



Overview on Battery Swapping and Battery-as-a-Service (BaaS) in China

Imprint

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Background

New Energy Vehicles (NEV) ¹ and in particular battery electric vehicles are widely seen as key to make transport more sustainable and climate-friendly, and, in line with the promotion of renewable energy, to reach the climate targets of the Paris Agreement. In its current stage, the direct electrification of vehicles comes along with challenges. Even though significant advancements in battery and charging technology and infrastructure were achieved in recent years, a key concern regarding battery electric propulsion is the relative limitation of range compared to the internal combustion engine (ICE) and the time needed to recharge the batteries. In addition, worries about battery depreciation and high costs are often hindering customers from switching from ICE to battery electric vehicles. Battery swapping² promises to solve those issues by, as a complement to conventional charging, allowing the change of battery packs within minutes.

In addition to battery swapping technology, Battery-as-a-Service (BaaS) is offering innovative business models linked to the energy sector. BaaS is typically defined as a service model enabling people to buy an electric car without buying its battery pack where customers can sign up for energy plans paying monthly rental fees for battery use, being able to choose battery packs of different capacities.

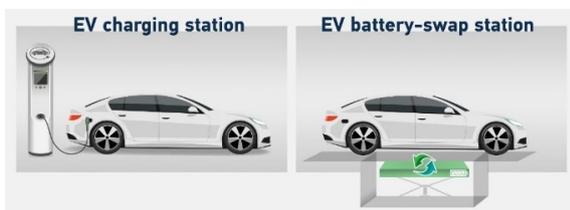


Figure 1: EV charging and battery swapping, Source: Yin Yating, CGTN

¹ Including battery electric, hybrid, plug-in hybrid and fuel cell electric vehicles

² In battery swapping stations, robots physically remove empty batteries from vehicles and replace them with fully charged batteries

History of battery swapping

The idea of swapping batteries and BaaS is not entirely new. Battery swapping was first proposed already in 1896 and, for trucks, put into practice between 1910 and 1924 by the Hartford Electric Light Company, a subsidiary of General Electric. Customers could purchase vehicles without a battery from the General Vehicle Company (GeVeCo) and the power could be purchased from Hartford Electric as a swappable battery. The vehicle owner paid a flexible per-mile charge as well as a monthly service fee for maintenance. In 1917, a similar service was operated for owners of Milburn Light electric cars in Chicago.³ In the 1970s, Mercedes tested battery swapping and built about 40 electric buses with a manual horizontal battery swapping system (see figure 2) but concluded that the technology is not safe. Thus, the project was not continued.⁴



Figure 2: Battery swapping on an electric Mercedes bus in the 1970s, Source: The Green

More recently, the concept of battery swapping was introduced by the company Better Place in 2008, which at its peak operated 21 battery swapping stations in Israel (see figure 3) and expanded in cities

³ https://en.wikipedia.org/wiki/Range_anxiety

⁴ <https://www.greenoptimistic.com/mercedes-versus-project-better-place-20090311/>

around the world.⁵ Despite its initial success, the company filed bankruptcy in May 2013, mainly due to financial issues and the fact that the NEV market was far from being ripe at the time and demand for the service was low.



Figure 3: Better Place Charging Station, Source: Wikipedia

Tesla in 2013 demonstrated battery swapping as a potential complement to fast charging with the ability to change the battery of a Tesla Model S within 90 seconds. Tesla then constructed a battery swapping station at Harris Ranch between Los Angeles and San Francisco offering the service at around EUR 50. But even though Tesla's battery swapping system was considered to be a technological breakthrough, the company's plans to deploy battery swapping stations were abandoned in 2015. Tesla due to lacking customer interest, -according to Elon Musk, "clearly, it's not very popular"-, then focused on the expansion of its supercharger network. Battery swapping became popular also in the field of scooter and kick-scooter sharing where companies such as Gogoro or Voi use the technology to solve the range problem and increase customer acceptance. Battery swapping is also widely used in warehouses in the operation of electric forklifts and is increasingly discussed as a partial solution to the electrification of long-haul heavy-

duty freight transport. Besides the battery swapping technology, BaaS models are getting increasingly popular as they offer opportunities especially for car manufacturers to get into the energy business itself, which is associated with the transformation towards electric mobility.

As described, both battery swapping and related energy business and service models are not new inventions but have never been successfully adopted on large scale. This could change now as in China battery swapping and BaaS are actively promoted by the government and pushed forward by companies such as NIO, Geely or Aulton New Energy Automotive Technology.

Battery swapping and BaaS in China

In China, the world's largest vehicle market, electro-mobility is an important key to industrial transformation, energy security, to promote clean transport and to achieve the 2030 carbon dioxide peaking and 2060 carbon neutrality targets set by Chinese president Xi Jinping in 2020. With about 5.8 million NEV on the road⁶ (May 2021), accounting for about half of global NEV population, and a total of 65,000 charging stations and 1.87 million electric vehicle charging piles⁷ (April 2021), China is the world's largest electric vehicle market reaching a domestic NEV market penetration of 8.7 percent.⁸ In the first half year of 2021, NEV sales reached 950,000 units, an increase of 220 percent compared to the same period in 2021 with total sales for 2021 expected to hit 1.8 million.^{9 10}

⁵ The company in 2011 also announced a cooperation agreement with the China Southern Power Grid Company and signed a Memorandum of Understanding with Chery Automobile to develop prototypes for electric vehicles to be used in regional state-sponsored pilot projects

⁶ http://www.xinhuanet.com/english/2021-06/19/c_1310016120.htm

⁷ http://www.china.org.cn/business/2021-06/19/content_77576332.htm

⁸ http://www.xinhuanet.com/english/2021-06/19/c_1310016120.htm

⁹ http://english.www.gov.cn/archive/statistics/202106/19/content_WS60cd566ac6d0df57f98db7ef.html

¹⁰ <http://www.chinadaily.com.cn/a/202105/17/WS60a1b90ca31024ad0babe2bb.html>

According to the *New Energy Vehicle Industry Development Plan (2021-2035)*, the country aims to achieve electric vehicle sales of about 20% of total new car sales (currently 5%).¹¹

With the increasing share of battery electric vehicles, a more diversified landscape of charging options is emerging to better meet the different demands of customers. This also includes battery swapping, which is promoted by the Chinese government and companies, such as NIO, Geely or Beijing Electric Vehicle Co Ltd. By the end of June 2021, 716+ battery swapping stations have been in operation in China with the majority of stations operated by Nio and Aulton New Energy Automotive Technology.¹² While still being in its infancy, many experts predict the market for battery swapping infrastructure and respective energy business models to significantly increase in the next years. According to Mr Zhang Feng, deputy general manager of Blue Park Smart Energy (Beijing) Technology, “in the next 5-10 years, the number of commercial vehicles with potential demand for battery swapping will reach 4 million” and “we believe that by 2025, the number of battery-swapping NEVs will reach 1.24 million, with 12,370 battery-swap stations needed”.¹³ Battery swapping in China is promoted by the government mainly in the form of guiding policy support, subsidies, pilot programs and standardization efforts as described below.

Policy support

The Chinese government has introduced various policies to guide and support the development of the battery swapping industry since 2019. In June 2019, the

*National Development and Reform Commission (NDRC), the Ministry of Ecology and Environment (MEE) and the Ministry of Commerce (MOFCOM) jointly issued the Implementation Plan for Promoting the Renewal and Upgrading of Key Consumer Products and Smooth Resource Recycling (2019-2020)*¹⁴, which proposes to encourage enterprises to develop NEV products with a combination of charging and swapping and flexible battery configuration.

In the *New Energy Vehicle Industry Development Plan (2021-2035)*, which was published by the *State Council Office of the People's Republic of China* on 02 November 2020, it is stated that battery swapping shall be encouraged, the construction of battery swapping infrastructure accelerated, the modular traction battery standard system shall be established and improved, by 2025 battery swapping services shall be significantly improved, and by 2035, the battery swapping service network shall be convenient and efficient. The plan functions as a top-level policy guiding investment, research and development (R&D), the formulation of subsequent policies and promotion programs, and the implementation of pilot projects.

In its *New Infrastructure Plan*, which was announced at the *2020 National People's Congress* by the CCP, China targets at the active promotion of and investment of about EUR 1.15 trillion into “new infrastructure” (新型基础设施) as a top-level development priority.¹⁵ In line with

¹¹ <https://transition-china.org/mobilityposts/china-issues-the-blueprint-for-its-electric-vehicle-and-intelligent-connected-vehicle-industry-development-for-the-next-15-years/>

¹² <https://www.caixinglobal.com/2021-07-13/china-juices-up-drive-into-ev-battery-swapping-centers-101739325.html>

¹³ <https://epaper.chinadaily.com.cn/a/202101/04/W55ff2575aa31099a234352f90.html>

¹⁴ http://www.gov.cn/xinwen/2019-06/07/content_5398219.htm

¹⁵ <https://www.china-briefing.com/news/how-foreign-technology-investors-benefit-from-chinas-new-infrastructure-plan/>

the *Made in China 2025*¹⁶ and *China Standards 2035 Plan*, “new infrastructure” refers to “digital, smart, and innovative” infrastructure including 5G networks, industrial internet, inter-city transportation and rail system, data centers, Artificial Intelligence (AI), ultra-high voltage power transmission, and new-energy vehicle charging stations.

In the *Report on the work of the government*, which was delivered at the fourth session of the *13th National People’s Congress of the People’s Republic of China* on 05 March 2021, it is stated that in 2021, “more parking and electric vehicle battery charging and swapping facilities will be built” (in 2021).¹⁷

It is expected that battery swapping will also play an important role in the 14th Five-Year Plan period (2021-2025) and will be promoted in various sectoral 14th Five-Year Plans, which will be released in the coming months.

Subsidies

Multi-level fiscal support measures, in particular the granting of national level vehicle purchase subsidies and the exemption of NEVs from the 10 percent vehicle purchase tax, are key to the successful uptake of electro mobility in China. During the Executive Meeting of the *State Council* on 31 March 2020, it was determined that the NEV purchase subsidy policy, which before was set to expire on 31 December 2020, would be extended for another two years until the end of 2022 with electric vehicles with battery swapping technology being exempted

from the upper limit of RMB 300,000 (EUR 38,600) list price above which no national level purchasing subsidies can be granted.¹⁸

Standardisation

On 06 May 2021, China's *State Administration for Market Regulation* (SAMR) approved the *National Standard for Battery Swap Safety Requirements for Electric Vehicles* (GB/T 40032-2021). The standard is the first mandatory standard governing the development of battery swapping in the EV industry. This is important because the lack of uniformity in standards is considered a key obstacle to the development of EV battery swapping systems in China. The standard was drafted by companies including NIO, Beijing Electric Vehicle Co Ltd, and GEELY and will come into effect on 01 November 2021 specifying safety requirements, test methods, and inspection rules for battery swappable electric vehicles (e. g. models with snap-on batteries need to be able to support at least 5,000 battery swaps, while models with bolt-on batteries need to be able to support at least 1,500 battery swaps).¹⁹

Pilot project promotion

China's *Ministry of Industry and Information Technology* (MIIT) and the *National Energy Administration* (NEA) recently decided to jointly organize a nationwide pilot project for the application of battery swapping, with the aim of implementing the *New Energy Vehicle Industry Development Plan (2021-2035)* by

¹⁶ Made in China 2025 refers to the Made in China (MIC) 2025 document, which was released in 2015 by the Ministry of Industry and Information Technology (MIIT) and outlines how China shall shift from being a low-end manufacturer to becoming a high-end producer of goods by transitioning the country’s existing manufacturing infrastructure and labor market towards producing more specialized output including the target sector of energy saving and new energy vehicles (Source: China Briefing)

¹⁷ <http://www.xinhuanet.com/english/download/2021-3-12/report2021.pdf>

¹⁸ More information can be found here: <https://transition-china.org/mobilityposts/recent-changes-to-new-energy-vehicle-nev-incentive-policies-in-china/>

¹⁹ <https://cnevpost.com/2021/05/10/battery-swap-national-standard-to-go-into-effect-nov-1/>

promoting the innovative application battery swapping, the in-depth integration of NEVs with the energy sector, and supporting the achievement of the 2030 carbon dioxide emission peaking and 2060 carbon neutral targets.²⁰ The project includes seven major areas, such as key technology R&D, the target of promoting battery swapping vehicle pilot projects in public sectors such as public transport, car rental, urban logistics and distribution, ports and mines, and promoting commercial operations in the private sector. Based on the actual demands of cities, reasonable and feasible goals for the promotion of battery swapping will be set to encourage first pilot projects in those fields.

Overview on selected companies related to battery swapping and BaaS in China

Since recent years, various Chinese companies are developing and expanding battery swapping infrastructure networks and respective BaaS models. Strategic partnerships are formed between automakers, shared mobility service and taxi companies, battery swapping service companies and energy companies aiming at bundling resources and knowledge and to share costs. It is expected that guided by government policies more such partnerships will emerge in the coming years. Below listed is a selection of companies, which are actively engaging in battery swapping, BaaS and mobile internet-based power solutions as part of their larger electro mobility and energy ecosystems.

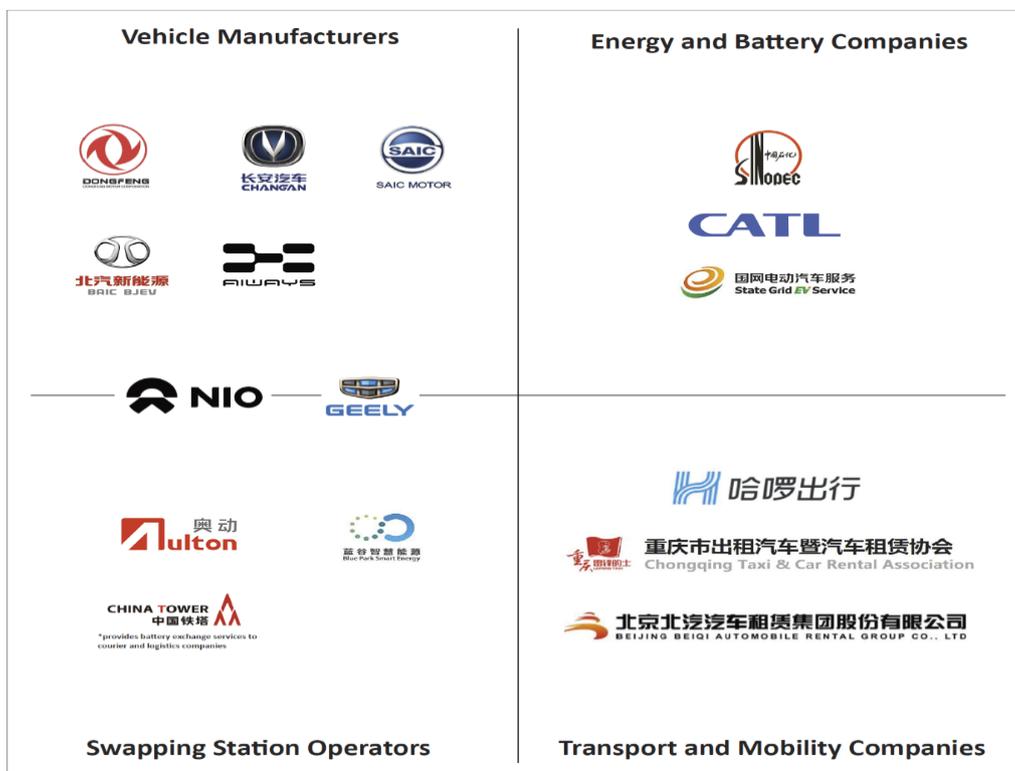


Figure 4: Selection of companies engaged in battery swapping and BaaS, Source: GIZ

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<https://new.qq.com/omn/20210427/20210427A0EGD300.html>

Car manufacturers

- **Aiways:** Aiways recently formed a strategic partnership with Blue Park Smart Energy engaging in battery swapping businesses, aiming to jointly develop battery swapping technologies and battery swappable electric vehicles, cooperate on the production and sale of facilities related to battery swapping stations, big data, as well as the brand promotion, so as to meet the energy supply demands for taxis and ride-hailing services. Over the next three years, the companies plan to co-deploy at least 20,000 electric vehicles equipped with swappable battery pack across 17 cities and build over 200 battery swapping stations to form a network for scale battery swap service.²¹
- **BAIC Beijing Electric Vehicle Co Ltd (BJEV):** BJEV operates 225 battery-swap stations in 19 cities in China. Already in 2018, BJEV sold its EV300 compact car for about EUR 9,900 including an all-you-can-swap deal for about EUR 50 a month.²² As of November 2020, the company had 22,000 battery-swapping vehicles on the road.²³ By the end of 2020, there were 142 taxi battery swapping stations in Beijing.²⁴
- **Changan Automobile Co.:** Changan Automobile launched its first battery swap station in Chongqing along with a consortium including CATL, Aulton New Energy Vehicle Technology Co., and State Grid and plans to expand into Hangzhou, Jinan and Zibo.
- **Dongfeng Motor Corporation Passenger Vehicle Company (DFPV):** Dongfeng Motors and Aulton recently formed a strategic partnership for battery swapping aiming to jointly develop the Dongfeng Fengshen E70 electric vehicle equipped with swappable batteries, which will be rolled out in Wuhan and Nanjing for ride-hailing service.²⁵
- **Geely:** Geely has established 39 battery swap stations in China, with plans to expand to 200 locations by 2023 and up to 1,000 locations through established agreements.²⁶ According to Mr. Yang Quankai, head of battery swapping at Geely, by 2025, the company will have 5,000 battery-swap stations in operation across China. Unlike other company's swapping stations, Geely's stations are front entry, rear exit with car plates being identified on entry and the respective fees are automatically charged to the driver's account. The average swap costs around EUR 7, to full replenish a car's full range (around 400km under NEDC range).²⁷ Geely's battery swapping stations have a capacity of 39 batteries serving up to 1,000 vehicles per day. Geely recently developed its first battery swapping vehicle, the Maple 80V.
- **NIO:** NIO offers BaaS subscription-based swappable batteries for customers, functioning as complement

²¹ http://autonews.gasgoo.com/new_energy/70018180.html

²² <https://electrek.co/2020/01/17/ev-battery-swapping-is-dead-in-us-but-china-wants-to-make-it-happen/>

²³

<https://epaper.chinadaily.com.cn/a/202101/04/WS5ff2575aa31099a234352f90.html>

²⁴ http://www.bj.xinhuanet.com/2020-12/11/c_1126849442.htm

²⁵ <http://autonews.gasgoo.com/m/70018137.html>

²⁶ <https://paultan.org/2021/06/18/geely-to-stick-to-integrated-battery-tech-for-evs-based-on-sea-platform-battery-swapping-still-a-long-way-off/>

²⁷ <https://www.dsf.my/2021/05/advantages-of-geely-battery-swapping-tech/>

to conventional charging. The BaaS service allows the company to sell vehicles without a battery. Customers can save EUR 8,900 when purchasing the vehicle with a 70kWh battery (see figure 5) and can sign up for different battery sizes (70kWh or 100 kWh with an upgrade from 70kWh to 100kWh being priced at EUR 7,400 or EUR 64 per month with the BaaS subscription) and so-called power plans. Currently, a 70.0-kWh pack is priced at about EUR 120 per month. NIO built its first battery swapping station in 2018, and by March 2021 operated 197 battery swapping stations in 80 cities in China.²⁸ In 2019, the company announced the completion of its first network of battery exchange stations where along the G2 motorway between Beijing and Shanghai eight stations were built over a length of more than 1,000 kilometers.²⁹ The company in 2021 will increase the total number of its battery-swap stations to around 700, and by 2025 aims to operate 4,000 battery-swap stations globally of which 3,000 are planned to be in China.³⁰ By the end of June 2020, the company had completed 500,000

battery swaps. NIO's second-generation battery swapping stations have a capacity of 13 batteries enabling 312 battery swaps per day. NIO in early 2021, signed an agreement with Sinopec, for strategic cooperation on battery swapping stations and has constructed a battery swapping station at Sinopec's Chaoying gas filling station in Beijing. On August 18, the EUR 101 million Weineng Wuhan Battery Asset Co., Ltd. joint venture, initiated by NIO, CATL, Hubei Science Technology Investment Group Co., Ltd. and Guotai Junan International Holdings Limited, was registered and established as a battery asset company, which will purchase battery packs and commission NIO to provide battery subscription and operation services to users.³¹ As the owner of battery assets, the battery asset company plays an important role in BaaS.

- **SAIC Motor Corp.:** The company cooperates with Aulton New Energy Automotive Technology to start operation of the first battery swap station for its EVs.

Vehicle Model	ES8	ES6	EC6
Basic Price	EUR 59,600	EUR 45,600	EUR 46,900
Basic Price incl. purchase subsidy	EUR 57,400	EUR 43,800	EUR 44,600
Basic Price incl. purchase subsidy and BaaS	EUR 48,400	EUR 34,900	EUR 35,700

Figure 5: NIO vehicle purchase prices (with 70 kWh battery), Source: GIZ based on NIO data

²⁸ <http://www.chinadaily.com.cn/a/202105/17/WS60a1b90ca31024ad0babe2bb.html>

²⁹ <https://www.electrive.com/2019/01/20/nio-completes-first-battery-swapping-route/>

³⁰ <https://electrek.co/2021/07/09/nio-plan-open-battery-swap-stations-to-other-electric-automakers/>

³¹ <https://www.nio.com/news/nio-launches-battery-service>

Battery swapping station operators and service providers

- **Aulton New Energy Automotive Technology:** As of May 2021, Aulton a Shanghai-based battery swapping station operator, has operated 316 battery swapping stations in more than 20 cities across China including Beijing, Shanghai, Chongqing, Guangzhou and Kunming. This year, Aulton aims at operating 500 new battery-swap stations, covering more than 50 cities, with the total number reaching 800. By 2025, the company will build 5,000 battery-swap stations in 100 cities in China, serving 22 million NEVs. Aulton's battery-swapping technology is currently compatible with nine models from seven mainstream automakers.³² Aulton has formed partnerships with about 14 automakers, including Changan Auto, BAIC Group, SAIC Motor, FAW Group, GAC Group, and Dongfeng Motor, and has co-developed 22 battery swappable electric vehicle models with the partners. For example, the company has a strategic partnership with Changan EV, which has recently handed over 100 battery swappable Eado EV460s to the Chongqing Taxi Operation Association using Aulton's battery swapping stations in Chongqing.³³ In addition, Aulton recently signed a strategic cooperation framework agreement with Sinopec aiming at combining their technologies and expertise to explore areas of commercial application for intelligent charging, and carry out practical cooperation in research and

application of battery charging and swapping.³⁴ On 20 July, Aulton has put into operation two battery swapping stations in Shanghai and Chongqing, which were built in partnership with Sinopec.³⁵



Figure 6: Aulton battery swapping station in Shanghai, Source: China News Service

- **Blue Park Smart Energy (Beijing) Technology:** In 2021, Blue Park Smart Energy (Beijing) Technology, a battery service subsidiary of BAIC, will build no less than 100 battery-swap stations nationwide. The figure is expected to reach 2,500, covering at least 120 cities in China by 2025.³⁶ In January 2021, SK Innovation announced that it rose to become a major strategic investor by acquiring 13.3 percent of shares.



Figure 7: Blue ParkSmart Energy (Beijing) Technology battery swapping station in Hangzhou, Source: SK Innovation

³²

<https://www.chinadaily.com.cn/a/202101/25/WS600e29bba31024ad0baa4ce8.html>

³³ <http://autonews.gasgoo.com/m/70018368.html>

³⁴ <https://pandaily.com/sinopec-and-nio-jointly-build-power-swap-station-at-beijing-chaoying-filling-station/>

³⁵ <https://cnevpost.com>

cdn.ampproject.org/c/s/cnevpost.com/2021/07/21/aulton-s-first-battery-swap-stations-with-sinopec-go-into-operation/amp/

³⁶

<https://epaper.chinadaily.com.cn/a/202101/04/WS5ff2575aa31099a234352f90.html>

- **China Tower Corporation Limited:** The telecommunications tower infrastructure service provider under its energy business operates about 24,000 battery exchange depots (not battery swapping stations as operated by other companies listed in this paper) in more than 100 cities across China providing power battery exchange services to low-speed electric vehicles of courier and logistics companies including Meituan, Ele.me, Fengniao, China Post, SF Express, JD.com, STO, YTO, ZTO, Best Express and Yunda.³⁷

Energy and battery companies

- **Contemporary Amperex Technology (CATL):** In 2019, CATL, together with Hellobike and Ant Financial, held a strategic cooperation conference in Shanghai at which they announced the establishment of a joint venture with a total investment of EUR 127 million involving the initiation of battery-swapping services for two-wheeled electric vehicles.³⁸ On August 18, Weineng Wuhan Battery Asset Co., Ltd., initiated by NIO, CATL, Hubei Science Technology Investment Group Co., Ltd. and Guotai Junan International Holdings Limited, was registered and established as a battery asset company, which will purchase battery packs and commission NIO to provide battery subscription and operation services to users.³⁹
- **China Petrochemical Corp (Sinopec):** Sinopec, in partnership with NIO launched a battery swap station in Beijing in April and plans to construct

5,000 battery swapping stations across China over the next five years. The company recently signed a strategic cooperation framework agreement with Aulton and Evergrande Group which includes the joint construction of charging and battery swapping facilities. On 20 July, Aulton has put into operation two battery swapping stations in Shanghai and Chongqing, which were built in partnership with Sinopec.⁴⁰



Figure 8: NIO battery swapping station launched at Sinopec fuel station in Beijing, Source: China Daily

- **State Grid EV Service:** As a subsidiary of State Grid, State Grid EV Service has signed strategic cooperation agreements with BAIC, FAW, Dongfeng, NIO and other OEMs, actively explored the application of the "vehicle-electricity separation" business model, and jointly built and operated battery swapping stations.

Transport and Mobility Companies

- **Chongqing Taxi Operation Association:** The association operates battery swappable Eado EV460s by Changan EV as taxis using Aulton's battery swapping stations in Chongqing.

³⁷ <https://www.bloomberg.com/news/newsletters/2021-04-06/hyperdrive-daily-battery-swapping-makes-a-comeback-in-china>

³⁸ <https://www.catl.com/en/othercase/523.html>

³⁹ <https://www.nio.com/news/nio-launches-battery-service>

⁴⁰ <https://cnevpost.com.cdn.ampproject.org/c/s/cnevpost.com/2021/07/21/aulton-s-first-battery-swap-stations-with-sinopec-go-into-operation/amp/>

- **Hellobike:** On 12 June, Hellobike held a strategic cooperation conference with CATL and Ant Financial Services Group in Shanghai, establishing a joint venture with an initial investment of 1 billion yuan aiming at launching a battery-swap service to position a basic energy network of two-wheeled electric vehicles. The three parties will integrate the superior resources and capabilities of industry, operation, and travel mobility and comprehensively build a travel ecosystem to provide green, intelligent, and safe battery-swap services for two-wheeled electric vehicle users.



Figure 9: Opening ceremony - Changan EV Eado EV460s as battery swappable taxi in Chongqing, Source: Aulton

Summary

The arguments for and against battery swapping as part of the wider electro mobility technology, service and business model ecosystem are manifold. Below listed is an overview on some of the aspects which should be taken into consideration when assessing the opportunities and challenges of battery swapping and BaaS.

Potentials of battery swapping and BaaS

1. Reduced vehicle purchasing costs due to the separation of vehicle body and battery since one of the most expensive part of the vehicle, the battery, is sharable,
2. With subscription-based BaaS models, customers do not own the battery and thus do not need to worry about battery depreciation, range decline and battery disposal, potentially increasing the acceptance for electro mobility and decreasing respective concerns,
3. Increased acceptance of second-hand electric vehicle purchase as the battery is not part of the vehicle,
4. Convenient travel and fleet operation as battery swap time is not significantly longer than the time to fill a tank, in particular for longer distance trips and commercial vehicles with long operating hours, including taxis, ride-hailing fleets and logistics vehicles,
5. Cost benefits for shared logistics, mobility, and delivery companies with large fleets with BaaS battery leasing models covering service, repair, and replacement cost of batteries,
6. New service and energy business models related to BaaS (e. g. subscription-based monthly power plans) as key for car manufacturers and battery operation companies to get into the energy business associated with vehicle electrification,
7. Extended battery life and safety with the battery operation company monitoring, maintaining and managing the battery centrally,
8. Reduced charging costs with charging at preferential rates during off-peak hours potentially leading to lower energy costs for customers,
9. Energy and cost saving as consumers can consider the capacity of the battery rented a day according to the daily mileage (depending on costs of specific energy/power plans),
10. Improved battery end of life (EoL) management and better management of battery recycling as onus of recycling lies with the battery swapping operator. This will prevent battery submission leaking from the consumer side,
11. Potentials for grid integration with battery swapping stations as grid-balancing energy storage devices,
12. Potential optimised land resource allocation compared to separate charging pile construction (solutions for charger integration e. g. into streetlamps can solve this problem)

Challenges of battery swapping and BaaS

1. Complexity due to lack of uniformity in standards with batteries of different car manufacturers and models having different chemistries, power and energy densities, and form factors and different drivetrains requiring different energy and power ratio, and car manufacturers being reluctant to share their battery and battery management systems standards,
2. Battery swapping stations are expensive (estimated EUR 350,000 to 1.3 million) including costs for land, labor, maintenance, electricity and the stored batteries requiring significant upfront investments,
3. Battery inventory management, planning and operation complexity related to the availability of sufficiently charged batteries in swapping stations when they are needed in low-, medium-, and high-density urban areas, rural areas as well as along highways,
4. Technical issues to prevent rainwater, snow or dust entering the vehicle electric system,
5. With battery technology and capacity as well as charging technology improving quickly, and solid-state batteries promising potential ranges of more than 1,000 km per charge, battery swapping might be an outdated technology in the near-term future,

Conclusion

Battery swapping must not be seen as a replacement of conventional charging but a complementary technology diversifying the choices of electric vehicle users. This includes conventional charging, on demand mobile charging, battery swapping, and the option to flexibly upgrade batteries to meet customer's specific and individual demands. Battery swapping and BaaS cannot only benefit vehicle owners but in particular the operators of commercial and shared vehicle fleets, such as ride-hailing, taxi or urban delivery fleets by increasing the operation time of vehicles. In addition, battery swapping might be a component of the roadmap to electrify long-distance heavy-duty freight transport. In addition, BaaS solutions where customers do not own the battery and sign up for flexible energy plans open new opportunities and business models for vehicle manufacturers or energy companies, potentially further accelerating the trend of vehicle electrification.

It can be expected that battery and charging technology in the future will advance leading to increased capacity and range, shortened charging time and lower costs. Thus, it is open which role battery swapping and BaaS will play in different application in the long run. For now, battery swapping and BaaS with the potential to reduce customer's concerns over limited range, long charging time and high costs of the battery can contribute to reducing the anxiety of customers to switch from ICE to battery electric vehicles thus supporting the overall uptake of and acceptance for battery electric mobility.

To fully tap the potentials of battery swapping and BaaS, overall costs for infrastructure construction, operation and maintenance need to be significantly lowered and utilization rates of battery

swapping stations must be increased. This can be achieved by sufficient governmental support both in terms of fiscal and non-fiscal support measures, in-depth cross industry/sector and manufacturer cooperation and partnerships, overall coordinated infrastructure and energy system planning, and further automation and technological development. Most importantly, standards need to be in place to ensure

cross manufacturer and model compatibility. In the future, also a flexibility in battery pack layouts aiming at the elimination of massive battery packs and the promotion of flexible configurations could be explored. In any case, the resource and environmental impacts of battery swapping should be carefully assessed when planning the deployment of battery swapping technology and systems.



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