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California Battery Swap Truck Forum Report

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California Battery Swap Truck Forum



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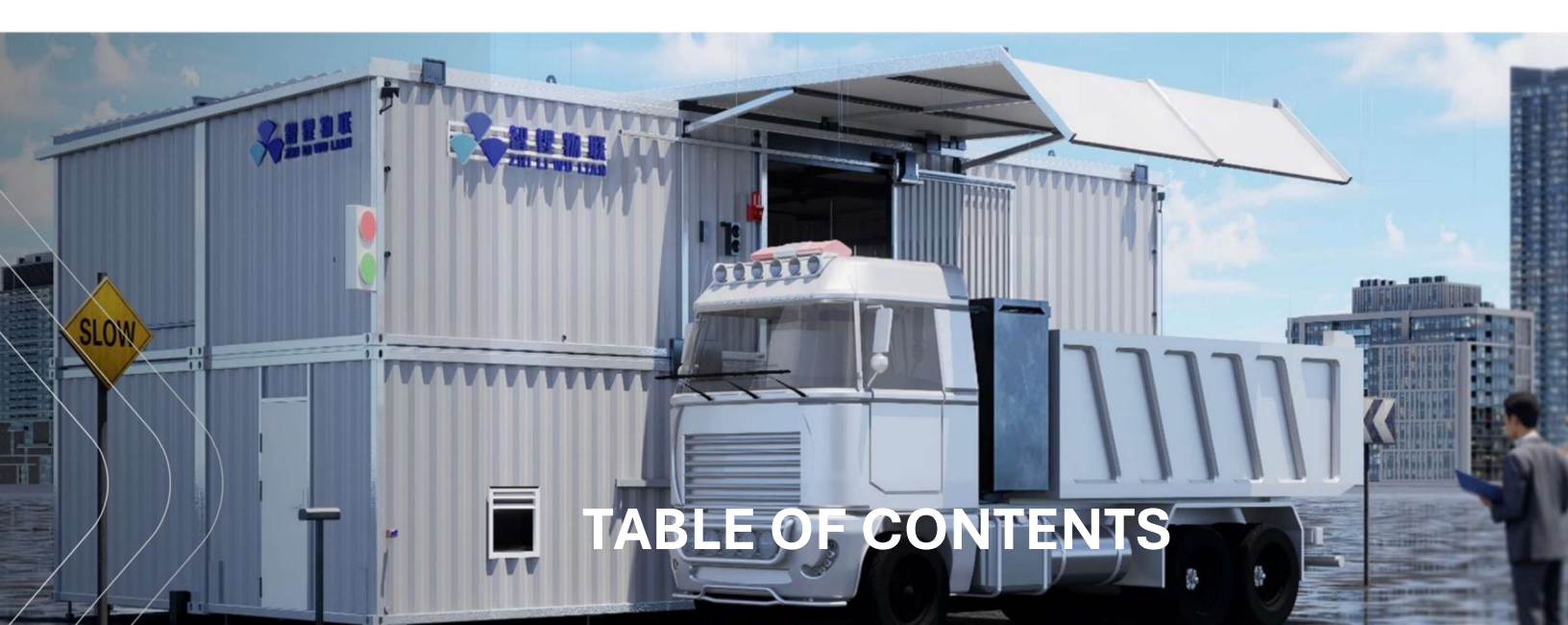


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Foreword

Following Governor Gavin Newsom's historic October 2023 trip to China, the State of California and China are actively exchanging best practices in key climate-related areas including clean transportation. Collaboration between China and California has also been memorialized in several recent climate cooperative agreements including a 2023 agreement between Hainan Province, China, and the California State Transportation Agency (CalSTA). As part of this effort, CalSTA, the California Energy Commission (CEC), and the University of California, Davis' Institute of Transportation Studies (UCD-ITS) convened the *California Battery Swap Truck Forum* on August 29, 2024 at the University of California, Davis.

To meet its climate, economic development, and energy security goals, China has emerged as a world-leader in the development and deployment of zero-emission vehicles (ZEVs). Likewise, through strong policy and regulations, investment in infrastructure, and support for private sector innovation, California is a leading market for ZEVs in the United States and globally. Therefore, ZEV deployment is a natural area of collaboration between California and China, particularly within the heavy-duty truck sector that is a major contributor to pollution and impacts communities along heavily trafficked freight corridors. California regulations require light, medium and heavy-duty trucks to transition to becoming zero-emission, and ZEV sales will accelerate to meet the requirements.

ZEV truck and infrastructure deployment is considerably further along in China than in California, which leads the United States. In 2023, 35,000 heavy-duty (equivalent to class 7 and 8) zero-emission trucks were sold in China compared with fewer than 1,000 in California. Roughly half of the zero-emission trucks sold in China used 'battery swap' technology that allows electric trucks to quickly exchange a depleted battery pack for a fully charged one in a matter of minutes. However, in California and the United States, battery swap technology is not widespread and is not currently being commercialized by major truck manufacturers.

After seeing battery swap technology being used by businesses in China and some of the operational benefits battery swap technology may yield, we convened the *California Battery Swap Truck Forum* to explore whether there is a business case for using heavy-duty truck battery swap technologies here in the United States. Additionally, we wanted to explore whether United States logistics companies or infrastructure operators would be interested in pursuing a battery swap demonstration project here in California.

Logistics companies, utility companies, California ports, and truck manufacturers were invited to participate in this full-day Forum. The Forum featured discussions with the leaders of companies in China who have used battery swapping trucks, researchers studying opportunities for use of battery swap in the United States, and

stakeholder discussion of the potential benefits and challenges of battery swap technology in California. Forum participants also shared to what extent they are aware of battery swap technology, how it may or may not be suitable for their operations, and their interest in participating in a battery swap demonstration.

In fact, information presented at the Forum seemed to validate some of our observations about the efficiency of battery swap operations. For example, research presented by the University of California Berkeley School of Civil and Environmental Engineering indicated a 16% to 38% increase in freight speed (ton-mile/hour) by using battery swap electric trucks versus conventional electric trucks because of the reduction of charging down-time. What is more, it is not just Chinese companies that are utilizing this business model – companies like the container shipping line Maersk and the U.S. freight firm Ability Tri-Modal provided information about their experience or plans to use battery swap electric trucks in their operations.

Finally, Forum participants *did* express a general desire to see a small and controlled battery swap electric truck demonstration in California on a short, fixed route. In response, this report outlines some hypothetical battery swap truck demonstrations that could occur in different regions of California with different participants who took part in the *California Battery Swap Truck Forum*. We are hopeful to see battery swap electric truck demonstration projects implemented in California that might yield data to support a business case for this innovative business model and would look forward to supporting this type of effort.

Signing of the California-Hainan Memorandum of Understanding in August, 2023. Pictured from left to right in the front row are Hainan Vice Governor Chen and California Secretary of Transportation Omishakin. Pictured from left to right in the second row are then-Deputy Director Zeng of the Foreign Affairs Office of Hainan, San Francisco Chinese Counsel General Zhang, Governor Newsom of California, Secretary Tong of California Government Operations, and Senior Climate Advisor Sanchez of the Office of Governor Newsom.



The California Energy Commission-led fact finding mission to China in December, 2023.



Secretary Omishakin and Director Wang visiting the Huasheng Cement Factory battery swapping truck facility in Hainan, China.



Director Li, Commissioner Monahan,¹ and Director Wang at the California Battery Swap Truck Forum



1. Background:

Battery-swapping heavy-duty trucks emerged as a plurality of the zero emission heavy-duty trucks (HDTs) being deployed in the Chinese market three years ago. Here is the [link](#) to an animated illustration of battery swapping vehicles created by the ICCT.

In 2019, only 5 percent of the new heavy-duty zero emission trucks were battery-swapping trucks. In 2021, only 3,200 were sold, however, in 2022, the sales jumped fourfold to 12,431 units, accounting for 49 percent of the New Energy Vehicle (NEV)² HDT market

¹ Commissioner Patty Monahan served on the California Energy Commission during the August 2024 *California Battery Swap Truck Forum* and co-hosted the event. She departed the Commission in January 2025.

² “New energy vehicles” is the term used in China for any vehicle powered by an alternative fuel source other than fossil fuels, including electric, hybrid, and hydrogen-powered vehicles, while a “Zero Emission Vehicle”

share. There are several reasons for the rise of battery swap heavy duty trucks (BSHDT), both economic and policy-driven.

1. Decline of battery prices.
2. Dramatic growth of China battery production capacity with its production in 2023 alone matching the global demand.³
3. Government policy encouragement.
4. Heavy polluting, hard-to-abate industries and regions, such as the steel plants in Tangshan, Hebei province, are trying to find the low-hanging fruit in local criteria air pollutant emission reduction technologies. In particular, after facing a call by the government to reduce their industries' air pollution, these institutions found it was easier and lower in cost and for them to convert their diesel HDTs.

Adopting BSHDTs offers roughly a dozen quantitative and qualitative advantages over fixed battery counterparts. The main advantages are characterized as **S.T.U.D.:**

- **Space saving:** Battery swap stations, some of them mobile, require minimal space compared to large parking lots with fixed chargers.
- **Time saving:** During the busy daytime, a battery-swapping HDT experiences a five-minute downtime for a battery swap, compared to the 30-60 minutes needed to recharge fixed battery trucks.
- **Utility integration:** BSHDTs can leverage solar-peak hours and the battery swapping stations, many of them mobile, can be placed near renewable energy sources.
- **Decreased purchase cost:** Owners of BSHDTs can reduce upfront costs in two ways: by purchasing trucks without batteries and leasing batteries from station operators, and by requiring fewer batteries overall compared to fixed battery trucks.

For a detailed discussion about the rise of BSHDTs, please refer the UCD-ICCT Background paper in [Annex 1](#).

On August 29th, 2024, the California State Transportation Agency, the California Energy Commission, and the Institute of Transportation Studies-Davis (China Center for Energy and Transportation) jointly hosted the California Battery Swap Truck Forum and invited many stakeholders in California. Those invited included representatives from shipping and logistics companies, utilities, ports, air quality management districts, state lawmakers and accompanying staffs, federal stakeholders, and universities. The forum also invited, Mr. Li

(ZEV) is a term used in the West which specifically indicates a vehicle that produces absolutely no tailpipe emissions when operating, essentially only encompassing fully electric battery vehicles and hydrogen fuel cell cars under most definitions.

³ <https://about.bnef.com/blog/china-already-makes-as-many-batteries-as-the-entire-world-wants/>

Liguo, the Secretary-General of the Battery Swap Truck Association in China, to give an in-depth introduction of BSHDTs' deployments in China.

The purpose of the forum was to educate American stakeholders about this new business model in China and explore the interests in implementing a BSHDT pilot demonstration project in California.

2. The list of key participants.

The key participants are listed in Annex 2.

3. Summary of speeches and presentations.

- a. Secretary Omishakin: Secretary Omishakin spoke about the importance of the relationship between China and California involving clean transportation and climate policies. Information sharing of best practices involving zero emission vehicle deployment, and the reduction of air pollution are paramount in this reciprocal relationship. Secretary Omishakin also spoke about his observations of battery swap cement trucks being operated in Hainan. His observations consisted of the increased efficiency in removable truck batteries used by BSHDTs compared to conventional battery electric trucks that require fixed batteries to be plugged into an electric charging station. He concluded his speech by voicing his desire to implement a battery swap project in California that might yield data to support a business case for this innovative business model.
- b. Commissioner Monahan: Commissioner Monahan spoke about the need for California to expand the charging network to support the transition to zero emission medium and heavy-duty vehicles. To support medium- and heavy-duty plug-in electric vehicles, California will need about 114,500 chargers for 155,000 vehicles in 2030, and 264,000 chargers for 377,000 vehicles in 2035. She stressed how communication with our international partners is important, in particular, partners who are succeeding in transitioning their heavy-duty vehicles to zero emission vehicles (ZEVs). Commissioner Monahan spoke about how it is essential for more people and entities to focus on the medium and heavy-duty vehicle transition as most of the focus has currently been on light-duty vehicles.

- c. Analisa Bevan, on behalf of Sydney Vergis: Analisa Bevan spoke about how under the Advanced Clean Fleets Regulation (ACF) new drayage trucks operating in California must be zero emission by the end of 2035. She addressed the fact that eight other states have adopted different Californian zero emission vehicle regulations and that the health savings for at-risk populations and financial savings for vehicle owners will stem from adopting zero emission trucks.
- d. Yunshi Wang: Director Yunshi Wang of the China Center for Energy and Transportation spoke about how BSHDTs are efficient as they only take 5 minutes to swap batteries. He presented a video about battery swapping in China in order for the audience to have a tangible understanding of the technology and business model. He went on to explain and present the perceived benefits of the battery swapping business model through the acronym of S.T.U.D., as is listed above. Director Wang went on to talk about the importance of battery-to-truck ratios. Both his center's research and his conversations with battery swap truck company owners reveal relatively similar results of the necessary number of batteries needed per truck to successfully operate. His researchers have modelled truck transportation of California-based freight and found that in a fixed route operation in Southern California, the ratio of batteries per truck can be as low as 1.2, meaning that for operations to be implemented smoothly, there would need to be 1.2 batteries per truck, not a larger ratio such as two or three batteries per truck. A common misunderstanding for battery swapping trucks is that there will be a need to deploy more batteries to operate them. As battery swap trucks can operate 24 hours a day without stopping, the 1.2 battery packs a single truck uses can cover the distance that two battery packs on a fixed battery truck would require to cover the same distance for business operations. Thus, battery swapping trucks can actually reduce the number of batteries needed in most shipping operation scenarios. For BSHDTs, when it comes to their ratio of either 1.2 or 1.5 battery packs vs two for a BEV truck, the cost-saving on batteries is significant and could potentially be game-changing, since battery cost accounts for half to two-thirds of the cost of a BEV truck sold in California today.
- e. Liguo Li, Secretary-General of the Battery Swap Truck Association in China: Director Liguo Li was the main invited guest speaker at the California Battery Swap Truck Forum as he flew from China for the event. In addition to being the Chief Technology Officer for the well-known Professor Ouyang Minggao's

Academician Workstation, Mr. Li has substantial operational and managerial experiences with BSHDTs as he operates one of China's long-haul BSHDT routes in China.

- (i) Director Li first laid out the economic advantages of BSHDTs: BSHDTs are efficient in land use as they require 60 percent less space than their battery electric truck (BET) counterparts; BSHDTs require less time to charge re-energize, in shipping they are lighter as they do not carry around extra battery weight that is left unutilized throughout the workday; and there is a lower total cost of ownership (TCO) compared to their BET and fuel cell counterparts.
- (ii) Director Li then went on to present on a comparative study between the costs of different energizing modes: battery swapping vs. hydrogen fuel cell vs. super charging. In this comparison, he explained how BSHDTs are the most cost-effective when the swap distance is between 80 km and 248 km (50 miles to 155 miles) and the swap station's utilization rate is above 43%, under 2021 battery technology capabilities.
- (iii) Director Li stressed how BSHDT purchase cost and upkeep is cheaper than diesel trucks, leading customers to seek this economic advantage which has led to the surge in sales.
- (iv) Director Li also went on to explain how interchangeability of both batteries and vehicle parts is the key for further expansion of the battery swapping industry.
- (v) Director Li concluded his speech by talking about how BSHDTs are growing rapidly in China, and are mature in short-haul routes with experimentation on multiple long-haul routes in China.

Director. Li's power point presentation can be provided upon request.

- f. Dr. Miguel Jaller, Professor of Civil and Environmental Engineering at UC Davis: Dr. Miguel Jaller moderated the panel session, presented on heavy-duty truck electrification in California, and provided background understanding of the complexity of goods movements. Jaller characterized trucking operations by explaining how vehicle classes have different vocations, diverse needs, and different distance travel requirements. He explained how for battery electric trucks, specific time windows of operations with heightened freight activity can be useful for scheduling optimal charging times. An area of exploration is the

spatial concentration of frequently travelled routes and that this is crucial for targeted charging/fueling/swapping station placements. Jaller stressed how the freight industry is a complex system with diverse requirements which necessitates the availability of different strategies and options. He concluded his presentation by explaining how there is no “one size fits all approach” to the freight transition to zero emission vehicles and that there are innovative technologies being developed, but these new technologies will require different supporting infrastructure requirements.

- g. Dr. Scott Moura, Associate Professor of Civil and Environmental Engineering at UC Berkeley: Dr. Scott Moura’s presentation and recent research has focused on BSHDTs and their potential adoption in California. In his presentation, he focused on the speed of freight by doing a comparison between hydrogen, battery electric trucks, and battery swap trucks. He found that if solely focusing on the speed at which freight can be shipped out of these three zero emission technologies, battery swapping is the fastest available as there is a 16% -38% increase in freight speed by using battery swapping relative to fast charging. On top of this, Dr. Moura presented his own battery-to-truck ratio calculations. He calculated that BSHDTs would require a 25%-40% excess battery capacity meaning that the battery-to-truck ratio would be 1.25-1.4. He concluded his presentation by stressing how BSHDTs have faster freight speed (ton-miles/hour), less unloaded vehicle weight, more capacity for cargo, they provide energy storage services in electricity markets, require less real estate & less power requirements, however, they do require excess battery capacity and higher capital cost of swapping facilities vs. regular fast charging (Not high-voltage charging above 500 kW).

Dr. Moura’s power point presentation can be provided upon request.

- h. Carlo Bertani, Decarbonization Lead at A.P. Moller - Maersk: Mr. Carlo Bertani gave a presentation of Maersk’s adoption and use of BSHDTs in China. Maersk is using roughly a dozen BSHDTs in both Shanghai and Shenzhen ports for their respective drayage needs. Maersk, a global freight liner also owns many drayage trucks helping to control all aspects of shipping goods from warehouse-to-warehouse between Asia and North America. Maersk is using BSHDTs in Shanghai and Shenzhen and the trucks they are operating are from both XCMG and Sany, China’s two largest BSHDT manufacturers. For Maersk, time and

efficiency are the most important aspects they focus on for their operations. They have found that owing to the less than two minutes required to recharge a truck involved with battery swapping, battery swapping is the preferred technology choice for their specific operations. Through their experiences of operating different models and generations of BSHDTs, they have found that under the chassis battery swap trucks are the preferred design for them owing to the increased speed of battery swapping and the safer design. Mr. Bertani also spent time addressing the potential risks of battery electric trucks, which include BSHDTs, stemming from the legal liability of potential battery fires and the need to extinguish battery fires.

- i. Mike Kelso, Executive Vice President, Ability Tri-Modal: Mr. Mike Kelso of Ability Tri-Modal presented on their strong interest in BSHDTs. Ability Tri-Modal has determined that for the zero-emission truck transition, battery swapping makes the most sense to their company and operations. They have been logging and keeping records regarding how their facilities will operate and integrate with BSHDTs through utilizing their warehouses' solar panels. Ability Tri-Modal has signed an agreement with an Australian company, [Janus Electric](#), to retrofit two Volvo Class 8 trucks to make them battery swap capable trucks. Each truck will have a 500-mile range and these trucks will be able to utilize Ability Tri-Modal's solar energy obtained from their warehouse roofs. The battery packs are swapped by operating a forklift and cooling is through air circulation.
- j. Aravind Kailas, Advanced Technology Policy Director, Volvo: Dr. Aravind Kailas of Volvo Group presented on the perspective Volvo Truck, a heavy-duty truck manufacturer, has when it comes to the zero-emission truck transition. Dr. Kailas explained how Volvo has not taken a strong look at battery swapping trucks during the design of their current battery electric truck offerings. He did provide a background to the mindset Volvo had when designing their conventional plug-in battery electric trucks and went on to explain how safety is a major priority for Volvo when it comes to designing new trucks and how the current, battery electric trucks, are designed to limit the damage from a potential battery fire. As of now, if the battery were to catch fire on their truck, their special design would contain the fire from spreading. Are there any similar designs in BSHDTs to prioritize this level of safety? How would their designs for the battery electric trucks be able to be transferred over to BSHDTs? Another aspect Dr. Kailas brought to the table is the fact that most of the heavy-duty truck manufacturers in the United States sell their trucks through dealerships who

have their own certifications from the manufacturers and sell warranties on the trucks. He brought up potential hurdles for truck manufacturers to address such as: through adopting BSHDTs, how would any malfunctions or broken parts which were broken through battery swapping be covered by any warranty? How would the dealerships obtain an electric vehicle (EV) certification required for them to sell this new type of truck model?

- k. Rachel Huang, Director, Customer & Grid Strategy, Sacramento Municipal Utility District (SMUD): Ms. Rachel Huang of SMUD gave a presentation on SMUD's zero carbon plan by 2030 and its EV Strategy. They currently have 3 large EV charging projects, including the Tesla Semi and its Super Charger. On top of this, SMUD is currently developing a vehicle-to-grid project, which would consist of light and medium-duty battery electric vehicles sending electricity back into the grid at specific times during the day to reduce pressure on the electricity grid. Ms. Huang also addressed how heavy-duty truck electrification can create large electrical demands and how initial charging options may be limited based on the volume of truck traffic on the roadways.

4. Q&A (including morning and afternoon) directed towards Director Li by audience members:

(i) Charging methods:

Q: How many batteries on charged onsite or offsite?

A: Batteries are mostly charged in the swap station, but some are charged offsite. Most battery swap truck stations have a capacity for 6-7 batteries to be charged at one time.

(ii) Cooling:

Q: What is the active cooling system for BSHDTs in China? Individuals are cautious after hearing about Tesla semi-truck that may have caught on fire.

A: The swappable battery pack uses less volatile Lithium iron phosphate batteries (LiFePO₄ or LFP) with a liquid cooling system. There are safety requirements that both the charging system and battery packs should be no higher than 45C. There is an active plumbing system such that if heat is detected to exceed 45C for one minute then the system will autonomously remove the battery and dumps it into a nearby water pool.

(iii) Electricity:

Q: What about the price of electricity? How do BSHDTs take advantage of the time-of-use for electricity rates?

A: Separated from trucks, BSHDTs have more flexibility to charge during off-peak hours compared to super chargers and fast chargers. Because of this, BSHDTs are able to take advantage of lower electricity prices.

(iv) Competing Technologies:

Q: Can you explain more about the advantages of BSHDTs compared to other zero emission truck technologies?

A: As of right now, the price of using hydrogen is very high and there is not an expected price parity for this fuel for the foreseeable future. In general, as compared to BETs and hydrogen fuel cell trucks, there is an efficiency loss and economic disadvantage; battery swapping is more flexible for electricity usage compared to super charging.

(v) Biggest challenge:

Q: What is the biggest challenge facing the expansion of BSHDTs?

A: As of right now, the standardization between battery swap trucks and battery swap stations is still lagging. A lack of standardization between different BSHDT models can cause customers and technology adopters to be hesitant. On top of this, the transportation network is not aligned with the utility support infrastructure impeding the expansion of battery swap stations as they will require appropriate charging infrastructure and utility capabilities along the shipping routes.

(vi) Automation and Monitoring:

Q: What kind of personnel are required to operate the battery swapping stations:

A: Battery swap stations are automated, saving labor cost, and batteries are remotely monitored for safety and changing needs. A driver drives the truck up to the battery swap station and scans a QR code with the phone loaded with the app. The station then begins swap the depleted battery for a charged battery. As the robotic claw is laser-guided, the station operates autonomously. One technician is able to manage multiple stations in case of a problem with batteries or operation.

(vii) Maintenance needs:

Q: What are the areas most needed to be maintained for battery swapping trucks?

A: The parts needed to be maintained the most are the contacts between the battery packs and the truck, the interlocks, and the case of battery packs. In earlier models of battery swap trucks, there were problems involving the contacts between the large battery packs and the trucks. However, current models have significantly reduced problems or pieces being broken during swaps. The same thing can be said about the cases of battery packs as earlier versions faced higher rates of damage, but contemporary versions now face negligible rates of breakdowns.

(viii) Cost:

Q: What are the costs of battery swap stations available on the current international market? What about insurance costs?

A: Battery swap station cost has come down dramatically in the past few years. A few years ago, battery swap truck stations costed the equivalent to a few million dollars. Today, that price has dropped to a couple hundred thousand dollars. In the same way, so has the insurance cost gone down from 1.5% to 0.5% of the battery cost. Currently battery swap station operators can charge almost the same service fee as the fast-charging operators do.

(ix) Reliability:

Q: What is the reliability of the battery swap trucks available on the international market?

A: At this moment in time, battery swap trucks face an uptime of over 99% on the Chinese market, even outcompeting their diesel counterparts. As battery electric trucks, including BSHDTs, have been used in China for over a decade. The reliability is compatible to the diesel or even better, because the driving system is much simpler. On top of this, as the Chinese zero emission truck sector is much more developed than that in the West, the truck manufacturing industry has worked out flaws the US industry is now facing. The first-generation battery electric trucks tend to have a lower reliability ratio; in a zoom-call with one of the largest truckload shipping companies in the US, its executives mentioned that their battery electric trucks have an uptime of 55-60% vs 99% for the diesel counterparts.

(x) Highway Safety:

Q: The popular BSHDTs carry the swappable battery packs on their backs (behind the cabins). Are there any safety issues?

A: No. The BSHDTs in China have to comply with the government safety code and Mr. Li has never heard of any accidents due to the location of the battery packs (on the back).

5. Breakout Sessions:

The California Battery Swap Truck Forum involved a break-out session in which Forum participants were broken into separate groups in order to converse with each other to answer, as a group, two sets of questions. All groups consisted of a port, trucking company, utility company, air quality management district, and members of state assembly committees. Below are the two different sets of questions asked to forum participants.

1. Opportunities and barriers for heavy-duty battery swapping in California

- Based on what you saw today on how this is used in China, how do you believe this technology could be or could not be adopted in your respective industry?
- What are potential uses of this technology in your respective industries?
- What are major inhibitors to this technology being used in your respective industries?

2. Designing a successful California battery swap pilot

- What would the ideal pilot project look like regarding the size and the duration of the pilot? What kinds of data generated from the pilot are important to you?
- Who would you want in a consortium for a pilot project?
- For trucking companies, what kind of user scenarios, including routes and use of local renewable energy, would you like to see in a pilot project?
- For ports and utility companies, what would be your specific requirements for a pilot project?

Feedback from stakeholders for potential uses of battery swapping trucks and potential inhibitors to the technology being adopted consisted of the following:

Opportunities and barriers for heavy-duty battery swapping in California:

- Participants expressed how battery swapping for trucks would make economic sense for short-haul routes, especially in routes which require two or three shifts per truck.

- The development of a standardized battery swap truck model among different OEMs that can utilize the same battery swap station was expressed as a potential barrier. Developing a battery swap station that can replace batteries of different sizes was also a concern expressed.
- Whether the business model of battery swapping will work in California as compared to China was also expressed. On top of this, a question was posed regarding the total costs involving fast charging vs battery swapping when it comes to building and installing infrastructure and conducting grid upgrades.

Designing a successful California battery swap pilot:

- Participants expressed a desire to see a small and controlled demonstration in California on a short, fixed route. The use cases expressed focused on both mining, port yard tractors, and drayage demonstrations.
- Forum participants believed that a successful pilot demonstration project should include data collection regarding the feasibility and profitability of battery to grid sales of electricity and the safety of the battery swapping system.
- Ports and utilities would need to know what kinds of data would be gathered from the demonstration and what the load management requirements would be to charge and operate the battery swap trucks. On top of this, there was expressed desire to understand what the roles of both utilities and the Public Utilities Commission would be in any demonstration project
- Participants asked as to how best to incentivize trucking companies to participate in a demonstration project.
- Forum participants also asked about where battery swap trucks and stations could be obtained. As there are no major truck manufacturers producing these trucks or battery swap stations in North America. This question is addressed at the end of the following section.

6. [Next step: Road to a pilot/demo project\(s\)](#)

Forum participants expressed a desire to see a small and controlled battery swap electric truck pilot demonstration in California project on a short, fixed route. In response, this report provides three fixed route hypothetical concepts for pilot

demonstration projects. Based on conversations with California ports, utility districts, trucking companies, and freight liners, there may be options for different regional pilot/demonstration projects. Listed below are the hypothetical demonstrations that could occur in different regions of California with different participants who took part in the California Battery Swap Truck Forum. It should be noted that these are hypothetical demonstrations, and that any Forum participants listed have not committed to participating in the demonstration and are listed only as hypothetical participants in a coalition to implement a battery swap truck demonstration project. Any project listed is open to development and none of these listed demonstrations limit the development and interpretation of other projects. Listed below are also potential competitive funding opportunities an entity or coalition can apply to in order to help implement a demonstration project. These programs are competitive and applications for funding to support a battery swap truck pilot demonstration project would have to compete against other projects based on the competitive criteria for each program.

As battery swapping is a mature industry for drayage routes, it may be recommended for a demonstration to occur on shorter, non-long-haul routes. Below are presented three hypothetical routes and hypothetical coalition partners in different regions of California.

1. Northern Demonstration Project:

Project partners may consist of UPS, Port of West Sacramento (or the Port of Oakland), California Mobility Center, Pasha Group, Sacramento Municipal Utility District, the Sacramento Air Quality Management District, Ocean Network Express, and the University of California, Davis. The demonstration project may take place from the Port of Oakland to the Port of Sacramento, which is 77 miles. There can be two battery swap stations, one located at each port. As these lower mileage routes are utilized on a large scale by battery swapping truck technology, this route may be of interest in a demonstration project.

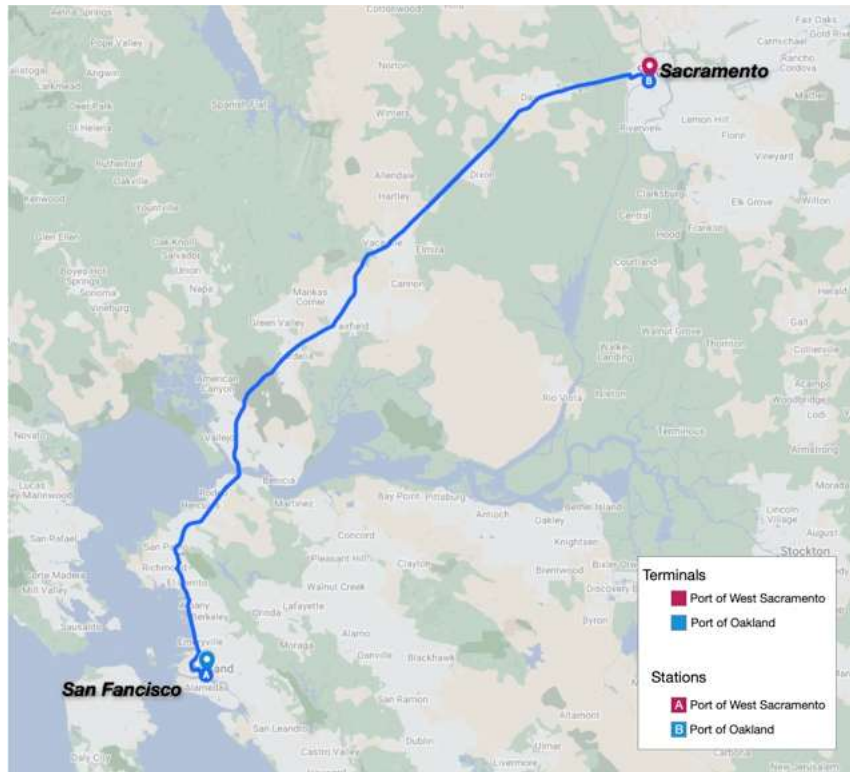


Figure 1: Northern Demonstration Project Route

2. South Demonstration Project:

A potential South Demonstration Project may consist of project partners such as the South Coast Air Quality Management District, the ports of Los Angeles or Long Beach, the Port of San Diego, trucking company Ability Tri-Modal, the Los Angeles Department of Water and Power, Maersk, and the University of California, Davis. This route may consist of a drayage operation between the Ports of Los Angeles or Long Beach and Ontario, California. There can be a battery swap station in operation at the Port of Los Angeles.

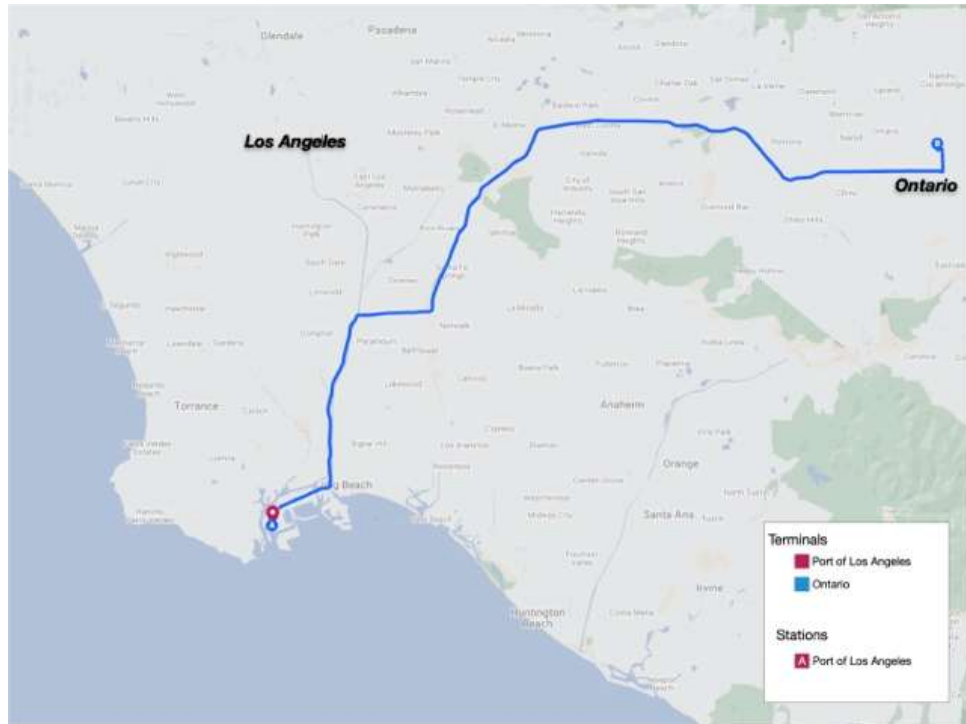


Figure 2: South Demonstration Route

3. Southern Border Demonstration Project:

A potential southern border demonstration project may consist of project partners such as the Port of San Diego, Pasha Group, the San Diego County Air Pollution Control District, San Diego Gas and Electric, and the University of California, Davis. A hypothetical demonstration route may consist of a drayage operation between the Port of San Diego and Tijuana, Mexico. Battery-to-grid electricity exchanges data can be observed and administered by San Diego Gas and Electric. Pasha Group, a logistics company, can operate the trucking portfolio.

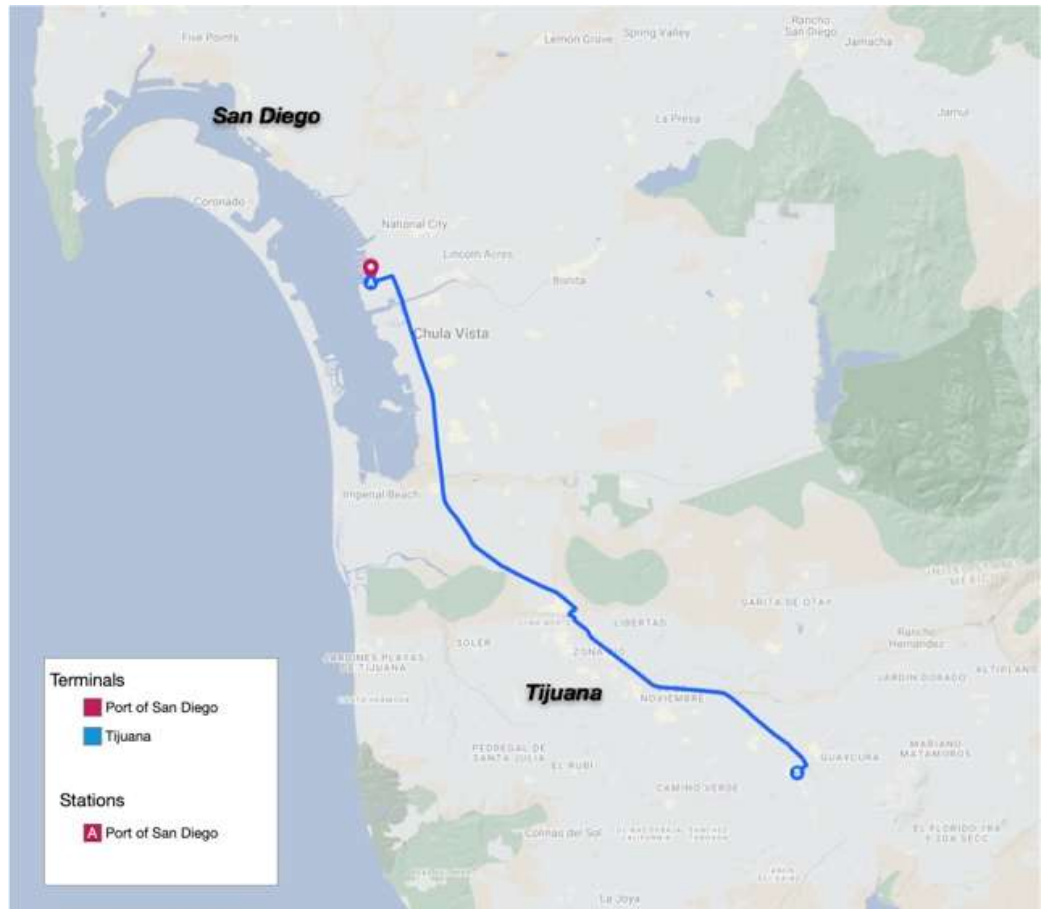


Figure 3. Southern Border Demonstration Route

In all cases, a trucking company's participation is key, as demonstrated by Ability Tri-Modal and its initiative to try the Australian Janus battery swapping trucks. However, it will remain important to have both a trucking company and a utility company involved in order to successfully obtain data on the speed at which freight can be shipped, what charging patterns of batteries will occur, and what battery-to-grid exchanges will look like. The final data category is important as the electricity exchanges can potentially provide income to battery swap companies and can potentially help to stabilize and create a more resilient electricity grid.

Forum participants asked where they could obtain those battery swap trucks and stations as there are no major truck manufacturers producing these trucks in North America. In response, this report suggests a few possibilities:

1. Pilot demonstration project participants could seek an arrangement with a Chinese company involved with battery swap truck operations (perhaps affiliated with the Chinese Battery Swap Truck Association) to temporarily donate a small amount of equipment for the purpose of implementing a pilot demonstration project. If the participants intend to have a large scale demonstration with 10-20 trucks, leasing those trucks at a discount might be another possibility.
2. Retrofit domestically available trucks to be battery swap capable, similar to the approach deployed by Ability Tri-Modal.
3. Additionally, pilot demonstration participants could also seek an arrangement with a company like Ability Tri-Modal to utilize its battery swap capable trucks in a pilot demonstration project or join Ability Tri-Modal to develop a demonstration with both the Janus trucks and the Chinese trucks donated or leased from the Chinese truck manufacturer.

Additionally, after the August 2024 California Battery Swap Forum, CalSTA, CEC and UC Davis were contacted by MITRE Solution Lead Director Ariel Castillo and Principal for Strategy and Innovation Jess Baker regarding a battery-swap project it is involved with. MITRE is a not-for-profit corporation committed to the public interest, operating federally funded R&D centers on behalf of U.S. government sponsors. MITRE collaborates with government, industry, academia, and other stakeholders to deliver innovative solutions that impact national security, health, transportation, the economy and other sectors and serve the public good. While MITRE did not present information at the Forum, it has claimed that it is advancing a new vehicle electrification concept aimed at providing an affordable option for the freight industry to transition existing heavy-duty diesel vehicles to electric power using high-power battery storage for extended ranges of 500+ miles. The concept combines battery storage, battery swap technologies, and microgrid capabilities to support long-haul transport to significantly reduce dwell time for truck operators from hours to minutes compared to fast charging. The new capability integrates propulsion, safety, controls/software, system/component engineering, and the ability for financial participation in electricity markets.

Conclusion:

In all cases, a freighter's participation is key, as demonstrated by Ability Tri-Modal and its initiative to try the Australian Janus battery swapping trucks.

7. [List of Funding Sources:](#)

The following is a list but is not comprehensive of the available public funding sources for a potential battery swap truck demonstration pilot. All of these are competitive programs in which an applicant will have to compete for any grants against other proposed projects. It is up to the applicant to determine whether each potential battery swap truck demonstration project will qualify for the following grant programs.

California Energy Commission:

In the past, the California Energy Commission (CEC) has funded innovative charging solution grant programs and the development and advancement of energy storage technologies that support and enable a reliable grid. Examples of such programs or solicitations include *Energize Commercial Vehicles* (MDHD ZEV Infrastructure Incentive Block Grant project), *Enabling Electric Vehicles as Distributed Energy Resources*, or *Energy Storage Innovations to Support Grid Reliability*. However, at the time of this report's publication, the CEC has no available funding available to support heavy-duty zero-emission truck demonstration projects. There may be more funding made available in fiscal year 2025.

Department of Energy:

[Long-Duration Energy Storage:](#) The LDES portfolio includes the following programs:

- (i) Long-Duration Energy Storage Pilot Program: These projects will advance a diverse set of LDES technologies towards commercial viability and utility-scale demonstrations.

- (ii) Long-Duration Energy Storage Demonstrations Program: These projects will help effectively demonstrate the commercial viability of innovative LDES technologies and facilitate wider commercial adoption.
- (iii) DOE/DOD Long-Duration Energy Storage Joint Program: These projects will demonstrate LDES technologies on government facilities through collaboration between DOE and Department of Defense (DOD).

California Air Resource Board:

At the time of this report's publication, the California Air Resources Board has no available funding available to support heavy-duty zero-emission truck demonstration projects. There may be more funding made available in fiscal year 2025.



Briefing on Battery Swapping Heavy Duty Trucks

Joint UC Davis and ICCT Team

China remains the world leader in zero-emission commercial vehicle sales and production. In 2023, more than 70,000 zero-emission commercial trucks were sold in China, compared to 18,473 units sold in California. Zero-emission technology represents 8% of China's straight truck sales and 6% of tractor truck sales.

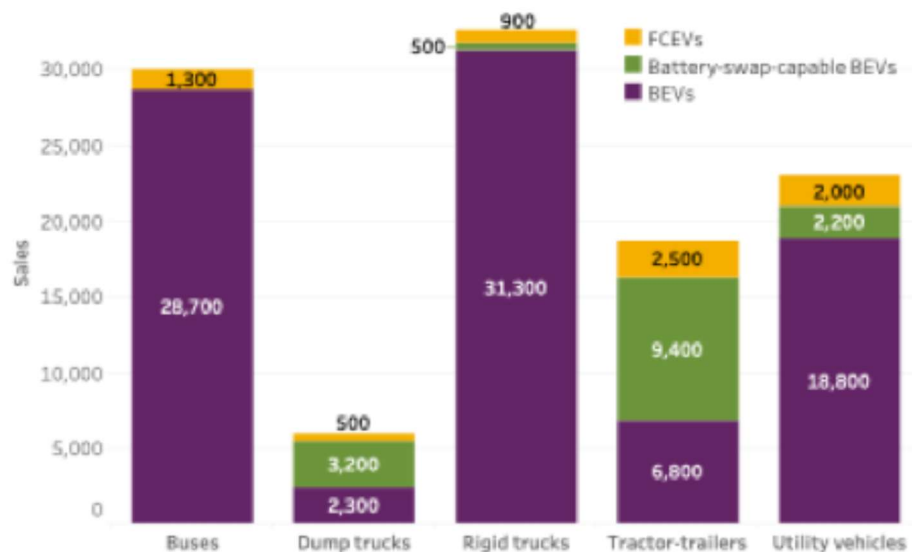


Figure 1. Zero-emission commercial vehicles by segment in 2023. Values are rounded to the nearest hundred

Zero emission heavy duty truck (12 tons and above) sales still account for below 4 percent of China's total HD truck sales in 2023 but is impressive in absolute numbers. About 34,257 units were sold last year as compared with [354 Class 7 and 8 ZE tractors](#) sold in California. Among those sold in China, 43 percent were battery-swapping HD trucks.

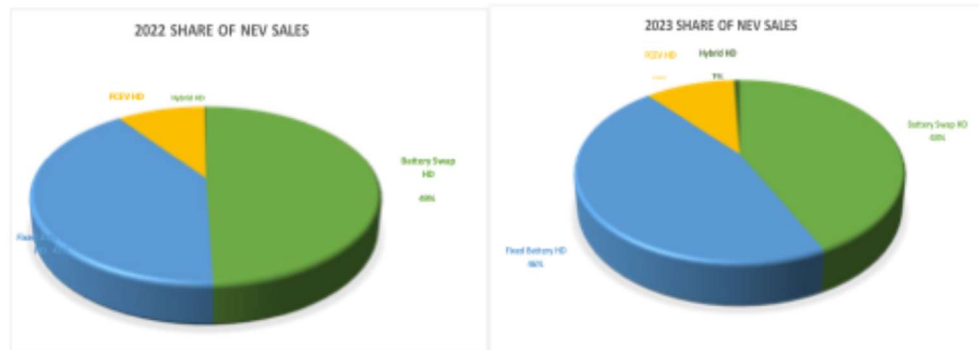


Figure 2. Zero-emission heavy duty truck sales by technology in 2022 and 2023

Battery-swapping HDTs emerged in the Chinese market three years ago. Here is the [link](#) to an animated illustration of battery swapping vehicles created by the ICCT. In 2021, only 3,200 were sold, in 2022, the sales jumped four folds to 12,431 units, accounting for 49 percent of the NEV market share. There are several reasons for the rise of BSHDS, both economic and policy-driven.

1. Decline of battery prices. According to Bloomberg, prices for LFP battery packs are now at \$75/kWh, enabling Chinese EVs to be priced at or below combustion cars in most vehicle segments¹. In July, China sold more electric cars than internal combustion engine cars. Cost of batteries plays a more significant role in HDTs than in passenger cars.
2. Dramatic growth of China battery production capacity with its production in 2023 alone

matching the global demand², and the leading batteries companies, except BYD, try to boost their sales to non-BYD EV makers.

3. Government policy encouragement. In October 2021, the Chinese national government initiated a two-year pilot program to promote battery swapping. Eleven cities were selected as the first batch of pilot cities, and three of them are expected to fully focus on battery-swapping HDTs. The program aims to put at least 100,000 swap-capable electric vehicles on the road and build at least 1,000 battery-swapping stations. Some Chinese provinces and cities are also using their own funds to subsidize the construction of battery-swapping stations. Hainan province, for example, provides subsidies equal to 15% of the total construction cost of a battery-swapping station³.

¹ <https://www.bloomberg.com/news/newsletters/2024-07-09/china-s-batteries-are-now-cheap-enough-to-power-huge-shifts>

² <https://about.lnnet.com/blog/china-already-makes-as-many-batteries-as-the-entire-world-wants/>

³ <https://theicct.org/china-is-propelling-its-electric-truck-market-again/>

4. Heavy polluting, hard-to-abate industries and regions, such as the steel plants in Tangshan, Hebei province, are trying to find the low-hanging fruit in emission reduction technologies. Steel plants in Tangshan found it harder to reduce emissions through decarbonizing steel-making process than through decarbonizing the transportation of raw materials and steel products through adopting battery- swapping HDTs⁴, so did Global shipping giant Maersk.
5. The physical separation of costly batteries from the glider trucks enables leasing and battery-as-a-service business models, which attracted more investors outside of fleets and OEMs.

Adopting battery swap HD trucks offers several advantages over fixed battery counterparts, characterized as **S.T.U.D.**:

- **Space saving:** Battery swap stations require minimal space compared to large parking lots with fixed chargers. Trucks can swiftly pass through for a battery swap, taking as little as five minutes. Mobile stations could be economically placed in less expensive areas in coastal California.
- **Time saving:** During the busy daytime, a battery-swapping HDT experiences a five-minute downtime for a battery swap, compared to the 30-60 minutes needed to recharge fixed battery trucks. This further eliminates hour-long waiting times that occur when chargers are occupied.
- **Utility integration:** Battery-swapping HDTs can leverage solar-peak hours and the battery swapping stations, many of them mobile, can be placed near renewable energy sources. A network of battery swapping stations can function as a virtual

power plant as in Tangshan City and contribute to micro-grid operations.

- **Decreasing in purchase cost:** Owners of battery swap HD trucks can reduce upfront costs in two ways: by purchasing trucks without batteries and leasing batteries from station operators, and by requiring fewer batteries overall compared to fixed battery trucks. Instead of two battery packs (i.e. 350 kWh x 2) on a fixed battery truck, a battery-swapping HDT in a Hainan cement company we visited only needs 1.15 batteries (350 kWh x 1.15) to cover the range of two battery packs in a fixed battery truck, about 300 miles⁵.

Challenges facing the battery-swapping HDTs. Presently, battery-swapping HDTs are mostly adopted in the close-loop duty cycles such as ports and mines as well as in short-haul use, mainly between ports and depots. Wider adoption, especially in long-haul trucks, requires the standardization of battery-swapping HDTs and the battery swapping stations. Several long-haul high-way routes (680-1000 km)⁶ have been under development since 2023. Here is the [link](#) to ICCT's blog on electric trucks in China, including battery swapping HD trucks.

⁴ <https://theelect.org/china-growing-re-electric-trucks-mar24/>

⁵ Interview with Hainan Huasheng Cement Company during California Delegation's Visit on March 21, 2024

⁶ https://autonews.gasgoo.com/new_energy/70627568.html

Annex 2. List of Participants

Battery Forum Registration

First Name	Last Name	Company
Gregory	Owen	Ability Tri-Modal
John	Gerra	Amazon
Aaron	Kurz	Assembly Transportation Committee
Kathleen	Chen	Assembly Utilities and Energy Committee
Stephanie	Choing	CA State Assembly Transportation Committee
Bernard	Soriano	California Department of Motor Vehicles
Sarah	Lim	California Energy Commission
Mark	Headrick	California Highway Patrol
Paula	Gruendling	California Public Utilities Commission
Benjamin	OBrien Hokanson	California Senate
Georgina	Landecho	California Vanpool Authority
Liz	Brisson	San Francisco Municipal Transportation Agency
Edward	Wright	San Francisco Municipal Transportation Agency
Jordan	Smith	Southern California Edison
Viktorija	Naujokaite	Trys parseliai
John Bryant	Cadiz	UC Davis
Shenyang	Chen	UC Davis
Lewis	Fulton	UC Davis
S. Coco	Herda	UC Davis
Reyhane	Hosseinzade	UC Davis
Aakansha	Jain	UC Davis
Hanif	Tayarani	UC Davis
Brad	Bayne	4 Gen Logistics
Michael	Kelso	Ability Tri-Modal
Karen	Schkolnick	Bay Area Air Quality Management District
Sydney	Vergis	California Air Resources Board
Jimmy	O'Dea	California Department of Transportation
Patty	Monahan	California Energy Commission
Marc	Perry	California Energy Commission

Michelle	Vater	California Energy Commission
Brian	Cocagne	California Highway Patrol
David	Fawson	California Highway Patrol
Orville	Thomas	California Mobility Center
Audrey	Neuman	California Public Utilities Commission
Shiva	Ourang	California Public Utilities Commission
Nguessan	Affi	California State Transportation Agency
Christine	Casey	California State Transportation Agency
Giles	Giovinazzi	California State Transportation Agency
Toks	Omishakin	California State Transportation Agency
Alana	Sanchez	California State Transportation Agency
Analisa	Bevan	CARB
Tom	Perlin	CH Robinson
Liguo	Il	China Association of Electric Heavy-Duty Truck Battery Swapping
Xiuli	Zhang	Energy Innovation
Chris	Busch	Energy Innovation: Policy & Technology LLC
Evan	Oneto	FedEx
Jessie	Denver	GO-Biz
Linda	Zhong	LiCAP Technologies
Greg	Sarvas	Los Angeles Department of Water and Power
Carlo	Bertani	Maersk
Margaret	Wong	McWong International, Inc.
Julie	Caskey	Oakland Mayor's Office
Evan	Fern	Office of Senator Cortese
Rose	Szoke	Port of Long Beach
Amber	Aviles	Port of Los Angeles
Tracy	Fidell	Port of Oakland
Angela	Clapp	Port of Oakland
Philip	Gibbons	Port of San Diego
Jaime	Lemus	Sac Metro Air District
Alberto	Ayala	Sacramento Metropolitan Air Quality Management District
Nick	Fiore	San Diego Gas & Electric

Harry	Marks	SMUD
Aaron	Katzenstein	South Coast Air Quality Management District
Sam	Cao	South Coast Air Quality Management District
Elaine	Shen	South Coast Air Quality Management District
Mei	Wang	South Coast Air Quality Management District
Fan	Xu	South Coast Air Quality Management District
Scott	Moura	UC Berkeley
Ruiting	Wang	UC Berkeley
Cristina	Cameron	UC Davis
Timothy	Hughes	UC Davis
Miguel	Jaller	UC Davis
Jean	Ji	UC Davis
Natalie	Ruiz	UC Davis
Alejandra	Soto	UC Davis
Daniel	Sperling	UC Davis
Danielle	Tong	UC Davis
Yunshi	Wang	UC Davis
Ryan	Bankerd	UPS
Karl	Simon	US Environmental Protection Agency
Aravind	Kailas	Volvo Group North America

Case Study – (this data was obtained by the Hainan New Energy Vehicle Promotion Center from the Huasheng Cement Factory and Qiyuan, a battery swap station operator)

Case Study of Huasheng Cement Factory

POSITIVE IMPACT (S)



- 40% increase in operations efficiency.
- 65% lower cost of operations compared to diesel and 33% lower for hydrogen.
- 50 trucks can utilize one single battery swap station, leading to a reduction of CO₂ emissions by about 3,945 tons a year.

The Huasheng Cement factory, located in Hainan Province, China, has rapidly adopted heavy-duty battery swap cement mixers. From an initial two trucks in July, 2021, there are now over 500 battery swap cement mixers and 21 battery swap stations in operation throughout the entire island province. Operating between 120-300 km per day (75-180 miles), the battery swap cement mixers have a kWh consumption rate of 1.6kWh/km. The program has been so successful that the factory owner plans to convert all of 500 the remaining diesel trucks to BSHDTs.

Battery Swap Charging



Acknowledgments:

The California Battery Swap Truck Forum would like to thank all Forum participants and panel members for their time and energy spent contributing to and learning about how battery swapping for heavy-duty vehicles may be a tool for transportation decarbonization in California and the United States. Thank you to Mr. Li who came all the way from China to attend and share his experiences to Forum participants. The California Battery Swap Truck Forum would not have occurred without the sustained support of Secretary Omishakin of the California State Transportation Agency, and his dedicated executive team and staff members, which include Alana Sanchez and Christine Casey. A special thanks is also in order for Mr. Giles Giovinazzi, Senior Advisor to the California State Transportation Agency, for his dedicated support of and organizing of the Forum. The California Energy Commission also contributed their time and energy to making the event Forum a success; thank you to former-Commissioner Patty Monahan of the CEC and senior staff member Ben Wender. Finally, we acknowledge Director Yunshi Wang of UC Davis and Timothy Hughes for their organization of the Forum.