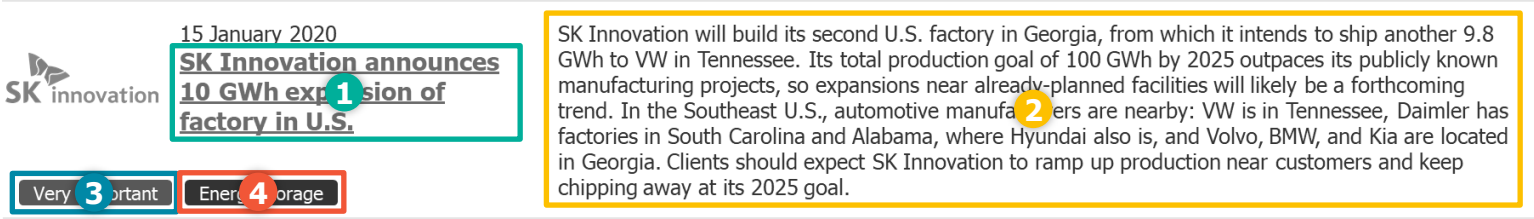
Singapore Battery Consortium

2022 Q4 Newsletter

SINGAPORE BATTERY CONSORTIUM

Understanding curation of recent industry developments and technology news

Recent industry developments and technology news are specifically curated based on the relevance to the progression of the industry. Each news event is categorized based on importance and area of focus (see below for description for both).



1. **Link**: Hyperlink to original news article. Note some news articles may be behind paywall.
2. **Analysis**: Writeup of the news event as it relates to industry development and recommendations for action.
3. **Importance**: Take on the potential importance of the event from "Truly Disruptive" to "Ignore"
4. **Area of Focus**: Category of the news event based on the to the topic.

Importance	Description
Truly Disruptive	A game-changing, landmark development
Very Important	Significant news that will have strong implications
Average Importance	Worth noting, but not likely to be too important or disruptive
Low Importance	An over-hyped development, which is not worth monitoring closely
Ignore	Misleading or irrelevant development, worth being cautious about

Area of Focus	Description
Built environment energy use	Hardware and software technologies for commercial and residential energy consumption
Business models and regulations	Novel business models for energy production, consumption, and distribution, as well as policies with transformational impact on new energy technology development
Energy for mobility	Energy sources for powering road, rail, aviation, and marine – includes movement of goods and people
Energy storage	Various forms electrochemical energy storage, such as Li-ion and solid-state batteries
Stationary storage	Utility-scale and long-duration energy storage for grid services, renewables integration and backup, and microgrid support

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Low-cost, sustainable battery raw materials continues to gain innovation interest

3 October 2022

Sparc Technologies to develop a biowaste-based, hard carbon anode

Low Importance | Energy storage

Current high prices of lithium and shortages in supply have put pressure on the battery industry. Another concern is that existing hard carbon materials are typically sourced from oil and gas byproducts, which require lengthy heating at high temperatures and consume large amounts of energy. Sparc and Queensland University of Technology have decided to develop a hard carbon anode from sustainably sourced biowaste using sodium-ion chemistry. While Sparc has good momentum in this uncrowded space, commercialization will depend on the economic viability of this solution in comparison to traditional hard carbon anodes.

3 October 2022

Xos Trucks unveils new range of DC fast chargers along with purchase order from Morgan Services

Average Importance | Energy for mobility

Xos' new suite of chargers range from 30 kW to 300 kW and come with a combined charging system 1 (known more commonly as CCS1) connector. The company will offer these chargers as part of its Xos Energy Solutions package. With the unveiling, Xos also announced a purchased order from Morgan Services to install nine chargers at its Los Angeles location. To stand out in the electrification space, a company would need to offer an entire package as opposed to just vehicles. Xos has set up the infrastructure to be able to do so, but long-term success will depend on the company raising additional funding; its falling stock price suggests that it will be tricky.

4 October 2022

MIT researchers have developed a low-cost battery with materials that are locally sourced

Average Importance | Energy storage

The new cell technology is an aluminum-chalcogen chemistry (aluminum sulfur and aluminum selenium), which uses aluminum as the negative electrode, elemental chalcogen as the positive electrode, and molten chloroaluminate electrolytes. Also, it uses a conversion mechanism to charge the cell, which means that instead of intercalating lithium ions during discharge, here selenium changes the lattice structure of the electrode. The research claims that polymerization of chloroaluminates supports ultrafast electrodeposition of aluminum while negating dendrite formation. The authors claim the estimated cell-level cost of aluminum-sulfur is USD 20.8 per kWh and aluminum-selenium is USD 127.8, which includes materials and packaging.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

The verdict is still out for second-life battery usage as real-world deployments continue to lag

4 October 2022

ESS Inc. to deploy largest flow battery system in U.S. with 2-GWh deal

Very Important | Stationary storage

Sacramento Municipal Utility District ordered 200 MW/2 GWh of flow batteries from ESS Inc. to begin operations in 2023, with the system delivered in phases. To support the delivery of the iron flow batteries, ESS Inc. will open an assembly facility in Sacramento, plus a long-duration energy storage Center of Excellence that will collaborate with local academic bodies. Historically, project announcements with such large capacity bids are met with skepticism; however, the additional investment in battery assembly and development is a promising sign that ESS Inc. has an opportunity to grow its deployments substantially.

12 October 2022

ANL team cracks the issue of grain boundaries in single-crystal CAMs

Very Important | Energy storage

Single-crystal cathode active materials (CAMs) last longer than polycrystalline particles because they don't have grain boundaries that crack during operation. But research from Argonne National Laboratory (ANL) found grain boundaries in supposed single-crystal nickel manganese cobalt (NMC). After the discovery, researchers developed a way to eliminate these boundaries, with a 25% increase in energy storage per unit volume and negligible performance loss over 100 cycles. While finding grain boundaries in single-crystal particles is costly and time-intensive ANL's proposed synthesis method can unlock further development in single-crystal materials.

12 October 2022

Kia and Deutsche Bahn to give EV batteries second life as stationary power storage

Low Importance | Stationary storage

Kia Europe is partnering with Deutsche Bahn startup Encore to use electric vehicle (EV) batteries as energy storage units for their second life. Encore with partners DellCon and Stabl is working on the procurement, quality check, and recalibration of batteries. The company has already set up a prototype facility of 24 72-kWh modules made from Kia Soul EV batteries as part of a microgrid for EV charging. The system is too small — equivalent to less than two EV batteries — to draw any conclusion about its impact. To gauge if Encore will make a difference in second-life applications, it will be critical to evaluate how Deutsche Bahn's logistics expertise adds value to the project and how maintenance and safety will be addressed.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Automakers continue to move up the value chain and playing direct roles in next-generation battery development

12 October 2022

GM partners with OneD Battery to develop silicon nanotechnology anode

Average Importance | Energy storage

n 2021, GM debuted its Ultium battery platform for EVs, and as an expansion into next-generation technology, it recently participated in a USD 25 million Series C funding round of OneD Battery and signed a joint development agreement with the company. OneD Battery develops a silicon anode technology that fills the surface and pores of graphite with silicon nanowires, which it claims solves the challenge of rapid rate expansion. OneD Battery is setting up a pilot manufacturing facility, and GM's investment in the company will bring in the automobile perspective in R&D as well as rigorous testing opportunities in different scenarios.

12 October 2022

Tesla to deliver first Semi trucks to Pepsi in December

Average Importance | Energy for mobility

Elon Musk tweeted to announce the start of production of the Tesla Semi trucks, with the first deliveries scheduled for December 1. It is unclear how many of the 100 trucks that Pepsi reserved in 2017 will be delivered on this date. The truck has a claimed range of 500 miles or 805 km, which will immediately put it on top of the competition. The Semi's timelines have been pushed back multiple times since its unveiling in 2017, but the announcement of a relatively short-term delivery date shows that the trucks are likely to finally hit the roads later this year. It remains to be seen whether Tesla can already produce these trucks at volume and scale up deliveries over 2023.

12 October 2022

Southern Germany to ease power flow with 250-MW Li-ion battery system

Average Importance | Stationary storage

To ease electricity transmission in southern Germany, Fluence Energy and German transmission system operator (TSO) Transnet BW will deploy the 250-MW/250-MWh "Netzbooster" project in Kupferzell. Project construction will start in 2024, finishing in 2025. The TSO expects to ease electricity transmission from the north to the south of the country, reducing line overload and providing reserve capacity and reactive power (mainly in the Baden-Württemberg region), resulting in cheaper grid expansion. Fast deployment of renewable energy assets introduces intermittency, less grid inertia, and the need to transmit electricity, pushing the deployments of utility-scale battery systems. For now, Li-ion offers the best cost-to-power solution for short discharge times (under four hours).

The U.S. continues to bolster its domestic battery industry with federal funding and grants

14 October 2022

Canoo secures binding purchase order from Zeeba for 3,000 electric vehicles

Average Importance | Energy for mobility

The 3,000-vehicle agreement will be fulfilled by the end of 2024 and is part of a larger order to purchase 5,450 vehicles. The order includes Canoo's Lifestyle Delivery Vehicles and Lifestyle Vehicles. Zeeba intends to add these vehicles to its fleet management services. This is the second purchase order Canoo has announced in recent months with Walmart's nonbinding order being the first. Canoo has had financial troubles recently, and it is unclear whether the company has been able to raise enough funding to fulfill this latest order. While the company has faced financial difficulties, Canoo in its Q2 earnings call claimed it had access to USD 250 million.

20 October 2022

Battery recycling Frankenstein, Cirba Solutions, receives USD 75 million grant from DOE

Very Important | Energy storage

Cirba Solutions will use the grant to increase capacity for battery material recovery. The company had previously pledged to spend an additional USD 200 million on capacity expansion. Cirba Solutions is a company formed by Retriev Technologies, Heritage Recycling, and Battery Solutions. All previous companies had a long history in the battery waste industry, though none of them were particularly strong in Li-ion battery materials recovery. Despite that, Cirba Solutions is well positioned in the U.S. due to its legacy logistics and waste handling networks.

21 October 2022

U.S. DOE awards USD 2.8 billion in grants to battery industry

Truly Disruptive | Energy storage

As part of the Infrastructure Law, 20 battery companies spanning the entire value chain will receive grant funding from the U.S. Department of Energy (DOE) to expand manufacturing. Selected technologies include lithium and nickel production, precursor and cathode material synthesis, graphite production, silicon anode materials, separator materials, and battery recycling. This round of funding is significant not only because of its size, but because it purposefully addresses all material needs in battery cell production. The Inflation Reduction Act passed late this summer placed restrictions on electric vehicle tax credits to encourage more domestic manufacturing of batteries, but without an existing battery supply chain, that would be a difficult task.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Commercial success of Na-ion batteries will largely hinge on CATL's manufacturing timeline

3 November 2022

Form Energy raises USD 450 million in Series E round

Average Importance | Stationary storage

The funding was led by TPG Rise and will be used to scale up manufacturing of Form Energy's iron-air battery. Form Energy's low-cost iron-air battery has attracted investors with promises of 100-plus hours of energy storage, but the company's main value proposition is its use of low-cost materials, especially in its air cathode. The company raised USD 240 million just last year and has completed its Series E just one year later without any public pilots or data on its technology; furthermore, Form Energy is offering 100-plus hours of energy storage in a market that doesn't have the high levels of renewable penetration that would enable its usage.

3 November 2022

Understanding how electrode surface quality affects dendrite growth in lithium-metal batteries

Average Importance | Energy storage

Researchers from Sogang University and Hyundai Motor Company have developed an electro-chemo-mechanical phase-field model that reveals the relation between surface topography and dendrite formation. The simulation showed that dendritic growth could be controlled by maintaining specific electrode height, controlling surface topography, applying voltage and external pressure, and avoiding misaligning electrodes. Further investigation of the computational statistics of surface roughness and collaborate with researchers to understand how much dendritic growth can be mitigated by making processing changes.

3 November 2022

CATL targets Na-ion battery production in 2023

Very Important | Energy storage

The battery manufacturer Contemporary Amperex Technology Co. Ltd. (CATL) has not released details on the scale of production or specific customers, but it will manufacture the batteries for electric vehicles (EVs). CATL's Na-ion battery uses Prussian blue cathode materials and a hard carbon anode, and it achieves 160 Wh/kg. Previous to CATL's announced intention to start producing Na-ion batteries last year, the battery chemistry was expected to debut in the stationary storage market. However, as the lithium industry struggles to keep up with demand, alternative battery technologies have grown. CATL's pack-level innovations that make packing efficiencies higher are likely to push performance high enough to suit low-range EVs.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Increased use of silicon is expected for Li-ion batteries as developers seek incremental performance improvements

3 November 2022

StoreDot achieves 1,000 cycles in silicon-dominant cells that are production ready

Average Importance | Energy storage

In March 2022, StoreDot unveiled its "100inX" project, which emphasizes fast charging and targets producing a battery by 2024 with a charge capability of 100 miles in 5 minutes. The 30-Ah extreme fast charging cells are in pouch format with an energy density of 740 Wh/L and a charge time of 10 minutes. They are made of an anode with 40% silicon content and a nickel-manganese-cobalt 811 cathode and can achieve 1,000 cycles at 35 °C. This announcement is important as the cells are ready for electric vehicle (EV) integration and will be supplied to the company's automotive partners like Volvo, VinFast, and Daimler for field testing

7 November 2022

Toyota begins operation on the grid-connected, second-life Sweep Energy Storage System

Very Important | Stationary storage

The first grid-connected Sweep Energy Storage System installation, a Toyota and Jera initiative, is now online in Yokkaichi, Japan. It has a 485 kW/ 1,260 kWh capacity and consists of second-life electric vehicle Li-ion batteries, nickel-metal-hydride batteries, and lead-acid batteries. The Sweep system can accommodate all battery chemistries and differences in their performance, capacity, and level of deterioration. The device has a control system that can provide continuous energy flow to the grid by sensing battery output and switching between a series of connected batteries in microseconds.

8 November 2022

Nano One fully acquires Johnson Matthey's battery materials business for CAD 10.25 million

Very Important | Energy storage

Nano One Materials, which previously worked with Johnson Matthey on cathode material development, will acquire a 2,400-tonne/a lithium-iron-phosphate (LFP) plant, certification systems to supply to battery cell manufacturers, and associated staff. The company will use the facility to scale up production of its "one-pot" technology, which eliminates the need for metal sulfates and lowers energy usage in cathode active material (CAM) production. Though the acquisition cost is a steal for Nano One — 6K's 3,000-tonne/a facility will cost USD 107 million and open in 2025 — it is instrumental for Nano One to demonstrate costs of its own cathode production process, which is expected to begin operation in 2023.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Novel cathode manufacturing processes aim to improve environmental impact of battery production

9 November 2022

Meta Materials, DuPont Teijin, and Mitsubishi Electric to mass produce Li-ion anode materials

Very Important | Energy storage

The three companies struck an agreement to collectively scale production of Meta's PLASMAfusion anode coating system. The solution involves depositing a thin layer of copper onto a polyester film substrate, which yields better safety and energy efficiency, while reducing battery weight and cost, versus existing copper-heavy anodes. Roll-to-roll manufacturing will enable mass production, and the group plans to apply the technology to the development of solid-state batteries next. This well-timed agreement comes amid a copper shortage and global pressure to improve the safety and range of batteries.

15 November 2022

Canoo plans to manufacture vehicles in Oklahoma

Average Importance | Energy for mobility

Canoo plans to produce its lifestyle vehicle and lifestyle delivery vehicle on the 120-acre site in Oklahoma City for deliveries in 2023. Canoo also recently announced a new battery manufacturing facility in the region; the company claims the facility can produce 3,200 MWh of battery modules after ramping up. These new facilities will contribute to Canoo's attempt to fulfill its claimed USD 2 billion worth of orders, USD 750 million of which are binding. However, Canoo's Q3 earnings release shows a cash balance of only USD 6.8 million with an additional USD 200 million accessible through an at-the-market offering.

18 November 2022

Novonix announces pilot facility in Canada to develop dry processed cathodes

Very Important | Energy storage

Novonix is building a demonstration facility with a target capacity of 10 tonne/a and will utilize a completely dry cathode active material (CAM) synthesis technology. According to a patent filed by Novonix, its "dry particle microgranulation" process creates an aluminum oxide-coated, nickel-manganese-cobalt (NMC) CAM formed through high shear and pressure with uniform particle morphology and size distribution. Current state-of-the-art NMC synthesis involves combining precursor chemicals in a continuous flow tank reactor and coprecipitating the CAM. This process requires resource-intensive washing and drying steps that Novonix claims its technology bypasses.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Charging infrastructure continues to be a key to the near-term adoption of heavy-duty electric vehicles

18 November2022

Electriq Power goes public via SPAC merger

Average Importance | Stationary storage

Electriq Power, a developer of residential and small business energy storage systems, will merge with TLG Acquisition One Corp, a special-purpose acquisition company (SPAC), to become a publicly traded company on the New York Stock Exchange. The transaction values the company at USD 495 million and will provide up to USD 125 million in cash. Electriq Power is working on raising additional capital before this transaction closes during the first half of 2023. The company states it will use the cash to "fund its growth," likely preparing to have enough residential storage systems to meet the growing demand in the U.S., where it will face fierce competition from LG Energy Solution, Tesla, and Sonnen.

18 November2022

Harvard spinoff, Quino Energy, launches organic flow battery chemistry

Low Importance | Energy storage

Aqueous organic electrolytes are a promising flow battery technology because of their low cost and inherent safety; however, organic molecules are susceptible to either decomposition or migration across the membrane. Organic flow battery chemistries can experience capacity fade of 0.1% per day, which prevents the technology from being cost competitive. Quino Energy has developed a chemistry using quinones that regain a redox-active structure through voltage manipulation, negating the need for most costly engineered organic molecules. In addition to a USD 4.5 million grant from the U.S. Department of Energy, Quino Energy most recently raised USD 3.3 million in seed funding.

18 November2022

Pilot and Volvo partnership will develop charging network for electric trucks

Average Importance | Energy for mobility

The two companies have signed a letter of intent to develop and build a charging network for Pilot customers' Class 8 trucks. The companies will explore opportunities to access public funding to build this network. The charging stations will be located at select Pilot and Flying J travel centers, but the companies did not reveal how many they plan to build. Volvo has been active in the medium- and heavy-duty charging infrastructure space both in the U.S. and Europe. It will likely take a while before this network materializes, but it will be a significant step forward toward widespread medium- and heavy-duty electrification.

RECENT INDUSTRY DEVELOPMENTS AND TECHNOLOGY NEWS

Critical mineral supply concerns will continue to catalyze battery recycling technology developments

21 November 2022

Beijing WeLion New Energy Technology recently closed a funding round of USD 208 million

Average Importance | Energy storage

The company's biggest customer is Nio, an electric vehicle company to which it will supply a semi-solid battery of 150 kWh and 1,000-km range by the end of 2022 or early 2023. The company is already producing solid-state cells for low-power applications, and solid-state batteries with a high nickel anode are under testing. Customers should note that WeLion will be the first company to have semi-solid batteries commercially used for electric vehicles, and with Nio's battery swapping model, it will have a better chance of understanding battery performance metrics with fewer batteries in the market.

22 November 2022

LiCAP Technologies partnering with Sakuu to provide electrodes for solid-state batteries

Low Importance | Energy storage

Under terms of a new partnership, additive manufacturer Sakuu Corporation will license LiCAP Technologies' electrode technology, and also the latter will supply electrodes for Sakuu's battery production. LiCAP develops a dry electrode technology that makes a film that can be used to laminate the current collector without need for drying or solvent recovery. LiCAP claims its production process reduces carbon footprint to one-third that of commercially available processes, uses less energy, and that the excess electrode materials can be recycled entirely.

28 November 2022

Evonik develops electrochemical lithium battery recycling technology

Average Importance | Energy storage

Evonik plans to commercialize a lithium recycling process using electrochemical cells with lithium-selective membranes from preprocessed battery waste, also known as black mass. This electrochemical process can potentially be used in upstream lithium extraction and refining from natural deposits of lithium brines, similar to a strategy from competitor Mangrove Lithium. However, Evonik first plans to scale up its pilot for the recycling market by working with established battery and metals recyclers and targeting on-site recycling at battery manufacturers and automakers. Electrochemically based technologies, while still in an early stage in the lithium refining and recycling market, offer companies a single-step refining process and a potential alternative to chemical precipitation and complex separations.

ZERO-EMISSIONS HEAVY-DUTY TRUCKS

The push for decarbonization in the trucking sector

Medium- and heavy-duty vehicles (MHDVs) are a big contributor to the transportation sector's greenhouse gas emissions. In the U.S., these vehicles were the cause of an estimated 25% of the total emissions from the transportation sector between 1990 and 2019.

As a result, there is an ongoing push to towards zero-emissions vehicles in the sector, part of which comes from regulators. Among these are electrification and the use of fuel cells with alternate fuels like hydrogen. Since most MHDVs tend to be commercially owned, such zero-emission vehicles also provide opportunities to potentially reduce total cost of ownership and increase profits by eliminating the need for fuel and simplifying maintenance.

There are different types of heavy-duty zero-emission vehicles – **battery electric, battery electric with wireless charging, battery electric with catenary wires, and hydrogen fuel cell trucks.**

ZERO-EMISSIONS HEAVY-DUTY TRUCKS

Battery Electric – Fast Charging

Among the different kinds of trucks, battery electric trucks are by far the most developed with several manufacturers selling them today. Technology has been continuously evolving with trucks suitable for short–haul trips available today. The range of currently available trucks are about 200-400 km depending on the load. Tesla and Nikola Motors claim their vehicles have higher ranges at up to 800 km and 560 km respectively, but their trucks are not on the market yet.

These trucks are typically charged overnight with AC chargers; charging times can be as low as two hours with fast DC chargers but this isn't widespread yet. For long haul trips, this would still be a bottleneck. Hence, work is underway to build megawatt charging stations where the charging time could be reduced to roughly 15-20 minutes.

Nearly every major truck manufacturer and several startups are developing electric trucks

Source: Tesla

ZERO-EMISSIONS HEAVY-DUTY TRUCKS

Battery Electric – Wireless

With wireless charging, trucks can be charged without a human operator needing to plug in at a charging point. These static charging points could be dedicated stations or be installed at points like bus stops, traffic lights etc. along the road. At the most advanced stage of development, one could envision wireless charging infrastructure on every road meaning that trucks would charge dynamically while being on the move.

While the capacity of each charger and vehicle is going to be lower than their wired equivalents, the presence of a widespread wireless charging infrastructure could reduce on-board battery pack size requirements and consequently, charging times. This technology is based on induction loops and is undergoing testing and development.

Companies such as **WiTricity**, **Momentum Dynamics, Wave**, and **Electreon** are developing wireless charging solutions.

Source: Sintef

ZERO-EMISSIONS HEAVY-DUTY TRUCKS

Battery Electric – Catenary Wires

Catenary wires are relatively common in public transit vehicles like trains, trams, and even buses. The most obvious advantage of these is that the vehicles do not have to make charging stops since they have access to a continuous supply of electricity. However, the downside is that the vehicles can operate only on fixed routes where these wires are installed. Incorporating new routes would require significant investment.

Trucks typically run on highways where installation of such infrastructure will not be straightforward. Furthermore, for large scale operations, any such network would need to be expansive.

Source: Clean Energy Wire

ZERO-EMISSIONS HEAVY-DUTY TRUCKS

Fuel Cell – Hydrogen

Fuel cell trucks, which use hydrogen, are being touted as the solution to range anxiety that battery electric trucks experience. In addition, refueling a truck with hydrogen is in principle much quicker than charging a battery, which could contribute to increased uptimes. Finally, fuel cells are far lighter than batteries, which leads to an increased load capacity.

Volvo and Daimler are aiming to develop trucks with a range of 1,000 km with refueling times of under 15 minutes.

For widespread adoption, an extensive refueling network is necessary though building out the required infrastructure remains a key challenge. Fuel cells and green hydrogen prices remain higher than fossil fuel counterparts but are expected to fall in price with both increased production volumes and lower cost renewable electricity.

Source: Hydrogen Central

ZERO-EMISSIONS HEAVY-DUTY TRUCKS

How promising are these zero-emission vehicles?

With the goal of curbing emissions high on the world's current agenda, one can expect the earlier discussed kinds of trucks to make their way to market within the next decade. As we saw in the preceding slides, each kind of truck has its own advantages and disadvantages, which would dictate when and where they would be deployed.

Despite the different characteristics and suitability of each of these truck types, it is important to understand their impact from a commercial perspective.

For instance, would any of the zero-emission truck types yield returns compared to an internal combustion engine (ICE) truck over a certain time period? If so, how long would it take before the costs per mile of a zero-emissions truck are less than that of an ICE truck? To answer these, we analyze trucking operations to compute these numbers and identify any tipping points.

Methodology: Cost Elements

This analysis quantifies the costs required to operate a truck, reporting results as a function of the costs per mile in USD. It does not consider some elements that will factor into the cost of such services, including amortizing R&D, marketing, and customer support costs, due to the challenges of estimating their magnitude. This analysis considers the following costs:

- **Vehicle costs:** Zero-emission trucks are currently more expensive than their diesel counterparts. Based on vehicles available in the market and those in development, we estimate the costs of the different truck types.
- **Refueling or charging costs:** We assume that the fuel of choice for the ICE truck is diesel. Each of the battery electric trucks has their own charging mechanism. For wireless charging, we assume that any supplemental charging is done using DC fast charging. Fuel cell trucks use green hydrogen. For all, the costs include both the capital costs of installing infrastructure and the energy costs to power the truck.
- **Operational costs:** For a truck, this includes driver wages, maintenance costs, and administrative costs like insurance. While estimating driver wages, we also consider regulations In determining operational costs, we also consider driving time regulations that stipulate how often and for how long a driver is required to take a break from driving

Using these cost estimates, we compute cost per mile values for different project lifetimes. The analysis includes freight data, such as annual vehicle kilometers travelled, from three regions – the U.S., Europe, using data from Germany, France, Spain and the U.K, and Asia, using data from China, Japan, India, and South Korea. Our analysis considers evolution of costs with time wherever applicable (for example, truck prices).

Methodology: Regional Data

Several parameters differ across the regions. These include, for example, driver wages and cost of energy (diesel, electricity, and hydrogen). Note that energy costs especially that of diesel are typically volatile. In the table below, we summarize some of the constant and region-specific variables.

Metric	U.S	Europe	Asia
Project lifetime (years)	20	20	20
DC fast charging price (USD per kWh)	0.30	0.44	0.21
Diesel price (USD per liter)	1.29	2.01	1.22
Hydrogen price (USD per kg)	16.50	13.91	10.5
Annual distance travelled (km)	100,000	100,000	100,000
Driver wages (USD per hour)	29.91	19.03	10.23

We assume that battery electric – wireless charging (BE-W) and battery electric – catenary wires (BE-C) charging costs are slightly more expensive than DC fast charging to account for infrastructure costs. For BE-W, we add a USD 0.02 surcharge per km and for BE-C, we add USD 0.01.

Methodology: Truck Data

For all geographies, we consider the same kind of trucks and project lifetimes. In the table below, we summarize the truck related cost parameters we consider in this analysis.

Metric		ICE	BE-F	BE-W	BE-C	FC-H
Vehicle cost (USD)	U.S.	120,000	300,000	340,000	330,000	420,000
	Europe	130,000	300,000	340,000	330,000	420,000
	Asia	90,000	225,000	250,000	240,000	375,000
Maintenance and administrative costs (USD per km)	U.S.	0.331	0.286	0.306	0.296	0.271
	Europe	0.354	0.314	0.334	0.324	0.300
	Asia	0.262	0.220	0.240	0.230	0.210
Range (km)		1,150	375	1,000	1,000	1,000
Refueling or recharging time (min)		15	90	5	0	15
Life (million km)		1.2	1.9	1.9	1.9	1.9

To reflect changing prices over time, we assume that diesel trucks become 1% more expensive each year, while battery electric and fuel cell trucks become 5% cheaper per year. We assume that the cost of hydrogen reduces by 3% each year. Finally, we assume that DC fast charging time declines from 90 minutes to 45 minutes by 2030.

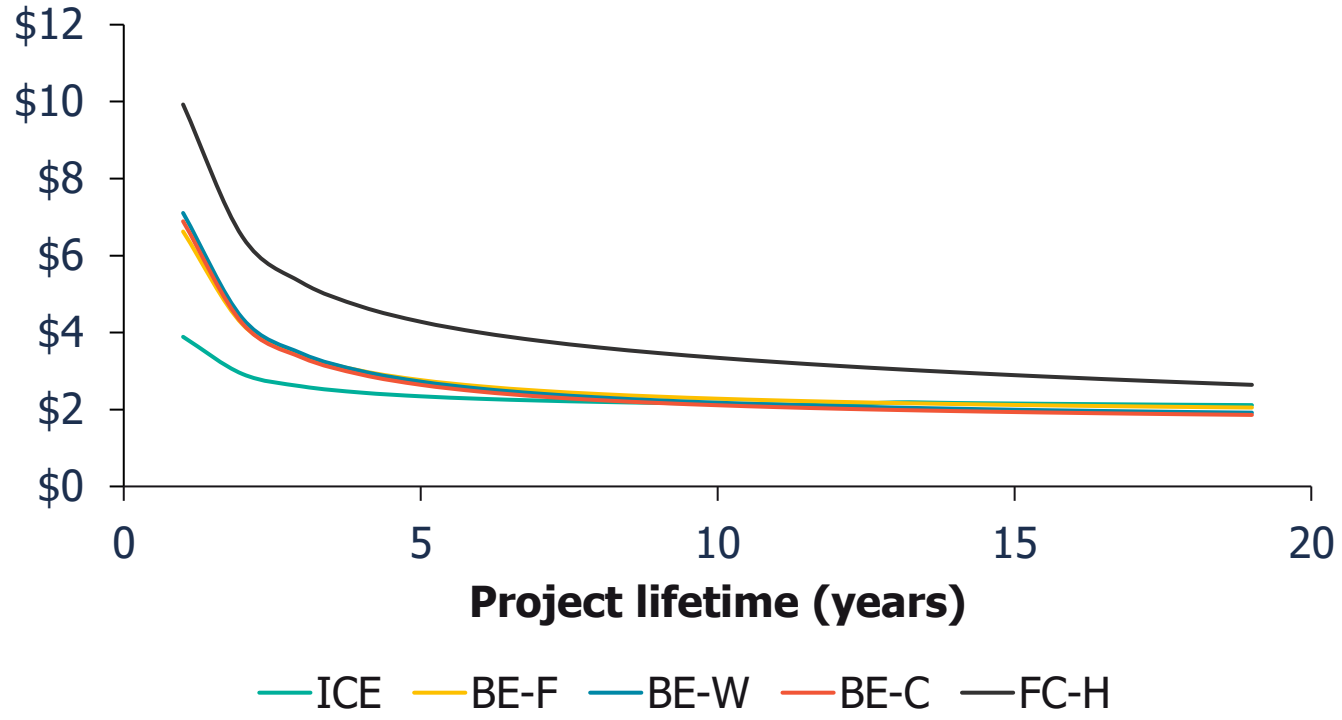
ZERO-EMISSIONS HEAVY-DUTY TRUCKS

U.S. – Cost per Mile

Diesel is relatively cheap in the U.S., which means that many zero-emission trucks do not achieve parity within a decade of operations. The exception is BE-C, which takes about 9 years and is helped by not needing to stop for charging. BE-W reaches parity roughly after ten years of operation, while BE-F takes a couple of years more. The high FC-H purchase prices coupled with the high hydrogen prices mean that FC-H trucks do not reach parity with ICE (or BE) equivalents within the next 20 years.

Costs per mile – U.S.

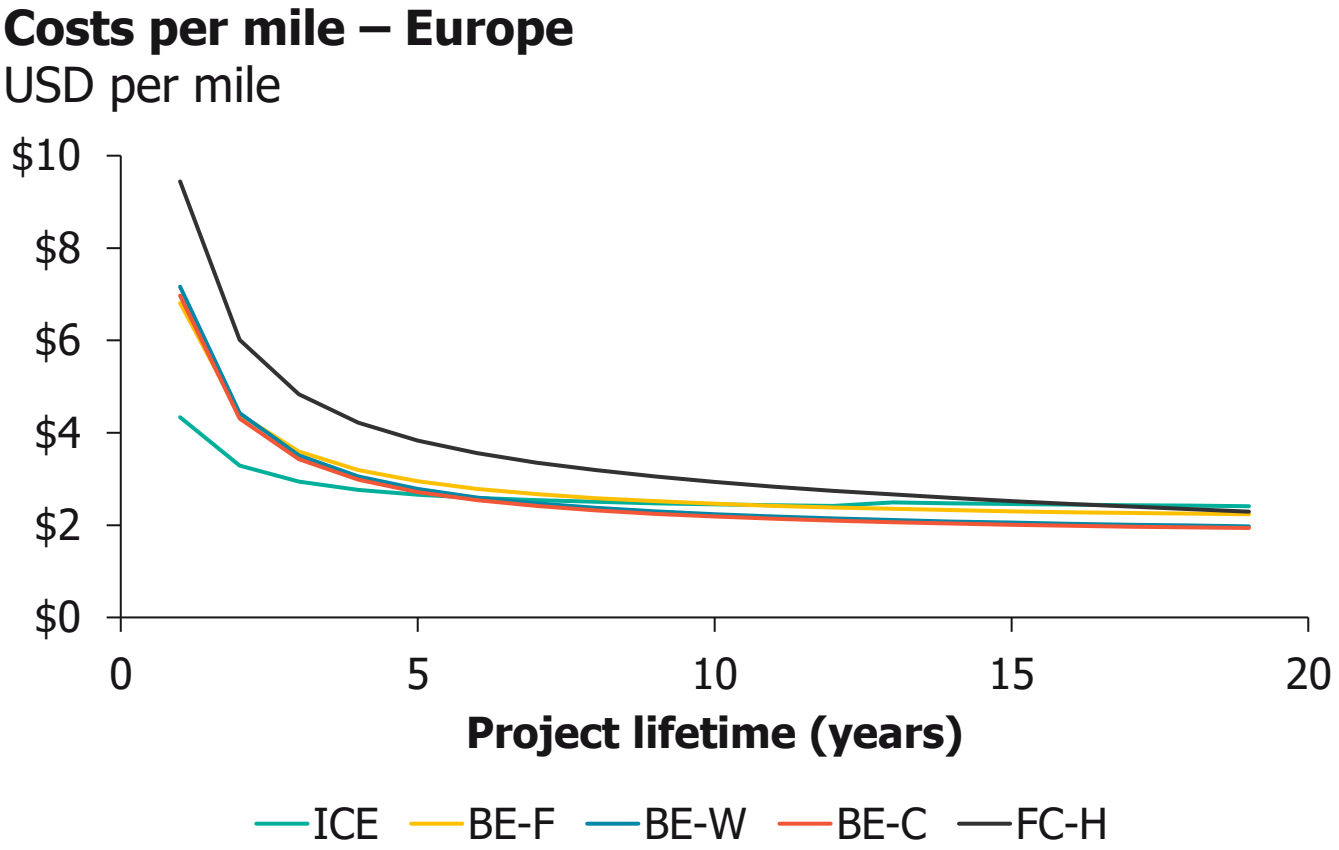
USD per mile



ZERO-EMISSIONS HEAVY-DUTY TRUCKS

Europe – Cost per Mile

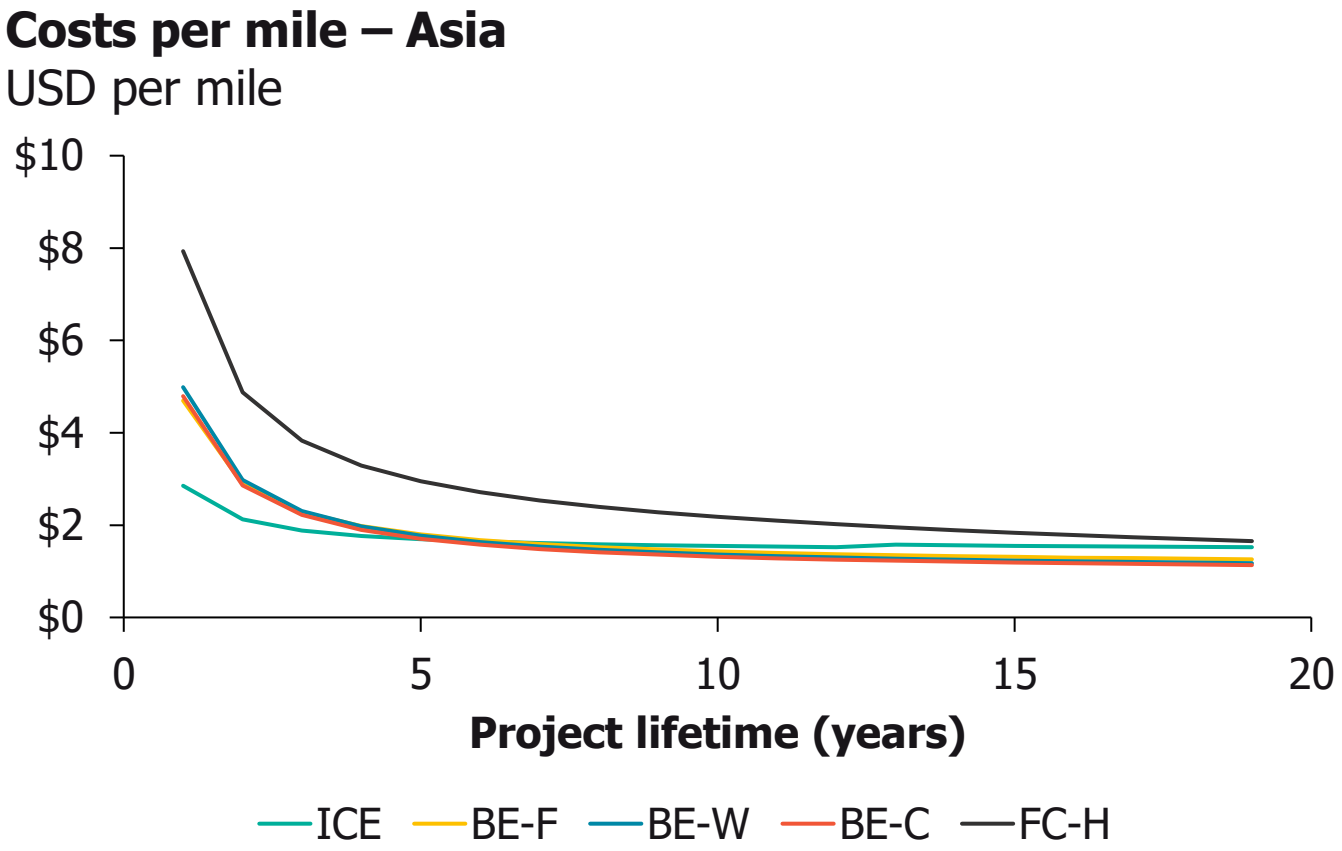
While both diesel and electricity prices are higher in Europe than in the U.S., diesel is significantly more expensive. As a result, the tipping points in Europe occur much earlier. Again, BE-C reaches parity the soonest in just under five years, while BE-W takes about six years. BE-F needs roughly 10 years to break even. The high diesel prices mean that even FC-H trucks reach parity, but this happens only after approximately 16 years.



ZERO-EMISSIONS HEAVY-DUTY TRUCKS

Asia – Cost per Mile

Costs across the board are lower in Asia compared to the U.S. and Europe. Labor costs being lower mean that the tipping points occur much sooner than in the U.S. or Europe. All BE trucks reach parity with ICE in under 6 years, with BE-C again doing it the soonest. Like in the U.S., FC-H trucks do not reach parity with ICE trucks in the next 20 years. Again, the low diesel prices in Asia are a key contributor to this.

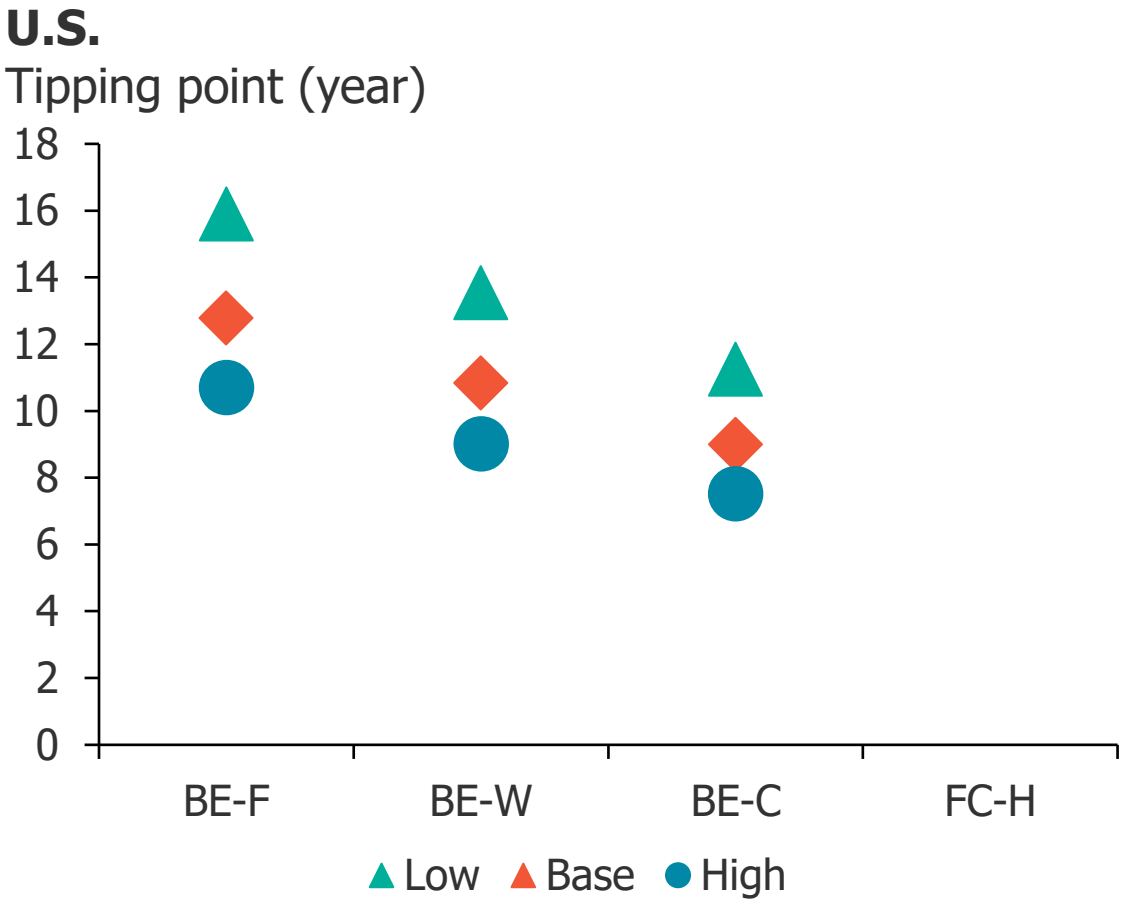


ZERO-EMISSIONS HEAVY-DUTY TRUCKS

Sensitivity Analysis: Annual Distanced Travelled

We vary the annual distance travelled to capture high and low scenarios. In the high scenario, we assume that a truck travels 20% more in a year, while in the low scenario, a truck travels 20% less. These are in comparison with the base scenario values (see slide 15). For all regions, we plot the tipping points in the costs per mile values for each of the zero-emissions trucks compared to diesel. The absence of a point in a plot indicates that costs per mile parity with diesel is never achieved within the project life span of 20 years.

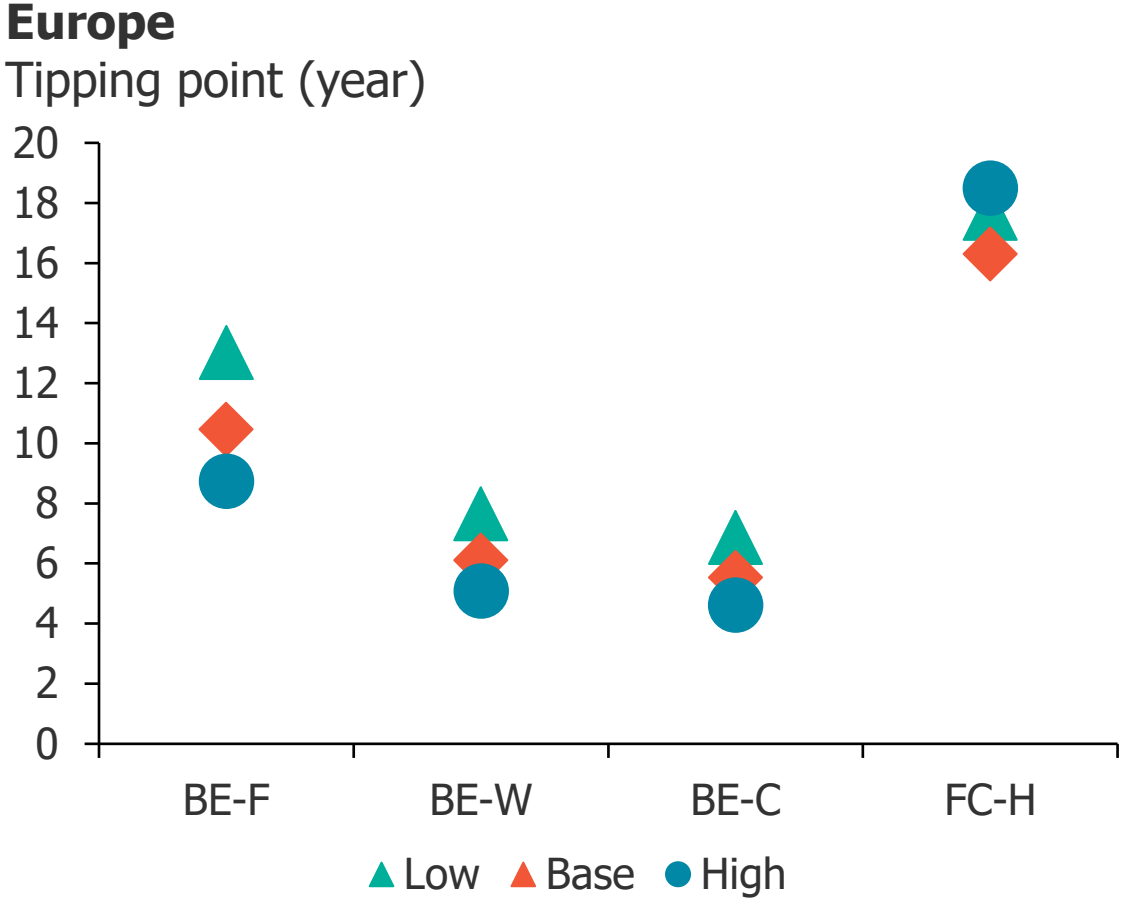
Across all regions, we observe that the tipping points occur sooner for the high scenarios. This is especially evident for BE-F where the difference in tipping points between the high and low scenarios in the U.S. and Europe is as high as 5 years. For BE-W and BE-C, the difference drops but still is considerable. This shows that the longer a charging stop for a truck, the more it is suited to heavy use from an economic perspective. Apart from in Europe, FC-H doesn't reach parity with ICE in any other region even in the different scenarios.



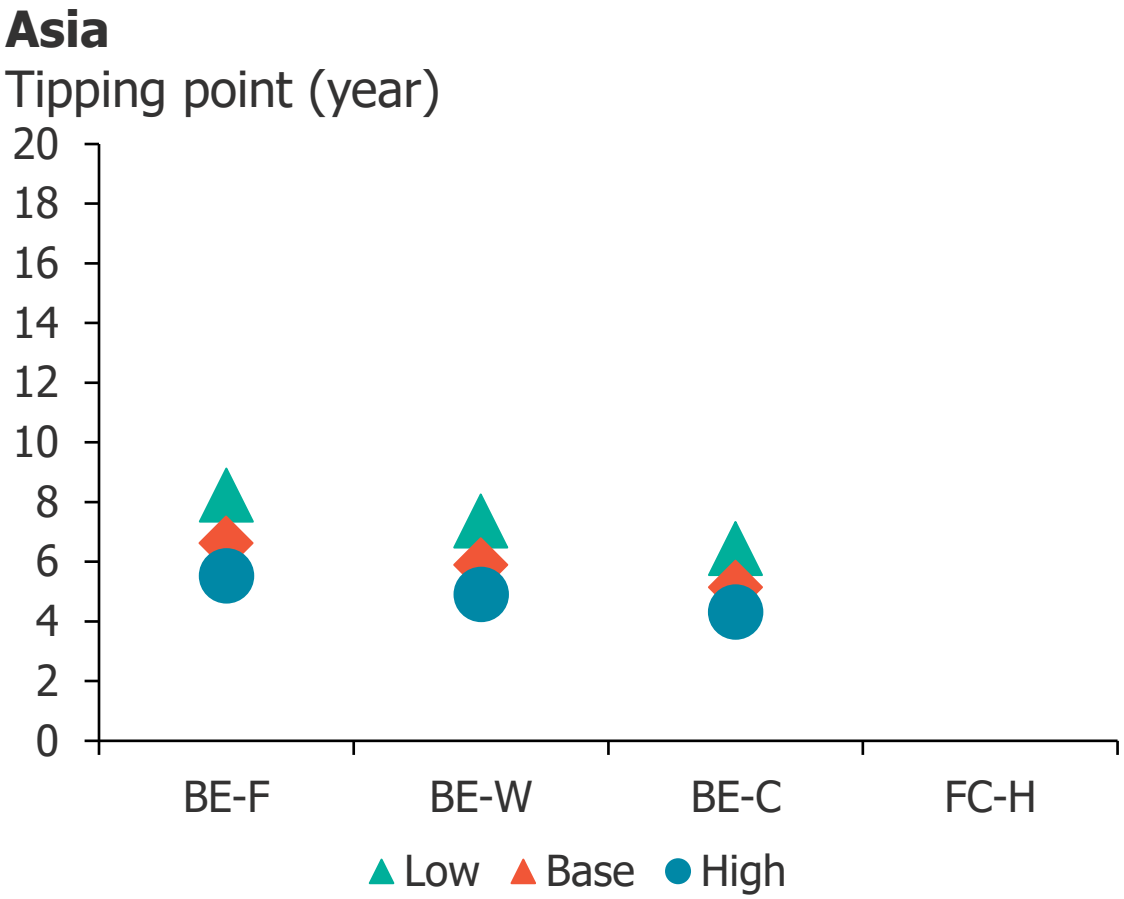
ZERO-EMISSIONS HEAVY-DUTY TRUCKS

Sensitivity Analysis: Annual Distanced Travelled

Europe



Asia



Source: Heliox

ZERO-EMISSIONS HEAVY-DUTY TRUCKS

What will adoption look like?

The current volatile energy prices make it even tricker to forecast what adoption might look like. However, the high initial costs associated with adoption of these zero-emission trucks automatically eliminates businesses that cannot afford hundreds of thousands of dollars from being able to do so. This holds for small or medium sized (family-run) businesses which are quite common in the trucking space. In the longer run, this could see them fall behind large corporations who can afford to take a short-term financial hit to offer lower prices and therefore capitalize in the longer run.

Governments can play the role of an equalizer by offering subsidies and in many regions, have been doing so. We did not consider subsidies in our analyses, but they will only pull the tipping points closer and give opportunities to smaller businesses to adopt these trucks sooner. They also help raise demand, which would ultimately even contribute to reduction in prices of not only the trucks but also fuel (or electricity). This is especially important for hydrogen.

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Lux Research is a leading provider of tech-enabled research and advisory solutions, helping clients drive growth through technology innovation. A pioneer in the research industry, Lux uniquely combines technical expertise and business insights with a proprietary intelligence platform, using advanced analytics and data science to surface true leading indicators. With quality data derived from primary research, fact-based analysis, and opinions that challenge traditional thinking, Lux clients are empowered to make more informed decisions today to ensure future success.

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