WORKING PAPER

APRIL 2024

Electrifying on-road freight: Port tractor-trailers and concrete mixer trucks in Hainan province, China

Authors: Tianlin Niu, Hongyang Cui, and Yihao Xie (International Council on Clean Transportation); Guozhu Guo (Hainan New Energy Vehicle Promotion Center); Song Wu and Hongqing Li (China Automotive Technology and Research Center)

INTRODUCTION

In July 2023, China's Hainan province released its *Medium- to Long-term Action Plan on New Energy Vehicle Deployment (2023–2030)*.[1] New Energy Vehicles (NEVs) include battery electric vehicles, plug-in hybrid electric vehicles, and fuel-cell electric vehicles. As shown in Table 1, Hainan classified all on-road vehicles into 11 categories and, as part of the Hainan NEV action plan, proposed a timeline for most categories to progressively shift to NEVs being 100% of new sales. Heavy-duty trucks (HDTs) were the exception.

While Hainan's plan acknowledges the need to accelerate the transition to NEV technologies for HDTs, it did not propose NEV sales share targets. Instead, the plan said NEV sales targets for HDTs would be set annually in separate policy documents, thereby ensuring that Hainan leads the nation in new energy HDT deployment.

1 Hainan Daily, 海南印发新能源汽车推广中长期行动方案 [Hainan issues medium- and long-term action plan for new energy vehicle deployment], Xinhua News Agency, August 9, 2023, http://hq.news.cn/20230809/6e473834f1054d53a3befd6830d76564/c.html.

Acknowledgments: This project is part of the International Climate Initiative (IKI). IKI is implemented by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) in close cooperation with Germany's Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) and the Federal Foreign Office (AA).

The authors are thankful for the constructive reviews and comments from Shiyue Mao, Lingzhi Jin, Hussein Basma, and Felipe Rodríguez of the ICCT. Any errors are the authors' own. We also thank Jennifer Callahan, Lori Sharn, Valerie Sheckler, and D'Errah Scott for editorial support.

IKI INTERNATIONAL CLIMATE INITIATIVE

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

www.theicct.org

communications@theicct.org

@theicct.org

icct THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Table 1

Hainan's 2022 sales share of new energy vehicles (NEV) and sales share targets.

Vehicle category		2022 actual NEV sales share (%)	2025 NEV sales share target (%)	2030 NEV sales share target (%)
Passenger vehicles	Private cars	41	60	100
	Government vehicles	100	100	100
	Taxis	100	100	100
	Ride-hailing vehicles	100	100	100
	Rental cars	100	100	100
Buses	Public buses	100	100	100
	Tour coaches	2.3	50	100
	Intercity coaches	69	50	100
Trucks	Sanitation trucks	6.5	60	100
	Light-duty trucks (< 4.5t)	37	100	100
	Heavy-duty trucks (≥ 4.5t)	15	N/A	N/A

Sources: Medium- to Long-Term Action Plan of Hainan Province on New Energy Vehicle Deployment (2023–2030); China Automotive Technology and Research Center (CATARC)

The detailed market sales shown in Table 2 further indicate that 20% of all tractor-trailers sold in Hainan in 2022 were electric, the second highest among all Chinese provinces. Most of these tractor-trailers used swappable batteries, as Hainan ranks first in the deployment of this technology across China. Compressed natural gas (CNG) and liquid natural gas (LNG) tractor-trailers also have a high market share in Hainan, accounting for half of sales in 2022.

For concrete mixer trucks in the cement industry, Hainan also has the highest sales share of battery electric trucks (BETs) in China, with about half of these trucks being swap capable.

Table 2

Tractor-trailer and concrete mixer truck sales by fuel type in Hainan, 2022.

	Fuel type	Sales	Sales share (%)	Sales share rank
Tractor-trailers (GCW over 40t)	Diesel	121	28	29
	Battery electric (total/swap capable)	84/6	20/18	2/1
	CNG and LNG	220	51	4
	Methyl alcohol	4	1	3
Concrete mixer trucks	Diesel	26	12	31
	Battery electric (total/swap capable)	191/91	88/42	1/1

Source: Beilong Zeda Technology Co. Ltd. (ZEDATA), Vehicles produced domestically in China, accessed July 20, 2023, http://www.zedata.cn/.

This study investigates two specific use cases of BETs in Hainan and collects first-hand empirical data on real-world operations. Based on that data, this study presents a total cost of ownership (TCO) analysis to evaluate the economic performance of battery electric HDTs, including both capital (CapEx) and operational expenditures (OpEx). This study concludes by recommending possible further policy measures that could be considered to promote zero-emission trucks in Hainan.

USE CASE RESEARCH

We visited the Xiaochantan Container Terminal at the Port of Yangpu in 2023 to learn more about the transportation of shipping containers (Figure 1). The annual freight activity at the terminal is 1.46 million twenty-foot equivalent units (TEU). A logistics company operating at the terminal owns 36 battery electric tractor-trailers for moving containers in the terminal.

Figure 1
Battery electric tractor-trailers at the Port of Yangpu.

Photos by Tianlin Niu

We also visited two cement plants in Hainan, Huasheng Cement and Xinhai Cement (Figure 2). Each plant has about 50 battery electric concrete mixer trucks in operation. Jiahua Logistics owns and operates the mixer trucks at Huasheng Cement while Xinhai Cement has its own fleet of mixer trucks.

Figure 2
Battery electric concrete mixer trucks at the Huasheng Cement plant.

Photos by Tianlin Niu

Much of the data in this analysis was obtained from on-site interviews with fleet owners and operators, who provided detailed information on everything from the purchase prices of trucks to battery ranges. We observed recharged batteries being placed in trucks at battery-swapping stations, photographed the fleets, and gathered information on local energy prices. We also collected real-world data on operational duty cycles by riding in the trucks and using a device to record vehicle speed and altitude during deliveries of containers and concrete.

TRUCK SPECIFICATIONS AND OPERATIONS

Table 3 outlines truck activity, energy consumption, and revenue for the two use cases. For in-port drayage of containers, we investigated diesel, battery electric, and LNG tractor-trailers. While all drayage trucks at the port have already been replaced by BETs, we included combustion-powered vehicles in this assessment for comparison and completeness.

One of the cement plants we visited uses a mix of diesel and BETs. LNG trucks have not been used since 2021 but are included in this assessment for comparison. In addition to these three powertrain technologies, we also investigated hydrogen fuel-cell electric concrete mixers as an additional technology pathway. While hydrogen fuel-cell electric trucks (FCET) are not yet used in these cement plants, they are being considered.

Table 3
Overview of two use cases in Hainan.

	In-port drayage of containers	Concrete delivery
Distance per trip	0.5 - 1 km (round trip)	20–60 km (round trip)
Trips per day	100–150	10–20
Annual activity	35,000 km	60,000 km
Truck service life	12 years	5 years
Fare[a]	~¥30/km	~¥20/km
Diesel truck energy consumption[b]	40 L/100 km (empty) 70 L/100 km (full load)	Empty: 30 L/100 km (empty) Full load: 60 L/100 km (full load)
BET energy consumption[b]	120 kWh/100 km (empty) 300 kWh/100 km (full load)	140 kWh/100 km (empty) 180 kWh/100 km (full load)
LNG truck energy consumption[b]	Average: 60 kg/100 km	Average: 50 kg/100 km
FCET energy consumption[b]	—	Average: 12.5 kg/100 km

[a] Fares are what fleet owners charge to transport freight (as estimated by fleet owners). Fares for concrete delivery depend on different factors for each trip, including load amount and trip length.
[b] For diesel trucks, energy consumption was empirically estimated by the fleet owner. For BETs, energy consumption was estimated by state of charge (SOC) changes and by the lengths of the operational trips we tested. For LNG trucks and FCETs, the estimated average value of energy consumed comes from the fleet owner and from our vehicle simulation.

Table 4 and Table 5 present the technical specifications of the trucks that were in operation during the two use case studies. When diesel or LNG trucks were no longer in operation in a fleet, we collected information on the last operational model. For the fuel-cell concrete mixer, we analyzed a commercially available model.

Both use cases deploy swap-capable BETs, which are offered by the manufacturer under a battery-as-a-service (BaaS) business model. Under that model, fleets do not pay upfront for batteries, lowering the purchase price of an electric truck to only slightly higher than the price of a diesel truck. Instead, fleet owners pay a battery rental fee every time a battery is swapped. This is a potentially attractive business model for small fleets with limited access to capital, as it turns a capital expenditure into an operational expense.

Fleet owners can also choose to purchase a complete BET including the battery. For in-port drayage trucks, which have a service life of more than 12 years, we assume that battery replacement is planned after 7 years of use if the owner did not choose the BaaS model.

Table 4

Use case of tractor-trailers for in-port drayage.

Powertrain	Diesel	Battery electric	LNG
Vehicle model	ZZ5371TQYM28102	SM4255TORBEV	ZZ5371VDMC32100
OEM	Sinotruk	SANY Marine	Sinotruk
Brand	HOWO	SANY	HOWO
Gross combination weight (kg)	70,000	70,000	70,000
Rated/Max engine power (kW)	196	150/200	196
Max engine torque (Nm)	1,100	1,400	1,160
Engine displacement (L)	10	—	9.7
Energy storage	300 L (diesel tank)	141k Wh (battery)	450 L (LNG tank)
Certified range (km)	1,100	120	250
Retail price (CNY)	350,000	600,000 (w/ battery) 400,000 (w/o battery)	400,000

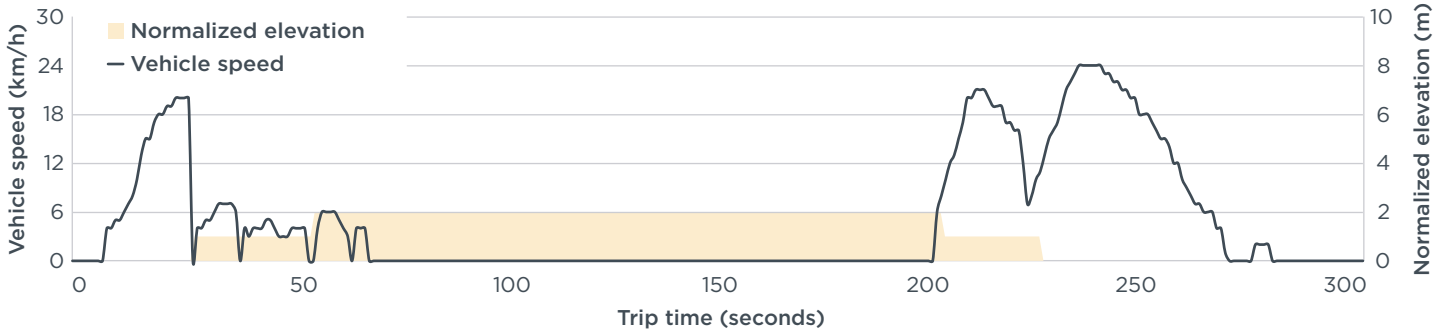
Table 5

Use case of concrete mixer trucks.

Powertrain	Diesel	Battery electric	LNG	Fuel-cell electric
Vehicle model	SYM5311GJB1F3	SYM5310GJB5BEV9	SYM5311GJB2F1	SYM5312GJB1FCEV
OEM	SANY Automotive	SANY Automotive	SANY Automotive	SANY Automotive
Brand	SANY	SANY	SANY	SANY
Gross vehicle weight (kg)	31,000	31,000	31,000	31,000
Payload (kg)	16,670	15,570	16,800	16,130
Rated/Max engine power (kW)	226	270/405	257	198/355
Max engine torque (Nm)	1,500	1,150	1,600	2,400
Engine displacement (L)	7.7	—	9.5	—
Energy storage	300 L (diesel tank)	282 kWh (battery)	600 L (LNG tank)	10×165 L (350 bar) (H_2 tank) 127 kWh (battery)
Certified range (km)	1,500	180	500	250
Retail price (CNY)	350,000	850,000 (w/ battery) 450,000 (w/o battery)	400,000	1,450,000

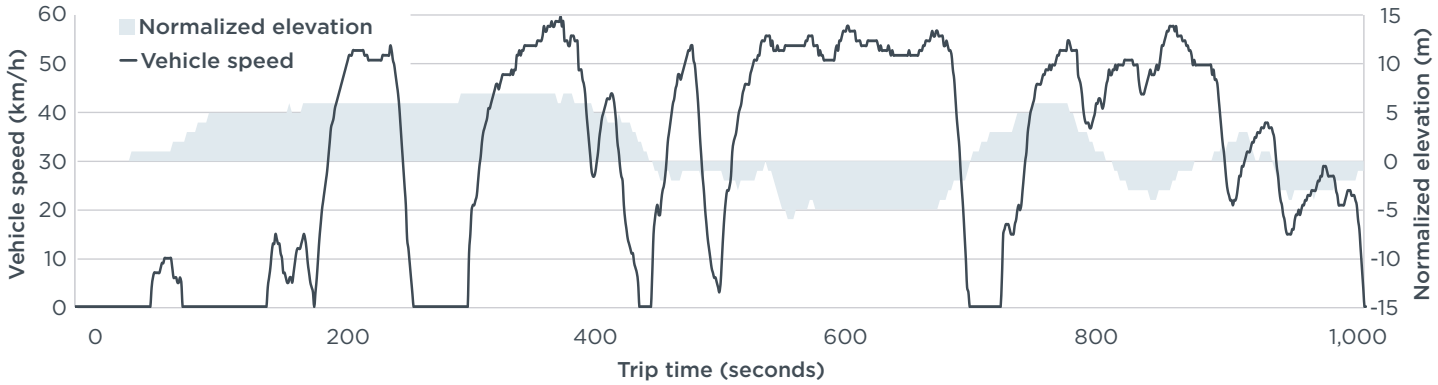
Figure 3 and Figure 4 show the real-world operational duty cycles for both use cases, as collected by a device recording second-by-second speed and altitude readings.

Figure 3
Operation cycle sample for in-port drayage (round trip).



THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION **THEICCT.ORG**

Figure 4
Operation cycle sample for concrete delivery (one way).



THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION **THEICCT.ORG**

TOTAL COST OF OWNERSHIP ANALYSIS

OVERALL METHODOLOGY

This study employed the ICCT's Analyzer of Zero-emission Transportation Energy and Costs (AZTEC) model.[2] The detailed methodology for using this model is illustrated in an earlier ICCT report.[3] In this study, we estimated the lifetime TCO of trucks in Table 4 and Table 5 for both use cases in Hainan. For comparison, we further analyzed the TCO of buying a complete BET besides of BaaS mode. The following section summarizes key input data and assumptions for estimating the CapEx and OpEx of different trucks in the two use cases.

2 International Council on Clean Transportation, *Analyzer of Zero-Emission Transportation Energy and Costs—Documentation* (2022), https://github.com/theicct/AZTEC-doc.

3 Niu Tianlin, Ma Yunxiao, and Zhang Yichen, *Real-World Use Cases for Zero-Emission Trucks: Market Review and Policy Suggestions for Guangdong Province* (Washington, D.C.: International Council on Clean Transportation, 2023), https://theicct.org/publication/real-world-zet-guangdong-oct23/.

CAPITAL EXPENDITURES

The fleet owners we interviewed all used loans to buy their trucks (including BETs purchased with a battery and BETs renting a battery under the BaaS model) with a 40% down payment, 10% interest rate, and 3-year loan term. Diesel and LNG trucks are subject to a purchase tax of 10% of the total vehicle retail price, which is reflected in Table 3 and Table 4. BETs and FCETs are exempt from registration taxes.

Fleet owners expect to use all trucks throughout the vehicles' lifetimes and to scrap them after 12 years for in-port tractor-trailers and 5 years for concrete mixer trucks. A China Automotive Technology and Research Center (CATARC) report shows the annual depreciation rate is 8% for Chinese diesel trucks and 12% for BETs and FCETs.[4]

OPERATIONAL EXPENSES—ENERGY

Energy costs are determined by the annual activity, average energy consumption (as shown in Table 3), and energy price. Table 6 shows the energy prices for Hainan used in this study.

Table 6
Energy prices in Hainan.

Energy type	Description of cost	Price (CNY)
Diesel	Annual average	7.78/L
Electricity[a]	Average basic electricity price	0.70/kWh
	Service fee for battery swapping	0.45/kWh
	Battery rental fee	0.55/kWh
LNG	Annual average	7.50/kg
Hydrogen	FCET refueling	80/kg

[a] Price is per kWh charged to replenish a battery; it does not refer to battery size or capacity.

From January 2021 to January 2023, the average retail price for diesel in Hainan was ¥7.78/L and the price for LNG was ¥7.5/kg (these prices were used in this study and were considered constant). The average electricity price reported by BET fleet owners was ¥0.7/kWh. The battery swapping station levies a fee of ¥0.45 per kWh for the swapping service. Fleet operators who purchased the complete truck (with batteries) pay the electricity price plus the service fee to swap a battery, or ¥1.15 per kWh charged. For the BaaS model, fleet owners pay the electricity price and the service fee, plus an average rental fee of ¥0.55 per kWh, for a total of ¥1.7/kWh. The hydrogen price is the real market price of hydrogen for FCET refueling purposes in 2023, according to our interviews with hydrogen suppliers.

OTHER EXPENSES—TAXES, FEES, AND MAINTENANCE

Diesel and LNG trucks are subject to an ownership tax of ¥60 per ton of curb mass per year, but zero-emission trucks are exempt. Furthermore, Hainan has no toll fees for highways but imposes a monthly traffic fee of up to ¥4,400 on diesel trucks; other trucks are exempt.[5] Other fees noted by local fleet owners are listed in Table 7.

4 Dongchang Zhao et al., 中国商用车 TCO 研究及中美对比 [Research on TCO of commercial vehicles in China and comparison between China and the United States] (Tianjin: China Automotive Technology and Research Center, 2022), https://www.efchina.org/Attachments/Report/report-ctp-20220701/%E4%B8%AD%E5%9B%BD%E5%95%86%E7%94%A8%E8%BD%A6TCO%E7%A0%94%E7%A9%B6%E5%8F%8A%E4%B8%AD%E7%BE%8E%E5%AF%B9%E6%AF%94.pdf/view?searchterm=%E4%B8%AD%E5%9B%BD%E5%95%86%E7%94%A8%E8%BD%A6+TCO.

5 Hainan Provincial Department of Transportation, 海南省交通规费征稽局收取车辆通行附加费收费标准[Standard vehicle traffic fees by Hainan Provincial Bureau of Traffic Regulations Fees], September 1, 2022, https://jt.hainan.gov.cn/xxgk/sfxm/202209/t20220901_3258480.html.

Table 7

Various overhead costs (CNY) in for each type of truck in this study.

		Diesel	LNG	BET	FCET
Port tractor-trailers	Insurance (CNY/year)	5,000	5,500	10,000 6,900 (BaaS)	—
	Traffic fee (CNY/year)	0	0	0	—
	Staff (CNY/year)	~150,000	~150,000	~150,000	—
Concrete mixer trucks	Insurance (CNY/year)	8,000	8,500	15,000 7,200 (BaaS)	20,000
	Traffic fee (CNY/year)	36,000	0	0	0
	Staff salary (CNY/year)	~130,000	~130,000	~130,000	~130,000

Maintenance costs vary greatly depending on a vehicle's powertrain and use. Fleet owners and local consultants estimated the maintenance cost for trucks in our study at ¥0.33/km for diesel trucks, ¥0.33/km for LNG trucks, ¥0.22/km for BETs, and ¥0.23/km for FCETs.[6] These numbers do not consider the replacement costs of batteries and fuel cell packs. Tire wear and tire replacement also affect maintenance costs. However, no data is available on whether there is any difference in tire lifespan for electric versus diesel trucks.

Revenue and profit

Revenue is estimated based on the fare, annual activity, and payload for each use case, as detailed in Table 3. The actual profit for each truck is the total revenue minus the TCO.

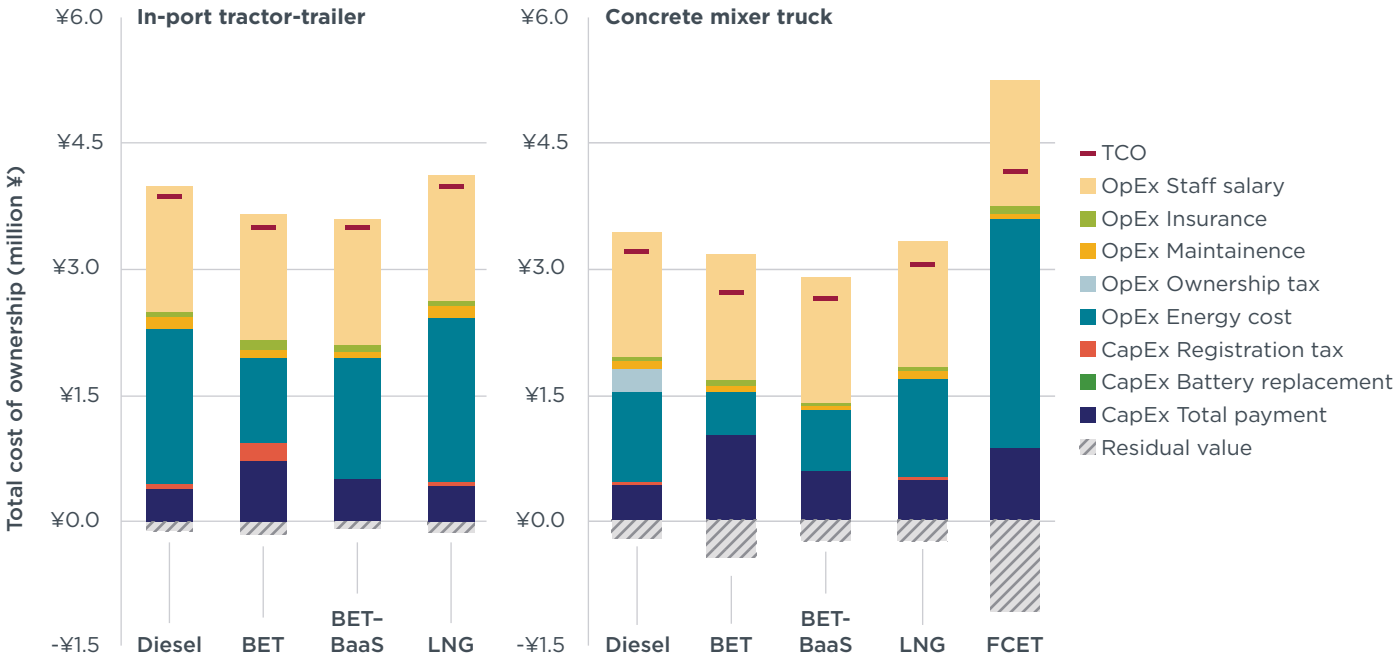
RESULTS AND DISCUSSION

Figure 5 presents TCO results using different powertrains for both use cases. Swap-capable BETs in BaaS mode can reduce costs by 10% for in-port drayage and by 17% for concrete delivery compared with diesel trucks. BETs show the same TCO reduction in non-BaaS mode for in-port drayage, but a slightly lower reduction of 15% for concrete delivery trucks in non-BaaS mode. The significantly reduced upfront costs are due to renting rather than purchasing batteries in the BaaS mode, which results in spreading CapEx into operating expenses. This may make it easier for buyers to choose BETs. LNG trucks have a similar TCO (±5%) to diesel trucks. FCETs have the highest TCO, especially for concrete mixer trucks.

6 Maintenance costs for diesel trucks, BETs, and LNG trucks were collected from local interviews. FCET maintenance costs came from Niu, Ma, and Zhang, *Real-World Use Cases*.

Figure 5

Total cost of ownership (TCO) of in-port tractor-trailers and concrete mixer trucks in Hainan.



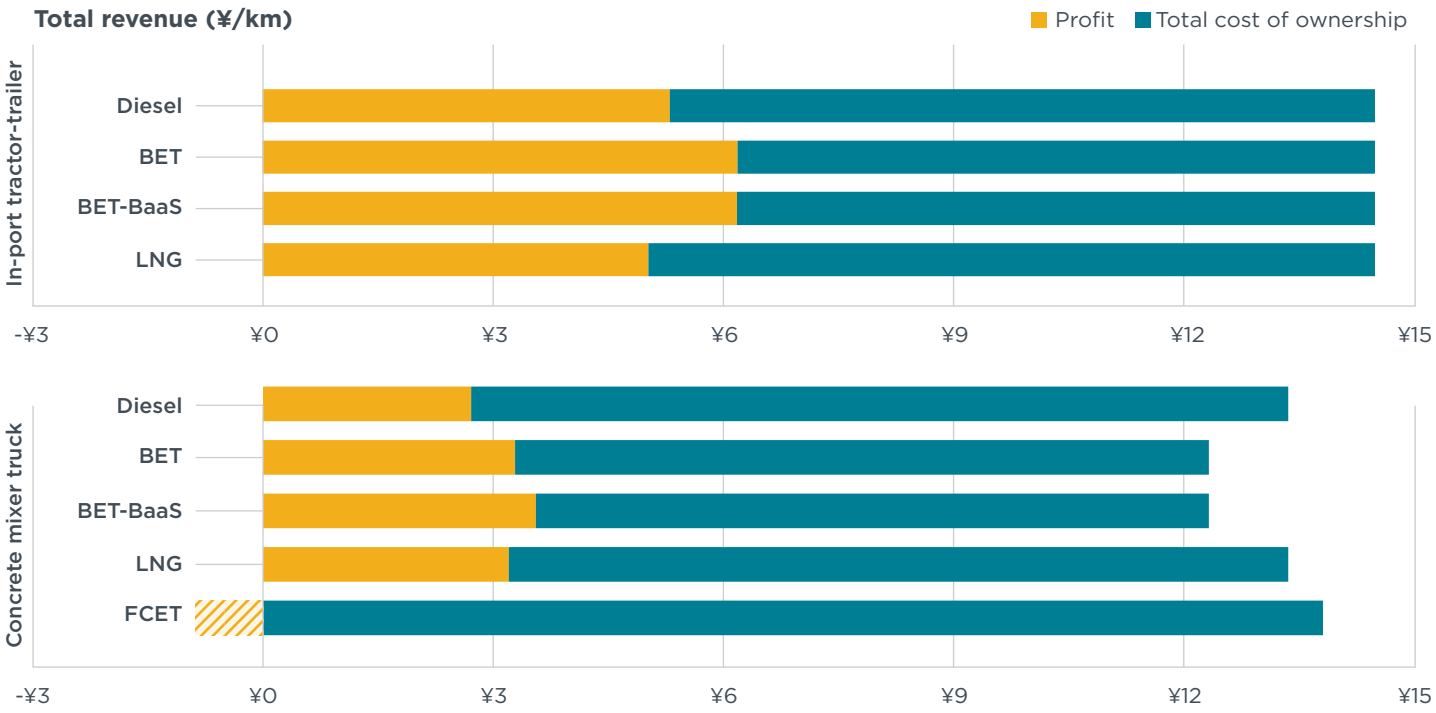
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION **THEICCT.ORG**

Figure 6 shows economic performance per kilometer for both use cases, including TCO and profit. (The length of each bar indicates total revenue.)

- Tractor-trailers used for in-port drayage always have the same total revenue, regardless of powertrain, because they each carry about two containers per trip.
- Battery electric tractor-trailers have 17% higher profit per kilometer than diesel trucks; there was little difference in profit between BETs with purchased batteries and BETs using the BaaS model.
- Concrete mixer trucks with different powertrains have different total revenue as BETs tend to carry lower payloads than diesel and LNG trucks because of battery weight.
- However, both types of battery electric trucks under a BaaS model have up to 32% higher profit per kilometer than diesel trucks.
- Concrete mixer trucks under the battery-purchase model are not as profitable as under the BaaS model but still show 22% higher profit per kilometer than diesel trucks.
- Fuel-cell electric concrete mixers would have negative profit; the total revenue from using an FCET cannot cover the much higher cost of refueling.

Figure 6

Economic performance of Hainan in-port tractor-trailers and concrete mixer trucks.



THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION **THEICCT.ORG**

FINDINGS AND RECOMMENDATIONS

This study investigates the real-world performance of BETs, including swap-capable trucks for in-port container delivery and concrete delivery in Hainan province. Our findings suggest swap-capable BETs achieved lower TCO and higher net revenue per kilometer than diesel and LNG trucks for both use cases. The BaaS model enabled by swap-capable BETs also addresses the financial challenges posed by the higher purchase price of BETs, because it reduces the upfront cost burden and provides higher economic benefits for fleet customers. FCETs are still far from reaching TCO parity with diesel trucks because of high refueling costs. To close this gap, lower hydrogen prices will be required.

Drawing on these findings, Hainan could consider three actions to promote the electrification of HDTs:

1. **Hainan could further develop NEV sales targets for HDTs in the Hainan NEV action plan.** Companies in different industries have taken the initiative and successfully deployed new energy HDTs in their fleets. The positive TCO outlook from our analysis of the two use cases shows that setting NEV sales targets for HDTs is economically feasible. It is important to recognize, however, that real-world performance of new energy HDTs can vary among different industries. Hainan will be well advised to consider differentiated NEV targets for trucks in different use cases. Additional analysis of other major use cases will be necessary to come up with ambitious yet sensible targets.

2. **Hainan could consider setting 100% NEV sales targets for certain categories or use cases of HDTs.** The electrification of in-port drayage, concrete delivery, and other similar short- and medium-haul use cases should be prioritized, as BETs in such use cases are proven to deliver cost savings and higher profits, compared with combustion engine trucks, for fleet owners in Hainan. The path of electrification for these use cases can be accelerated, including consideration of a 100% NEV new sales target before 2030.
3. **Hainan could provide incentives for innovative solutions.** This could include supporting the construction and operation of battery-swapping stations and encouraging the BaaS business model. Providing sufficient recharging/refueling stations and battery-rental services would further ensure the viability of real-world BET operations. The BaaS model has proven to be an effective approach for Hainan fleet owners in the container transport and cement industries. Hainan's efforts could also focus on facilitating cooperation between fleet owners and battery-swapping service suppliers to help promote adoption of the BaaS model.

www.theicct.org

communications@theicct.org

@theicct.org

Please share your valuable insights about NDC-TIA knowledge product(s) by taking this short survey: https://tinyurl.com/ndctia-survey

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

BEIJING | BERLIN | NEW DELHI | SAN FRANCISCO | SÃO PAULO | WASHINGTON DC