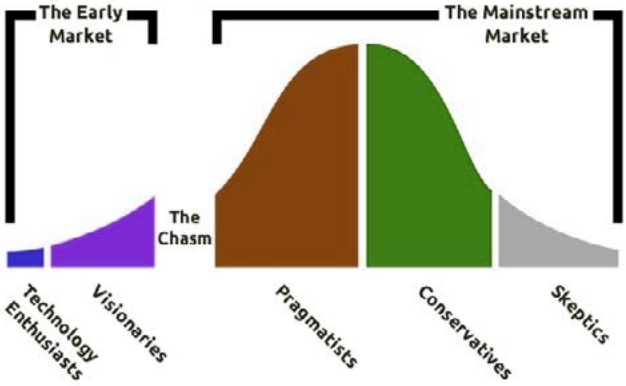


Figure 22: Multi-aspect analysis of battery-swapping system. (LeadBoxer, 2016).

Looking at the development of NEVs from a marketing perspective or innovation perspective the penetration of NEVs is just hitting the early adopter's stage. In the field of innovation studies some academics refer to the chasm that separates early adopters from the mass market.

Innovation is when the chasm is crossed and the novelty reaches the vast majority of the market. Not until the market penetration rate is about 20-30% of the total market can the innovation be sustainable.

With a total penetration of only 3% of new sales of the vehicle market in Europe, we are still in the invention phase, searching for solutions for scaling up the technology, products and finding suitable business models for crossing the chasm. We are not there yet. The innovation is not yet visible.

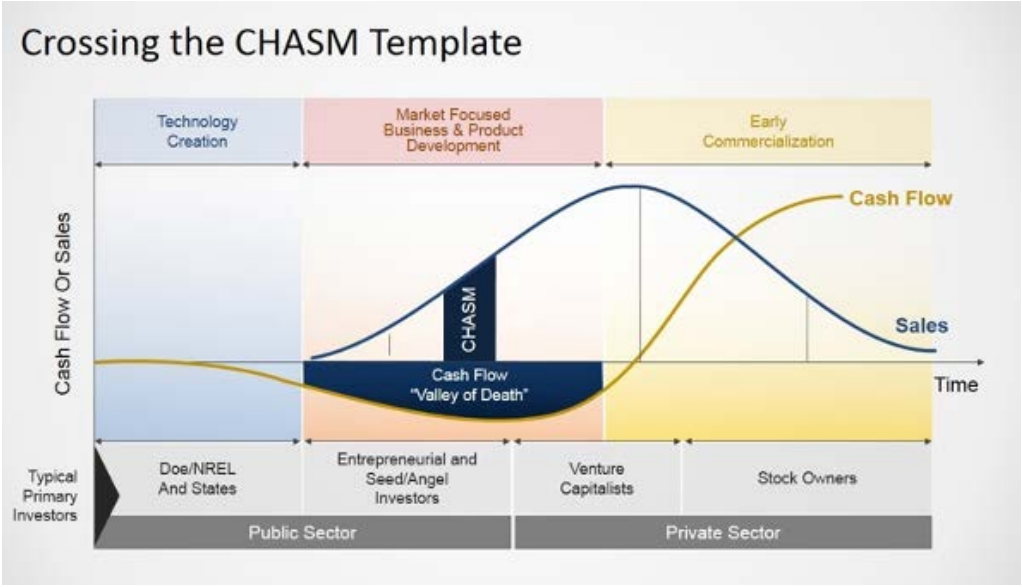


Figure 23: Multi-aspect analysis of battery-swapping system (Slide Model, 2020).

The success of Tesla is only the beginning of the race. It was not until 2020 that Tesla made its first profits and its bottom line was finally in the black.

The Chasm concept was coined by Moore (Moore, 2014). This approach identifies phases of development and penetration of markets from early visionary customers to gradually maturing markets and growing numbers of customers in mass markets. The idea uses a traditional biological approach to describing the process as overlapping S-curves. Technology matures and gradually dies, then it is taken over by new technologies etc. Not until the mass market is reached will there be positive cash-flow for entrepreneurs and companies exploring and exploiting solutions. Until then, somebody has to cover the losses somehow.

In this respect China is a bit different. By the end of 2020, China had about 5.5 million NEVs, equaling a penetration rate of about 1.75%. More than 1.36 million new EVs were added in the whole of 2020, accounting for about 5.4% of total vehicle sales for the year. This means that conventional automotive technology is still dominant and will remain so for many years to come.

The specific customer conditions in China are that:

- 70% of NEV users drive less than 80km per day.

- only 68% of electric vehicles have their own charging pile.

- 21% of users drive short distances and have access to a parking place but mostly without a possibility for setting up a private charging pile.

- About 49% of users make short distance trips but do not have parking spots and need to find external charging piles.

- About 21% of users have a strong need to make long-distance journeys but do not have parking spots and thus don not have a charging opportunity.

- Only about 9% have a strong need for regular charging because they drive long distances and have private parking spots and might have access to private charging piles.

Source: Lei Ye, engineer and author of NIO analysis

These customer analysis conditions need to be understood in the light of the very large population size and density of Chinese cities, which makes it even more difficult for users of NEVs to have access to charging opportunities.

The highway network in China is developing quickly. In 2020 China had about 150,000 km of highway. Considering the density of battery-swapping stations based on a distance between swapping stations of 200 km, it would need about 750 battery-swap stations to cover the entire highway system. However, this is just an indicative number because in reality the proprietary adoption of systems implies a much larger number, one system for each brand.

We also see based on China, the country with the densest concentration of NEVs, that it is important to understand the context and yet, even in China, the penetration level of NEVs is very low.

MULTI-PERSPECTIVE ANALYSIS ON BATTERY-SWAPPING IN CHINA

Technology perspectives

Battery-swapping technology is basically a simple technology that has existed for decades. The idea is not new, but the way it is executed has developed and it is now used in commercial and practical vehicle battery-swapping systems. However, it is the fine details that make the difference between failure and success.

Three fundamental issues are critical:

a. Volumes.

b. Standardization of the technological solutions and processes used for swapping.

c. Safety of the swapping and charging operations.

a. Volumes of swapping stations, swapping operations and vehicles

Major considerations are the volume of vehicles that need to swap their battery, the geographical distribution of these vehicles, the timing during the day of swap operations and the swap volumes that fully automated battery-swap stations need to be profitable. This is a chicken and egg question. The more NEVs and EVs there are, the more swapping stations are needed. Where are the tipping and balance points that ensure there is adequate availability of battery-swapping as the numbers of NEVs increases? If there are not enough swapping opportunities people will not buy NEVs. They also need to be distributed where the NEVs are and meet the requirements. For this reason, battery-swapping has been deployed in big cities and initially focused on commercial customers such as taxis. BAIC and NIO have focused on cities and highways. Few customers swap batteries at night, but taxis are driving 24/7 and they need a continuous electricity supply, sometimes swapping batteries several times every day. Fully automated swapping systems need to be operating near to their maximum capacity for operations to be profitable.

b. Standardization of the technological solutions and processes used in swapping.

Every NEV OEM views the battery system as their propriety technology, even if they buy batteries from independent global suppliers. OEMs also design vehicles based on a fully integrated vehicle and battery system. This has become the dominant business model; OEMs sell the complete system. The fast development of batteries also creates difficulties in integrating with the electronics, hence the system integration is crucial. Ultimately, OEMs have to ensure the overall system quality of all systems irrespective of who is their supplier.

To achieve battery-swapping volumes there is a need for standardization of components, subsystems, interfaces between systems and integration with the electronics. Among these, battery and battery management system are the most important and most difficult to standardize. The decoupling of vehicle, batteries and electronics requires a complete redesign of the vehicle. This is one of the main barriers to swapping technology.

Therefore, a city's taxis can have only one brand and one battery-swapping operator. This of course creates a monopoly situation. Once you chose one vehicle supplier, you buy the entire system for the life cycle of the vehicle and operations.

Both BAIC and NIO have developed product architectures aimed entirely at the separation of battery and vehicle and at the same time have standardized systems across their vehicle ranges. BAIC use only one battery design and one swapping system in all their vehicles, cars and SUVs. Standardization among different OEM brands is needed to create economic feasibility for the technology route, however it has not yet started.

c. Safety in swapping and charging operations

Batteries have developed greatlay in respect of their technology content, energy density, charging capacity, connections between internal cells and to the vehicle and swapping system etc. Nevertheless, the battery remains one of the most challenging sub-systems of NEVs. there is a risk of them catching fire, particularly during charging. The safety issue has emerged as one of the most critical aspects of batteries.

With the battery-swapping model, each swapping operation must be performed correctly and accurately because any mistake could cause a battery incident. When the battery needs to be swapped multiple times during the life of the EV, the connection between the battery and the EV must be reliable.

In the work of BAIC the entire swapping system is designed to handle 8,000 swaps and development requirements are targeting 10,000 swaps.

Also, the swapping station itself has to be safe. Each swapping station contains multiple battery packs which are charged at different currents depending on the status of each battery. Stations cannot be located too close to residential areas because, like gasoline stations, battery stations require safety arrangements and special fire-fighting capabilities.

Business perspectives

In the main, it is relatively easy to resolve technology issues. It is more complicated to master the business-related aspects of battery-swapping.

As mentioned, volumes and standardization are crucial aspects influencing the economic outcome of swapping solutions. The total cost for charging vehicles by battery-swapping will probably always be more expensive than charging by cable.

To achieve large-scale battery-swapping solutions, new ecosystems need to be developed that can complement each other.

Every player has their own interests, motives and, in the main, wants to make a profit. There must be sufficient business for all the participating business players. To achieve this and to develop suitable solutions for all stakeholders, new business models need to be developed, not just business models at the individual company level where each company acts independently from the other companies.

The separation between vehicle OEM manufacturer and battery supplier changes the business logic in the favor of battery suppliers. Based on the old business logic, OEM automotive manufacturers will lose business if they divide their business into vehicles and batteries.

Success of the swapping system solution requires stakeholders to develop a new collaborative business model sharing information, responsibilities, risks, costs, investments and profits in a new approach. There is a risk that the old OEMs will simply continue as before and that it will be newcomers who develop both system solutions and new business models.

The future standards for batteries, safety regulations, interoperability etc. are among the major concerns of the stakeholders in the swapping technology sector.

Economic perspectives

Economic scale is crucial for making battery-swapping successful.

Experience from China indicates that a few years ago the cost of battery-swapping solutions was 125% higher than for cable-charging. The cost for establishing battery-swap stations is higher than for equivalent cable-charging systems. Both of these price indicators are reducing with improved economies of scale, as the learning curve is followed, and as new technology creates new opportunities. In the future, it is likely that swapping stations will be operated by a single person for security reasons. However, the competence needed and the level of training are high and thus the cost of the technician represents a considerable cost.

In the fully integrated car-battery concept, the car has one battery pack, when using the battery-swapping system the same car needs 1.3 batteries on average to allow for swapping - based on the experience of TELD, China's largest charging service provider. Somebody in the value chain will have to pay for the 0.3 extra batteries. Ultimately, it will be the customer, the question is when and how. This is why the business model used is important.

In Beijing, by the end of 2020, operators had built battery-swap stations at a radius of 2.53 kilometers to each other in the most dense urban area. In a few less dense suburbs, the value increases to about 5.6 km in radius. This was to demonstrate to customers that swapping solutions were permanent and easily accessible.

On the other hand, if there are too many battery-swap stations and too few cars using the system, the stations will not survive. Conversely, if there are not enough stations, buyers will not buy the car because of the lack of convenience after they have bought it. This is a tricky balancing act, and one of the biggest headaches for BAIC setting up swapping stations.

There are important differences between b2b and b2c markets. Each needs different solutions. Technically, swapping stations could use the same solution but different brands have different strategies.

This shows that in China initial actions are targeted at the large public transportation sector, buses and taxis. Experience shows that the public transportation sector is demanding, has a high traffic density, carries a large amount of people, places high demands on access to vehicles, and is also sensitive to business and economic outcomes. The decision to focus on public transportation is also a relatively easy one for the decision makers and policy makers. After these systems have been developed and experience gained, it might be possible and the timing correct to exploit other sectors and the private consumer sector.

Although NIO has achieved success in exploiting b2c swapping stations, BAIC believes that consumer market demand could become large scale in 2023-2025.

Market and customer perspectives

As the electrification of transportation is a new and rapidly growing industry all customers, operators and investors find themselves in a novel business situation. There is little large-scale experience of long term operations that have proven commercially profitable.

The established cable-charging system has emerged as the dominant solution largely due to early Tesla solutions and because it is a technically easy and relatively cheap way to charge NEVs, and because of the assumption that many people can charge at home during the night. For the early adaptors and early pioneers that may well have been the case, but as the market grows and new customers enter the NEV market, new solutions will be expected.

Imagine a customer buys an NEV for $85,000, with a 50-65% cost of the NEV attributed to the integrated battery. The battery has a price of $40-60,000. Will the customer be willing to swap that new expensive battery for something they know nothing about? To give away a new battery and receive an older one? Who is responsible? Who will guarantee compatibility and reliability?

The Chinese subsidy system for NEVs includes special green NEV licenses. In some cities, it is only if citizens can provide a certificate of access to a charging pile that they can buy the car with the registration plate. This has become an issue in China because many people do not have charging piles.

Although China has the largest number of charging piles in the world, considering the total population in relation to numbers of NEVs, China is under-performing in installing new charging piles when compared with western countries. As a result of these practical and regulatory issues, battery-swapping systems are perceived as a favorable solution.

Thus, for the reasons given, the new emerging business models involving the basic separation of vehicle from battery and charging will receive attention from customers.

Power and control perspectives

The transformation from the fossil-fuel-based economy and ICE automobiles to renewable energy and electrically powered new energy vehicles mean that the relationships between the old stakeholders are being questioned, shaken-up and disordered. The old power relationships are changing and new ones are emerging.

For more than a hundred years, the old brands have established their reputation and powerful position in the market and society. The required technological and engineering skill represent a huge barrier to new entrants into established markets.

Now, with the advent of NEVs, the power relationships are being questioned, changed or are likely to be changed. The old OEMs are used to controlling their product architecture and making money based on the entire vehicle system. Adopting battery-swapping systems is based on the assumption that the old manufacturers can change their mindset, their way of operating and their business model in order to attract new customers, adopt to new technologies etc.

So far, we have not seen successful exploitation of battery-swapping systems. Only new market entrants are choosing the swapping system and it is only they who are developing the new business model based on decoupling vehicle, battery and charging.

If a traditional OEM manufacturer chooses this new business model and new product architecture, it is a reasonable assumption that they will not feel totally safe about the decision.

After separation of vehicle and battery, the vehicle OEM manufacturer becomes a car frame and body maker. The technical content of the vehicle is greatly reduced and there will be a loss of bargaining power vis-à-vis battery manufacturers who are becoming the major supplier to NEVs. The brand differentiation between different NEVs is already considerably reduced with the shift to NEVs. The old mechanical solutions are being replaced by commodity-based electric solutions. This explains why many traditional, particularly premium large car companies, are reluctant to go down the battery-swapping route. At least for the time being, Tesla, Mercedes Benz, Volkswagen, BMW and BYD, and other premium car companies, are not choosing battery-swapping. At the same time, there is a huge interest dispute. Who would be willing to give up their profits during the transformation stage of the entire industry for the benefit of other organizations?

The separation of vehicle and battery first requires standardization of battery, battery management system, interface and software management. The electric vehicle, like a mobile phone, is a product that changes rapidly from generation to generation. There are upgrades almost every year. The separation of vehicle and battery requires strict standardization of battery and software and the solidification of control management software. New models must achieve software and hardware compatibility with the first generation, second generation and Nth generation of batteries, which will greatly hinder and constrain the innovation of electric vehicle technology.

This transformation might look like a technological issue, but we believe that the most important aspect is control and power in the automotive industry.

National energy supply perspectives

There is also a national energy supply perspective in respect of battery-swapping systems.

If the battery-swapping system were introduced in Beijing with its 35-40 million citizens, and all vehicles used battery-swapping systems, their daily storage capacity would be equivalent to the daily power operation of the city. That would means doubling the required energy. What does this mean? If EVs charge during valley periods, they will contribute to peak shaving and valley filling, i.e., balancing supply and demand, but if NEVs charge during the peak period, it could cause a blackout of the entire transmission system. The impact of fast charging mode is especially high because a fast-charging pile is equivalent to the voltage and energy of dozens of slow charging piles. With the development of the new energy vehicle industry, the energy supply bottleneck could well erode development of the whole industry.

Seen in this light, battery-swapping systems can support the adjustment and improvement of the whole energy structure and create an overall energy storage system making the variation in the production based on renewable energy less critical and the overall system more robust. Battery-swapping based EVs can provided distributed energy storage through centralized charging, and absorb wind energy, solar energy, hydropower, etc., helping to promote the whole energy structure reform.

Multi-aspect readiness analysis of battery-swapping in China

When the USA decided to go to the moon, NASA needed an analytical tool to analyze and compare different technologies based on their maturity levels, in terms of whether a particular technology was available in the lab, at testing level, prototyping level or ready for full scale commercialization. The model NASA developed used Technology Readiness Levels (TRL) with nine different levels. This was to provide NASA with a systematic comparison tool, although these kinds of comparison are not easy and are subject to judgments, estimations and assumptions.

In our previous work on the exploration of inductive charging development in China in 2018 we developed a model using basic TRLs. Our analysis identified that there are at least three other aspects where it was important to understand and to explore how and why they look as they do. Those were political readiness, economic readiness and societal readiness, in addition to the classic technology readiness levels.

There were many questions in the case of the moon landing project, but politics society and citizens all supported the project. Moreover, money was available, and the main outstanding issue was that of technological readiness and when the needed technology would be ready to be exploited. When it comes to the electrification of transportation all of those aspects cannot be put in place so easily.

To put a technology in place, politics needs to accept and support implementation of the technological solution. However, there are many competing solutions. Also, when it comes to societal aspects, people may have different opinions and probably, would make different choices depending on the economy, user friendly solutions etc.

Based on the four main aspects that we developed in 2018, we are using this approach to consider the readiness of the battery-swapping system in the Chinese context.

In this model we estimate how the battery-swapping can be positioned according to those four aspects.

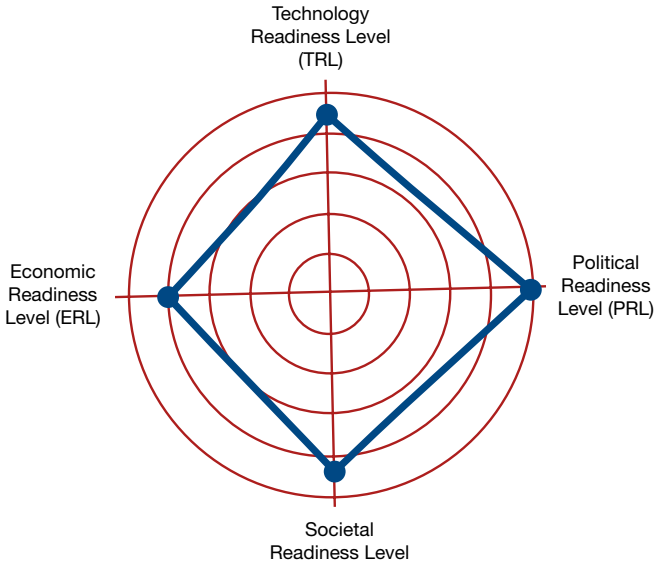


Figure 24: Multi-aspect analysis of battery-swapping system (Own construct).

Political readiness level (PRL)

As the Chinese government has put the batery-swapping technology on the national strategic list of technologies of high importance, the estimation is that this technology has got highest recognition possible. The next step is to put in a number of implementation situations. This indicates that investments will be directed to the development of technology and that industry working in this chosen direction.

The separate vehicle and battery model influences property ownership, taxation, insurance, etc. for consumers and other stakeholders. Different Chinese government agencies have taken action to update regulations and procedures according to the requirements of the new battery-swapping model. In 2021 national congress and entrepreneur delegations have submitted further proposals in this direction to the Chinese government.

Technological readiness level (TRL)

Battery-swapping is no longer an immature technology. All the established systems show that technology works in fully automated systems and has been working for several years. Hundreds of thousands of swaps and operational systems indicate that the technology is operationally ready.

One challenge is that battery-swapping needs to be integrated with the product architecture to enable full connection between the swapping of old and new batteries. Several independent brands use different solutions and therefore the battery-swapping system needs to be brand matched. This lowers the usability of the system. There is an obvious lack of standardization in respect of the interface between NEVs and swapping stations.

Societal readiness level (SRL)

The business model which has been put in place, separating the cost of the car from the battery, ownership from renting, charging from take-and-pay solutions, means that the business model appeals to customers that feel NEVs are too risky, prefer cheaper NEVs that are perceived to be lower in quality, and increases the level of trust of Chinese suppliers instead of consumers favoring western high-status brands.

The availability of swapping stations also supports the willingness to shift for swapping system solutions.

The safety of electrification, battery and swapping systems seems to be acceptable, and customers appear to learn from experience in the taxi area and apply it to the private sphere.

Economic readiness level (ERL)

Here the economic refers to two perspectives, one relates to the operators of swapping stations and the other relates to customers/consumers of services. This is the area in which the battery-swapping model faces the most challenges.

Our information indicates that NIO is losing money from its business selling NEVs and battery-swapping solutions. However, it is difficult to identify differences between the losing areas, whether it is the NEVs themselves or the swapping systems. Nevertheless, companies need to find the right balance between

charging for swapping solutions and charging fees. For customers the business model enables them to find the most economical solution that fits their needs; the flexibility and freedom from problems means that customers will be willing to pay more for the higher value.

To make the battery-swapping model attractive to customers, price and convenience are the key. To make the solution convenient to customers, the stations need to reach a certain density level. However, stations themselves are expensive to build and operate. The battery-swapping price is currently more expensive than the charging solution for customers. Each brand establishing its own station to serve their own brand vehicles is not economical for the company and involves waste for society as well. Sharing battery-swap stations among different brands is the best solution for reducing costs for each brand and customers as well. Shared stations require standardization of batteries and open battery management systems. To achieve those goals requires difficult negotiations and compromise, otherwise, it will be difficult to secure the long term economic feasibility of the battery-swapping route.

Based on this multi-aspects model, there are some obvious improvements, however, we do not think that there will ever be one solution that is a solution for all aspects all of the time.

BATTERY-SWAPPING GOING INTO CHINA AND GOING OUT FROM CHINA

Dynamics of innovations - from abroad to China

New-incoming players in China are Geely and SKI of South Korea, who are quickly developing battery-swapping systems in the eastern part of China. The establishment is new and it is too early to consider it in detail. Bearing in mind that Geely owns Volvo and the new Polestar, it is worth speculating that they might introduce battery-swapping solutions to Europe or the USA.

The latest newcomer is the South Korean company, SK Innovation, one of the world largest battery manufacturers. The battery-swapping business is receiving international attention and is growing with the support of the Chines government as a strategic technological direction.

The future is not yesterday, nor is it where we are today. The future is ahead of us and few can estimate correctly what the future will be. Few could have predicted the success of the iPhone and few can predict the future of battery-swapping for NEVs.

But sometimes we need to listen to visionary entrepreneurs with insight, experience and a sense of the future. One such voice is:

> *”In the next 5-10 years, the number of commercial vehicles with potential demand for battery-swapping will reach 4 million. We believe that by 2025, the number of battery-swapping NEVs will reach 1.24 million, with 12,370 battery-swap stations needed.”*
>
> Zhang Feng, deputy general manager of Blue Park Smart Energy (Beijing) Technology, speech at 2020 China International Battery Switching Mode Industry Summit Forum, December 2020, in Shanghai.)

Some analysts stated that Zhang’s forecast for China’s NEV battery-swapping market is conservative. (Dandan, 2021).

Finally, in 2020 all of the forces necessary for driving battery-swapping solutions came together: politics, institutions, policy, electricity producers, transmission system and electricity distributors, automotive manufacturers, and battery-swapping operators and in their symbiotic relationship jointly pushed for large-scale diffusion of battery-swapping systems.

Dynamics of innovation - From China to international business

We also aware of the establishment of Japanese NEV manufacturers who develop complete systems for battery-swapping and focus on small NEV cars suitable for other Asian markets such as Thailand and Indonesia. We are also aware of a rapidly growing interest in battery-swapping in India focused on three wheelers and small NEVs.

It is interesting to note that these battery-swapping system solutions are emerging in the fast-growing Asian markets with mainly Asian manufacturers. With a strong footprint in their home markets and operationally effective solutions it is not impossible that their solutions might diffuse to the rest of the world.

The future will reveal all.

As is also apparent in the computer and apps age, consumers are renting and buying based on a subscription model. In the shared economy, it may be that cars remain private while batteries and charging become just as simple as using gasoline to fill a car. Thus, the reduced prices might push the demands down the economy scale to lower income groups. As we have seen from other areas business models might be more important than the technology itself. Battery-swapping technology combined with a subscription business model introduced by new entrants to the automotive industry in China might very well be the game changing solution that attracts a new generation of electric vehicle owners and drives the separation solution so that it becomes a new standard. In early 2021 we can see at least three Chinese brands actively introducing battery-swapping and also that the interest in battery-swapping is booming in India. Now with Europe going through an electric car boom and Chinese brands becoming established in Europe, such as NIO in Norway, it is not impossible that they will become game changers in the old fashioned European automotive mass market focusing on young middle-class customers used to different subscription business models. It is a question of the right timing!

Although the idea of battery-swapping is not new, the timing is now right for large scale commercialization. The future will reveal all.

The success of Chinese developers also shows the importance of controlling the swapping technology and the overall ecosystem of car design, car manufacturing, energy supply and energy distribution need to be integrated in a coherent technological system and business ecosystem. This demonstrates the success of the Chinese swarm approach in which many players combine and complement their efforts to create and operate the large-scale systems needed to develop/explore and commercialize/exploit the new battery-swapping technology and systems.

The fact that Chinese consumers might be able to buy the car and its batteries separately according to their needs, could also help expand the growth and development of the EV market in China. Whether or not westerners think EV battery swaps are a good idea, the Chinese Government likes it. China's Ministry of Industry and Information Technology issued a statement:

> *"We will actively promote the demonstration application of battery-swap mode and improve the system and standardization. As the next step, we will optimize the development environment, guide enterprises to improve battery-swap technology, promote the formation of a more mature business model, and further improve the convenience of new energy vehicle usage."*

Given that the Chinese government has expressed its attitude in this clear way, it is highly likely that they will strongly support the further development of the technology, entire technical systems and eco-environment to make this a viable and usable solution in China. The outcome is more than technology. The outcome is a new evolution of industry, an emerging new ecosystem and a strong domestic market for the new industry to establish a strong footprint. Now there is evidence of the first internationalization of Chinese NEVs exploiting solutions developed in the domestic market.

Battery-swapping triggers automotive industry transformation in manufacturing

We have noticed that the introduction of battery-swapping was led by the companies in the new and emerging electric vehicle segment of the automotive industry. In doing so, they are challenging the established relationships and positions of players focused on the ICE market. As mentioned earlier, in China there are at least 200 electric vehicles brands and providers. Some are pure technology developers and some are both developers and manufacturers. NIO is one example of an electric vehicle developer targeting the premium EV segment with a battery-swapping system, but without their own manfacturing capacity. They rely on collaborative partners for the manufacturing.

This is breaking the traditional value chain and the perception that developers and manufacturers need to be one and the same company, which has been the dominant business logic in the automotive industry. This highlights the emerging new business logic of separating development and manufacturing, aside from decoupling vehicle from battery, in the new fast-developing electric vehicles market.

This raises new questions about the identity and understanding of who is the electric vehicle brand owner, developer and manufacturer, besides who are the technology providers? The main historical solution has been integration of those roles. The traditional approach and expectations are being questioned and revised as part of the electrification process. We are used to seeing China as the factory of the world, meaning that development is located in the west and manufacturing located in China to achieve economies of scale and take advantage of lower salary levels. The thinking behind economies of scale is based on assumptions that there is a relation between large volumes and manufacturing economies of scale.

A different business logic applied to traditional ICE vehicles than the logic we see in the emerging electric vehicles that have a lot fewer mechanical parts but a lot more electrical and electronic parts, software and batteries. Modern electric cars are more like hundreds of interconnected computers placed in a body on four wheels.

The core competences of the automotive industry are changing from mechanical engineering to electronics and software engineering, design and branding of basically standardized systems. Very much like modern personal computers, laptops etc.

However, what we now see is that there is a systemic separation between electric companies focusing on development, sales and branding while others focus on large-scale manufacturing. This was traditional in the electrical industry and is now also being applied to the automotive industry. NIO is just one example. There are other illustrations of this dynamic in the emerging electric vehicle automotive industry.

- Foxconn is one of the largest manufacturers of electronic products in the world. They have become a major assembler of Apple products and are well-known for flexibility and fast adaptation to dynamics.

- Foxconn and Fisker, a start-up company established in 2005 in the electric vehicle sector and taken over in 2014 by Chinese company Wanxiang, has reached an agreement to jointly produce more than 250,000 electric vehicles per year. That makes Fisker a clear developer while Foxconn is entering the electric vehicle manufacturing sector. The manufacture of high-tech smartphones and computers seems to be more similar to the manufacture of electric vehicles that you might at first think.

- Foxconn has invested 750 million US $ in establishing manufacturing capacity in Wisconsin, US.

- Foxconn is also collaborating with Fiat Chrysler and Geely in the manufacture of electric vehicles.

- Foxconn has also launched new projects that can be used to develop electric and autonomous vehicles - providing customizable basic technology kits. This indicates that in the future electric vehicles may well become commodities, customized products based on standardized subsystems and components and that variation will come more through software engineering and control than through mechanical engineering.

”The last thing an electric car startup should do is to build its own factory. Frankly speaking, I think this is a very stupid idea.”

CEO of Fisker

Fisker´s luxury sport utility vehicle ”Ocean” is expected to be launched in 2022 and will be manufactured by Foxconn. Magna Steyer in Austria has for some time being manufacturing the BW X3 as sub-contractor. Magna is expected to start building the Fisker Ocean electric SUV by the end of 2022.

“The Fisker and Foxconn partnership brings together two global leaders in innovation that will join forces to unlock the potential of the electric vehicle industry.”

Fisker and Foxconn joint press release

“Foxconn’s participation in the electric vehicle industry delivers a refreshing thrust into the Information and Communication Technology (ICT) industry that is already focused on this exciting sector. The key success elements of electric vehicle development include the electric motor, electric control module and battery. We have two major advantages in this regard, with an exceptional vertically integrated global supply chain and the best supply chain management team in our industry. Coupled with our accumulated engineering capabilities, Foxconn has been critical to the success of many ICT companies over the past 40 years and we look forward to extending this success with Fisker.”

Fisker and Foxconn joint press release

However, the rapid electrification of vehicles is speeding up this transformation and separation between vehicle developers and manufacturers.

“The new collaboration between Foxconn and Fisker will revolutionize the automotive industry model by introducing ICT capabilities – which help automakers accelerate their transition to new, innovative, and efficient manufacturing processes and business models. The collaboration between our firms means that it will only take 24 months to produce the next Fisker vehicle -- from research and development to production, reducing half of the traditional time required to bring a new vehicle to market,”

Foxconn Technology Group Chairman Young-way Liu in Fisker and Foxconn joint press release.

Although global collaboration is an old phenomenon, the rapidly increased electrification of the automotive industry and transportation will have a major impact on the global business set-up and we will see new combinations and recombination of players.

Manufacturing is the new core competence in those times of transformation to transportation electrification

Conclusions and final comments

The transformation to electric vehicles is right at the start of the energy, transportation and technology revolutions. This transformation process started twenty years ago and is now growing exponentially. The anticipated 250 million electric vehicles in ten years from now will impose great demands on transformational changes, from the capture of renewable energy, to the transmission system and energy provision to electric vehicles as we currently recognize them, that is mainly battery-driven for at least the next 5-10 years.

From the initiation of this research in the Sweden-China Bridge Project the aim has been to deepen our understanding of the dynamics of the development of electrification of transportation, focusing on China. The choice of China for this research is due to the speed and scale of the transformation in China in respect of renewable energy and electrification of transportation.

In a short period, China has become the largest producer of electric vehicles and the largest market for electric vehicles, and has also established the largest charging infrastructure and taken the lead in establishing a large number of companies focusing on electric cars. The Chinese city Shenzhen has become the most electrified city in the world with 100% electric taxis, buses and a high proportion of electric logistic vehicles, based on stationary fast-charging infrastructure. However, although this is promising, the fast-charging system as we know it today, will not be sufficient to support the fast-growing electrification of transportation. New solutions are needed and battery-swapping has emerged as one such new solution. Now in 2020, it can be seen that China has developed battery-swapping technology from the discovery and exploration phase to large-scale commercialization, diffusion and innovation implementation.

This paper shares the experiences of developing and establishing the battery-swapping technology in China through the entrepreneurial activities of a number of stakeholders, transmission system operators, OEM manufacturers, swapping station operators and green investors. Based on a dialogue between industry and politics, battery-swapping was included in the national strategic listings and became a high-priority development route. This recognition encouraged new entrants into the area, and we can see growing interest in this direction. The success of this approach is also due to a cluster initiative forming joint understandings and a new ecosystem of complementary interests and capabilities which overcomes disputes and self-interest among stakeholders. The success is also due to the timing of technology maturity and establishment of a new business model that can utilize the potential of battery-swapping.

In this case, we can also see the necessity to have a system perspective for developing integrated system solutions (both societal, social, technology and business perspectives) for energy production, electricity distribution and vehicle charging systems based on users' different needs and expectations. In addition, it can be seen that the new technology is opening up new opportunities for improving the transformation towards a sustainable world and improving the living conditions of people. We have seen that is it only through joint efforts, collaboration and dialogue, early experiments and trial & error, with visionary people and the efforts of partners and competitors, is it possible to develop new solutions for the benefit of many.

We need to keep in mind that the electrification of transportation is at the start of its diffusion and we have yet to see which technologies will form the main future development path. We see new alternative technologies emerging, for example hydrogen technology is in the early stage of commercialization. It is likely we will see several parallel development processes.

We live in times of transformation and times of technological and societal revolution. We have experienced steam power, fossil-fuel driven industry and society, and now we are facing a new revolution in renewable energy and the electrification of the whole of society.

We have seen how digitalization transformed photography, how smart phones communications and now we are seeing the beginning of a new energy revolution transforming the old energy industries and

the mechanical engineering-based vehicle industry into renewable energy industries, and electronically and digitally interconnected new energy vehicles. Some industries will become obsolete and new industries will arrive. Old technology will be discarded and new technology will take over. The new innovation stands in front of us and we are right in the middle of a new big wave. We are in the middle of the transformation and we can influence it.

It makes no sense investing in the electrification of transportation and the introduction of electric vehicles if the energy sourcing and distribution still relies on fossil-fuel energies such as coal and oil. We need to have a system perspective and ensure that the whole of industry has the same target of zero CO2 emissions from operation of the entire transportation system. We see that up-scaling of vehicles will to a large extent require more energy. A main question is where the new energy will come from. The second is how we can create a balance between energy production and energy consumption across the entire energy system. The third key question is how to design the charging system to manage the challenge of the growing number of electric vehicles. Global charging of almost 300 million EVs by 2030 will be a great challenge.

For this reason, China has made strategic decisions to establish another technology route to ensure EV charging, the battery-swapping system. Battery-swapping is seen as complementary to stationary cable-based systems. Battery-swapping was placed on the national strategy list in 2020, and thus the technology will be supported by central government with new industry entrants developing new solutions. Addition to the national strategic list is a very important indicator of what is important and where the support will be directed. From 2020-2021 we will see many more players entering the battery-swapping system.

To achieve this introduction of battery-swapping we will see the establishment of a new ecosystem of players in the new energy sector. Key players are complementary and cover the entire energy system and value chain, from energy producers and energy providers, transmission system operators, battery producers, OEM vehicle manufacturers, third party swapping station operators through to investors. That is complemented by a new business model in which the vehicle is separated from the battery, and charging is offered on a buy-rent-subscription model, as well as charging being offered via alternative subscription models. In this way, the entrance price level for consumers is significantly decreased, sometimes by more than 50% of the car price, and customers can chose an operational cost level based on their needs. Flexibility and adaptability to customer requirements are increased in comparison with a customer buying an integrated system solution. The influence from digital business models is substantial.

The traditional vehicle business logic is mixed with new business logics from the digital, software and IT-business sectors to form a new flexible model focusing on servitization rather than hardware and functionality, based on decomposition and customer choices.

APPENDIX

THE HISTORY OF BATTERY-SWAPPING IN CHINA

Introduction

As mentioned, China has become the world's largest market for electric vehicles. To really understand the differences with the past and to compare its situation with the rest of the world, we need to consider the size of the population, the general income of population etc.

Taking into the consideration that diffusion of NEVs in China is to a large extent located in the eastern parts of China, the future development of the rural part of China will probably increase demand for NEVs in the central and western parts. This is likely to be supported by the new strategy for development of China introduced by the 14th five-year plan focusing on dual circulation development processes, one domestic and one global. It is possible that the major growth of NEVs will be in the central parts of China, in those cities referred to third or fourth tier cities, which are still multi-million-citizen cities with a growing middle-class population, as a main development engine and in the eastern part of China as a transformation instrument for replacing ICE vehicles. This might also reflect the Chinese success of smaller and cheaper NEVs suitable for lower income regions.

The Chinese NEV market is larger than the European and US markets combined. Taking into consideration the size of India and the growth of the Indian economy and increase in demand for electrified solutions, it is not difficult to see where the future main markets for NEVs might be. The answer is very probably in Asia.

BATTERY-SWAPPING IN CHINA

Nothing is new under heaven

The idea of battery-swapping was introduced in China as early as 2002 by Chinese national transmission system operators. This was the beginning of the electrification of vehicles. Some pioneering transmission system operators saw the opportunity of battery-swapping from the electricity production and the transmission system operators' perspectives and tried to develop and put it into practice solutions with the vehicle manufacturers. The electricity producers and transmission system operators quickly realized that large scale electrification of vehicles and transport would have a huge impact on the consumption of electricity and the transmission system. They also quickly realized that the large-scale electrification of transportation required the redevelopment and restructuring of the transmission system in order to support large numbers of electric vehicles charged using the emerging static, individual and decentralized charging stations in huge volumes all over China. Energy is difficult to store after it has been produced. The balancing issue is crucial, and the stability of the transmission system is important.

Large-scale electrification creates challenges that the operators of the transmission system and electricity producers have to overcome. The NEV manufacturers focus was on the vehicles and quick scaling-up of the manufacturing of NEVs, the management of stiff competition, survival in the new landscape, and not at all on the overall system extending from production to the consumption of electricity.

The old ICE energy system was a centralized solution, from gasoline/diesel production/import to distribution via gasoline stations to ICE vehicles. It was separate from the electricity production, distribution and consumption system. The emerging electrification of transportation, and the transformation from gasoline/diesel to electrical energy, demanded other solutions that were also complicated. There was a need for a decentralized system solution that was independent of the old centralized system of electricity production, distribution and consumption. It was this situation that built awareness of battery-swapping solutions.

However, neither the battery-swapping technology, nor the timing for commercialization was in place and political ambition for the exploitation of battery-swapping was missing in that early phase.

The automotive industry at the beginning of electrification was struggling to develop basic solutions to capture the market and introduce new electric vehicles to the market. They were focusing on proprietary solutions and their own brands that could give each manufacturer easy and profitable solutions and which meant they could differentiate themselves from other manufacturers. There were no coordinating powers or forces at that time. The dominant technological and economic interest among electricity producers, transmission system operators, swapping system operators and vehicle manufacturers was not aligned, and thus they could not find a common understanding of the long-term development nor develop joint solutions to the overall electrification of transportation. Nevertheless, although vehicle electrification technology developed very quickly, there were no reliable and economically feasible swapping solutions in place in 2002.

Gradually the technology was developed and matured to a level at which vehicle manufacturers could see the opportunities ten years later. Also, the political awareness and acceptance did not exist in 2002, which was not the case ten years later when the large-scale development and exploitation of battery-swapping began.

Some early initiators of the battery-swapping system never gave up. One such player is Aulton New Energy Automotive Technology that today is one of the largest nationwide battery-swap station operators in China.

Battery-swapping is an old idea

Despite the current increasing interest in battery-swapping, the idea of battery-swapping is quite old. Different projects appreciated the prospects of battery-swapping and tried it out before then giving up on it. Back in the 1970s Mercedes-Benz (MB) explored battery-swapping solutions using specially constructed MB small buses (Sandru, 2009). MB built about 40 electric buses to test the approach. Their testing used a system with a horizontal swapping solution as shown in the photo. These experiments were conducted with the battery technology available at that time and MB found that the swapping system was not reliable and safe - mainly due to battery design, cable based connections, and lack of standardized system solutions. At the time, MB estimated that it would take about 10 years before the system was ready.

Figure 25: Mercedes-Benz battery-swapping solution in the 1970s (Sandru, 2009).

This was an overestimation of the technology's maturity and underestimation of the technical barriers and MB without doubt underestimated the business implications involved in introducing battery-swapping in a commercial context. It would take almost 50-years before battery-swapping saw technological and business solutions that enabled viable operation.

Commercialization started in Israel …

Although several NEV manufacturers tried a small-scale battery-swapping approach for experimental and learning purposes, none succeeded in creating a commercially viable solution that could be considered an innovation. The modern story of battery-swapping started in Israel with a company called Better Place in 2007. By 2013 they had succeeded in producing 500 operational NEVs. Better Place also established a test-facility in Quanzhou city in the Quandong province.

Figure 26: Better Place battery-swap station (Beedham, 2020).

After initially focusing on Israel, a small country with high gasoline prices, it quickly rolled out its marketing in Australia, Japan, Denmark, and US/California. Better Place established operations in large cities such as Tokyo and Yokohama hoping that customers would like their solution. However, they did not succeed in persuading vehicle manufacturers to adopt their solution and design cars to fit their swapping solution.

Better Place failed to attract a broad group of automakers to participate in its program. At that time, the battery was seen as the core IP of the vehicle and most carmakers rejected a third party interfering with the heart of its vehicle or telling it how to design its cars in order to optimize swapping. It is analogous to the buyer of a BMW accepting the engine from a Fiat or Skoda.

The French car manufacturer Renault tried to make the solution practical in collaboration with Better Place, however, they made only one car compatible with the solution. The Better Place solution took five minutes to exchange a battery compared to at least one hour of static cable-based charging. Better Place ceased trading in 2013 after losing more than $800 million.

Better place developed a solution during the early days of vehicle electrification. Their focus was small cars, not heavy trucks or buses. They did not control the entire value chain and their ecosystem was underdeveloped. Their business model was to sell the solution to car manufacturers who would have to change the design of a car to make it suitable for the technology, to develop a new ecosystem for diffusion and develop a new business model to scale up the concept and make it profitable. The swapping technology was the least of their worries compared with the other issues. Unfortunately, Better Place failed in commercializing this great idea at the time, but the baton was to be taken up by other players as will become apparent.

The former CEO of Better Place, Mr. Shai Agassi, argued that battery-swap stations would cost $500,000 to build. That is also the cost of today's Chinese battery-swap stations, but they are smaller in size, can handle more operations and have higher capacity thanks to their advances in design, including fully automated swapping capacity - an improvement on the Better Place design, some 8 years later.

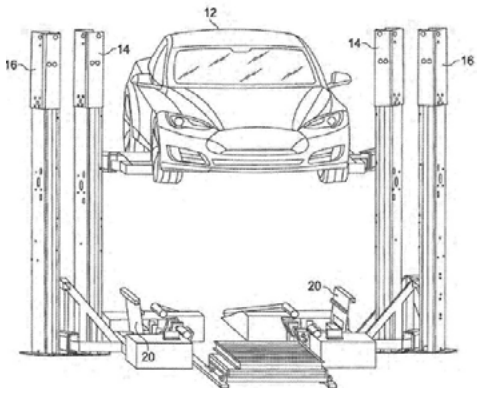
… and moved to the USA to become an invention

The first modern and successful electric car was the US-based Tesla that when it came on the scene took the world by surprise. The Tesla car was a game changer at that time, and to a large extent, still is. Tesla become the role-model providing a blue-print for the modern electric vehicle with the most advanced electronics, infotainment system, internet-upgradable software systems, autonomous driving capabilities (although to limited level), leading battery-based technology, and fully developed infrastructure for charging the cars. Many laughed, and many more were skeptical, but not anymore.

Not many people know that at the start Tesla designed a fully modular car ready for battery-swapping.

They joined the market before the time for vehicle electrification had arrived. Tesla started with a high-end car design focusing on premium customers willing to pay more for new technology and a new approach in 2013. Tesla designed its Model S to be compatible with a battery-swap system—boasting a fresh, fully charged battery in as little as 90 seconds.

Figure 27: Tesla battery-swapping solution.



(US Patent 20170259675, Owano, 2017).

Also, Tesla tried to develop swapping technology. It developed one patented solution as the picture on the left below illustrates. Tesla initiated this technology with its services in the U.S. in 2013 when Elon Musk showed off Tesla's battery-swapping technology base on its Model S.

Tesla states that the battery-swapping process takes approximately three minutes, noting that "time is needed to remove the titanium and hardened aluminum ballistic plates that now shield the battery pack." The company says that swap time "could be reduced to less than one minute, even with shields," given further automation to the swapping process and refinements to the design of the vehicle undercarriage.

"Battery-swapping is Tesla's second innovation. After the Model S drives to a designated spot at a Supercharger station, the transformation magic begins in the car's shadow. The floor opens, computer-controlled tools unscrew the 39 fasteners that attach the 61-by-100-by-4-inch battery pack to the car, and a fixture lowers the 1300-pound box containing more than 7000 cells into a pit. A fully charged replacement battery is hoisted into place, and all power, cooling, and battery-diagnostic connections are restored. Automatic screwdrivers spin the fasteners to their factory torque spec, completing the swap in a minute and a half."

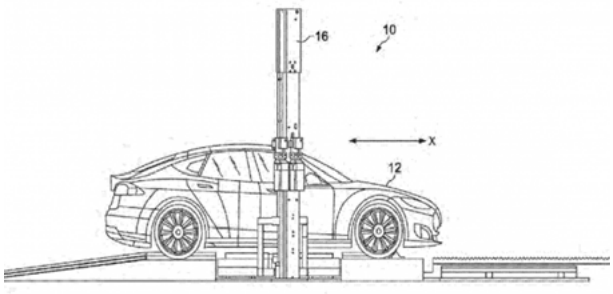


Figure 28: Tesla battery-swapping solution. (Owano, 2017).

There is no service mechanic working under the car. The Model S was designed for rapid, automated battery changing with quick-release hydraulic and electrical connections. From the start, Elon Musk's engineers were smart enough to realize that hours spent recharging is a kill-joy for anyone hoping to use an electric car for long trips. Tesla's battery-swap service uses the same assembly equipment in place at the Model S plant in Fremont, California. Supercharger stations up and down the West Coast's Interstate 5 and from Washington, D.C., to Boston should begin offering this convenience by the end of this year. That was the plan and the dream but it never became a reality.

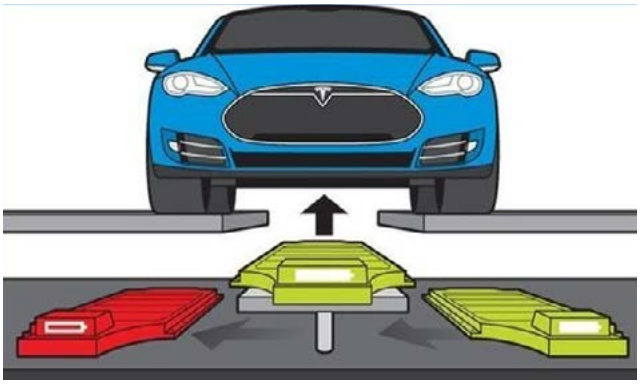


Figure 29: Operation of Tesla battery-swapping. (Luxury Perspective, 2014).

The original plan was to establish both fast charging stations and battery-swap stations all over USA, as the picture below shows. However, the swapping stations never were established nationwide.

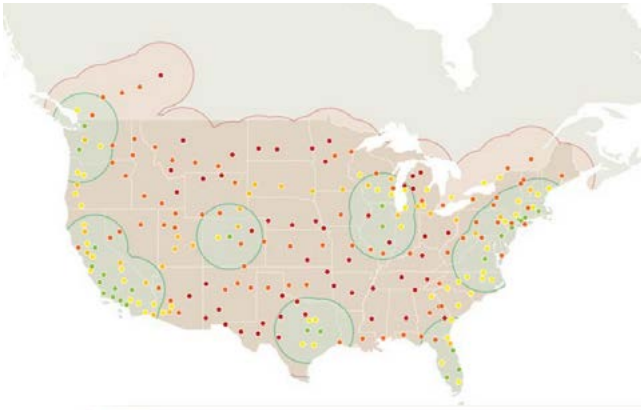


Figure 30: Distribution of Tesla charging stations in US.

After two years on trial, the plan for introducing battery-swapping wasn't working well. Only 2% of 200 invited Model S owners who were invited to try the technology and service were interested. Tesla got into the battery-swapping idea and patented one solution and opening its first and only — battery-swap station in Harris Ranch, on the high-way between San Francisco and Los Angeles in California (a distance of 617 km), in 2013.

Figure 31: Elon Musk tweet.

"We built the pack swap into the car because we weren't sure if people would want to choose the pack swap or not. We thought people would prefer Supercharging, but we weren't sure, so that's why we built the pack swap capability in. And, you know, based on what we're seeing here, it's unlikely to be something that's worth expanding in the future, unless something changes."

Smith, 2015

After that trial, Tesla closed down the chosen approach in 2015. Their focus came to be a large-scale roll-out of rapid charging systems widely spread across all of their markets. Subsequently, Tesla also went for a fast charging solution for heavy .

"We've invited all the Model S owners in the area to try it out, and of the first round of 200 invitations, only four or five people were interested," Musk said at the meeting. "Clearly it's not very popular."

"We have, basically, the L.A.-to-San Francisco pack swap capability in place, and I believe all Model S owners in the California area have been invited at this point to try it out. And what we're seeing is a very low take rate for the pack swap station. So, we did an initial round of invitations, where we did basically, like, 200 invitations, and I think there were a total of four or five people that wanted to do that, and they all did it just once. So, like, okay, clearly, it's not very popular. And then we said, okay, let's expand that invitation to all customers, but I would expect that all customers behave roughly like that initial sample group."

Sorokanich, 2015: Musk at Tesla´s shareholder meeting in 2015

We must keep in mind that the focus was on the technology as such and not a specific business model focused on value adding elements. In those early days, the early adopters were more interesting in the car itself than on battery-swapping solutions. From the beginning, Tesla was focused on its own car and battery design and technology. Therefore, the company tightly controls inventory and warranty claims. Also, in the early days the quality and capacity of

contemporary batteries were important issues. Tesla also decided to establish Gigafactory's to design and manufacture high-capacity and high-quality batteries for their own use. Tesla was also well aware of the cost of the batteries and wanted the profits to go to Tesla rather than the battery suppliers. Put together, Tesla wanted to control as much of the value chain as possible. Their main headache became manufacturing quality and manufacturing capacity, which took many years to solve but does not form part of the scope of this paper.

There are no plans to standardize batteries soon, because each drivetrain requires a different energy and power ratio. Therefore, battery-swap stations need to be tightly controlled by the automaker to manage inventory and swapping technology to operate fast and smoothly.

We also need to consider that during those early days of new electric vehicles, Tesla was an outsider coming up with radically new ideas. Tesla did what Toyota did some years earlier when it invented the hybrid Prius. It was the world's first hybrid-car, and everybody in the automotive industry was laughing. Today nobody is laughing at Toyota's visionary approach and determination to make the hybrid successful. Toyota created the market, developed the hybrid car and seized the market share before anybody else woke up, and when they did it was too late. Tesla is also similar to Apple when they launched the iPhone. Everybody laughed at Apple and their iPhone, a smart phone without a keyboard. Today nobody is laughing any more, including Ericsson, Nokia and Motorola. Today, most of the automotive companies are developing hybrids and almost all are developing pure electric cars, buses and trucks. Thanks are due to Tesla (the inventor) and Tesla the company.

What we also need to reflect upon is that Tesla created a business model for their new cars. They sold the car at a very expensive price and offered a life-long free-of-charge electricity charging system. For many people, particularly those that could make a company pay for a company car, they got a car that was convenient, did not need gasoline, traditional servicing and was free of charge to use. Just plug-in, have a coffee and charge the car. Why would this kind of customer choose battery-swapping that was as expensive as filling the car with gasoline?

The car design, the business model Tesla developed and the dominant class of customers, helped Tesla to outline a dominant business model. Nowadays, Tesla no longer offers free charging. Now the Tesla solution has become a dominant business model. Sell the car with a huge battery, the bigger the better the car, the longer distance you can drive the better car, price does not matter because the premium already pays for the status, access to cities via government licenses, free parking in the city for NEVs etc. The time has not yet arrived in the western world for swapping systems and a new business model. Maybe not yet. Maybe is it just around the corner. Maybe it will be Chinese manufacturers that demonstrate the alternative way of launching NEVs in the future.

We will see later that most of the ideas created by Better Place and Tesla were further developed and put into large-scale practice in China. The major difference was that Chinese suppliers integrated the technology into a new ecosystem design integrated with a new business model for a new segment of customers, the urban middle class living in large Asian cities that cannot afford expensive premium model western NEVs. Tesla had ideas but no business model capabilities at the time and the Chinese market developed later in a different way. The market and the business logic in China were not aligned with a western approach.

From Tesla to Siemens in Germany

The cable-based charging solutions came to be the dominant solution for all the subsequent brands that adopted electric cars, either through manual handling of cables from the charging pile to the vehicle, or via automatic charging solutions with contacts approaching the vehicle from above or below.

Figure 32: Bus undergoing conductive charging. (Electric Vehicle News, 1014).

The picture above shows one automatic solution developed by Siemens in Germany that is actually a wired charging system for buses but which can also be used by trucks, although not for small cars such as taxis or private cars.

In the Siemens case the technology works very well. However, Siemens is only the technology provider, it does not design and manufacture vehicles and nor does it control the entire ecosystem of transportation electrification.

Thus, the possibilities for influencing decision-making among vehicle manufacturers and transmission system operators is limited.

The Tesla approach to battery-swapping was a brilliant technical idea, but businesswise it was a failure. Also, Tesla did not provide a total system solution that was practically usable and customer friendly with an ecosystem approach that would appeal to customers.

It was in reality just one technology demonstrator that did not attract customers. Similar conclusions can be drawn about Siemens's technology.

The advantage with this Siemens solution, which serves as just one illustration of many similar actually old-fashioned tram solutions, is that buses can be made cheaper because they only need smaller battery packages as these can be recharged during running. However, there are disadvantages as well. The flexibility is lower; the system is designed for fixed routes and requires expensive investments every-time you want to change the routes. What is important at the end of the day, is the driving cost per mileage km.

This system is also less flexible in respect of technological upgrades as the vehicles become more advanced and form elements of the interconnected city and need to interact with many other functions. The technical inflexibility becomes more important as the technology moves towards digitalization and the interconnectivities of the entire transportation system.

… to innovation in China

China is the largest EV market in the world, with 3.1 million electric vehicles in active use in 2020. As part of its ”Made in China 2025” plan, the world’s second-largest economy vows to become a global leader in new energy vehicles (NEVs), which also includes plug-in hybrids and hydrogen fuel cell vehicles. China has set a target for NEVs to account for a fifth of its total auto sales by 2025. Those targets are also reflected in the fourteenth five year plan introduced at the beginning of 2021.

Figure 33: Two-wheeler with battery-swapping.

Two and three wheelers have been highly dominant in China and Asia for a long time because of economic reasons and the density of cities. Car use started to grow in China after 1980. Modern large-scale battery-swapping was initiated in China due to its simplicity in design, its suitability as an environmental solution, and because of the ease of charging in average people’s homes.

The diffusion of modern e-scooters was also supported by the growth in e-commerce, where they were used for large scale distribution of purchased goods etc., as local distributors for a fast-growing online market. Several manufacturers developed battery-swapping as small-sized systems for scooters that were user friendly, had a modular scooter design and allowed battery recharging by connection to an average family’s electrical system.

In the main, charging of small two-wheelers is largely performed using normal home chargers.

There were about 300 million electric two-wheelers in China in 2019. Growth is estimated as an additional 70 million units in 2019.

The fleet of three wheelers in China is the largest in the world with about 50 million units in 2019. And the total number is still growing.

When the large-scale electrification of transportation started in China about twenty years ago, e-scooters were a role model and provided a learning background, very different to the situation in the west.

Some entrepreneurs also saw battery-swapping as a possible large-scale business and technology solution for NEVs that had stared to emerge at that time. This was the birth of the modern battery-swapping solutions for NEVs in China. A similar situation can be seen in India and other Asian countries.

BAIC takes the lead in battery-swapping

In 2010, one of the China's largest producers of NEVs, the Beijing Electric Vehicle Marketing Co. (BEIC JEV or BJEV), founded in the same year as part of the BAIC Group, developed and established the first battery-swap stations in China. In 2010 BAIC also started R&D on battery-swapping. To begin with, they used the Better Place technology but then gradually developed their own solutions. The first BAIOC battery-swapping system was launched in 2021.

The initial focus was on b2b solutions, in particular, taxi systems in the Beijing area. This was a strategic target because it is possible to approach the taxi system collectively and possible to fully cover its operating area with suitable solutions.

The first batch of ten battery-swap stations commenced operation October 29 2016 offering services across eight urban districts in Beijing. In 2016, 50 EV battery charging and swap stations were put into operation in Beijing to meet the battery-swap needs of at least 6,000 EV taxis. BAIC intends to establish battery-swap stations in 19 cities in China for 16,000 electric taxis. As a company, BAIC ranks 160th among the Fortune 500 listed companies.

"In 2016, 50 EV battery charging, and switch stations will be put into operation in Beijing and are expected to address the battery-swap needs of at least 6,000 EV taxis. Taxi drivers will be able to remove the battery once it starts running out of power and replace it with a fully charged one at the nearest station. The station locations have been planned so that drivers will not need to travel more than five kilometers for swapping battery. By the end of 2017, Beijing will be home to 200 EV battery charging and swapping stations, which will meet the requirements of 30,000 EVs. In preparation for the 2022 Olympic Winter Games in Beijing and Zhangjiakou, BAIC BJEV will replace 50,000 existing taxis with EVs equipped with switchable batteries,"

Xu Heyi, chairman of BAIC Group.

The statement was made in 2016. In 2019, BAIC announced plans for an additional 3,000 swap stations, enough to supply half a million electric vehicles by the end of 2022. A further 20,000 vehicles are to be added

Figure 34: Taxi in BAIC battery-swapping station (www.baic.com).

in 2020. BJEV itself currently offers three models that support battery replacement – including the EU260 and EU300 sedans.

This illustrates the speed of electrification in China as a whole.

"The control of air pollution is one of our current priorities and we are focusing on reducing pollution caused by vehicle emissions through boosting the adoption of EVs. As a forward-looking company, BAIC Group has a long track record of research and practice in the field."

Zhou Zhengyu, director of the Beijing Municipal Commission of Transport

The stations look like car wash units and mainly serve the company's taxi fleet.

BAIC BluePark New Energy Technology Co., which was the entity established by BAIC for commercialization of the solution, provides the service and operations. The BAIC Group, and its various entities, including BAIC JEV, has become the second-largest manufacturer and seller of electric vehicles in China. Here there are some important differences in comparison with the early Israeli, French and US approaches. BAIC is a large scale electric vehicle manufacturer, full system integrator of vehicles and battery-swapping systems, system developer and system commercialization business player.

They developed the original battery-swapping solutions, developed practical solutions, and developed their own cars that could utilize the solution. Then they set up their own entity to commercialize the product and also developed a new business model ensuring both business success and customer satisfaction. The initial focus was large taxi customers who were operating taxis in tough conditions and for whom a one-hour battery charge was a problem. Understanding of the market and customer combined with appropriate system solutions ensured market success. It was a very different solution to the earlier pioneering solutions.

"This will make cars much more affordable,"

Ma Fanglie, president of BJEV,
at an industry forum in 2020, China Daily.

Recently BJEV revealed a new version of its budget EV300 small car, priced at the equivalent of about $11,700, with unlimited battery swaps allowed for a monthly battery subscription of about $64. Scaling up of the system is now taking place with a new business model based on energy subscriptions, very similar to the new approaches in the smartphone area of application subscriptions.

In 2018 BJEV sold the EV300 compact car for about $12,000. It included an all-you-can-swap deal for about $60 a month.

BAIC's electric cars are not well known outside China. They are small and affordable, with prices targeted at middle class Chinese consumers. Making battery-swapping available in those models could represent a real opportunity for greater EV adoption in China.

The goal of BAIC is to supply half a million electric vehicles with battery-swapping by the end of 2022.

"BJEV wants to decouple the costs for the batteries from the purchase price of the electric cars through the battery exchange principle against the background of falling subsidies in China – by leasing the batteries."

BAIC Group and the State Grid Electric Vehicle Service Co., Ltd. (called "State Grid EV" for short) signed a framework agreement on July 27, 2020, to cement their strategic cooperation to promote the development of the NEV industry. To achieve fast development of a battery-swapping system, it is necessary to have a proper developed ecosystem with car manufacturers, technology development partners and state transmission system providers to ensure adequate electrical capacity for charging stations and charging piles.

"We plan to invest more than 10 billion yuan ($1.4 billion) to build 3,000 battery swap stations capable of serving 500,000 electric vehicles by the end of 2022."

Ma Fanglie, president of BJEV,
at an industry forum in early September.

Under the agreement, BAIC and State Grid EV will create an in-depth collaboration in businesses such as the sale of complete vehicles and packages of charging services, battery power packs, battery-swapping, green power, the smart energy service, and capital investment. BAIC BJEV and BAIC Mobility will promote the charging service packages offered by State Grid EV and cooperate on the connectivity and operation of charging piles, the EV community charging business, and new technologies such as plug-and-play, high-power charging and the automatic charging, in order to jointly form an ecosystem and a marketing model integrating complete vehicles, charging piles and charging service.

BAIC become the third largest stakeholder in Daimler in 2019. BAIC Group acquired a 5 percent stake in Daimler AG, providing reassuring group profitability in a dynamic market. With the German automotive giant having a new leader at the helm, it is seeking further success in China, and Europe. The partnership with Daimler has been profitable. BAIC 2018 profits grew 4.2 percent year-on-year to 37 billion yuan and were primarily the result of increased sales from the joint venture with Mercedes-Benz.

"It has been a long-term wish to deepen the partnership with Daimler through investment. We have joined hands for more than a decade and the partnership has yielded remarkable results."

BAIC's ambition is to expand in both NEV and charging infrastructure and particularly in battery-swapping. BAIC/BJEV is working on decoupling the costs of batteries from the purchase price of electric cars based on the battery-swapping system, by leasing out the batteries.

”We will separate the batteries from vehicles and lease them to car owners, making the cars much more affordable”.

Ma Fanglie, president of BJEV, at an industry forum, September 2020.

In preparation for the 2022 Olympic Winter Games in Beijing and Zhangjiakou, BAIC BJEV is to replace 50,000 existing taxis with EVs equipped with swappable batteries.

In the new vehicle models, EU220 to EU260, EU300 and EU5, all models will use the same battery-swapping system in respect of sizes and formats thus enabling all vehicles to use the same swapping system solutions. All vehicles now have a standardized modular design based on the same ideas.

In 2020 BAIC battery-swapping systems, vehicles and swapping stations, reached their fourth generation. The 4.0 generation requires only 75 square meters compared to 150 in earlier systems. By the end of 2020, BAIC had set-up 187 battery-swap stations and sold 18,000 battery-swapping vehicles, covering 19 cities.

A total of 4.8 million battery-swapping operations have been performed, equivalent to a total 690 million kilometers. The BAIC solution is the largest battery-swapping system in the world.

NIO launches “Battery-as-a-Service” to make EV ownership even easier

The transformation from old solutions to new battery-swapping technology has technical, economic and psychological aspects:

”I was actually unwilling to change the battery in the first month when I got my new car,” …
”I didn’t want to give away my battery. It was new!”

NIO ES6 owner.

NIO is one of the newest and one of smallest Chinese EV manufacturers. Some consider NIO to be one of the most innovative EV companies in China. NIO had about 9,000 employees in 2020.

NIO is developing a wide range of e-scooters, e-motorcycles and e-micro mobility solutions, all the way up to modern small cars. All are based on the idea of flexible battery-swapping solutions.

Financially NIO is facing some trouble with a $390 million loss in the first quarter of 2019, cancelled plans for its own factory and the postponement of a new model. NIO cars are manufactured by JAC, another Chinese car manufacturer. This is a quite normal situation for many Chinese NEVs. They own the design and the brand; they develop business models but the manufacturing is outsourced to a few large manufacturers.

Figure 35: NIO scooter (www.nio.com)

Figure 36:
NIO board (www.nio.com)

NIO has introduced a new series of EVs and provides lifetime free battery-swapping services for those who buy brand new cars. Batteries are the most expensive portion of an electric vehicle. By removing what is essentially a large mass of chemicals sitting in the vehicle from the sticker price, NIO is addressing the higher-price pain point of EVs.

Figure 37: New NIO ES8 EV car suitable for battery-swapping (www.nio.com).

This approach is a reminder of the early days of Tesla offering life-time free charging for the Tesla EV. NIO customers can either buy a new car with a battery as one purchase and then pay for their own charging or the customer can buy the car separately from the battery which is then rented from NIO. In this way the purchasing price is reduced and the cost is distributed over the lifetime of the car. NIO has introduced a battery-swapping plan that makes the price of an electric car $10,000 cheaper.

A third solution is that customer buys the car and rents battery and charging using subscription-based solution fitting the driving needs of the customer.

The system solution is standardized and fully automated. From driving in to driving out takes less than three minutes during which the battery is automatically exchanged. People in the car can remain inside during the battery-swapping process; it is similar to an automatic car wash. Of course, the payment system is automatic as well. Each station has five places for swappable batteries.

The performance of the new NIO ES6 is such that a driver has up to a 400 km range and if travelling between Beijing and Shanghai (about 1,400 km) drive all the way while taking advantage of up to five battery-swap stations on the way. At most, each pod contains five batteries, enough to serve up to 70 customers every day, when operated 24/7. The ES6 is all-wheel-drive and available with either a 70 or 84kWh battery providing 536 bhp and delivering 0–100 km/h in 4.6 seconds.

According to NIO, 50.1% of its customers used its battery-swapping services in 2020.

Figure 38: NIO ES6 at a battery-swap station. (www.nio.com).

NIO has already completed more than 700,000 battery swaps in 58 cities by 2020

By the end of 2020 NIO had installed 35,000 NIO chargers for static charging.

In addition, NIO is setting-up “NIO’s Power Mobile team” offering an impressive 40-60kW mobile charging service wherever the electric vehicle might be. These mobile vans can supply a charge to any brand of electric vehicle for both emergency charging and as a white glove valet charging service.

NIO’s battery-swapping technology has been available since 2014. NIO built its first battery-swap station in May 2018, and, as of June 2020, the company had completed more than 700,000 battery swaps.

A relatively unknown supplier of EVs, NIO has no less than 143 battery-swap stations in 64 different cities in the eastern part of China, and these have been operating for about three years.

The NIO business model lowers the initial car-purchasing investment by $10,000 while customers take out a battery subscription package to match their needs. The more battery swaps, the higher the price. Renting a 70-kWh battery with six swaps a month costs about $23-$26.

In June 2020, 40 percent of the 452 battery-swap stations in China were found in its capital Beijing, and the rest along the eastern coast where the economy is stronger. At the time of its creation, NIO had 141 stations across the country. NIO planned to build an additional 300 new stations during 2020.

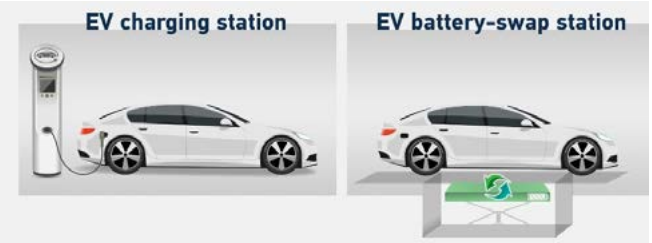


Figure 39: The principal model of the NIO battery-swapping system (Tianyu, 2020).

Figure 40: A standardized and fully automated NIO battery-swap station, in Beijing, China, August 3, 2020 (Tianyu, 2020).

Figure 41: Distribution of NIO’s battery-swap stations in eastern China (Tianyu, 2020).

Illustration of the impact of battery-swapping

Let us illustrate some consequences of battery-swapping systems:

- An average NEV/ICE vehicle owner drives 20,000 km annually.
- An average NEV/ICE vehicle owner drives about 400 km per week annually.
- That means an average NEV owner need to make 50 battery swaps annually, which is one battery swap per week.
- Driving the same distance in an ICE vehicle would cost the owner about $4,000 annually which is $330 per month (Swedish price level). Based on Chinese gasoline prices it would be $150.
- Customer prices for renting batteries from NIO and subscription on six battery swapping per month is about $30 in China.

One possible conclusion is that, at first glance, the battery-swapping solution might be cheaper for customers at first glance. Of course, other aspects relate to the variation in gasoline prices, government taxes, local salary costs, real-estate and operating labor costs for swapping stations etc.

Figure 42: Distribution of NIO swapping-stations along two highways (Randall, 2019).

The figure shows battery-swap stations and their density along two major highways in eastern China, Beijing-Shanghai and Beijing-Shenzhen. There are eight battery-swap stations between Beijing and Shanghai (156km between stations on the 1,250 km route) and 14 stations between Beijing and Shenzhen (157 km between stations on the 2,200 km route).

For comparison, the distance between Copenhagen in Denmark and Rome in Italy is about 1900 km and between Stockholm in Sweden and Rome in Italy is about 2550 km.

In 2020, a 70.0-kWh pack with six swaps per month was priced at about 180 RMB/$28. For those who don't want to swap batteries but still need the pack, the rental cost for the battery pack was about 150 RMB/$23 a month.

There has been speculation in China that NIO is working on plans to set up a battery asset management company in August 2021 to drive separation of the car from the battery - more specifically in collaborative agreements with some of China's largest automotive lithium-ion battery makers as investors.

"With the support of our partners, we've dedicated ourselves to deploying our battery swap network in order to offer users a worry-free driving experience on China's highways. The deployment of our battery swap network on the G4 expressway is the beginning of providing a charging experience beyond refueling,"

NIO co-founder and president, Lihong Qin.

In 2020 NIO announced that:

"All ES8 Founders Edition owners, as well as owners who have put down a deposit on the ES8 Standard Edition, will be able to enjoy 12 free battery swaps every year at any service station across China."

During 2020, NIO delivered more than 4,000 ES8 model fully electric SUVs to the Chinese market.

To support the diffusion of the NIO battery-swapping solutions, there will be an additional 1,100 battery-swap stations by 2021.

"Sorry, but the reason Tesla abandoned battery-swapping is because it doesn't work financially.

Think about the number of Tesla supercharging stations in the world today: about 11,000. Now if Nio has similar sales success that means there will be at least 11,000 additional batteries out there tying up Nio's capital for One Swap Per Station Per Charge Time. That is, the depleted battery is not able to be used again until it is fully charged, so the longer it takes to charge the more batteries Nio must own. So it's in Nio's interest to charge those batteries as quickly as possible, like supercharging them, right?
Well if you can supercharge a battery outside of the car, then you can supercharge it inside the car, too. So, why do you want to swap a battery out in the first place??? This doesn't make economic sense, and I haven't even made the argument about battery packs stacking up in the wrong swap stations while other stations run out of fully charged batteries. Sigh. And people think these Nio guys are smart.

Elon Musk,

https://electrek.co/2018/11/01/nio-battery-swap-station-next-tesla-supercharger/

That may be so, but times are changing. The ideas are persistent. The solutions when Tesla tried them and the solutions now at the time of NIO and BAIC are technically similar but business-wise very different. What we saw in the Tesla battery-swapping solution was technical invention but what we see in the NIO and BAIC solution is a new business model enabling commercialization and what it looks like is market success and rapid growth in China.

NIO is expanding the ecosystem for growth

As we have seen in the BAIC case, NIO is expanding its ecosystem with big national transmission system companies. In December 2020, NIO reached an agreement with the State Grid EV Service for cooperation in a large-scale charging and battery-swap stations project.

The motivation for this collaboration is based on the core elements of the NIO business model.

The increasing relative prices of batteries, in relation to the entire car, the separation of the prices for cars, batteries and charging solutions makes sense to more people in the fast-growing Chinese NEV market. Chinese cities are very large with very high population densities, and there is a huge challenge in installing large numbers of private individual charging piles that can charge NEVs over-night as is common in smaller western cities where wealthy people live in large houses and can afford expensive Tesla cars and have an individual private charging station outside their house.

This is typically a major issue in the big and densely populated Chinese cities, and many other Asian cities. This is another driver towards the development of swapping systems and the growth of the new business model which is suitable for both the middle and lower-classes living in big-cities that want to own a car but do not have access to a personal charging spot.

FROM NICHE TO LARGE SCALE, DIFFUSION OF BATTERY-SWAPPING IN CHINA

Geely enters battery-swapping

The BAIC group and NIO have demonstrated similar solutions over the last years. The strategic collaboration with national transmission system operators illustrates the strong partnership between industry and national strategic interest. This direction receives strong political support. (Zhenhuan, 2021).

In late 2020 Geely (owner of Volvo Cars) (founded in January 1986 and headquartered in Hangzhou) announced it was entering the battery-swapping business by establishing operations in Chongqing.

Its new battery-swap station has 39 charging positions. The station can support nearly 1000 battery swaps per day. It takes 90 seconds to finish a battery swap and the users do not need to get out of their vehicles during the process. Geely is planning to build 35 battery-swap stations in Chongqing by the end of 2020 rapidly growing this to 100 stations during 2021 and to 200 by 2023.

> *"We have established intelligent battery-swap stations in Chongqing, Hangzhou (in Zhejiang province), and Jinan and Zibo (in Shandong province),"*
>
> Yang Quankai, head of battery-swapping at Geely

By 2025, Geely Technology Group will have 5,000 battery-swap stations across China.

Geely announced the progress of going the battery-swapping route at the 2020 China International Intelligent Industry Expo, which showcased its dual-compartment smart battery swap station, covering

Figure 43: Geely new battery-swapping station (Zhang, 2022).

an area of about 126 square meters. It has 39 built-in charging bins, vehicles can battery swap at great speed in the station, a single station daily service to reach nearly 1,000 car times.

> *"A car can be battery swap from driving into the battery swap station, to the vehicle intelligent identification, inspection, and then to the chassis battery replacement, intelligent payment, the vehicle leaves the battery swap station and other aspects of the process is very smooth".*
>
> *"The battery swap station is based on high modularity, high compatibility, high security, high intelligence of the battery swap technology platform, developed with battery swap, charging, monitoring, fire, intelligent temperature control, battery maintenance and other functions as one of the intelligent energy replenishment terminal, can to new energy Car users to provide safe, convenient, efficient and reliable replenishment service."*
>
> Zhang, 2020.

South Korean SKI enters the Chinese battery-swapping market

Early in 2021 it was announced that the South Korean company SK Innovation is expanding its strategic collaboration with BAIC that started in 2013 by entering the battery-swapping business in China. This has been made possible by a strategic investment by SKI in Blue Park Smart Energy (BPSE), a subsidiary of the BAIC Group (Hampei, 2021). This joint venture aims to expand swapping technology and provide access to high-quality batteries from the South Korean company, which is one of the main battery suppliers to major NEVs in the world including those of Ford and VW.

SKI being one of the largest battery suppliers in the world and also a large operator of gasoline stations in South Korea is looking to expand its operations in S Korea with battery exchange stations and energy storage systems.

Figure 44: BAIC new Blue Park Smart Energy swapping station (Hampei, 2021).

BATTERY-SWAPPING GOES GLOBAL …

Battery-swapping in India …

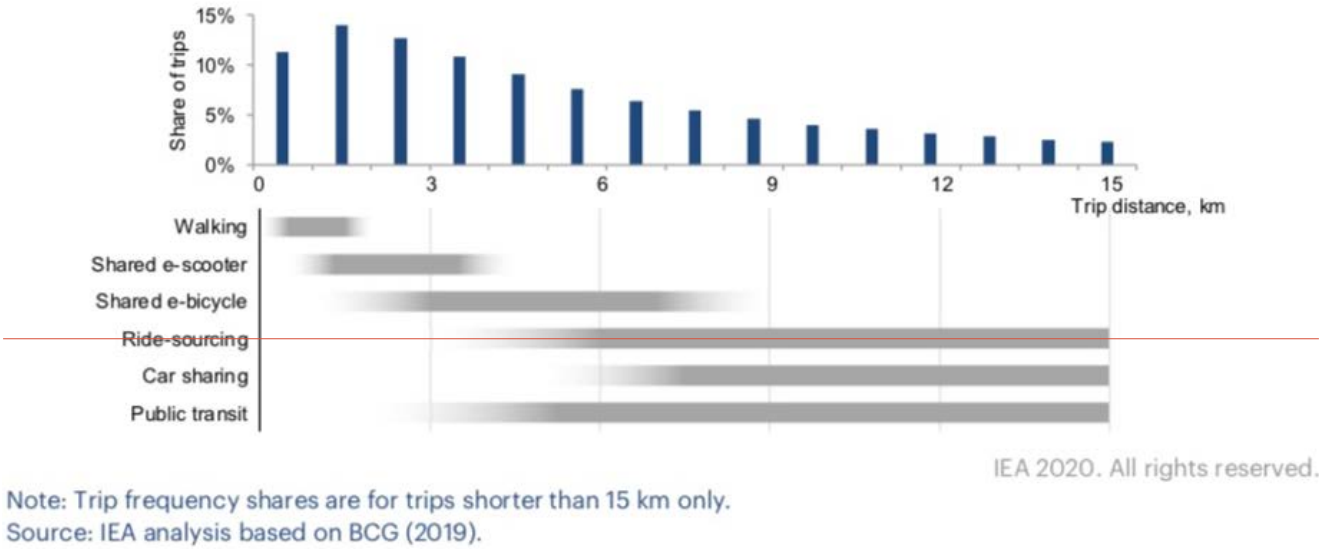
We are used to talking about standard four-wheel cars when we talk about NEVs. Both in China and in the rest of Asia two- and three-wheelers are both popular and sold in large volumes. They are also being electrified and one solution is battery-swapping for two- and three-wheelers. This micromobility has developed very quickly and meets very important demands for short distance transportation, particularly in densely populated and very large Asian cities.

The two- and three-wheeler segments are large. By 2019 the entire segment had a level of about 300 million units. And it is expected to grow to 400 million by 2030, which is about 33% growth in ten years. This segment comprises 40% of the entire global NEV market.

In China and in the rest of Asia, as well as in Europe and USA about 50% of passenger kilometers are journeys under 8 kilometers. In the west people use their cars even for short trips. In the USA many cities are built around the car as the main transportation solution. E-scooters and e-bikes are a fast-growing system solution, and shared e-scooter trips are expected to grow from 230 million in 2019 to 850 million in 2028.

The figure below shows the proportion of trips under 15 kilometers in the USA and suitable mobility trip distances.

We need to bear in mind that this is based on the USA context, history and transportation traditions. In Asia the context is different and as we have seen the likelihood of micromobility being used is higher. This is due to the sizes of cities in China and Asia, the population density of cities, and traffic density.



Note: Trip frequency shares are for trips shorter than 15 km only.
Source: IEA analysis based on BCG (2019).

Figure 45: Trips under 15 kilometers in the USA and suitable mobility trip distances (IEA, 2020).

Two- and three-wheelers

Electric two and three wheelers represent the major share of the total vehicles in use. This market is also easier to electrify from a technical and regulatory point of view and has more customer-friendly charging solutions. This is true for China and India as the largest economies in Asia but also for another 10 countries in the ASEAN area.

China is taking the lead in the two- and three-wheeler market as well as for standard four-wheelers. There were about 300 million electric two-wheeler vehicles in China in 2019. It is expected that this market will grow by 33 million in 2020 and 36 million in 2021.

The fleet of three-wheelers in China is the largest in the world comprising about 50 million units in 2019. And the total number is growing.

India has rapidly become another fast-growing electric vehicle market, that is comparable to China in its early phases. India had 600,000 electric two wheelers in 2018, and the growth is estimated to about 55,000 extra electric two-wheelers in 2018 which is expected to increase to 126 thousand in 2019. India had about 1.5 million electric three-wheelers in 2019 and sales are increasing with new domestic brands.

However, some important distinctions exist in the Indian market making it different to many other countries. India has almost the same population size as China but is smaller which means a much higher population density. Compared to China, India is lagging behind in terms of economic development. Two and three-wheelers dominate the Indian auto market, and over 80 per cent of total vehicles in India are two-wheelers. This will impact the development of electric vehicles in India.

Another important aspect is the economic situation of the population and the affordability of high-priced electric vehicles as is the case in the rest of the world. The high upfront cost of EVs is due to the high price of the battery pack, which constitutes 40-60 per cent of the value of an EV. In the case of battery-swapping, the battery packs are often separated from the vehicle and owned by energy operators. Therefore, the end-user will only need to pay when they swap a used battery for a charged one.

The Indian government has been exploring different technologies and different approaches to the electrification of transportation due to environmental issues and is learning from the fast development of the world in this area.

Figure 46: Illustration of battery-swapping in India on popular two- and three-wheelers (EVReporter, 2021).

Thus, to develop India's electric car industry, the government will, bearing in mind the local conditions, also have to recognize 'battery-swapping' alongside the other charging models if it wants to kick-start a fast deployment of EVs in India's domestic market.

Thus, battery-swapping technology may well undergo faster adoption in the electric two-wheeler and three-wheeler mobility segment. In this segment (small vehicle), battery-swapping technology represents a leapfrogging opportunity for India's EV dreams because it offers cost-effectiveness for consumers and several comparative advantages over dedicated charging infrastructure and fossil-fuel approaches in terms of ease of use.

In all instances, the conversation revolves around the deployment of EV charging points because a lack of charging infrastructure is hindering the expansion of EVs. If India envisages a break-out on the electric mobility front in the coming years, then it will be crucial to create an EV charging ecosystem alongside this expansion.

In 2020 there were several companies working on battery-swapping solutions, primarily focusing on two- and three wheelers. One example of this fast development is that in 2021 100 electric vehicle battery-swap stations are to be installed in Bengaluru in India.

The lack of clear government policies, lack of standardized systems and technology solutions are some key barriers to further development of battery-swapping solutions in India.

One driver in this direction is that oil companies are working on new plans for establishing 20 battery-swap stations in Chandigarth and more stations in Amritsar and Bengaluru. Gradually this development will take off.

Although India is lagging behind, when India starts this process of electrification based on local conditions, the growth is expected to be high and fast. A recent report suggests that India's EV battery-swapping market is projected to reach $6.1 million by 2030, registering 31.3% growth during 2020-2030. The Indian battery-swapping market is predicted to generate a revenue of $6.1 million by 2030, during the forecast period (2020–2030). Considering service type, the market is divided into a subscription model and pay-per-use model, with the subscription model division predicted to grow at a faster pace in the years to come, because the growing utilization of battery-swapping technology in commercial vehicles would result in the growing adoption of the subscription model.

On the basis of vehicle type, the Indian electric vehicle battery-swapping market is sub-divided into commercial vehicle, two-wheeler, and three-wheeler, as per a report by P&S Intelligence. The three-wheeler category is expected to dominate the market and is predicted to capture more than 90.0% of the market in 2020. This can primarily be ascribed to the fact that the daily operating hours of these vehicles are rising, and that their batteries need to be recharged/exchanged quickly for further use.

Battery-swapping in Europe …

Technology development is a dynamic process. As it spreads from one part of the world to another, it is transformed and adopted to local conditions, and later when it comes back it might be very different, and hopefully will have been developed further. It is a mutual learning process. Where this process starts and ends depends on the observer.

The experience from China on battery-swapping solutions and experience of successful implementation and commercialization is influencing development in Japan, the US and also in Europe. Who and where ideas originate from is not easily pinpointed.

Sometimes ideas from one industry influence another industry. The fast development of smartphones and the business models in high-tech business are diffusing to other areas, especially when the traditional automotive industry is based on intensive collaboration between new players and software, electronics, electrical systems and machinery are all integrated together. The future automotive industry will be more like the smartphone industry than we might currently envisage. The flow of ideas across industries will probably be even more important in the future.

Battery-swapping in Italy

Fiat

Maybe the most advanced car solution coming to the market is the Italian Fiat Centoventi. This new Fiat model has a modular design giving the customer many options to suit its wishes (Beedham, 2020).

As the battery in an electric car is one of the most expensive items, and the item causing most customer worries about quality and durability as well as the item that drives secondhand prices down, the new Centoventi will give customers an opportunity to flexibly select a battery capacity from short range to 500 km driving range after purchasing the car, and probably battery-swapping solutions that make this possible. Fiat's dream sees the Centoventi with a modular battery pack which has a starting range of about 100 km (about 62 miles) with the potential to increase this up to 500 km (about 310 miles).

Fiat's design comes with one factory-fitted battery but could be expanded with an additional three. Each battery would increase the vehicle's range by 100 km (about 62 miles). Additional batteries could be bought when a driver's needs change. The energy packs could even be rented if a driver needed a little temporary extra range. Fiat is claiming that changing batteries would be as simple as swinging by a local Fiat dealer or service station and having them fit the new power packs. The batteries would mount into the floor pan of the car on sliding rails, to make fitting them relatively easy. In principle, it would only take a few minutes.

This Fiat could be the first large-scale battery-swapping system solution, outside China.

What we also see is the influence from the smartphone market and the business model becoming dominant in this rapidly changing market, the use of separation between hardware, software and functionally, the emerging subscription model, giving the consumer a high level of freedom to choose and adopt to new demands. The downside is locking in customers in a supplier trap with business model lock-in.

Figure 47: Fiat Centoventi with battery-swapping (Beedham, 2020).

Once you chose one supplier it becomes more complicated to switch to another particularly when new smart vehicles are fully interconnected with outside business, smart and intelligent cities and communities, customized functions etc. This is what both BAIC and NIO has developed and demonstrated in practice. Whether this will be a main path for the diffusion of battery-swapping remains to be seen.

Logo Flymove

Logo Flymove is another Italian automaker focusing on super-sport car design, with its sights on the development and manufacture of electric cars based on fully integrated battery-swapping systems.

They have plans to go commercial in Europe, China and US with their proprietary swapping system, starting in 2021.

Figure 48: Logo Flymove with battery-swapping (Source: https://www.flymovedianche.com/en/).

Battery-swapping in Germany

In Germany one approach to developing and putting battery-swapping into practice is shown by Adaptive City Mobility. Here the focus is on small city-oriented vehicles, based on manual swapping of modular battery designed solutions placed in a quite simple vehicle design as demonstrators.

The ACM car concept is designed for a 60-80 km/h driving speed, with a normal driving range of up to 160 km per charged system. Automatic swapping stations will be developed.

Figure 49: Adaptive City Mobility battery-swapping.

Battery-swapping in Finland

In Finland too, there are examples of prototyping and the demonstration of vehicle and battery-swapping system solutions - the Tank-Two company with operations in Finland, USA and Germany.

In the Tank-Two solution the traditional battery is replaced by a new kind of smart and intelligent battery, the string battery. The Tank-Two is not a typical swapping technology but rather is based on exchanging the used and empty small string batteries with charged ones from a central system.

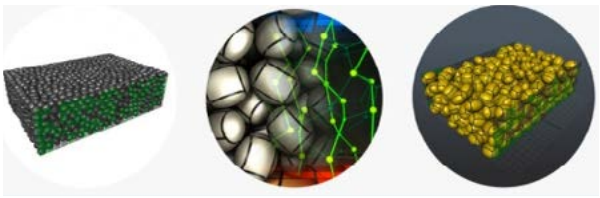


Figure 50: Tank-Two alternative energy.

Battery-swapping in Sweden

In Sweden too there is one company working on prototype battery-swapping solutions, Powerswap. Powerswap has developed and demonstrated a fully automatic battery swap system solution for electric vehicles. With Powerswap you can swap the battery pack in 3 minutes. Powerswap's business model is based on sales of battery swap equipment and licensing agreements with OEMs and battery makers.

Power Swap do not make vehicles to go alongside their new system solution nor do they develop and install distributed swapping stations.

Their business model looks very much like the Better Place solution. Power Swap is dependent on vehicle OEMs adopting this system, totally redesigning their vehicles to match this modular designed battery-swapping system and building the battery-swapping infrastructure.

Figure 51: Powerswap battery-swapping (https://powerswap.se/).

Figure 52: Powerswap battery-swapping in detail (https://powerswap.se/).

New battery-swappig in USA

A new company in battery-swapping in USA is the start-up Ample. Ample opened its first electric vehicle battery swap stations — in the San Francisco Bay Area in 2020 focusing on Uber drivers with electric vehicles as Ample's first customers.

Ample now operates five battery swap stations in the San Francisco Bay Area specifically for Uber drivers. Participating drivers with supported electric vehicles can exchange a spent battery for a fully charged one in less than 10 minutes.

Participating drivers in the Ample program, with supported electric vehicles with Ample modular battery pack design, can exchange a spent battery for a fully charged one in less than 10 minutes. Ample can replace a few modules in a pack or all of them, depending on how much of the battery was drained and how far it needs to go before returning home for an overnight recharge. Companies trying battery swaps in the past exchanged the entire pack, not individual modules within them.

From the start, the stations have a maximum capacity of 90 cars per day.

Figure 53: Ample's modular electric vehicle batteries.

"Battery swapping has massive challenges in terms of capital requirements," he said. "Just like bike-sharing, it's not evenly distributed. It might make sense to have stations along a particular route, but demand can spike around travel, like at Thanksgiving time. They will have to move heavy batteries from place to place to make this work."

"But there are some risks that are kind of low tech if you're going to be taking batteries out of your vehicle over and over again, like dealing with dirt and grime from the road that can get introduced into your system."

Scott Case, CEO of Ample in Kolodny, 2021.

Battery-swapping in Japan … goes international

In Japan too several new approaches to develop and commercialize battery-swapping solutions are emerging.

The Japanese electronic manufacturing company Sony has announced a new car, Vision-S concept based on flexible system solutions and battery-swapping, Tesla has demonstrated a new Cybertrack model that also has flexibility in design and uses battery-swapping solutions.

Another commercial example is the startup Japanese EV maker Fomm and the established technology supplier Fujitsu who have entered an alliance aimed at developing what it calls a Battery Cloud Service; it would give users the choice between charging batteries at home or exchanging a depleted one for a fully charged pack at a service station in just five minutes. The partnership will start with a battery solution that provides a very small four-wheeled urban EV, to be initially sold in Thailand, with a 150km driving range (Halvorsson, 2018)..

Another Japanese manufacturer, Honda, earlier this year revealed the Mobile Power Pack World—intended for a wider ecosystem that could be used to power a home in a power outage, a work site, or a camp-site. Its partner in the venture is Panasonic, which is also the official supplier of lithium-ion cells for Tesla vehicles and Tesla's partner in the Gigafactory that manufactures them.

In 2021 Honda announced a first "research experiment" with the Mobile Power Pack in Indonesia, where it will be given a market test in electric motorcycles and other mobility products.

Figure 54: Fomm new car for battery-swapping (Halvorsson, 2018).

At charging-station kiosks, users will be able to exchange their battery instantly for a fully charged one. This is another effort to develop new technical solutions with supportive business models.

It is interesting to note that the large Japanese manufacturers joint the battery manufacturers to jointly develop and commercialize vehicles and batteries in an integrated modular design suitable for battery-swapping aiming at emerging Asian markets and not the mature markets of US and Europe. This might be an indication of the dynamics in the rapidly growing Asian markets and also that Asian customers care more about smart, practical and economically feasible solutions than prestigious brands from the USA and Europe.

Very probably we will see battery-swapping system solutions from other manufacturers in the future.

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