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A Feasibility Study on Up-Scaling in Sweden

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## Kort sammanfattning

Rapporten fokuserar på den kommersiella genomförbarheten av ett batteribytessystem för tunga lastbilar i Sverige. Genom att studera affärsmodeller, kompatibilitet med svenska regelverk och integration i transportverksamheten har vi utforskat hur disruptiva teknologier, ekosystemeffekter och cirkularitet skulle kunna möjliggöra en snabb introduktion och uppskalning av ett batteribytessystem. Ett särskilt fokus har legat på Kina för att analysera statusen för batteribyten och de processer som har lett till den snabba utvecklingen och uppskalningen där. I Kina krävde batteribyte en ny affärsmodell där aktörer såsom energiproducenter, batteritillverkare och maskinindustri går i spetsen för utvecklingen och spridningen av batteribyten. Batteribyte är nu den dominerande tekniken för eldrivna lastbilar i Kina.

Exempel på fördelar med batteribyte som förespråkas är att det bara tar några minuter att byta batteri, minskad investering för lastbilsägare, låg påverkan på det lokala elnätet och att fordons- och batterilivscykler separeras. En simuleringsstudie om batteribyte för tunga lastbilar i hamnverksamhet visar i denna rapport på tydliga fördelar jämfört med kabelladdning.

Det finns dock ett par utmaningar med att införa batteribyte i Sverige. För det första finns det inga tydliga förespråkare för batteribyte inom industrin. Till exempel är de svenska och europeiska fordonstillverkarna tveksamma eftersom det utmanar deras nuvarande affärsmodell och att de kan ta rollen som grindvakter. För det andra omfattar inte de nuvarande standarderna och regelverken för fordon och energisystem i Sverige och i EU batteribyte.

Rapporten tar också upp behovet av kunskap och utbildning av personer vid batteribytesstationer, samt vikten av social hållbarhet vid elektrifiering av tunga transporter.

**Nyckelord**

Batteribyte, elfordon, ellastbilar, laddinfrastruktur, transportsystem, logistik, affärsmodeller, ekosystem.

## Abstract

The report focuses on the commercial feasibility of a battery-swapping system for heavy trucks in Sweden. By studying business models, the compatibility with Swedish regulations, and integration into transport operations, we explore how disruptive technologies, ecosystem effects, and circularity could enable a rapid introduction and diffusion of a battery-swapping system. A special focus is on China, covering the status of battery-swapping there and analysing the processes that have led to its rapid development and deployment. In China, battery-swapping creates a new business model where actors from energy production, battery manufacturing, and the mechanical industry spearhead the development and diffusion of the technology. Battery-swapping is now the dominant technology for electric trucks in China.

Advantages of battery-swapping include: only a few minutes battery swap time, reduced investment for truck owners, low impact on the local power grid, and separation of vehicle and battery life cycles. A simulation study in this report shows that battery-swapping for heavy trucks in harbour operations could offer clear advantages compared to cable charging.

However, there are several challenges to introducing battery-swapping in Sweden. First, it has no clear promoters in the industry. Swedish and European vehicle manufacturers are hesitant because it challenges their current business model, and that they may instead take the role of gatekeeper. Second, current standards and regulatory frameworks for vehicles and energy systems in Sweden and in the European Union do not include battery-swapping.

The report also addresses the need for knowledge and training of people at battery-swapping stations, and the importance of social sustainability in the electrification of heavy vehicle transport operations.

**Keywords**

Battery swapping, electrification, electric trucks, charging infrastructure, transport system, logistics, business models, eco systems.

# Sammanfattning

Om Sverige ska nå ett fossilfritt godstransportsystem till 2045 måste elektrifieringen av lastbilsflottan ta fart. Näringslivet förväntas stå för omställningen, men för att marknaden för godstransporter på väg i Sverige ska elektrifieras behövs fordonslösningar som åkerier och logistikföretag har råd med och som ger en utnyttjandegrad i nivå med dieseldrivna lastbilar. Baserat på erfarenheter från Kina, där batteribyte för tunga fordon har utvecklats till en kommersiellt konkurrensmässig lösning, är denna laddteknik mogen och har stor potential att skalas upp i Sverige relativt snabbt. Trots detta saknar Sverige idag kunskap och erfarenhet av batteribyte för tunga fordon. Denna rapport fokuserar på den kommersiella genomförbarheten av att etablera ett batteribytessystem för tunga lastbilar i Sverige. Genom att studera affärsnyttan, förenligheten med svenska regelverk och integration i transportverksamheten utforskar vi hur disruptiva teknologier, ekosystemeffekter och cirkularitet kan möjliggöra en snabb utveckling mot gröna, hållbara och effektiva transporter. Flera forskare har bidragit till denna rapport, var och en med sin egen expertsyn på olika aspekter av elektrifiering av transporter och batteribyten. Även om de övergripande temana stämmer överens med varandra är varje forskares perspektiv unikt och redovisas i separata kapitel i rapporten.

Det första perspektivet är bakgrunden till batteribyte och hur det har vuxit fram till att bli en kommersiellt konkurrenskraftig elektrifieringslösning för tunga lastbilar. Ett särskilt fokus ligger på Kina, statusen för batteribyten och de processer som har lett till denna snabba utveckling och utbredning. Utvecklingen av ekosystem för tunga lastbilar återspeglar ett dynamiskt samspel mellan tekniker, aktörer och roller, särskilt är detta tydligt under övergången från fossilbaserad till elektrisk teknik och batteribytesteknik. Introduktionen av batteridrivna elfordon i Kina markerade en viktig vändpunkt, vilket gjorde tidigare teknik och leverantörer föråldrade och lyfte fram nya nyckelaktörer som mineralproducenter, batteriföretag och mjukvaruutvecklare, som med traditionella OEM (Original Equipment Manufacturers) driver utvecklingen. Batteribytestekniken medförde ytterligare förändringar, som till en början möttes av tveksamhet från traditionella OEM på grund av oro över kontroll och anpassning av affärsmodeller. Detta ledde till att energiproducenter, distributörer och nya aktörer gick i spetsen för denna innovation. Energiföretag som SPIC var tidiga förespråkare och drev på införandet av batteribyte. Nya aktörer från maskinindustrin, som Foton och Sany, såg möjligheter inom batteribyte, vilket ledde till innovationer inom design av laddstationer och affärsmodeller. Traditionella bränsleleverantörer som BP såg så småningom potentialen och samarbetade med fordonstillverkare för en global expansion. Batteritillverkare som CATL anpassade sig också och blev nyckelaktörer i utvecklingen av batteribytessystem. Denna utveckling fortsatte med introduktionen av intelligenta transportsystem, som satte internet, molntjänster och högteknologiska autonoma systemleverantörer i förgrunden, förvandlade fordon till datorer på hjul och minskade inflytandet från traditionella OEM. Det övergripande temat är den dynamiska karaktären hos teknik, produkter, fordon, tjänster och affärsmodeller. Elektrifieringen av transporter som är en stor samhällsomställning mot förnybar energi och nya energifordon, kräver att företag anpassar sig och förnyar sig. Denna omvandling handlar inte om att ersätta en teknik med en annan, det handlar om en mosaik av lösningar som passar olika behov och scenarier. Till exempel, även om kabelladdning för närvarande dominerar i västvärlden, är dess begränsningar för framtida storskalig användning uppenbara. Shenzhens erfarenhet som en starkt elektrifierad stad med omfattande infrastruktur för kabelladdning belyser behovet av alternativa lösningar. På samma sätt visar Shanghais strategi på behovet av att integrera kabelladdning med batteribyte och vätgasteknik, samt på behovet av lösningar som är skräddarsydda för olika driftsscenarier. Denna utveckling understryker vikten av att inte se batteribyte som alternativ till kabelladdning, elvägar eller vätgaslösningar, utan som en kompletterande och integrerad lösning av ett bredare, adaptivt laddsystem.

Det andra perspektivet är den tekniska integrationen av batteribytessystem under svenska driftsförhållanden. Batteribytestekniken erbjuder en rad tekniska fördelar jämfört med traditionell kabelladdning av fordon. Det ger möjligheter att optimera energianvändningen, minska

investeringskostnaderna i laddinfrastrukturen, minska effektbehovet (belastningen) på elnätet och minska osäkerheten i investeringen för fordonsägare. Genom bättre planering och kontrollerad laddning kan batteribytesstationer bidra till en mer stabil, effektiv och kostnadseffektiv användning av elenergi i energisystemet samtidigt som nyttjandegraden av fordon/fordonsflotta ökar genom att undvika långa laddningstider. Ett batteribyteskoncept kan användas för flera ändamål: genom att byta ut urladdade batterier mot laddade på fordon och fungera som en balanserare av det lokala elnätet. Elnätsföretag välkomnar batteribyte eftersom det kräver betydligt lägre toppeffekt. Fordonen behöver inte konstrueras om i någon större utsträckning jämfört med de nuvarande fordonen, vilket möjliggör snabb uppskalning och integrering i fordonsflottan. Batteribyte lämpar sig väl för tunga fordon då det finns gott om placeringsalternativ för batteriet. För en storskalig och hållbar utveckling av batteribyten är det viktigt att utveckla och standardisera batterier och laddinfrastruktur, och detta kräver ett nära samarbete mellan industri, myndigheter och andra intressenter. Batteribytesfordon har fördelen att de också kan laddas via kabel precis som ett vanlig batterifordon. Dessutom kan ett batteri i ett batteribytessystem laddas med låg effekt, vilket ger betydande fördelar: längre livslängd, kontrollerad laddning och låg effektförbrukning från den installerade effekten i elabonnemanget. Ett standardiserat batteri kan också lättare tillhandahålla nättjänster i sitt ”andra liv”. Detta stärker Sveriges utveckling för ett robust elnät. Slutligen möjliggör batteribyteskonceptet en framtidssäker investering eftersom fordon kan dra nytta av förbättringar som tillhandahålls i framtida batterigenerationer, såsom energikapacitet, vikt etc.

Det tredje perspektivet handlar om vad som behövs när det gäller certifiering, licenser och tillstånd för batteribytessystem för att kunna vara i drift i Sverige. Att introducera ett batteribyteskoncept för tunga lastbilar kräver en grundlig översikt över nödvändiga tillstånd, regler och certifieringar. För batteribyteskonceptet för tunga lastbilar är det viktigt att skapa en europeisk samsyn kring regelverk för exempelvis standarder. En nära dialog med berörda myndigheter och intressenter samt noggrann planering och förberedelser kommer att underlätta processen och minska risken för oförutsedda hinder. Batteribyteskonceptet skiljer sig från de nuvarande affärsmodellerna relaterade till fordonsförsäljning, bränsleförsäljning och elnätsverksamhet och därför behöver flera befintliga regelverk ses över och justeras, och nya behöver skapas. Till exempel, vid fordonsförsäljning, skulle man köpa fordonet och prenumerera på batteriet, till skillnad från de flesta traditionella batterielbilar där köpet inkluderar både fordonet och batteriet i samma affär. Detta gäller även registreringen då ett batteribytesfordon kan ta batterier av olika vikt och kapacitet, vilket inte är tillåtet enligt gällande regelverk. En rekommendation för att snabbt införa batteribyteskonceptet i Europa är att dra lärdom av Kinas standardiseringsprocess för batteribyte.

Det fjärde perspektivet utforskar ekosystemet för batteribyte och dess aktörer, roller och relationer. Konceptet med batteribyte involverar en mängd olika intressenter. Nyckelaktörer som är konsekvent närvarande i alla batteribytessystem, vilket ofta lyfts fram i litteraturen, inkluderar leverantörer av transporttjänster (t.ex. tredjepartslogistik (3PL) och åkerier), operatörer och ägare av batteribytes-stationer (BSS), elleverantörer, fordonstillverkare och batteritillverkare. Den diskurs om roller som ofta diskuteras inom innovationslitteratur visar att det uppstår nya roller som väntar på lämpliga aktörer inom ramen för batteribyten. Olika typer av initiativtagare spelar en avgörande roll i detta sammanhang. Trots initiativtagarnas betydelse har ingen aktör fullt ut tagit på sig denna roll i den svenska kontexten. Detta identifieras som en viktig orsak till att omställningen till ett elektriskt transportsystem i Sverige hittills har ägnat lite uppmärksamhet åt batteribyte jämfört med länder som Kina och USA, där initiativtagarna är mycket inflytelserika aktörer. Relationsfrämjare, som kan överföra kunskap och medla i förhandlingar mellan olika intressenter, är lika viktiga. Leverantörer av transporttjänster behöver ta på sig flera viktiga roller vid batteribyte. Separationen av batterier från fordon gör det möjligt för leverantörer av transporttjänster att ta på sig olika roller när det gäller ägandet av centrala resurser jämfört med traditionell kabelladdning. Leverantörer av transporttjänster kan äga, leasa eller delta i en gemensam resurspool för teknik, inklusive batterier och fordon. Leverantörer av transporttjänster fungerar som viktiga relationsfrämjare och underlättar kommunikationen mellan intressenter, inklusive transportköpare, fordonstillverkare och operatörer av batteribytesstationer. Dessutom kan leverantörer av transporttjänster ha en viktig roll som expertförmedlare, med tanke på deras expertis inom logistiksystemet och transportköparnas behov. Beroende på vilka roller transporttjänstleverantörer väljer att spela måste olika relationer med olika aktörer etableras för att underlätta implementeringen och uppskalningen av batteribytessystem. Leverantörer av transporttjänster är starkt beroende av elleverantörer, som tillhandahåller den nödvändiga resursen el för laddning av batterier. Leverantörer av transporttjänster är också i hög grad beroende av den viktiga resurs som batteribytesstationen tillhandahåller, särskilt när det gäller tillgången till laddade batterier vid den tid och plats som krävs. Jämfört med kabelladdade fordon kan batteribyte öka transporttjänstleverantörernas beroende på grund av ett begränsat antal potentiella operatörer av batteribytesstationer. Förhållandet mellan leverantörer av transporttjänster och fordons- och batteritillverkare är beroende av tillgången på funktionella fordon och batterier, som är kritiska resurser. Baserat på de viktigaste resultaten är det nödvändigt att slå fast behovet av nya roller och av att aktörer tar på sig nya roller, till exempel rollen som finansiella främjare. Slutligen spelar fordonsindustrin en mycket central roll som andra aktörer inte kan, och det finns en risk att denna industri tar på sig rollen som ”grindvakt”, vilket skulle kunna hindra införandet av batteribyte för tunga fordon i Sverige och Europa.

Det femte perspektivet utforskar affärsmodeller för batteribyte och hur detta skulle kunna se ut på den svenska marknaden. För närvarande (december 2023) finns ingen efterfrågan på fossilfria transporter och speditörer köper fortfarande transporter främst på pris. Ur ett systemperspektiv är lastbils-tillverkare och elnätbolag dominerande aktörer gentemot sina kunder (transportföretag). Men eftersom både lastbilstillverkare och elnätbolag är passiva i en potentiell utveckling av batteribyten, är övergången till eldrivna frakter i hög grad upp till transportföretagen själva att hantera. Här är varuägarna/transportköparna en viktig aktör som skapar den nödvändiga efterfrågan på fossilfria frakter i Sverige, till exempel att ha längre kontrakt med speditörer för att minska den ekonomiska risken i att investera i eldrivna lastbilar. I detta sammanhang har batteribyte en unik fördel jämfört med kabelladdning. FCR-marknaden (Frequency Containment Reserve) skapar möjligheter för aktörer att investera i batterier och laddning, som en kompletterande verksamhet (försäljning av batteribackup till elnätsbolagen). Detta kan vara en drivkraft för till exempel transportföretag att investera i batteribyte av lastbilar och batteribytesstationer. Detta kräver dock en utveckling av regelverket för att bli möjligt. När det gäller symbiotiska affärsmodeller (där relationen mellan partners utvecklas över tid) kan vi också se att batteribyten gör det möjligt att skapa regionala infrastrukturer för laddning för regionala transporter. Transportföretagen i vår studie hävdar att de flesta rutter med stora volymer är mer lämpade för batteribyte än kabelladdning, särskilt för transporter som kräver extra laddning under dagen. Transporter där batteribyte inte har någon specifik fördel är transporter som endast kräver laddning under natten. Effektivitetsmässigt för transportföretaget är batteribyte, med sina korta bytestider, en möjliggörare för att öka fordonsutnyttjandet och att använda fordonet i flera skift. Dessutom ger FCR-marknaden i Sverige transportföretaget (eller en grupp av lokala transportföretag) en affärsmöjlighet i att äga en egen batteribytesstation. Således är batteribyte en pådrivande faktor för elektrifiering för ett transportföretag – där intäkter från FCR-marknaden kan kompensera för de högre elkostnaderna och fordonskostnaderna.

Det sjätte perspektivet går djupare in på konkreta affärsmodeller för batteribyte och ger även ett exempel på en implementering i en hamnverksamhet. Detta perspektiv diskuterar det föränderliga landskapet för batteribyteslösningar för elektriska tunga lastbilar i Europa, och belyser dess befintliga tillämpning i personbilar i länder som Sverige, Norge, Holland och Tyskland och potentialen för expansion inom lastbilslogistik. Trots osäkerheten hos svenska lastbilsägare avseende utländska lastbilstillverkare finns det ett växande intresse, med upp till en tredjedel som anser batteribyte är genomförbart om de uppfyller tekniska standarder och hållbarhetskrav. Övergången från diesel- eller kabelladdning till batteribyte ses som lönsam eftersom den tar itu med utmaningarna med kabelladdning, såsom långa laddningstider och problem med tillgänglig nätkapacitet. Tekniken för batteribyte i tunga lastbilar har mognat och visat sig vara effektiv, där den främsta utmaningen är att anpassa den till den svenska marknaden genom en lämplig affärsmodell. En simuleringsstudie ger ytterligare stöd för batteribyte och visar att ett enda batteri i en enda bytesstation effektivt kan hantera olika driftsscenarier och bibehålla systemets effektivitet trots ökat antal lastbilar eller minskade batteristorlekar. På detta tillvägagångssätt förenklas logistiken, stilleståndstiden minskar och miljöpåverkan och investeringskostnader minimeras, vilket gör det till en lovande lösning för effektiv och hållbar drift av tunga lastbilar. Dessa resultat är avgörande i formandet av en kostnadseffektiv och lönsam affärsmodell för batteribyte för tunga lastbilar i godstransportlogistik.

Det sjunde perspektivet beskriver kunskapsbehov och utbildning i batteribytessystemet, baserat på dokumentation och intervjuer från kinesiska aktörer. Syftet är att undersöka de grundläggande tillvägagångssätten för etablerade batteribytesstationer i att utbilda sin personal för att ha kunskap i att övervaka, driva och följa upp den dagliga driften av stationer. Vi söker förståelse för vilka angreppssätt som finns i utbildningen, de primära syftena med utbildningen, det huvudsakliga innehållet i utbildningstillfällena och det förväntade läranderesultatet av de utbildningsaktiviteter som erbjuds till driftspersonalen. I vår forskning har vi gjort empiriska observationer, besökt ett antal batteribytesstationer, genomfört intervjuer med chefer, läst igenom och tolkat dokument om utbildning. Vi har utforskat och undersökt arbetsbeskrivningar och åtgärder för hantering av batteribytesstationer i praktiken av företag som är relevanta för innehållet i denna rapport, samt utbildning och träning av personal på bytesstationer. Arbetsbeskrivningen för batteribytesstationen har tonvikt på hälsa, säkerhet och miljöskydd. I denna finns även detaljerade beskrivningar av åtgärder för hantering av säkerhetsrisker, hantering av farliga arbetsmoment, hantering av dolda faror, hantering av personlig skyddsutrustning, hantering av arbetsordrar samt hur drift och underhåll av laddnings- och bytesutrustning ska gå till. Det är intressant att se den tydliga ansvarsfördelningen i de olika chefsnivåerna. Arbetsbeskrivningarna och åtgärderna vi undersökt är baserade på kinesiska nationella lagar, förordningar och standarder. Ett viktigt område är personalens individuella säkerhet och hälsa, som har hög prioritet i personalutbildningen. Den näst mest kritiska är miljörisker och vilka olyckor som kan påverka luft, mark, grundvatten etc. Det tredje kritiska utbildningsområdet gäller stationens säkerhet och brandbekämpning. Ett ytterligare område är den att hantera batteribytesstationerna, där tonvikten ligger på ansvar relaterat till arbetsledare och operatörer. Det pågår en teknisk utveckling mot ökad automatisering av batteribytesstationerna. Som det är nu är hela processen med att registrera inkommande fordon, byta batterier, checka ut, dokumentera bytesproceduren och utvärdera det utbytta batteriet helt automatiserad. För övervaknings- och uppföljningsarbetet behövs dock fortfarande människor. Automatiseringsutvecklingen pågår och det är rimligt att förvänta sig att även övervaknings- och uppföljningsarbetet kan komma att automatiseras helt i framtiden.

Det åttonde perspektivet handlar om modellering och simulering av elektrifierade transporter och undersöker dess roll och användbarhet för att optimera elektrifierade transportsystem. Den tar upp frågan om vilka metoder, modeller och simuleringar som kan användas för att på ett adekvat sätt analysera möjligheter och effekter av en uppskalning av batteribyte för tunga fordon. Flera enkla samt mer avancerade fallstudier togs fram, tillsammans med en listning av några olika simuleringsverktyg som finns tillgängliga. Fördelarna med att inkludera nuvarande och framtida logistiklösningar och deras energibehov diskuterades, samt hur beräkningar kan hjälpa till att jämföra olika laddnings-lösningar och hjälpa till att inkludera dessa i framtida regelverk som AFIR (Alternative Fuel Infrastructure Regulation). Modellering och simulering handlar om att identifiera nyckelfaktorer, att visualisera och att optimera. Det är viktigt att optimera batterianvändningen i samhället för att få den mest hållbara lösningen, vilket innebär att välja de bästa avvägningarna. Modellerings- och simuleringsverktyg kan hjälpa olika aktörer i samhället att förstå avvägningar och möjligheter ur sina perspektiv, och systemplaneringsmodeller kan visa hur enskilda aktörers beslut antingen kan moderera eller förvärra andra aktörers beslut.

Det nionde perspektivet handlar om social hållbarhet för elektrifierade transporter och batteribyte. Den pågående övergången till elektrifiering av tunga lastbilar förändrar transportsektorn och ställer både företag och arbetstagare inför möjligheter och risker. Uppfattningar om elektrifiering i allmänhet och batteribyte specifikt analyseras genom en lins av sociotekniska föreställningar. Med hjälp av intervjuer och fokusgrupper med chefer på åkerier, forskare och experter som är involverade i denna studie, samt lärare och elever på ett gymnasieprogram för lastbilschaufförer, undersöker studien hur olika principer för social hållbarhet inom transporter kan eller inte kan påverkas av elektrifiering och batteribytesteknik. De principer för social hållbarhet som ingår är hälsa, inflytande, kompetens, opartiskhet och meningsskapande. Resultatet visar på komplexa och osammanhängande föreställningar som påverkas av de olika intervjupersonernas ställningstaganden. Medverkan av både experter och icke-experter i intervjuerna och fokusgrupperna ger också en inblick i hur olika aktörer förhåller sig till pågående och framtida sociotekniska omvandlingar. Resultaten belyser att det inte finns en enda föreställning om vare sig elektrifiering eller batteribyte, utan att det finns flera föreställningar. Att införliva arbetstagares och användares föreställningar kan bidra till att utveckla tekniska lösningar och affärsmodeller som är lättare att ta till sig. Att utveckla strukturer som uppmuntrar till aktivt deltagande av arbetstagare och användare kan också ta hänsyn till flera sociala hållbarhetsperspektiv. Resultaten pekar också på att ett flertal principer för social hållbarhet kanske inte bäst hanteras genom elektrifiering och batteribytesteknik, såsom jämställdhet och arbetsvillkor relaterade till övervakning av arbetare. En viktig rekommendation är att bjuda in dem som påverkas av pågående förändringar i ekonomiska och tekniska strukturer att bidra till att skapa alternativa föreställningar. Detta kan öppna upp för vägar som gör sådana förändringar bättre anpassade till deras situation, och därigenom både demokratisera förändringen inom branschen och öka sannolikheten för acceptans av den förändringen.

## Summary

If Sweden is to achieve a fossil-free freight transport system by 2045, electrification of the truck fleet must accelerate. The business sector is expected to be responsible for the transition, but for the on-road goods transport market in Sweden to electrify, hauliers and logistics companies need affordable vehicle solutions that provide utilization rates on par with diesel-powered trucks. Based on experience from China, where battery-swapping for heavy vehicles has developed into a commercially competitive market, this charging technology is mature and has high potential for near-term scaling in Sweden. Yet, Sweden currently lacks knowledge and experience with battery-swapping for heavy vehicles. This report focuses on the commercial feasibility of a battery-swapping system for heavy trucks in Sweden. By studying the business case, the compatibility with Swedish regulations, and integration into transport operations, we explore how disruptive technologies, ecosystem effects, and circularity could enable rapid development towards green, sustainable, and efficient transport. Several researchers have contributed to this report, each one with their own expert view on different aspects of electrification of transport and battery-swapping. Though the general themes are consistent with each other, each researcher's perspective is unique, as captured in separate chapters in the report.

The first perspective is on the history of battery-swapping, how it has emerged to become a commercially competitive electrification solution for heavy trucks. A special focus is on China, the status of battery-swapping and the processes that have led to this rapid development and deployment. The evolution of heavy truck ecosystems reflects a dynamic interplay of technologies, actors, and roles, especially evident during the shift from fossil-based to electric and battery-swapping technologies. Initially dominated by fuel producers and mechanical engineers, the industry witnessed a change with the advent of fuel injection and electronic controls, bringing forward companies like Bosch. However, introducing battery electric vehicles marked a significant turning point, rendering previous technologies and suppliers obsolete and elevating new players like mineral producers, battery assembly companies, and software developers, with traditional Original Equipment Manufacturers (OEMs) driving development. Battery-swapping technology introduced further changes, initially met with hesitation by traditional OEMs due to concerns over control and business model adaptation. This led energy producers, distributors, and new entrants to spearhead this innovation. Energy companies like SPIC were early advocates, pushing for the adoption of battery-swapping. New actors from the machinery industry, such as Foton and Sany, recognized opportunities in battery-swapping, leading to innovations in station design and business models. Traditional fuel suppliers like BP eventually saw the potential, collaborating with vehicle OEMs for global expansion. Battery manufacturers like CATL also adapted, becoming key players in developing swapping systems. This evolution continued with the introduction of intelligent transport systems, which brought internet, cloud services, and high-tech autonomous system providers to the forefront, turning vehicles into computers on wheels and diminishing the role of traditional OEMs. The overarching theme is the dynamic nature of technology, products, vehicles, services, and business models. The electrification of transportation, a major societal shift towards renewable energy and new energy vehicles, demands that businesses adapt and innovate. This transformation is not about replacing one technology with another, but about a mosaic of solutions fitting diverse needs and scenarios. For instance, while cable charging is currently predominant in the West, its limitations for future large-scale use are evident. Shenzhen's experience as a heavily electrified city with extensive cable charging infrastructure highlights the need for alternative solutions. Similarly, Shanghai's approach of integrating cable charging with battery-swapping and hydrogen technologies showcases the necessity of diverse solutions tailored to different operational scenarios. This evolution underscores the importance of not viewing battery-swapping as an alternative to cable charging or hydrogen solutions but as a complementary and integral part of a broader, adaptive system.

The second perspective is on the technical integration of battery-swapping systems into the Swedish operating environment. The battery-swapping technology offers a range of technical advantages

compared to traditional cable charging of vehicles. It provides opportunities to optimize energy usage, reduce investment costs in charging infrastructure, decrease the power demand (load) on the electrical grid, and reduce uncertainty in the investment for vehicle owners. Through better planning and controlled charging, battery-swapping stations can contribute to a more stable, efficient, and cost-effective use of electrical energy in the power system while increasing the utilization rate of the vehicle/fleet by avoiding long charging times. A battery-swapping concept can be used for multiple purposes, exchanging discharged batteries for charged ones on vehicles and balancing the local electricity grid, for example. Power grid companies welcome battery-swapping as it requires substantially lower peak power compared with fast charging. Vehicles do not need significant redesign compared with current vehicles, enabling rapid scaling and integration into the vehicle fleet. Battery-swapping is well suited for heavy vehicles as there are multiple placement alternatives for the battery. For large-scale and sustainable development of battery-swapping, it is important to develop and standardize batteries and swapping infrastructure, and it requires close cooperation between industry, authorities, and other stakeholders. Battery-swapping trucks have the advantage that they can also be cable-charged just like a standard battery electric truck. Also, a battery in a battery-swapping station can be charged with low power, which brings two significant advantages: longer lifespan, controlled charging, and low power draw from the electricity grid. A standardized battery can also more easily provide grid services in its “second life.” This reinforces Sweden's development of a robust electricity grid. Finally, the battery-swapping concept allows for a future-proof investment as vehicles can benefit from improvements provided in future battery generations, such as energy capacity, weight, etc.

The third perspective is on what is needed regarding certification, licenses and permissions for battery-swapping systems to become operational in Sweden. Introducing a battery-swapping concept for heavy trucks requires a thorough overview of necessary permits, regulations, and certifications. For the battery-swapping concept for heavy trucks, it is important to create a European consensus on regulations for standards, for example. Close dialogue with relevant authorities and stakeholders and careful planning and preparation will facilitate the process and reduce the risk of unforeseen obstacles. The battery-swapping concept differs from current business models related to vehicle sales, fuel sales, and the electric power business; thus, existing regulations need to be reviewed and adjusted, and new ones need to be created. For example, in vehicle sales, one would purchase the vehicle and subscribe to the battery, unlike most traditional battery electric vehicles where the purchase includes both the vehicle and battery. This affects vehicle registration, as a battery-swapping vehicle can take batteries of different weights and capacities, which is not allowed under current regulations. A recommendation for swiftly introducing the battery-swapping concept in Europe is to learn from China's battery-swapping standardization process.

The fourth perspective elaborates on the battery-swapping ecosystem and its actors, roles, and relationships. The concept of battery-swapping involves a variety of distinct stakeholders. Key actors consistently present across all battery-swapping systems, as commonly highlighted in the literature, include transport service providers (such as third-party logistics and hauliers), operators and owners of battery-swapping stations, electricity suppliers, vehicle manufacturers, and battery manufacturers. The innovation management literature discusses the emergence of new roles awaiting suitable actors within the context of battery-swapping, such as relationship managers and financial backers, yet no actors have fully assumed these leadership roles in the Swedish context. The fact that no battery-swapping promoters have taken the initiative in Sweden is identified as one reason the transition towards an electric transport system here has paid little attention to battery-swapping compared with countries like China and the USA, where promoters are very influential actors. Transport service providers assume several vital roles in battery-swapping. The separation of batteries from vehicles allows transport service providers to take on diverse roles concerning the ownership of central resources, compared to traditional cable charging. Transport service providers can own, lease, or participate in a shared resource pool for technologies, including batteries and vehicles. Transport service providers serve as essential relationship managers, facilitating communication between stakeholders, including transport buyers, vehicle manufacturers, and battery-swapping station operators. Further, transport service providers can play important roles as experts, given their expertise in the logistics system and transport buyers' needs. Depending on the roles transport service providers choose to play, different relationships with various actors must be established to facilitate the implementation and scaling of battery-swapping. Transport service providers heavily depend on electricity providers, who supply the essential resource of electricity for charging batteries. Transport service providers also rely significantly on the crucial resource provided by the battery-swapping station, specifically regarding the availability of charged batteries at the required time and location. Compared to cable charged vehicles, battery-swapping might increase the transport service providers' dependency due to a limited number of potential battery-swapping station operators. The relationship between transport service providers and vehicle and battery manufacturers depends on the availability of functional vehicles and batteries, which are critical resources. Finally, the vehicle industry plays a very vital role that other actors cannot play, and there is a risk that this industry takes on the role as a gatekeeper, which could hinder the introduction of battery-swapping for heavy vehicles in Sweden and Europe. Based on the key findings there is a need to acknowledge the need for new roles and for actors to take on new roles.

The fifth perspective explores business models for battery-swapping and how this could look in the Swedish market. For the moment (December 2023) there is no demand for fossil-free freight, and shippers are still buying vehicles primarily based on price. From a systems perspective, the truck manufacturers and grid companies are the dominant actors compared with their customers (i.e., transport companies). However, with both truck manufacturers and grid companies being passive in a potential battery-swapping development, the transition to electric freight is left to transport companies to manage. Here, the goods owners/transport buyers are important actors creating the necessary demand for fossil free freight in Sweden (e.g. from longer contracts with shippers to reduce the financial risk in investing in electric trucks). In this context, battery-swapping has a unique advantage compared with cable charging. The FCR (Frequency Containment Reserve) market creates opportunities for actors to invest in batteries and charging as a complementary business (i.e., selling battery back-up to the electricity grid companies). This could be a driving force for transport companies to invest in battery-swapping trucks and stations. However, this requires development of the current regulations. In terms of symbiotic business models, where the relationship between partners develops over time, we can also see that battery-swapping makes it possible to create regional infrastructure for charging of regional transport. Transport companies in our study argue that most large volume routes are more suitable for battery-swapping than cable charging, particularly transports requiring extra charging during the day. Transports where battery-swapping has no specific advantage are transports requiring over-night charging only. In terms of efficiency for the transport company, battery-swapping, with its short swapping times, is an enabler to increase vehicle utilization and to use the vehicle in several shifts. In addition, the FCR market in Sweden gives the transport company (or a group of local transport companies) a business opportunity in owning their own battery-swapping station. Then, battery-swapping is an electrification driver for a transport company, where revenues from the FCR market may compensate for the higher electricity costs and vehicle costs.

The sixth perspective goes deeper into concrete business models for battery-swapping and gives an example of an implementation in harbour operations. This perspective discusses the evolving landscape of battery-swapping solutions for electric heavy trucks (EHT) in Europe, highlighting its existing application in passenger vehicles across countries like Sweden, Norway, Holland, and Germany and the potential for expansion in truck logistics. Despite the uncertainty among Swedish truck owners about foreign suppliers, there is a growing interest, with up to one-third considering such solutions viable if they meet technical and sustainability standards. The switch from diesel or cable charging to battery-swapping is seen as profitable, addressing the challenges of cable charging, such as long recharge times and grid capacity issues. The technology for battery-swapping in heavy trucks has matured and proven effective, with the primary challenge being its adaptation to the Swedish market through a suitable business model. A simulation study further supports this, showing that a single battery in a single swapping station can efficiently handle various operational scenarios, maintaining system efficiency despite increased truck numbers or decreased battery sizes. This approach simplifies logistics and reduces downtime and minimizes environmental impact and investment costs, making it a promising solution for efficient and sustainable heavy truck operations. These findings are crucial for shaping a cost-effective and profitable business model for battery-swapping in heavy truck logistics.

The seventh perspective describes people's knowledge needs and training in the battery-swapping system, based on documentation and interviews from Chinese actors. The purpose of this research is to explore the approaches experienced battery-swapping station operators take in training their staff to monitor, operate, and report on the daily operations of stations. We strive to understand contemporary approaches in training, the primary purposes of training, the main content of training sessions, and the expected learning outcome of the activity being offered to operating staff. In our research we have done empirical observations, visited a number of battery-swapping stations, conducted interviews with managers and reviewed training documentation. We have observed the operating procedures for battery-swapping station management in actual practice as well as the training and education of swapping station personnel. The battery-swapping station operation manual emphasizes occupational health, safety, and environmental protection. Measures for hierarchical management of safety risks, management of hazardous operations, management of hidden dangers, management of personal protective equipment, management of work tickets, and management and maintenance of charging and swapping equipment are detailed. It is interesting to see the distinctive distribution of responsibilities along the hierarchical management chain. The operation manual and measures are based on Chinese national laws, regulations, and standards. Personal safety and health conditions is of high priority in staff training. The second most critical is environmental risk and exposure to accidents that can impact air, earth, groundwater, etc. The third critical training area concerns the station's safety and firefighting. Another area is directed at managing the battery-swapping stations, where the emphasis is on responsibility related to supervisors and operators. There is ongoing technological development toward increasing automation of the battery-swapping stations. So far, the entire process of registering incoming vehicles, changing batteries, checking out, documenting the swapping procedure, and evaluating the exchanged battery is fully automated. However, manual supervision and monitoring is still needed. The development of automation is ongoing, and it is reasonable to expect that supervising and monitoring might be automated in the future as well.

The eighth perspective is on modelling and simulations of electrified transport. This chapter examines the role and utility of modelling in optimizing electrified transport systems. It addresses the question of what methods, models, and simulations can be used to adequately analyse the possibilities and effects of upscaled battery-swapping for heavy vehicles. Several simple and more advanced cases are provided, and some available simulation tools are listed. The benefits of including current and future logistic solutions and their energy needs are discussed, as well as how calculations can help compare different charging solutions and help include these in future regulations such as AFIR (Alternative Fuel Infrastructure Regulation). Modelling and simulation involve identifying key factors, visualising, and optimising. It is important to optimize battery usage in society for the most sustainable solution, which means choosing the best trade-offs. Modelling and simulation tools can help different actors within society understand the trade-offs and opportunities from their perspectives, and system planning models can show how individual actors' decisions can either moderate or exacerbate decisions by other actors.

The ninth perspective is on social sustainability of electrified transport and battery-swapping. The ongoing shift to electrification of heavy trucks is changing the transport sector and presenting both companies and workers with opportunities and risks. Perceptions about electrification in general, and battery-swapping specifically is analysed through a lens of socio-technical imaginaries. Using interviews and focus groups with managers at haulier companies, researchers and experts involved in

this feasibility study, and teachers and students at a high school program for truck drivers, the study explores how different principles of social sustainability in transportation may or may not be affected by electrification and battery-swapping technologies. The social sustainability principles included are health, influence, competence, impartiality, and meaning making. The results present complex and incoherent imaginaries which are influenced by the positions held by the different interviewees. Specifically, the inclusion of both experts and non-experts in the interviews and focus groups provides insight into how different actors relate to socio-technical transformations. The results highlight that there is no single imaginary about either electrification or battery-swapping, but multiple imaginaries. Incorporating workers' and users' imaginaries may assist in developing technological solutions and business models that are more easily adopted. Developing structures encouraging active involvement by workers and users would also address several social sustainability perspectives. The findings also point out that several social sustainability principles may not be best addressed through electrification and battery-swapping technologies, such as gender equality and working conditions related to surveillance of workers. A key recommendation is to invite those affected by ongoing changes in economic and technological structures to contribute to creating alternative imaginaries. This may open trajectories that make such transitions better adapted to their situation, thereby both democratizing the transition within the industry and improving the likelihood of its acceptance.

# Foreword

The swapping idea is not new. When a pony express (1860-1861) rider reached a relay station in the American West, he would quickly swap his exhausted horse for a freshly fed and watered one, continuing the delivery of mail with minimum delay. In ancient Sweden messages, called *budkavle*, were delivered throughout the country in the same way; when a carrier ran out of energy the *budkavle* was given to the next carrier. We recall this delivery system with relay races in running, skiing, and orienteering. This idea of pre-charging for quick swapping later also extends to modern machines. When the rechargeable battery in our cordless power tool runs out, we swap it for another fully charged battery so we can continue working. The electric scooter company Gogoro maintains 2,500 battery-swapping stations in Taiwan, so riders of its scooters never have to charge batteries on their own. Oslo Taxi recently decided to buy Nio cars with battery-swapping for its fleet, saying that taxi vehicles and drivers don´t make money when the vehicle is standing still charging. Of course, battery-swapping can be applied to larger electric vehicles as well, but this charging solution is not well explored in Sweden.

This project would not have taken place without the project Sweden-China Bridge[1], a collaborative platform for electrification of transportation systems, led by Halmstad University and financed by the Swedish Transport Administration. When exploring the rapid electrification of transport in China, it was found that battery-swapping was taking off rapidly for both passenger vehicles and trucks. Two reports were issued[2], followed by seminars with Swedish truck manufacturers and other participants. One of these, a logistics association in Östergötland called Logistikia[3], became interested in further exploring battery-swapping, and its members have been a part of the team ever since. These activities have helped put battery-swapping onto the Swedish agenda for electrifying road transport.

The research team in this project has been following the development and deployment of battery-swapping for heavy duty trucks for several years. Thanks to the Swedish Energy Agency and their research program Research and Innovation within Electromobility we have now been able to carry out a one-year feasibility study on how to introduce and scale up battery-swapping for heavy duty trucks in Sweden. The team members bring broad expertise from different disciplines, and we have studied battery-swapping from these multiple perspectives. In this report we have captured these perspectives in separate chapters. Some of the chapters overlap somewhat, as is natural when describing the same phenomenon from different perspectives. We hope that the combination of perspectives in this report faithfully captures the potential, both the opportunities and the challenges, of battery-swapping as an enabler of electric freight transport in Sweden.

We thank the Swedish Energy Agency for financing this study. We thank all partners and respondents who have given us the valuable information contained in this report.

[1] https://www.hh.se/forskning/var-forskning/forskning-vid-akademin-for-foretagande-innovation-och-hallbarhet/forskningsprojekt-vid-akademin-for-foretagande-innovation-och-hallbarhet/sweden-china-bridge.html

[2] https://www.hh.se/download/18.2b9e5ca178b21e43bf3d30a/1617969697755/Sweden-China%20Bridge%20-%20Battery-Swapping%201.0%5B55%5D.pdf. https://www.hh.se/download/18.7b11fe917c2ac07303bf9d3/1632994342544/Sweden-China%20Bridge%20-%20Exploring%20Battery%20Swapping%20for%20Heavy%20Trucks%20in%20China%201.0%5B68%5D.pdf.

[3] https://logistikia.se/.

We hope that this report will contribute to a successful introduction and deployment of battery-swapping systems for heavy duty trucks in Sweden.

Gothenburg, January 2024

*Arne Nåbo*
*Project leader during the project beginning, and end months*

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*Project leader during the middle period of the project, April to September 2023*

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De slutsatser och rekommendationer som uttrycks är författarens/författarnas egna och speglar inte nödvändigtvis myndigheten VTI:s uppfattning./The conclusions and recommendations in the report are those of the author(s) and do not necessarily reflect the views of VTI as a government agency.

## Glossary

| | |
|---|---|
| 3PL | Third party logistics, such as warehousing and transportation, etc. |
| AADT | Annual average daily traffic. |
| AC-charger | Alternating Current charger. |
| AFIR | Alternative fuels infrastructure regulation (European Union). |
| AI | Artificial intelligence. |
| API | Application Programming Interface. |
| Back-end supplier | An organization that develops data processing solutions. |
| BCS | Battery Charging Station. |
| BEHT | Battery Electric Heavy Truck |
| BEV | Battery electric vehicle. |
| BM | Business Model. |
| BMI | Business Model Innovation. |
| BMS | Battery Management System. A system that controls and optimizes functions such as charging, swapping, frequency balancing, etc. The BMS can also communicate with the grid and the vehicle/fleet planning systems. |
| BSS | Battery-swapping station. |
| CCS | Combined Charging System standard supports both AC and DC charging. |
| CGE | Computable general equilibrium models. |
| Charging infrastructure | Infrastructure required for the charging of electric vehicles. The concept includes the entire chain from the electricity grid to the charging point. However, the term is often used interchangeably with just the charging point. |
| Charging operator | An operator that provides charging points and charging stations, and takes care of the operation and maintenance of charging infrastructure, as well as measuring electricity consumption and billing the user. |
| Charging station | is a location with one or more charging points for charging vehicles. |
| DC-charger | Direct Current charger. |
| Digital infrastructure | Enables digital communication. The infrastructure consists of hard infrastructure such as wires, cables, masts and base stations, and soft infrastructure that deals with laws, standards and internet protocols. |
| Digitalisation | To use the digital format to analyze, change, develop, distribute, streamline or automate. |
| DSO | Distribution system operators (electricity). |
| E-Charge | A project on electrification of heavy trucks, led by CLOSER at Lindholmen Science Park. |
| EHT | Electric Heavy Truck |
| Electricity network company | Organization that owns the electricity network within a network area. |
| EMS | Energy Management System. |

| | |
|---|---|
| ERL | Economic Readiness Level. |
| EU | European Union. |
| EV | Electric Vehicle. |
| FC | Fuel Cell. |
| FCEV | Fuel Cell Electric Vehicle. |
| FCR | Frequency Containment Reserve. |
| FFI | Vinnova-program ”Fordonsstrategisk forskning och innovation”. |
| FMS | Fleet Management System. |
| GDPR | EU law sets mandatory rules on how organizations and companies can use personal data in a privacy-friendly way. |
| GPS | Global Positioning System. |
| HVO | Hydrated Vegetable Oil. |
| ICCT | The International Council on Clean Transportation. |
| ICE | Internal Combustion Engine. |
| IEA | International Energy Agency. |
| LCA | Life Cycle Assessment. |
| LSP | Logistics service provider. |
| LTL | Truck load (LTL) transports. |
| MATSim | A multi-agent simulation tool. |
| MCS | Megawatt Charging System, charging connector. |
| MGA | Modelling to generate alternatives. |
| NIM | Nobil Intelligent Module. |
| Nobil | A database containing information on charging stations. |
| OCPI | Open Charge Point Interface. |
| OEM | Original Equipment Manufacturer. |
| PRL | Political Readiness Level. |
| R&D | Research and development. |
| REEL | A project on electrification of heavy trucks, led by CLOSER at Lindholmen Science Park |
| Regional electrification pilot | Projects that have received support from the Swedish Energy Agency's call for regional Electrification pilots for heavy transport. |
| RES | Renewable Energy Sources. |
| SCB | Sweden – China Bridge, a collaborative research project between Sweden and China. |
| SoH | State of Health of a battery. |
| SRL | Societal Readiness Level. |
| STI | Sociotechnical imaginaries. |

| | |
|---|---|
| STS | Science and Technology studies. |
| Svk | Svenska kraftnät. |
| TCO | Total cost of ownership. |
| TEN-T | Trans-European Transport Network. |
| Third party | Person or body recognized as independent of the parties involved in the matter under consideration. |
| Third-Party Provider | A company that develops new software or soft and hardware services for the electrified transport system. |
| TIMES | A modelling tool used to model energy systems and their related economies. |
| TMS | Transport Management System. |
| TRL | Technology Readiness Level. |
| V2H | Vehicle-to-home, i.e., the home can use electricity from the vehicle. |
| V2G | Vehicle-to-grid, i.e., that the batteries of electric vehicles can be used as battery storage and deliver electricity back to the electric grid. |
| VKT | Vehicle kilometer traveled. |
| VTI | Swedish National Road and Transport Research Institute. |
| WTO | World Trade Organization. |

# Table of contents

# 1. Introduction

## 1.1. Why battery-swapping and why this project?

If Sweden is to achieve a fossil-free freight transport system by 2045, electrification of the truck fleet must accelerate. The business sector is expected to be responsible for the transition, and the industry organization Mobility Sweden has adopted a target of 50% of new heavy-duty vehicles being electric before 2030. There is currently no clear demand for electrified truck transport, though, and thus no market for electric trucks. One explanation is that the industry has very small margins and consists of many independent small and medium companies with an average fleet of only 7-8 vehicles. A typical electric truck can carry a load for 200-300 km but then must stop to charge, at which point there are two options: a) fast charging for 1-2 hours at high power, which puts a disproportionate load on the electricity grid, or b) slow charging at low power for 8-10 hours, which significantly lowers the vehicle's utilization rate and becomes commercially burdensome, especially when the capital cost of a heavy electric truck is about two times that of a diesel-powered truck. We are still in the early phases of electric truck adoption, with a few early adopters testing the usability of the technology. The step to scaling up electric vehicle fleets is a big one. Investments in vehicles with expensive batteries and in charging infrastructure are challenging and risky, which inhibits the pace of adoption.

In order for the on-road goods transport market in Sweden to electrify, vehicle solutions are needed that hauliers and logistics companies can afford, which provide utilization rates on par with diesel-powered trucks. Based on experience from China, where battery-swapping for heavy vehicles has developed into a commercially competitive market, this charging technology is mature and has high potential for scaling in Sweden in the near term. Yet, while the first battery-swapping truck designed for Europe was unveiled by the Chinese heavy equipment manufacturer XCMG at the Hannover Motor Show in 2022, and Germany has initiated a pilot project for battery-swapping trucks driving between Berlin and Dresden (e-Haul), Sweden currently lags in knowledge and experience of battery-swapping for heavy vehicles.

### 1.1.1. The advantages of battery-swapping for heavy trucks and some challenges

The inherent advantages of battery-swapping to multiple market participants create the conditions for it to become a disruptive innovation in different sectors simultaneously. Ironically, this is partly because battery-swapping is less disruptive to the existing operations of both transportation and energy systems than other vehicle electrification options. Existing state of the art uses modular battery-swapping stations, either fixed or mobile units, which can autonomously replace a discharged truck battery with a fully charged one in 3-5 minutes. While the truck continues operation after this, the discharged battery is recharged in the swapping station at rates supported by the station’s grid connection. A study by Vallera et al., 2021, found that the impact to the grid was reduced for battery-swapping compared with plug-in electric vehicles, electric road systems, or hydrogen fuel cell vehicle.

Station modularity offers scalable deployment as the technology gains market share. Since battery-swapping trucks can also use existing cable charging points to charge their batteries, deployment of battery-swapping trucks is not entirely dependent on the availability of swapping stations; this avoids the vehicle/infrastructure chicken-and-egg problem that inhibits the deployment of other electrification technologies. Since the battery-swapping experience from a driver’s standpoint is similar to refueling with diesel, placement considerations for swapping stations are similar to those of existing liquid fueling stations; this is not necessarily true for cable charging. Thus, battery-swapping stations can be collocated with fueling stations, sharing real estate and connections with the transportation system (e.g., off-/on-ramps), and gradually replacing fuel pumps with modular charging stations as fleets transition and demand shifts. This provides a low-cost and convenient transition pathway from diesel drivetrains to battery electric trucks. As deployment accelerates, efficiencies of scale should also reduce the unit cost of the modular swapping stations.

Decoupling transportation services from grid power flows with battery-swapping is unique in electrified transport, and this provides immense operational flexibility. For the carrier, it changes the vehicle ownership cost model, for example separating the purchase of the truck from the leasing of battery capacity and the consumption of energy. Since the working capacity of a battery in a swappable truck may be varied on a use case basis, rather than fixed at the time of vehicle purchase, this allows for smaller, lighter, and cheaper batteries to be used when supported by the mission, reducing average costs. Over the lifetime of a vehicle, the average battery capacity per kilometer travelled should be smaller for a battery-swapping truck than an equivalent truck with a battery that cannot be swapped, reducing the demand for critical minerals in transportation over the long term (see chapter 8). Since the lifetime of a diesel truck is greater than that of a typical battery, battery-swapping may extend electric vehicle lifetimes. As battery technologies improve over time, new batteries may bring the cost and performance benefits of these improvements to existing trucks without the disruption and cost of a major vehicle upgrade. With battery-swapping carriers highlight the advantages of avoiding the operational downtime losses of cable charging, reducing vehicle capital investments, and avoiding the risks of battery ownership.

Since charging does not disrupt transportation operations, battery management can be optimized separately, reducing overall system costs. Batteries in a swap station may be charged slowly in a temperature-controlled environment to minimize degradation and capacity loss, extending lifetimes. Slow-charging batteries also reduces costs to the station owner, since the peak power draw from the grid can be reduced. With batteries in both vehicles and swapping stations that can all be charged at night the beneficial effects of smart charging could be greater in a battery-swapping environment than with cable charging. With a robust grid connection and significant battery capacity, a battery-swapping station can also participate in electricity markets (battery-to-grid), providing balancing and other services to the grid. This reduces the energy storage investment required in the electric power system, which may reduce the cost of providing electricity to all electricity customers. While the provision of energy services is noted as a potential second-life use case for batteries that have been removed from traditional electric vehicles, there is no discrete first life or second life of a battery in a swap station; instead, the choice between transportation or energy services is made on a continual basis. Thus, battery-swapping provides dynamically shared storage between the electricity power system and the transportation system, which can increase resilience in the event of a crisis in either sector. As a battery’s capacity degrades over time, it may still have some value for transportation, and a battery swap station can capture this value by offering it (at a reduced price) as a lower-capacity battery. When a battery becomes so degraded that it has only material salvage value remaining, recycling a battery from a swapping station should be cheaper, as there would be no cost for removal from the vehicle.

In short, the benefits are numerous. Battery-swapping heavy trucks are fully electric, familiar to users of diesel trucks and advantageous compared to trucks with fixed batteries, beneficial to the electric power system, quickly deployable, and rapidly scalable. Battery-swapping is already the dominant technology for electric truck charging in China, it is being introduced into places such as Brazil and New Zealand, and Germany has a demonstrator running, and it could rapidly establish itself in Europe and Sweden within a few years.

The challenge is that battery-swapping creates completely new business models, and Sweden lacks knowledge and experience with battery-swapping for heavy vehicles. Both established and new actors need to find new ways of working together to create both business value for themselves and societal values. Also, current regulatory frameworks within the vehicle- and energy sectors do not consider battery-swapping systems, thus needs to be reviewed and revised. These challenges are specifically addressed in this study.

### 1.1.2. How this project contributes

This project focuses on the commercial feasibility of establishing a battery-swapping system for heavy trucks in Sweden. In studying the business case, we explore how disruptive technologies, ecosystem effects, and circularity could enable rapid development towards green, sustainable, and efficient transport. This feasibility study will provide important knowledge about what is required for the expansion of logistics based on battery-swapping as well as guidance on how a market for electrified freight transport can be created.

The emergence of battery-swapping as a viable commercial enterprise in China has also been studied in the project "Sweden-China Bridge, A Collaborative Academic Platform for The Electrification of Transportation Systems", funded by the Swedish Transport Administration. That project published two reports on battery-swapping in China. (Danilovic & Liu, 2021, Liu & Danilovic 2021). In collaboration with that project, the participants in this study had a unique opportunity to study first-hand the development and upscaling of battery-swapping in China. Transferring the experience from China into a European and Swedish context has been very valuable for this feasibility study.

In another related project, ongoing in parallel, a battery-swapping demonstrator is planned by a consortium in Östergötland led by the collaboration platform Logistikia, whose members include transport companies that are already testing the commercial viability of electric trucks. The battery-swapping demonstrator, including the plans for upscaling based in Östergötland, gives this feasibility study a concrete study object and provides invaluable access to the points of view of the actors (hauliers, energy companies, etc.) who will invest in and use battery-swapping systems and to the authorities (county administrative boards, municipalities, etc.) responsible for facilitating their establishment through permitting and regulation. These two activities, the feasibility study and demonstrator project, are complementary, and both are needed to fully evaluate the business conditions for upscaling battery-swapping.

The primary target groups for the feasibility study are the politicians, decision makers on national level within research and innovation, the logistics industry, transport companies and hauliers. The fragmentation of this industry implies that they need electrification solutions that work with their existing business models. Another target group includes energy companies and power network operators, to help them see vehicle charging solutions as beneficial components of the energy system and not as a burden. For the automotive and battery industries, battery-swapping technology represents a new way of thinking. They need to decide which parts of the new ecosystem they want to actively participate in and which established and new players they should collaborate with. The risk of being sidelined by the rapid emergence of battery-swapping is of losing market share.

## 1.2. Project objectives

The overall goal of the project is to accelerate the transition to electric freight transport in Sweden. As a research project, it aims to increase knowledge of the commercial requirements for market adoption of electric freight solutions. This includes creating a better understanding of which technology solutions are possible, how these could affect existing logistics operations, and what new business models may arise. Recognizing that battery-swapping is potentially an important and overlooked technology option, this report identifies the important actors, both existing and new, that could play a role in the transition toward an electrified freight transport future that incorporates battery-swapping. It aims to identify opportunities and challenges, as well as potential tools that could be used by all stakeholders to identify actions they can take to capture the opportunities of the electrified transport future.

Although fossil-free logistics of the future will largely be carried out by commercial actors, the public sector has a crucial role to play in the transition process. Therefore, another aim of the project is to better understand how public authorities and other public sector actors can accelerate the electrification of freight transport.

A transition to electric trucks will have major effects on transport companies' production systems. An important part of the project is therefore to create knowledge that directly addresses the actors in the transport industry by highlighting issues such as: Which logistics operations are best suited for electrification with battery-swapping and how does the outlook appear in the short and long term compared with other fossil-free alternatives? How does one optimize logistics flows and scheduling for drivers, vehicles, charging, and loading to minimize downtime for trucks?

By understanding the relationships between actors in the logistics system for electric freight transport, we can, given the technical conditions, increase the knowledge of the business needs to facilitate the emergence of a functioning market for electrified freight transport.

## 1.3. Reader´s guide to this report

Several researchers have contributed to this report, each one with his/her own expert view on different aspects of electrification of transport and battery-swapping. Though the general themes are consistent with each other, each researcher's perspective is unique. Therefore, we have chosen to include the contributions "as delivered" in separate chapters, allowing the insights from each to stand on their own and minimizing the risk of introducing bias. We invite the reader to engage with the perspective of the researchers in each chapter, to test the insights and conclusions within against their own perspective and experience. The chapters in this report are organized as follows:

Chapter 1 *Introduction* gives the reader the background to battery-swapping technology, its advantages and the objectives of this study.

Chapter 2 *Executive summary - conclusions and proposals* summarizes our findings, highlighting the most important conclusions and proposals.

Chapter 3 *Global outlook of battery-swapping progress for heavy trucks and the dynamics of actors* gives the background of modern battery-swapping technology, and its development and deployment globally. This chapter pays special emphasis to the experience of China, where a commercial battery-swapping market has emerged.

Chapter 4 *Technology integration and feasibility* describes how battery-swapping could be integrated into the Swedish operating environment (e.g., interaction with the Swedish electric power grid).

Chapter 5 *Certifications, licenses and permissions* describes regulatory considerations that could inhibit or facilitate the transition to electric freight with battery-swapping.

Chapter 6 *Actors, roles, and interorganizational relations in battery-swapping* elaborates on the battery-swapping business ecosystem, emphasizing new key roles and actors.

Chapter 7 *Business Models for Battery-Swapping in Sweden* explores the business case for battery-swapping in the Swedish market, focusing on electric trucks.

Chapter 8 *Strategic Business Models for Battery-Swapping, including Harbor Transport Systems* explores and proposes a business model for establishing battery-swapping solutions for heavy trucks in Scandinavia, focusing on truck and battery-swapping station operators.

Chapter 9 *Knowledge needs and training for the battery-swapping business* aims to explore training approaches at battery-swapping stations, focusing on staff capacity for monitoring, operation, and daily station management.

Chapter 10 *Modelling and simulations of electrified transports – benefits and needs* provides a comprehensive examination of the role and utility of modelling and simulations in optimizing electrified transport systems.

Chapter 11 *Social sustainability perspectives on electrification and battery-swapping in the heavy trucking sector* analyses perceptions about electrification in general, and battery-swapping specifically, understanding them through a lens of socio-technical imaginaries.

Appendix 1 *Battery-Swapping Explorative Trip to China* is a short report from a study tour to China in November 2023 where several of the researchers participated. This trip was not a part of this project, but we believe it adds value to this report.

# 2. Executive summary – Observations and recommendations

## 2.1. Introduction

This chapter presents the observations and recommendations regarding battery-swapping that the authors consider the most important to communicate to the report's target groups, i.e., government, authorities, regional actors, the energy and automotive industries, logistics companies, researchers, etc. These are the results of the discussions that the participating researchers have had during the project's meetings and workshops, and which have matured during the project. The observations and recommendations are aimed to facilitate discussions among actors on moving towards action. In this way, the researchers can challenge the organizations involved in electric transportation to consider battery-swapping as part of the future vehicle charging landscape. The research results are conveyed in a series of observations and related recommendations for consideration.

## 2.2. Observations and recommendations

### 2.2.1. On battery-swapping technology

#### Observation

Battery-swapping technology is ready for full-scale operations (TRL 9: Actual system proven in operational environment). Heavy-duty vehicles, swapping stations, batteries, and software platforms to manage the batteries have been fully developed and implemented in China. It has been implemented in different industries (mining, construction, etc.) and in different climates (sub-tropical to arctic).

#### Recommendation

Battery-swapping is a viable technology option for goods transport and should be considered for deployment in the Swedish operational environment by logistics operators, hauliers, and their customers.

### 2.2.2. On introducing battery-swapping in Sweden

#### Observation

Battery-swapping is an important complement to cable charging and is well-suited for many transport missions. For battery-swapping to be deployed throughout Sweden, it needs to be tested under Swedish conditions in real logistics operations.

#### Recommendation

A demonstrator followed by a pilot is recommended before a full-scale implementation. We recommend that the Swedish government give the Swedish Energy Agency a commission to initiate and finance a battery-swapping demonstrator for heavy trucks.

### 2.2.3. On business model for truck operators

#### Observation

Truck operators are concerned about the uncertainties that a new technology brings, such as battery-swapping. Also, they lack experience of international truck OEMs with battery-swapping. In spite of this, all 25 companies we have talked with say they would prefer battery-swapping solutions as they like its benefits.

#### Recommendation

To handle the uncertainties and lack of experience of international trucks with battery-swapping, we propose that truck operators take total leasing solutions, financial leasing, and operational leasing in an integrated package. The swapping solution can be based on subscription or pay-as-you-use the swapping solution.

### 2.2.4. On battery-swapping and AFIR

#### Observation

AFIR (alternative fuel infrastructure regulation) provides a strong incentive to implement charging infrastructure in Europe. However, the implementation measures do not accommodate battery-swapping as a charging option, despite the technology being mentioned in an annex. It is vitally important to incorporate battery-swapping into the next update of AFIR, so that the regulation does not inhibit this technology from playing a role in the European charging infrastructure.

#### Recommendation

The Swedish Energy Agency (the Swedish representative in the AFIR negotiations) should elevate battery-swapping on the agenda for the next update of AFIR.

### 2.2.5. On speeding up the transition to electric freight

#### Observation

The introduction of battery-swapping for goods transport in Sweden will speed up the transition to electric freight. The fragmented Swedish shipping industry requires electrification to be economic for the individual truck owner/operator, and battery-swapping enables electric trucks to become more profitable than cable charged trucks, with shorter stops, greater flexibility (i.e., different batteries for different missions), and less demands on changes to the electrical system compared to fast charging stations. In addition, a battery-swapping station can create additional sources of income for transport and logistics companies, which is another enabler for an electrified freight transport industry.

#### Recommendation

Transport companies are recommended to invest in battery-swapping stations so they can quickly build up their own fleet of electric trucks for several different types of transport missions.

### 2.2.6. On modelling battery-swapping

#### Observation

Battery-swapping creates different opportunities and challenges for different actors and participants in the logistics and energy systems. Though the future is uncertain, modelling different scenarios from each market perspective can help identify potential opportunities and hindrances. For example, separating the battery from the truck could lower the initial cost of an electric truck and reduce risk to the vehicle owner, but it also challenges existing vehicle sales models. Managing a stockpile of vehicle batteries for dual use in transportation and energy markets creates a new commercial opportunity with no current analog, but new validation models for estimating a battery's state of health and new data communication protocols will be needed to support battery interoperability among vehicles.

#### Recommendation

The Swedish Energy Agency should develop a publicly-available modelling system (i.e., a system of models) of the interrelated transportation logistics system and the energy system to evaluate the potential advantages and risks to existing businesses and new entrants from the introduction of battery-swapping in freight transport. This system will inform the decision-making process to enable battery-swapping as a charging option, and it will foster better communication among market participants across both energy and transport systems.

### 2.2.7. On communicating battery-swapping technology

#### Observation

The report highlights battery-swapping's considerable technical and operational advantages over traditional cable charging in many aspects, but also some difficulties. Strategic planning and continuous innovation can make battery-swapping an important complementary solution for sustainable and efficient transport in Sweden and the EU.

#### Recommendation

The Swedish government should sponsor a pilot project to demonstrate the viability of battery-swapping in a Swedish logistics context.  It should use its position in the EU to communicate its potential to other member states, and it should ensure that international regulations and agreements accommodate battery-swapping as a viable freight transport electrification option.

### 2.2.8. On standardization and industry collaboration regarding battery-swapping

#### Observation

Standardization and collaboration are key for the scalability of battery-swapping. To realize the full potential of this technology, there is a need to develop and standardize batteries and swapping infrastructure. This requires close cooperation between vehicle manufacturers, battery suppliers, government authorities, and other stakeholders. Such collaboration will help create a robust and sustainable infrastructure for battery-swapping. It is also important to align regulations and certifications, particularly regarding vehicle adaptation and safety, and to establish dialogues with relevant authorities for a smoother implementation process.

#### Recommendation

Representatives from Swedish industry and the concerned authorities should actively promote European standardization and harmonization of battery-swapping solutions.

### 2.2.9. On social sustainability perspectives on electrification and battery-swapping

#### Observation

Social sustainability issues are important to consider in developing battery-swapping technologies. A socially sustainable transport sector means that there are no structural obstacles to health and working conditions, influence, competence development, impartiality, or individual and collective meaning-making. Including interviews and focus groups with experts and non-experts in the study provides insight into how different actors relate to ongoing and future socio-technical transformations. Incorporating workers and users may assist in developing technological solutions and business models that are simultaneously innovative and future-oriented without ignoring the needs of the existing workforce. Developing structures that encourage active involvement by workers and users would help address several social sustainability perspectives.

### Recommendation

In the continued development of technologies, strategies, and business models for electrification in general, and battery-swapping specifically, the active inclusion of workers' and users' perspectives and competence development should be included by all decision-makers to ensure that social sustainability perspectives can be addressed.

# 3. Global outlook of battery-swapping progress for heavy trucks and the dynamics of actors

Authors: Professor Mike Danilovic, Dr. Jasmine Lihua Liu, Dr. Harrison John Bhatti.

## 3.1. Abstract

The development of battery-swapping solutions for heavy trucks shows impressive speed in development, implementation, and market penetration. It also indicates exciting dynamics between the main aspects and actors related to the development and expansion of battery-swapping solutions.

From the beginning, the impetus for developing the system solution was energy producers that realized the impact of the electrification of transport. To support the first generation of swapping systems, the entire system consisting of stations and heavy trucks was developed by the energy companies. The traditional OEMs were hesitant to adopt the battery-swapping solutions due to the uncertainty of the business and the survivability of their standard operations. After redesigning the Eco system, the traditional heavy truck OEMs adopted the battery-swapping system solutions.

The next phase of this development was driven by companies from the machinery industry that recognized a market opportunity due to the hesitation of traditional truck OEMs. They saw heavy trucks as a natural expansion of their engineering competence and desire for growth and development.

Finally, the third step is driven by battery manufacturers and high-tech companies, searching for commercialization opportunities for their new technology, making vehicles in general ‘computers on wheels’, and becoming intelligent system solution providers.

Even the battery-swapping solutions are undergoing rapid development, improvements, and new solutions are being introduced. We observe that battery-swapping solutions are entering their product's third phase.

However, this rapid development brings standardization challenges; new incompatible solutions challenge the dominant solution.

Battery-swapping as a system solution has existed in parallel with integrated truck-battery solutions, needing to be swappable. Although battery-swapping has rapidly achieved 50% of the Chinese market for electric heavy trucks, the alternative solutions are balanced. However, we observe that the heavy trucks in China are undergoing development, integrating new advanced vehicle designs and new technology, making them intelligent with built-in autonomous driving, where battery-swapping and alternative energy sourcing, such as battery and hydrogen, are becoming standard solutions.

The new generation of heavy trucks observed in China indicates that the center of gravity for developing new generations of trucks utilizing new technologies is becoming in China.

The dynamics are evident between technology, products, and actors in all three main areas of development we have explored: the battery-swapping solutions, battery-swapping stations, and the heavy trucks utilizing the battery-swapping as one system solution.

We also see that the traditional Western domination in vehicle technology, design, and operational efficiency is being challenged by the new generations of Chinese trucks and battery-swapping system solutions that are becoming the typical new dominant solution in the Chinese context. We have identified that the new Chinese intelligent truck systems show substantial new technology levels and that autonomous driving and interconnectivity to the external environment are becoming standard solutions.

Globally, we see indications that battery-swapping for heavy trucks is expanding to Japan, the USA, Australia, and New Zealand, and early phases of development are taking place in Germany.

## 3.2. Background

We live in turbulent times. The transformation from fossil energy to renewable, and transportation systems from internal combustion engine (ICE) technology to fossil-free solutions transforms entire societies, the transport industry and vehicles. This transformation does not upgrade the technology or polish established vehicle design and how the logistics system operates. We argue that this transformation is dramatic and radical and substantially impacts all levels, from societies, industry, businesses, companies, and citizens.

Innovation is radical, like the transformation from analog to digital photography, from traditional mobile phones to smartphones, etc. In such a transformation, old technologies and companies are outdated, and new ones are coming in. Kodak and Nokia represent such dramatic consequences of innovation taking place.

When it comes to energy and transportation systems, this transformation is complicated as the scale and scope of renewable energy and electrification of the transportation system have a global, political, and industrial impact. This transformation is not industrial and business-driven; it is politically driven as a mission of societal transformation.

The transportation system is global. Airplanes, ships, trains, trucks, and cars operate across regional and national boundaries. Thus, the standardization of solutions is crucial for the evolution of the transportation system. However, different solutions are being developed and competed for acceptance by industry, businesses, and consumers in the early stages of technology development. Various technologies and solutions based on different business models have different diffusion patterns in the society. Many solutions will fail, and after some time, other solutions will emerge suitable for various operational scenarios, demands, and energy supplies.

We can observe that the electrification of transportation systems can be achieved differently. Electric road systems represent conductive technology solutions with wires in the air or rails in the ground. Cable charging is another conductive technology. Inductive wireless technologies are being developed but have not been implemented on any large scale yet. Battery-swapping has been introduced as a complementary solution to other recharging technologies. Hydrogen and fuel cell technologies are being developed and introduced while still needing to be on a large-scale basis.

Those solutions do not exclude each other; they can be complementary, combined, and applied to different operational and business scenarios. They show a variation of technological and business maturity. None of these technologies can be seen as the perfect solution for all needs. They need to be seen and understood as complementing each other.

### 3.2.1. Status of the heavy trucks market in Europe

According to our own data analysis, the dominant actors and their market share in the European market for heavy trucks are the following:

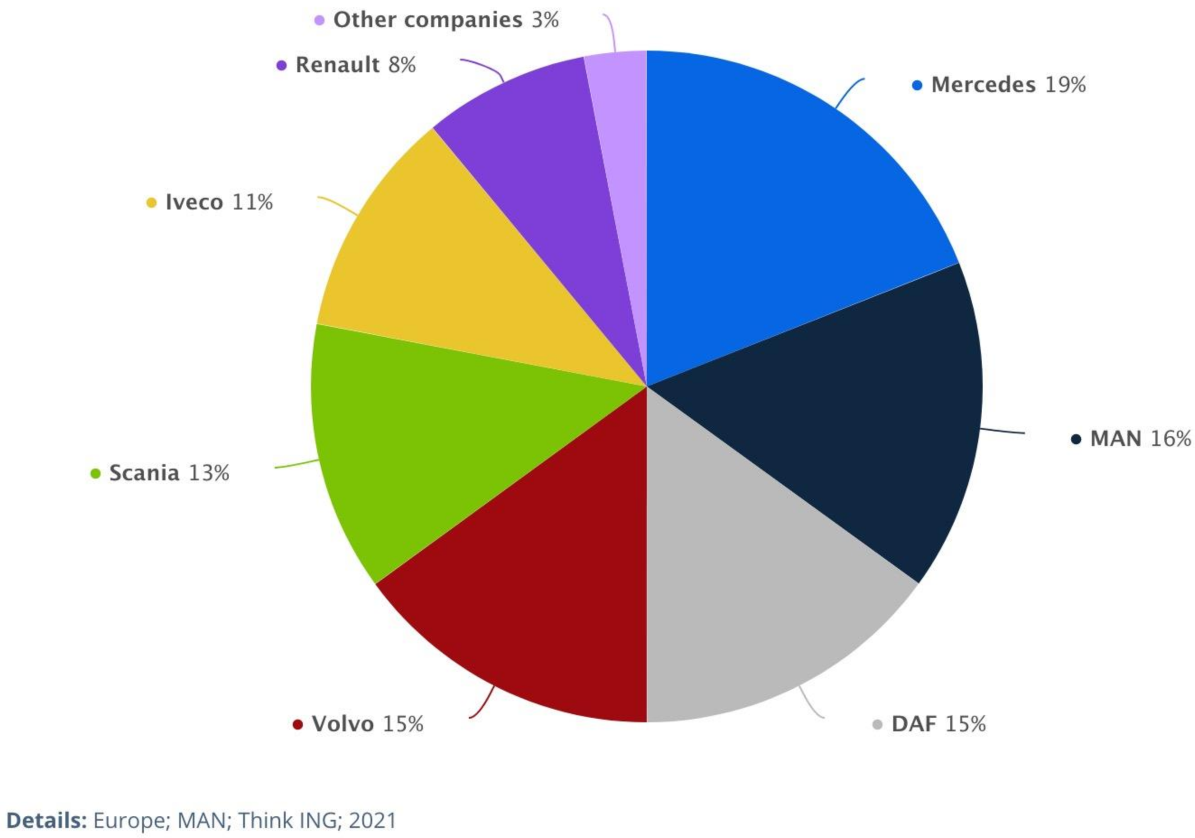


*Figure 1. Market share of medium and heavy commercial vehicles in Europe in 2021, by producer. Source: Statista, 2023.*

In the Figure 1, we see that main European manufactures have following market share of heavy trucks in 2021.

- Volvo trucks, with a market share of 15%
- Renault trucks, with a market share of 8%
- Scania with a market share of 13%
- MAN with a market share of 16%
- Mercedes-Benz (Daimler), with a market share of 19%
- DAF, with a market share of 15%
- Iveco with a market share of 11%
- Other with a market share of 3%

European truck OEMs dominate the European market. How this situation might look in the future is an open question. The Chinese truck manufacturers have yet to initiate the market diffusion to European markets. Chinese passenger vehicle manufacturers introduced new brands to Europe in 2023 and will scale up their efforts to expand the European market in 2024. A similar situation might happen when Chinese truck manufacturers enter the European market in a few years. Based on our experiences from our research in the development of China, the question is not if but rather when and with what intensity level this might happen. According to our understanding, Chinese suppliers of

BEHT might enter the European market in 2024-2025. Considering the technological advancements of modern Chinese trucks and multi-energy sourcing being developed, we also have reasons to believe that the impact on the European truck market might be substantial.

### 3.2.2. Where is Europe heading, and how do we make it?

> *"A new study by the European Automobile Manufacturers' Association (ACEA) shows that there are currently 6.2 million medium and heavy commercial vehicles on the EU's roads, the average age of which is 13 years. Almost 98% of all these trucks run on diesel. Just some 2,300 – or 0.04% of the total fleet – are zero-emission trucks" (Source: ACEA, 2021)*

European truck makers estimate that around 200,000 zero-emission trucks will have to be in operation by 2030 to meet the CO2 targets for heavy-duty trucks. Based on ACEA's new data, this would require a staggering 100-fold increase in the space of under 10 years.

The European Commission has outlined objectives to have about 80,000 zero-emission trucks on the road by 2030, which is much lower than what is required by the CO2 regulation (-30% emissions) (ACEA, Ibid).

> *"European truck manufacturers are committed to bringing zero-emission trucks to the market,and will be rapidly increasing their range of zero-emission vehicle offerings over the next few years. However, they cannot make such a radical and unprecedented shift alone." (Source: ACEA, Ibid, ACEA's Director General, Eric-Mark Huitema).*

This shows that European manufacturers are facing two major challenges. One is to scale up the development and manufacturing of zero emissions heavy trucks, and the other one is to develop collaborative solutions between European manufacturers and with leading international partners.

### 3.2.3. Battery-powered heavy trucks is dominating the scenery

Most of the zero-emission heavy vehicles (ZE-HDV) sold in the EU-27 are battery vehicles. Only about 100 are expected to be fuel-cell-powered by 2023. Almost all fuel-cell-powered vehicles were registered in Germany and the Netherlands and had a 6x2 axle configuration.

For the battery-powered trucks, about half had a 4x2 axle configuration, and the rest had 6x2.

The gas market share for heavy trucks was about 3% in 2022. That decreased from 2021, when their market share was 4%. This means that battery-based configurations are the dominant solutions so far, and thus, our focus is on BEHT (Mulholland and Rodríguez, 2023).

### 3.2.4. Status of the heavy trucks market in China

China is the largest global market for heavy trucks, with about 85% of the global sales of heavy trucks. More than 1,39 million heavy trucks were sold in 2021, and 670,000 heavy trucks were sold in 2022. An estimated 52,000 electric medium- and heavy-duty trucks were sold in China, representing 18% and 4% of total sales in China and about 80% and 85% of global sales, respectively (Source: IEA, Global EV Outlook 2023: Trends in heavy-duty vehicles).

From 2016 to 2020, China's heavy truck sales surged from 728,000 units to 1,617,000 units. In 2021, a combination of factors such as a sluggish freight market and demand overdraft led to an annualized 14.1% slump in heavy truck sales to 1.39 million units, projected to be around 1.2 million in 2022. China's heavy truck fleet is estimated to reach 11.7 million heavy trucks in operations in 2025. (Source: Global and China Heavy Truck Markets, 2021-2022 & 2027, https://www.prnewswire.com/news-releases/global-and-china-heavy-truck-markets-2021-2022--2027---sales-of-china-vi-tractors-may-surge-301503014.html).

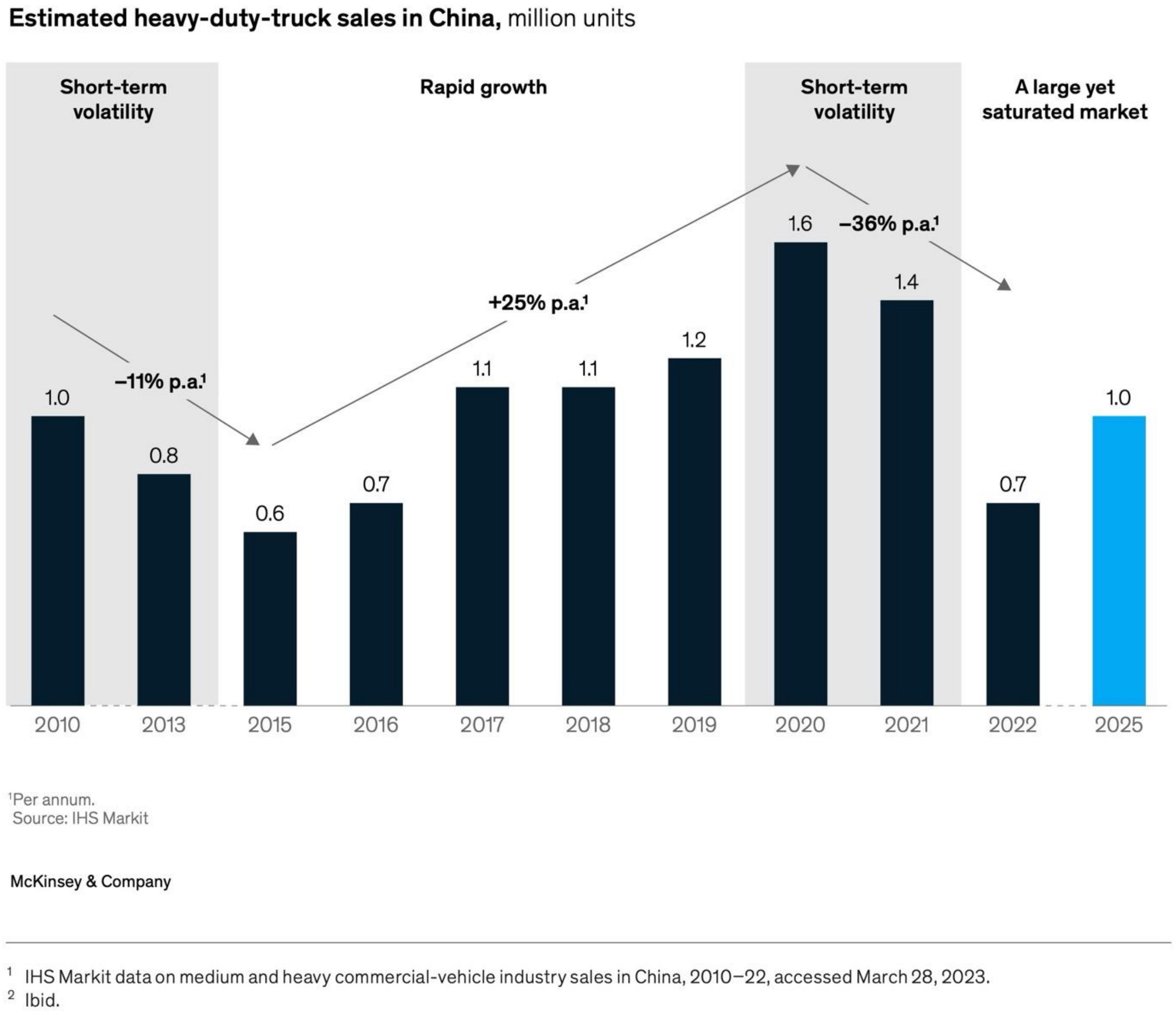


*Figure 2. Estimated heavy-truck sales in China, 2010-2025. Source: Fang, et.al., 2023.*

The stagnating freight market and the increasing imbalance between supply and demand have brought about slowing demand for heavy trucks since April 2021. Transport overcapacity, falling freight rates, and insufficient construction of infrastructure projects led to less-than-expected orders from heavy truck end users. The over-heated heavy truck market in 2020 overdrew part of demand in 2021. The full implementation of China Phase VI Emission Standards kicked companies into high gear to produce China V models from early 2021, and dealers across the country also went all out to stock up, which moved up the release time of the end demand and caused the plummeting demand for heavy trucks in the second half of 2021.

In 2018, China finalized China VI standards that will apply to new heavy-duty diesel vehicles nationwide in two stages. China VI-a is mainly equivalent to Euro VI and have been applied from July 2019, urban HDVs from July 2020, and all new HDVs from July 2021.

In 2021, the total sale of heavy trucks was 1.39 million units, including about 250,000 China VI heavy trucks, or 18% of the total, 4% higher than in 2020 (14%). In 2021, the first year implementing the China Phase VI Emission Standards, China VI diesel heavy trucks shared lower than 1/5. In the future, as the restriction on China V and below vehicles becomes stricter, the sales of China VI heavy trucks will sustain growth, which may soar the sales of tractors.

In 2022, the demand for heavy trucks in China was estimated to open low but going up. The market will enter the phase of stock competition, thanks to the Winter Olympics and post-covid economic recovery. The resumption of infrastructure projects is expected to create opportunities for the construction vehicle market, the goal of "double carbon" (carbon peaking and carbon neutrality) will push the new energy vehicle market, and the phase-out of old diesel vehicles is expected to leave the scope for replacement and update.

Intelligent connected vehicles are taken as one of the key industrial growth drivers in the future, according to the Action Plan for the Development of the Intelligent Connected Vehicle (ICV) Industry, a policy issued by the Ministry of Industry and Information Technology (MIIT) in 2018. The Intelligent Connected Vehicle Technology Roadmap 2.0 released by the National Innovation Center of Intelligent and Connected Vehicles in 2020 indicates that in 2025, the sales of ICVs at levels of PA (partial automation) and CA (conditional automation) will make up more than 50% of the total. In 2021, the MIIT set up an Intelligent Connected Vehicle Promotion Group to carry out pilot projects of urban and intelligent connected vehicles.

Intelligent transportation has been as important as a national strategy, and intelligent connected heavy trucks have also become a development trend. In August 2018, Beijing announced a regulation: China V and above diesel heavy trucks registered in Beijing must be connected to the Beijing Municipal Ecology and Environment Bureau before December 31, 2021. National strategies and transportation policies will favor adopting intelligently connected heavy trucks, which may be a new sales driver in 2023-2024.

For the reasons stated above, the development of the heavy truck market and chosen technology is critical to understand as the dominant position of China and the technology and solutions Chinese manufacturers are conducting and deploying might impact the rest of the world.

### 3.2.5. Electrification of transport in China - From fossil-based to electrified heavy trucks

As technology matures, BEHT will grow in popularity over the next ten to 15 years and be used in various applications, driving electrification in the entire heavy duty trucks (HDT) ecosystem. In China and globally, diesel-based trucks with internal combustion engines (ICE) dominate HDT road transportation, including long-haul, short-haul, and local or urban deliveries. Electrification will become increasingly central to road transportation as the total cost of ownership for electric HDTs becomes competitive with that of ICE HDTs, thanks to maturing technology and infrastructure. The Figure 3 indicate that new energy vehicles will dominate the heavy truck market by 2040.

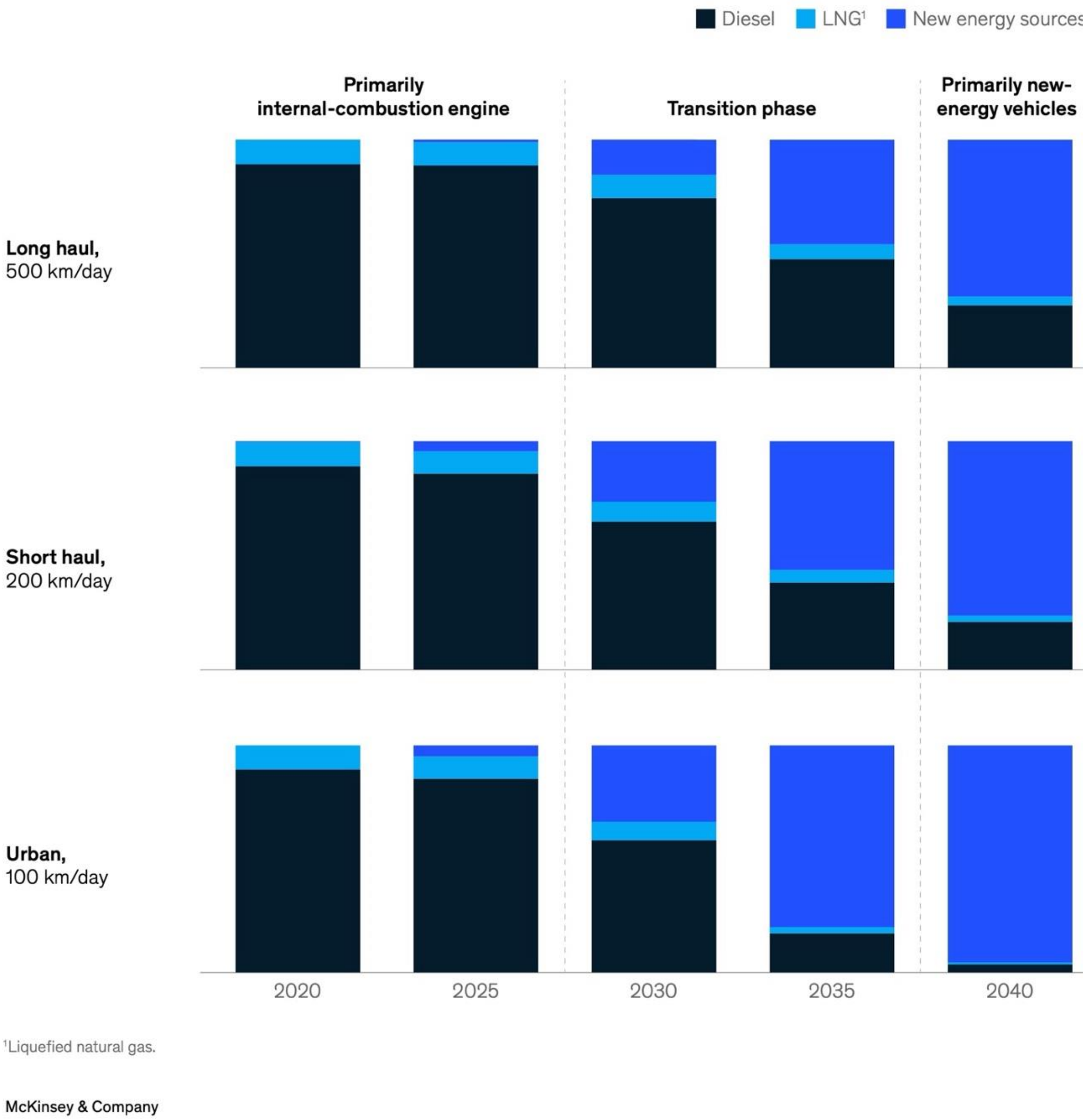


*Figure 3. Projected market shifts based on disguised data show a transition toward electric heavy-duty trucks in China from 2030 to 2035. Source: Fang, et.al., 2023.*

Due to the difficulties of charging in long-haul trucking, these vehicles may be slower to electrify than others. Long-haul trucking is one of many applications in which that can hinder electrification. Charging solutions are emerging, including overnight slow charging, highway fast charging, hybrid charging, and battery-swapping.

## Powertrain solutions for heavy-duty trucks

According to McKinsey's analysis of the Chinese heavy truck situation, four scenarios are identified (Source: Ibid):

1. Hybrid heavy-duty trucks (HDTs) could meet the needs of medium-distance transportation as a transitional solution before new battery technology is ready for the market. However, the technology could be more economically and environmentally viable for long-haul trucking.
2. Technologies and infrastructure associated with battery-electric-vehicle (BEV) products are the most mature and may be the most widely adopted in the short term. Because currently available battery technology doesn’t have sufficient performance to provide the range or

charging speed required for long-haul transport, applications of BEV technology would mostly be in short-haul and local transportation.

3. Battery-swapping solutions show promise for long-haul trucking. The rapid development of battery swap options may stimulate the development of battery electric HDT. Battery-swapping for heavy trucks is becoming one dominant solution for BEHT in China and our focus in this report.
4. Fuel cells are another technology route. However, the technology still needs to be mature for large-scale diffusion, lacks supportive infrastructure, and has yet to hit upon a workable business model. We have reasons to see that fuel cell HDTs will likely reach widespread adoption in 2030.

Based on our research, we have reasons to believe that battery-based solutions (cable charging and swapping solutions), and hydrogen-based solutions are not exclusive but rather will coexist for a long time as complementary solutions.

### 3.2.6. Our focus is on battery-swapping solutions for heavy trucks

This report focuses on the evolution of battery-swapping technologies and their implementation in different parts of the world. The focus is on heavy trucks. This report is an update on the global development and diffusion in areas where we have identified battery-swapping to be developed and established.

For the overview of the history status of passenger vehicles and heavy trucks domain, please see our reports published in 2021 (Danilovic and Liu, 2021; Liu and Danilovic, 2021).

### 3.2.7. The purpose of this research

Our research is explorative.

We aim to explore and understand

- the patterns of technology development of battery-swapping solutions in China and internationally
- the impact that those patterns of technology development and establishment have on the roles and on the interactions between related actors for the battery-swapping solutions.

### 3.2.8. Short history of battery-swapping

We can trace the history of modern battery-swapping to Better Place, an Israel-based company founded in 2007 by Shai Agassi. When battery charging was still infancy, battery-swapping technology was as promising and futuristic as it was not entirely in line with the supply of vehicles suitable for swapping batteries. Although a profitable venture, Better Place crumbled before celebrating its sixth anniversary.

A similar tale of failure awaited battery-swapping at Tesla. Elon Musk tried out the newer technology on the Model S in the United States with only 90 seconds to swap an EV battery. However, Elon Musk soon discovered battery-swapping wasn't working well among Tesla customers. Tesla commented that battery-swapping is "riddled with problems and unsuitable for wide-scale use." So, they dropped the project and went ahead with superchargers. The work of Better Place was moved to China, and the fast development of EVs needed matching recharging solutions. Thus, battery-swapping came to be suitable for growth in China.

### 3.2.9. The dynamics of relations and roles among stakeholders and critical actors

Although battery-swapping has a history in France in 1881 and the US in 1896, modern solutions were developed by Tesla and Better Place. However, the large-scale development and implementation were conducted in China for passenger vehicles and heavy trucks. We notice that battery-swapping for passenger vehicles is being diffused to many countries such as the USA, Norway, Sweden, Germany, Holland, etc. We also notice that the battery-swapping for heavy trucks is diffused to countries such as New Zealand, Australia, the USA, Germany, and Italy.

In this report, we intend to give an overview of this development for heavy trucks and present an analysis of the learning outcome and the implications of this development.

We need to understand that the battery-swapping system solutions are based on dynamic interplay between different vital actors:

- Energy producers and providers to the grid system
- Battery-swapping technology developers
- Battery manufacturers
- OEMs of trucks applying battery-swapping solutions
- Operators using battery technology-equipped trucks

As we have seen in our reports from 2021, these key actors need to collaborate and develop complementary solutions. We have also noticed that when traditional OEMs of trucks hesitate to introduce battery-swapping solutions, new entrants see this hesitation as an opportunity and offer unique solutions for trucks utilizing the battery-swapping systems.

## 3.3. Battery-swapping for heavy trucks status quo in China

The Chinese national and several local governments have encouraged battery-swapping technology since 2020, and the share of swap-capable vehicles in China's electric truck sales has been increasing. In 2022, 48.8% of the electric trucks sold in China were swap-capable (Zan, 2023 a). This number is expected to rise to about 75% in a few years. These swap-capable electric trucks are mainly used for short-haul applications at ports, mining sites, and urban logistics. They are typically equipped with a 141 kWh or 282 kWh battery and have a typical one-way trip length of less than 100 km. However, the swapping solutions allows 350-450 kWh batteries with an operational range of up to 400 km.

Compared with today's plug-in charging technologies, the critical advantage of battery-swapping is the short time required to recharge. With plug-in charging, it usually takes 40 minutes with DC fast charging or several hours via regular charging to recharge an electric truck. In contrast, battery-swapping takes 3–6 minutes. This speed can appeal to truck owners because trucks are used for commercial purposes; faster charging leaves more time to deliver goods and generate profits.

The market for electric trucks is snowballing in China, with 25,477 battery-electric trucks sold in 2022. Of those 25,477, 12,431 trucks were designed for battery-swapping, and while the sales of ordinary trucks have grown at a rate of 61.7% since 2021, the segment with swappable batteries grew by 274% (Zan, 2023 a). Battery-swapping is seen as a crucial enabler, and different truck makers have launched several initiatives. For instance, in June 2023, CATL launched its new Qiji Energy platform, which works with 171 kWh battery packs based on LFP cells from CATL. The total system development needs the collaboration of critical actors such as battery manufacturers, swapping system developers, and vehicle developers integrating new battery design and operating under the logic of the selected swapping solution.

One of the leading Chinese academic researchers, Professor Ouyang Minggao, an academician of the Chinese Academy of Sciences and a professor at Tsinghua University, said that the market penetration rate of new-energy heavy trucks was only 2% in 2022. It was preliminarily estimated that the market penetration rate would exceed 10% by 2025, striving to be close to 50% by 2030.

### 3.3.1. Battery-swapping heavy trucks market performance in China from January to August 2023

From January to August 2023, 7952 battery-swapping heavy trucks were sold in China, a year-on-year increase of 26.64%, achieving rapid growth in sales. Among them, 1328 battery-swapping heavy trucks were sold in August, a year-on-year increase of 73.37% and a month-on-month increase of 48.38%, setting a new high for monthly sales within the year (Zan, 2023 b).

Battery-swapping electric heavy truck sales volume


*Figure 4. Battery-swapping EHT sales volume from January to August 2023 in China. Source: Evpartner.*

From January to August 2023, the total sales of new energy heavy trucks were 16,920, with battery-swapping electric heavy trucks (EHT) accounting for 47.00%. 7,249 pure electric (excluding battery-swapping) heavy trucks were sold, accounting for 42.84%; 1,689 fuel cell heavy trucks were sold, accounting for 9.98%; 30 plug-in hybrid heavy trucks were sold, accounting for 0.18%.

*Table 1. New energy heavy truck sales by energy supply type from January to August 2023 in China. Source: Evpartner*

| Energy supplement types | Sales units | Percentage |
|---|---|---|
| Battery-swapping EHTs | 7952 | 47.00% |
| Pure electric (excluding battery-swapping) | 7249 | 42.84% |
| Fuel cell heavy trucks | 1689 | 9.98% |
| Hybrid heavy trucks | 30 | 0.18% |
| Total | 16920 | 100% |

According to China's GB/T 15089-2001 "Classification of Motor Vehicles and Trailers" standard, N3 is used as the vehicle classification type, which complies with the Ministry of Industry and Information Technology regulations for new energy vehicles. In this report, new energy heavy trucks only refer to pure electric heavy trucks, fuel cell heavy trucks, the plug-in (including extended range) hybrid heavy trucks with a total vehicle weight of ≥ 12,000 kg, including tractors (including semi-trailer tractors), and dump trucks (including dump garbage trucks), freight trucks, mixer trucks, specialized vehicles (such as sanitation and engineering vehicles), excluding chassis, military vehicles, and export vehicles.

### Battery-swapping electric heavy truck vehicle types distribution

From January 2023 to August 2023:

- 7,952 battery-swapping EHTs were sold, of which 4,819 electric tractor vehicles (including semi-trailer tractors) were sold, accounting for 60.60%, making them the major model of battery-swapping EHTs.
- One thousand nine hundred fifty-one (1,951) electric dump trucks were sold, accounting for 24.54%.
- One thousand one hundred seventy-four (1,174) electric mixer trucks were sold, accounting for 14.76%; 8 specialized battery-swapping EHTs (sanitation and engineering) were sold, accounting for 0.10% (Zan, 2023 b).

*Table 2. Battery-swapping EHT vehicle types from January to August 2023 in China. Source: Evpartner.*

| Battery-swapping EHT vehicle types | Sales units | Percentage |
|---|---|---|
| Electric tractor vehicles (including semi-trailer tractors) | 4819 | 60.60% |
| Electric dump trucks | 1951 | 24.54% |
| Electric mixer trucks | 1174 | 14.76% |
| Specialized EHTs (sanitation and engineering) | 8 | 0.10% |
| Freight trucks | 0 | 0.00% |
| Total | 7952 | 100% |

Among the top 10 best-selling models for battery-swapping EHTs, the top three models were all semi-trailer tractors, namely:

- XCMG Group's XGA4254BEVWCA,
- Farizon’s HN4250B36C6BEV (CAMC branded), and
- Dongfeng’s LZ4250H5DZBEV1 (Chenglong branded).

Among the best-selling models for battery-swapping EHTs are 8 tractor models, 1 dump truck (including a self-dumping garbage truck), and 1 mixer truck.

Among them,

- XCMG Group has 4 models, while
- Farizon Commercial Vehicles, Dongfeng Liuqi, Sany Group, SAIC Hongyan, China FAW, and Shanxi Automobile Group each have 1 model.

### Battery-swapping electric heavy truck OEM distribution

In August 2023, a total of 24 enterprises sold battery-swapping EHTs. The monthly sales were 1,328 vehicles, a year-on-year increase of 73.37% and a month-on-month increase of 48.38%, setting a new high for monthly sales within the year. In August 2023, the sales champion enterprise was Shanxi Automobile Group, with sales of 351 trucks, accounting for 26.43%; the runner-up enterprise in sales is XCMG Group, with 234 units sold, accounting for 17.62%; the third place selling enterprise is Farizon commercial vehicles, with sales of 155 vehicles, accounting for 11.67%. The total sales of the top ten enterprises were 1,168 vehicles, accounting for 87.95% of the total domestic sales of that month, with sales concentrated in top enterprises.

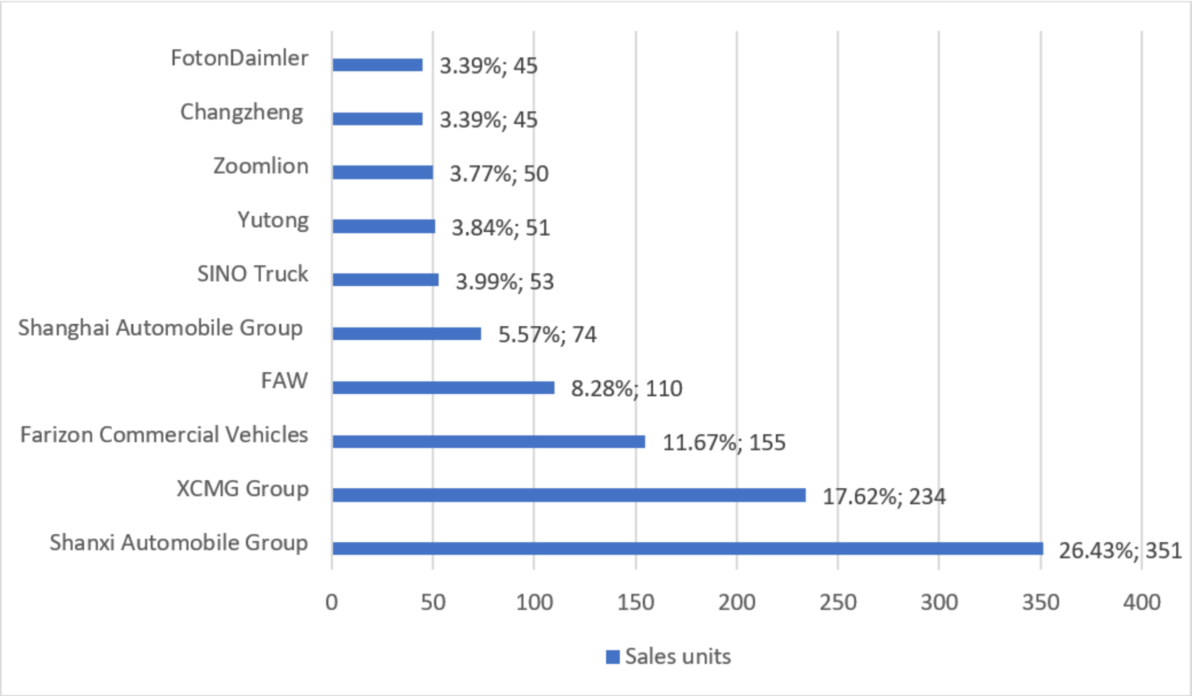


*Figure 5. Top ten Battery-swapping EHT OEMs in August 2023 in China. Source: Evpartner.*

As stated at the beginning of this section, from January to August 2023, about 38 enterprises sold battery-swapping EHTs with a total sales volume of 7,952 units, a year-on-year increase of 26.64%.

Among them, the total sales of TOP3 enterprises reached 4,003 vehicles, accounting for 50.34%; the total sales volume of the top 10 enterprises reached 6,838 vehicles, accounting for 85.99%. Seven (7) companies have sold over 400 vehicles, and 15 have sold over 100. XCMG Group is the only company with sales exceeding 1,700 units to win the sales championship.

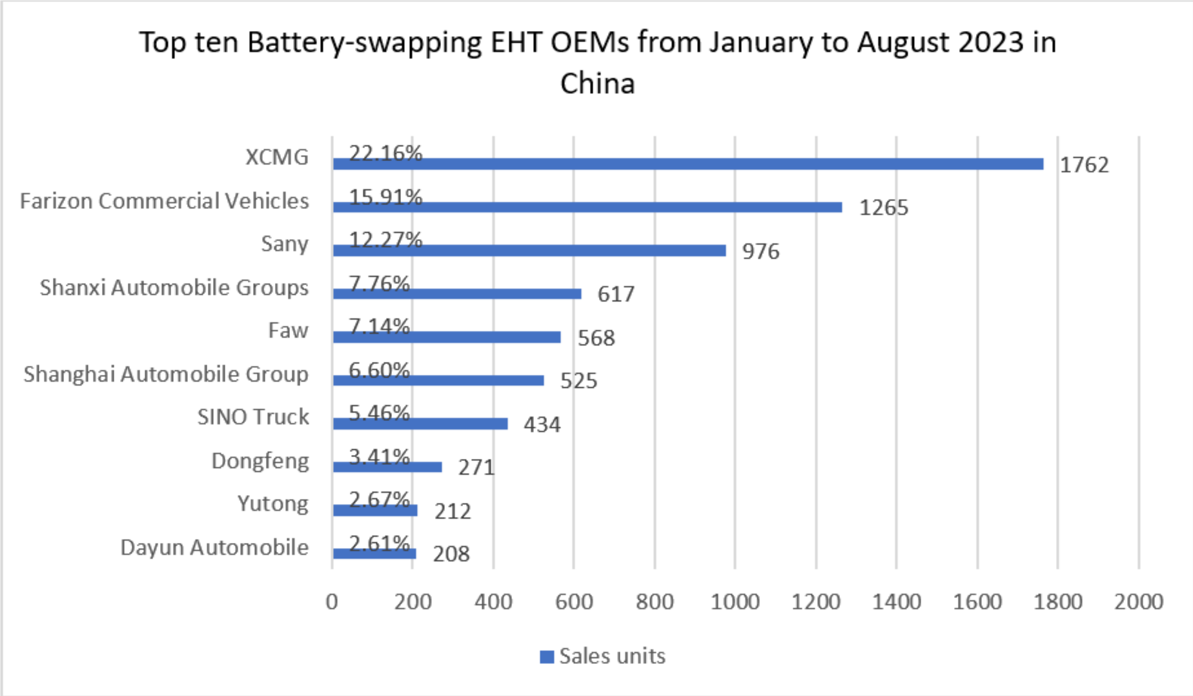


*Figure 6. Top ten battery-swapping EHT OEMs from January to August 2023 in China. Source: Evpartner.*

Compared to the sales from January to August 2022, new energy heavy trucks rose rapidly from January to August 2023; seven out of the top 10 companies achieved sales growth. Among them, Sany Group experienced a year-on-year increase of 838.46%. Three of the top 10 companies experienced a sales decline. The sales of the top 10 companies have shown positive and negative growth, reflecting the increasingly fierce market competition and the differentiation of user recognition of truck OEMs' products. It's noticeable that the top three battery-swapping EHTs, namely XCMG, Sany, and Farizon, are all comparatively new truck producers moving from the engineering machinery industry and passenger vehicle field. These actors take action faster than the established heavy truck brands in developing battery-swapping EHTs. However, considering the industry's early-stage development status, judging which brands will win is too early.

### Battery-swapping electric heavy truck geographical distribution

The application of new energy heavy trucks is mainly concentrated in high energy-consuming enterprises, and the area where high energy-consuming enterprises are located has become a key area for promoting the application of new energy heavy trucks. The Atmospheric Environment Department of the Ministry of Ecology and Environment of China has stated that it will continue to encourage the application of new energy heavy trucks in rental, environmental sanitation, postal, and other work areas while promoting the substitution of old motor vehicles. In the projects of important industries such as coal mining, steel, thermal power, coking, and coal chemical engineering, guaranteeing clean transportation will be an essential requirement for future project applications. It will be a crucial focus of subsequent supervision.

From January to August 2023, a total of 138 cities had sales of battery-swapping EHTs, with most cities selling less than 30 vehicles. There are 25 cities with sales exceeding 100 vehicles, nine cities exceeding 200, and five cities exceeding 300. Among them, Tangshan City has sales of 616, ranking first. Five hundred seventy-seven (577) vehicles were sold in Xuzhou City, ranking second, while 420 were sold in Shijiazhuang City, ranking third. With the support of the "Work Plan for Stable Growth in the Steel Industry", the cities where steel companies are located will expand the application of new energy heavy trucks, and sales will continue to grow. Coastal port cities such as Shanghai, Shenzhen, Rizhao, Guangzhou, and Tianjin will expand the application of new energy heavy trucks. From a sales perspective, the monthly sales of port cities are unstable, but the cumulative sales are steadily increasing.

### 3.3.2. Battery-swapping heavy truck supportive policies

National and local policies support promoting and applying new energy heavy trucks.

#### At the central government level:

In early April of this year, the Ministry of Transport, the Ministry of Natural Resources, the General Administration of Customs, the National Railway Administration, and China Railway Group jointly issued the "Action Plan for Promoting the High-Quality Development of Rail Water Intermodal Transport (2023-2025)", which specifies that the proportion of bulk goods transported by new energy vehicles through rail and water intermodal should reach 80%.

On June 20th, the Ministry of Finance, the Ministry of Industry and Information Technology, and the State Administration of Taxation issued a notice on the continuation and optimization of the tax reduction and exemption policy for new energy vehicle purchases. The Announcement clearly states that the approach of reducing and exempting the purchase tax on new energy vehicles will be extended until December 31, 2027.

On August 25, 2023, the Ministry of Industry and Information Technology, the National Development and Reform Commission, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Ecology and Environment, the Ministry of Commerce, and the General Administration of Customs jointly issued the "Work Plan for Stable Growth in the Steel Industry," which clearly stated that promoting green transportation and encouraging the use of pipe racks or new energy vehicles for medium and short distance transportation.

On September 1, 2023, seven departments, including the Ministry of Industry and Information Technology, issued a notice on the issuance of the Work Plan for Stable Growth in the Automotive Industry (2023-2024). The proposed Work Plan encourages the application of new energy vehicle battery-swapping modes and promotes the deep integration and development of new energy vehicles and energy. Moreover, it also promotes the demonstration and application of medium to long-distance and medium-to-heavy-duty fuel cell commercial vehicles.

#### At regional level:

Many regional governments have issued supportive policies—three representative ones are listed as illustrations.

On March 17$^{th}$, 2023, Tangshan municipality (the city operating most battery-swapping EHTs in China) issued the "Beautiful Tangshan Construction Action Plan (2023-2027)", which clearly stated to promote the application of battery-swapping EHTs and fuel cell EHTs.

On July 13, 2023, the Sichuan Provincial Government issued the "Opinions on Supporting the Construction of Ecological Priority Green and Low Carbon Development Pilot Zone in Yibin City," implementing the "Electric Yibin" action, supporting the construction of comprehensive electrification pilot zones for public sector vehicles, and deepening the pilot application of new energy vehicle battery-swapping models.

On June 28th, the municipality of Jinan City, Shandong Province, issued the "Jinan City Carbon Peak Work Plan", encouraging new operating vehicles and machinery at ports to prioritize using new or clean energy. Other promoted measures include accelerating the upgrading and transformation of transportation infrastructure, promoting the construction of gas stations, hydrogen refueling stations, and charging and battery-swapping stations, and achieving full coverage of important transportation hubs, public yards, logistics parks, and other areas. By 2025, 700 charging and battery-swapping stations will be built in the city, and the number of charging and battery-swapping infrastructure (including all charging types) will exceed 80,000.

The introduction of policies continues to support expanding the application of new energy-heavy trucks. However, the number of cities with substantial EHT sales in the market still needs to grow. With significant policy support and the implementation of new EHT application projects, it is easier to support the substantial growth in the ETH market. It can be seen that the current sales of EHTs are still mainly driven by policies and have yet to develop into a stage of market-independent driving. The main sales markets of EHTs are concentrated in areas with high environmental pressure and large subsidy amounts.

### 3.3.3. Battery-swapping heavy truck industry value chain structure

#### Traction battery- CATL is the dominant supplier

At the upstream of the battery-swapping EHT industry chain, CATL occupies the majority of the market share of power batteries. Currently, most battery-swapping EHTs are equipped with lithium iron phosphate batteries from CATL, with a battery capacity of 282kWh or 350kWh.

In 2020, CATL entered the battery-swapping EHT field. In July 2020, the first batch of battery-swapping EHTs, in cooperation with CATL and Foton New Energy, was delivered in Beijing, China's first commercial application project for battery-swapping EHTs.

In February 2022, CATL and Sany officially operated the first battery-swapping EHT line-haul transportation route in China - Funing project. The Funing project runs between CATL and Jiangyin Port in Fuqing, with a one-way distance of 175 kilometers. In the future, a battery-swapping station network is planned to be built throughout Fujian Province. A subsidiary of CATL and a subsidiary of Fujian Provincial Highway Group will establish a joint venture to construct a battery-swapping highway station network in Fujian Province and promote the construction and operation of battery-swapping stations in Fujian's highway service areas.

Electric vehicles consume more energy at high speeds compared to medium to low speeds. Using battery-swapping implies that batteries are usually smaller in size and thus have less capacity, which would lead to an unreasonably short driving distance between swaps on highways. Therefore, the application of battery-swapping EHTs is currently limited to short-haul transportation scenarios, mainly used in short-distance transportation scenarios in enclosed areas such as ports, docks, and industrial zones. The operation of the Fu Ning Main Line marks a new stage in the attempt of CATL in battery-swapping.

In September 2022, CATL released the MTB (Module to Bracket) heavy truck battery-swapping solution. The back-mounted battery-swapping cabinet can be equipped with two different battery packs, with an overall power range of 140KWh-600KWh. This battery-swapping solution for EHTs has been first applied to the SPIC battery-swapping EHT Project.

In June 2023, CATL released a new generation chassis battery-swapping solution for EHTs - Qiji Energy, which consists of Qiji battery blocks, Qiji battery swap station, and Qiji cloud platform. According to CATL company website material,

- The Qiji battery block is based on the third generation LFP battery chemistry and has passed over 200 safety and reliability tests, including fire, compression, and immersion. Through the modular design of a single 171kWh battery block, users can choose the number of 1-3 batteries according to different road conditions, distances, loads, and other scenarios to achieve need-based battery configuration. With the chassis-mounted battery-swapping solution, the truck can ensure driving range and occupy less space, thus leaving more space for payload volume.

- Qiji Battery-swapping Station adopts the design concept of standardization, modularization, and high efficiency. It can provide battery-swapping services for different vehicle models and brands.
- QIJI cloud platform is designed to implement all-scenario data aggregation. The data of battery-swapping relating to the vehicles, stations, and batteries are exchanged and analyzed on the cloud platform.  Furthermore, battery asset monitoring, intelligent dispatching, one-click appointments for battery-swapping, transportation route planning, and other functions can be realized through big data computing via the QIJI cloud platform.

*Figure 7. CATL Qiji chassis battery-swapping solution for EHTs. . Source: https://www.catl.com/en/solution/commercialEV/.*

Two months after the "Qiji" solution was released, on August 24th, 2023, the green logistics line- a particular line for battery-swapping EHTs on highways in China - the "Ningde Xiamen Line" was officially opened. The entire length of the Ningxia Line is about 420 kilometers, with a total of 4 battery-swapping stations. As the world's first intelligent new energy heavy-duty truck (capable of L3 level autonomous driving) to adopt chassis battery-swapping technology, 20 DeepWay intelligent EHTs have become the first batch of trucks operating on the Ningxia Line.

### The construction speed of battery-swapping stations is accelerating but facing profit difficulties.

The construction and operation of battery-swapping stations are the core links in promoting and applying battery-swapping EHTs. Some enterprises have accumulated experience operating battery-swapping stations but have yet to enter a rapidly growing period.

Heavy truck battery-swapping operators include battery manufacturers such as CATL and Gotion High-Tech, as well as companies such as Qiyuan Core Motive Power, State Grid, and Aulton New Energy, as well as heavy truck battery-swapping ecosystem enterprises such as Enneagon Energy and Goohier Green Energy.

By October 2023, the cumulative delivery of Enneagon Energy's heavy-duty truck battery-swapping stations will have exceeded 353.

The operation of battery-swapping stations requires the ability to leverage the upstream and downstream industrial chains. Operators must rent batteries from battery asset banks and communicate and cooperate with various industrial chain links. At present, the biggest challenge for operators of battery-swapping stations is still the difficulty of making profits. The reason is that, besides being a heavy asset investment and having a long investment return period, the more difficult obstacle to overcome is the unstable utilization ratio of the battery-swapping EHTs in actual operation. Therefore, the battery-swapping station cannot guarantee stable and sustainable profits.

#### Investment in battery assets is the biggest challenge for the entire industry.

Complex value chain enterprises are behind the business model of separating EHT bodies and batteries. The enterprises consist of an ecological circle of battery-swapping EHT solution, from manufacturing batteries to the final recycling of exhausted batteries. Investment in battery assets is the biggest challenge for the entire industry, with high risks. Battery banks participate in early-stage financing, purchase batteries, and then rent them to users, charging them rent and earning profits. They keep track of the value of the battery throughout its entire life cycle and recycle retired batteries at last.

From the perspective of battery asset banks, battery asset holders need help with issues such as battery safety, whether batteries can be used universally after introducing national standards, and difficulties in recycling after retirement due to inconsistent battery property rights. For the financial solution provider of battery asset banks, the lithium battery industry is undergoing rapid changes, and investment risks are high. Therefore, the battery asset banking business in the battery-swapping heavy truck industry chain has become the most challenging obstacle.

However, with the implementation of the battery-swapping model, many large enterprises have laid out battery banking businesses, gradually forming a commercial closed loop between enterprises, users, and battery asset companies.

In May 2020, State Power Investment Corporation established Qiyuan Core Motive Power Technology Co., Ltd., mainly focusing on the technology and implementation of battery-swapping heavy trucks, proposing the business concept of "battery-swapping heavy trucks + battery banks + battery-swapping stations in one."

In May 2022, Ganfeng Lithium announced that the company would establish a joint venture with Yangtze Power, Three Gorges Water Resources, and Yangtze River Green Development Fund to carry out integrated battery asset management services covering battery system integration, battery product leasing, and sales, and battery recycling.

Some EHT operators also build and operate their battery-swapping stations. However, establishing a battery asset bank will undoubtedly help integrate resources and work with relevant enterprises to promote the unification of battery technology, solving the problem of "operational difficulties" in battery-swapping.

### 3.3.4. In solid need to establish a unified national interchangeability standard system

With tens of thousands of battery-swapping EHTs and several hundred battery-swapping stations, several short-and medium-distance inter-city battery-swapping transportation networks ranging from 200 kilometers to 400 kilometers have emerged in China.

Li Liguo, Secretary General of the China Battery-swapping EHT Promotion Alliance, pointed out that standardization seriously restricts the development of EHTs. The industry can move forward only by achieving cross-brand compatibility and exchanging battery-swapping products.

*"Battery-swapping EHTs are moving from short-distance and closed operation scenarios to medium to long-distance line-haul scenarios, making establishing a unified national interchangeability standard system increasingly prominent.*

*Taking the vehicle-mounted battery-swapping system as an example, the overall structure of the battery frame is a regular rectangular shape, and the size deviation is around 5-10%. However, the height of the battery pack varies greatly, with different battery capacities, layers, and base differences, which cannot be interchanged. This is where the technological innovation and technical barriers of various enterprises lie. Therefore, regarding interchangeability standardization, there are technical barriers, also technical barriers, and great industrial cooperation obstacles to cooperation and mutual trust."*

*Li Liguo, Secretary General of the China Battery-swapping EHT Promotion Alliance*

At the World Traction battery Conference held in Yibin in June 2023, Vice Minister of Industry and Information Technology of China Xin Guobin, stated that the Ministry of Industry and Information Technology will study and develop a standard system for battery-swapping technology, promoting the standardization of battery size, interface, communication protocol, and other standards.

During the conference, the China Battery-swapping EHT Promotion Alliance and the China Electric Vehicle Charging Infrastructure Promotion Alliance launched the "Heavy Truck Battery-swapping Industry Interconnection and Exchange Development Initiative." The SPIC Qiyuanxin Motive Power, China Petroleum, Three Gorges Green Power, CATL, SAIC Hongyan, Geely, Foton, Shanxi Heavy Duty Truck, Heavy Duty Truck, Yutong Bus, Sany and XCMG, etc. enterprises in the heavy truck battery-swapping industry chain have jointly responded.

In this proposal, all parties propose to be "guided by the government policy, gather consensus in the industry; lead by national standards and industry standards, promote in segmented key areas; achieve compatibility and sharing at the station end, national interoperability and exchange; lead by leading enterprises, open interface patents; manage digital assets, and support the industry through finance solutions."

As the leading enterprise in the power batteries field, CATL has excellent advantages in promoting the unification of battery-swapping standards. According to data statistics, from the beginning of 2022 to the end of April 2023, the total installed capacity of EHT batteries in China was 3.45 GWh, with a market share of 93.4% for CATL. The cumulative sales of battery-swapping EHTs equipped with CATL batteries are 12,114, with a market share of 92.1% for CATL.

### 3.3.5. Striving to span the operational scenario from short-haul to line-haul

The sales of new energy heavy trucks continue to increase in China, with the rapid development of various technological routes, and the overall market situation continues to improve. It is believed that new-energy heavy trucks will first be applied in production bases such as coal and steel factories under strict environmental policies management. In the short term, new energy heavy trucks will be mainly implemented to replace traditional fuel-heavy trucks in specific scenarios.

Taking Hebei Province as an example, there are many high energy-consuming enterprises such as steel, coal, and port enterprises in the province. The rich operating scenarios are the reason for the continuous growth of sales of new energy heavy trucks in Hebei Province.

In the actual operation scenario of electric heavy trucks, short-haul transportation is still the main "stage" of heavy truck operation, and medium and long-distance transportation is currently in the pilot stage.

The scenario’s limitation to short-haul transportation may make heavy truck operators hesitant to adopt EHTs. The limited sales area of EHTs makes it impossible to achieve large-scale market effects and insufficient to support significant sales growth in the entire market.

Breaking through the limitations of operational scenarios has always been an unavoidable topic for new-energy heavy trucks. Various new energy heavy-duty truck manufacturers adhere to different technical routes, actively engage in R&D, and launch new energy heavy trucks with ultra-long endurance capabilities to fill the gap in the medium to long-distance operation scenarios of new energy heavy trucks.

Hydrogen fuel cell heavy trucks do not emit pollution in their operation and have relatively light vehicle weight, making them one of the most promising solutions for future long-distance transportation of new energy heavy trucks. Battery-swapping EHTs only require the appropriate layout of battery-swapping stations on medium to long-distance transportation lines to achieve long-distance EHT transportation, considered the most feasible development route for new energy heavy-duty truck line-haul transportation. Charge-based pure EHT (excluding battery-swapping) solutions focus on increasing their battery capacity and charging and recharging speed to improve their driving range per charge.

For example, in June 2023, the Sany Mota 1165 electric tractor truck completed its first journey of 817.5 kilometers on a single charge with a total weight of 40.45 tons of cargo. According to data released by Sany, the Sany Mota 1165 adopts a 4-chargers fast charging method to replenish energy, with a traction battery capacity of 1165 kWh. Practical actions have proven that EHTs can also run "long-distance" like fuel-heavy trucks. However, the disturbance of the fast-charging solution of EHTs brings to the grid side, and the high power capacity requirement it addresses to the grid must be handled in actual operation.

The battery-swapping EHT achieves line-haul transportation by arranging battery-swapping stations on specific lines. For example, in 2022, the first green logistics line (non-high way) for battery-swapping EHTs in China, the 175km long “Fuqing Ningde Line” was officially implemented. The Fuqing Ningde Line was extended to the "Ningde Xiamen Line" (high way) one year later; the entire length is about 420 kilometers, with 4 power stations.

### Forward-developed new generation battery-swapping electric heavy trucks speeding up their operation scenario expansion

The key point of the “Ningde Xiamen Line” is the Qiji EHT chassis battery-swapping solution launched by CALT, which was presented earlier in this report.

At present, most battery-swapping ETHs on the market use traditional back-mounted battery-swapping solution, which is limited by a series of problems such as high vehicle center of gravity, large wind resistance, and short range, making it difficult to adapt to long-distance transportation on high-speed mainlines.

At the same time, the construction of EHT battery-swapping stations in China is mainly concentrated in application scenarios with relatively fixed transportation lines such as ports, large steel mills, power plants, and mines. This scattered construction model of battery-swapping stations makes it difficult to form a nationwide battery-swapping station network system, preventing the rapid and comprehensive advance of the electrification of heavy trucks.

In 2018, the pioneer company of battery-swapping EHT solutions, Qiyuan Core Motive Power, developed and produced the world's first battery-swapping EHT. In 2019, Qiyuan launched the world's first EHT batter-swapping station. The battery-swapping EHT Qiyuan developed was redesigned based on the structure of the fuel truck. Based on the fuel vehicle platform, the powertrain is modified by replacing the engine and gearbox with a power battery, motor, and electronic control system.

Traditional ICE-based chassis limits the flexible layout and intelligent integration of new energy components such as batteries and motors, fuel-cell and hydrogen storage.

In 2023, several companies launched their new generation of battery-swapping EHTs designed based on total electric truck structure from the beginning. They call it forward-developed battery-swapping EHTs.

On May 30th, Farizon Commercial Vehicles (a subsidiary company of Geely) launched the first

new energy heavy-duty truck digital intelligence architecture in China, GXA. One of its core features is that it can be compatible with different energy types and meet users' energy needs in different scenarios. At the same time, the Farizon G series heavy-duty truck has been launched, achieving a 500km regional line-haul EHT solution. The G EHT adopts a modular chassis battery-swapping mode, smooth surface, and astreamlined appearance, forming an aerodynamic design. According to the enterprise information, the overall drag coefficient is less than 0.45, optimized by more than 20%, and can reduce energy consumption by 6%.

The electric drive systems were full-stack self-development by Farizon. The 1200V platform IGBT chip specially designed for the powertrain system of new energy commercial vehicles has been taped; the self-developed i-MPS multi-motor flexible torque central drive chain reduces the cost of EHTs and expands its application scenarios. The battery-swapping technology is also actively deployed. Farizon is adopting a scheme of back-mounted swap, chassis swap, and side swap solutions simultaneously for the time being. The Farizon approach is a scenario-based choice of behind-the-cabin and under-the-chassis-mounted battery-sapping solutions.

*Figure 8. Farizon G EHT. Source: https://www.geelycv.com/#/productpedigree/detail?id=63.*

On June 1st, DeepWay Company, a new producer of new energy heavy trucks, officially delivered customers the first batch of intelligent new heavy trucks. According to the company statements, this is the first-generation intelligent EHT of DeepWay (capable of L3-level autonomous driving). The wind resistance coefficient of the truck is as low as 0.35Cd, and it adopts an integrated charging and swapping system, which can achieve a driving range of 300km under a load of 49 tons. It can operate in express delivery, bulk coal, and ports.

Chassis battery-swapping has become a common choice in this batch of forward-developed battery-swapping EHTs, and Inteligentization (autonomous driving solution) is merging with electrification. Compared to the first-generation battery-swapping EHTs that are redesigned based on the chassis structure of the fuel truck, the forward-developed new-generation trucks can increase the driving range of EHTs, and the distance among battery-swapping stations can also be expanded. It is equivalent to reducing the quantity of battery-swapping stations and reducing the construction cost of stations.

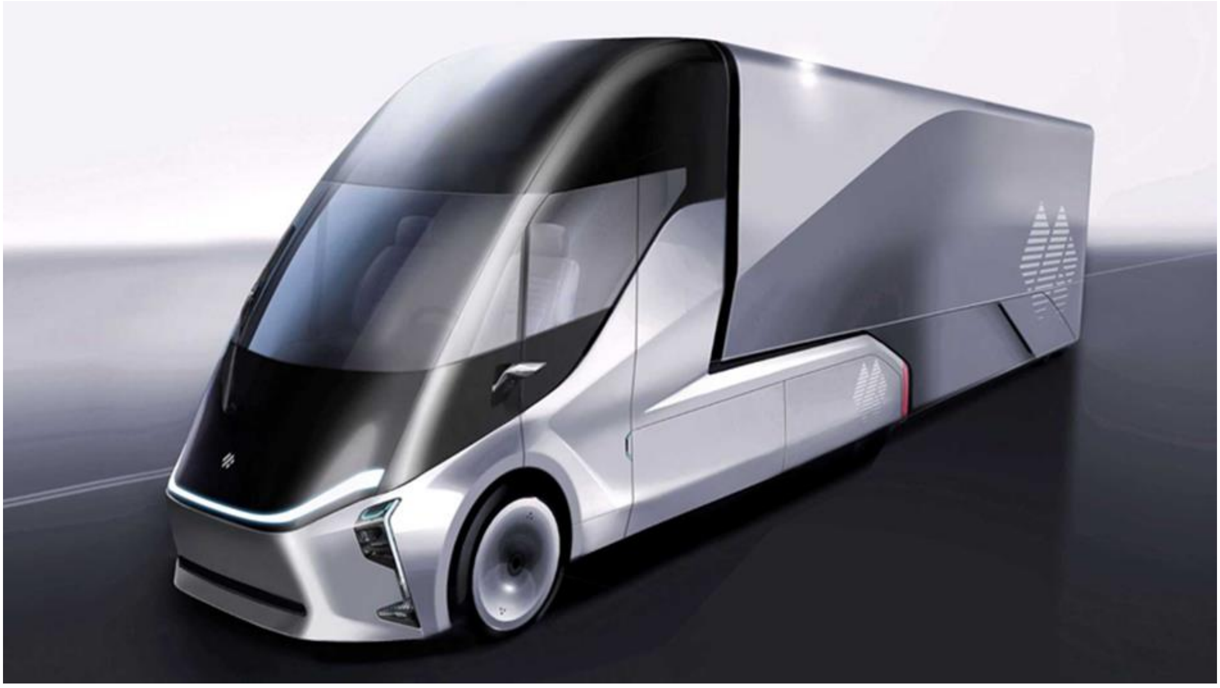

*Figure 9. DeepWay EHT. Source: http://k.sina.com.cn/article_5251720140_13906e3cc0010142fc.html.*

The increased number of battery-swapping EHTs being developed has accelerated the expansion of battery-swapping EHTs to medium- and long-distance transportation scenarios.

### Battery-swapping EHTs operating in long-haul transportation need further hard-working.

Operating battery-swapping EHTs for long-distance transportation is feasible from the current perspective but still needs further development. For back-mounted EHTs, the current mainstream methods for battery-swapping on the market are swapping from the top, single, and dual sides. The early pilot demonstrated mode was the top swapping mode, with lower technical requirements and construction costs for the battery-swapping station. Correspondingly, the new generation of chassis swapping mode has higher standards for battery-swapping technology, and the construction cost of a single battery-swapping station will further increase.

In addition, the chassis swapping mode will further increase the truck's requirements for operating road conditions. In scenarios with uneven roads and complex road conditions, the issue of scratching the vehicle battery pack cannot be ignored.

In March 2023, the Technical Committee for Standardization of Electric Vehicle Charging Facilities in the Energy Industry released the "Research Report on the Standardization Construction of New Energy Vehicle Battery-swapping Pilot Cities," which pointed out that exploring the application of heavy-duty truck battery-swapping for medium distance line-haul transportation has achieved significant results.

Baotou City constructed the "Erdos Baotou" coal transportation trunk line; Chongqing has carried out an overall layout of battery-swapping stations along the Yangtze River, connecting Dazhou in

Sichuan, Kaizhou, and Wanzhou in Chongqing and constructing the first inter-provincial battery-swapping EHT trunk line network in China; Tangshan City plans to build the first "three vertical and one horizontal" battery-swapping trunk line network in China, and part of the network that has been put into operation serves more than 20 surrounding steel enterprises currently; Shudao Group has launched the "Chengdu Chongqing Battery-Swapping EHT Corridor" project, creating the first highway EHT battery-swapping corridor in China.

It can be seen that operating battery-swapping EHTs for long-distance transportation is feasible and has been put into operation on some main lines. However, many difficulties need to be further improved for mass application. It is believed that in the future, with the acceleration of research and development by truck companies and the maturity of the operation mode of the battery-swapping station and other related industrial chains, the widespread operation of battery-swapping EHTs for long-distance transportation will become a reality.

The business model of "separating truck body and battery" for battery-swapping mode is a solution from the users' perspective to reduce initial purchase costs and improve the convenience of energy replenishment. Although the actual implementation of this mode faces many challenges, the active exploration of the industry chain enterprises in various fields shows the market prospects of this mode are significant.

## 3.4. Major development of battery-swapping for heavy trucks in China

### 3.4.1. Aulton

Aulton is one of the major players in the battery-swapping market in China as an independent developer and manufacturer of battery-swapping solutions for passenger cars and heavy trucks. Two other independent developers and manufacturers of battery-swapping solutions are ZhiLiWuLian and Enneagon.

Aulton's focus so far has been on passenger vehicles. The company has worked with 14 national vehicle makers to make their electric vehicles compatible with Aulton's battery-swapping network. These include BAIC, FAW, Dongfeng Motor, Changan, SAIC and GAC. The result is said to be 24 electric vehicle models. The Aulton network of battery-swapping stations is growing in nearly 30 cities across China, including Beijing, Shanghai, Guangzhou, Changchun, Wuhan, Chongqing, Kunming, and Sanya. Aulton claims to have over 50,000 users so far. Aulton aims to establish at least 10,000 battery swap stations to serve more than 10 million electric vehicles by 2025.

Incidentally, Aulton is also active in Germany regarding passenger vehicles. With the German company InfraMobility, this German-Chinese joint venture is called Infradianba and was founded in 2019. Infradianba installed a European battery swap pilot plant for taxis in Berlin's Westhafen district in 2019.

In Germany, the Aulton joint venture has also outlined its plans for further expansion in Berlin: by 2027/2028 at the latest, the network will be expanded to 30 battery exchange stations to electrify the Berlin taxi industry. By 2030, 200 to 300 exchange stations should have been established to cover "other regional commercial transport." Infradianba is also collaborating with MG Motor on a taxi with exchangeable batteries, which will be presented in December 2023.

For some time, Aulton has been developing battery-swapping solutions for heavy trucks. The following sections intend to illustrate their new solutions for heavy trucks in collaboration with OEMs.

#### Foton & Daimler, in partnership with Aulton

Aulton has developed generic swapping stations that can handle multiple swappable batteries for several OEMs of passenger vehicles. Aulton specializes in battery-swapping, with more than 800 battery-swapping stations in operation in 58 cities in China. The company offers a platform independent of the brand, works with more than 20 EV producers, and supports over 30 models.

Aulton is dedicated to the R&D of new energy vehicles with battery-swapping technology and the commercial operation of battery-swapping stations. With over 3,000 global battery-swapping patents and relevant patent applications, it achieves a 20-second ultra-fast battery swap for passenger vehicles and a 40-second battery swap for commercial vehicles. It has deployed over 807 battery-swapping stations in 58 cities nationwide, forming a closed-loop mindset and business model encompassing battery pack R&D, production, cooperation with vehicle manufacturers, battery swap facility operations, cascade utilization, and recycling.

Aulton is the world's first company to develop an *"all-domain buckle-on-chassis battery-swapping solution"* and has realized the continuous applications of the technology from passenger vehicles to heavy trucks.

Foton Daimler, the manufacturer of Mercedes-Benz trucks in China, has partnered with Aulton, one of China's leading companies in battery-swapping systems. Through the partnership, Foton Daimler will develop a chassis for electric trucks, adapted for swapping the batteries using Aulton's system.

> *"Beijing Foton Daimler Automotive Co., Ltd. (referred to as "Foton Daimler") and Aulton New Energy Automotive Technology Co., Ltd. (referred to as "Aulton") established a strategic partnership to jointly promote the rapid implementation of the battery-swapping project for heavy trucks.*
>
> *Under this strategic cooperation framework, the two parties will complement each other's strengths and work closely together to achieve mutually beneficial cooperation. Foton Daimler will develop battery swappable vehicle models based on the GTL platform, while Aulton will provide globally leading battery-swapping solutions dedicated to heavy trucks." (Source: Shanghai (Gasgoo)- July 6, 2023)*

The actual design and function of the joint swapping station and trucks remains to be seen. Still, the swapping station might resemble passenger vehicles, i.e., swapping batteries from the truck's bottom in automatic stations. (Source: https://autonews.gasgoo.com/m/70023566.html )

### Aulton designs a second-generation battery-swapping solution for trucks

In September of 2023, at the China International Exhibition Center in Beijing, Aulton introduced the second generation of battery-swapping solutions for heavy trucks based on the "bottom of the vehicle battery-swappable solution" in collaboration with Foton and Daimler.

*Figure 10. Aulton´s second generation battery-swapping solution for trucks. Source: Xianning News Network China Youth Network.*

Gathering 20 years of new energy technology heritage, Aulton´s electric heavy-duty truck battery-swapping introduced a second generation of battery-swapping solutions for trucks. The Aulton´s bottom-chassis mounted battery-swapping system placement integrates the electromechanical gearbox with the middle and rear axles, reducing the weight of the power system by 500 kg (Source: Xianning News Network China Youth Network).

Through the modular design of a single battery with 171kWh of power, users can customize the battery for different road conditions, distances, and loads. For subdivided scenarios, users can choose the number of batteries from 1 to 3 and distribute power as needed. Moreover, according to different transportation routes, a 171/342/513kWh intelligent power swap can be realized, flexibly matching the power to the most appropriate operation scenario and adapting it to different lines. Taking the maximum battery capacity of 513kWh as an example, based on a conservative estimate of power consumption of 170kWh per 100 kilometers, the actual cruising range can reach more than 300 kilometers (without battery replacement midway). However, the current cruising range of pure electric heavy trucks is usually only 100-200 kilometers.

The vehicle can form 8 combination drive modes according to different wheel end torque and power requirements, combined with the number of gears, to meet the complex working conditions of the vehicle applications. The energy saving exceeds 3%; for hilly scenes, a predictable driving algorithm based on high-precision maps is proposed, which actively adjusts the vehicle speed and battery SOC, fully utilizes the potential energy of the slope, and recycles electricity, saving 4%-6% of energy. The energy consumption of the entire vehicle is optimized by 9%-15%, and compared to traditional BEHT (Source: Xianning News Network China Youth Network).

*Figure 11. Aulton´s second generation battery-swapping solution for trucks. Source: Xianning News Network China Youth Network.*

The choice of under-the-chassis placement of batteries opens the opportunities for a new design of the cabin, being more adaptable to user needs. On the one hand, the sleeping area of the cabin can be further enlarged, thereby improving the comfort of the driver. On the other hand, in a traffic accident, while the vehicle is driving at high speed, the chassis-mounted swapping system can release energy by moving the cab backward, thus improving the safety protection level during high-speed driving.

*Figure 12. Aulton´s second generation battery-swapping solution for trucks. Source: Xianning News Network China Youth Network.*

Until now, Aulton New Energy heavy trucks have covered seven major scenarios: steel plants, mining areas, and ports where domestic electric heavy trucks are mainstream applications. The product lines include traction, dumping, mixing, sanitation, etc., which can meet the industry's and users' needs in all scenarios. At the same time, it has passed the test of typical characteristics in China, such as extreme cold in the north, high humidity and heat along the coast, and mountainous areas in the southwest. It has a cumulative driving mileage of 26 million kilometers. The market and users have widely recognized the product.

### 3.4.2. Introduction of the third generation of battery-swapping systems for heavy trucks

Previous discussions reflected battery-swapping based on the traditional truck design. However, the development is fast, and new generations of heavy trucks are entering the market.

Tesla Semi has been introduced, as well as Volta, representing a new generation of truck design that is slim, aerodynamic, and more effective, and also uses a contemporary interior cockpit design. However, the Tesla Semi and Volta trucks are fully electric, built on a fully integrated battery-vehicle design, and do not utilize battery-swapping. Thus, we do not cover those here.

However, we have identified several Chinese trucks that look like Tesla Semi but utilize battery-swapping solutions and advanced technology that we will introduce.

### 3.4.3. JAC

Since the commercial use of battery-swapping for trucks, the dominant placement of the swappable battery has been behind the cabin. However, as we will show, the new generations of swapping-based heavy trucks in China have started to adopt new solutions.

JAC is a truck OEM developing new-generation battery electric heavy trucks (BEHT) with swapping solutions in collaboration with DeepWay.


*Figure 13. JAC's new-generation battery-swapping-based electric heavy truck. Source: JAC.*

The JAC electric truck has two electric motors, 246kW each, and a top speed of 89 km/h with a swappable battery pack of a range of about 350 km. The choice of making the JAC’s battery packs swappable assumes the consequences of large-scale BEHT usage.

*” As more trucks get electrified, they will probably get megawatt-hour-capacity battery packs and charging speeds ranging from about 350 kW to 1 MW, and even faster in the future. For large fleet operators and also for truck stops on the major highways in a lot of countries, depending on how busy they can get, and looking at it simplistically, having, say, 50 stalls at the very big truck stops or depots would work out to 17.5 MW to 50 MW! (50 x 350 kW to 1 MW.) 50 MW is the capacity for a small town and let us say there is a rollout of a 50-charging-stall set up at 1,000 truck stops. This will be like upgrading or developing new substations and associated grid infrastructure for 1,000 “new” small towns. This will be a big opportunity for players in this industry and the associated downstream industries, with loads of job creation opportunities and a boost to the local economy.” (Source: J https://www.thebioenergy.net/tesla-semi-like-electrical-truck-from-jac-noticed-in-china/e).*

*Figure 14. JAC's new-generation battery-swapping-based electric heavy truck. Source: JAC.*

JAC already has a presence on the African continent, and it could be one of the best options for the continent shortly due to challenges in developing the electricity supply chain and charging infrastructure to accommodate high-capacity cable charging solutions along the highways and in dense cities. JAC sees that battery-swapping is incredibly usable in such scenarios and operational environments.

### 3.4.4. Farizon

Geely’s commercial vehicle brand, Farizon Auto, has introduced its next-generation electric semi-truck, the Hometruck electric semi-truck concept. It is built on a modular architecture based on battery-swapping solutions such as standard solution, and will be produced and delivered starting in 2024.

The Hometruck is named after the original aspiration of its designers to make a semi-truck that feels like home, meeting its drivers' living and emotional needs. Semi-truck drivers worldwide spend excessive time in their vehicles, often more so than at home. The mobile space created by the Hometruck integrates “work, life, and entertainment,” satisfying the vital needs of its driver.


*Figure 15. Geely Farizon Hometruck is a new-generation battery-swapping-based electric heavy truck. Source: Geely.*

The semi-truck architecture can accommodate several powertrain options, including a range extender, methanol hybrid, and pure electric, with battery-swapping as a standard solution. The latter will allow the Hometruck to charge at service stations across highways “*in minutes.*”

*Figure 16. Geely Farizon Hometruck is a new-generation battery-swapping-based electric heavy truck. Source: Geely.*

Hometruck is an example of the new generation of intelligent solutions, as it can connect to the logistics network’s big data platforms to help drivers obtain the most optimal orders in real-time, analyze and track deliveries, and calculate operating costs along the routes. The semi truck’s sensors are used to analyze traffic data in real-time and receive route recommendations. In addition, the truck maker says the energy management system can manage the Hometruck’s power or fuel supply to achieve the most optimal economic performance while also being able to recommend optimal refueling or recharging routes to the driver.

*Figure 17. Geely Farizon Hometruck, new generation battery-swapping based electric heavy truck. Source: Geely.*

Due to standard hardware sensors such as lidar, millimeter-wave radar, ultrasonic radar, and 5G and V2X communication, the Hometruck can utilize L4 hands-off autonomous drive functions. It will also introduce convoying features for longer journeys, allowing trucks to communicate with each other. Additionally, the semi-truck will be fully capable of being upgraded over time using Over the Air (OTA) software upgrades.

The cockpit includes both a driving and a living area, with the latter consisting of a bathroom complete with a shower and toilet, single bed, refrigerator, tea maker, kitchen, and even a small washing machine. One direction of new Chinese heavy trucks is to add home-like solutions as standard solutions.

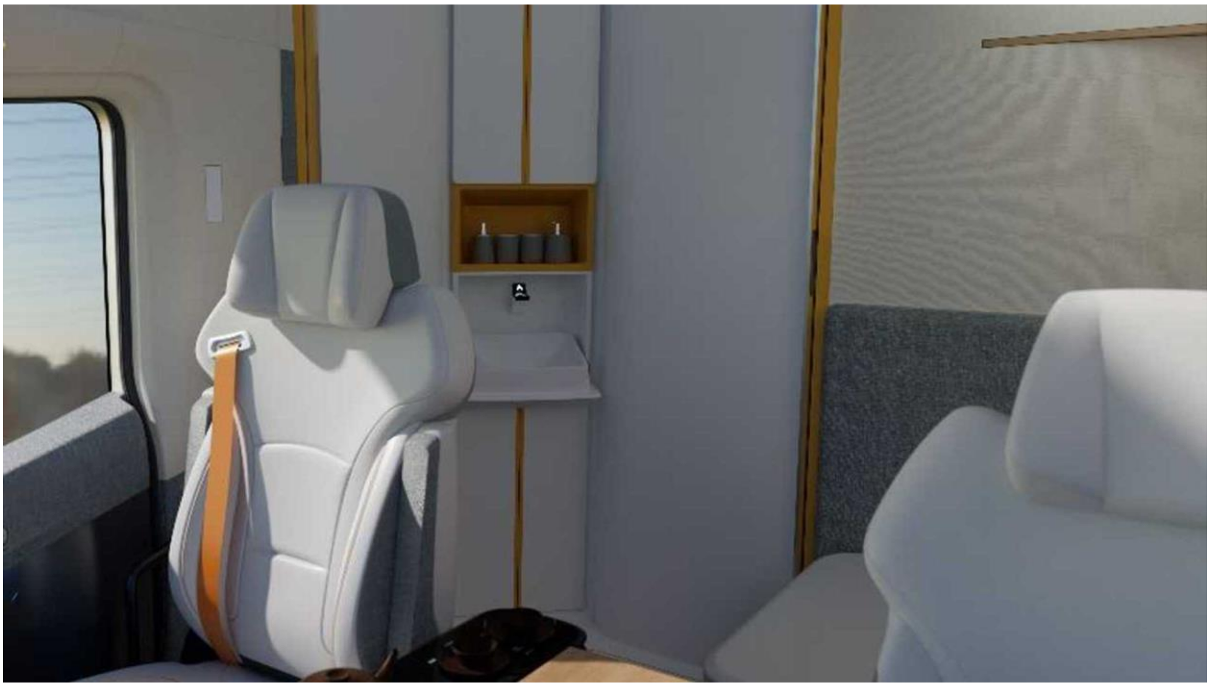

*Figure 18. Geely Farizon Hometruck, new generation battery-swapping based electric heavy truck. Source: Geely.*

Driver comfort has been brought forward as a major incentive to increase vehicle safety with the theory that well-rested drivers are more attentive and more focused.

According to Geely, the Hometruck will target global markets like Europe, Korea, Japan, and North America.

### 3.4.5. WindRose

WindRose Technology was established in September 2021. The Jinsha River (WindRose) created a new energy-heavy vehicle for early investment. WindRose Technology announced it would obtain iassetsfrom integrated logistics enterprise Glory Logistics. For the strategic acquisition of 10 million yuan, both parties signed orders for 200 pure electric heavy vehicles. This is the most significant order for solutions directly from research and development of pure electric vehicles in China. The first vehicles will be delivered in 2024.

In June 2023, WindRose sold 1200 trucks, 1000 in the US and 200 in China, before production started.

In the design of the chassis, the WindRose has adopted a new self-researched electronics device architecture, a vehicle electric controller, and a wire control chassis jointly developed with suppliers, realizing the redundant wire control system designed for high-level automatic driving have now achieved L3 and L4 level redundancy planning.

Regarding power integration, the model ordered by Rongqing Logistics is a tram model with an operational range of about 600km. The frame has subversively adopted a sink structure with greater space utilization, a more reasonable layout of energy storage devices, a lower center of gravity for the entire vehicle, and better driving stability. The body uses a nest structure and many non-metallic overlying materials. The whole vehicle model is very streamlined, and the target value of the wind resistance coefficient is 0.34. The entire vehicle adopts many modular designs, with a lighter weight and a more robust generalization, which will completely change the production logic of heavy trucks in the future. To meet the customer's demand for rapid replenishment, WindRose is equipped with an 800V high-voltage platform, which is suitable for MCS MW charging technology。

Regarding power integration, the strategy of simultaneous development of pure electricity and hydrogen fuel will be adopted, and the CHTC voyage will be 600km and 1000km, respectively. Autopilot vehicles are not just a simple superposition of "automatic driving + heavy vehicle" but is a deep fusion of autopilot technology and heavy vehicle carrier. The chassis system, power generation, and human-machine interaction of traditional vehicles cannot adapt to the design requirements for the safety and performance of automatic driving。

WindRose focuses primarily on semi-truck designs for the US and Chinese markets. The US has over four million semi-trucks, many of which are due for electrification on the road. China has nearly seven million semi-trucks and sells over one million new heavy trucks yearly.

> *"WindRose is the first self-driving vehicle manufacturer in China based entirely on the new energy architecture and is the leader of the technological change in the heavy vehicle industry. This coincides with the idea that non-technology promotes technological development with "final thinking." (Source: https://autonews.gasgoo.com/new_energy/70028854.html*


*Figure 19. WindRose new battery-swapping-based electric heavy truck. Source: WindRose.*

Compared with the air drag coefficient (or wind barrier coefficient) of the traditional flat-headed heavy truck type up to 0.5-0.6, this new energy heavy truck's wind barrier coefficient is only 0.2755. This data is even lower than some popular fuel SUV models, equivalent to the mainstream pure electrical SUV wind resistance coefficient at the market end, which can effectively save energy consumption.

Battery-swapping is a standard solution designed once the entire truck is created.

In the new WindRose semi-truck, the integrated battery is designed to be exchanged and swapped in fully automated battery-swapping stations. The swapping station is under development and will be deployed to the market in 2024.

*Figure 20. WindRose new battery-swapping-based electric heavy truck. Source: WindRose.*

The technical specifications of the new WindRose:

- Battery - High energy density lithium battery with 506kwh (4 packs) and 759kwh (6 boxes) configurations to meet different transportation distance requirements.
- Charge – 600 - 1,000V voltage platform with a Charging power of up to 1,000A.
- Recharging speed, from 15% to 80% of the whole battery capacity, is about 37 min.
- Power - Two motor configurations of 3 and 4 motors that can meet different operational needs of varying product usage conditions and business context.
- Operating range: MAX 420 km (260 miles), MAX 470km (290 miles), or MAX 630 km (390 miles) (Source: WindRose)

It is possible to choose two different sizes of battery (506 or 759 kWh) that, combined with a choice of motors, offer a driving range between 420-630 km. WindRose represents the new generation of high-end trucks with high technological content and new aerodynamic design, to which battery-swapping is the standard solution.

### 3.4.6. DeepWay

In September 2021, DeepWay **(DeepWay - Shenxiang Xingchen)** launched the first intelligent new-energy heavy truck with an advanced design, low wind coefficient, integrated battery-swapping system solution, and dual-energy sourcing, battery, and hydrogen. DeepWay is equipped with a

500kWh battery pack, and at a whole load of 49 tons, DeepWay can operate up to 300 km. Baidu has equipped the truck with its Highway Intelligence System, which includes 11 onboard cameras, one infrared detector, five millimeter-wave radars, and a LiDAR sensor. It has also been designed to offer end-to-end autonomous driving. DeepWay was developed in collaboration with vehicle designer Pininfarina in Italy.

DeepWay, which is majority-owned by truck logistics company Lionbridge Logistics, makes Level Four (L4) unmanned commercial vehicles fully self-driving and only require occasional human intervention that runs on Baidu’s Apollo autonomous driving platform.

*Figure 21. DeepWay new battery-swapping-based electric heavy truck. Source: DeepWay.*

On April 10, 2023, DeepWay announced that the world's first commercial vehicle bottom-side swap station was built in Tianjin. DeepWay's swap technology, "Star Shift," only takes 4 minutes to swap, and the one fully charged battery can last up to 300 kilometers.

As we know, most contemporary electric heavy trucks are "oil-to-electric" models, meaning that they are modified ICE trucks to utilize electric motors and battery-based energy storage. The cab, power train, and chassis resemble traditional diesel-based heavy truck product architecture. The chassis space of conventional models is limited, and the traction battery in the first generation of swapping solutions is arranged behind the cabin so that the power exchange equipment can be hoisted for power exchange, i.e., back-mounted power exchange system solution.

Bottom-side battery-swapping replacement has gradually become a new trend of industry focus, being introduced by JAC, WindRose, Geely in their Farizon, and DeepWay as truck OEMs and by Aulton as a third-party independent battery-swapping system developer and provider to OEMs.

The chassis-type battery swap is a solution based on a new model being researched and developed. For the models under development, the transmission, fuel tank, and urea tank installed on the original chassis are removed, and the chassis space is more significant, which is convenient for the layout of power batteries with more considerable capacity, which further upgrades the battery life of the whole vehicle. At the same time, the layout of the traction battery at the bottom of the heavy truck can further increase the cargo space of the cargo box, make the structural layout of the whole vehicle reasonable, effectively improve the operating efficiency, reduce the center of gravity and drag coefficient of the truck, and make the heavy truck run more smoothly.

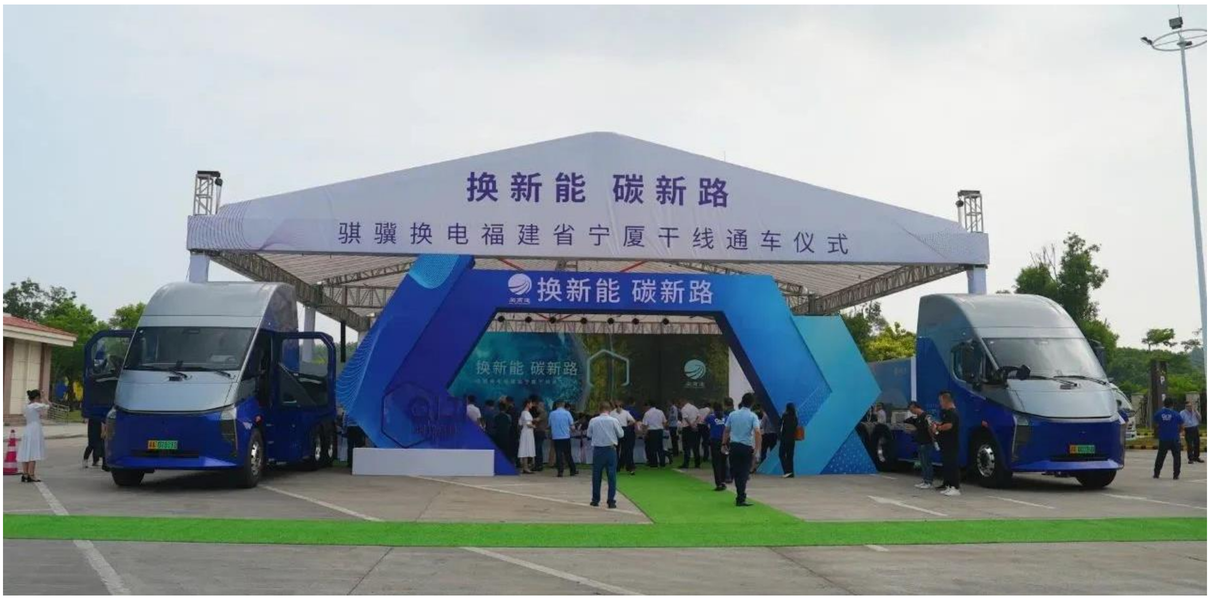


*Figure 22. DeepWay new battery-swapping-based electric heavy truck. Source: DeepWay.*

Pioneering bottom-mounted battery-swapping technology globally, the DeepWay Shenxiang Xingchen accommodates battery packs under the truck, seamlessly aligning with CATL's "QIJI Energy" product to facilitate a swift 6-minute battery-swapping process. Moreover, this innovative approach liberates cargo space by housing battery packs beneath the truck, increasing cargo volume by 9.6%, effectively resolving the challenge of heavy-duty truck range and operational costs.

With an energy density of 130Wh/kg, DeepWay's battery is approximately 30% higher than conventional battery-swapping heavy trucks. Its battery capacity can reach 466kWh.


*Figure 23. DeepWay new battery-swapping-based electric heavy truck. Source: DeepWay.*

From the perspective of the convenience of battery replacement, the technology of bottom battery replacement is more technically complicated, the requirements for battery replacement equipment are higher, and the cost of battery replacement is expected to increase. Secondly, the swappable battery located at the bottom of the heavy truck, which has high requirements on the road conditions of the vehicle, makes it necessary to consider the damage to the battery caused by scratches on the bottom and stones.

### The interior design of DeepWay

The interior of DeepWay's new truck cabin, which is very close to a passenger car. Self-driving heavy trucks have become intelligent terminals. All the data generated by this vehicle can be directly observed, tracked, recorded, and even instructed in the background. In China, trucks used to be driver-owned, and thus, vehicles' design is directed to satisfy the needs of the owners, operators, and beneficiaries of truck operations. It is not unusual that long-haul transport on trucks is conducted with the entire truck driver's family onboard.

*Figure 24. DeepWay new battery-swapping-based electric heavy truck. Source: DeepWay.*

DeepWay has designed, developed, and manufactured trucks independently instead of collaborating with traditional truck OEMs like other intelligent driving companies. The consideration is that the traditional approach is a renovation approach.

> *"DeepWay has overcome the constraints imposed by the engine through forward design, and from the perspective of aerodynamics. The truck's design wind drag coefficient is currently 0.35, the lowest wind drag coefficient in the truck industry. Although DeepWay has yet to use ideal products such as hub motors, at least we can use distributed electric drive bridges. We can design our wire-controlled chassis from the beginning, allowing the truck to have natural hardware backup, software redundancy, and safety backup". (Source: Wan Jun, CEO of DeepWay, https://www.prnewswire.com/news-releases/DeepWay-raises-770-million-in-series-a-round-to-accelerate-mass-production-of-smart-electric-heavy-duty-truck-and-further-rd-exploration-301782965.html)*

> *"Intelligent driving requires high-speed communication; even if we cannot achieve a centralized E/E architecture, we must complete at least four major domain-controlled E/E architectures. This way, our contact can provide the fastest feedback and execute actions in milliseconds. These can only be achieved through complete forward design. Only by fully utilizing the advantages of electric drive can we develop a chassis that supports intelligent driving with wire control, backup redundancy, and safety backup. We have achieved reconstructed aerodynamic optimization appearance, distributed drive, and new high-speed communication that support the E/E architecture of intelligent driving". (Source: Ibid)*

This vehicle uses a distributed motor design. It can be driven independently on the front and rear axles and the left and right wheels. If the electric drive axle on the front axle fails, the rear axles can still work correctly. Chinese green energy firm GCL Energy Technology is partnering with autonomous driving commercial vehicle company DeepWay Technology to provide battery-swap services for electric heavy trucks along the Beijing-Shanghai Highway.

## 3.5. Global development of battery-swapping for heavy trucks

### 3.5.1. Japan and USA

Mitsubishi Fuso (part of the German Daimler Truck manufacturing company) has collaborated with the US company Ample on its battery-swapping technology for large electric trucks. The focus has been on smaller "last mile" electric logistic trucks rather than the larger, long-distance semi-trucks. Ample is a battery-swapping company that initially focused on passenger vehicles but is now focused on heavy truck businesses.

> *"When we set out to build our next-generation battery-swapping station, one of our most important objectives was to build a station that can support larger delivery vehicles. Accounting for 25–30% of global emissions in towns and cities, last-mile delivery is a key sector to prioritize in an electrification solution. Accounting for 25–30% of global emissions in towns and cities, last-mile delivery is a key sector to prioritize in an electrification solution—our work with Mitsubishi Fuso and our partnership to deliver modular battery-swapping to electric trucks. Our partnership will deliver Mitsubishi Fuso electric trucks powered by Ample's Modular Battery-swapping technology. The initial deployment will leverage Mitsubishi Fuso's latest all-electric FUSO eCanter starting this winter in Japan." (Ample voice).*


*Figure 25. Ample and Mitsubishi Fuso battery-swapping station for trucks. Source: https://cleantechnica.com/2023/07/26/battery-swapping-for-large-trucks-is-this-the-way-to-go/.*

Mitsubishi Fuso (Mitsubishi Fuso Truck and Bus Corporation) is not rolling out in high volumes in cities worldwide. Initially, the operational range with battery-operated trucks is limited to 100-300 km, which is a challenge. With battery-swapping, their trucks can achieve longer distances and increase operational efficiency. In March 2023, MFTBC launched the new model of its electric light-duty truck, "eCanter," which satisfies customers' urban transportation needs by providing a range from 99km to 324km.

> *" With battery swap stations located in the right places, truck drivers can easily stop for a few minutes to get fresh, grab a snack, or grab a coffee while the truck battery gets swapped out for a new one. Or, if swap stations were located where the truck is making a pickup or delivery, drivers may not need to stop for a swap at all. Location, location, location. And planning." (Mitsubishi Fuso voice).*

> *"With our next-generation swapping stations, Ample will offer last-mile delivery trucks a gas-station-like experience where electric trucks can get a full charge in 5 minutes, ensuring maximum on-the-road vehicle utilization. In addition, Ample's drive-through experience will further simplify the experience for the vehicle operator who doesn't need to back out of the station at the end of a swap. And while a truck is being swapped, it can be loaded and unloaded, allowing for additional operational efficiencies." That all sounds well planned and convenient." (Mitsubishi Fuso voice).*

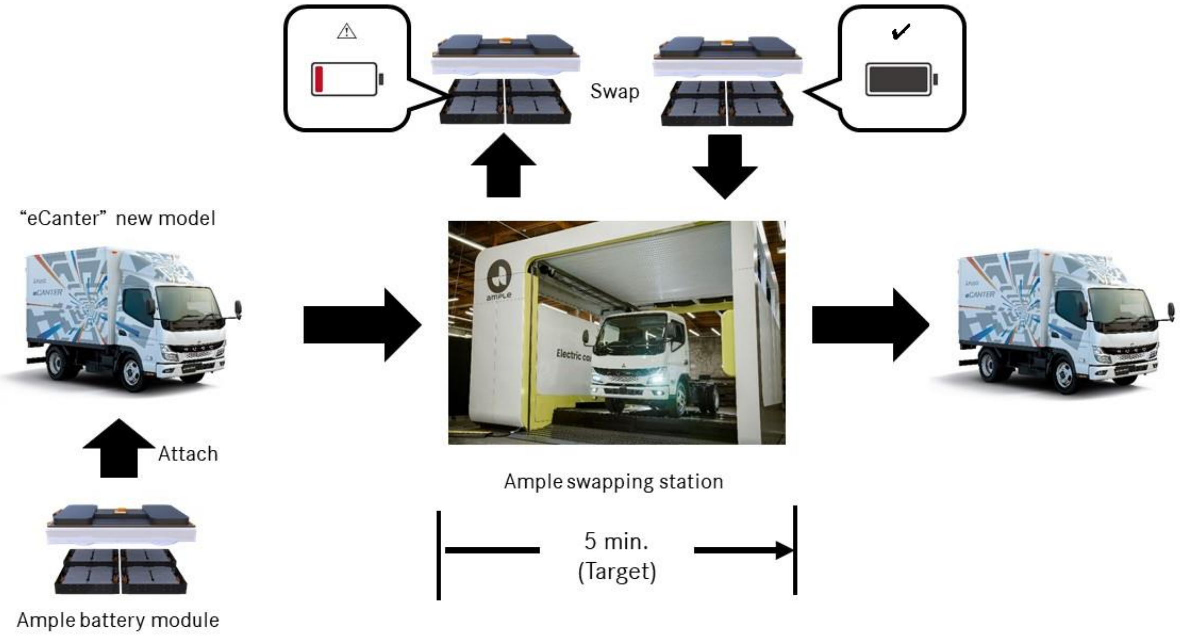


*Figure 26. Ample and Mitsubishi Fuso system design. Source: https://www.mitsubishi-fuso.com/en/news-main/press-release/2023/07/26/mitsubishi-fuso-and-ample-to-partner-on-battery-swapping-technology-for-electric-trucks/.*

Ample has been working for seven years on the technology development for heavy trucks, focusing on last-mile transport solutions.

> *"In addition to our live deployments, we worked with other types of fleets — specifically in the last-mile delivery space — to understand the impact of battery-swapping on their use cases. When working with these fleets, we continuously heard that despite well-intentioned efforts to electrify fleets, drivers could spend upwards of 10–12 hours, or 25% of a work week, at a charging station. We've heard from cities that, in the race to electrify, there is a lack of reliable EV charging for city dwellers who don't have access to garages and the option of overnight charging, and our new solution seeks to fix that. By design, we've invented our system to facilitate a lateral move from gas to be just as fast, as simple, and as cheap, all while being a completely green solution." The new design cut battery swap time down from 10 minutes to 5 minutes. " (Ample voice).*

### 3.5.2. Australia

*Figure 27. Early with swappable batteries from the front. Source: https://www.januselectric.com.au/.*

Janus Electric, a startup based in New South Wales, Australia, started battery-swapping solutions in traditional trucks by modifying the old ICE technology. They dismounted the large diesel engine from the hood in the front of large trucks and exchanged it with a swappable battery in a manual fork-based small vehicle.

Janus Electric has continued this development of battery-swapping by redesigning electric trucks with side-mounted large batteries that are swapped from the side of the truck.


*Figure 28. Janus Electric modified truck with swappable batteries from the side of the truck. Source: https://www.januselectric.com.au/.*

The Janus JE410 was purchased originally as a Kenworth T410 Glider and was then converted by Janus Electric into a battery electric vehicle (EV). According to Janus, this is Australia's first entirely manufactured electric Class A truck.


*Figure 29. Janus Electric modified truck with swappable batteries from the side of the truck. Source: https://www.januselectric.com.au/.*

> *"Fuel tanks have been replaced with exchangeable batteries providing 620kWh in total and an electric blower discharge that works off the battery. Under the bonnet, a 350kW motor can produce around 490 horsepower with a range of four to six hundred kilometers attached to a 12-speed gearbox. The truck, rated to 70 tonnes, can also operate using a concrete plant's power by plugging external power into it."*

*Figure 30. Janus Electric side-mounted swappable battery for heavy trucks. Source: https://cleantechnica.com/2023/03/06/truck-stops-are-very-big-in-america-could-battery-swapping-be-an-option-for-charging-all-those-trucks/.*

Cement Australia purchases around 20 Kenworth models a year. With a 2050 target for achieving net-zero emissions, they decided to trial a converted truck.

It should be noted that Janus Electric is modifying existing heavy trucks into battery-swapping solutions. Initially, the swapping was conducted manually, but Janus Electric claims to be developing swapping stations adapted to their modified truck and battery design.

Janus Electric is scaling up the sizes of battery-swapping trucks.


*Figure 31. Janus Electric modified Volvo FH16 with battery-swapping solution. Source: https://chargedevs.com/newswire/who-says-heavy-duty-evs-wont-work-170-tonne-620-kwh-battery-electric-truck-hits-the-road-in-australia/.*

Janus Electric has partnered with mining giant OZ Minerals and logistics provider Qube to trial an electric triple road train. The converted Volvo FH16 8×6 prime mover can take 170 tons of load and deliver 720 hp and 2,500 Nm of torque. It sports 620 kWh of battery capacity and a Volvo 12-speed gearbox. The monster truck is now at work, carting the equivalent of three shipping containers of copper concentrate from the OZ Minerals Carrapateena mine to the Whyalla port, 165 km away.

> *The cost of converting diesel trucks to Janus Electric technology ranges from $150,000 to $200,000, depending on the vehicle specifications, said Forsyth, adding that operators can expect to save between 10 and 30 percent in costs compared to a diesel-powered equivalent. (Source: https://chargedevs.com/newswire/who-says-heavy-duty-evs-wont-work-170-tonne-620-kwh-battery-electric-truck-hits-the-road-in-australia/)*

> *"It'll be towing a triple road train with three tri-axle trailers and two tri-dollies behind it, so grossing out at about 160 tonnes, the equivalent of what diesel vehicles are carrying," Janus Electric CEO Lex Forsyth told Big Rigs. "It's the heaviest-rated on-road electric truck in the world."*

> *"We're starting to step into our stride now. We know we've got the technology, know-how, and the will and the ability to deliver, and this is just demonstrating what we can do here in Australia, leading the world in this technology and engineering across the transport sector."*

*(Source: https://chargedevs.com/newswire/who-says-heavy-duty-evs-wont-work-170-tonne-620-kwh-battery-electric-truck-hits-the-road-in-australia/)*

The EV will use a purpose-built charging and battery-swap station, which is expected to get 200-400 km of range. Janus says a battery swap can be completed in the same time it takes to refuel a legacy vehicle. Initially, the truck will do two to three rotations on the day shift, and it is expected to be running 24/7 once drivers are trained and up to speed.

### 3.5.3. New Zealand

The Chinese XCMG (Xuzhou Construction Machinery Group Co Ltd) was founded in 1943 and is China's largest construction equipment manufacturer; its automated heavy truck manufacturing facility can produce a heavy truck every four minutes.

XCMG established Etrucks' first 50-tonne off-road mining truck, which is about to clock up 18 months of service in 2021 in Dunedin.

The Etrucks XCMG E700 has been in operation in New Zealand since 2022.


*Figure 32. XCMG E700 operating in New Zealand. Source: https://etrucks.co.nz/project_category/etrucks/.*

On the Auckland–Hamilton run, the truck's 282kWh LFP (lithium iron phosphate) swappable battery used 66% of its energy over a trip that measured 108km. The country's first fully automated battery-swapping station is scheduled to open in Auckland at a yet-to-be-specified location and is expected to be up and running by the middle of 2022. However, at the time of writing this report (end of 2023) the station is not yet operational.

*"This will allow a variety of ownership models for the batteries. In time, an option similar to the 'swap a tank' for your barbecue LPG tank will be available. That will considerably lower the truck's purchase price, and each charged-up swap battery will still cost less than the equivalent amount of diesel." (Source: https://etrucks.co.nz/project_category/etrucks/).*


*Figure 33. E700 for milk transport. Source: https://etrucks.co.nz/project_category/etrucks/.*

Fonterra, a local transport company, has launched New Zealand's first electric milk tanker, the Milk-E. The tanker should support Fonterra's fleet decarbonization. Fonterra says the Milk-E is the first fully electric milk tanker in New Zealand and might be the first in the world.

New Zealand's first electric milk tanker, Milk-E, has been officially launched by the Minister for Energy and Resources, Hon. Dr Megan Woods, in Morrinsville. The electric milk tanker –New Zealand's first such truck, and maybe even the world's – named Milk-E, is entering the fleet of New Zealand dairy co-operative Fonterra, which received $NZ427,000 in co-funding to purchase the electric truck cab and chassis and convert it into a milk tanker.

The battery swap E700 trucks will be offered in 6x4 and 8x4 configurations. Changes to the battery configuration have allowed the team to trial other additions to improve milk collection efficiencies, reduce safety concerns, and reduce the work required to customize a Fonterra tanker. A battery swap system is being installed at the Waitoa site where Milk-E will be based to trial how this could work within a fleet to minimize downtime from battery charging.

> "It's been great to see the team turn challenges into opportunities, so in addition to trialing Milk-E's on-road ability, we're also trialing a new electric pump, hose configuration, and cabinetry. We're pleased to see this project come to life. New Zealand has ambitious targets to reduce carbon emissions rapidly, and transport is key, but heavy freight has proven hard to decarbonize. This project could be replicated across several New Zealand businesses." *(Source: https://www.fonterra.com/nz/en/our-stories/media/new-zealands-first-electric-milk-tanker.html)*

The tanker is about the same size as a regular tanker and will operate with the trailer at 46 tonnes GVM (gross vehicle mass). The cab and chassis are built by XCMG – a Chinese construction machinery group. A Fonterra team has fitted the tanker tank to it, the same as Fonterra's regular tankers.


*Figure 34. Fonterra E700 trucks with battery-swapping solution. Source: https://etrucks.co.nz/project_category/etrucks/.*

The focus of establishing XCMG in New Zealand has been on setting trucks and creating operational business-based experiences, learning the New Zealand way of operating different scenarios, and gaining an understanding of the New Zealand context.

The strategy was establishing trucks and developing a business ground for the next step in establishing swapping stations that need a specific market volume to operate financially.

### 3.5.4. Germany

In a three-year project called eHaul, a German consortium of business and science, the TU Berlin, the Fraunhofer Institute, and Bosch are dedicated to developing an automated battery-swapping station for heavy electric trucks.

A consortium led by researchers at TU Berlin has launched a €6.5-million project to develop an automated battery exchange station for electric heavy vehicles. The eHaul project is funded by Germany's Federal Ministry for Economic Affairs and Energy, with further financial input provided by partner organizations.

Other partners are Fraunhofer Institute for Transportation and Infrastructure Systems (IVI); IBAR Systemtechnik GmbH; Robert Bosch GmbH; and Unitax Pharmalogistik GmbH.

Long-haul heavy trucks are used for journeys of distances that a single battery charge cannot cover. Haulage companies can't afford to lose hours waiting for a battery to charge, notes Professor Dr. Stefanie Marker, head of the Chair of Naturalistic Driving Observation for Energetic Optimization and Accident Avoidance at TU Berlin.

Professor Marker suggests that a network of battery exchange stations for heavy trucks could solve the problem. Project eHaul is a feasibility study on such a solution, adds Jens-Olav Jerratsch, team leader in Professor Marker's research group and project leader for the joint project.

EHaul aims to determine whether large swappable batteries for trucks of up to 40 tonnes are a sensible alternative in the transport sector with daily trips of over 300 km. To this end, the initiators want to test their concept of an automated battery-swapping station in practice. The plan is, therefore, to set up a battery-swapping station in the south of Berlin. In parallel, the consortium has just commissioned two electrified trucks, which will then be used by two logistics companies in regular operation.


*Figure 35. eHaul battery-swapping station. Source: eHaul project.*

For over a year, the truck duo will drive to the swapping station as part of an actual delivery operation. In the future, a specially developed robot will take over the battery change on-site, which will only take a few minutes.

> *"Both vehicles are fitted with several sensors to record data affecting energy consumption during regular operations: the energy consumption of the engine, the load, the weather, the altitude profile of the route, secondary energy consumption such as air conditioning in the driver's cabin as well as the energy required to maintain cargo hold temperatures." (Source: https://www.electrive.com/2021/03/11/project-ehaul-examines-charging-truck-batteries-with-robots/)*

Also pursuing a battery-swapping system for trucks is the RouteCharge project from the German "ICT for Electromobility" technology program. RouteCharge focuses on a medium-sized truck in the range of 18 tonnes and medium operational distances of up to 300 km. RouteCharge does not necessarily aim for a fully automated battery exchange. The project participants attach importance to the fact that the batteries remaining in the exchange station deliver primary energy outputs. Thus, the eHaul project is primarily directed toward technology development and demonstration of the functions of battery-swapping for heavy trucks. At this point, it is unclear whether the eHaul and RouteCharge projects consider the swapping station only for battery-swapping purposes or if there will be storage of batteries in the system that can be used for energy storage, energy balancing, etc. Neither is it clear that the software in the system is expected to evaluate the quality of batteries and keep track of the life cycle of batteries in use.

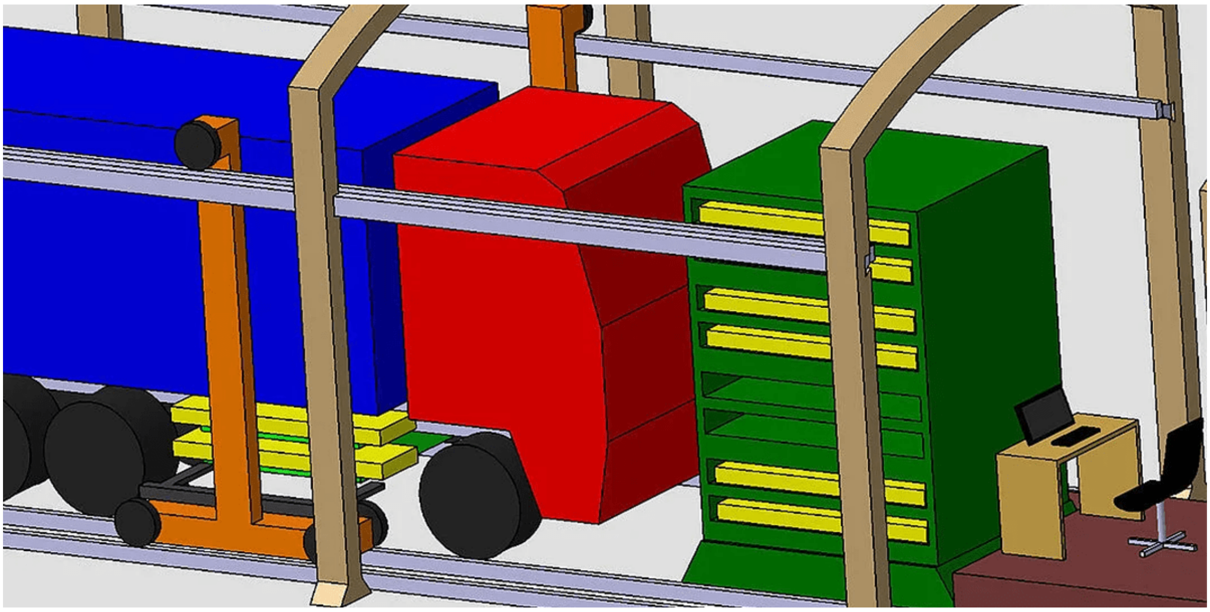

*Figure 36. Príncipe sketch of the eHaul swapping system design. Source: eHaul project.*

During 2023, the eHaul consortium intends to test the technical feasibility of its approach, energy consumption data, and economic viability. The central question is how a system must be designed to be economical and offer a natural alternative for the logistics industry.

> *"If we could begin by electrifying just a few vehicles, the high mileage of these vehicles alone would create a significant absolute impact. Unfortunately, there are not yet very many electric vehicles in the truck segment of up to 40 tonnes, as these are usually only produced on direct demand. The problem is that most large trucks are used for distances that cannot be covered on a battery charge.*
>
> *"Haulage companies also can't afford to lose hours waiting for a battery to charge." Therefore, a network of battery charging stations is a potential solution from the logistic operator's perspective.(Source: https://www.electrive.com/2021/03/11/project-ehaul-examines-charging-truck-batteries-with-robots/)*

### 3.5.5. Italy

#### Iveco

Iveco is an Italian BEHT OEM that is adopting the idea of swapping batteries for trucks. Although their solutions differ from the basic idea of changing batteries in a few minutes, their solution is to standardize batteries in modules placed in cassettes of different battery sizes. The "swapping" or "battery-in-a-cassette" is conducted in the Iveco service station and can take two hours. Thus, this solution is not entirely in line with the idea of swapping, which is expected to be conducted in a few minutes. Still, this solution shows the growing interest in creating flexible solutions in adopting variations of battery capacities to optimal scenarios and operational designs.


*Figure 37. Iveco eDayly trucks based on "cassette-style battery" and "battery-in-a-box" interchangeable systems. Source: https://www.autocar.co.uk/car-news/technology/iveco-battery-swaps-could-be-key-electric-vans.*

Iveco has launched a new electric van that showcases a different use for an easily swapped, cassette-style battery. The Iveco e-Daily comes with the option of three battery sizes – 37, 74, and 111kWh, for WLTP ranges of between 74 and 217 miles –allowing users to remove or add elements to the modular battery pack retrospectively. This way, the operators can adapt the truck for different scenarios.

Chinese battery manufacturer Microvast provides the battery pack solution. It uses an NMC (nickel-manganese-cobalt lithium-ion) cell chemistry similar to that already used in many modern EVs but built into the modular packs that can be slotted in and out of the Iveco chassis. The cassette-style battery pack allows greater flexibility for transport operators and enables the adoption and optimization of the design of electric trucks for specific logistic scenarios.

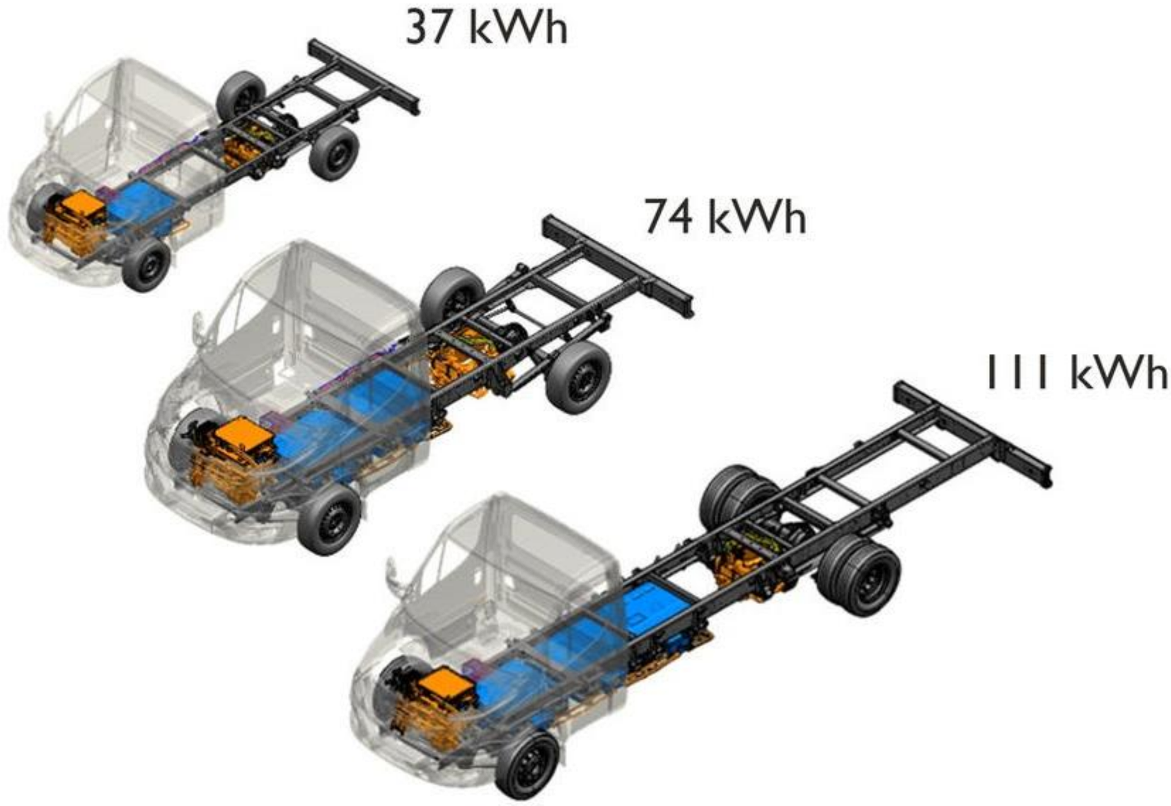


*Figure 38. Iveco eDayly trucks based on "cassette-style battery" and "battery-in-a-box" interchangeable systems. Source: https://www.autocar.co.uk/car-news/technology/iveco-battery-swaps-could-be-key-electric-vans.*

If a van is being used as a last-mile delivery vehicle and doesn't need a long-range, the smaller battery would suffice to keep costs and the environmental impact down as well as increase the maximum payload by removing battery weight of (in the Iveco's case) 270kg per 37kWh li-ion pack.

But if the vehicle's usage changes and a longer range would be useful, it can be taken into one of Iveco's servicing stations, which can up the cell count to 74 or 110kWh. Similarly, cell packs can be removed if necessary and swapped between the fleet's vehicles as needed.

> *"The system is quite unique to us. We've developed it in-house. Our ladder-frame chassis is perfectly designed for that modularity – not just for [battery] electric but also for adaptation to hydrogen in the future." (Source: Mike Cutts, business line director at Iveco.)*

*Figure 39. Iveco eDayly trucks based on "cassette-style battery" and "battery-in-a-box" interchangeable systems. Source: https://www.autocar.co.uk/car-news/technology/iveco-battery-swaps-could-be-key-electric-vans.*

Iveco and Hyundai have partnered on hydrogen and other future projects, with Hyundai's fuel cell tech already having been showcased in Iveco van and bus concepts – although neither firm has categorically suggested Iveco's modular battery tech could make it into Hyundai's passenger vehicles.

## 3.6. Analysis and Reflections

We see some patterns in the global overview of battery-based electric heavy trucks and battery-swapping based development for heavy trucks.

### 3.6.1. Towards customization of energy storage and resupply of energy

One is that some OEMs chose only to offer integrated vehicle-battery solutions. We can observe that there are reasons behind this: trust that the capacity of batteries is increasing, that the recharging speed is improving, that the prices of batteries will go down, and that the market for battery-swapping solutions is limited and lacks commercial interest.

The other direction is that some OEMs offer battery-swapping solutions parallel to their other integrated system solutions. In those cases, battery-swapping is one of several options. However, looking at the newest Chinese heavy trucks, WindRise, Farizon and DeepWay, we can see that battery-swapping has become a standard solution with no option to reject or exchange for only cable recharging. It is also important to notice that electric trucks based on battery-swapping always can be recharged with cable, while the electric truck designed to be recharde with cable cannot be used for battery-swapping. Thus, battery-swappable solutions offer two way of recharging, cable and swapping.

However, an emerging third option, represented by WindRose, Farizon, and DeepWay, sees energy storage from a customer perspective and designs the trucks to offer customers a complete selection opportunity. Battery-swapping is not an option for the customer; it is built in from the start and cannot be rejected. However, the customer can can choose which option they prefer, battery or hydrogen, or combinations of those two. The truck is designed with different energy storage solutions, batteries with various capacities capable of operating as normal BEHT, hydrogen, and fuel cells, and battery-swapping is a standard solution.

Figure 40 illustrate the complementarity between cable charging, battery-swapping and hydrogen with fuel cells. The boundaries between these three technologies are not clear, it is rather blurred. Different operational scenarios, transport logics, business conditions, owners preferences etc. determine how these three alternative technologies can be complementing each other. As we see it, there three technologies are not excluding each other.

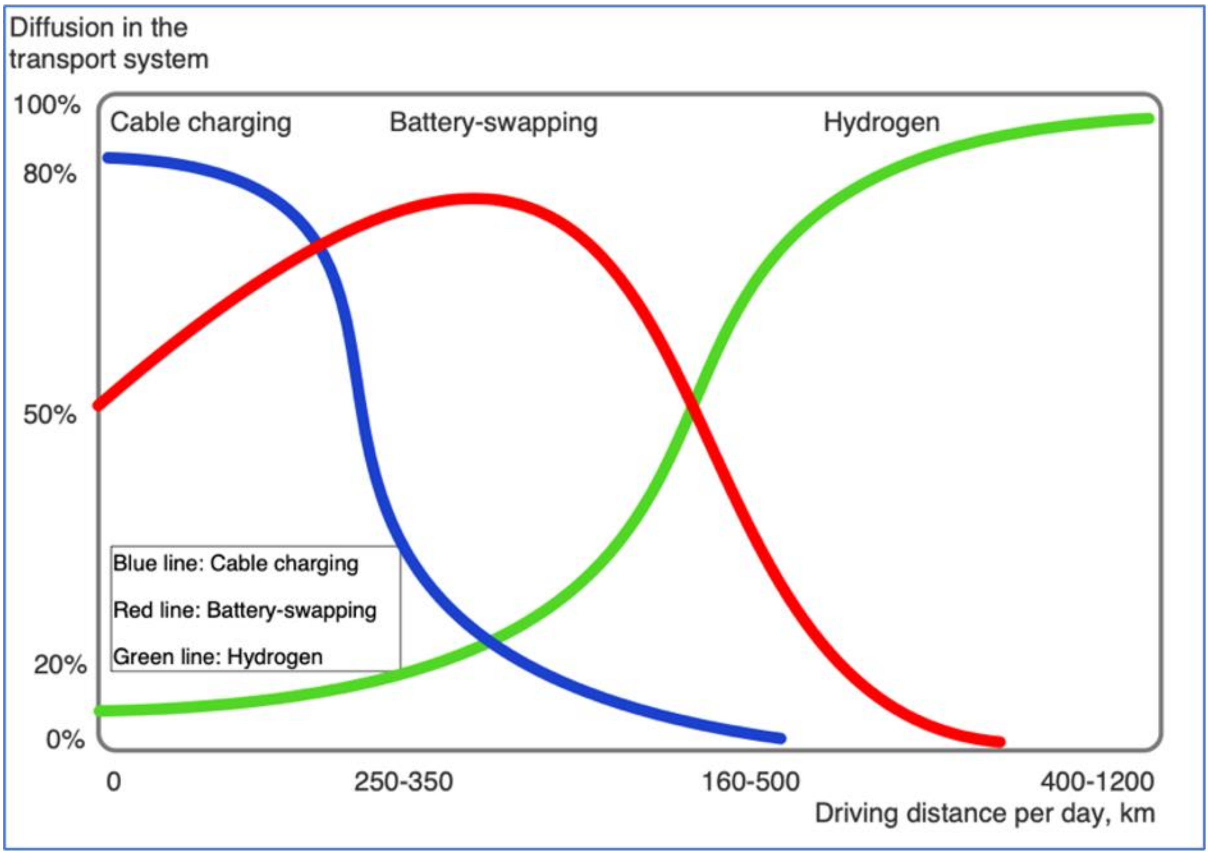


*Figure 40. Illustration of the logic between the three complementary options: Battery integrated cable charging, hydrogen refuelling, and battery-swapping solutions. Source: The Authors.*

This way, the technical and operational limitations are reduced. The shortcomings of the vehicle-battery integrated system, such as long recharging time, access to charging piles, and the necessity to recharge only via cable, need to be updated. With the built-in battery-swapping solution as a service, the customer overcomes the chosen technologies' operational and economic limitations. In the case of DeepWay, the customer can choose the battery-cable recharging and hydrogen refuelling solution, and the battery-swapping is always there. Battery-swapping has become a standard system solution; it no longer needs to see technologies as competing; they are complementary and take a customer perspective in the vehicle design from the start. The total system design is more flexible and leaves it to the customer to choose the solution depending on the needs and operational scenario.

The business and operational logic and scenarios can determine the chosen solution. The flexibility is there for the customers and operators to select the optimal solution.

### 3.6.2. Towards Inteligentization of heavy trucks – redefinition of the vehicle industry

We see in the case of DeepWay that two major actors are entering the heavy truck development: the logistic provider Lionbridge Logistics and the intern services and developer of autonomous systems Baidu. While the first actors provide experience and need from the logistic perspective, the other is creating a commercial platform for developing and commercializing advanced technology, intelligence, autonomous driving technology, and interconnectivity. The DeepWay is not developed and manufactured by established heavy truck industry OEMs.

The Inteligentization of vehicles, the introduction of autonomous driving, and interconnectivity in multiple dimensions require high computational power and communication bandwidth; Baidu provides both aspects. Both aspects are needed. We need computing power. High computing power without high bandwidth creates bottlenecks in the total system. If both computing power and bandwidth are increased, the overall power cost will be high, significantly slowing down technology development. There must be a balance between solutions.

Energy costs, fuel costs, and electricity costs are essential to be balanced and reasonably predictable. Professional logistics and truck operators make considerable investments in new energy-heavy trucks, and they need good predictability of the operational cost, including taxation of different energy sources.

Operating intelligent vehicles on 5G, and soon 6G, will be related to the overall communication capacity, which will determine the upper level of Inteligentization of vehicles and the interconnectivity between the vehicles, and between the vehicles and the roads, and other external systems. Thus, cloud computing system solutions will bottleneck the entire transport system.

Those aspects indicate new challenges between companies, industry, national and global technology provision and operations. Thus, cybersecurity becomes a crucial aspect of intelligent system solutions.

As indicated in our research, building a modern, intelligent vehicle is no longer an issue for traditional OEMs.

New high-tech companies are developing the most advanced and intelligent heavy trucks. Where is the next generation of heavy trucks coming from?

Building a good vehicle is no longer the industry's own business. We need to realize the vertical and horizontal value chains, the production and supply of solar cells, photovoltaics technology, the production and distribution of electricity, cloud computing, the internet capacity and capabilities, and semiconductors everywhere, and the demands on solutions are strong! The entire industrial base is needed to handle the future transport industry, and the old industry base is not the base for the future development of the transport industry!

We have reasons to believe that the traditional transport industry in strong countries and among traditionally strong brands might be unable to sustain itself - only two countries in the world, China and the United States, have industrial layouts qualified for the large-scale development of intelligent systems solutions of electric vehicles.

Small countries with traditional vehicle developers and manufacturers based on old mechanical-electric technologies might need more support to sustain themselves and rely more and more on suppliers. In the end, as it looks now, the suppliers are increasingly concentrated in China and the United States.

Understanding battery-swapping needs to be placed on the system-level analysis as follows.

### 3.6.3. Four integrated development processes

1. Development of battery-swapping systems – behind the cabin, along the chassis, or under the chassis.
2. Development of the battery-swapping stations – mini, standard, or flexible and modular design containing a variation of number of batteries.
3. Development of heavy trucks – from old frame models to modern skateboard design, pure electric, and incorporating intelligent technology such as smart solutions.

4. Inteligentization of heavy trucks - autonomous operated and flexible energy storage including swappable solutions, integrating the vehicle with operations, roads, cities, and the logistical eco-system.

### Development of battery-swapping systems in China

For the overview of the development and commercialization of battery-swapping in China, please see (Danilovic and Liu, 2021; Liu and Danilovic, 2021).

Based on our observations of battery-swapping progress in China, we can see three distinctive generations of development highly related to swapping technology, vehicle technology, and battery-swapping stations that are the heart and the system integrator.

Three generations of swapping system development

#### The First generation of battery-swapping for trucks

The first generation was based on the initial and the first generation of electric truck development. One solution was placing the swappable battery behind the cabin. The motivation behind this solution was the vehicle design with a mechanical gearbox and mechanical power train and the truck frame not enabling the best positioning of the large capacity swappable batteries along the chassis or under the chassis positioning.

Another solution was placing the battery on the side of the chassis. This solution needed batteries to be swapped from both sides of the truck. This solution did not achieve commercial success on the truck market but was very successful on the bus market.

#### The Second generation of battery-swapping for trucks

However, when electric trucks of the modern new generation started to enter the market, with new vehicle architecture without mechanical gearboxes and with electric motors, new opportunities were created to position batteries along and under the chassis of trucks.

Now, the new Aulton, CATL and and Ampel battery-swapping solutions emerged. To develop battery-swapping systems, the vehicle development as system also needed to take place. Thus, the vehicle product architecture and the design of the battery-swapping system are related and need to be considered as highly dependent systems.

#### The Third generation of battery-swapping for trucks

When truck development continued, the newest generations of trucks was created, with fully electric system design, autonomous driving systems, and extensive experiences in battery-swapping technology, system solutions, and the necessity to find more excellent system solutions with flexibility and services instead of only focusing on vehicles, the OEMs introduced new swapping solutions that from the beginning was fully integrated part of the vehicle design complemented by battery and hydrogen as energy storage and energy supply.

Here, we can see that both WindRose, Farizon, and DeepWay are introducing battery-swapping as a standard solution and letting the customer determine if they want to buy the battery, rent it, charge with cable, or swap the empty batteries with fully charged, or even if the customers want to use hydrogen as part of the total system energy provision solutions.

In the third generation of battery-swapping, the servitization of solutions is taken to a new level. The vehicle technology and design are needed to achieve this and enable fully integrated battery-swapping solutions.

## 3.7. Battery-swapping positioning – behind the cabin, along the chassis, or under the chassis?

The placement of the battery-swapping system, the battery holder, behind the cabin, on the side of the chassis, or under the chassis has been a ping-pong issue.

The answer to this question is related to

- the technology maturity of the heavy vehicle, i.e., the generation of heavy trucks and the product architecture,
- it has to do with scenarios for truck operations,
- it is related to perceived security and safety issues and
- it has ideological and cognitive aspects.

Battery-swapping mode: The battery-swapping design at the bottom of the chassis improves the safety and experience of the vehicle. The battery-swapping structure at the bottom and the long front aerodynamic cabin increase the cargo box volume by 9.6%, according to DeepWay.

Charging mode: Large capacity supports most operating scenarios, the supercharging network is gradually established, and the layout of high-power charging stations is accelerated. Charging infrastructure continues to improve.

Unmanned/autonomous driving is finally realized through forward design, which is technically feasible and commercially sustainable. OEMs in the latest generations of trucks are engaged in autonomous driving, and building trucks is just one of the tools or processes. The target is searching for an effective carrier for autonomous driving as an idea and a final solution.

> "When designing, we can break some of the past structural constraints and costs to achieve better prices, lighter weight, more optimized performance, and more optimized energy consumption. After customers use electricity, the operating cost is lower. We already have *vehicles* running on the road. This is currently the lowest power consumption level for trams".
>
> "It can give me a hematopoietic function. Every *vehicle* in Deep Way has gross profit, which can support my continuous investment in intelligent driving. We do not need to continue to need blood transfusions from the equity market".
>
> "Many *vehicles* have been sold and have become our data collection vehicles. The development of self-driving heavy trucks often requires using expensive and limited data collection vehicles to collect data. The data collected by a mass-produced vehicle differs entirely from that collected by the data-collection vehicle we purchased. These data will continuously optimize our model and improve our ability to drive autonomously".
>
> "Our ultimate goal is to produce commercial vehicles with high-level autonomous driving capabilities, save driver costs, and achieve the lowest TCO in the logistics industry. Our solution is to make and sell intelligent new energy-heavy trucks first" (Source; CEO, DeepWay).

The total design of a heavy truck balance different design parameters: the aerodynamic design minimizing the air resistance, energy sourcing in terms of battery and hydrogen energy, battery-swapping or even swapping of hydrogen tanks, and the capability to recharge via cable. We must remember the control aspect of the battery as an asset being controlled by the battery manufacturer. Other elements are also influencing the total design of the heavy truck. The positioning of the battery is thus a balancing act between many aspects. It is not purely a question of one design parameter.

Based on our understanding, there is no ultimate battery positioning behind the cabin or under the chassis. Placement behind the cabin is more accessible to design and operate at a lower cost and improves the capability to serve many different vehicle types and scenarios, while under the chassis, it might improve the place of gravity, shorten the total length of the vehicle, and achieve a lower point of gravity. Every design is a balancing act.

To sum up, both battery replacement schemes have room to increase R&D investment and improve the convenience of battery replacement. Both battery replacement methods need to be revised to avoid the problem of inconsistent standards for battery replacement of heavy-duty vehicles. At present, the battery replacement technology of the rear-mounted battery replacement solution is relatively mature and suitable for short-term transportation scenarios; chassis battery replacement has excellent potential in medium and long-distance transportation, such as trunk lines, but it still takes time to improve the battery replacement technology level and reduce replacement costs.

Based on the above analysis, rear-mounted and chassis battery replacements have advantages and disadvantages. Which method can be favoured by the market for battery replacement of heavy trucks?

The capacity scenario is critical in revitalizing the entire power swap industry chain, and different capacity scenarios will adapt to other power swap solutions.

## 3.8. Three generations of swapping stations

With the growing number and market share of battery-swapping solutions, and as more OEMs adopted the system solutions, the experiences explored the need for an upgraded new design of battery-swapping stations enabling a high level of modularization, increased speed of swapping and more efficient storage of batteries while being recharged in the station. This analysis reflects the development of battery-swapping behind the cabin placement as this is the oldest and is still the dominant solution on the market.


*Figure 41. Three generations of battery-swapping stations. Source: The Authors.*

Over time, the station's size can be minimized, the moving system miniaturized, the battery storage slots minimized and optimized, and the entire station has been adapted to specific needs and application areas, truck selection, etc.

*Figure 42. Different application areas for battery-swapping. Source: The authors.*

The first generation of battery-swapping stations, the origin of both mobile and stationary solutions, were designed to hold seven batteries in the station, and were further developed in internal functionality, functional capacity, sizes of the station and number of batteries in operations to fit specific needs and scenarios and the need for flexible solutions, i.e., scalability of the stationary design. The latest, 3rd generations of battery-swapping stations have new robots capable of swapping from side of the vehicle, faster in swapping movements and more efficient in terms of swapping speed.

## 3.9. The modular design of battery-swapping stations

### 3.9.1. Modular and scalable design – Three primary sizes

As battery-swapping became the new normal in the development of EHT in China, several OEMs started to design their swapping stations to offer full-system solutions to their customers.

### 3.9.2. Modularization of swapping stations

The growing size of the market for battery-swapping systems, the growing market share, now passing 50% of the EHT share in China, and the experiences of utilization of battery-swapping have pushed the manufacturers of swapping stations to diversify and develop different sizes for specific scenarios and modular design enabling the stations to expand as the demands for swapping changes.

### 3.9.3. Mini stations

The smallest battery-swapping stations now contain 3-4 batteries of sizes between 282-450MWh sizes. Stations are easily transportable as it only takes one day to set them up or move them. Thus, these stations can be located at long-term placement or on short-term deployment in temporary locations.

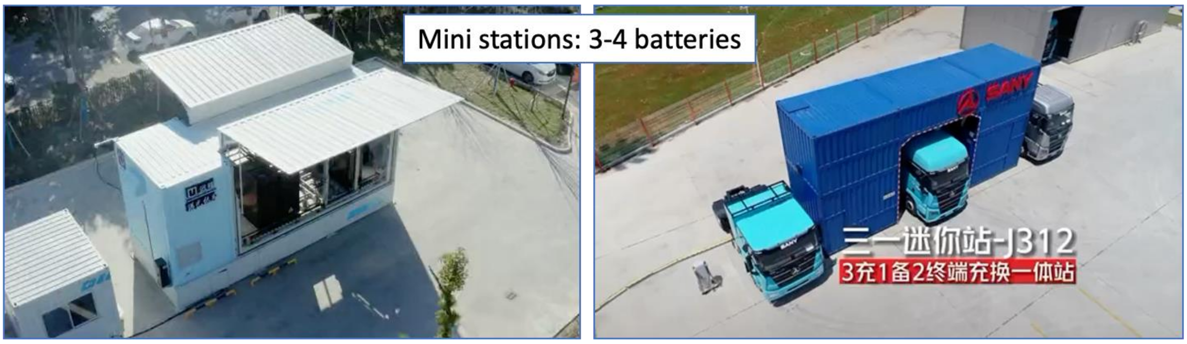


*Figure 43. Mini battery-swapping stations. Source: The Authors.*

### 3.9.4. Standard stations

The standard swapping stations were designed to hold seven batteries operated by a fully automatic exchange/movable system based on a vertical lifting or horizontal moving system.

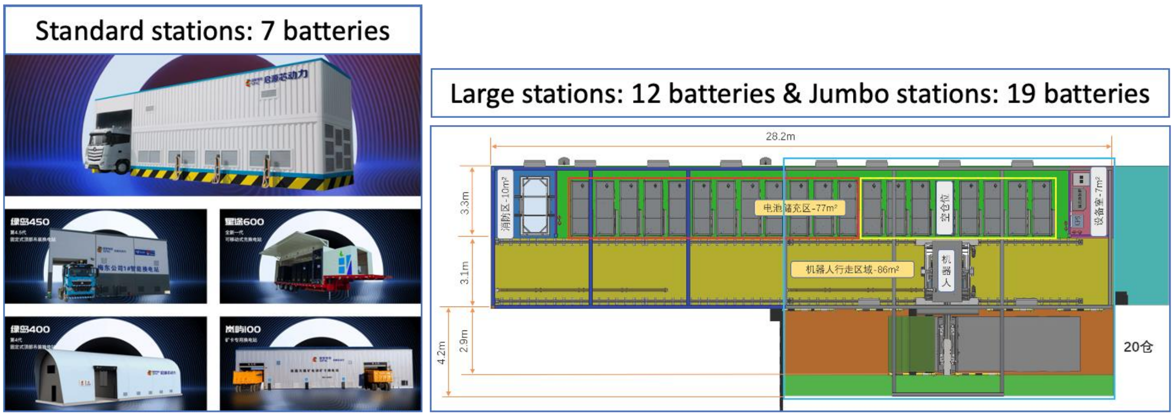


*Figure 44. Standard and large battery-swapping stations. Source: The Authors.*

Also, the standard system has been adopted for specific scenarios with different designs, functionality, etc.

### 3.9.5. Large stations

The standard stations are flexible through modular design, enabling flexible expansion from seven to 12 or 19 batteries system.

The largest station with 19 battery slots is about 11m x 28m, thus minimizing the land needed to recharge vehicles.

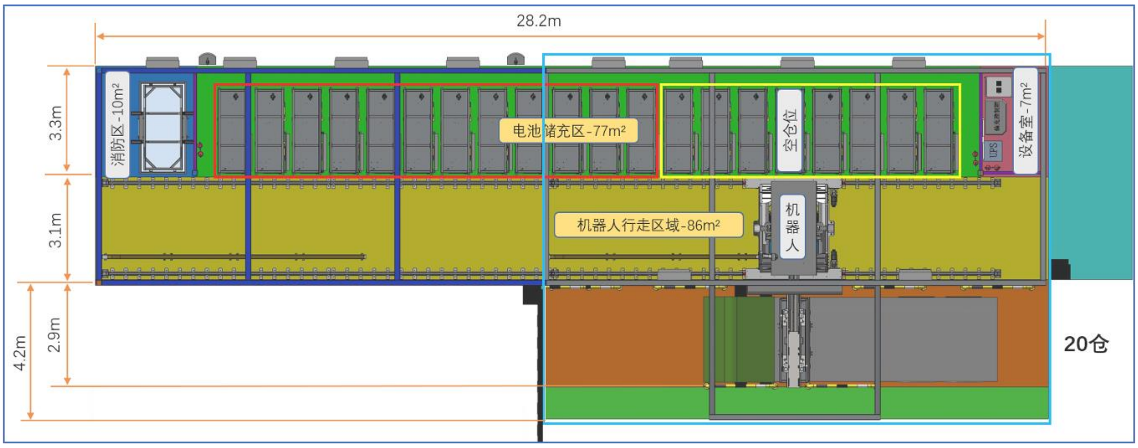


*Figure 45. Large battery-swapping stations. Source: The Authors.*

It should be noted that all battery-swapping stations can supply cable charging as well via adaptable cables with different standards. Thus, battery-swapping stations can be the standard recharging station that is flexible, modular, and adaptable to needs for swapping or cable charging and to energy supply variations in power effect and capacity.

## 3.10. System approach – New actors and new business opportunities

Probably the most critical aspect of battery-swapping stations is the total system approach they hold and the total system solution they offer. Thus, battery-swapping defines a new ecosystem of actors and enables different business opportunities.

### 3.10.1. The horizontal value chains

As Bhatti (2023) elaborates on the horizontal value chain, the battery-swapping system connects energy production and distribution with electricity consumption. Battery-swapping is a dual electricity flow and eco-system, enabling electricity to flow from energy sources to vehicles. It allows the flow the other way, i.e., from the station and its battery storage to the grid system and via an intelligent microgrid system to other operators, customers, etc. This way, it handles energy balancing on the higher system level.

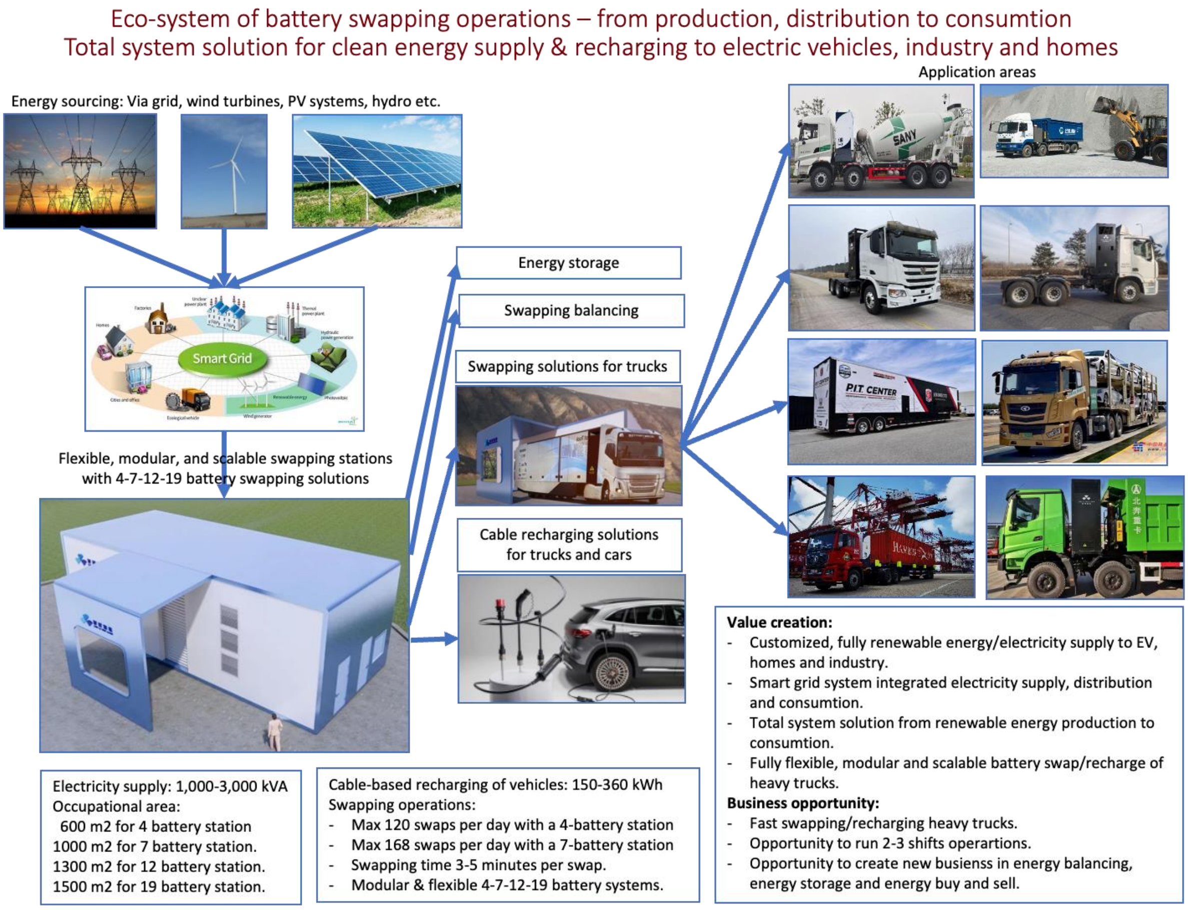


*Figure 46. Total battery-swapping-based system solution. Source: The Authors.*

The station can be provided with electricity via the grid system, connected solar power, and wind turbines, and via a connected, intelligent microgrid system, can combine and distribute electricity between and among all associated components.

The battery station can have several cable charging piles that complement the battery-swapping solutions. If the swapping station is designed for trucks, the cable charging can also be used for passenger vehicles.

Battery-swapping stations can be scalable and flexible system solutions. The number of batteries can vary and can be designed for various purposes, such as swapping, balancing, and storage.

The battery-swapping system can be equipped and adapted to different operational scenarios, container transport, various truck sizes, concrete blenders, etc. It can comprise batteries of different sizes. Today, four battery capacities are available, 150, 282, 350, and 450 kWh batteries, from the suppliers of the behind the cabin based systems.

The operational capacity for the standard battery-swapping station with four batteries is about 120 swaps, with seven batteries being 168 swaps per day. With 19, the maximum number of swaps is about 450 per day. In practice, the practical upper limit for a standard station is about 120 swaps per day in two shifts of operations.

Regardless of the technology route, cable, or swapping, one critical aspect of charging infrastructure is the system's physical size and land. Battery-swapping is relatively sparse in land use; for mini stations, only 500m2, 1000 m2 for standard stations, and 1500 m2 for the largest station.

### 3.10.2. From a centralized to decentralized energy system perspective - Integrating horizontal energy distribution value chain

As stated in the previous section, the battery-swapping system brings in a dual eco-system, a directed flow of energy/electricity, and business related to this dual flow as a dual eco-system.

Figure 47 shows the interplay between the battery-swapping ecosystem's vertical and horizontal value chains. Battery-swapping is a system integrating those two inseparable and interdependent flows.

#### The dynamics of actors in the development of heavy trucks

This chapter presents the analysis of the various actors that are part of a logistics system and their roles, as well as their business conditions, to contribute to the electrification of the logistics system. This includes questions about financial and logistical requirements to deliver competitive transport, what type of collaboration is needed between the various actors for rapid implementation of BS in Sweden, and whether new roles/actors are needed that currently do not exist in the systems, e.g., to finance the investments in new technology.

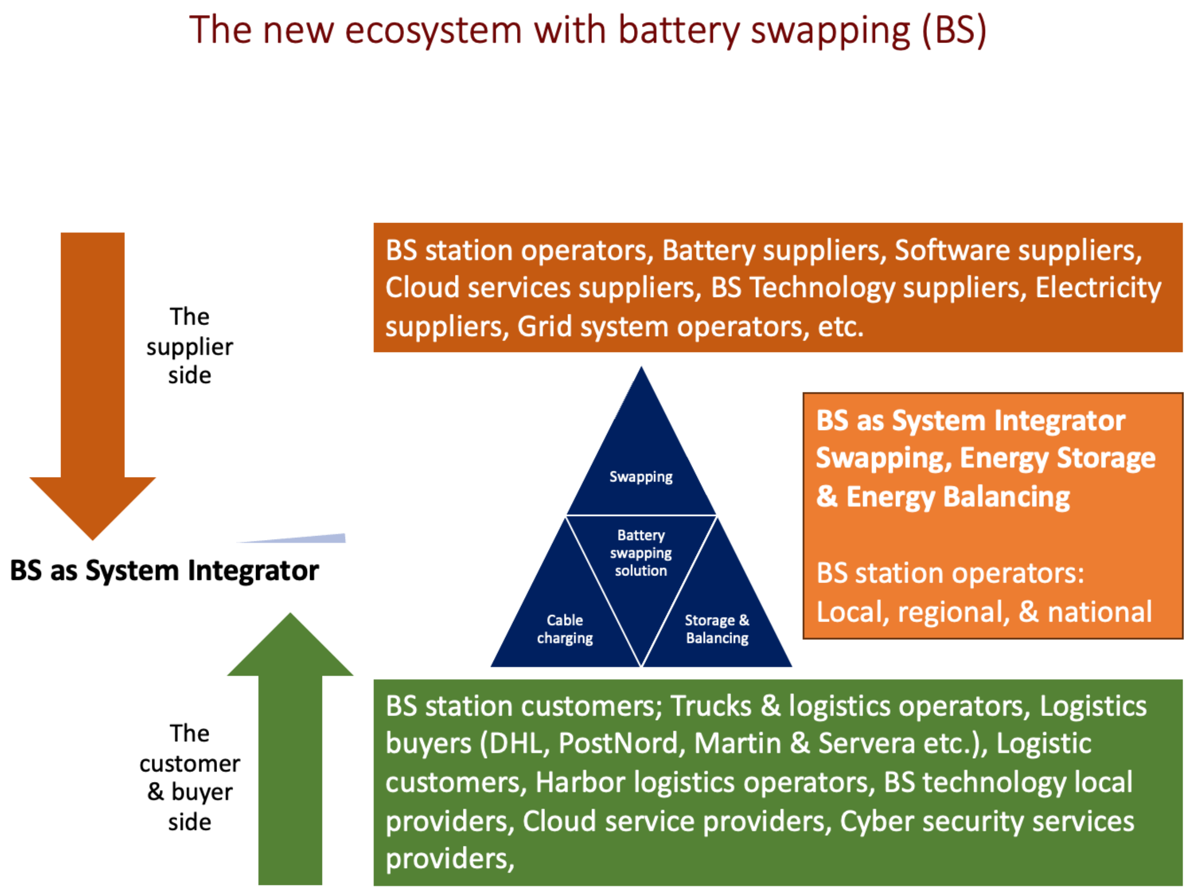


*Figure 47. New eco-systems based on battery-swapping. Source: Authors.*

Battery-swapping-based trucks and swapping system solutions are gradually passing different phases, and the driving forces for technology and product development are changing.

1. The first generation of battery-swapping for heavy trucks was based on a traditional vehicle structure with a frame along the vehicle. The solution that evolved was the placement of batteries in movable holders behind the cabin. Even the “behind the cabin” design has passed several technological alternations.

- The first-generation battery-swapping systems were initiated by energy producers such as SPIC. A new eco-design was created to enable R/D and manufacturing (Danilovic & Liu, 2021; Liu & Danilovic, 2021).
- The first generation of battery-swapping-based vehicles was successfully commercialized by new companies from the machinery industry, such as Foton and Sany, entering the truck manufacturing domain. They took the newly developed battery-swapping solutions, developed new trucks for battery-swapping solutions, and entered the transportation business.

2. Aulton designed the second generation of battery-swapping solutions. In their new solution, batteries were placed on the side of the chassis and are swappable from the bottom or the side of the truck frame.

- This solution can be applied either to the first generation of electric trucks or the third generation of trucks originally designed for the full-electric vehicle design, eliminating the mechanical gearbox and power train.

3. The third-generation battery-swapping systems were designed by newcomers from outside, seeing the opportunity of the growing logistic business, realizing the option in the Inteligentization and digitalization, and developing a new generation of battery-swapping-based trucks.

- The third generation of battery-swapping for trucks is built on the new aerodynamic design of the new generation of trucks. The aerodynamic design of the cabin is one of the design parameters that together with vehicle dynamics and the gravity of trucks are pushes the swappable battery placement from behind the cabin to be built in the vehicle and swappable from the side or vertically from the vehicle frame down. Additional aspects is that the battery manufacturers try to increase their control by placing the battery below the schessis and this way compete with the dominant design of the battery behind the cabin solution.
- In the third generation of swapping systems, the swapping is not an add-on function. It is built into the vehicle from the start and is to be seen as a service offered to the customer and operator to choose from. They can choose to use cable-based charging, battery-swapping, or mix both solutions based on the operational scenarios of their business.

Those different systems contain both truck development and swapping system development. They need to be seen as integrated development processes.

### Dynamics of logics – The inner circles and the outer circles

Our analysis shows two circles/processes of actors shaping and reshaping the scenery of battery-swapping development in China.

### Inner circle – The horizontal value chain

It relates to battery-swapping system solutions, battery technology, and battery suppliers.

- Energy producers
- Grid system operators
- Battery manufacturers
- Swapping station operators and cable charging providers
- OEM implementing BS solutions
- New OEM introducing BS as a new solution
- High-tech companies such as Baidu and Huawei

- Investors in the infrastructure

### Outer circle – The vertical value chain

Related to logistics operations and transport companies operating under the BS technology and solutions.

- OEM with EV trucks
- Battery manufacturers
- Charging system providers
- Logistic operation buyers
- Truck transport operators
- Customers to logistic/truck operators

The introduction of BS as a technology and business solution influences the existing relations of the ECO system. New actors are entering the scene and changing the business logic. Thus, actors' dynamics follow the design of technology, products, services, and business models.

### The battery-swapping system is the system integrating process for flexibility and adaptability

DeepWay and WindRose are developing new-generation trucks that have already incorporated battery-swapping as a system solution. It is, thus, up to the customer to use the solution if applicable to their operational scenario and business logic, allowing the customer to decide on the solution, refueling hydrogen, cable charging, or battery-swapping. Thus overcoming the barriers between different technical solutions. Each technological route, cable charging of batteries, hydrogen and fuel cells, and battery-swapping, has pros and cons. The technical, commercial, and business conditions are dynamic. What is not economically feasible today might be so in the future. Countries have different contextual, legal, political, and economic preconditions for technological routes. In the design of DeepWay and WindRose, it is up to the customer to determine which solutions are favorable based on the conditions mentioned and judge which solutions are optimal for a different business situation. Short distance, intensive transport flow, and long haul are examples of operational logic that truck operators need to handle with transport vehicles. As transport vehicles specialize in energy sources, the flexibility of truck operations could be improved.

With this integrated approach, the truck OEM does not need to develop, manufacture, and support different technology routes. All versions include battery-swapping as a system solution. Customers decide which and when to use.

Cable charging is probably most suitable for local transport & short distance range transport or low-intensity operations that enable truck recharging in 1-3 hours during the shift operations.

Conversely, battery-swapping suits local, regional, and intensive transport operations, particularly if the truck operating company needs flexibility and 2-3 shift operations. Battery-swapping also supports long haul transport as swapping of batteries is fast and enables efficient use of drivers' operating time.

The hydrogen and fuel cell solutions are yet to be commercially available but might be in 5-10 years. Hydrogen might be best suited for intensive, regional & long-distance transport operations.

### Dynamics of energy sourcing

The dominant technology for electrification is based on batteries. They need to be recharged. That can be achieved through conductive technologies such as static or dynamic cable charging or wires in the road, inductive recharging, or battery-swapping. The forthcoming technology is hydrogen, despite some believing that the cost disadvantage of hydrogen does not enable large-scale implementation of hydrogen. On the contrary, we are gradually learning to produce hydrogen cheaply and in increased volumes. Thus, soon, we will face hydrogen technology that needs refuelling infrastructure.

Each of these technologies has pros and cons. No one is perfect, and no one fits them all. The main question is how to use the best technologies for different operational scenarios, not try to use one that only fits into some functional plans.

#### Inteligentization

The latest heavy trucks are embedded with intelligent solutions, embracing autonomous driving and integrating battery-swapping. New actors enter the scenery and create heavy trucks as their development and innovation platform. We have all reasons to believe this is only the beginning of a rapid and advanced introduction of intelligent solutions to heavy trucks and all vehicles.

With the challenges of short labour, increased labour cost for drivers, need for longer operational time daily, increased speed in operations, the necessity to improve efficiency, etc., we see that the level of Inteligentization is only at the beginning of its path.

New technologies drive new product design, demanding new approaches to commercialization, i.e., new business models.

## 3.11. Conclusions

### 3.11.1. Dynamics of technologies, actors, and roles

During the time of fossil-based technologies and internal combustion engine technologies, the eco-system of heavy trucks was relatively stable. Fuel producers dominated it, and mechanical engineering was the key technology. Gradually the technology shifted to fuel injections and electricity, giving rise to new key suppliers, such as the German Bosch.

When battery-electric vehicles were introduced, the old vital technologies and critical suppliers became obsolete, and some new ones entered the scene. Mineral producers, battery cell and battery assembly companies, and software developers became the new key suppliers, but the main developing force was among the traditional OEMs.

When battery-swapping was introduced, the traditional OEMs were hesitant. The main hesitation was losing control of the primary subsystem of electric vehicles, i.e., the batteries. The uncertainty in business consequences and the necessity to develop new business models left traditional OEMs to lose speed in the development. Thus, the initiative for battery-swapping came from the energy producers, energy distributors, and new entrants in the heavy truck domain.

The early signals for change came from energy producers and electricity distributors such as SPIC, which realized early the implications of large-scale battery-based recharging. SPIC pushed the OEMs to adopt battery-swapping technologies. Later, some new actors, such as Foton and Sany, originating from the machinery industry, realized the opportunities in the new logic and swapping batteries, station design, and new business logic of decoupling vehicles, batteries, and charging.

Gradually, traditional fuel suppliers such as BP realized the potential of battery-swapping and joint strategic collaboration with OEMs of vehicles, such as NIO, to support the establishment of battery-swapping stations globally. The traditional battery manufacturers now realized battery-swapping was a significant and exciting direction and wanted to grasp a more substantial portion of the market. Companies such as CATL started to design new swapping solutions, and gradually, they began to be critical players not only as battery suppliers but also as developers of new swapping systems.

When Inteligentization came to the transport industry, new actors became critical, such as internet and cloud services providers, high-tech such as autonomous system suppliers, etc. Gradually, the vehicles became computers on wheels, and the roles of traditional OEMs started to crumble. The latest case of DeepWay development is only one illustration of such change.

### 3.11.2. Dynamics of technologies and business

Our main point is that technologies, products, vehicles, services, and related business models are all dynamic relations. When one component changes, the other must adapt or leave the old ecosystem.

The ongoing electrification of the transportation system is a paradigmatic transformation of technologies, products, and societies. Businesses must learn how to commercialize the potential of technologies to achieve the targets of the mission-driven societal transformation towards renewable energy, new energy vehicles, and related recharging infrastructure.

### 3.11.3. Battery-swapping is a complementary solution to cable charging

There has never been one solution that fits everyone's needs all the time. Based on that empirical observation, we argue that there is not and will probably not be one solution that fits all customers' needs soon.

The prevailing dominant recharging solution today in the West is cable charging. This is a sufficient solution for now, but not for the future and the large-scale diffusion of EHTs. The arguments are that the development of batteries and cable charging technology will solve all needs in the future.

We have reasons to question this position.

Recharging solutions must reflect the variation of technologies and customer operational scenarios. This variation is increasing, and the solutions adapt more to specific scenarios and customers. To understand this, we must look for those ahead of us. To countries that are ahead of us in the electrification of transport. Those ahead of the west are China, and they have experienced situations and scenarios we are approaching.

#### Example Shenzhen city

With its 14 million citizens, Shenzhen has been developed to be the world's most intensive electric vehicle city. No other city comes close to its 22.000 electric cars, 18,000 electric buses, and 68,000 electric logistics vehicles. All are being recharged with cable chargers in places larger than football courts. This large-scale electrification demands a large physical area and very stable and high-capacity provision of electricity. Only cable charging was available when Shenzhen was electrified about 15 years ago. Today, there are alternative solutions.

#### Modern city Shanghai

With its 35 million population, Shanghai is developing system solutions where different technologies are merged into an integrated solution. Here, cable charging is used for specific scenarios, combined with battery-swapping and new infrastructure for hydrogen that is being rolled out. Each technology is directed to a particular operational scenario it suits best.

Based on our previous work, battery-swapping should be seen as something other than excluding cable charging solutions or the forthcoming hydrogen solutions.

## 3.12. References

ACEA, 2021, *Zero-emission trucks: 100-fold increase needed in EU fleet, new data shows*, https://www.eubusiness.com/Members/ACEA/zero-emission-trucks

Bhatti, H, J., 2023, *Sustainable Electromobility - A System Approach to Transformation of Transportation*, Dissertation, ISBN: 978-91-89587-11-3, Halmstad University Press, Sweden.

Danilovic, M., Liu, L., 2021, *Exploring battery-swapping for electric vehicles in China 1.0, Sweden-China Bridge*, ISBN: 978-91-987011-0-4, Sweden.

Fang, T., Jiang, P., Will, A., Zhou, T., Zhuang, A., 2023, *China's heavy-duty-truck industry: The road ahead - Premiumization, electrification, autonomous driving, and a value pool shift to solutions and services will shape the future of heavy-duty trucks in China*, McKinsey, 2023.

Global and China Heavy Truck Markets, 2021-2022 & 2027, https://www.prnewswire.com/news-releases/global-and-china-heavy-truck-markets-2021-2022--2027---sales-of-china-vi-tractors-may-surge-301503014.html).

Basma, H., and Rodríguez, F., 2023, *A total cost of ownership comparison of truck decarbonization pathways in Europe* , ICCT, Working Paper 2023-28, November 2023.

Mulholland, E., and Rodríguez, F, 2023, *Zero-emission bus and truck market in Europe: A 2022 update*, Fact Sheet Europe, ICCT, August 2023

Liu, L, J., & Danilovic, M., 2021, *Experiences of Battery-swapping for Electric Heavy Trucks from China*. Summary of the Sweden-China Bridge battery-swapping EHTs webinar. ISBN: 978-91-987011-8-0, Sweden

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https://baijiahao.baidu.com/s?id=1768507355233241832&wfr=spider&for=pc

https://www.catl.com/en/news/6041.html

https://baijiahao.baidu.com/s?id=1775184478341524910&wfr=spider&for=pc

https://baijiahao.baidu.com/s?id=1767603124319703691&wfr=spider&for=pc

https://www.spicqyxdl.com/news-center/2023082201/

https://baijiahao.baidu.com/s?id=1757043213318406499&wfr=spider&for=pc

https://baijiahao.baidu.com/s?id=1783675198361590457&wfr=spider&for=pc

https://www.thebioenergy.net/tesla-semi-like-electrical-truck-from-jac-noticed-in-china/e)

Statista, 2023, Market share of medium and heavy commercial vehicles in Europe in 2021, by producer.

Wan Jun, CEO of DeepWay, https://www.prnewswire.com/news-releases/DeepWay-raises-770-million-in-series-a-round-to-accelerate-mass-production-of-smart-electric-heavy-duty-truck-and-further-rd-exploration-301782965.html)

Wuxi, eastern Jiangsu province-based GCL Energy.

Zan, J. a, *12431! In 2022, battery-swapping heavy trucks increased by 285%,* EVPARTNER, https://baijiahao.baidu.com/s?id=1757043213318406499&wfr=spider&for=pc, accessed November 10,2023

Zan, J. b, *16920 new energy heavy trucks sold in the first eight months*, EVPARTNER https://www.evpartner.com/news/135/detail-58266.html, accessed November 10, 2023

# 4. Technology Integration and Feasibility

Authors: Petter Huddén, Per Haugland.

## 4.1. Conclusion/Summary

The battery-swapping technology offers a range of technical advantages compared to traditional cord charging of vehicles, within electrical systems, vehicle ownership, and in the transportation system at large.

Battery-swapping technology provides opportunities to optimize energy usage, reduce investment costs in charging infrastructure, decrease the power demand (load) on the electrical grid, and reduce uncertainty in the investment for vehicle owners. Through better planning and controlled charging, battery-swapping stations can contribute to a more stable, efficient, and cost-effective use of electrical energy in the power system while increasing the utilization rate of the vehicle/vehicle fleet by avoiding long charging times.

Through strategic planning and continuous innovation, battery-swapping can become a central solution to meet the increasing demands for sustainable and efficient transport in Sweden, the EU, and globally.

### 4.1.1. List of Conclusions:

Technically, battery-swapping concept fits into all transport systems.

- A battery-swapping concept can be used for multiple purposes, partly by exchanging discharged batteries for charged ones on vehicles. It can also act as a balancer of the local electricity grid.
- Power grid companies welcome battery-swapping as a significant enabler in electrification efforts, as battery-swapping requires substantially lower peak power from the grid, which accelerates the potential scaling rate of an electrified vehicle fleet.
- Vehicles do not need significant redesigning based on current vehicle constructions, enabling rapid scaling and integration into our vehicle fleet.
- Battery-swapping is well-suited for heavy vehicles as there are plenty of placement opportunities on existing vehicle platforms where fuel tanks, combustion engines, or drivetrains were previously located.
- For large-scale and sustainable development of battery-swapping, it is important to develop and standardize battery technologies and charging infrastructure. Close cooperation between industry, authorities, and other stakeholders is crucial to create a robust and sustainable infrastructure for battery-swapping technology.
- Battery-swapping has the advantage that it also can be cable-charged just like a standard BEV, increasing the application potential.
- Technically, the conclusion is that the shared business model, where the investment is separated between the vehicle and battery, extends the lifespan of the investment and creates higher flexibility as you can purchase a battery-swapping -adapted vehicle but still cable-charge the vehicle throughout its lifespan. The vehicle lifespan is decoupled from the battery life cycle.
- Battery-swapping enables a longer lifespan and a second life for the battery. A battery-swapping battery requires lower power when charged from the grid, which entails two significant advantages: longer lifespan, controlled charging, and power draw from the installed power in the electricity subscription. This is a huge advantage as our electricity grid capacity can handle a high scaling rate of an electrified vehicle fleet. A standardized battery-swapping

battery can also more easily serve a second life with grid services. This reinforces Sweden's development of a robust electricity grid.

- Iterative development potential. The battery-swapping concept allows for a future-proof investment as vehicles can benefit from future battery development advantages such as energy capacity, weight, etc. For example, a battery-swapping vehicle in generation 1.0 can benefit from battery generation 2.0, 3.0, etc., similar to the development of light bulbs. A standardized lamp socket (E20) can utilize future generations of LED bulbs…
- Battery-swapping will become part of the total solution in the electrified transportation system, alongside several solutions such as BEV (tethered), Hydrogen and Electric Roads. Battery-swapping also has a high compatibility possibility with traditional BEV and electric road solutions.

*Table 3. Comparison between cable charging BEV and battery-swapping.*

| Description | BEV | Battery-Swapping | Benefit / SWOT | Calculation |
|---|---|---|---|---|
| **Concept explanation** | Battery electric vehicle, with built-in battery | Vehicle with possibility to swap batteries and also use cable charging | | |
| **Purchase** | Vehicle owner buys complete vehicle concept from start and have to decide battery capacity for the whole lifetime | Vehicle owner buys vehicle separate from battery. Battery can be bought or rented. Means separating cost parameters | Flexible ownership in LCA. Minimize risk of miscalculated investments | |
| **Finance – bounded / unbounded cost** | Buy vehicle + battery = high fixed cost | Buy vehicle + rent battery capacity = higher factor of non-fixed cost | Lower finance risk with battery-swapping and lower investment cost. Enables higher rate of investment / accelerate electrification | |
| **Purchase strategy** | Need to decide battery capacity for total lifetime. Risk of factor to "buy to big battery" | Flexible battery capacity calculation. Start with small, then adjust. Change strategy if the transportation mission will change | Cost and climate footprint reducement | |
| **Use case** | Fits for one working shift. Hard to enable two working shifts due to possible charging time or available charging power | Enables two working shifts | Divided/half fixed cost in two business/use case. Big impact TCO to reach cost parity. | |
| **Lifetime – low/high power charging** | Big factor of high power charging (over 100 kW) shorten battery lifetime | Low power charging in controlled battery-swapping stations BMS (Battery Management System) | Extended lifetime (+1 - +2 years) will reduce cost | Approx 40% is battery cost in investment = 1,5 – 2 million SEK / 5 year = 300-400 kSEK/year in extra lifetime |

| Description | BEV | Battery-Swapping | Benefit / SWOT | Calculation |
|---|---|---|---|---|
| **Charging cost – high power** | Big factor of high power charging need. Depot and public | Low factor of high power charging need | Affects total energy cost. Mostly affect battery swapping operators cost but will affect vehicle owner | Public charging: High cost 5-8 SEK/kWh and low control factor. Depot charging: Low and controlled kWh cost but will affect power tariffs cost from DSO. Battery-swapping: Controlled low power charging guarantees an even and plannable cost development |
| **Loading capacity** | Bigger battery size = heavier vehicle = decreasing loading weight | Smaller battery size (CH figures decreasing with 10-20%) = higher loading weight = closer to todays planning/loading capacity | Enables higher transport efficiency and planability | |

## 4.2. Short description of battery-swapping technology

### 4.2.1. General

A battery-swapping concept consists of a battery exchange station containing several standardized batteries, along with vehicles adapted for battery-swapping. The battery replacement is carried out in an automated manner. It's an ecosystem of components that are modified to suit each other. The battery-swapping station is connected to the electricity grid and can charge the batteries optimally at low power and at the most cost worthy grid tariffs. The setup can be either stationary or mobile, meaning that it can be moved. It can be charged at one location and then moved to swap batteries where, for example, the desired power in the grid is available. The vehicles are designed to undergo battery replacement but can also be cable-charged like regular trucks with fixed batteries. Implementing battery-swapping vehicles may require adjustments to the vehicle's design depending on battery placement. An automated battery swap takes between 5-10 minutes.

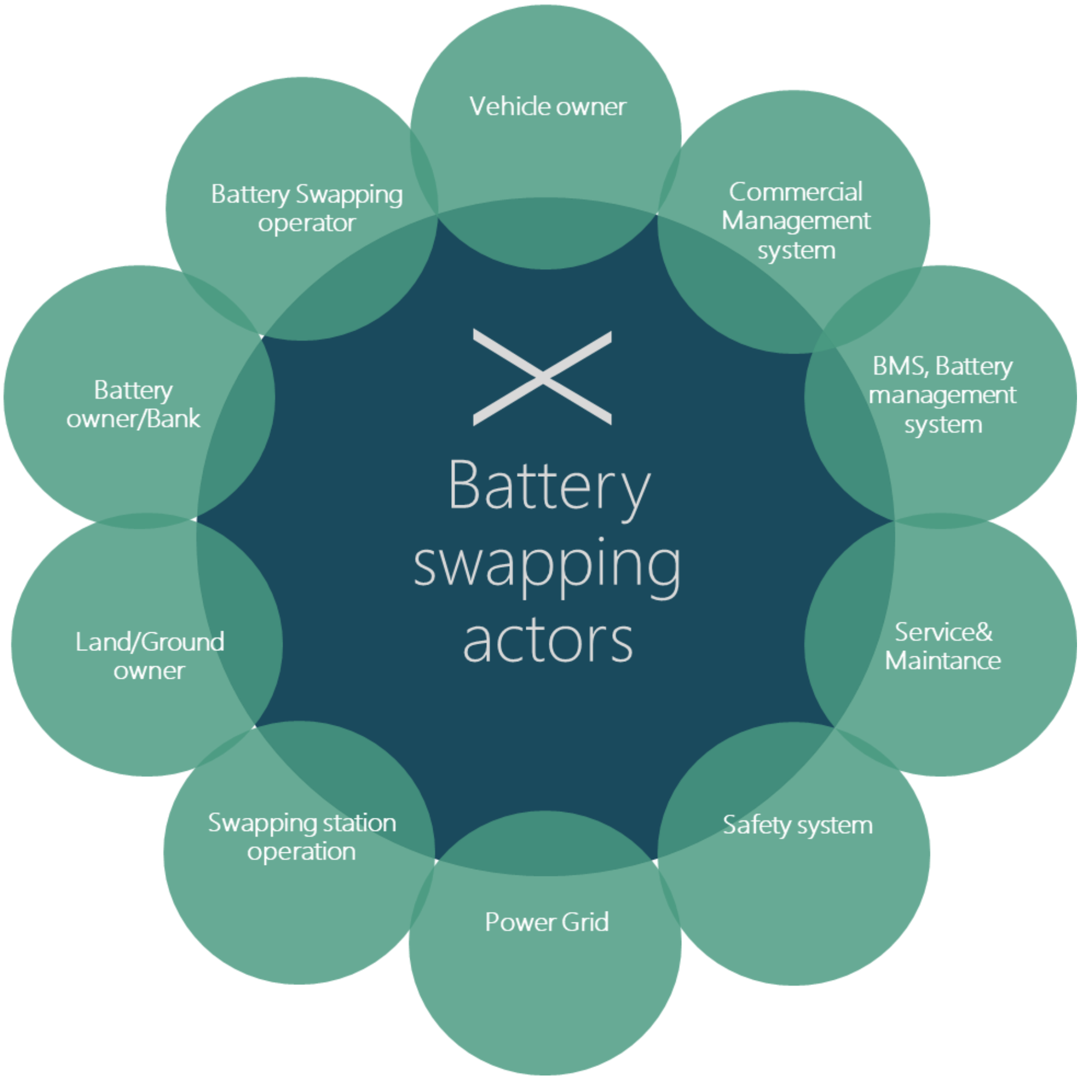


*Figure 48. Actors in the eco system that require technical solutions.*

### 4.2.2. Vehicles

Battery placement can occur in different places: behind the cabin, under the vehicle, on the sides of the chassis, or in the front under the cabin. In China, it is common to place the battery behind the cabin.

On the passenger car side, NIO can be mentioned, which places the battery under the vehicle.

Short description and conclusions regarding different placements:

Behind cabin: A battery placement behind the cabin offers a good weather-protected location and does not affect the current prevailing drivetrain. A battery weighs about 3000kg, and its high placement affects the vehicle's center of gravity and can influence driving characteristics, especially at higher speeds. The placement also affects other constructions on the vehicle, such as possible crane placement or potential payload on freight trucks. This solution fits well in short distance with tractors.

Under chassis: In the under-mounted variants, we have seen that the entire battery pack is contained in a module. This placement presupposes an axle-equipped electric motor, which only exists on electric trucks of generation 3 (not Volvo, Daf, Scania, Renault). The placement provides a low center of gravity and is suitably adapted for higher speeds (Longhaul). It may be more sensitive to moisture and dirt.

| | |
|---|---|
| Side by side | Two battery modules are suspended on the side of the chassis. This placement requires more complex robotic battery-swapping equipment. A side-hung solution demands high load-bearing capacity in the construction to handle about 1500 kg per side. The placement offers a low center of gravity and is suitably adapted for higher speeds (Longhaul). It may be more sensitive to moisture and dirt. |

Today, battery-swapping systems already exist in other sectors such as trucks, mining, construction machinery, and agricultural machinery. Standardizing the battery-swapping battery is important during the scaling up of battery-swapping -adapted vehicles. The battery change take place in an automated battery-swapping station. A battery-swapping -adapted BEV vehicle can also be charged/operated in the same way as a traditional BEV with a fixed battery. The only difference is the function of a quick battery swap. A battery-swapping -adapted vehicle can use cable charging in the same charging infrastructure as a regular BEV vehicle.

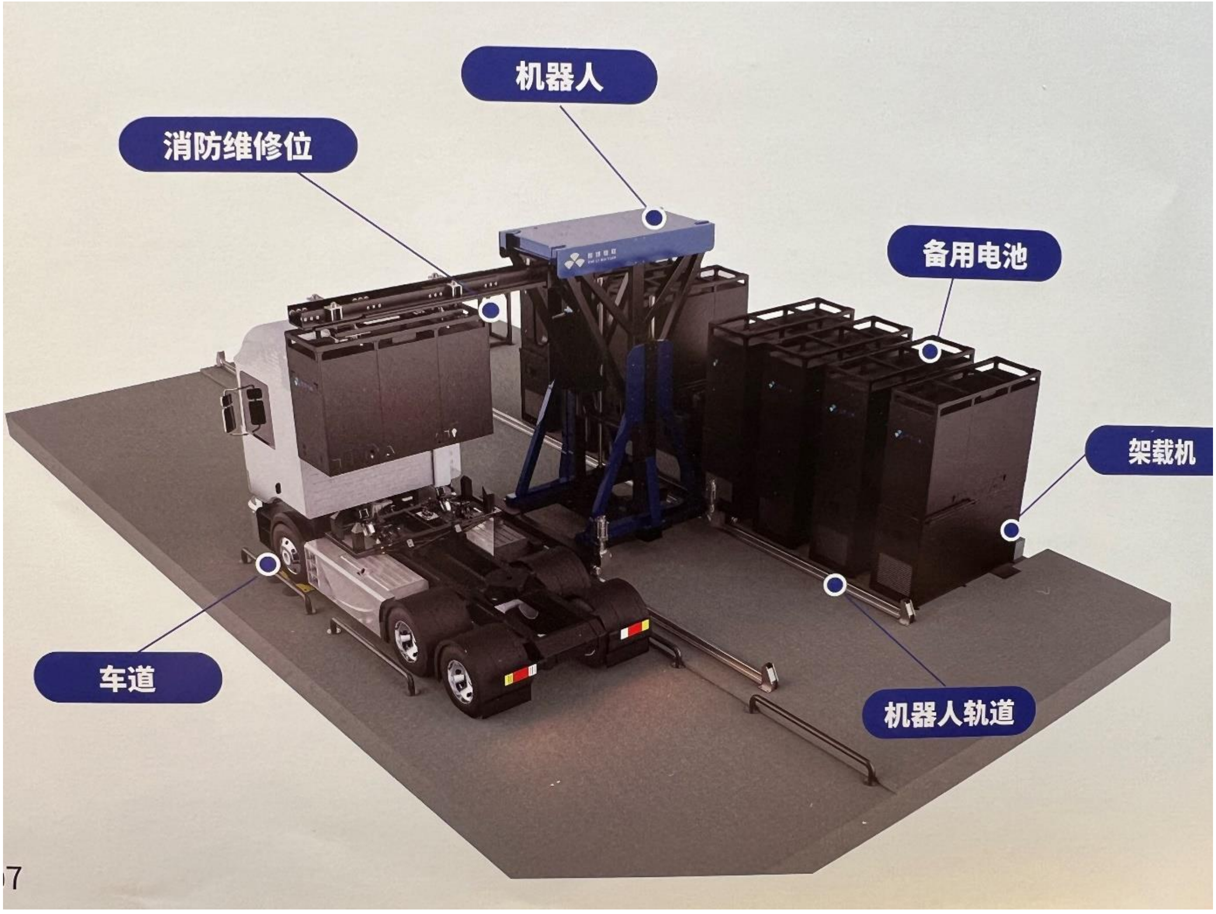


*Figure 49. Chinese example of a vehicle with the battery mounted behind the cabin and a battery-swapping station. Source: Battery-Swapping producer Zhi Li Wu Lian in Yibin, China.*

### 4.2.3. Battery-swapping station

A Battery-swapping station is an automated unit where the vehicle passes through or drives close to the station.

A Battery-swapping station can be stationary or mobile. A stationary one requires establishment, see the section on permits. A mobile battery-swapping station is described as a trailer with automated equipment on it. It can be charged at one location but perform a battery swap at another location, for example where there is no grid power, such as large construction sites or infrastructure projects.

A battery-swapping station contains an automated storage system for the batteries. Battery-swapping stations come in several variants with different storage capacities regarding number of batteries. A battery-swapping station can be built modularly so that the number of batteries can be increased over time. A battery-swapping station has an integrated BMS (Battery Management System) that controls and optimizes several functions such as charging, swapping, frequency balancing, etc. The BMS can also communicate with the grid and the vehicle/fleet planning systems.

A battery-swapping system can easily be integrated with other charging infrastructure as they usually also offer cable charging connected to the battery-swapping station. This has an economic advantage in terms of investment, user opportunity, and operating costs.

The operator of the battery-swapping station is responsible for all operations of the stations' facilities. This responsibility includes system support for safe and optimized charging, business-related system integrations with vehicle owners. In addition, processes and organization are needed to handle safety issues such as the risk for fire. There are also needs to have trained staff for service and maintenance. A question that we do not yet have an answer to is how to practically insert or remove batteries from the station from a service perspective. What does that vehicle or solution look like? That and many remaining questions we hope to get answers to during the study trip to China in November 2023.

### 4.2.4. Battery design and standardization:

It is important to highlight the need for standardized battery design to enable battery-swapping between different truck manufacturers. The batteries can come in different sizes with different energy capacities. The standardization of battery technology and connection specifications is crucial for the battery-swapping concept to be successful.

### 4.2.5. Placement of battery-swapping stations:

Similar to the development of other charging infrastructures, a battery-swapping station can be placed in a public, semi-public, or non-public context and has the same economic dependencies on high utilization of the investment. A battery-swapping station solution can be easily placed on a smaller land area. This affects the planning of traffic flow in its immediate environment. This should be compared to a cable charging station that requires a large land area and complex land planning to be adapted to long charging times. Furthermore, this brings both economic and time-saving advantages. It is likely to also affect safety aspects for drivers, but this has not been investigated in this project.

### 4.2.6. Power grid and grid connection

The concept of battery-swapping can serve multiple purposes in relation to the power grid. It can act as a pure energy consumer but can also offer grid benefits and act as a balancer in the local power grid.

Battery-swapping, or battery exchange technology, offers several advantages compared to traditional cable charging of electric heavy trucks, especially in terms of impact on the power grid and cost-effectiveness.

Power grid companies with whom we have had dialogue in the project welcome battery-swapping as it enables predictable power consumption, which in the long run allows for a faster development pace of an electrified transport sector.

Battery-swapping technology offers several advantages in optimizing energy use, reducing costs, and reducing the load on the grid compared to traditional cord charging of heavy trucks. Through better planning and controlled charging, battery-swapping stations can contribute to a more stable, efficient, and cost-effective use of electric energy.

With battery-swapping, a grid-aware national charging strategy is enabled, which hopefully will become the norm.

### 4.2.7. Different grid connection options:

#### Only Energy Consumer:

Connecting a battery-swapping station as a pure energy consumer to the grid is straightforward. It follows the same regulations as for connecting any other charging equipment. However, it is always recommended to have an early dialogue with the power grid company to ensure available and feasible power. A recommendation is also to discuss a possible scaling rate together with the power grid company. The same conditions apply for a mobile battery-swapping station as for a stationary one.

#### Flex Market / Grid services:

Flex market services through frequency and power balancing. The flex market is a new market in an early phase of maturity. Technical conditions already exist for a battery-swapping station to function as an energy storage facility. Conditions and standards are not set at the national level. The possibility of grid connection with this service is referred to specific dialogue with the relevant grid owner. Here, there is an opportunity for an additional income stream for an operator of a battery-swapping station. (See chapter 7.)

#### How is the power grid's power requirement affected by battery-swapping compared to traditional cable charging?

Example (simplified):

Battery-swapping:

A battery-swapping station with 10 batteries can plan and distribute its charging over time, allowing it to even out the load on the power grid. As the batteries can be charged during low-load periods, such as at night, the station does not need to draw a large amount of power at once.

Calculation: 10 batteries x 300 kWh (energy per battery) = Total station energy of 3000kWh. Charging possibility over the entire 24 hours of the day.

3000kWh / 24 hours = **125 kW** power requirement on the power grid.

Traditional cable charging:

If 10 trucks are instead charged individually and unplanned, they can cause a high and uneven load on the power grid, especially if several trucks are charged with high power simultaneously. This uneven load can lead to peak loads and potentially disruptions in the power grid.

Calculation: 10 batteries x 300 kWh (energy per battery) = Total energy of 3000kWh. Charging possibility if the vehicles can be charged at night simultaneously at 12 parking spaces with installed charging equipment.

3000kWh / 12 hours = **250 kW** power requirement on the power grid.

Result: Battery-swapping has **50% less power need** than traditional cable charging

#### Subscribed Power and Costs:

Battery-swapping: By having a controlled charging schedule, a battery-swapping station can optimize its subscribed power, which is the maximum power the company is expected to draw from the power grid. This can result in lower fixed fees from the power grid company. Additionally, by charging the batteries during periods with lower energy prices, the station can benefit from lower variable costs.

Traditional charging: Trucks charged unplanned may require high subscribed power to ensure that the grid can handle the high power peaks, leading to higher fixed fees. They may also happen to charge during periods with higher energy prices, resulting in higher variable costs.

Predictability and Flexibility:

Battery-swapping: With battery-swapping, a high degree of predictability can be achieved, as the station can anticipate and control when and how much each battery is charged. This makes it possible to optimize both energy consumption and costs.

Traditional charging: Unplanned charging of trucks can lead to unpredictable and varying loads on the power grid, making planning more difficult.

## 4.3. Interaction with Other Systems

Just like with other electrification solutions, a higher degree of digitization is welcomed to communicate with the energy system's actors (charging operator, battery-swapping station, etc.) as well as with the vehicle/vehicle owner's planning systems (TMS, VMS, etc.).

## 4.4. Inventory and analysis of relevant standards

Currently, there are no standards for battery-swapping in Europe, and consequently, none in Sweden either.

It needs to be investigated whether the Chinese standard can be fully applied or if it requires adjustments.

Is standardization needed? Technically, a conceptual solution only needs to adhere to the current regulations for electrical safety and vehicle construction. The need for standardization is purely business-related and creates security for all involved parties. We can draw a parallel with the development of the video format in the 1980s. There were several parallel formats, and all worked fundamentally well technically. Eventually, it was customer demand that drove the decision towards a common standard, VHS. Similarly, battery-swapping might evolve. Different solutions may suit different transportation systems. However, there are significant advantages if stakeholders, together with relevant authorities such as the European CEN, CENELEC and ACEA, start working on formulating desirable standards for voltage, placements, module dimensions, etc. This instills confidence in parties to invest in the technological solution.

## 4.5. Suggestions on actions to create feasibility.

From a technical perspective, we do not see any obstacles to deploying a battery-swapping concept solution in Europe. However, it's a matter of trust and security in investment.

To promptly introduce the battery-swapping concept, it is suggested that we initiate tests and demonstrations of the concept in the European/Swedish transport context. Furthermore, it is recommended to learn from the Chinese market and the concept that has progressed the furthest in market establishment, development, and standardization efforts. By July 2023, China has an annual new sales rate of 60% of 62,000 heavy-duty vehicles adapted for battery-swapping.

# 5. Certifications, licenses and permissions

Authors: Petter Huddén, Per Haugland.

## 5.1. Summary and conclusions

Introducing a battery-swapping concept for heavy trucks requires a thorough overview of necessary permits, regulations, and certifications. For the battery-swapping concept for heavy trucks to be swiftly and cost-effectively successful, it is important to create a European consensus and regulations for standards, for example. Close dialogue with relevant authorities and stakeholders, along with careful planning and preparation, will facilitate the process and reduce the risk of unforeseen obstacles along the way.

The battery-swapping concept differs from current business models related to vehicle sales, fuel sales, and electricity grid business. Several existing regulations need to be reviewed and adjusted. For example, in vehicle sales, one would purchase the vehicle and subscribe to the battery, unlike traditional battery electric vehicles where the purchase locks the vehicle and battery into the same deal. This affects the registration regulations regarding varying battery weights.

A recommendation for swiftly introducing the battery-swapping concept in Europe is to learn from the battery-swapping concept in China, where established standards and a good and extensive market reception exist. 60% of all battery electric trucks in China in June 2023 are battery-swapping adapted.

Below, relevant regulations and authorities are presented.

## 5.2. Existing standards for vehicles and charging stations

Here we describe the currently applicable regulations for permits and certifications specifically related to battery-swapping and traditional cable charging.

There is today no existing established product or concept based on battery-swapping standard for heavy vehicles in Europe.

There are lessons to be learned from passenger cars, where manufacturers like NIO (China) and AMPLE (US) already have products registered and certified at the market.

For heavy vehicles, there are standards in China for battery-swapping that need to be examined to see if Europe/Sweden can transfer or adapt them to an European norm.

### 5.2.1. Vehicles

All vehicles need to be type-approved by the respective market's registration authority to ensure compliance with all technical and safety requirements.

Battery-swapping-adapted vehicles need adjustments for the battery-swapping station's battery exchange technology and for driving characteristics as battery placement can affect weights, etc. Trucks must meet certain technical and safety requirements to participate in the battery-swapping concept. This may include requirements for battery placement, fasteners, and connection points. Furthermore, the choice of battery placement can affect the vehicle's weights and driving characteristics.

This adaptation requires the vehicles to undergo a certification process to ensure compliance with all applicable rules and standards.

Battery safety: The vehicles must have systems (BMS) to ensure that only approved and well-functioning batteries are used. This can include communication systems between the vehicle and the battery to monitor the battery's status and performance.

### 5.2.2. Vehicles during import

Imported vehicles must also meet the respective country's import regulations. Importing and registering trucks in Sweden, for example, requires certain certifications and permits. In addition to the applicable import permits, the following requirements must be met.

Type Approval: To import and sell vehicles in the EU, including Sweden, they must be type-approved according to EU rules. This means that the vehicle must meet technical requirements, including safety requirements, set by the EU. This can be done through a so-called Small Series Type Approval (STA). For a swift procedure in this matter, it is recommended to collaborate with an already authorized importer. This will facilitate the import and documentation regarding a new vehicle concept.

Registration: The truck must be registered with the Swedish Transport Agency before it can be driven on Swedish roads. To register the vehicle, you as the importer must have a company in Sweden. Additionally, the truck must have a valid foreign registration certificate.

### 5.2.3. Battery-Swapping Station:

Battery-swapping station regulations for building permits, electrical connection permits, as well as meeting fire safety requirements and occupational safety requirements.

Battery-swapping stations may require special building and usage permits depending on their size, location, and expected traffic volume.

Comply with applicable safety and fire protection regulations, especially considering the potential risks of handling large batteries. This includes firefighting equipment, emergency exits, and training for staff.

Waste Management: The stations must have permits and infrastructure to handle defective or expired batteries, which includes recycling and safe storage.

A battery-swapping station is considered an energy storage station and follows the same regulations regarding certifications and permits as described below.

Certification: The energy storage facility must be certified according to relevant European standards, such as CE marking, indicating that the product complies with European safety, health protection, and environmental standards.

Electrical Safety: The energy storage facility must meet the electrical safety requirements set by Swedish authorities. Electrical safety can be checked by authorized electrical installers and electricians.

Environmental Requirements: The energy storage facility must meet relevant environmental requirements set by Swedish authorities, such as waste management.

Installation Permit: Installing an energy storage facility usually requires an installation permit from the municipal building permit authority. Depending on the battery-swapping station's size and capacity, special agreements or permits may be required to connect the station to the grid, especially if high power is required, so early dialogue with the relevant electricity grid company is recommended.

## 5.3. Involved Authorities and Regulations in Sweden and the EU:

To successfully introduce battery-swapping technology for heavy trucks, it is necessary to collaborate with and understand the requirements from both national and European authorities. A close dialogue to carefully understand and comply with the applicable rules and certifications is needed. Thorough planning and preparation will facilitate the process and reduce the risk of unforeseen obstacles along the way.

### 5.3.1. Involved Authorities in Sweden:

The Swedish Transport Agency (Transportstyrelsen) plays a central role as they are responsible for vehicle type approval, vehicle standards, traffic safety and road transport.

The National Board of Housing, Building and Planning (Boverket) and municipalities are responsible for regulations regarding building permits, land planning, and land use permits for the construction of battery-swapping stations.

The Swedish Work Environment Authority (Arbetsmiljöverket) oversees regulations regarding working conditions at battery-swapping stations, with safety requirements for workplaces, especially considering the potential risks of handling large batteries.

The Swedish Environmental Protection Agency (Naturvårdsverket) is responsible for Environmental Impact Assessments (EIA) for new infrastructure projects and guidelines for handling used or defective batteries.

The Swedish Civil Contingencies Agency (MSB) and municipalities are responsible for protection against accidents and other societal risks, such as fire safety requirements for battery-swapping stations.

The Swedish Energy Agency (Energimyndigheten) oversees rules for connecting battery-swapping stations to the electrical grid and the development of guidelines for safe electricity distribution and charging.

The Swedish Customs (Tullverket) is responsible for monitoring and controlling all imports and exports of goods to- and from Sweden.

Together, these authorities must collaborate to create a coherent and efficient regulatory framework. Swedish national grid (Svenska Kraftnät) and local electricity companies are also important players in ensuring that the infrastructure is ready to meet new energy needs.

### 5.3.2. At the EU level:

EU authorities and regulations: At the European level, it becomes important to coordinate with EU's various authorities and comply with relevant directives and regulations. European Commission, through its different Directorates-General like DG MOVE (Mobility and Transport) and DG ENER (Energy), governs guidelines and legislation that can affect the introduction of battery-swapping technology.

## 5.4. Roadblocks and enough Electricity Supply

### 5.4.1. Vehicles:

The regulations at the Transport Agency for the registration of battery-swapping-adapted vehicles need to be reviewed. Today, there are issues with registration due to different battery sizes, as only one battery size (a fixed service weight) can be registered. Dialogue with the car manufacturer NIO indicates that there are challenges in fully utilizing the potential of the concept under the current regulations on their application.

There is a risk that established vehicle manufacturers who strategically choose a different technological solution, such as cable charging, will oppose the introduction of the battery-swapping concept. The underlying rationale may be that they have invested so much in the current technology that it is difficult to change the strategy. However, just like the passenger car sector, the truck market will probably be characterized by new players who can deliver future-proof solutions and products.

### 5.4.2. Battery-swapping Station:

The need to develop European standards and regulations is crucial for the successful establishment of battery-swapping in Europe.

### 5.4.3. Electric Grid:

It is desirable and of economic importance that grid connection rules and grid benefit functions will be established and standardized. These functions refer to grid services on the Electricity Grid's Flex Market, such as frequency balancing and power balancing. For more information, see Svenska Kraftnäts project Stockholm Flex (https://www.svk.se/sthlmflex).

There is a need for relevant stakeholders in the transport and electricity grid system to understand the potential of the battery -swapping concept with a high degree of electrification and a lower impact on power compared to traditional cable charging.

### 5.4.4. Is there enough power in the grid for a larger scaling of the battery-swapping concept?

Our assessment is that battery-swapping, like other charging solutions, will face challenges in accessing the desired power availability in the local electricity grid. The same relevance applies to planning an establishment in an optimal way geographically. Since a battery-swapping solution requires less power demand from the electricity grid per charged/“swapped” battery compared to cable charging, battery-swapping promotes a higher development rate and relevance in the electrification evolution journey. However, a threat in this context could be that the parallel development of high-power charging for cable charging concepts may limit the possible network connection of battery-swapping stations. For instance, permits and/or establishment of high-power charging may have already been carried out at a specific location with the electricity grid's room for available power.

# 6. Actors, roles and interorganizational relations

Authors: Maria Björklund, Mats Abrahamsson, Uni Sallnäs.

## 6.1. Summary

The concept of battery-swapping involves a variety of distinct stakeholders. Key actors consistently present across all battery-swapping systems, as commonly highlighted in literature, include transport service providers (such as third-party logistics (3PLs) and haulers), operators and owners of battery-swapping stations (BSS), electricity suppliers, vehicle manufacturers, and battery manufacturers.

The discourse on roles frequently discussed in innovation management literature reveals the emergence of new roles awaiting suitable actors within the context of battery-swapping. Various types of promoters play a crucial role in this context. Despite the importance of promoters, no actor has fully assumed this role in the Swedish context. This is identified as a key reason why the transition towards an electric transport system in Sweden has so far paid little attention to battery-swapping compared to countries like China and the USA, where promoters are very influential actors. Relationship promoters, who are capable of transferring knowledge and mediating negotiations between different stakeholders, are equally important.

Transport service providers assume several vital roles in battery-swapping. The separation of batteries from vehicles allows transport service providers to take on diverse roles concerning the ownership of central resources, compared to traditional plug-in charging. Transport service providers can own, lease, or participate in a shared resource pool for technologies, including batteries and vehicles. They can also invest in infrastructure, such as solar panels. Transport service providers serve as essential relationship promoters, facilitating communication between various stakeholders including transport buyers, vehicle manufacturers, and battery-swapping station operators. Further, transport service providers can have an important role as expert promoter, given their expertise of the logistics system and transport buyers' needs.

Depending on the roles transport service providers choose to play, different relationships with various actors must be established to facilitate the implementation and scaling of battery-swapping. Transport service providers heavily depend on electricity providers, who supply the essential resource of electricity for charging batteries. Transport service providers also rely significantly on the crucial resource provided by the battery-swapping station, specifically regarding the availability of charged batteries at the required time and location. Compared to plug-in vehicles, battery-swapping might increase the transport service providers' dependency due to a limited number of potential battery-swapping station operators. The relationship between transport service providers and vehicle and battery manufacturers depends on the availability of functional vehicles and batteries, which are critical resources.

Based on the key findings regarding the different roles and relationships within battery-swapping, several propositions are suggested:

1. There is a need to acknowledge the need for new roles and for actors to take on new roles.
2. A larger number of actors is needed both compared to traditional fuel (diesel) and plug-in due to the extra activity regarding operating battery-swapping stations.
3. Other actors than the transport service provider needs to take on the role as financial promotors.
4. Transport service providers can play a critical role as expert promotor due to their understanding of the market's logistics needs, as well as changes needed in the logistics system design.

5. Transport service providers needs to take on different roles in different phases of the process of implementation and upscaling.
6. The vehicle industry plays a very central role that cannot be played by other actors, and there is a risk that this industry takes on the role as gatekeeper.
7. The transport industry needs to take on new roles and form relations with new actors to reduce their resource dependence and dependence towards other actors.

## 6.2. Actors involved

The concept of battery-swapping encompasses a multitude of distinct stakeholders, as depicted in Figure 50. The need for involvement of different actors are also found in the literature, such as the following quote: *"for the battery-swapping transport revolution to happen there is need of involvement not only of the **automotive and battery industries**, but also of the **robotic and electrical device industries**, the **electrical grid operators** (particularly Distribution System Operators) and **national authorities**, present **fuel service station owners**, and, of course, **consumers**" (Vallera et al., 2021, pg. 6).* The difference between Figure 50 below and the original figure by Stahre (2023) targeting plug in solutions is the clear separation between the vehicle and the battery, as well as the new actors and activities related to the battery-swapping station.

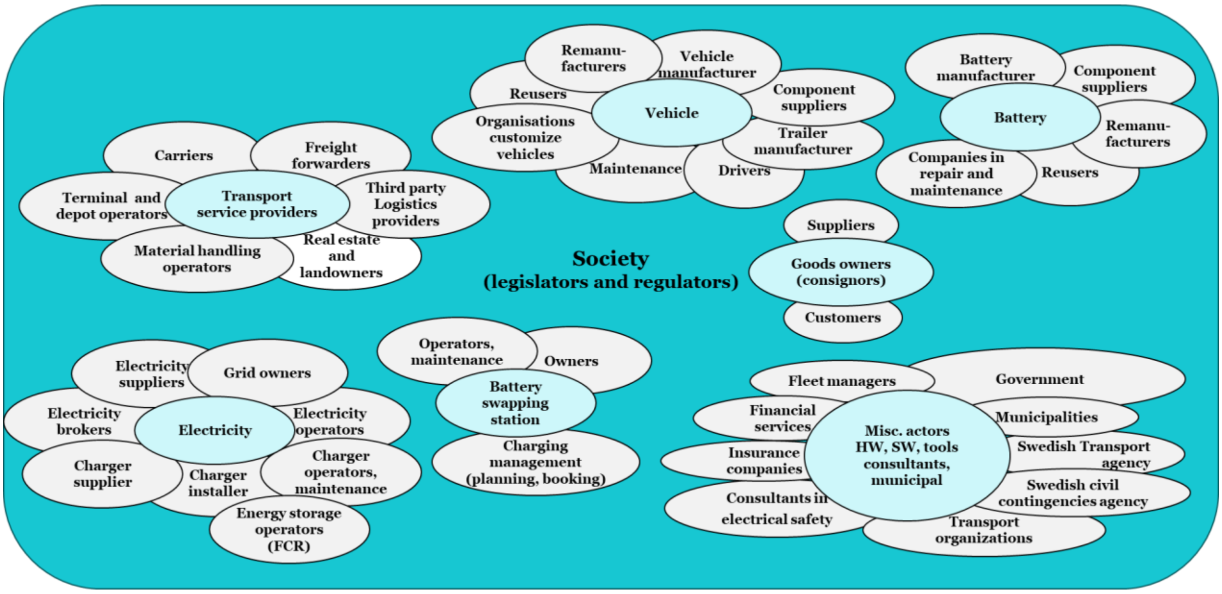


*Figure 50. Actors involved in battery-swapping. (Adopted from working material in the research project REEL by Stahre, 2023)*

## 6.3. Main actors and their roles

Amongst the key actors consistently present in all variants of battery-swapping systems, and more commonly put forward in the literature, are transport service providers, operators and proprietors of battery-swapping stations (BSS), electricity suppliers, vehicle manufacturers, and battery manufacturers. Nevertheless, it is imperative to acknowledge the significant roles played by various other entities in the facilitation and expansion of battery-swapping solutions. These include real estate and landowners, financial institutions such as banks, governmental authorities at local and national levels, as well as the proprietors of goods (see Figure 50). Below, some of the main actors are described in more detail.

**Transport service providers** (e.g., 3PLs and haulers) assume a pivotal role as the operators of vehicles integrated into the battery-swapping system. They may either own the batteries and vehicles themselves or lease them from unidentified actors. Transport service providers, in addition to their operational function, serve as the primary customer of battery-swapping stations. Studies into battery-swapping for personal cars have shown that BSS customers that own their batteries and vehicles have a different behaviour than those who subscribe to the service for battery leasing, charging, and swapping (Lidicker et al., 2011). The Swedish transport market is mainly characterized by a few large 3PLs and their transport supply chains with both 1st and 2nd tier transport providers, and a large extent of the companies are small firms with 1-3 employees.

**Operators and proprietors of battery-swapping stations** bear significant responsibilities in ensuring the consistent availability of charged batteries. They also play a role in warranting the quality of the batteries and exchanging damaged ones. Battery-swapping station operators emerge as key customers for electricity suppliers. Moreover, they play a crucial role as balancing actor within the electricity system, thereby mitigating customers' exposure to fluctuations in electricity prices—a substantial impediment to customer adoption, as evidenced in studies such as Weiller et al. (2015). Furthermore, the workforce required for the administration and operation of battery-swapping services significantly influences the cost and revenue structure of such systems, as elaborated in the research of Lidicker et al. (2011).

**Electricity suppliers** are essential in their role to provide the energy required to charge and power electric vehicle batteries. Apart from ensuring the batteries in the BSS are adequately charged, the energy mix used for charging is another parameter to consider. In particular, a switch to battery-swapping may entail requirements for enhancing the proportion of renewable energy in the electricity grid. This, in turn, might pose a challenge for electricity suppliers.

**Vehicle and battery manufacturers** play integral roles in both the development and assurance of high-quality and functional batteries and battery-swapping vehicles, so that BSSs in a next step make batteries accessible for the vehicles developed for this technique. This actor group, exemplified by companies like Tesla, has garnered considerable attention in the battery-swapping business model literature, as reflected in studies such as Feng and Lu (2021). Furthermore, they play central roles in the development of standards for batteries and can hinder the development if not all vehicle manufacturers are convinced and follow the suggested standard (Revankar & Kalkhambkar, 2021).

**Public policy,** and thereby policy makers, play critical roles as the infrastructure requires large initial investments and since authorities can facilitate cooperation between stakeholders (Valleria et al., 2021). Furthermore, in a battery-swapping initiative involving a Chinese enterprise it was put forward that swapping was supported by national policies regarding battery standards and battery-swapping safety requirements (Feng and Lu, 2021).

## 6.4. New roles

The concept of ownership versus leasing clearly underscores the flexibility in assigning roles within the system, indicating ample opportunity for both new and established actors to assume novel responsibilities. The extant body of literature on innovation posits a variety of central roles needed as new products enter the market. Nyström et al. (2014) enumerate seventeen distinct roles that organizations and individuals can undertake, encompassing functions such as coordinator, promotors, service and product developer, resource enabler, integrator, and contributor. It is noteworthy that actors within these networks can concurrently occupy multiple roles, and the nature of these roles may evolve in response to changing network dynamics, which also is true in a BSS setting.

Expanding upon the discourse on roles, this underscores the emergence of new roles awaiting suitable actors. Diverse forms of **promoters** play a pivotal role in this context. One example is **expert promoters**, who possess the required technological and managerial expertise with competences typically associated with battery and vehicle manufacturers and their suppliers. In both China and USA this role is played by, e.g., new strong and innovative technology driven firms. However, in a Swedish context the promotors have been rather absent according to the experts we consulted, and the few traces of actors playing part of this role has been travelling between transport service providers, energy companies and battery firms. Equally essential are **relationship promoters**, capable of transferring knowledge and mediating negotiations between different stakeholders. They serve to interconnect these actors and form the necessary networks crucial for facilitating the implementation and scaling of BSSs.

Another critical role in search of an actor pertains to financing battery-swapping solutions. Introducing new technology often entails substantial initial costs for building the requisite infrastructure. In this regard, **sponsors, investors, and promoters** are suggested to be indispensable. Furthermore, the identification of gatekeepers (i.e., actors controlling the access to something) assumes central significance in gaining access to the necessary resources.

## 6.5. Potential roles of transport service providers

The separation of batteries from vehicles enables transport service providers to assume diverse roles when it comes to the **ownership of central resource**s, as compared to traditional plug-in charging. Transport service providers can own, lease, or participate in a shared resource pool for technologies, including batteries and vehicles. For instance, they may own the vehicles while leasing the batteries or engage in a collaborative battery pooling system to have partial ownership of the batteries.

Moreover, transport service providers can **invest in infrastructure**, such as solar panels, thereby facilitating electricity supply, a function conventionally undertaken by energy companies. Battery-swapping offers more flexibility compared to plug-in charging, allowing transport service providers to strategically locate solar panels along their distribution systems, not necessarily confined to their terminal locations.

Transport service providers potentially serve as crucial **relationship promoters**, fostering communication between various stakeholders including transport buyers, vehicle manufacturers, and BSS operators. Larger 3PL operators can facilitate relationships with secondary transport suppliers, shippers, and vehicle/battery manufacturers, leveraging their central position in the network to identify gatekeepers and facilitate the transition to battery-swapping. In terms of **expert promoters**, transport service provider may also have a crucial role. Specifically, this actor has a unique competence about the logistics and transport needs of the logistics market. For battery-swapping to become a reality, there is a need for an actor-spanning understanding of, e.g. which transport flows that are suitable for this technology and for this, transport service providers have valuable expertise.

Despite their pivotal role, transport service providers may be reluctant to undertake **financial sponsorship** or investment due to the narrow profit margins prevalent in the transport industry (Piecyk and Björklund, 2016). Therefore, it is likely that other actors need to take this role. However, transport service providers can potentially take on the role of financial sponsorship if there is a possibility to transfer these costs to the transport buyers.

## 6.6. Relationships and actor dependencies

Relationships between actors are formed due to the need to get access to other actors' resources. This is one important point of departure in resource dependency theory, pioneered by Pfeffer and Salancik in 1978 and adopted by several researchers since, such as by Chu et al. (2021) and Huo et al. (2015) in a logistics context. They argue that when others take the existence of organisations for granted, they rather discuss how organisations manage to survive. A fundamental aspect of this is the ability to acquire and maintain resources. While this would be unproblematic if organisations were to exist in a vacuum, organisations in fact exist in the surroundings of other organisations and they depend on others for the necessary resources. They are embedded in a surrounding that is not dependable, meaning that it can change. Change can lead to organisations not surviving or to organisations changing in accordance with the changes in their surroundings. Electrification at large, as well as battery-swapping specifically, poses significant changes for logistics actors, causing them to adapt to such new circumstances.

In resource dependency theory, three determinants of dependencies between organisations are put forward: The *importance* of the desired resource, the *discretion* of the resource and the *concentration* of resource control. The *importance* of a resource can be measured in two different ways according to Pfeffer and Salancik (1967). The *relative magnitude* of an exchange is measured through the proportion of total inputs or proportion of total outputs accounted for by that exchange. An organisation that produces one product is more dependent on its customers that an organisation that produces a variety of products sold to a variety of markets. The *criticality* of the input or output is measured by the extent to which an organisation can cope in the absence of the resource or the absence of the market for the output. A resource can be critical even though it might not be the relative magnitude is low.

Next, the discretion of a resource is described as *"the capacity to determine the allocation or use of the resource." (p. 48).* There are four bases for the discretion of resources: *possession* of resources, i.e. who owns the resource and what effects does that have; *access* to resources, for which it is acknowledged that access is possible without ownership; the *ability to control* the use of a resource; and, lastly, the *ability to regulate possession* of resources though, for example, rules.

The third and final determinant of dependencies between actors is concentration of resource control (Pfeffer and Salancik, 1967). This determinant is related to *"the extent to which input and output transactions are made by relatively few, or only one, significant organizations" (p. 50).* One aspect of this is the possibilities of the focal organisation to be able to substitute sources for the same resource.

An analysis of the dependencies between the transport service provider and other central actors based on these determinants put forward in the literature follow:

Based on the different roles the transport service providers decide to play, different relations with different actors must be formed to facilitate implementation and upscaling of battery-swapping. Transport service providers heavily rely on **electricity suppliers**, who possess the crucial resource electricity for charging batteries. Please note that the energy and electricity suppliers operate within a complex system, and that this report does not aim to go into this system in detail. Nonetheless, given the indispensable role of electricity within the system, its control lies predominantly with these electricity providers. The presence of multiple electricity companies diminishes the reliance on any single entity due to their relatively substantial market presence, but the dependency of the actor group (i.e., electric suppliers) remains. To mitigate this dependency further, some transport service providers have begun investing in solar panels alongside the implementation of plug-in charging systems. This strategic move not only enables them to exercise greater control over the resource but also reduces their reliance on external electricity providers.

Transport service providers are also highly reliant on the vital resource provided by the **Battery-Swapping Station** (BSS), specifically concerning the availability of charged batteries at the required time and location. Without ownership and operation of the BSS, the transport service providers access to this resource may be constrained. Initially, the market may witness limited involvement, resulting in a high relative magnitude for those undertaking BSS operations. The dependence on BSSs can be alleviated through e.g., contract agreements between the transport service provider and the BSS operator, leading to increased resource access. One way for transport service providers to diminish the dependency on external BSSs, is to take control of the resource themselves and assume the role of BSS operators. This would, however, increase the number of other actors that the transport service providers are dependent on, such as energy operators. Furthermore, also other actors such as vehicle and battery manufacturers or entrepreneurial firms can take over the role as operating BSS, decreasing the relative magnitude of the exchange. However, compared to plug-in vehicles, battery-swapping might provide a shortcoming increasing the transport service providers' dependency due to limited number of potential BSS operators. For plug-in technology, the transport buyer (i.e., sender or receiver of the goods) can facilitate charging, something that is visible within the REEL project (The REEL project's homepage). However, it is not likely that the transport buyer steps in and take on the role of operating BSS.

The relationship between transport service providers and **vehicle- and battery manufacturers** hinges on the availability of functional vehicles and batteries, which are critical resources. However, the global market's vastness, with multiple manufacturers providing BSS-compatible vehicles, has led to a reduced relative magnitude and control of resources by vehicle manufacturers, subsequently lessening the transport service providers' reliance on them. Nevertheless, a certain degree of dependence persists, given that these resources are evaluated without the transport service providers adopting the role of manufacturers themselves. Currently, there is no availability of BSS vehicles in the Swedish market. In contrast to plug-in solutions, the ownership of vehicles and batteries can take various forms, including leasing and shared economies. Consequently, the augmented investment costs associated with the new technology can be managed through diverse approaches.

A relationship that exhibits fewer dependencies from transport service providers' perspective is the one concerning public policy, particularly in terms of legal requirements, such as those related to the work environment. Considering the relatively short duration required for swapping, there may be no necessity for transport service providers to alter vehicle routes. In contrast, for slower charging plug-in hybrids, the demands concerning driving and rest times might compel the transport service providers to reconsider distribution structures. It appears that public policy holds greater significance from the standpoint of vehicle- and battery manufacturers than for transport service providers, primarily owing to the imperative for the development of standards, among other factors.

Finally, the dependencies between the actors from a more financial/economical and product offering perspective will be further elaborated on in the business model chapter. One key finding applying this perspective is the dominant role of the technology provider towards the transport companies, as well as the transport companies being the system actor with the weakest financial strength.

## 6.7. Propositions

The key findings regarding the different roles and relations within the battery-swapping, this chapter can be summarized in several propositions:

1. There is a need to acknowledge the need for new roles and for actors to take on new roles.
2. A larger number of actors is needed both compared to traditional fuel (diesel) and plug-in due to the extra activity regarding operating Battery-Swapping Stations.
3. Other actors than the transport service provider needs to take on the role as financial promotor.
4. Transport service providers can play a critical role as expert promotor due to their understanding of the market's logistics and transport needs, as well as changes needed in the logistics system design.
5. Transport service providers needs to take on different roles in different phases of the process of implementation and upscaling.
6. The vehicle industry plays a very central role that cannot be played by other actors, and there is a risk that this industry takes on the role as gatekeeper.
7. The transport industry needs to take on new roles and form relations with new actors to reduce their resource dependence and dependence towards other actors.

## 6.8. References


Chu, Z., Hou, Y. & Wang, Y., (2021). "Examining guanxi as an environmental-dependency-coping strategy in China: A 3PL provider's perspective", *International Journal of Logistics Research and Applications*, Vol. 24, No. 5, pp. 511-529.

Feng & Lu, 2021: Construction planning and operation of battery swapping stations for electric vehicles: a literature review, *Energies*.

Huo, B., Liu, C., Kang, M. & Zhao, X., (2015). "The impact of dependence and relationship commitment on logistics outsourcing", *International Journal of Physical Distribution & Logistics Management*, Vol. 45, No. 9/10, pp. 887-912.

Lidicker, J., Lipman, T., Williams, B. (2011) Business model for subscription service for electric vehicles including battery swapping, for San Francisco bay area, California, *Transportation Research Record: Journal of the Transportation Research Board*, No. 2252, Transportation Research Board of the National Academies, Washington, D.C., pp. 83–90.

Nyström, A.G., Leminen, S., Westerlund, M. and Kortelainen, M. (2014), Actor roles and role patterns influencing innovation in living labs, Industrial Marketing Management, Vol. 43 No. 3, pp. 483-495.

Pfeffer, J., & Salancik, G. R. (1978). The External Control of Organizations: A Resource Dependence Perspective. Harper & Row.

Piecyk, M. I., & Björklund, M. (2015). Logistics Service Providers and Corporate Social Responsibility Sustainability Reporting in the Logistics Industry. International Journal of Physical Distribution & Logistics Management, Vol. 45, No. 5, pp. 459-485.

REEL project homepage: https://closer.lindholmen.se/projekt/reel

Revankar, S.R. & Kalkhambkar, V.N., Grid integration of battery swapping station: A review, Journal of Energy Storage, Volume 41, 2021, 102937, ISSN 2352-152X.

Stahre, F. (2023). Working material from the ongoing REEL project (financed by the Swedish Energy council), work package on business models.

Vallera, A.M., Nunes, P.M., Brito, M.C. (2021) Why we need battery swapping technology, Energy Policy, Volume 157, pp. 112481, ISSN 0301-4215.

Weiller, C., Amy Shang, Andy Neely, Yongjiang Shi (2015), Competing and Co-existing Business Models for EV: Lessons from International Case Studies, University of Cambridge. http://www.innovation-portal.info/wp-content/uploads/2015-January-Business-Models-for-EV.pdf (Accessed 20230907)

# 7. Business Models for Battery-Swapping in Sweden

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## 7.1. Summary

To describe and better understand the system of battery-swapping in Sweden, we are using a model describing different actors and its different roles in the system for electric trucks. For the moment (December 2023) there is no demand for fossil free freight and shippers are still buying transports primarily on price. From a systems perspective the truck manufacturers and grid-companies are dominant actors vs. their customer's (transport companies). However, with both truck manufacturers and grid companies being passive in a potential battery-swapping development, the transition to electric freight is very much left to transport companies to manage. Here, the goods owners/transport buyers are an important actor creating the necessary demand for fossil free freight in Sweden, e.g. from longer contracts with shippers to reduce the financial risk in investing in electric trucks.

In this context, battery-swapping has a unique advantage compared to cable-charging. The FCR-market (Frequency Containment Reserve) creates opportunities for actors to invest in battery and charging, as a complementary business (selling battery back-up to the electricity grid companies). This could be a driving force for e.g. transport companies to invest in battery-swapping trucks and battery-swapping stations. In terms of symbiotic business models (where the relationship between partners develops over time), we can also see that battery-swapping makes it possible to create regional infrastructures for charging, for regional transports.

Another important question is which transports are most suitable for battery-swapping, compared to cable-charging. Transport companies in our project argue that most of the large volume transports are more suitable for battery-swapping than cable-charging, in particular transports requiring extra charging during the day. Transports where battery-swapping has no specific advantage are transports requiring over-night charging only and regional less than truck load (LTL) transports.

In terms of efficiency for the transport company, battery-swapping is with its short swapping times, an enabler to increase vehicle utilisation and to use the vehicle in several shifts. In addition, the FCR-market in Sweden gives the transport-company (or a group of local transport companies) a business opportunity in owning their own battery-swapping station. Then, battery-swapping is an electrification-driver for a transport companies – where revenues from the FCR-market may compensate for the higher electricity costs and vehicle costs.

With a focus on transport companies and their business models, this chapter summarizes following key findings:

1. There is no market demand for electric freight and no demands on electric trucks in Sweden today.
2. Battery-swapping is an enabler for a more profitable transport company industry.
3. Introduction of battery-swapping for goods transports in Sweden will likely speed up the transition to electric freight.
4. Battery-swapping allows electrification of freight to be local or regional.
5. Battery-swapping is an electrification-driver for a transport companies – where revenues from the FCR-market may compensate for the higher electricity costs and vehicle costs.

## 7.2. Business models in theory

Swedish transport providers in general have modern vehicle fleets, which has allowed the conversion to alternative fuels, e.g., renewable diesel, to be relatively simple if you have been able to use existing vehicles and the same fuel infrastructure. A market was therefore quickly created for e.g., HVO in Sweden, which could take place within the framework of the transport providers existing business models. However, a conversion to electric trucks requires completely new business models because they are significantly more expensive than the equivalent diesel trucks and the infrastructure for charging does not exist today. Battery-swapping requiring an infra structure with battery-swapping stations is adding another complexity compared to existing business models for the goods transport industry.

Theoretically, a business model can be defined in many ways. The most common model is the business model canvas (Osterwalder et.al., 2005 and Osterwalder & Pigneur, 2010), defining a business model from its 4 pillars and 9 building blocks. In this project and in line with the theories on resource-based view of the firm, we consider electric trucks to be a "resource leading to a competitive advantage that is hard to imitate" for competitors with e.g., diesel trucks only (Barney, 1991, Barney & Clark, 2007).

Much of the literature on battery-swapping in the business model domain primarily focuses on Battery-Swapping Stations (BSS) for private cars and taxis (examples can be found in Feng & Lu, 2021; Lidicker et al., 2011; Wu et al., 2022; Liang & Zhang, 2018; Zhang et al., 2018), rather than for trucks. Weiller et al. (2015) proposed two distinct business model forms for electric vehicles (encompassing both swapping and charging). These models differ based on their focus, one addressing barriers to consumer adoption (such as reduced battery ownership costs, minimized customer exposure to electricity price fluctuations, risk sharing among stakeholders, and addressing range limitations), while the other concentrates on value creation and capture (including technological innovation, intelligent charging infrastructure, and flexibility in the business model). In comparing one business model for battery-swapping (BYD's business model) and fast charging (Wanxiang's business model), Weiller et al. (2015) identified significant differences in battery costs, upfront vehicle costs, customer exposure to electricity prices, and risk distribution, with the swapping model having greater advantages in addressing adoption barriers, especially related to EV purchasing costs. In the research identified, we notice that business models have evolved with a strong focus on vehicle manufacturers in the passenger car business (such as Tesla) and entrepreneurs, as more entrepreneurs have entered the battery-swapping market (Feng and Lu, 2021).

The company in focus in this study is the transport company investing in electric trucks and e.g., swapping stations. A business model for these transport providers should describe how this operative resource, the electric trucks, can be used to provide value for customers and society in terms of fossil free transports and a swift electrification of freight. Therefore, we are using a more generic way to describe a business model, including three mutually dependent parts; the market position (relating to customers), the offering to customers (relating to values provided) and operational resources needed to provide these services (relating to the total costs for the services provided) (Kindström, 2005). The business model used in this project is described in Figure 51 and is also used in other projects related to logistics systems (Björklund et.al. 2017, Abrahamsson, 2017, REEL).

The market position describes which customers segments requiring in this case electrified transports, the relation the company should have with these customers (contracts, planning etc.) and which position to take on market in relation to other transport solutions (e.g., with HVO and diesel trucks) or other companies providing electrified freight.

In terms of the offering to customer, electric freight with battery-swapping is creating value for the customers (e.g., less carbon footprint for the customers products) but also for the society (less emissions from the transport sector, less noise, etc. and a swift transition from diesel to electric goods transports). In our model, value propositions targeting different groups of customers willing to pay for electric goods transports are fundamental in generating the revenue streams necessary to cover the extra costs for electric trucks compared to diesel trucks. These values define the potential revenues from electric freight.

The operational resources should contribute with high efficiency (services produced to low costs) but is also defining what the company can offer customers in terms of offered services (Abrahamsson, 2017 and Sandberg & Abrahamsson, 2019). Fossil free transports are such an offering requiring electric trucks as a resource. More specific, the operative resources needed to provide the service offered to customers is represented by the total costs for the operation of electric trucks in daily business, including vehicle costs, charging costs, vehicle utilization etc. The resources can include own resources as well as those which are available from various partners, which in this project can be partners providing battery-swapping stations. Then the resources needed includes availability of charging infrastructure, the relation between key actors in the system, and general market development. In addition, we can discuss how the society can be more active in the transition to electric freight by promoting different components in the business model e.g., with different incentives to maximize social values.

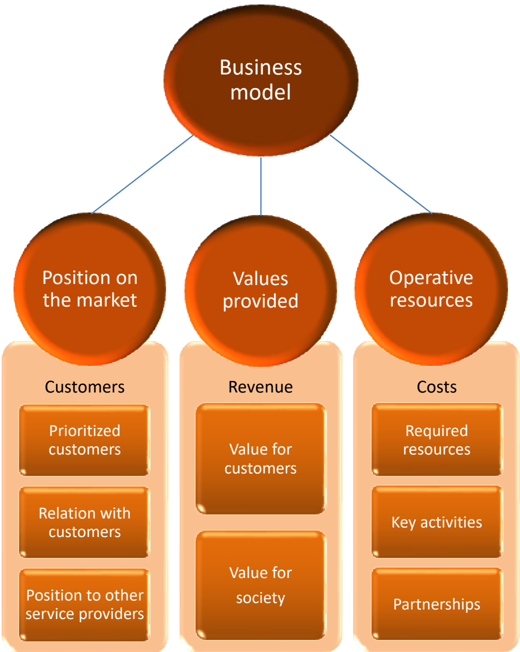


*Figure 51. Components in a business model for electric freight.*

A fundamental approach is that a business model requires a market on which the services are provided, generating revenues to the company. In consequence, if there are no demands from customer, there is no market for the actual business model.

Based on this the business model should provide answers to a range of different questions:

- What are the key values in electrification of freight?
- Is there a market big enough for at transition to electric trucks?
- Are there new transport demands on the business as a consequence of the transition to electric trucks?
- In which markets, segments and industries do we find short term and long-term customers?

- What resources and capabilities are needed in the system as a whole and which actors need to be involved (Shippers, Transport providers, Grid companies, Truck manufacturers, Society, battery-swapping station providers, etc.).

In addition, there are societal values to be considered in electrifying freight, e.g., in terms of efficiency, which include factors that can help facilitate electrification, e.g., to allow electric trucks to distribute in cities at night or low peak hours, which would make the logistics system as a whole more efficient.

## 7.3. The systems perspective – The transport- and logistics system

The resource requirements for battery-swapping significantly differ from those for battery charging, including factors like space needed at location site, charging infrastructure, and grid support. Additionally, fuel is commonly purchased before it can be sold (Swapnil et al., 2021), as opposed to electricity. Therefore, a systems perspective is crucial to understand the context for the business model for battery-swapping and what is required in terms of e.g., infrastructure to initiate and develop a battery-swapping system on a market. Early studies were rather pessimistic, estimating that it would take 6 to 15 years to become profitable due to expensive technology and an immature and small market (Lidicker et al., 2015). Early failures in battery-swapping system implementation can be attributed to the substantial investments required for establishing the infrastructure (Wu et al., 2022). Feng & Lu (2021) note that the battery-swapping system market for cars initially remained small, which hindered large investments required due to the high costs associated with battery-swapping system construction. Earlier studies also indicates that more than 50% of the cost shares of Electric Vehicles (EVs) are attributed to batteries (Swapnil et al., 2021).

There are two key factors affecting the life-cycle net income of battery-swapping systems in literature: battery cost and battery-swapping price (Liang et al., 2021). Batteries can be owned or leased, resulting in a significant reduction in the vehicle's acquisition cost (Ban et al., 2021; Swapnil et al., 2021; Mahoor et al., 2019). But leasing the battery also reduces risks related to degradation and replacement for the vehicle owner (Ban et al., 2021). In consequence, factors influencing cost and revenue structures include the number of subscribers, the personnel required to operate the service, and administrative aspects related to subscribers (Lidicker et al., 2011). Based on passenger electric cars with battery-swapping, Feng & Lu (2021) propose a revenue-generating approach where customers pay a service fee for using the charging station. Vehicle owners may in these systems incur additional charges to cover the health gap of the swapped batteries for leased batteries (Swapnil et al., 2021).

To describe and better understand the system of battery-swapping for trucks in Sweden, we are using a system model describing different actors and its different roles in the system for electric trucks on the Swedish market, in which battery-swapping is a technology for charging the trucks, see Figure 52. In such model various operation technologies with different system designs and scales can be applied, including a single battery-swapping station, multiple battery-swapping stations, an integrated battery-swapping station and battery charging station, and multiple battery-swapping stations and battery charging stations (Wu, 2021).

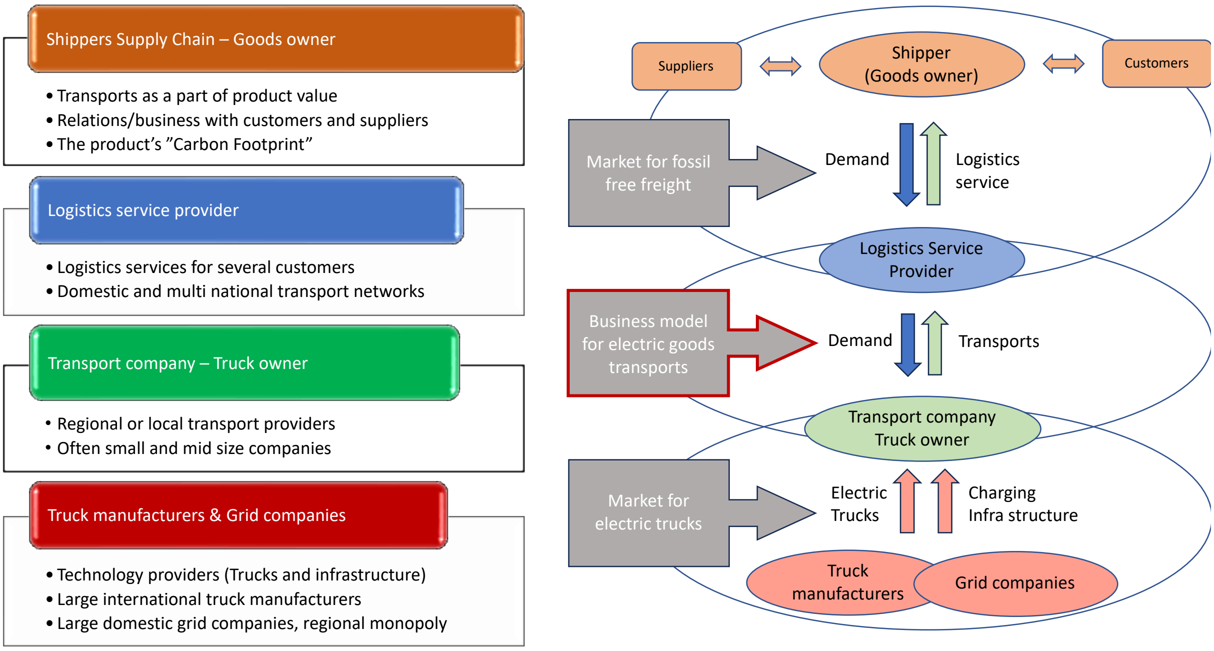


*Figure 52. A system model for electric goods transport.*

A prerequisite for economically sustainable business models for the different actors (as the transition works in Sweden, with business as the initiator and driver for change) is that there is a market (demand) and that there is a willingness to invest in electrical technology (battery-swapping stations and battery-swapping trucks). If this does not exist, then it is required that the government builds or initiates new infrastructure for, in this case, battery-swapping (which we do not see as likely).

Based on the actors in Figure 52, we can conclude that:

- For the moment (December 2023) there is no solid demand for fossil free freight. Shippers are still buying transport primarily on price (Trafikanalys, 2022).
  - However, we can expect this to change in the future (market driven or forced by society)
- From a systems perspective the technology providers are dominant actors vs. their customer's (transport companies), both financially and in the offerings of products and services. It is more or less a power relationship between truck manufacturers and haulage companies, where the haulage companies are closely tied to the manufacturers' technology and aftermarket.
- In addition, the transport companies, who is expected to do the investments in electric truck, are probably the weakest actor in the system in terms of financial strength (Transportstyrelsen 2020).
  - This is confirmed in an article in SvD (20231025) where Scania's VD confirms that the order intake for all-electric trucks is far from satisfactory. Scania have a capacity to deliver 25 000 – 30 000 BEV per year but have only sold 200 BEV the first 9 month of 2023. This is valid also for Volvo where BEV's only only counts for 1,5% of the trucks sold.
- For the moment (December 2023) existing providers of technologies are not offering and have no plans to offer battery-swapping technologies.

From a systems perspective, battery-swapping is offering possibilities to a fast transition to electrified freight – where several types and sizes of trucks can be electrified simultaneous with relative short implementation times if using existing (Chinese) technologies and standards. In addition, the potential battery lifetime will be longer compared to cable-charging, because of slow charging in optimal conditions. The connection to the grid will be gentler with less energy required for each station (compared to fast cable-charging stations). This means that battery-swapping has the potential to "protect the electricity grids", e.g., in a limited geographical area avoiding peaks in the electric system and the batteries in a battery-swapping station can be used as energy storage. These are important factors, with potential to drive the development towards battery-swapping.

We also do not see the grid companies taking on this issue. In terms of business models, we therefore focus on the business models of hauliers (battery-swapping trucks) as well as other actors who invest in the necessary infrastructure (battery-swapping stations with batteries).

For the transport company, based on our interviews in the project, who is expected to invest in electric trucks, we have identified following opportunities and challenges with battery-swapping as a technology for electrification.

*Table 4. Opportunities and challenges with battery-swapping.*

| Opportunities | Challenges |
|---|---|
| Vehicle utilization: Battery-swapping is faster than cable-charging | The industry has weak profitability and cannot handle the financial risk from large investments in a new technology |
| Battery size can be adapted to the actual transport task | Diesel is still a very good and profitable alternative |
| Battery-swapping stations can be mobile | Price pressure on transports, which is considered by the buyers as a standard commodity with low value |
| Better match between the lifetime of the vehicle (> 10 years) and that of the batteries (< 5 years) | New players in the system with financial muscle may be needed, which can lead to major challenges for existing transport companies |
| Less financial risk if you don't own the battery yourself | |

Another important actor in the transition to electric freight is the truck manufacturers, which is a large and important industrial business sector in Sweden and in the EU with a big impact on the goods transport industry. We have identified large challenges with battery-swapping as a technology for the truck manufacturers. The most important challenge (according to our contacts at e.g. Scania) is that they want to have control over the batteries in the trucks, because it is both a critical component and a large part of the total cost for the truck. We also think that truck manufacturers in the EU are afraid that an introduction of the battery-swapping technology will make it easier for Chinese competitors to compete on the European market. With no European standard for battery-swapping developed in Europe and no sharp agenda for the transition to fully electrified freight, rises questions marks for the truck manufacturers. In consequence, they see more problems than benefits with one more charging technology to develop, in which there might be other strong actors in the eco-system for freight. This means that we are not expecting the truck manufacturers to drive the market of battery-swapping in Sweden.

With both truck manufacturers and grid companies being passive in a potential battery-swapping development, the transition to electric freight is too large for today's hauliers to manage themselves. Simply because they don’t have the financial conditions to take the costs for electric trucks, within existing business models, in a large-scale transition. However, battery-swapping provides the opportunity for more players to share the investments by differentiating between ownership of the trucks (the transport companies) and the batteries (other actor). A prerequisite for this is that there is a market for another actor in ownership of batteries and charging. This in turn requires a rapid scale-up that creates volumes for such a market as the basis for a financial sustainable business model. Initially, it will require close relationships between transport companies, battery operators but also goods owners (shippers) buying transports, to create economic conditions for electric trucks.

However:

- In terms of business models, the demand for fossil-free transports is the basis for electric freight (a demand that does not exist today). Only when such a market exists, it is possible to evaluate whether there is a market for the technology battery-swapping or not. Here, the goods owners/transport buyers are just as important actor as the transport companies.
- The FCR-market (Frequency Containment Reserve) as it looks today creates opportunities for actors to invest in battery and charging, as a complementary market (selling battery back-up to the electricity grid companies). This also requires a long-term perspective on the market conditions, as this is a driving force for new players to invest in the transition.
- In terms of symbiotic business models, battery-swapping has the advantage that it is possible to create regional infrastructures for charging, for transports that are primarily regional. Creating such clusters with battery-swapping stations and transport companies with battery-swapping trucks is something that can be done on a regional basis.
- In the same way, there are opportunities to create regional demand for fossil-free transport, by large regional players working together to create such a market/demand. It can be important players in an industry with large transport needs, e.g., in the construction industry, the forestry industry, last mile distribution, etc. Here, the public sector has an important role in driving development in those industries where, through their own transport needs, they are a large transport buyer (e.g., in the construction industry where the municipal public housing companies are often the dominant developer). See e.g. the CoZev-initiative (https://www.cozev.org).

Another observation slowing down the transition to electrification of freight, is that society has an overconfidence in market forces to do the transition. However, there are no clear rules for the market to take the lead. Instead, there is a fear for Chinese technologies on the Swedish market and there are no financial incentives for the market actors to drive the transition. Instead, the authorities in Sweden have decided to focus on and promote two other technologies for electrification of freight, cable-charging and electric roads, where the trucks are charged while running. However, in august 2023, Trafikverket decided to stop the first full-scale electric road project between Örebro and Hallsberg because of much higher construction costs than expected. In this context, we think that battery-swapping can also be a cost-efficient alternative to electric roads.

## 7.4. Experiences from China

Experiences from China indicates that there is no standard solution for how to design a battery-swapping system, with its actors and their roles. However, with the market maturing the most common model seems to be a “vehicle/battery value separation” where:

- The transport company are buying the truck without a battery from the truck manufacturers and rent or lease the battery from a battery asset company.
- The vehicle operator pays a battery rental fee for the right to use the battery for e.g a year and another fee each time they swap battery.

In consequence the purchase price for the electric truck will be lower and the risk in term of battery depreciation over time will be reduced. This means that the start-up costs for the transport companies will be lower – after paying a deposit for the battery they can start operating the truck. And transport company can increase or reduce the battery size if operational demands for their truck change (Liu & Danilovic, 2021).

Battery asset companies, owning batteries and swapping stations, can store and recharge batteries of different capacities and sizes for different demands from the truck companies. These companies are in China energy producer, truck manufacturers or private equity companies. In all cases this value separation of vehicle and trucks opens for a new battery-market, optimizing the use of the battery, its lifetime and after lifetime market and optimizing how the batteries are charged in relation to the regional grid prerequisites (Liu & Danilovic, 2021).

In China the market for battery-swapping is maturing and different market actors and roles have been developed during the last five years. In Sweden there are no actor on the market driving the introduction and development of battery-swapping for heavy vehicles. In consequence and in short term the transport company is very likely to take both their traditional role investing in electric vehicles and the role on investing in and managing the swapping stations.

## 7.5. The transport company's business model

In terms of business model for battery-swapping, there are some critical issues from a transport company perspective relating to the different components of the business model:

### 7.5.1. Position on the market

The market for fossil free freight, is totally dependent on the demand for such services on the transport market. A demand that needs to be much bigger than today. Electric trucks on the roads today are primarily demo-trucks and there is no demand for fossil free freight large enough to drive a rapid transition to electric freight (SvD, 20231025). In consequence, it is hard to identified market segments willing to pay extra for fossil free transports, making these transports profitable.

Even if there are some reports on cases where electric trucks can be competitive compared to diesel trucks, it is hard for a transport company themselves to deliver such services. Considering the investment in electric trucks is much higher than an equivalent diesel truck, the transport companies need longer contracts with shippers to reduce the financial risk. Such risk reduction requires logistics partnerships with shippers, e.g., 3-5 year contracts instead of one year contract which is common today. This requires a direct relation between the transport company and the shipper, and in many cases a truck dedicated for that specific shipper.

Another important question is which transports are most suitable for battery-swapping, compared to cable-charging. Our dialogues with transport companies gives at hand that most of the large volume transports are more suitable for battery-swapping than cable charging, from a transport company perspective, including transports requiring extra charging during the day, e.g.:

- Forest products - Regional transports, large volumes (Full Truck Load)
- Agricultural products - Regional transports, large volumes (Full Truck Load)
- Gravel & construction materials - Local transports, large volumes (Full Truck Load)
- Groceries & general goods to retailers - National transports with high volume (Full Truck Load)
- Industrial supplies – National transports, with long distances (Less than Truck Load)

Transports where battery-swapping has no specific advantage are transports requiring over-night charging only and regional less than truck load (LTL).

Position on the market is also about the relation to other service providers, e.g., any other existing actors who can invest in battery-swapping stations. However:

- Both truck-manufacturers and grid companies are passive in the market development for battery-swapping.
- In the existing eco-system for goods transports in Sweden, there are no logic actor who can develop a battery-swapping infrastructure in short term.
- But battery-swapping can be a business opportunity for other actors, not yet in the transport sector, e.g., new start-ups or private equity companies, or companies now investing in charging infra-structures for cars.

### 7.5.2. Values provided.

The value for customers with electric freight is twofold. First it will make the total carbon footprint for the shippers smaller, and it will have a market value for some the shippers. With battery-swapping the availability of the trucks will be higher compared to cord charging, which makes it possible for the logistics service providers to offer a larger portfolio of fossil free freight services to the shippers.

The value for society is the potential of faster transition to fossil free freight with battery-swapping, compared to cable-charging, because of gentler impact on the grid and more transport sectors that can be electrified.

### 7.5.3. The operative resources with battery-swapping

The parallel REEL-project (where many of the demo-trucks in Sweden are included), indicates almost a cost parity in total costs of investing in and operating an electric truck compared to equivalent diesel trucks, e.g., about 4,25 MSEK per year (27-ton truck operating in 2 shifts, operating 250 km/day). These calculations are based on cases where the transport companies also own their charging stations, electricity prices on 1,25 kr/kwh and 20% public co-funding for the truck and 40% public co-funding for the charging stations. The figures do not include the extra costs for setting up the electrified operations, neither interest rate which can be significant, as electric trucks requires heavier investments. On the other hand, the figures do not include maintenance costs, which is expected to be lower for electric trucks. To summarise, the figures do indicate that there is a potential business case for electrification.

Battery-swapping as an operative resource has some advantages compared to cable-charging BEV’s, summarised in Table 5 below.

*Table 5. Differences between cable (cord)charged BEV´s and battery-swapping.*

| Descriptions | BEV – Cord charged | Battery Swapping | Benefit / SWOT |
|---|---|---|---|
| Concept explanation | Battery electric vehicle, with Bounded battery<br>Charging time > 45 minutes | Vehicle with possibility to swap batteries and also use cable charging. Swapping time 5-10 minutes | Higher Vehicle utilisation |
| Purchase | Vehicle owner buy complete vehicle concept from start and have to decide battery capacity for whole lifetime | Vehicle owner buy vehicle separate from battery. Battery can be bought or rented. Means separating cost parameters | Flexible ownership in LCA. Minimize owners' risk of miss calculated investments |

| Descriptions | BEV – Cord charged | Battery Swapping | Benefit / SWOT |
|---|---|---|---|
| Finance - Fixed /unbounded cost | Buy Vehicle + Battery = high fixed cost | Buy vehicle + rent battery capacity = Higher factor of non-fixed cost | Lower finance risk with BS and lower investment cost → enables faster electrification of freight |
| Purchase strategy | Need to decide battery capacity for total lifetime. Risk factor of "buy to big battery" | Flexible battery capacity calculation. Start with small, then adjust. Change strategy if the transportation mission will change | Cost and climate footprint reducement |
| Use case | Fits for 1 working shift. Hard to enable 2 working shift due possible charging time or effect | Enables 2 working shifts. | Divide/half fixed cost in two business/use case. Big impact TCO to reach cost parity |
| Lifetime – low/high effect charging | Big factor of high effects charging (over100 kW) shorten its lifetime | Low effect charging in controlled BS-stations BMS (Battery management system) | Extended lifetime (+1-2 year) will reduce cost. |
| Charging cost → high effect | Big factor of high effect charging need. Depot and Public | Low factor of high effect charging need. | Affects total energy cost. Mostly affect BS operators cost but will affect vehicle owner |
| Loading capacity | Bigger battery size = heavier vehicle = decreasing loading weight | Smaller battery size = Higher loading weight = closer to today's planning / loading capacity | Enables higher transport efficiency and planability |

However, in short term, investments in battery-swapping trucks will very likely also require investments in battery-swapping stations, because there is no public battery-swapping infrastructure in place. We have identified following issues for a transport company investing in battery-swapping stations:

- In terms of efficiency, battery-swapping is with its short swapping times, an enabler to be able to increase vehicle utilisation and to use the vehicle in several shifts.
- In terms of plannability, battery-swapping can reduce uncertainty for transport companies in the cost of electricity and thereby increase plannability.
- The existing FCR-market in Sweden gives the transport-company (or a group of local transport companies) a business opportunity in owning their own battery-swapping station.
- With a FCR-market – battery-swapping is an electrification-driver for a transport companies, including trucks and battery-swapping stations.
- Battery-swapping stations connected to the FCR-market may also have a positive impact on price fluctuation on electricity – where revenues from the flex market may compensate for the higher electricity costs.

## 7.6. Total costs for a transport company with its own battery-swapping station

The Swedish transport industry is dominated by rather small transport companies, with less than 10 trucks and with low profitability. The profit margin in the industry is low, only about 5%. This makes it difficult to invest in fleets of BEV, required for the fast transition to fossil free freight expected by the authorities. In this context, battery-swapping seems to be a good opportunity, if the company are investing in its own battery-swapping station for serving a fleet of battery-swapping trucks and to be a part of the FCR-market for extra revenues.

A detailed calculation of the total costs for different trucks, shows that a BEV is about 200 000 SEK more expensive per year, due to bigger investment costs, se Table 6 below.

*Table 6. Cost calculation for different trucks.*

| | Fossil diesel | HVO | RME | Biogas, flytande LBG | Biogas, gasform CBG | BEV Cord charging | BS-station for 7 Batteries 2,5 MWh |
|---|---|---|---|---|---|---|---|
| **Investment** | 699 877 | 699 877 | 707 444 | 775 544 | 775 544 | 903 653 | 3 387 120 |
| **Energy** | 207 130 | 207 130 | 530 380 | 285 880 | 386 830 | 235 700 | 1 964 300 |
| **Service & Maintence** | 81 850 | 81 850 | 76 567 | 89 950 | 75 100 | 64 845 | 100 000 |
| **Personal** | 647 934 | 647 934 | 647 934 | 647 934 | 647 934 | 647 934 | 700 000 |
| **Overhead** | 143 637 | 143 637 | 143 637 | 143 637 | 143 637 | 143 637 | 150 000 |
| **Total cost/year** | 1 780 428 | 1 780 428 | 2 105 962 | 1 942 944 | 2 029 044 | 1 995 769 | 6 301 420 |

This project indicates that battery-swapping gives the transport company a potential extra income if connecting their battery-swapping station to the grid and be a part of the FCR-market (Frequency Containment Reserve). We have estimated the total cost for a battery-swapping station on 2500 kWh and 7 batteries, serving 7 electric trucks, to 6,6 MSEK per year, based on following cost components:

- Estimated cost for such battery-swapping station is 10 000 kr/kWh = 25 MSEK
- Depreciation on 7 years and rest value of 20% and interest rate of 3% is equal to about 3,3 MSEK/year in investment costs.
- If each battery is fully charged every day (3,5 SEK/kWh), 250 days per year. The cost for charging will be 2500 x 250 x 3,5 = 2,2 MSEK per year
- Additional costs for insurance, handling, OH-costs etc. is estimated to 1 MSEK per year.

Figures from the company Vialumina on the potential revenues on the FCR-market, indicating that a battery-swapping station on 2500 kWh, connected 50% of its time to the grid can generate revenues about 10 MSEK on the FCR-market, equal to a profit on 3,4 MSEK per year.

This very indicative calculation, shows that a transport company investing in a battery-swapping station, has a significative potential revenue on the FCR-market. However, it also shows that such investments require a fleet of 7 or more electric trucks in operation.

Our cost calculations indicate that the total annual costs for these trucks, will be about 235 000 SEK cheaper than an electric truck for cable-charging (calculated charging costs/year), equal to the total cost for a diesel truck. In this calculation, we have not considered the costs for charging time. For cable charging the charging time is at least 45 minutes (up to 80%) while the time for swapping batteries is expected to be 5-10 minutes (100% charged battery). For many transport companies this difference is of major importance for the total availability of the truck.

Considering the high cost for a battery-swapping station, direct investments in battery-swapping stations, where several transport companies are sharing a battery-swapping station is of potential interests. It is similar to today's sharing systems for fuel pumps, where a transport company let other transport companies using their diesel station. Such common investments are easier with battery-swapping than with fast charging stations because battery-swapping stations requires less grid capacity, as long as the swapped batteries a slow charged during low-peak hours. Local based cooperation's between transport companies and/or providers of battery-swapping stations, located where the grid can provide sufficient energy could be a driver for faster electrification of freight.

## 7.7. Hypothesises on battery-swapping relating to business models.

Based on the business model analysis above and the fact that if companies that will invest in and operate electric trucks are not profitable, there will never be any transition to fossil free freight in Sweden, we have defined following three hypothesises:

1. *Battery-swapping is an enabler for a more profitable transport company industry.*

This hypothesis is supported by following logics:

- Battery-swapping enables electric trucks to become more profitable than cable-charged trucks.
    - Shorter stops, higher flexibility
    - Less interference for power grid restrictions
- A battery-swapping station becomes an alternative source of income through the Flex business.
    - The battery-swapping station is connected to the power grid and becomes part of the local capacity equalization.
- Own battery-swapping station can give the transport industry better control over its total costs and capacity.
    - This includes being able to buy a truck without a battery - where the batteries are leased for the different trucks used.

2. *Introduction of battery-swapping for goods transport in Sweden will speed up the transition to electric freight.*

This hypothesis is supported by the following logics:

- A haulage company that invests in a battery-swapping station can build up its own fleet of electric trucks more quickly.
    - Battery-swapping offers greater flexibility in the planning of the vehicles compared to cable charging, allowing higher vehicle utilisation to be able to drive 2 shifts.
        - This means that several different types of transport can be electrified.
        - This also allows for alternative use of the trucks (different batteries for different missions)
    - Battery-swapping makes less demands on changes to the electrical system compared to fast charging stations.
        - A battery-swapping station requires 2-3 MW – Slow charging of 8-20 batteries.
        - Dependence on e.g., the grid companies' regional expansion is decreasing.
- A battery-swapping station can be shared between several haulage companies.

- The existing "Flex market" is favourable for such investments.
- Subsidies for investments in electric trucks and in battery-swapping stations for companies would accelerate a transition to electric freight transport.

3. *Battery-swapping allows electrification of freight to be local or regional.*

This hypothesis is supported by the following logics:

- Battery-swapping enables clusters of transport to be electrified at once.
    - Instead of today where haulage companies buy car by car.
- A battery-swapping station with 7 batteries enables at least 80 battery changes per day.
    - This makes it possible to service a fleet with e.g., construction vehicles in a city or cluster of local distribution vehicles, etc.
    - A mobile battery-swapping station could support large civil engineering projects, e.g., "Ostlänken" or regional trucks in the forestry industry.
- Such a battery-swapping station can be shared between different transport companies or run by a separate company in an industry sector.
    - This enables new actors to be active in the transition on commercial grounds.

## 7.8. Referencies:

Abrahamsson, M., Affärsmodeller för citylogistik & samordnad varudistribution – Handbok för kommuner och private aktörer, Forskningsrapport LiU-IEI-RR—17/00283-SE, 2017.

Björklund, M., Abrahamsson, M. & Johansson, H. (2017), Critical factors for viable business models for urban consolidation centres, Research in Transport Economics, vol 64, pp 26-47

Osterwalder, A., Pigneur, Y., & Tucci, C. (2005). Clarifying business models: Origins, present, and future of the concept. Communications of the Association for Information Systems, 16, 1–25.

Osterwalder, A., & Pigneur, Y. (2010). Business Model Generation – A Handbook for Visionaries, Game Changers and Challengers. Hoboken, New Jersey: John Wiley and Sons, Inc.

Kindström, D. (2005). The integration of E-business into mature and established companies—A business model approach. Linköpping Studies in Management and Economics, 67, Dissertations from IMIE, No. 96.

Barney, J. (1991). Firm resources and sustained competitive advantage. Journal of Management, 17(1), 99–120.

Barney, J., & Clark, D. (2007). Resource-based theory: Creating and sustaining competitive advantage. Oxford, England: Oxford University Press. Logistics-Based Business Model 141

Sandberg, E & Abrahamsson, M., Logsitikdriven affärsutveckling, Studentliteratur, Lund, 2019

Ban et al. (2021): Mingfei Ban, Zhanpeng Zhang, Chengyu Li, Zhenjie Li, Yiqi Liu (2021), Optimal scheduling for electric vehicle battery swapping-charging system based on nanogrids, International Journal of Electrical Power & Energy Systems, Volume 130, p. 106967.

Feng & Lu, 2021: Construction planning and operation of battery swapping stations for electric vehicles: a literature review, Energies, 2021

Liang, Y., H., Cai, H., Zou, G.  (2021): Configuration and system operation for battery swapping stations in Beijing, Energy, Volume 214, p. 118883

Liu, J. L., & Danilovic, M., Exploring Battery Swapping for Heavy Trucks in China 1.0, Sweden-China Bridge, Report 2021-2, September 2021.

Lidicker, J., Lipman, T., Williams, B. (2011) Business model for subscription service for electric vehicles including battery swapping, for San Francisco bay area, California, Transportation Research Record: Journal of the Transportation Research Board, No. 2252, Transportation Research Board of the National Academies, Washington, D.C., pp. 83–90.

Swapnil R. Revankar, Vaiju N. Kalkhambkar, (2021) Grid integration of battery swapping station: A review, Journal of Energy Storage, Volume 41

Trafikanalys, rapport 2022:2, Godstransporter och konkurrenskraftens utveckling

Transportstyrelse, Rapport 2020-2586, Transportmarknaden i siffror 2019 Översikt av utvecklingen på marknaderna för väg- och järnvägstransporter

Weiller, C., Amy Shang, Andy Neely, Yongjiang Shi (2015), Competing and Co-existing Business Models for EV: Lessons from International Case Studies, University of Cambridge. http://www.innovation-portal.info/wp-content/uploads/2015-January-Business-Models-for-EV.pdf (Accessed 20230907)

Wu, H. (2022), A Survey of Battery Swapping Stations for Electric Vehicles: Operation Modes and Decision Scenarios," in IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 8, pp. 10163-10185.

Wu, S., Zhuge, G., Han, W Xie  (2022): Economics of Battery Swapping for Electric Vehicles—Simulation-Based Analysis Y - Energies

Zhang, T., X Chen, Z Yu, X Zhu (2018), A Monte Carlo Simulation Approach to Evaluate Service Capacities of EV Charging and Battery Swapping Stations, in IEEE Transactions on Industrial Informatics, vol. 14, no. 9, pp. 3914-3923

# 8. Strategic Business Models for Battery-Swapping, including Harbor Transport Systems

Authors: Professor Mike Danilovic, Dr. Jasmine Lihua Liu, Dr. Harrison John Bhatti.

## 8.1. Abstract

This chapter explores and proposes a business model for establishing battery-swapping solutions for electric heavy trucks (EHT) in Scandinavia, focusing on truck and battery-swapping station operators.

The proposed business model for battery-swapping stations is designed to be both financially and operationally practical. It involves leasing the trucks and their batteries rather than buying them altogether. Additionally, there's a subscription-based model for swapping batteries. This allows truck owners to exchange their discharged batteries for fully charged ones. They also have the option to recharge their trucks using cable charging if they prefer. We suggest adopting a franchising model for the battery-swapping stations to support this system. This approach will ensure consistent support, regular software updates, and ongoing research and development to improve the system over time.

Here, we can present the expected economic outcome of those two business models:

**OUTCOME: Profits for battery-swapping truck operators**

Our analysis shows that the truck operators can make an increase in profit by shifting from diesel-based operations to battery-swapping EHTs on the level of:

**Change from diesel:** 263,000 – 232,200 SEK /year/truck
= 26,000 – 23,000 EURO /year/truck

The higher profit (left) comes from estimating two swaps per day, while the lower is based on the assumption of one swap per day.

Our analysis shows that truck operators can make an increased profit by shifting from contemporary cable-charging EHTs to battery-swapping EHTs on the level of:

**Change from cable charging:** 390,000 – 512,000 SEK /year/truck
= 38,000 – 50,000 EURO /year/truck

The lower profit (left) comes from estimating two swaps per day, while the higher is based on the assumption of one swap per day.

Our analysis shows that battery-swapping station operators can create revenues based on the number of swaps conducted daily.

**OUTCOME: Profits for battery-swapping station operators**

| Swaps per day | Profits per year | Payback time |
|---|---|---|
| 20 | 10 million SEK (1,0 million EURO) / year | 3,6 years |
| 40 | 18 million SEK (1,8 million EURO)/ year | 2.0 years |
| 80 | 37 million SEK (3,7 million EURO/ year | 1.0 year |

The proposed business models indicate reasonable profitability for battery-swapping trucks and battery station operators.

Our simulation-based optimization modeling shows that the battery-swapping based solution can enable continuous operations for five tractors with a battery of 150kWh on each of the five tractors and in the swapping station. Compared to similar cable-charged tractor solutions, the battery-swapping-based solution reduces the fleet's total battery capacity by 40%, although it adds one battery in the swapping station.

This improves the operational profitability of the entire system. As illustrated above, the effects of battery-size reduction have yet to be incorporated into the profitability analysis.

## 8.2. Background

Battery-swapping has been established in China for passenger vehicles, heavy trucks, and working vehicles such as concrete mixers, garbage processing, etc. Battery-swapping for heavy trucks has also been established outside China, in New Zealand, Australia, Germany, and the USA.

As this project intends to explore conditions for establishing battery-swapping for heavy trucks in Sweden and the Nordic countries, we need to understand that there are several perspectives on creating an understanding of the conditions and ways to develop battery-swapping for heavy trucks as one complementary charging solution.

The authors of this report have extensive experience in business model perspective via our research and several industrial cases of developing (business model innovation, BMI) and implementing business model (BM) since the 1990s. Professor Mike Danilovic and Dr. Jasmine Lihua Liu developed and implemented a new business model in 2014-2016 for the second-largest global wind turbine manufacturer, Goldwind, and the regional energy producer in Sweden, Varberg Energy.

The Goldwind case is thoroughly explored and analyzed in the doctoral dissertation of Jasmine Lihua Liu, who published and defended her Ph.D. dissertation in 2019.

The Sweden-China Bridge project published two extensive reports in 2021 on battery-swapping for passenger cars and heavy trucks. We conducted several seminars and gained interest from the OEMs of heavy trucks and the logistic transport industry. This report shall be understood in light of the rapidly growing interest in battery-swapping solutions to complement the current dominant solution based on cable-charging.

Existing current cable-based recharging solutions have some shortcomings that we are addressing with battery-swapping solutions, such as long recharging time, high prices for current electric heavy trucks (EHT), challenging electricity and power supply in the grid system, lack of charging piles suitable for heavy trucks along the road system, and lack of physical space for large volumes of trucks for simultaneous recharging along the highways (Danilovic, Liu, 2021; Liu, Danilovic, 2021, See “Regeringsuppdrag om elektrifieringen av transporter” report chapter 3 also Chapter 3 of this report).

## 8.3. Introduction

Innovation has become a new buzzword with many different meanings. Innovation is the radical development, change, and implementation of new ideas, technologies, products, and services. Some include social and societal development under the innovation umbrella. On the other hand, we relate our position to the traditional approach to innovation, focusing on technology, products, services, and manufacturing, although complementary aspects might be necessary. Thus, the fundamentals for innovation are the manifest archetype and artifacts.

From our perspective, Innovation is both the process of developing and the actual outcome of the process, i.e., the innovation as a result. The first-generation iPhone was an innovation, while the upgrades to the contemporary iPhone 15 are product updates, although the manufacturer claims differently. The boundary needs to be clarified, and it can be seen and understood differently.


*Figure 53. Two faces of Innovation – Technology and commercialization. Source: (Author).*

From our perspective, Innovation is like a coin, and one side is the underlying technology, products, and services. The other side is the commercialization, business, and money-making that must be done to enable the technology, products, and services to be exploited and diffused in reality.

It is crucial to realize that both sides are needed and that they are complementary to each other. Innovation can only take place once there is a business model that can support the commercialization process.

> *"Technology by itself has no single objective value. The economic value of a technology remains latent until it is commercialized in some way via a business model ... Companies commercialize new ideas and technologies through their business models ... In fact, it is probably true that a mediocre technology pursued within a great business model may be more valuable than a great technology exploited via a mediocre business model." (Chesbrough, 2010)*

As Chesbrough (2007) states, with the development of technology and economy, with the shortening of product life, the traditional version of "innovation" of inputting extensive internal research efforts and waiting patiently for novel products to emerge is no longer enough. Technology company Kodak was dedicated to focusing on its R&D of film technologies, and it is still the company that owns the most patents in film. However, having the leading edge in the film field did not stop Kodak from bankrupting in 2012.

> *"Today, innovation must include business models, rather than just technology and R&D."*

> *"Business models matter. A better business model often will beat a better idea or technology." (Chesbrough, 2007).*

Many examples from business demonstrate Chesbrough's assertion. Many winning products we are familiar with today, which were innovative at one time, may not be the most technically advanced ones, but the ones accompanied by better business models. Google was not the company that first invented search engines or sponsored ads, but it was better at business model innovation (BMI) and became the most successful search engine company (Afuah, 2014). Apple was not the first to bring digital music players to the market. Still, the company wrapped promising technology in a business model that combined hardware, software, and service and changed the game's rules. The iPod with the iTunes store accounted for almost 50% of Apple's revenue after introducing the products (Johnson et al., 2008).

When, in the last century, we started to become interested in innovation as a source of wealth and growth, we also became interested in commercialization. We realized we could create higher value by commercializing discoveries and inventions better, quicker, and with higher economic potential. Later, this became known as the commercialization of innovations, and business models became the vehicle for creating successful innovation.

## 8.4. Battery-swapping as innovation?

Battery-swapping can be traced back to 1860 in France and the USA. As electric vehicles died early, so did battery-swap as a solution. Two main reasons can be seen to explain the death of electric vehicles and battery-swapping at that time. One reason is the lack of recharging infrastructure, and the other is the lack of electricity to supply recharging and swapping stations. Thus, battery-swapping died in the early development phase and cannot be considered anything other than an invention.

Modern battery-swapping was introduced by Tesla in 2003 but has never been put into commercial operation. Only one demo site was established between San Francisco and Los Angeles. Also, here, the solution was merely an invention.

Better Place established battery-swapping as a technology and collaborated with Renault but went bankrupt before it could establish the solution on the market on any significant scale. Better Place collaborated with Chinese suppliers, bringing the solutions to the commercial stage. In 2023, battery-swapping for heavy trucks will have about 50% of China's electric heavy trucks (EHT) market. This number is expected to rise to about 70% in a few years (Danilovic, Liu, 2021; Liu, Danilovic, 2021, See also Chapter 5 of this report). Thus, battery-swapping as a technology and commercial solution has been established on the market and should be considered an innovation. In the Chinese context, this new technology was complemented by a business model decupling EHT from the battery (Danilovic, Liu, 2021; Liu, Danilovic, 2021, also see chapter 3). Operators buy the truck, rent the battery, and subscribe to a swapping solution. Thus, the business model supported the battery-swapping technology, making it an innovation and commercial success in the Chinese market. Now, we can observe that battery-swapping is gaining international momentum (Also see Chapter 3 of this report).

Suppliers developed new business models based on decoupling and separating vehicles and batteries to support the establishment of battery-swapping as a business success. In such models, customers buy EHT and rent the battery while customers either pay while using swapping solutions or subscribe to swapping.

Here, we can see that a new business model supported technology, products, and services.

The main question is if the battery-swapping solutions for EHT could be applied in the Swedish context and how the business model could support the implementation of the solution.

The battery-swapping system is well-developed technologically, as it is already well-designed and established on a large scale. However, the business model must be developed to enable its diffusion in Sweden under Swedish industrial and business conditions.

## 8.5. Purpose of this research

This report explores the business model outline for the Swedish context to indicate if battery-swapping for heavy trucks is also feasible to be established in Sweden.

## 8.6. Methodological approach

In our research on exploring business models for commercializing battery-swapping in Sweden and Nordic countries, we have used multiple methodological approaches:

- Explorative approach searching open-minded for understanding how different actors perceive electrification of transport, battery-swapping-based solutions, their needs and expectations for suitable solutions in their business scenarios.
- Participative approach with participants in seminars and workshops enabling people in business life to communicate and interact with us, exchange experiences, and influence our interpretations of their experiences and expectations.
- Interviews, seminars, and workshops were methods to enable participation and exchange of information with business people from European EHTs OEM and logistic operators.

## 8.7. Prototyping the business model for battery-swapping

Business models need to be adequately defined behind the desktop (Liu, 2019). We have worked on this project with an experimental approach and, through dialogue, created solutions, tested and challenged them, and reworked and reevaluated them. Gradually, the presented business model emerged and is presented in this report.

The prototyping process contained a series of activities:

- Communication with Scania, Volvo Trucks, Traton, and DAF to explore how the dominant truck OEM perceived the battery-swapping as a solution and how they consider it could be implemented in Sweden.
- Communication with two large regional logistic networks (buyers and truck operators) to explore the logistic operator's perception of electrification, barriers to electrification, and perception of battery-swapping as an option.
- Personal communication with 25 truck operating companies.
- Several seminars & workshops with logistic and truck operating companies on business models for establishing battery-swapping systems.

Those seminars, workshops, and interviews identified barriers and solutions to implementing battery-swapping systems.

They showed the alternative solutions to Business model (BM) for battery-swapping trucks (BS-EHT) and battery-swapping stations (BSS)

1. Buying EHT or Leasing EHT?
2. Buying battery or leasing battery?
3. Should we subscribe to battery-swapping or pay on the use occasions?
4. Leasing complete system operations (EHT, battery, and battery-swapping station)?

Several options were discussed and evaluated, and finally, the proposed business model emerged.

## 8.8. A theoretical approach to the business model

A business model consists of a firm's underlying core logic of market and customer segmentation and identification of needs and expectations, i.e., business opportunities, value proposition as the solution and offer to customers on a specific market segment, the architecture of the value, and the revenue model. Among them, the underlying core logic of the value proposition is the strategic element that the business model concept shares with the strategic concept. A business model represents a set of strategic choices and their operating implications (Shafer, 2005).

> *"Constructing business models in environments characterised by high complexity and ambiguity has much in common with Weick's notion of sense making. Sense making is about contextual rationality. It is built out of vague questions, muddy answers, and negotiated agreements that attempt to reduce confusion."(Chesbrough and Rosenbloom, 2002)*

The process of sense-making is the process of identifying the core logic of the company. It is choosing what to do and what not to do to achieve the company's unique positioning. The business model's core logic is the strategy's positioning choice. The business model is a relatively simple way to delimit and organize critical decisions. The business model makes the strategic choices explicit (Morris et al., 2005). The initial business model is a proto strategy, an initial hypothesis for delivering value to the customer (Chesbrough & Rosenbloom, 2002).

The business model will develop the value proposition based on the identified core logic. Based on the value position, it will configure a set of activities, resources, networks, and processes to create and deliver value to the customer. The initial business model will work as a conceptual and action tool to facilitate the analysis, testing, and validation of the firm's strategic choices (Shafer, 2005). Through trial and error (experimentation), the business model provides feedback to adjust the original assumptions and core logic. The revised assumptions and core logic will guide further business model design and implementation revision.

Thus, the business model becomes the glue between the corporate strategy and operation, as shown in Figure 54. Business models can derive from operations and the strategic perspective. A successful business model can be the company's engine and, thus, the strategy driver.

At a given time, a business model reflects the realized strategy (Shafer, 2005), a blueprint translation of a company's system that connects the strategy design and operation (Osterwalder, 2004). From a dynamic perspective, a business model not only represents a company's strategy but also is an analytical tool that the company can implement to propose, test, validate, revise, and renew its strategy. Companies try their strategic options through business models (Shafer, 2005). The recognized strategy needs to be translated into a business model for implementation and business creation; the validated new model prototype will be remembered as the company's new business strategy. We can say that the business model combines both design and operational aspects; it is not a strategy but shares the core logic (positioning) element with strategy. Sometimes, the business model reflects strategy; sometimes, it is upgraded to strategy.

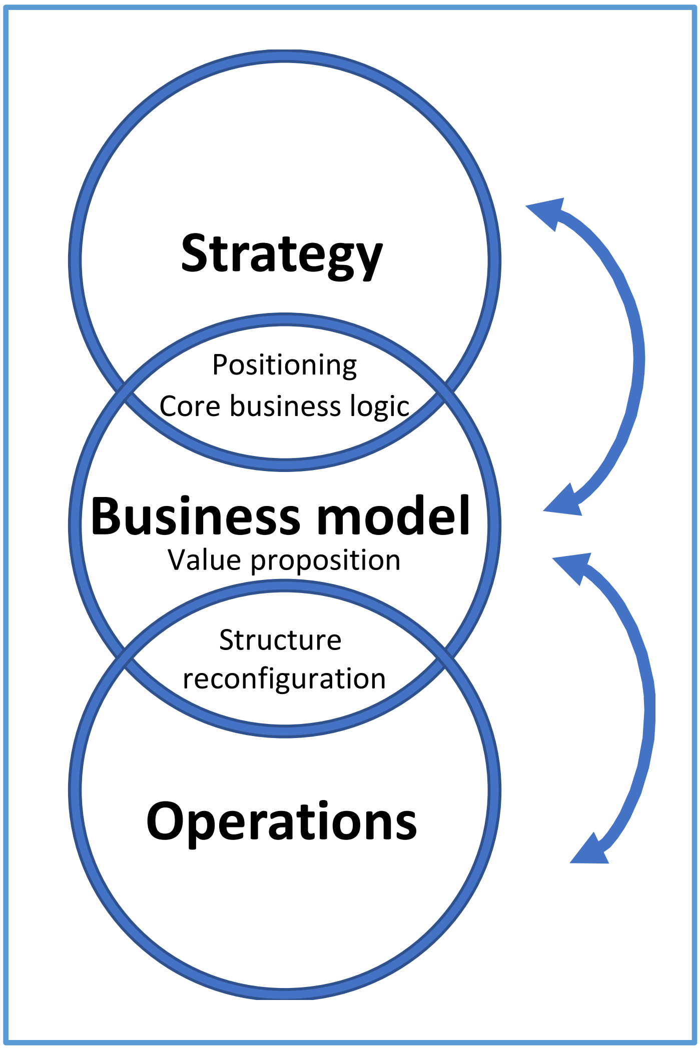


*Figure 54. Business model and corporate strategy.*

The business model's role in a company is the vehicle that the company drives to explore business opportunities and to propose, test, and validate value proposition and its embedded theory of business to exploit the business opportunity, figure out a business strategy accordingly, and implement the plan. The business model is the organization's configurational enactment of a specific opportunity (Spieth et al., 2014). Holistically and systematically, the business model is capable of zooming out to participate in the creation of the company's strategic direction, ensuring the company is on the right path, and zooming in to see the detailed infrastructure and configuration of the strategy implementation process that ensures the work is carried out efficiently (Spieth, 2013). The business model is the vehicle that the company uses to journey along with the movement of the marketplace, change with the customers, cope with the uncertainty of the environment, and be capable of utilizing emerging market opportunities and achieving sustainable competitiveness.

## 8.9. Innovation and business model innovation

The business model concept originates in corporate practice (Bock et al., 2010). During 1998-2001, during the dot-com bubble, there was a sharp rise in the use of information technology and a decrease in coordination and transaction costs for making business online (Osterwalder et al., 2005). With the emerging knowledge economy and the outsourcing and restructuring of financial services (Teece, 2010), abundant new business design options that broke traditional industry boundaries were presented to managers. Many novel business models were generated to *translate technical success into commercial success* (Schneider and Spieth, 2013).

The business model concept became prevalent from the mid-1990s, experienced a dramatic increase from 1995 to 2000 (Zott et al., 2011), and grew rapidly in popularity among academics and practitioners from 2000 to 2010 (Goyal et al., 2017). "It is more widely used nowadays than almost any other concept in strategy" (Badan-Fuller and Morgan, 2010).

Today's business landscape is characterized by complexity and uncertainty, and business models are created to solve challenges in corporate practice (Teece, 2010; Zott et al., 2011; Schneider and Spieth, 2013). While entrepreneurs use business models to commercialize new technology and convince investors for funding, and established companies use business model innovation (BMI) to continue prosperity, academic research on business models still seems to lag behind practice. Business model research originates in e-business, strategic management, innovation, and technology management.

In the strategy field, researchers identified four value creation sources: novelty, lock-in, complementarity, and efficiency; recognized business models as one potential source of a company's competitive advantage; and distinguished the relationship between business model and strategy (Zott et al., 2011).

In the innovation and technology management field, the business model is perceived as a vehicle for commercializing technical innovation, and it also represents a new dimension of innovation: business model innovation (BMI).

Even though each field achieved specific progress in business model research, the literature has mainly developed in silos, and scholars disagree on what a business model is (Zott et al., 2011). Business models are frequently mentioned but rarely analyzed as an interdisciplinary topic and thus need to be better understood (Teece, 2010). What, then, is a business model?

The emergence of the business model concept was not theory-driven but rather pragmatic-driven (Morris et al., 2005). Seeing the flourishing of the idea in management practice, researchers tried to understand what it was. The business model has been perceived as a conceptual tool or a model, a representation, a statement, a description, an architecture, a structural template, a framework, a pattern, a set, an activity system, a market device, a blueprint, and a new unit of analysis (Zott et al., 2011). Different researchers provide different definitions.

What is to be noted is that a business model is a story that explains how business is conducted and that it is about how a company makes money. It is a story about money making, in other words.

A business model is a representation of how a company makes money. A business model needs to explain how a company *hopes* to make money; it is not a strategy either. A business model is the core design, the logic, that enables an organization to capture, create, and deliver value to meet explicit or latent needs.

Table 7 summarizes the representative definitions of a business model by different scholars.

*Table 7. Selection of definitions of the business model concept. Source: Liu, 2019.*

| | |
|---|---|
| Timmers (1998) | An architecture of the product, service, and information flows, including a description of the various business actors and their roles, a description of the potential benefits for the various business actors, and a description of the sources of revenues (p. 4). |
| Linder & Cantrell (2000) | An operating business model is the organization's core logic for creating value. The business model of a profit-orientated enterprise explains how it makes money. Since organizations compete for customers and resources, a good business model highlights the distinctive activities and approaches that enable the firm to succeed – to attract customers, employees, and investors and to deliver products and services profitably (p.2). |

| | |
|---|---|
| Amit & Zott (2001) | Transaction content, structure, and governance are designed to create value by exploiting business opportunities (p. 511). |
| Chesbrough & Rosenbloom (2002) | The heuristic logic connects technical potential with realizing economic value (p. 529). |
| Magretta (2002) | Stories that can explain how enterprises work. A good business model answers Peter Drucker's age-old question: Who is the customer? And what does the customer value? It also answers every manager's fundamental questions: How do we make money in this business? What underlying economic logic explains how we can deliver value to customers at an appropriate cost? (p. 4) |
| Afuah (2004) | The set of activities a firm performs, how it performs them, and when it performs them as it uses its resources to perform activities, given its industry, to create superior customer value (low-cost or differentiated products) and put itself in a position to appropriate value. |
| Osterwalder (2004) | An abstract conceptual model that represents the business and money-earning logic of a company (p. 15). |
| Morris et al. (2005) | A concise representation of how an interrelated set of decision variables in the areas of venture strategy, architecture, and economics are addressed to create sustainable competitive advantage in defined markets (p. 727). |
| Nielsen (2005) | A business model describes the coherence in the strategic choices, which makes possible the handling of the processes and relations that create value on the organization's operational, tactical, and strategic levels. The business model is, therefore, the platform that connects resources, processes, and the supply of a service, making the company profitable in the long term (p. 4). |
| Osterwalder et al. (2005) | A conceptual tool containing elements and their relationships allows the expression of a specific firm's business logic. It describes the value a company offers to one or several segments of customers and the architecture of the firm and its network of partners for creating, marketing, and delivering this value and relationship capital to generate profitable and sustainable revenue streams (p. 17). |
| Shafer et al. (2005) | A representation of a firm's underlying core logic and strategic choices for creating and capturing value within a value network (p. 202). |
| Weill, Malone, D'Urso, Herman & Woerner (2005) | It consists of two elements: (a) what the business does and (b) how the business makes money doing these things (p. 5). |
| Chesbrough (2007) | A business model performs two important functions: it creates and captures a portion of that value. The first function requires defining a series of activities to yield a new product or service and add value throughout the various activities. The second function requires establishing a unique resource, asset, or position within that series of activities in which the firm enjoys a competitive advantage (p.22). |
| Casadesus- Masanell & Ricart (2010) | A reflection of the firm's realized strategy (p. 195). |

| | |
|---|---|
| Johnson, Christensen & Kagermann (2008) | A business model comprises four interlocking elements that create and deliver value when combined. The four elements are customer value proposition, profit formula, key resources, and key processes (p. 60). |
| Osterwalder & Pigneur (2010) | A holistic interdependent system that describes how an enterprise will create and deliver value to their customers while generating profit with internal and external operations (p. 14). |
| Osterwalder and Pigneur (2010) | Value proposition; Customer segments; Customer relationships; Channels; Key activities; Key resources; Key partners; Cost structure; Revenue stream (p. 16, 17). |
| Demil & Lecocq (2010) | The description of the articulation between different business model components or building blocks to produce a proposition that can generate value for consumers and thus for the organization (p.227). |
| Teece (2010) | Articulates the logic and provides data and other evidence demonstrating how a business creates and delivers value to customers. It also outlines the architecture of revenues, costs, and profits associated with the business enterprise delivering value (p.173). |
| Zott & Amit (2010) | A system of interdependent activities that transcends the focal firm and spans its boundaries. The activity system enables the firm, in concert with its partners, to create and appropriate a share of that value (p. 216). |
| Baden-Fuller & Haefliger (2013) | A system that solves the problem of identifying who is (or are) the customer(s), engaging with their needs, delivering satisfaction, and monetizing the value (p. 419). |
| Berglund & Sandström (2013) | A high-level description of how a firm creates, delivers, and appropriates value centered on a focal firm but transcends the boundaries of the focal firm (p. 276). |
| Afuah (2014) | A framework or recipe for making money - for creating and capturing value (p. 4). |
| Wirtz et al. (2015) | A simplified and aggregated representation of the relevant activities of a company. It describes how marketable information, products and/or services are generated by means of a company's value-added component. In addition to the architecture of value creation, strategic as well as customer and market components are taken into consideration to achieve the superordinate goal of generating, or rather, securing, the competitive advantage. (p.41). |

The business model field is very much like the rest of the social sciences, with many different perspectives and approaches limiting the areas of shared understanding and standard definitions. We must accept diversity, as other researchers have studied the field from various perspectives, with different philosophical positions and methodologies in different empirical areas, thus shaping different conclusions.

> *"A successful business model creates heuristic logic that connects technical potential with realisation of economic value." (Chesbrough, 2010)*

**Firstly, a business model represents a firm's underlying core logic** (Linder and Cantrell, 2000; Chesbrough and Rosenbloom, 2002; Shafer, 2005; Osterwalder, 2004; Osterwalder et al., 2005; Teece, 2010), which Peter Drucker names the "theory of the business." It includes assumptions about the environment (society and its structure, the market, the customers and competitors and their values and behaviours, and technology), which define what an organization is paid for; assumptions about the mission of the organization, which define what an organization considers to be meaningful results; and assumptions about the core competencies needed to accomplish the organization's mission (Drucker, 1994). The underlying core logic "reflects managers' hypothesis of what customers want, how they want it, how the enterprise can organize to meet those needs, get paid for doing so, and make profit (Teece, 2010)".

> *"Bill Gates knows that [...] competition today is not between products, it'ś between business models. He knows that irrelevance is a bigger risk than inefficiency. And what is true for Microsoft is true for just about every other company." (Hamel and Sampler, 1998)*

A firm's business model aims to exploit a business opportunity by creating value for the parties involved (Amit and Zott, 2010). To achieve the goal, the assumptions about the environment, the company's mission, and core competencies must fit reality because the organization's businesses are built on these fundamental assumptions. If the basic assumptions don't work, companies can work hard every day but stagnate (Drucker, 1994). That is why doing the right thing is more important than doing the item in the right way. As Drucker (1994) emphasizes:

> *"The theory of the business ... is a hypothesis about things that are in constant flux — society, markets, customers, technology."*

Eventually, every business theory becomes obsolete and then invalid and thus has to be tested constantly and revised when necessary.

Based on the theory of business or fundamental assumptions, managers make strategic choices about what to do, what not to do, and what value they will offer their customers. These strategic choices are conceptualized and expressed explicitly by the company's business model (Morris et al., 2005), representing a company's business and money-earning logic. A business model is a story or narrative that explains how business is conducted and how a company makes money. A business model reflects strategic choices (Shafer, 2005).

**Secondly, the architecture of value** lists the partners and channels through which value is produced and delivered (Afuah and Tucci, 2001) or the business structure, processes, and infrastructure that fulfill the value (Osterwalder, 2004). Business model core logic choices define the architecture of the business, and expansion paths develop from there on out (Teece, 2010). A business model is an ambitious concept: it does not just try to explain what businesses do and how to do it.

> *"It seeks to explain process and content at the same time" (Zott et al., 2011).*

Based on different core logic and value propositions, other business models imply different sets of activities, resources, and capabilities to create and deliver customer value. From an activity system perspective, a system of interdependent activities is carried out by a value network consisting of a focal firm and its partners, including suppliers, distributors, and coalitions that extend the firm's resources to create and deliver the value (Zott and Amit, 2010). The business model also describes how the activities are linked, who performs what activities, and where the activities take place.

**Thirdly, the revenue model** of the business model translates the two former dimensions in costs and revenue flows (Mubosson-Torbay, 2002; Magretta, 2002; Weill and Vitale, 2001). For-profit organizations must make money to survive (Shafer, 2005). Magretta (2002) argues that to be successful, a business model must pass both "the narrative test" (is the core logic feasible?) and "the numbers test" (can the reason generate profit?). The business model also seeks to simultaneously explain value creation and capture (Zott et al., 2011). It shows the company's economic profit equation.

In summary,

> *"a business model explains how an organization proposes, creates, delivers, and captures value" (Osterwalder & Pigneur, 2010).*

A business model describes holistically and systematically how enterprises do business (Casadesus-Masanell and Ricart, 2010). A business model is perceived as a management tool and an intelligent collective device (Doganova and Eyquem-Renault, 2009). It can help companies explore business opportunities emerging in the environment, enhance their capabilities to manage uncertainty, and ultimately strengthen their competitive advantage.

## 8.10. Symbiotic business model approach

In our research on Goldwind's business model innovation, we have identified a symbiotic business model that shaped Goldwind and the wind turbine industry. In the symbiotic business model, the political, institutional, and business actors co-create and co-shape value creation through mutual understanding and actions based on continual dialogue (Liu, 2019).

- Symbiotic relationships exist in two dimensions: horizontal and vertical. The horizontal symbiotic relationship is the seamless complementary collaboration along the industry value chain. The vertical symbiotic relationship refers to political, institutional, and business actors who co-create, co-develop, and co-achieve social, political, and economic targets.
- The symbiotic relationship is achieved via ongoing dialogue between political and business actors by using regulatory tools with the support of institutional actors.
- Specific informal social network-based trust-building mechanisms play complementary roles that support the smooth functioning of the symbiotic business model for the co-development of the industry.
- There are plural logics in the symbiotic business model, and multiple logics are absorbed in the symbiotic business model through the senior manager's cognitive model and carried out in the strategic choices of the enterprise in the business model design and implementation.

### 8.10.1. The symbiotic political and business relationship in the co-creation of emerging industry

> *"The challenges clean technologies face are seldom technical; they are political (and social).*
>
> *"The State has historically served not just as an administrator and regulator of the wealth creation process, but a key actor in it … across the entire innovation chain, from basic research to applied research, commercialization and early-stage financing of companies themselves. … The State has been key to creating and shaping markets, not only 'fixing' them.*
>
> *"Key to the future of the green revolution taking off will be the building of innovation ecosystems that result in symbiotic public-private partnerships rather than parasitic ones." (Mazzucato, 2015)*

As Mazzucato (2015) stresses, developing a renewable energy industry and electrification of transport to create green development for our society is a mission beyond the scope of business and any particular sector. The government needs not only to 'fix' the market for the industry. Without direct government involvement and participation, there would be no industry for the electrification of transport. It works in the way that:

*"The 'alienesque' State leads the way for the 'domesticated' animals - the private companies – to act" (Mazzucato, 2015).*

According to Mazzucato (2015), first of all, the government not only 'crowded in' the initial investment when the industry was at a very early stage of high risk but also 'dynamized it in' by creating the vision, the mission, and the plan to achieve results. Then, public sector officials worked directly with firms to identify and pursue the most promising innovative paths.

Business actors carefully collect, interpret, and analyze information on government intentions and directions. New policies and regulations are kept close track of. Decisions are made in line with the current political direction. Leadership in an organization requires an understanding of changing trends and governmental programs. Swiller Field (1986) argued that people of a particular culture "naturally know how to act" in that cultural context.

As Scott (1987) points out, when institutional beliefs, rules, and roles, which are embedded in the cultural infrastructure, come to be coded into the structure of organizations, such shared beliefs, practices, and parts not only provide order to organizational forms and procedures but also exert direct influence on the individual participants' behavior. Thus, orderliness and coherence of cross-organizational boundaries can be reached.

Governmental organizations develop a collective mindset and share a business model that integrates the political, institutional, and regulatory actors and activities. The economic, societal, political, etc., multi-logics are integrated and spoken out by political actors, then followed voluntarily by institutional and industry organizations. This brings the consequence that the multi-logic way of thinking is shared among different kinds of organizations; thus, they speak the same language when they work together on programs and/or businesses.

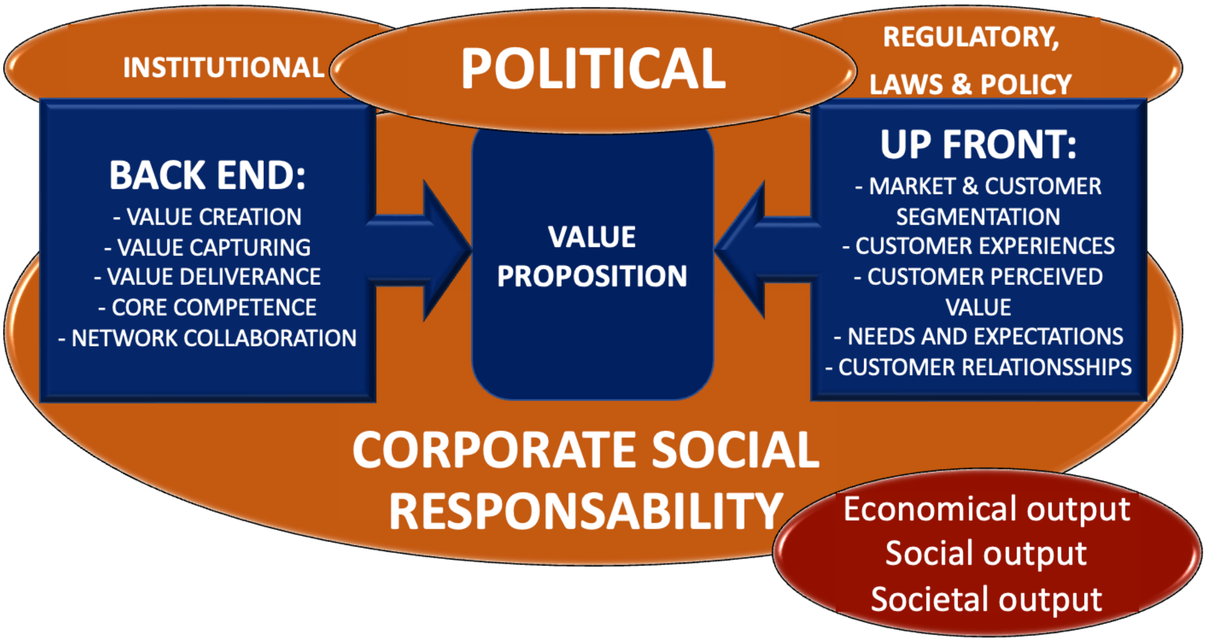


*Figure 55. The symbiotic business model. Source: (Liu, 2019).*

In Figure 55, we have conceptualized and depicted the core contents of a symbiotic business model, where the interplay between political and institutional actors with regulatory factors influences the symbiotic business models of companies.

These relations among business, political, and institutional actors and regulatory processes lead to the conclusion that political and business actors have a symbiotic relationship of co-creation, co-development, and co-achievement of social and societal targets as well as shared business opportunities, fulfilling both the social and societal targets and needs of politics and of the business.

### 8.10.2. There are plural logics in the symbiotic business model

Organizations are shaped by interconnected belief and value systems (Scott, 1987), and multiple institutional logics influence organizations' business models. Different institutional actors have other logic and various types of targets to achieve. The target for political actors is to get votes; the target for industry associations is to improve the long-term development of the whole industry by promoting collaboration among industry enterprises and creating normative standards for how the industry should work; the target for businesses is to create sustainable value by providing technology, products, and services to customers and stakeholders. Companies doing it well and efficiently might make sustainable profits; otherwise, they will not.

As we have seen during the process of developing the battery-swapping in the Swedish context, via interviews, seminars, and workshops we held during this project, we observed multiple industrial, business, and institutional logics influence the business model.

For instance, the business logic for logistics buyers differs from that of the truck logistics operators and electricity suppliers, following the regulations originating from old times before we even had EHTs. All the business actors had the strategy of building business models that needed to be synchronized with other actors along the vertical or horizontal value chain. This illustrates unsynchronized decisions made on multiple logics, including business, political, institutional, and societal logic.

All these different logic co-influence companies' strategies, business models, and service demand and supply,

> *"Via a broad array of adaptive mechanisms occurring over a period of time ranging from co-optation of the representatives of relevant environmental elements to the evolution of specialized boundary roles, and to mirror or replicate salient aspects of environment differentiation in their own structures. They (organizations) incorporate environmental structure." (Scott, 1987).*

Organizations imitate environmental elements in their structures, and their systems reflect socially constructed reality. By designing a company structure that adheres to the prevailing rationalized concepts in the institutional environment and the organizational field, organizations demonstrate that they act on collectively valued purposes appropriately and adequately that are acceptable by the environment and institutional actors. Thus, organizations become legitimate, strengthen their support, and secure survival. The long-term survival prospects of organizations increase as state structures elaborate and organizations actively respond to standardized rules.

> *"Business models may serve as integrative devices in which plural logics are combined as a strategic response." (Laasch, 2018)*

The plural logic in the logistic, transportation, and electricity provision industry are fragmented and does not support each other or support all actors to shift from diesel fuel to EHTs. Business "organizations *compete not only for customers and resources but also for political power and institutional legitimacy, for social as well as economic fitness*" (DiMaggio and Powell, 1983). Only when the multiple, plural logics in the business reality are taken care of can the business succeed in the long run.

## 8.11. On business model innovation

Every company has a business model – otherwise, there would be no business to handle. Some must know their business model; some have developed quite advanced and complex business models. At any point in time, every company has at least one business model, but over time, companies can change and develop new business models. According to Sosna et al. (2010), new companies need to design their initial business models to commercialize their business ideas, and established firms may need to renew their existing business models to cope with the changed business environment.

According to Bucherer et al. (2012):

> *"Business model innovation is a process in which a company deliberately changes the core elements and business logic of its business model."*

There is a dynamic process at work in companies' business models.

A business model is a static representation of how a company does business. On the other hand, BMI is, by definition, a dynamic approach. Conceptually, we can perceive a business model life cycle involving specification, refinement, adaptation, revision, and reformulation (Morris et al., 2005). BMI focuses on transformation and dynamics, i.e., the changes in contemporary business models. The transformative character of BMI makes it the counterpart to static approaches previously considered (Lecocq and Demil, 2010).

*Table 8. Summary of selected business model innovation definitions. Source: Liu, 2019.*

| **Author(s)** | **Definition** |
|---|---|
| Malhotra (2000) | Paradigm shift that involves a fundamental rethinking of the respective company instead of only changing the business process and workflow level. |
| Linder & Cantrell (2000) | A change model is the core logic for how a firm will change over time in order to remain profitable. |
| Mitchell & Cole (2003) | When a company makes business model replacements that provide product or service offerings previously unavailable to customers and end users, we refer to those replacements as business model innovations. |
| Voelpel et al. (2004) | Business model reinvention is based on disruptive innovation, not incremental change or continuous improvement. |
| Pohle & George (2006) | Innovation in the structure and/or financial model of the business. |
| Johnson et al. (2008) | The reinvention of a business model by means of identifying an entirely new customer value proposition. |
| Lindgardt et al. (2009), BCG BMI Report | Innovation becomes BMI when two or more elements of a business model are reinvented to deliver value in a new way. |
| Teece (2010) | Process of designing a new or modifying the firm's extant activity system. It aims to renew a firm's core business logic consciously rather than limit its scope of innovation to single products or services. |
| Zott & Amit (2010) | Designing a modified or new activity system relies on recombining a firm's and its partners' existing resources and does not require significant investment in R&D. |
| Gambardella & McGahan (2010) | A firm adopts a novel approach to commercializing its underlying assets. |
| Bucherer (2012) | A process in which a company deliberately changes its business model's core elements and business logic. |
| Casadesus-Masanell & Zhu (2013) | The search for new business logic of the firm and new ways to create and capture value for its stakeholders. |
| Markides (2013) | The discovery of a fundamentally different business model in an existing business. |
| Euchner & Ganguly (2014) | Any innovation that creates a new market or disrupts the competitive advantage of key competitors. |

| Author(s) | Definition |
|---|---|
| Massa & Tucci (2014) | The activity of designing - i.e., creating, implementing, and validating – a new business model suggests that the process of business model innovation differs if an existing business model is already in place vis-à-vis when it is not. |
| Zott & Amit (2015) | The design and implementation of an activity system new to the focal firm or the product–market space in which the focal firm competes. |
| Wirtz (2016) | The design process for giving birth to a fairly new business model on the market is accompanied by an adjustment of the value proposition and/or the value constellation. It aims to generate or secure a sustainable competitive advantage. |
| Foss and Saebi (2017) | Designed, novel, nontrivial changes to the key elements of a firm's business model and/or the architecture linking these elements. |

Some researchers emphasize a fundamental paradigm kind of change or disruptive change that creates a new market or change that is "new to the market"; some researchers stress the evolution of core logic or value proposition of the business; some researchers perceive it as the change of the company's activity system. In the two most recent literature review papers in the BMI field, Zott and Amit (2015) and Wirtz (2016) seem to adopt a more wide-ranging and all-encompassing scope of change that includes both "new to the market" and "new to the company" approaches in the BMI concept.

## 8.12. Basic business model

A business model is not a model in the traditional manner; it is a narrative, a story, of how an industry or business entity is acting to do business. All business models are representations and can work as pedagogical and analytical tools that can support the development and communication of business models.

We are building on the essential work of Business Model Canvas developed by Osterwalder (Osterwalder et al., 2005). We use it as a representation, a communicative approach to guide conversations, and an analytical tool, not a template for designing a business a business model.

Based on our extensive research, we have developed a symbiotic business model (Figure 55) that represents critical elements of a comprehensive approach to exploring, understanding, and designing accurate business models, presented in Figure 56 as an essential element of a business model approach.

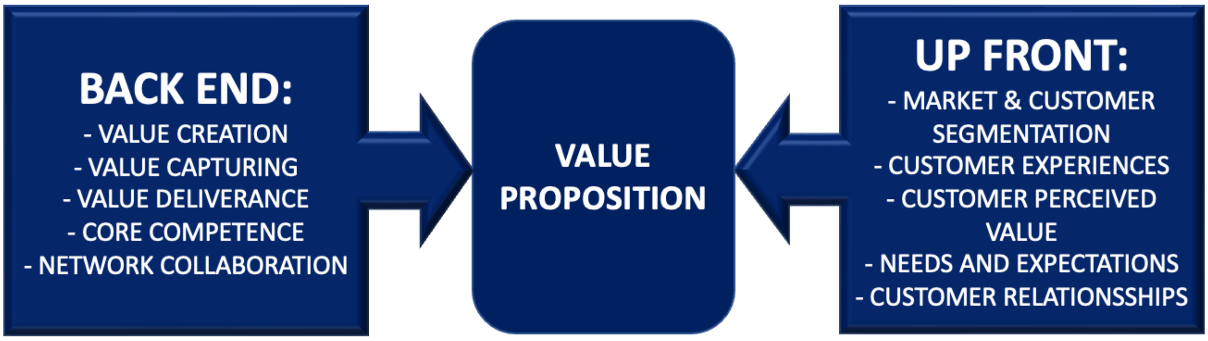


*Figure 56. Basic elements of a business model. Source: (Liu, 2019).*

This model consists of three key elements.

- The upfront side reflects on the segmentation of markets and customers and the understanding of their experiences, needs, and expectations in the future. The fundamental assumption in the business model perspective is to develop solutions that fit market and customer expectations and solve customer headaches. The up-front answers the questions of WHO the customer is, WHAT is to be solved by the supplier, and WHAT the customer is prepared to pay for.

- The value proposition is the answer to the market and customer expectations. The value proposition describes the value creation from the supplier to the market and customer. The value proposition is explorative, a narrative of what is being created, delivered, and paid for by the market and customers. The value proposition answers the question of WHAT is to be designed and HOW this value is expected to be delivered to a specific customer.
- The back end answers the question of WHO is supporting (suppliers) the value creation and HOW the value proposition is created by a network of suppliers and sub-solutions integrated into the value proposition to the selected customer.

Other elements are relevant and critical for developing a business model, creating and delivering the values, cost structure, revenue structure, etc. However, in our work, we use the most straightforward possible description and narrative of the business model as a pedagogical tool.

The business model innovation process, the development of the new business model, or the transformation of existing business models is an interactive process that can start in any of those critical elements. However, based on our experiences, we prefer to start the business model innovation from the up-front perspective, exploring, understanding, and developing solutions that are expected to solve the customer's headache. Based on that, the value proposition is defined with actors in the exco-system design who collaborate, how the value proposition de facto is created and delivered, and the selection of distribution channels and places.

## 8.13. Business model innovation – Process of defining new business model

Figure 56 was used to educate and communicate with participants in workshops, interviews, and training sessions needed on the company levels when being developed and implemented.

- The business model contains complementary strategies of actors, collaborative structures linking actors and their activity systems into processes to create and deliver value and capture value in the ecosystem, and tangible and intangible resources of actors.
- The business model has a subjective side and an objective side. The subjective is the system of meanings among actors, and the objective is the flows of goods and services and financial transactions among actors.
- The business model is an open social system (people) that transforms needs and expectations into delivering goods and services and financial flows. As an open social system, the actors (people) enact and create meaning in their actions based on their interpretation and understanding of the sense-making and sense-giving process of interaction with each other.

BMI is a strategic management tool that management utilizes to cope with environmental changes, use emerging business opportunities, and create sustainable competitive advantage. BMI is an organizational change process consisting of activities centred on value. The outcome of BMI is an innovative BM.

As discussed earlier in this chapter, the newness of a BMI requires a novel value proposition and the underlying architecture supporting the value proposition. At this moment, we present the working definition of BMI in our research as follows:

> ***BMI means to define and redefine management's theory about what customers value and its concrete implementation.***

BMI is the dynamics of the system of value creation activities. This dynamic is the process of defining and redefining elements or subsystems of the ecosystem business model in which all actors might have their business models.

- Suppliers, customers, and other stakeholders that comprise the ecosystem of the company's business participating in the BMI process can contribute to the BMI outcome.

> *"We need to develop a business model based on strategic partnerships that create value for our company and the industry as a whole. We cannot do everything in this era of specialization." (Pohle and Chapman, 2006)*

Value creation and capture happen within a value network. Business models' systemic and boundary-spanning nature implies that firms must take an open system perspective, collaborating with partners along the value chain and other stakeholders when carrying out BMI (Berglund and Sandstrom, 2013). Collaboration across competitive boundaries can benefit all (Pohle and Chapman, 2006).

### 8.13.1. Informal and formal social institutions and political factors may influence the firm's engagement in BMI and the outcome of the BMI.

> *"Business models must morph over time as changing markets, technologies, and legal structures dictate and allow … the business environment itself is a choice variable; firms can select a business environment or be selected by it; they can also shape it." (Teece, 2010)*

Even though many definitions of business models are explicitly concerned with how firms interact with the environment, the existing literature still primarily studies BMI challenges from a firm-internal perspective. Companies' BMI is carried out under interdependence and restricted environmental freedom (Berglund & Sandstrom, 2013). Companies' BMI also changes the landscape of the environment with its innovative force and action. The research on the BMI process and outcome must be based on the understanding of the interaction between companies' BMI and its surrounding environmental factors, mainly institutional and political factors that have been ignored to a large extent in past research.

BMI is tightly linked to entrepreneurial vision, imagination, and judgment and requires top-management commitment and action (Foss and Saebi, 2017).

A heuristic approach to BMI implies that the business model is developed in a trial-and-error process, not a laboratory. The innovation of a business model is conducted in real life, with real-life companies and real-life people's interpretations, expectations, and experiences. The BMI is, therefore, the key and precedent to successful business.

BMI is typically contextualized in some way.

> *"… both boundaries and conditions in at least many industries continue to evolve rapidly. Therefore, the research agenda needs to consider the role and temporal and spatial position of the BMI phenomenon in the design and evolution of industry." (Spieth et al., 2014)*

As Teece (2010) states, a business model cannot be assessed in the abstract; its suitability can only be determined against a particular business context. The outcome of BMI is the product the company generates under a specific environment. The BMI process can only be understood under the context in which it was carried out.

## 8.14. Reflections

There is no generic definition of a business model, how it operates, and how it generates outcomes.

In our perception, a business model is a narrative that explains how a company makes value to its customers and collaborates with other companies to create that value. It is assumed that the customer company is willing to pay for the value creation only if the perceived value exceeds the perceived cost.

The business model is a foundation for developing a business plan, financial analysis, and strategies.

The business model analysis reflects the business aspects on the corporate level. It is less trustworthy that an industry can have the same business model, although we can observe mimicking between companies in the same industry and across sectors (Liu, 2019).

The chosen system approach includes truck operators, potential battery-swapping station operators, and logistic buyers. It is critical in our analysis to explore and understand how different but related actors interfere with and influence each other.

Our system approach comprises a vertical and horizontal analysis of related elements (Bhatti, 2023).

## 8.15. Prototyping business model for establishing battery-swapping in Sweden

In this section, we intend to present the findings and results of the business model innovation analysis based on interviews, seminars, and workshops.

### 8.15.1. Up-front analysis - Segmentation of markets and customers (Strategic choice of market and customers)

Our identification of markets and customers is based on strategic evaluation of development in the global and regional flow of goods and the geographical situation of Sweden as a regional logistical hub. Based on this reflection, our business model innovation prototyping focuses on harbor operations and container transportation.

### 8.15.2. Defining the markets and customers - Exploring the context:

- Sweden is a logistical corridor, a logistic hub in Scandinavia, linking Norway, Sweden, Finland, the Baltic states, Poland, Germany, Denmark, and the UK.
- To a minimal level, the logistic flow between all those countries can be conducted on land-based transportation. The critical transport between those countries is via bridges, ships, and ferries utilizing container solutions on trailers, trains, and trucks.
- The logistic and transportation trend is that container-based transport is becoming more critical, and trailer-based transportation is increasing. This is a global trend that must be addressed.
- International long-distance transportation is based on containers transported on large trans-continental ships, reshipped to smaller vessels, and transported to various harbors.
- Container transportation needs in-harbor tractor/trailer-based transportation to logistics hubs where the goods might be reallocated to trucks of different sizes for continual transit to the final destination.
- Containers can also be transported on trains, smaller ships, and trailers, preferably 6-wheelers.

The selected customers for battery-swapping solutions are truck/trailer operators that transport to and from harbors-hubs and need flexible transport solutions enabling trailers to run short and long distances, one and two-shift operations, etc. This selection is based on extensive dialogue with transport operators.

The other customer is the logistics buyer, who can support truck operators by guaranteeing transport volumes and long-term obligations that truck operators can turn into business opportunities and invest in buying new charging infrastructure using battery-swapping solutions.

The third customer is those actors who can take on the new role of battery-swapping station operators. This could be truck operators, transport network of transport operators, or harbor operators that see opportunities to improve efficiency in the in-harbor and between harbor-hub transport operators.

Our analysis focuses on the truck-operating actors and battery-swapping station operators, regardless of which actors see this as a business opportunity.

We are excluding in our analysis.

- Energy suppliers and energy distributors. Although they are critical for battery-swapping operations, we exclude those actors to reduce complexity as they are not primarily part of logistic operations.
- Battery-swapping-based vehicle manufacturers. OEMs are critical for setting up battery-swapping operations, but today, there are no battery-swapping-based truck OEMs in Europe.
- Battery manufacturers. Although battery manufacturers are essential actors, we are excluding these actors at this point.

Our market and geographical focus are

- Sweden is a Northern European "harbor and logistical hub." Swedish harbors connect the rest of Northern Europe via truck and container transportation, besides train and air transport.
- We focus on transporting containers to/from intensive harbors and logistical hubs in Sweden, Norway, Finland, Denmark, Germany, Poland … Baltic states, etc.
  Container transports and trailers for container transport.

## 8.16. Sweden is the Nordic logistic hub


*Figure 57. Sweden as a logistical hub in Northern Europe. Source: (Authors).*

Figure 57 illustrates the main transport flows from Germany via Denmark and Sweden to Norway, Finland, and the Baltic states. Sweden is the largest country in the Nordic area and, thus, the most significant transport recipient via bridges, ships, and roads. For those reasons, Sweden must develop its capabilities to serve the Nordic region with efficient transport solutions. Thus, battery-swapping might play an important strategic role as a complementary solution for Sweden and all Nordic countries and actors to existing emerging cable-based solutions.

### 8.16.1. Linking Sweden and Denmark with EV transport and swapping stations

Figure 58 shows the harbor locations in Sweden and some in Denmark towards Sweden. It shows that the link between Denmark and Sweden has several sea-based transport routes operated with ferry lines. Only one bridge, Copenhagen-Malmö, and all the others go via harbors to harbors before containers and goods can be handled at logistical hubs inside Sweden.

Transport linkages between Germany and Sweden must go via Denmark or ferries directly via the Baltic Sea.

Transport linkages between Poland and Sweden must go via harbors as no land corridors exist. Options are via Germany and Denmark.

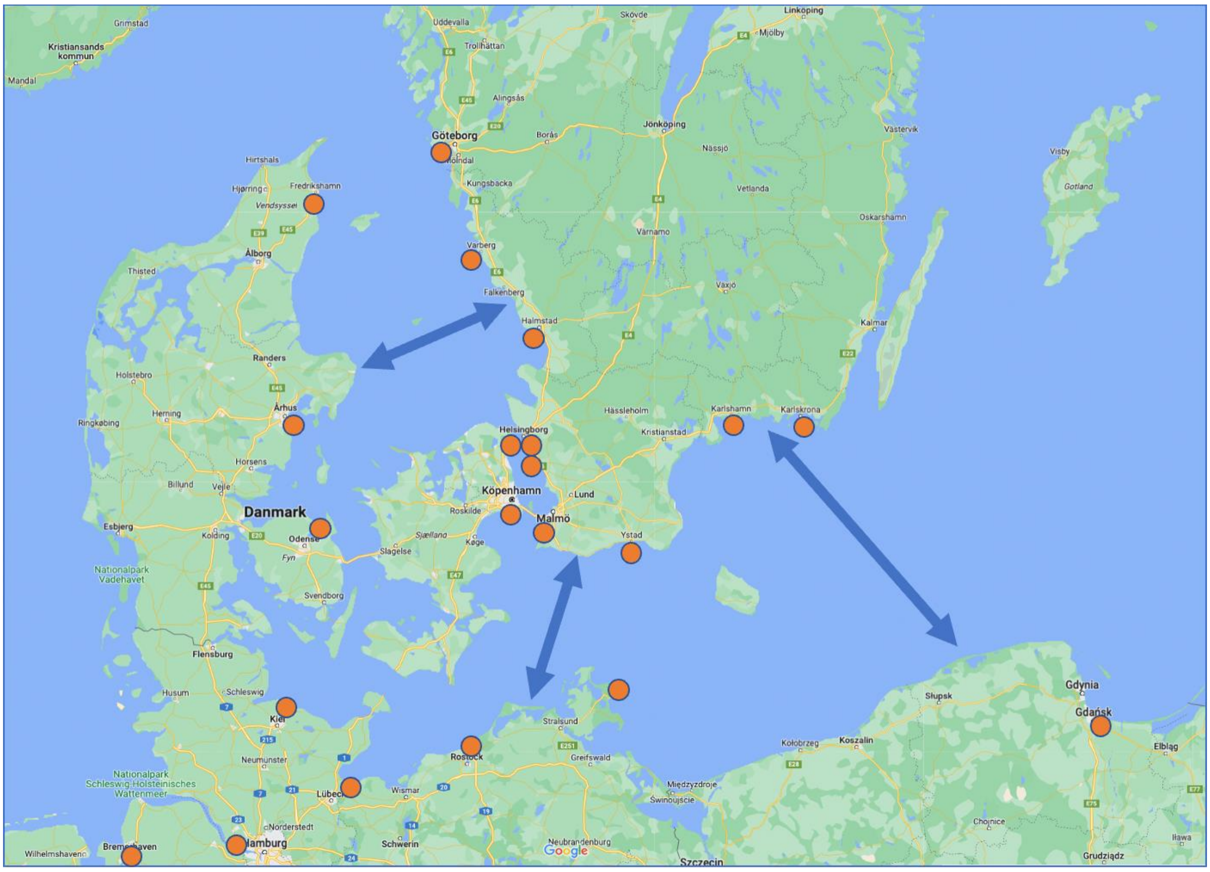


*Figure 58. Sweden as a logistical hub between Sweden, Denmark, Germany and Poland. Source: (Authors).*

### 8.16.2. Linking Sweden and Finland/Baltic countries with EV tractors and battery-swapping stations

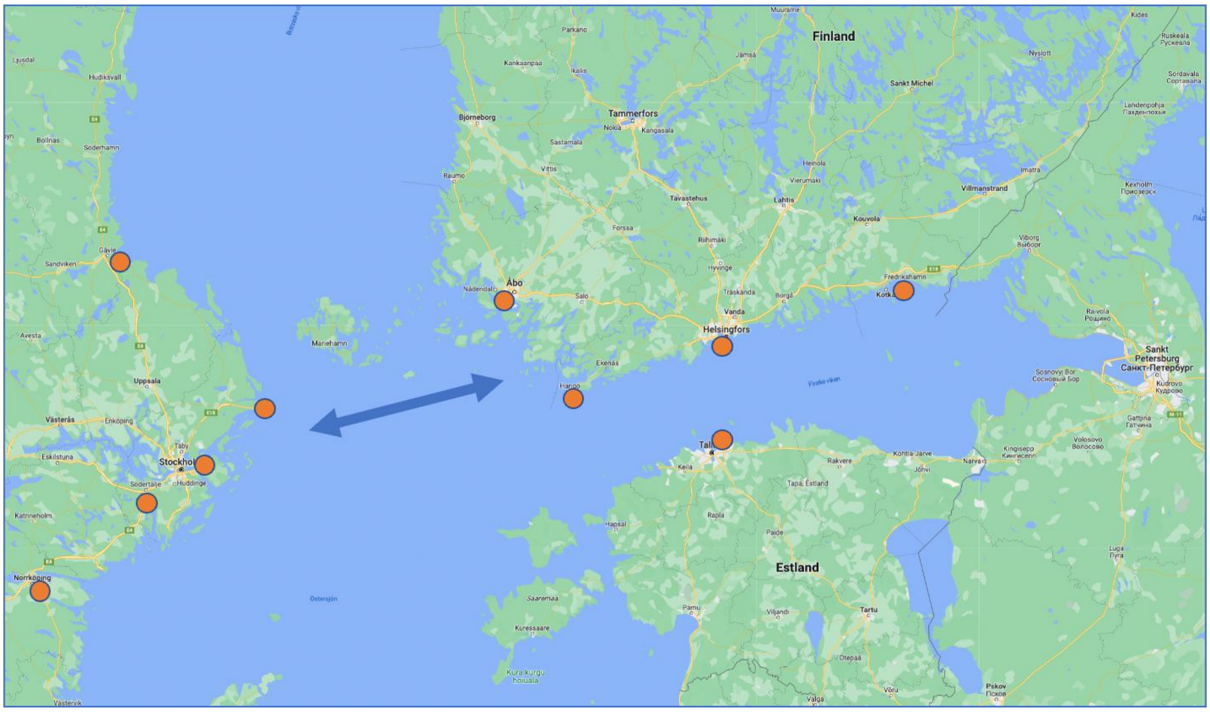


*Figure 59. Sweden as a transportation link to Finland and the Baltic states. Source: (Authors).*

As we see, Sweden's position as the logistical hub and as a transportation link calls for considering how battery-swapping stations can be placed close to harbors and selected hubs to support in-harbor operations from ports to logistical hubs and finally to customers.

The characteristics of battery-swapping solutions are that a single battery-swapping-based truck or tractor can operate about 150-175 km one way before the battery must be swapped for a fully charged one. Thus, battery-swapping stations must be strategically placed, enabling transport vehicles to optimize transport flow.

Several optimizing aspects must be considered: the sizes of batteries in use, from 150-282-350-450 kWh, are standard today, to locations of stations, the dimensioning of battery-swapping stations from 3 to19 batteries in modular design stations, to the business model in use.

The enclosed battery-swapping simulation case shows how we can use optimization modelling to design the in-harbor, close-to-harbor, and between-harbor and logistic hub operations to optimize the solutions.

### 8.16.3. Fully deployed battery-swapping systems in Southern Sweden

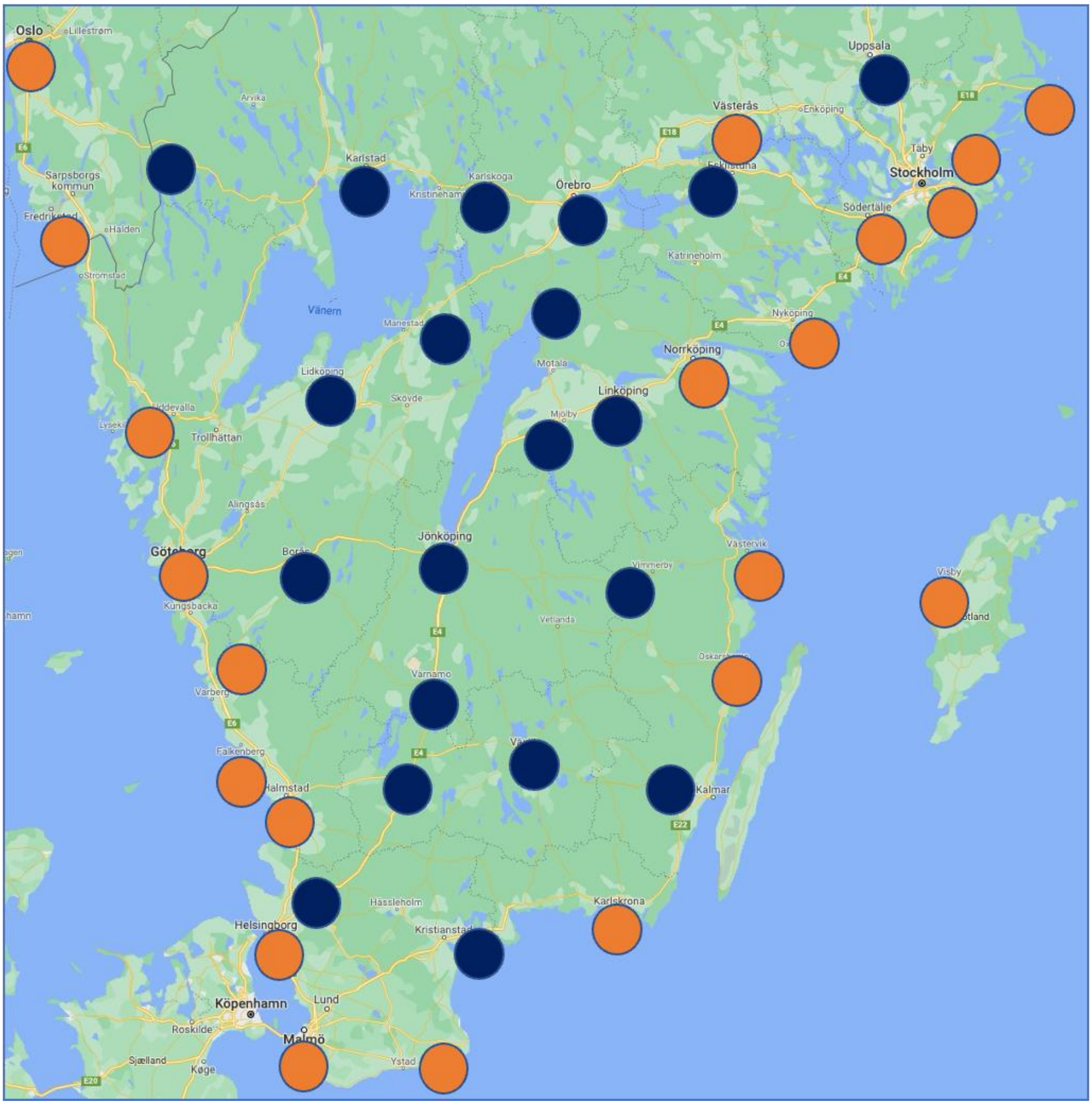


*Figure 60. Fully deployed battery-swapping stations in southern Sweden. Source: (Authors).*

Figure 60 shows how battery-swapping stations can be deployed to cover harbors and some vital logistical hubs in Sweden. Figure 60 is based on our experiences of battery-swapping-based operations, the normal driving distances, and the normal operational capacity of battery-swapping stations. Based on daily battery-swapping solutions, our calculations show that the positioning of 38 battery-swapping stations can serve a maximum of 6,500 trailers and trucks.

What must be noted is that the battery-swapping stations are flexible and scalable solutions. They can be gradually added to new operations places, removed, and reallocated to new areas where swapping is needed.

## 8.17. The Swedish context is different.

The dominant solution in China is that trucks and batteries are physically integrated into the truck but business-wise separated in the dominant business model. Trucks can be bought while batteries are rented. Swapping is based on subscription (Danilovic & Liu, 2021; Liu % Danilovic, 2021; Chapter 3 in this report).

We have been in touch with truck operating companies in Sweden, and they've shared that the most popular business model, like the one mentioned earlier, has been heavily influenced by the practices of truck suppliers in China. In the case of Chinese suppliers offering trucks with battery-swapping capabilities, they often recommend a full-leasing contract. This contract would cover both the truck and the battery. The main advantage of this approach is that it significantly reduces the financial and operational risks for the truck operators. Chinese truck suppliers are absent in the European market, and thus, they are not known; the quality of trucks still needs to be explored and discovered, and solutions regarding service, maintenance, and spare part supply still need to be proven to work according to customer expectations. To reduce risks, a full leasing model is preferred.

A mix of subscription and single-use payments is suggested as a solution for battery-swapping stations. The option to recharge at night in the depot supports the pay-as-you-use swap solution.

## 8.18. Complementary charging infrastructure technologies.

The contemporary European suppliers of EHT only deliver fully integrated truck battery solutions that do not adopt battery-swapping solutions.

Our experiences, based on interviews, seminars, and workshops, indicate that contemporary European EHT manufacturers are hesitating to adopt battery-swapping solutions due to the following reasons:

- Uncertainty of their business situation if they lose control of the battery.
- Uncertainty if there is a similar market/customer situation and acceptance among truck operators to choose battery-swapping solutions.
- Financial uncertainty as they have invested heavily in the dominant solutions with fully integrated truck-battery solutions that cannot be overturned easily.
- Uncertainty on how the suitable business model might look in the Swedish, Scandinavian, and European contexts.
- All contemporary OEMs have designed cable-charging solutions and presented that the large-scale electrification of heavy trucks can be managed by cable-charging. This hinders them from opening up a new solution that can compete with cable-charging solutions.

### 8.18.1. Battery-swapping as a complementary solution

Based on our previous work (Daniels et al., 2021), battery-swapping should be seen as something other than excluding cable-charging solutions or the forthcoming hydrogen solutions.

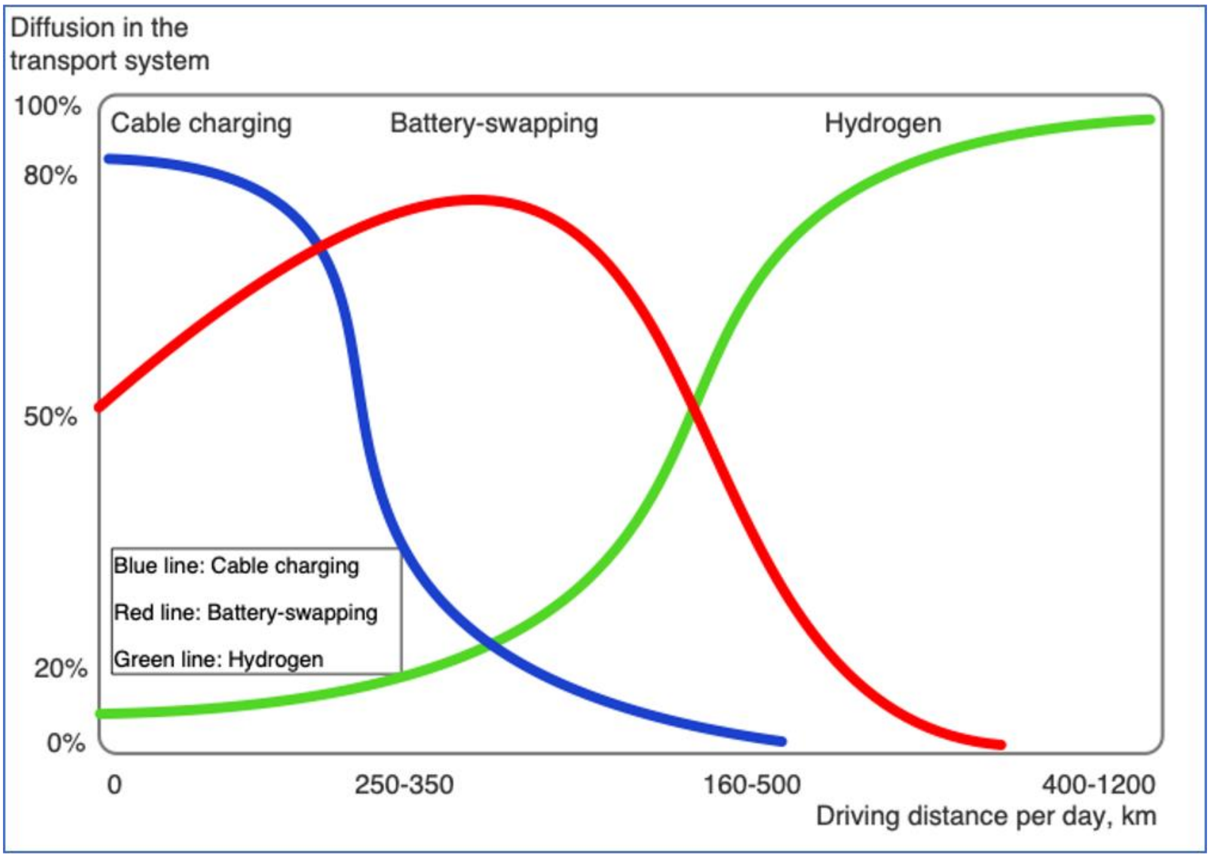


*Figure 61. Battery-swapping as a complementary solution. Source: (Daniels et.al., 2021).*

In our analysis of how different charging solutions operate from technological, operational, and economic perspectives, we conclude that cable-charging is most suitable for local transport & short distance range transport or low-intensity operations that enable truck recharging in 1-3 hours during shift operations.

Conversely, battery-swapping suits local, regional, and intensive transport operations, particularly if the truck operating company needs flexibility and 2-3 shift operations.

The hydrogen and fuel cell solutions are not operationally and business-wise available yet; it might take 5-10 years before they are suited for intensive, regional & long-distance transport operations. It needs to be seen from the system perspectives of producing green hydrogen and creating the distribution and refuelling infrastructure for hydrogen-based transport operations.

## 8.19. Value proposition

The “heart” of a business model is the solution to the customer's headache, solving the problems for the customers, creating solutions and value that make the customer capable of solving their challenges and creating value for them.

The value proposition is the narrative of value creation and delivery to customers. The value proposition we have designed is as follows.

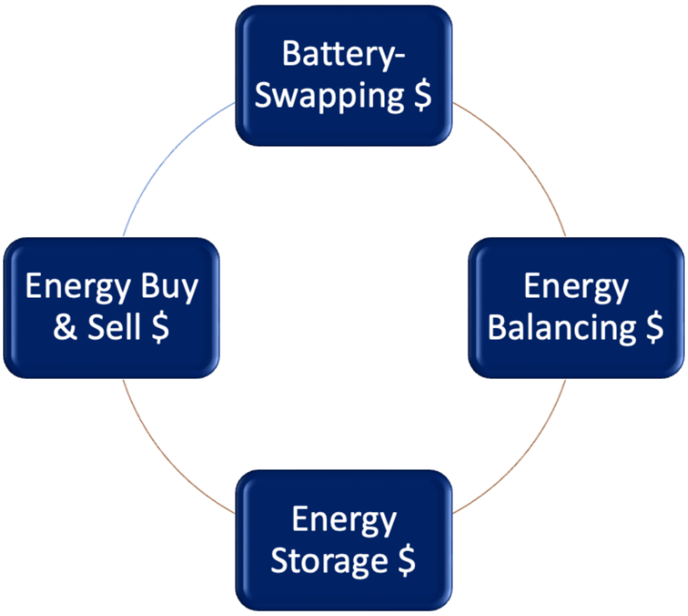


*Figure 62. Multiple revenue streams based on battery-swapping solution. Source: (Authors).*

The core value creation is the system approach that enables flexible multi-revenue stream solution in a fully integrated system solution:

- A total system solution enables a scalable recharging solution that supports the energy producers’ grid system operators to supply electricity to the large scale of charging systems without power peaks and valleys in a balanced system solution.

In this situation, the value proposition that is defined is related to:

- Creating a decentralized energy system that can support localized electricity production and distribution to users recharging vehicles.
- Integrated cable-charging and battery-swapping solution.
- Enables a complementary charging infrastructure to traditional cable-charging and the forthcoming hydrogen energy solutions.
- Recharging of batteries can be adjusted and flexible from 50 kW to 450 kW charging power.
- It enables scalable system solutions adapted to localized recharging needs and scaled to fit EHT's future growth.
- Enable scalable and adaptable battery solutions that optimize scenarios, from small batteries of 150 kWh to large scale 450 kWh. Battery development in the future can be integrated into the battery-swapping redesign as an option.
- It enables flexible system solutions from small stations of 3-4 batteries to large stations containing 19 batteries.

The system approach is the most valuable solution in the battery-swapping solutions, designing the decentralized and localized energy integration system in two dimensions:

- The horizontal integration of the value chain from energy production, from integrating grid, wind, and solar energy production distribution to consumption in charging and swapping vehicle batteries.
- The vertical integration of different vehicle systems that utilize battery-swapping as an integrating solution supports several vehicle brands to utilize the same recharging infrastructure to effectively use batteries also in their second and third life. Thus, this approach helps extend the lifespan of batteries, leading to more efficient use of rare-earth minerals and metals. As a result, there is a reduced negative impact on the environment.

## 8.20. Back-end design

To utilize the full scope of value creation based on battery-swapping solutions, the new eco-system needs to be considered from the localized battery manufacturing, battery recycling, strategic research and development of the battery-swapping systems and recharging systems to enable scalability and adaptability in the future technology development of vehicles, intelligent interconnectivity of vehicles and the business environment. The eco-system of a battery-swapping solution differs from one based on a cable-charging solution.

According to our analysis, one of the most critical aspects that need consideration in setting up battery-swapping stations and optimizing the system solution is the grid system capacity, adaptability, cybersecurity, and robustness of operations to ensure stability and safety.

In the contemporary combustion technology (ICE) system, the fuel is generic and unrelated to any specific vehicle OEM. Petrol and diesel are generic energy sources or carriers that all vehicle brands can use in their ICE-technology engines. A similar system solution regarding the battery-swapping solutions needs to be explored to create a standard system solution that several OEMs of trucks can exploit. Otherwise, there is a risk of competing with non-standard solutions that may not be sustainable in the long run.

The contemporary approaches to cable-charging indicate a similar situation where different proprietary solutions are competent with each other, creating challenges for vehicle operators.

## 8.21. The integrative political, institutional, and regulatory role in establishing a battery-swapping system

Lack of standardization is one of the critical aspects of creating innovation (Liu, 2019). This is challenging as vehicle development, battery technology progress, and vehicle OEMs' strategic positioning are divergent processes that individual companies with high ambitions drive. However, the collective usage of recharging systems requires standardization and flexibility. Those requirements must be balanced, and the user's and operators' needs should be the design and development force.

The political, institutional, and regulatory actors must improve their collaborative solutions to accomplish this. Today, institutional and political decision-makers rely on industry to develop and roll out suitable recharging system solutions. The decision-makers from the EU to the national Swedish level are trying to be technology neutral in deciding which solutions and which eco-system is to be deploying different solutions. The EU AFIR decisions focus on cable-charging infrastructure and, in the future, the hydrogen infrastructure. However, the full-scale implementation of battery-swapping as a system solution requires more involvement by institutional and political actors in the design of the total charging infrastructure. The transformation of the energy system to renewable and transportation system to electrified solutions is not driven by industry. Political actors drive it, and therefore, the political decision-makers need to create conditions and frames for industrial actors to develop solutions that align with the mission-driven societal transformation.

In addition, the regulatory actors must revise the contemporary legal and regulatory standards to utilize the battery-swapping systems' capacities fully. One example is the capacity of battery-swapping to provide fully integrated swapping, energy balancing, and energy buy/sell solutions that, following contemporary regulations, cannot be fully utilized as it requires that specific and dedicated batteries only are used for energy balancing functions and cannot be part of the swapping eco-system (Danilovic & Liu, 2021, Liu & Danilovic, 2021).

Transforming to renewable energy and electrifying transportation systems is a mission-driven societal and industrial transformation. The industry needs to push this transformation from ICE technology to electric, battery-based, or hydrogen-based solutions. It is a political decision made via laws, policies, and regulations imposed on the industry. Thus, it is challenging to expect industry to take full responsibility for such a transformation that is not business-driven but contains a high level of political motives beyond industrial logic and business logic.

Because mission-driven social and industrial transformation is above the industry and business level, the political, institutional, and regulatory actors must understand that there are no technology-neutral solutions. All solutions sections are based on specific technologies and thus are technology-subjective with implications and consequences.

This is a crucial aspect of the symbiotic business model that the political, institutional, and regulatory actors communicate and have an intensive dialogue with industry to actively support the development and implementation of complementary system solutions that align with the mission-driven assignment towards what the society needs. The interests of industry and society are only sometimes synchronized well.

## 8.22. Results

The outcomes of this project are a proposed business model focusing on truck operating actors and battery-swapping station operators. The target for the business model project is truck operators focusing on container transport in harbors and to/from ports and logistical hubs. This choice is strategically chosen. Step-by-step, other areas of truck operations can be enrolled, such as regular trucks, concrete mixers, garbage transporters, working machines, etc.

### 8.22.1. Proposed business model for truck operators

We have communicated with about 25 truck and logistic operating companies. All 25 companies we have talked with say they prefer battery-swapping solutions for the previously mentioned reasons. We have observed very positive reactions among truck and logistic operators to battery-swapping solutions.

A battery-swapping equipped truck allows the operator to recharge the vehicle via cable when suitable and appropriate or swap the battery when that is the best solution. In the daytime, the swapping solution enables flexibility and speed, enables two to three operational shifts, and allocates relatively limited physical space for operations.

Of the 25 companies we have talked with,

- One-third stated they would not choose any international truck OEM due to a lack of trust and experience.
- One-third say they can choose international suppliers if the business situation is suitable and service, maintenance solutions, and spare parts solutions are reasonable. Their operational margins are small, and the traditional EHTs from contemporary EHT suppliers are not

economically feasible. This group could take on international battery-swapping-based new truck solutions for these reasons.

- One-third falls in between those two groups. They are followers, and depending on the experiences among early adopters, they can join the adopters of the battery-swapping solutions team.

One appreciated feature of battery-swapping is the opportunity to create new multi-stream businesses for truck operating companies, such as energy balancing and energy storage and energy buy/sell, that they cannot do. Only a battery-swapping system solution can provide an integrated solution. Separate solutions exist today.

Traditional European truck suppliers can provide high-quality trucks with well-developed service, maintenance solutions, and spare parts supply. Truck operating companies know the offers and conditions of European-based truck OEMs as they have long-term experiences and relations with European OEMs.

The European newcomers want to offer new battery-swapping trucks, tractors, and batteries. Swapping stations need to prove themselves and create suitable and sustainable solutions. Technology has already been proven to work well with thousands of battery-swapping-based trucks that have been in operation for several years, and several hundreds of battery-swapping stations are already operational. However, the remaining key is to design an appropriate business model that suits the Swedish and Nordic truck operating companies as customers to trucks and stations.

### 8.22.2. Business model proposal for truck operators

To handle the uncertainties and lack of experience of international trucks with battery-swapping, we propose that truck operators take total leasing solutions, financial leasing, and operational leasing in an integrated package.

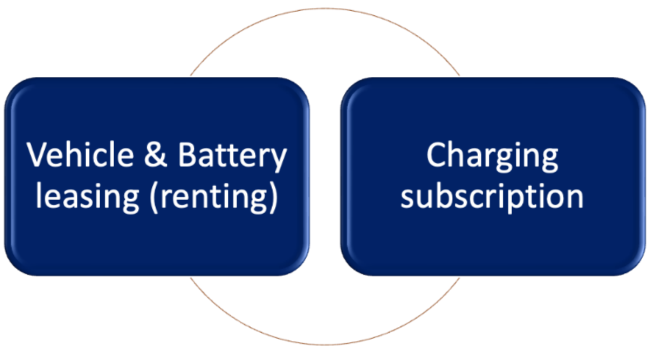


*Figure 63. Proposed business model for truck operating companies. Source: (Authors).*

- Unlike established business solutions in China, we propose integrated vehicle and battery packages with options to change batteries based on changing operational needs. Thus, creating flexibility when needed.
- The proposed full-lease contract time is six years, a usual economic life cycle of trucks and tractors for container transportation scenarios.
- The leasing company might have second usage of second-hand trucks after the leasing period.
- The swapping solution can be based on subscription or pay-as-you-use the swapping solution.

- The system provider can provide a total system solution with suitable wind and solar power systems, flexible and expendable cable-charging, adjustable speed in recharging batteries in the swapping station, and flexible charging speed in the cable charging solution.

### 8.22.3. Business model proposal for battery-swapping station operators

Some questions are essential to answer. Who are the operators of the battery-swapping stations? It can be independent station operators, truck operating companies, contemporary fuel station operators, or even truck OEMs that see the charging infrastructure as an interesting complementary business to ensure the growing market for their EHTs.

We can already see that three major European truck OEMs (Volvo, Daimler, and Traton Group) have established a joint venture to build and operate a system of cable-charging stations across Europe. Thus, it is reasonable that contemporary truck OEMs can expand their charging infrastructure to also include battery-swapping solutions.

An adaptable business model can be designed depending on the answers to those questions. It can vary to suit different station operators' needs.

Our solution and proposal are based on the basic ideas of integrated buying and operating the stations with a franchising design to ensure service and system upgrades. The economic life cycle of the stations is estimated to be ten years, as the estimated and expected life cycle of batteries is between eight and ten years.

### 8.22.4. Results of the proposed business models for truck operators and station operators

Our analytical business model generated data during meetings with truck operators, seminars, and workshops. Also, assumptions are developed that are important for calculating the economic outcome.

We have presented the data collection and analysis results to truck operating companies to evaluate and critically reflect on the assumptions and interpretations of the results. Adjustments have been made accordingly.

This adjustment process is continuous as prices on fuel and electricity, supply of electricity, prices on batteries, interest rates, government taxes, etc., vary over time, and the calculations are thus bound to the time when they are made.

We have calculated operational costs for contemporary diesel-based operations, cable-charging solutions, and optional battery-swapping solutions.

Here, we can present those three results:

**OUTCOME: Profits from battery-swapping operations**

Our analysis shows that the truck operators can make an increase in profit by shifting from diesel-based operations to battery-swapping on the level of:

**Change from diesel:** 263,000 – 232,200 SEK /year/truck

= 26,000 – 23,000 EURO /year/truck

The higher profit (left) comes from estimating two swaps per day, while the lower assumes one swap per day.

Our analysis shows that the truck operators can make an increased profit by shifting from contemporary cable-charging EHTs to battery-swapping on the level of:

**Change from cable-charging:** 390,000 – 512,000 SEK /year/truck

= 38,000 – 50,000 EURO /year/truck

The lower profit (left) comes from estimating two swaps per day, while the higher assumes one swap per day.

Profitability estimates are based on the following primary data and assumptions:

*Table 9. Summary of selected business model innovation definitions. Source: the authors.*

| **Cost SAVING per YEAR, vs. DIESEL** | **2 swap per day** | **1 swap per day** |
|---|---|---|
| Investment cost | -500 000 kr | -500 000 kr |
| Maintenance cost | -50 000 kr | -50 000 kr |
| No extra cost for battery degraduation | -150 000 kr | -150 000 kr |
| Savings on diesel consumption | -823 200 kr | -462 200 kr |
| Operational cost, Truck & Battery renting | 600 000 kr | 600 000 kr |
| Operational cost, swapping cost, (2 swaps per day) | 660 000 kr | 330 000 kr |
| SUM COST SAVING, Annualy | -263 200 kr | -232 000 kr |

*Table 10. Profitability for shifting from cable-charging to battery-swapping. Source: The authors.*

| **Cost SAVING per YEAR, vs. CABLE CHARGING, regional op.** | **2 swap per day** | **1 swap per day** |
|---|---|---|
| Investment cost | -600 000 kr | -600 000 kr |
| No cable chargers at depo | -200 000 kr | -200 000 kr |
| No cable charging cost. Total 110,000 kWh á 4 SEK | -440 000 kr | -250 000 kr |
| Efficiency dure to no charging time needed, 2h/1h per day x 600 SEK/h | -262 000 kr | -130 000 kr |
| No extra cost for battery degradation | -150 000 kr | -150 000 kr |
| Operational cost, Truck & Battery renting | 600 000 kr | 600 000 kr |
| Operational cost, swapping cost, (2 swaps per day) | 660 000 kr | -330 000 kr |
| Second operational shift | ? | ? |
| SUM COST SAVING, Annualy | -392 000 kr | -400 000 kr |

As we can see from the tables above, introducing the 2nd truck operations shift might have significant value adding to the revenue side. However, this is not estimated as it depends on the respective scenario.

Overall, the shift to battery-swapping trucks is profitable for truck operators regardless of whether they shift from diesel or the current cable-charging solution.

Our analysis shows that battery-swapping station operators can create revenues based on the number of swaps conducted daily.

| **Swaps per day** | **Profits per year** | **Payback time** |
|---|---|---|
| 20 | 10 million SEK (1,0 million EURO) / year | 3,6 years |
| 40 | 18 million SEK (1,8 million EURO)/ year | 2.0 years |
| 80 | 37 million SEK (3,7 million EURO/ year | 1.0 year |

In our analysis, we see that the determining parameter is the number of swaps that, in turn, are determined by the size of the battery-swapping-based truck fleet.

We can see that the already low number of swaps, such as 20 per day, create reasonable profitability, although 40 daily significantly improves profitability.

40 swaps per day are estimated to equal a truck fleet of 40-50 trucks operating one shift daily.

The battery-swapping enables two and three-shift operations that significantly might influence the number of swaps and thus the profitability for swapping station operators.

There is a balance of sharing profitability between truck operators and station operators.

If the cost for swaps is high, the truck operators might prefer cable-charging and vice versa. In our analysis, we have created a transparent situation and determined parameters that suit truck and station operators' needs. This has been conducted as some large truck operating companies might see swapping stations as business opportunities combining swapping, and multiple revenue streams.

## 8.23. Conclusions

We conclude that when introducing battery-swapping solutions for EHT, we must consider that such system solutions exist outside of the European context of truck logistic operations. However, battery-swapping exists for passenger vehicles in Sweden, Norway, Holland and Germany. We know that these systems are growing and expanding across Europe.

The uncertainty among truck operators regarding international suppliers of battery-swapping-based trucks is apparent. However, we have noticed that as much as one-third of the explored truck operators can well imagine battery-swapping solutions under the assumption that technical and operational qualities are acceptable and sustainable.

The profitability for truck operators is reasonably high regardless of whether they shift from diesel or cable charging to battery-swapping solutions.

The significant barriers in the case of cable-charging are the long recharging time, accessibility to charging piles with high capacity/speed, accessibility to charging piles along the roads, and the influence of the fast-charging solution of EHTs brought to the grid side. The high-power capacity requirement it addresses to the grid and the overall cost level for current EHTs is perceived as high. An additional challenge is the time to establish cable-charging piles, the administrative process to get the permits, the effect of access to electricity in the grid system, etc. Although the current regulatory framework in Sweden guarantees that all requested charging piles will be provided with electricity, the time to accomplish this still needs to be determined.

Truck operating companies are hesitating about shifting to cable-charging solutions for all those reasons.

Here, we can present those three results where we compare battery-swapping with diesel and cable-charging:

**OUTCOME: Profits for truck operating companies shifting from diesel to battery-swapping operations**

Our analysis shows that the truck operators can make an increase in profit by shifting from diesel-based operations to battery-swapping on the level of:

**Change from diesel:** 263,000 – 232,200 SEK /year/truck

= 26,000 – 23,000 EURO /year/truck

The higher profit (left) comes from estimating two swaps per day, while the lower is based on the assumption of one swap per day.

**OUTCOME: Profits for truck operating companies shifting from cable-charging to battery-swapping operations**

Our analysis shows that the truck operators can make an increased profit by shifting from contemporary cable charging EHTs to battery-swapping on the level of:

**Change from cable charging:** 390,000 – 512,000 SEK /year/truck

= 38,000 – 50,000 EURO /year/truck

The lower profit (left) comes from estimating two swaps per day, while the higher assumes one swap per day.

Our analysis shows that battery-swapping station operators can create revenues based on the number of swaps conducted daily.

| OUTCOME: Profits for battery-swapping station operators | | |
|---|---|---|
| **Swaps per day** | **Profits per year** | **Payback time** |
| 20 | 10 million SEK (1,0 million EURO) / year | 3,6 years |
| 40 | 18 million SEK (1,8 million EURO)/ year | 2.0 years |
| 80 | 37 million SEK (3,7 million EURO/ year | 1.0 year |

The overall conclusion is that the technology for battery-swapping for heavy trucks has matured, is available on the market, and has proven to work functionally and efficiently. The main remaining question is how it might work in the Swedish context. A suitable and customized business model is essential to support battery-swapping commercialization for heavy trucks. This report provides a first concrete draft of such a business model that shows reasonable profitability for the two main actors: battery-swapping station operators, and truck operators, utilizing the functionality of battery-swapping system solutions.

## 8.24. Optimizing transport flow based on battery-swapping solution – The Harbor Transport Case

### 8.24.1. Simulation approach to optimization of battery-swapping operations

In this chapter, we introduce an optimization approach to explore if battery-swapping as a system solution can be utilized to optimize the total system solution and, thus, support the transformation of the entire operational scenario to one that is battery-swapping based.

### 8.24.2. System approach

This case study focuses on harbor transport missions limited to in-harbor transport and from the harbor to a nearby factory. The total distance is 8 km from the harbor to the factory and from the factory to the harbor. Trucks operate daily. The total number of tractors is five, taking containers from ships at the harbor to a factory and products back from the factory to ships at the harbor.

The harbor chooses between two alternative technological paths: cable-charging tractors with fixed batteries or tractors with swappable battery capability. The first technical path leads to the fixed battery-based tractors available on the market with a standard battery size of 300 kWh and more. Thus, the fleet of five tractors is based on 1500 kWh total fleet battery capacity. In contrast, the second alternative is the swappable battery capability tractors. If battery-swapping is introduced, several questions must be answered. One is how many batteries the swapping station must hold to support the fleet’s seamless operations. The other one is determining the smallest battery size in the station and among the five tractors that can support the expected logistics flow. In this case, we have discussed the battery-swapping technological path.

### 8.24.3. Results of the Simulation Analysis

#### Minimizing the Total Fleet Battery Capacity

Our simulations show that battery-swapping can be accomplished with the smallest battery size of 150 kWh in the station and each tractor. In this situation, the number of batteries increases from five to six. At the same time, the total fleet battery capacity decreases from 1500 kWh to 900 kWh, 750 kWh in all five tractors, and 150 kWh in the station.

The conclusion is that while the number of batteries increases by one battery, the total number of enrolled fleet battery capacities decreases from 1500 to 900 kWh, i.e., 600 kWh lower capacity, a total decrease of 40%.

This shows that the critical aspect of battery-swapping is improving operational efficiency, profitability, and environmental impact. The battery-swapping can serve the expected operational efficiency and daily operations. In that case, lowering battery capacity has both an environmentally positive impact as well as an economic impact as lower battery size reduces the cost and investment in tractors.

#### Minimizing the investment cost

Investing in one battery-swapping station with one battery brings economic value as the investment price is lower due to only one battery with a small size being used, and the total fleet battery capacity is decreased by 40%. Additional revenues are coming from the normal operations of those five tractors.

#### Minimizing the negative environmental effect

The more important effect is the positive impact on the environment as battery-swapping solutions reduce the total fleet capacity of batteries, lower volumes of metals and minerals, and impact all humankind and the environment. We have reasons to see that truck battery-swapping saves the environment and the wallets of transport operators.

### 8.24.4. Impact on the business model innovation – Optimizing the operational efficiency

This simulation shows that the battery-swapping solution impacts the system level of the eco-system of the battery-swapping solution (harbor operations, transportation company, and the buyer of the transportation services, as well as the provider of the scarce electricity).

In our business model analysis, we demonstrate the impact of the new business model for transportation and logistics operators and battery-swapping station operators. However, the analysis of the outcome of the harbor cases shows that the cost level and the revenue side of battery-swapping operations significantly affect logistic operators of the harbor and transport operator, logistics buyers, and battery manufacturers as they can provide more batteries with fewer minerals to other buyers, and the society by lowering the negative impact on the environment and the recycling challenges of the life cycle of batteries.

Thus, the outcome might influence pricing and offers from the battery-swapping system supplier to its customers.

### 8.24.5. Introduction

Incorporating electric trucks into fleets has become a significant approach to lower carbon emissions in the rapidly evolving logistics and transportation system. Employing trucks with the ability to swap batteries has the potential to increase the trucks' availability and decrease costs; however, the efficiency of these trucks depends heavily upon the efficiency of the battery-swapping system.

This analysis considers the use case of battery-swapping trucks transporting containers between a harbor and a warehouse. It uses real operational data on the operations of a battery-swap electric truck to simulate how such operations could be performed using battery-swappable trucks. The model is also used to estimate the expansion in the battery-swapping fleet as port activity increases in the future.

We begin by summarizing existing truck operations at the harbor, specifically examining a truck's workload and distance covered during morning, afternoon, and evening shifts. The energy required to perform the equivalent work with battery-swapping trucks drives model requirements for swapping, including the time required in each shift for swapping batteries and how many spare batteries are needed at the battery-swapping station. Our aim is not merely to meet current needs but also to develop a plan to grow to accommodate future increases in harbor activity.

The existing schedule and expected future truck operations for 2023 – 2026 are shown in Table 11. Trucks operate between a harbor and a warehouse, a distance of 8 kilometers per round trip. The current demand is 8 rounds daily, performed with a single truck. Including the time spent driving, loading and unloading goods, and taking short breaks, each round takes approximately 1 hour, and the truck covers a total distance of 64 kilometers each day. Under the current demand, all of these trips can be made in the morning shift, which runs from 06:00 to 14:30, with a lunch break from 10:00 to 10:30. In 2025, 4 more trucks will be added to the system, and the total demand split among these 5 trucks will be 40 trips per day. In 2026, this will be increased to 50 trips per day with the same 5 trucks.

*Table 11. Operational schedule and the increase in number of trucks from 2023 - 2026.*

| Parameter | 2023 | 2024 | 2025 | 2026 |
|---|---|---|---|---|
| The total number of transports (round trips) from the harbor to the warehouse per day (one round is about 8km) | 8 | 8 | 40 | 50 |
| Expected number of transports per truck during the morning shift, before lunch (06:00-10:00) | 4 | 4 | 10 | 13 |
| Expected number of transports per truck during the morning shift, after lunch (10:30-14:00) | 4 | 4 | 10 | 13 |
| Expected number of transports during the afternoon shift, before dinner (14:00-18:00) | 0 | 0 | 10 | 12 |
| Expected number of transports during the evening shift, after dinner (18:30-22:00) | 0 | 0 | 10 | 12 |
| The weight of a fully loaded container, in tones. | 30 | 30 | 30 | 30 |

To address the energy requirements for this scenario, we estimate the energy consumption of the existing truck per kilometer, which reflects typical electric truck performance. Using this estimate, we can calculate the daily energy usage and the number of operational days before the battery reaches depletion. Further, based on the number of operational trucks, we determine the minimum number of batteries required at the swapping station each year from 2023 – 2026. The investigation is based on the number of trucks, the travel distance per truck, and the recharge time for batteries, providing a dynamic view of the system's operation over the simulated period. This model will determine the minimum number of batteries needed in this swapping station, ensuring that the swapping station operates efficiently with a lean inventory of batteries.

### 8.24.6. Method

We used one case scenario from one medium-sized harbor undergoing electrification and rapid expansion of inside harbor transportation.

Today, the electricity supply to the harbor area is weak, and it does not enable enough electricity to set up more than 150 kW cable chargers.

We assume that a battery-swapping solution can be one possible solution to optimal electrification supporting the forthcoming growth of fleet operations.

A systematic approach is taken to calculate the operational duration of an electric truck's battery before a swap is required. The process involves a series of assumptions based on standard operational parameters and estimated energy consumption rates for electric trucks.

*Table 12. Represents the battery capacity and distance covered by a truck with a fully charged battery.*

| **Performance characteristics of the battery swap electric truck (XCMG E700) (Whittle, 2021)** | | |
|---|---|---|
| Battery capacity | 282 kWh | 150 kWh |
| Distance covered (15-20% battery residual charge) | 140 – 160 km | 80 km |
| Vehicle efficiency (kWh/km) | 1.4 – 1.7 | 1.5 – 1.6 |

Here, we assume a battery-swapping electric truck (XCMG E700) with two battery sizes, either a 282 kWh battery or a 150 kWh battery. The key operational question is how long the truck can continue operating before it swaps batteries. This is not merely a question of calculation but a critical factor in scheduling maintenance and ensuring uninterrupted service. With a daily driving distance of 64 km, the truck with a 282 kWh battery can run for approximately 2 days, which means the truck needs to swap its battery within 48 hours, while the truck with a 150 kWh battery can run for approximately 1 day, which means the truck needs to swap its battery within 24 hours.

Another challenge is to minimize the number of batteries at the swapping station when the number of trucks is increased in 2025 to 5 trucks, and the number of rounds ramped up to 50 per day in 2026 with five trucks for efficient and uninterrupted operations.

*Table 13. Scenario assumptions.*

| **Year** | **Number of trucks in a fleet** | **Drayage demand** |
|---|---|---|
| 2023-2024 | 1 truck | 8 rounds/day |
| 2025 | 5 trucks | 40 rounds/day |
| 2026 | 5 trucks | 50 rounds/day |

To optimize the system so that fewer batteries are required at the swapping station, we need to calculate the minimum number of batteries needed to ensure that each truck can get a fully charged battery when it comes in for a swap. Here are some factors that need to be considered:

We have determined that each truck with a 282 kWh battery requires a battery swap within approximately 48 hours. This means that within 48 hours, a fraction of the trucks will require a swap. Specifically, each truck will require $\frac{1}{2.35}$ swaps per day. With 5 trucks, the total number of swaps needed per day would be $5 \times \frac{1}{2.35} = 2.12$

In contrast, each truck with a 150 kWh battery requires a battery swap within 24 hours. This means that within 24 hours, a fraction of the trucks will require a swap. Specifically, each truck will require $\frac{1}{1.25}$ swaps per day. With 5 trucks, the total number of swaps needed per day would be $5 \times \frac{1}{1.25} = 4$

With both types of batteries, we assume discharged batteries are charged in the swapping station at three different average charging rates: 50 kW, 75 kW, and 150 kW. The charging time of a battery depends on the average charging power.

$$Charging\ Time\ (hours)\ =\frac{Battery\ Capacity\ (kWh)}{Charger\ Power\ (kW)}$$

*Table 14. Charging time with a 282 kWh and 150 kWh battery with different charging power*

| Charging Power | 282 kWh Battery | 150 kWh Battery |
|---|---|---|
| 50 kW | 5.64 hours | 3 hours |
| 75 kW | 3.76 hours | 2 hours |
| 150 kW | 1.88 hours | 1 hour |

### With a 282 kWh battery

With 50 kW, it takes 5.64 hours to recharge a battery, and each battery can be charged $\frac{24\ hours}{5.64\ hours} = 4\ times$ per day if it is continuously cycled through charging as soon as it becomes available. Similarly, 75 kW and 150 kW take approximately 6 times, and 12 times per day, a battery will be available for swapping after recharging.

The total number of battery swaps needed per day for all 5 trucks is approximately 2.12. This means that, on average, we need to perform a little over 2 battery swaps per day to accommodate all 5 trucks.

### With a 150 kWh battery

With 50 kW, it takes 3 hours to recharge a battery, and each battery can be charged $\frac{24\ hours}{3\ hours} = 8\ times$ per day if it is continuously cycled through charging as soon as it becomes available. Similarly, 75 kW and 150 kW take approximately 12 times, and 24 times per day, a battery will be available for swapping after recharging.

The total number of battery swaps needed per day for all 5 trucks is approximately 4. This means that, on average, we need to perform 4 battery swaps per day to accommodate all 5 trucks.

To find out the minimum number of batteries needed at the swapping station, we divide the total number of swaps by the number of times a single battery can be charged per day:

$$Batteries\ required\ =\frac{Total\ no.of\ swaps}{No.of\ times\ a\ battery\ can\ be\ charged\ per\ day}$$

*Table 15. Number of times a battery can be charged in 24 hours and the batteries required at the swapping station.*

| Charging Power | No. Of times battery can be charged per day | | Batteries required at the swapping station | |
|---|---|---|---|---|
| | 282 kWh | 150 kWh | 282 kWh | 150 kWh |
| 50 kW | 4 times/day | 8 times/day | 0.53 | 0.5 |
| 75 kW | 6 times/day | 12 times/day | 0.35 | 0.33 |
| 150 kW | 12 times/day | 24 times/day | 0.17 | 0.16 |

Since we cannot have a fraction of a battery, we would need at least 1 battery per day to meet this average demand in both cases, with a battery size of 282 kWh and 150 kWh.

In other words, there is only the need for one spare battery in the system across all five trucks, in either battery size case, as long as the trucks can be scheduled so they don't all show up at once.

For 2026, the total number of rounds of trucks ramped up from 40 to 50, but the number of trucks remains the same as five, meaning each truck travels 80 km/day.

Based on the above calculation, the energy consumption of the truck is 1.88 kWh/km with a 282 kWh battery and a 150 kWh battery.

In this case, when the total number of rounds of trucks ramped up to 50, then it means the total energy consumption per truck is about 150 kWh/day, traveling 80 kilometers daily.

As the truck has a 282 kWh battery capacity and consumes 150 kWh battery per day, it means that the truck needs to swap its battery after 1.8 days, sometimes during the second day of operation. In contrast, the truck that has a 150 kWh battery capacity and consumes 150 kWh of battery per day requires a battery swap during each day of operation.

### With a 282 kWh battery

Since we have determined that each truck requires a battery swap approximately during the second day of operation, it means that within 36 hours, a fraction of the trucks will require a swap. Especially, each truck will require $\frac{1}{1.8}$ swaps per day.

As in 2026, each truck travels 80 km/day, and with 5 trucks, the total number of swaps needed per day would be $5 \times \frac{1}{1.8} = 2.7$ times.

### With a 150 kWh battery

Each truck travels 80 km/day, and with 5 trucks, the total number of swaps needed per day would be $5 \times \frac{1}{1} = 5\ times.$

In this case, we assume three different chargers with three different charging speeds: 50 kW, 75 kW, and 150 kW at the swapping station. The recharging time of a battery will vary depending on the charging speed.

*Table 16. Number of times a battery can be charged in 24 hours with different charging power.*

| Charging Power | Charging Time | | Time a battery can charge in 24 hours | |
|---|---|---|---|---|
| | **282 kWh** | **150 kWh** | **282 kWh** | **150 kWh** |
| 50 kW | 5.64 hours | 3 hours | 4 times | 8 times |
| 75 kW | 3.76 hours | 2 hours | 6 times | 12 times |
| 150 kW | 1.88 hours | 1 hour | 12 times | 24 times |

With the 282 kWh battery, the total number of battery swaps needed daily for all 5 trucks is approximately 2.7 times. However, with the 150 kWh battery, the total number of battery swaps needed daily for all 5 trucks is about 5 times.

This means that, on average, with a 282 kWh battery, we need to perform about 3 battery swaps per day to accommodate all 5 trucks, each traveling 80 km/day. In contrast with a 150 kWh battery, we need to perform about 5 battery swaps per day during operations to accommodate all 5 trucks, each traveling 80 km/day.

To find out the minimum number of batteries needed at the swapping station in 2026, we divide the total number of swaps by the number of times a single battery can be charged per day:

$$Batteries\ required\ = \frac{Total\ no.of\ swaps}{No.of\ times\ a\ battery\ can\ be\ charged\ per\ day}$$

*Table 17. Number of times a battery can be charged per day and batteries required at the swapping station with different charging power.*

| Charging Power | No. Of times battery can be charged per day | | Batteries required at the swapping station | |
|---|---|---|---|---|
| | 282 kWh | 150 kWh | 282 kWh | 150 kWh |
| 50 kW | 4 times/day | 8 times/day | 0.67 | 0.62 |
| 75 kW | 6 times/day | 12 times/day | 0.45 | 0.41 |
| 150 kW | 12 times/day | 24 times/day | 0.22 | 0.20 |

Since we cannot have a fraction of a battery, we would need at least 1 battery per day to meet this average demand even though, specifically, in this case, we have a 282 kWh battery or a 150 kWh battery.

### 8.24.7. Results and Discussion

The energy consumption of a truck traveling from the harbor to the warehouse and back, covering a total distance of 8 kilometers is approximately 17.625 kilowatt-hours (kWh) of energy on each round trip. Given the total battery capacity of 282 kWh and 150 kWh, this consumption rate is significant, indicating that the truck can make approximately 16 round trips (282 kWh / 17.625 kWh per trip) and 9 round trips (150 kWh / 17.625 kWh per trip) respectively, before depleting its battery as shown in Figure 64.

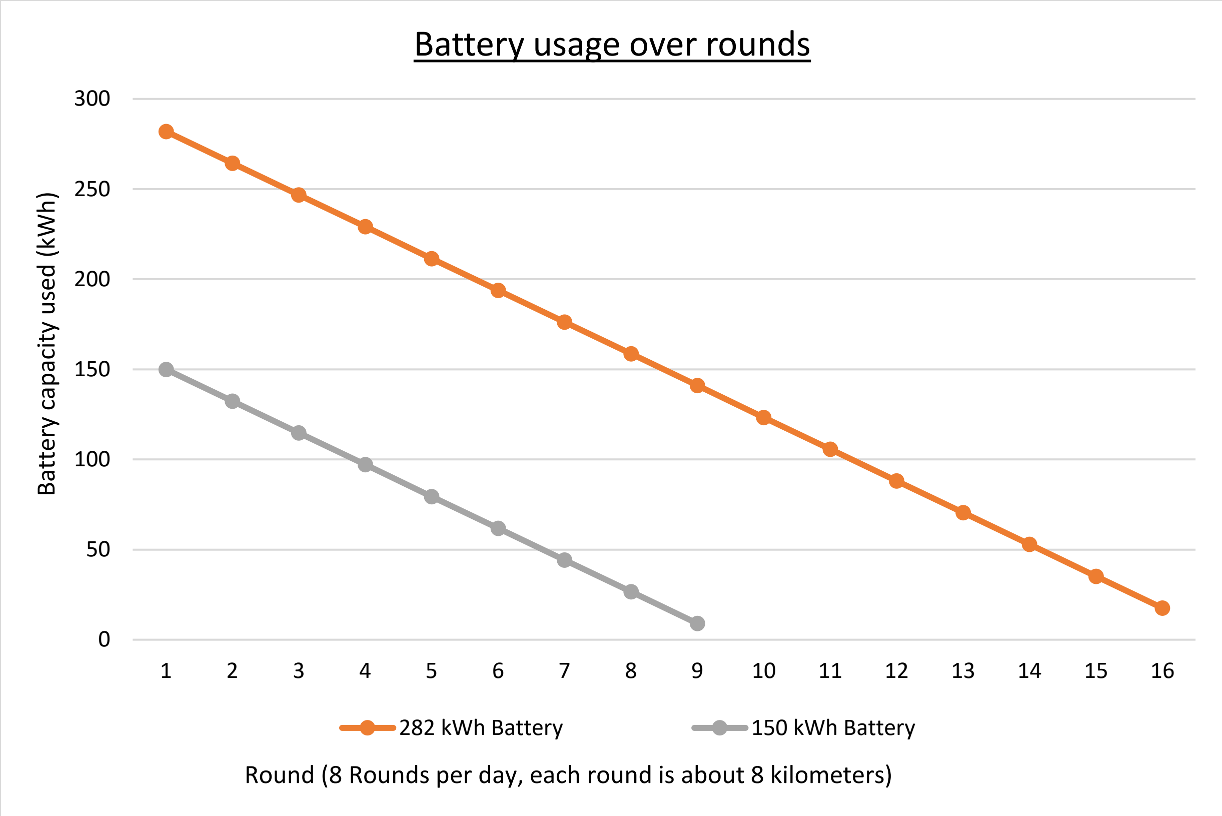


*Figure 64. Represents the usage of a 282 kWh and a 150 kWh battery in each round.*

This analysis is crucial for understanding the efficiency of the truck's energy usage, particularly in the context of its operational range and the frequency of recharging required.

The impact of different charger capacities on charging time, speed, and efficiency is also analyzed. Three types of chargers are considered: 50 kW, 75 kW, and 150 kW. For a 282 kWh battery and a 150 kWh battery, the 50 kW charger takes approximately 5.64 and 3 hours to fully charge the battery, while the 75 kW charger reduces this time to 3.76 and 2 hours, respectively. The most efficient option, the 150 kW charger, can fully charge the battery in just 1.88 hours and 1 hour, respectively, as represented in Figure 65. This comparison highlights the significant differences in charging efficiency and operational downtime associated with each charger type. The 150 kW charger offers a considerable advantage in reducing charging time, effectively doubling the charging speed compared to the 75 kW charger and nearly tripling the speed of the 50 kW charger. This increased efficiency can greatly enhance the operational capacity of the truck, allowing for more frequent trips and less downtime. For logistic operations where quick turnaround is critical, the choice of charger can substantially impact overall efficiency and productivity.

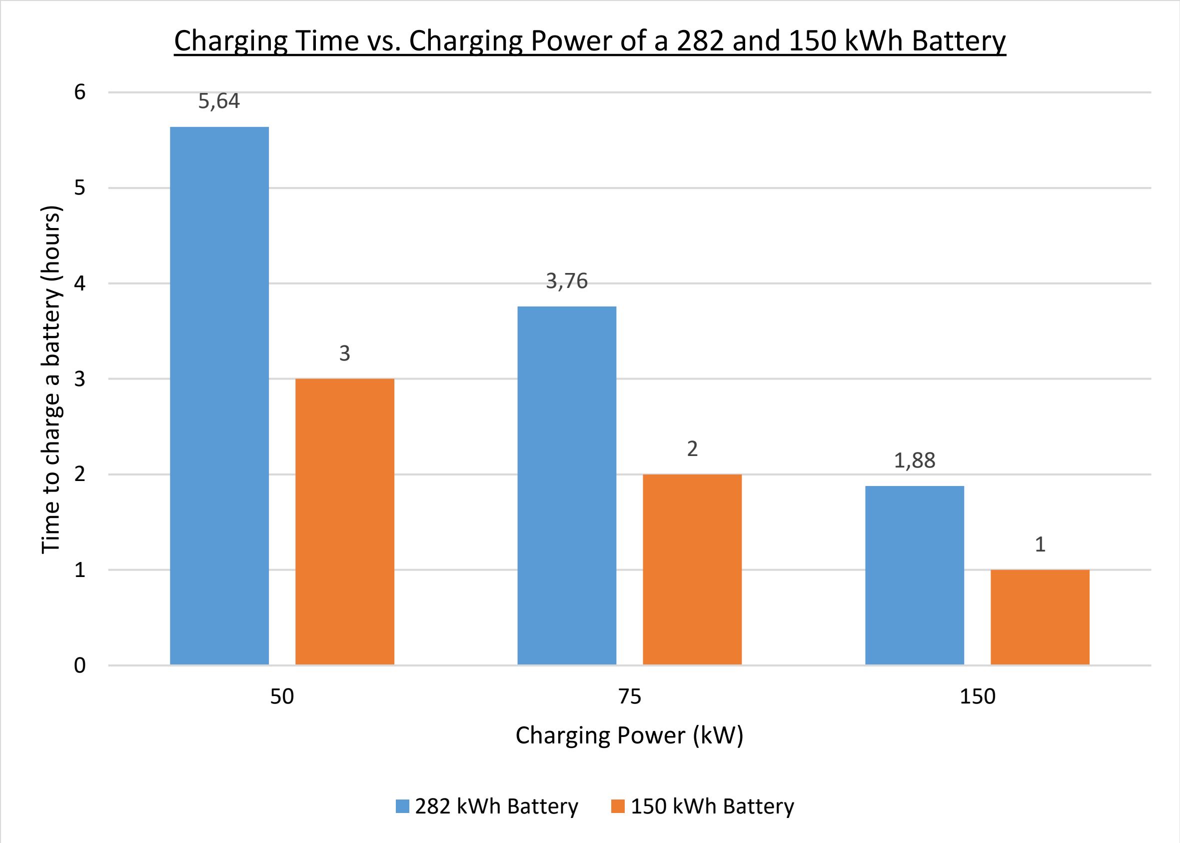


*Figure 65. Represents the charging time of a 282 kWh and 150 kWh batteries charged with different power of chargers*

Further, it investigates the operational implications of using different chargers to scale up the truck fleet over time. In 2023-2024, with one truck making 8 rounds per day, the total daily travel distance is 64 km. Even with varying charger capacities (50 kW, 75 kW, and 150 kW) and associated charging times (5.64, 3.76, and 1.88 hours respectively), the operation can be sustained with just one battery at the swapping station.

*Table 18. Batteries required at the swapping station with all assumed scenarios.*

| **Charging Power** | **Charging time (hours)** | | **2023–2024** 1 Truck (Total 8 rounds/day) | **2025** 5 Trucks (Total rounds 40/day) | | **2026** 5 Trucks (Total rounds 50/day) | |
|---|---|---|---|---|---|---|---|
| | 282 kWh battery | 150 kWh battery | 282 or 150 kWh | 282 kWh | 150 kWh | 282 kWh | 150 kWh |
| 50 kW | 5.64 | 3 | 1 | 0.53 | 0.5 | 0.67 | 0.62 |
| 75 kW | 3.76 | 2 | 1 | 0.35 | 0.33 | 0.45 | 0.41 |
| 150 kW | 1.88 | 1 | 1 | 0.17 | 0.16 | 0.22 | 0.2 |

This strategy allows for a continuous cycle where a discharged battery can be immediately swapped for a fully charged one, ensuring smooth daily operations without significant downtime.

The feasibility of this approach is further tested in 2025, when the fleet expands to 5 trucks, each making 8 rounds per day, maintaining the same travel distance of 64 km per truck. The total rounds per day increased to 40. Even in this scenario, the single battery-swapping system remains effective, as the differential charging times can be managed to ensure a constantly available charged battery.

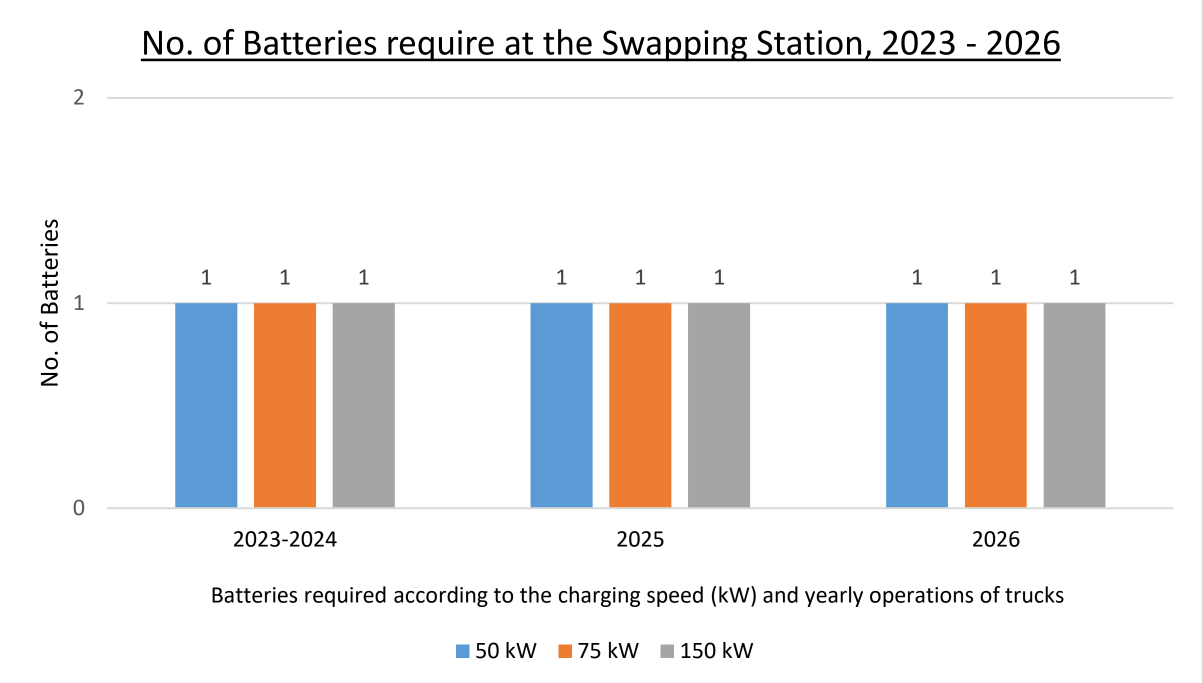


*Figure 66. Represents the number of batteries required at the swapping station based on the yearly operation.*

In 2026, the operational intensity will increase, with 5 trucks making a total of 50 rounds per day and each truck traveling 80 km per day. The one battery-swapping system would still be sufficient despite the increased demand and travel distance. This indicates that even under escalating operational demands, the battery-swapping station provides a resilient and efficient solution in conjunction with varied charger capacities. It highlights the strategic advantage of the battery-swapping system in accommodating different levels of operational intensity without requiring a proportional increase in the number of batteries or charging infrastructure.

### 8.24.8. Conclusion

This simulation-based case study demonstrates that a single battery at the swapping station can support a range of operational scenarios, from a single truck making 8 rounds per day in 2023-2024 to a fleet of 5 trucks completing 50 rounds per day in 2026. Despite the variations in charging times across different charger capacities (50 kW, 75 kW, and 150 kW), the system's efficiency is maintained.

The first key finding is that even with an increase in the number of trucks and the intensity of operations, the need for only one battery at the swapping station remains constant.

The second key finding is that even if we decrease the battery size from 282 kWh to 150 kWh, it would be sufficient to handle five trucks with the respective conditions.

This simplifies logistical planning and ensures continuous operation with minimal downtime. More importantly, the ability to transport a larger volume of goods from the harbor to the park with more trucks while relying on a single battery at the swapping station underscores the system's scalability and efficiency.

This approach significantly enhances operational capability, allowing for an increased frequency of trips and higher cargo throughput, essential for efficient logistics in harbor-park transport scenarios.

This study also demonstrates that a battery-swapping solution can reduce the total battery capacity in use and thus minimize the environmental impact by lowering the minerals and rare earth metals used.

In addition, this case shows that the total investment cost can be reduced by lowering the total tractor fleet battery capacity by about 40%, which improves the profitability of the total system solution.

Those findings from this simulation case significantly contribute to the business model being designed regarding the cost and revenue sides of the proposed business model.

## 8.25. References

AFUAH, A. 2014. *Business Model Innovation Concepts, Analysis, and Cases,* New York, Routledge.

AFUAH, A. & TUCCI, C. L. 2001. *Internet business models and strategies: text and cases,* New York, Irwin/McGraw-Hill.

AMIT, R. & ZOTT, C. 2001. Value creation in e-business. *Strategic Managment Journal,* 22**,** 493-520.

AMIT, R. & ZOTT, C. 2010. Business Model Innovation: Creating Value in Times of Change. *WP-870.* IESE Business School, University of Navarra, Spain.

BADAN-FULLER, C. & MORGAN, M. S. 2010. Business Models as Models. *Long Rang Planning,* 43**,** 156-171.

BADEN-FULLER, C. & HAEFLIGER, S. 2013. Business Models and Technological Innovation. *Long Range Planning,* 46**,** 419-426.

BERGLUND, H. & SANDSTROM, C. 2013. Business model innovation from an open systems perspective: structural challenges and managerial solutions. *International journalof product development,* 18**,** 274-285.

BHATTI, H.J., 2023. *Sustainable Electromobility: A System Approach to Transformation of Transportation* (Doctoral dissertation, Halmstad University Press).

BOCK, A. J., OPSAHL, T. & GEORGE, G. 2010. Business model innovation and strategic flexibility: A study of the effects of informal and formal organisation. *Academy of Management Annual Meeting.* Montreal, Canada.

BUCHERER, E., EISERT, U. & GASSMANN, O. 2012. Towards Systematic Business Model Innovation: Lessons from Product Innovation Management. 21**,** 183-198.

CASADESUS-MASANELL, R. & RICART, J. E. 2010. From Strategy to Business Models and onto Tactics. *Long Range Planning,* 43**,** 195-215.

CASADESUS-MASANELL, R. & ZHU, F. 2013. Business Model Innovation and Competitive Imitation: The Case of Sponsor-Based Business Models. *Strategic Management Journal,* 34**,** 464-482.

CHESBROUGH, H. 2007. Business model innovation: it’s not just about technology anymore. *Strategy and leadership,* 35**,** 12-17.

CHESBROUGH, H. 2010. Business Model Innovation: Opportunities and Barriers. *Long Range Planning,* 43**,** 354-363.

CHESBROUGH, H. & ROSENBLOOM, R. S. 2002. The Role of the Business Model in Capturing value from Innovation: Evidence from Xerox Corporation's Technology Spin-off Companies. *Industrial and Corporate Change,* 11**,** 529-555.

DANIELS, D, DANILOVIC, M, WEHNER, J, KÄCK, S, NORDIN, L, Regeringsuppdrag om elektrifieringen av transporter. Samspelet mellan energisystemet och transportsystemet /

Government commission on the electrification of the transport sector. The interplay between energy system and transport system, VTI Reoport 1128, 2022.

DIMAGGIO, P. J. & POWELL, W. W. 1983. The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organisational Fields. *American Sociological Review,* 48**,** 147-160.

DOGANOVA, L. & EYQUEM-RENAULT, M. 2009. What do business models do? Innovation devices in technology entrepreneurship. *Research Policy,* 38**,** 1559-1570.

DRUCKER, P. F. 1954. *The practice of managment,* New York, Harper & Brothers.

DRUCKER, P. F. 1994. The theory of the business. *Havard Business Review,* September**,** 95.

DRUCKER, P. F. 1999. *Management: Tasks, Responsibilities, Practices,* Oxford, United Kingdom, Butterworth-Heinemann.

EUCHNER, J. & GANGULY, A. 2014. Business Model Innvoationin Practice. *Research-Technology Management,* November-December**,** 33-39.

FOSS, N. J. & SAEBI, T. 2017. Fifteen years of research on business model innovation: how far have we come, and where should we go? *Journal of Management,* 43**,** 200-227.

GAMBARDELLA, A. & MCGAHAN, A. M. 2010. Business-Model Innovation: General Purpose Technologies and their Implications for Industry Structure. *Long Range Planning,* 43**,** 262-271.

GIOIA, D. A., CORLEY, K. G. & HAMILTON, A. L. 2012. Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology. *Organizational Research Methods,* 16**,** 15-31.

HAMEL, G. & SAMPLER, J. 1998. The E-Corporation More than just Web-based, it's building a new industrial order. *Fortune,* December 7**,** 80-92.

JOHNSON, M. W., CHRISTENSEN, C. M. & KAGERMANN, H. 2008. Reinventing Your Business Model. *Havard Business Review,* 86**,** 52-60.

LAASCH, O. 2018. Beyond the purely commercial business model: organisational value logics and the heterogeneity of sustainability business models. *Long Range Planning,* 51**,** 158-183.

LECOCQ, X. & DEMIL, B. 2010. Business Models as a research program in strategic management: An appraisal based on Lakatos. *M@n@gement,* 13**,** 214-225.

LINDER, J. & CANTRELL, S. 2000. Changing Business Models: Surveying the Landscape. Institute for Strategic Change.

LINDER, J. C. & CANTRELL, S. 2001. Five business model myths that hold companies back. *Strategy Leadership,* 29**,** 13-18.

LINDGARDT, Z., REEVES, M., STALK, G. & DEIMLER, M. S. 2009. Business Model Innovation When the Game Gets Tough, Change the Game. The Boston Consulting Group.

MAGRETTA, J. 2002. Why business models matter. *Harvard Business Review,* 80**,** 86-92.

MAGRETTA, J. 2012. *Understanding Michael Porter: the Essential Guide to Competition and Strategy,* New York, Harvard Business Review Press.

MALHOTRA, Y. 2000. Knowledge management and new organisation forms: a framework for business model innovation. *Information Resources Management Journal,* 13**,** 5-14.

MARKIDES, C. 2013. Disruptive innovation: in the need of better theory. *Journal of Product Innovation Management*, 23**,** 19-25.

MASSA, L. & TUCCI, C. L. 2014. Business Model Innovation. *In:* DOGSSON, M., GANN, D. & NELSON, P. (eds.) *The Oxford Handbook of Innovation Mannagement.* Oxford, UK: Oxford University Press.

MAZZUCATO, M. 2015. *The entrepreneurial state,* London, AuthemPress.

MITCHELL, D. & CAROL, C. 2003. The ultimate competitive advantage of continuing business model innovation. *Journal of Business Strategy,* 24**,** 15-21.

MORRIS, M. H., SCHINDEHUTTE, M. & ALLEN, J. 2005. The entrepreneur's business model: toward a unified perspective. *Journal of Business Research,* 58**,** 726-735.

MUBOSSON-TORBAY, M. 2002. E-business model design, classifications and measurements. *Thunderbird International Business Review,* 44**,** 5-23.

NIELSEN, C. 2005. Modelling transparency: a research note on accepting a new paradigm in business reporting. *University of Aarhus, Aarhus School of Business.* Aarhus: University of Aarhus.

NIELSEN, C. & LUND, M. 2014. An introduction to business models. *In:* NIELSEN, C. & LUND, M. (eds.) *The Basics of Business Models.* Copenhagen: Ventus.

NIELSEN, C. & ROSLENDER, R. 2014. Frameworks for understanding and describing business models. *In:* NIELSEN, C. & LUND, M. (eds.) *The Basics of Business Models.* Copenhagen.

OSTERWALDER, A. 2004. *The Business Model Ontology-a proposition in a design science approach.* Docter, University of Lausanne.

OSTERWALDER, A. & PIGNEUR, Y. 2010. *Business Model Generation,* Hoboken, Wiley & Sons.

OSTERWALDER, A., PIGNEUR, Y. & TUCCI, C. 2005. Clarifying Business Models: Origins, Present, and Future of the Concept. *Communications of the Association for Information Systems,* 16**,** 1-40.

POHLE, G. & CHAPMAN, M. 2006. IBM'  s global CEO report 2006: Business model innovation matters. *Strategy and Leadership,* 34**,** 34-40.

SCHNEIDER, S. & SPIETH, P. 2013. Business Model Innovation: Towards an Integrated Future Research Agenda. *International Journal of Innovation Management,* 17**,** 14-34.

SCOTT, W. R. 1987. The Adolescence of Institutional Theory. *Administrative Science Quarterly,* 32**,** 493-511.

SHAFER, S. S., H.LINDER, J. 2005. The power of business models. *Business Horizons,* 48**,** 199-207.

SOSNA, M., TREVINYO-RODRIGUEZ, R. N. & VELAMURI, S. R. 2010. Business Model Innovation through Trial-and-Error Learning. *Long Range Planning,* 43**,** 383-407.

SPIETH, P. 2013. Business Model Innovation: Towards and Integrated Future Research Agenda. *International Journal of Innovation Management,* 17**,** 1-34.

SPIETH, P., SCHNECKENBERG, D. & RICART, J. E. 2014. Business model innovation : state of the art and future challenges for the field. *R&D Management,* 44**,** 237-247.

SWILLER, A. 1986. Culture in Action: Symbols and Strategies. *American Sociological Review,* 51**,** 273-286.

TEECE, D. J. 2010. Business Models, Business Strategy and Innovation. *Long Range Planning,* 43**,** 172-194.

TIMMERS, P. 1998. Business Models for Electronic Markets. *Electronic Markets,* 8**,** 1-8.

VOELPEL, S. C., MARIUS, L. & B., T. E. 2004. The wheel of business model reinvetion: how to reshape your business model to leapfrog competitors

WEILL, P., MALONE, T. W., D'URSO, V. T., HERMAN, G. & WOERNER, S. 2005. Do Some Business Models Perform Better than Others? A Study of the 1000 Largest US Firms. MIT Sloan School of Management.

WEILL, P. & VITALE, M. 2001. Place to space: migrating to ebusiness models. Boston: Harvard University Press.

BERGLUND, H. & SANDSTROM, C. 2013. Business model innovation from an open systems perspective: structural challenges and managerial solutions. *International journalof product development,* 18**,** 274-285.

BUCHERER, E., EISERT, U. & GASSMANN, O. 2012. Towards Systematic Business Model Innovation: Lessons from Product Innovation Management. 21**,** 183-198.

CASADESUS-MASANELL, R. & ZHU, F. 2013. Business Model Innovation and Competitive Imitation: The Case of Sponsor-Based Business Models. *Strategic Management Journal,* 34**,** 464-482.

CHESBROUGH, H. & ROSENBLOOM, R. S. 2002. The Role of the Business Model in Capturing value from Innovation: Evidence from Xerox Corporation's Technology Spin-off Companies. *Industrial and Corporate Change,* 11**,** 529-555.

DIMAGGIO, P. J. & POWELL, W. W. 1983. The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organisational Fields. *American Sociological Review,* 48**,** 147-160.

EUCHNER, J. & GANGULY, A. 2014. Business Model Innvoationin Practice. *Research-Technology Management,* November-December**,** 33-39.

FOSS, N. J. & SAEBI, T. 2017. Fifteen years of research on business model innovation: how far have we come, and where should we go? *Journal of Management,* 43**,** 200-227.

GAMBARDELLA, A. & MCGAHAN, A. M. 2010. Business-Model Innovation: General Purpose Technologies and their Implications for Industry Structure. *Long Range Planning,* 43**,** 262-271.

JOHNSON, M. W., CHRISTENSEN, C. M. & KAGERMANN, H. 2008. Reinventing Your Business Model. *Havard Business Review,* 86**,** 52-60.

LAASCH, O. 2018. Beyond the purely commercial business model: organisational value logics and the heterogeneity of sustainability business models. *Long Range Planning,* 51**,** 158-183.

LINDER, J. & CANTRELL, S. 2000. *Changing Business Models: Surveying the Landscape* [Online]. Institute for Strategic Change. [Accessed].

LINDGARDT, Z., REEVES, M., STALK, G. & DEIMLER, M. S. 2009. *Business Model Innovation When the Game Gets Tough, Change the Game* [Online]. The Boston Consulting Group. [Accessed].

MALHOTRA, Y. 2000. Knowledge management and new organisation forms: a framework for business model innovation. *Information Resources Management Journal,* 13**,** 5-14.

MARKIDES, C. 2013. Disruptive innovation: in the need of better theory. *Journal of Product Innovation Management*, 23**,** 19-25.

MASSA, L. & TUCCI, C. L. 2014. Business Model Innovation. *In:* DOGSSON, M., GANN, D. & NELSON, P. (eds.) *The Oxford Handbook of Innovation Mannagement.* Oxford, UK: Oxford University Press.

MAZZUCATO, M. 2015. *The entrepreneurial state,* London, AuthemPress.

MITCHELL, D. & CAROL, C. 2003. The ultimate competitive advantage of continuing business model innovation. *Journal of Business Strategy,* 24**,** 15-21.

OSTERWALDER, A., PIGNEUR, Y. & TUCCI, C. 2005. Clarifying Business Models: Origins, Present, and Future of the Concept. *Communications of the Association for Information Systems,* 16**,** 1-40.

POHLE, G. & CHAPMAN, M. 2006. IBM' s global CEO report 2006: Business model innovation matters. *Strategy and Leadership,* 34**,** 34-40.

SCOTT, W. R. 1987. The Adolescence of Institutional Theory. *Administrative Science Quarterly,* 32**,** 493-511.

SPIETH, P. 2013. Business Model Innovation: Towards and Integrated Future Research Agenda. *International Journal of Innovation Management,* 17**,** 1-34.

SPIETH, P., SCHNECKENBERG, D. & RICART, J. E. 2014. Business model innovation : state of the art and future challenges for the field. *R&D Management,* 44**,** 237-247.

VOELPEL, S. C., MARIUS, L. & B., T. E. 2004. The wheel of business model reinvetion: how to reshape your business model to leapfrog competitors

*Journal of Change Management,* 4**,** 259-276.

WHITTLE, L. 2021. *Cover Story: XCMG E700*. Deals on Wheels. Available: https://www.dealsonwheels.co.nz/trucks/features/2107/xcmg-e700-cover-story [Accessed 2023-11-09].

WIRTZ, B. W., GÖTTEL, V. & DAISER, P. 2016. Business Model Innovation: Development, Concept and Future Research Directions. *Journal of Business Models,* 4**,** 1-28.

ZOTT, C. & AMIT, R. 2015. Business Model Innovation: Toward a Process Perspective. *In:* SHALLEY, C. E., HITT, M. A. & ZHOU, J. (eds.) *The Oxford Handbook of Creativity, Innovation, and Entrepreneurship.* New York: Oxford University Press.

WIRTZ, B. W., GÖTTEL, V. & DAISER, P. 2016. Business Model Innovation: Development, Concept and Future Research Directions. *Journal of Business Models,* 4**,** 1-28.

WIRTZ, B. W., PISTOIA, A., ULLRICH, S. & GÖTTEL, V. 2015. Business Models: Origin, Development and Future Research Perspectives. *Long Range Planning,* 14**,** 36-54.

ZOTT, C. & AMIT, R. 2015. Business Model Innovation: Toward a Process Perspective. *In:* SHALLEY, C. E., HITT, M. A. & ZHOU, J. (eds.) *The Oxford Handbook of Creativity, Innovation, and Entrepreneurship.* New York: Oxford University Press.

ZOTT, C., AMIT, R. & MASSA, L. 2011. The Business Model: Recent Developments and Future Research. *Journal of Management,* 37**,** 1019-1042.

# 9. Knowledge needs and training for the battery-swapping business

Authors: Dr. Jasmine Lihua Liu, Professor Mike Danilovic

## 9.1. Background

Battery-swapping has become one crucial complementary technology for recharging heavy trucks. Battery-swapping has a 50% market share for electric heavy trucks in China in 2023.

By November 2023, 3394 battery-swapping stations have been installed in China (source: EVCIPA). Among the 3394 battery-swapping stations, about 400 are for heavy trucks. The acceleration is rapid, and almost all heavy truck OEMs offer vehicles with battery-swapping solutions.

So far, all battery-swapping stations are operated by manual operating staff. There are plans to make stations autonomous and operate unmanned.

## 9.2. Purpose of this research

The purpose of this research is to explore the basic approaches experienced battery-swapping stations take in training their staff to have the capacity to monitor, operate, and follow up the daily operations of stations.

We strive to understand what contemporary approaches are in training, the primary purposes of the training, the main content of training sessions, and the expected learning outcome of the activity being offered to operating staff.

## 9.3. Methodological approach

In our research on exploring training programs and activities for operating commercial battery-swapping stations, we conducted a series of activities:

- Empirical observations of how battery-swapping stations are operated in practice in the Chinese context.
- We visited the battery-swapping station developed and built by ZhilIWulian in Yibin City. Those observations were conducted while visiting ZhilIWulian in Yibin City and spending two days at the battery-swapping station.
- We visited a battery-swapping station operated by Geely in Hangzhou.
- We have also visited a battery-swapping station developed and operated by DeepWay in Beijing/Tianjin.
- Interviews were conducted with the management of the battery-swapping system and managers responsible for operating stations better to understand the training content and procedures of the staff.
- We have conducted three interviews with the owner of the battery-swapping station, the local manager responsible for daily operations, and the person operating the battery-swapping station.
- We have conducted two interviews with operational managers of the Geely battery-swapping station in Hangzhou. A battery-swapping station operated by Geely in Hangzhou.
- Those Interviews were conducted while visiting ZhilIWulian in Yibin City and spending two days at the battery-swapping station.
- Exploration of available document packages on training staff for operating battery-swapping stations in China.

- We have explored the relevant documents regarding the training and preparing employees to work, supervise, and operate the battery-swapping stations.
- All documents we accessed are written in Chinese and unavailable in English for natural reasons.

## 9.4. Limitations to our approach

We want to stress that this research is related to understanding the conditions of training the staff operating the battery-swapping stations in the Chinese context.

It is not our ambition to elaborate and suggest how the Swedish actors operating battery-swapping stations shall organize, manage, and train the staff for operation. That is beyond the scope of this project.

## 9.5. Analysis of the training packages and activities

We have explored and examined the operation manual and measures for battery-swapping station management in actual practice by companies related to the content of this report, as well as the training and education of swapping stations. The total number of pages we have examined of the seven documents is about 130.

The battery-swapping station operation manual emphasizes occupational health, safety, and environmental protection. Measures for hierarchical management of safety risks, management of hazardous operations, management of hidden dangers, management of personal labor protective equipment, management of work tickets, and management and maintenance of charging and swapping equipment are implemented. It is interesting to see the distinctive distribution of responsibilities along the hierarchical management chain. Responsibilities are regularly followed up and evaluated.

The operation manual and measures are based on Chinese national laws, regulations, and standards. Formalized rules are specified to manage personnel, equipment, processes, and safety risks and dangers.

According to the manual, the following general training content is needed:

- occupational health and labor protection knowledge
- management ability of charging and swapping station personnel,
- relevant laws, regulations, rules, and standards on occupational health and labor protection.

The detailed Job skills and training requirements for different positions in the charging and battery-swapping station are summarized as follows.

### 9.5.1. The training of people

The selection of individuals working for battery-swapping stations is based on the fact that those targets for selection need to have high-school educational background and essential experience in driving trucks or equivalent vehicles.

The training is conducted theoretically following the content of the seven training packages and in one week of supervised practical work at the site.

There are several leading roles in managing the battery-swapping stations:

#### Station supervisors, daily.

- Supervisors usually have a high school education; some also have a university education and a background complemented by administration training to support their work as supervisors.

- In this role that handles administration, ensure that the economic transactions work according to different trucks entering the battery-swapping station and checking in and swapping batteries.
- Training the station supervisors is conducted entirely by the station ownership with limited support from the station provider.

- **Station operators, daily operations.**

- Every battery-swapping station has a pool of trained staff in the monitoring room supervising operations, ensuring that swapping operations work smoothly without interruptions.
- Training of station operators is entirely in charge of the battery-swapping station ownership in collaboration with the provider of the station and the technical systems.

- **Service and maintenance staff on an on-call basis.**

- The training of service and maintenance staff is advanced and needs to be covered in this report. The battery-swapping station has areas for daily supervision and monitoring regular operations, particularly areas with high voltage equipment and special regulations and how to handle these areas.
- People need specialized electrician training as basic training complemented with specific training regarding high voltage chargers, safety, and firefighting.

### 9.5.2. Occupational health, safety, and environmental protection manual of battery swap station

The guidebook is formulated regarding relevant Chinese national laws, regulations, standards, and management systems of the company.

Relevant Chinese laws, regulations, and systems are defined as follows:

- Work Safety Law of the People's Republic of China
- Environmental Protection Law of the People's Republic of China
- DL/T5027 "Typical Fire Protection Regulations for Power Equipment"
- GB50140 "Code for Design of Building Fire Extinguisher Configuration"
- GB50444 Code for Acceptance and Inspection of Building Fire Extinguisher Configuration
- GB/T 51007 Code for Design of Battery Swapping Stations for Electric Vehicles
- GB 2894 "Safety Signs and Guidelines for Their Use"
- Regulations on Fire Protection Management of Organs, Groups, Enterprises and Institutions

I. Training of battery-swapping station operators

### 9.5.3. Position setting and responsibilities

1) The charging and swapping station shall be set up with a power station chief and a guard on duty.
2) The chief of the power station is the first person responsible for the charging and swapping station and shall be fully responsible for the occupational health and safety management of the charging and swapping station.
3) The duty chief and the duty guard are responsible for the inspection, testing, and maintenance of the charging and swapping equipment, ensuring the normal operation of the equipment and

ensuring that the environment of the charging and swapping station area is clean, safe, and stable.

4) The duty chief and the duty guard are responsible for the normal operation of the charging and swapping monitoring equipment and communication network and conduct real-time and effective monitoring of the charging and swapping process.
5) The chief and the guard on duty are responsible for guiding customers and providing customers with charging and replacement services.
6) The chief and the duty guard are responsible for the environmental protection and emergency response of the battery swap station and cooperate with the disposal and investigation of environmental emergencies.
7) The duty chief and the guard on duty should take the initiative to accept the inspection of government departments and the supervision of the public and do an excellent job of controlling relevant public opinion.

#### 9.5.4. Job skill requirements

1) The duty chief and the duty guard should understand the structure of electric vehicles, be familiar with the working principle of charging and swapping equipment, be proficient in the operation and service specifications of charging and swapping stations, master basic safety management knowledge, and have emergency response capabilities.
2) The duty chief and the duty guard should master the working principle of charging and swapping equipment, the basic knowledge of power batteries, the structure of electric vehicles, master the safety operation procedures of the post, and the ability of equipment detection, fault judgment, and processing. It is necessary to understand the basic knowledge of the electrochemical performance of the power battery and the application of the power battery and master the use of the monitoring system.

#### 9.5.5. Training Requirements:

1) The chief of the charging and swapping station and the duty post must undergo pre-job three-level training to understand relevant laws and regulations. Understand the rights and obligations of employees; understand the company's occupational health, safety, and environmental protection management system; understand the main hazards and environmental factors and their control measures existing in this position; understand the technical knowledge of occupational disease hazard prevention and control and labor protection, understand typical accident cases in the industry, understand the safety knowledge of electric vehicles, electricity safety specifications, operating procedures existing in this position, emergency handling methods and electric shock first aid methods, and hold a certificate to work after passing the assessment.
2) All personnel must obtain the locally recognized operation certificate, such as the local charging and replacement station does not have the operation certificate requirements, all personnel must be trained and assessed before they can take up their posts; all local duty officers, equipment maintenance personnel, must obtain low-voltage electrical work certificates if involving 1000V and above voltage electrical operations also need to obtain high-voltage electrician certificates. Personnel engaged in special operations, such as electricians and motor vehicle drivers, should be subject to on-the-job and on-the-job physical examinations and establish employee physical examination files.
3) The daily safety education activities of the charging and swapping station personnel should be carried out at least once a month.

4) The charging and swapping station operators shall strictly operate with the operating procedures and safety production management regulations and end illegal operation and unsafe behavior.
5) The operator of the charging and swapping station must closely monitor the operation status of the charging and swapping station equipment to ensure safe and efficient operation. If an abnormal situation is found, the charging and swapping operation should be stopped immediately through the emergency stop button, reported in time, and made a detailed record.
6) When the charging and swapping station operator goes to work, it is strictly forbidden to leave the post, string the post, slip it, sleep on it, or do things unrelated to work.
7) At least one person per shift in the monitoring room, carry out less manned or unmanned sites, take the form of inspection, and the emergency contact number must be posted on the site and keep the communication unimpeded.
8) Carrying out other operations in the charging and swapping area is strictly forbidden during the charging and swapping process. It is strictly forbidden for non-professionals to approach or touch the charging and swapping equipment. Personnel are strictly forbidden to enter or approach the battery-swapping work area.
9) If the successor does not arrive during the shift, the personnel on duty shall not leave without authorization and must complete the handover procedures before leaving work.
10) Those who do not have the conditions for occupational disease protection shall not carry out or transfer operations that may produce occupational disease hazards.

### 9.5.6. Training of equipment maintenance and inspection personnel

### 9.5.7. Job skill and training requirements

Equipment maintenance and inspection personnel need to carry out professional training and obtain qualifications before taking up their posts involving high-voltage equipment inspection need to hold a high-voltage electrician certificate.

## 9.6. Measures for the management of hierarchical management and control of security risks

This training package aims to identify the safety risks in activities, places, and facilities and to plan and implement organized supervision and control of risk control measures.

- Safety risk: The combination of the likelihood of a hazardous event or exposure during a production or business operation and the consequent severity of personal injury, health damage, property damage, or environmental impact.
- Inherent risk assessment: the process of analyzing and assessing the risks associated with dangerous and harmful factors and ecological and environmental factors by using qualitative or quantitative analysis methods without considering the control measures taken and obtaining assessment results.
- Control risk assessment: The process of implementing risk assessment and deriving assessment results on the premise of considering the control measures that have been taken.

### 9.6.1. Security risk assessment

- According to the identified dangerous and harmful factors, the existing risk control measures should be investigated, from engineering control, organization and management, education and training, personal protection, and emergency measures. Risk classification: The process of ranking different risks according to the degree of attention required according to risk assessment results. The risk classification is divided into four levels from high to low: A (significant risk/red), B (high risk/orange), C (average risk/yellow), and D (low risk/blue).

- Risk management and control methods at different levels of management and control are determined according to different levels of risk, required management and control resources, management and control capabilities, and the complexity and difficulty of control measures.

Personnel should get training in identifying and evaluating dangerous and harmful factors in each post.

### 9.6.2. Training Requirements:

- "Safety Risk Classification Control List" and "Post Safety Risk Notification Card" should be developed by the company's management.
- All departments should train to identify dangerous and harmful factors, and personnel engaged in relevant operational activities must understand the hazardous and harmful factors and master the control measures.
- Education and training should also be carried out when the list is updated and revised.

*The General Management Department is responsible for the safety risk management and control in the whole process of the company and organizes the identification and risk assessment of hazards and hazards at least once a year. (Source: Owner of the station).*

Special emphasis is placed on management responsibilities for identifying dangerous and harmful factors and preventing accidents.

## 9.7. Measures for the management of hazardous operations

The main purpose of this training package is to clarify responsibilities and to ensure a clear responsibility structure for operating swapping stations:

- Strengthen the management of dangerous operations of charging and swapping stations, reduce the occurrence of production safety accidents, ensure the safety of operators, and ensure the normal operation of charging and swapping stations; management measures are formulated.
- The comprehensive management department is the focal point for managing dangerous operations in each charging and swapping station.
- The operation and maintenance management personnel are responsible for examining and approving the application for dangerous operation of each charging and swapping station.
- The safety management post is responsible for supervising the implementation of dangerous operations.
- Dangerous operations include temporary electricity use, hot work, high-altitude work, lifting and hoisting operations, and non-stop power and live operations.
- Temporary electricity: Temporary electricity refers to the electricity used temporarily at the construction site during construction, generally including temporary power electricity and temporary lighting electricity.
- Hot work refers to the operation of welding, cutting, open flame baking, grinding, etc., which can directly or indirectly produce an open flame by introducing an ignition source.

- Work at height: Any operation carried out at a height of more than 2 meters (including 2 meters) on the datum of the fall height.
- Lifting and hoisting operations refer to using overhead cranes, gantry cranes, tower cranes, tire cranes, lifts, and other lifting equipment for operations.
- Uninterrupted operation and live operation: Non-stop operation refers to operating live equipment near live bodies or on the shell of live equipment. Live work relates to work directly on live equipment or conductors.

### 9.7.1. Job skill and training requirements of hazardous operation workers

1) Understand the dangerous operation process and be familiar with the operation and equipment conditions.
2) Dangerous workers are in good physical condition and do not suffer from the occupational contraindications of corresponding dangerous operations.
3) Do not engage in dangerous work after drinking alcohol or taking drugs that reduce judgment and mobility.
4) Participate in the 's risk analysis, identify the corresponding hazards, and plan and implement the safety control measures of the operation.
5) Have a strong sense of responsibility, be able to deal with problems correctly, and can deal with emergencies.
6) Obey the management of on-site guardians and have the right to refuse to operate in violation of the requirements of the relevant system.
7) For special operations or special equipment operations, operators must hold valid certificates for corresponding special operations or special equipment operations.

### 9.7.2. Job skill and training requirements of dangerous work guardians

1) Understand the dangerous operation process and be familiar with the operating environment, operation, and equipment status.
2) Have a strong sense of responsibility, deal with problems correctly, deal with emergencies, and master the knowledge of first aid.
3) After receiving the guardianship task, check and implement the operation safety control measures one by one, carefully check the situation of the operation site, take timely steps if abnormal conditions are found, and do not leave the scene during the operation.
4) When relevant violations are found, they have the right to request to stop the operation and report to the person in charge of the site.

- Job skill and training requirements of temporary electricity operators

According to the content of the operation, targeted safety education should be carried out for temporary electricity operators. The operators and guardians should hold the corresponding operation qualification certificates (high/low voltage electricians). The operators shall not have epilepsy, syncope (history of syncope seizures in the past year), stage II and stage III hypertension, red-green color blindness, heart disease and apparent electrocardiogram abnormalities (arrhythmia), limb joint motor dysfunction, and other diseases.

- Job skill and training requirements of fire workers

According to the content of the operation, targeted safety education should be carried out for the hot workers. The operators and guardians should hold the corresponding operation qualification certificates (welding and thermal cutting operation certificates). The operators shall not suffer from cardiovascular diseases, hypertension, epilepsy, active corneal diseases, respiratory diseases, etc.

- Job skill and training requirements of work at height

According to the content of the operation, targeted safety education should be carried out for the operators. The operators and guardians should hold the corresponding operation qualification certificates (height work permit). The workers at heights shall not suffer from heart disease, hypertension, epilepsy, fear of heights, and other conditions.

- Job skill and training requirements for lifting and hoisting workers

All personnel involved in the operation of hoisting equipment or hoisting equipment maintenance who must hold a certificate to work shall be trained. After passing the assessment, with a valid certificate to work, operators shall not have epilepsy, mental illness, hypertension, hypotension, arteriosclerosis, heart disease, or other diseases.

- Job skill and training requirements for live work operators

According to the content of the operation, targeted safety education should be carried out for the operators. The operators and guardians should hold the corresponding operation qualification certificates (high/low voltage electricians). The operators shall not have epilepsy, syncope (history of syncope seizures in the past year), stage II and stage III hypertension, red-green color blindness, heart disease and obvious abnormal electrocardiogram (arrhythmia), limb joint motor dysfunction, and other diseases.

## 9.8. Measures for the investigation and management of hidden dangers

The primary purpose of this package is to establish and improve the safety work for hidden work-related hazards and ensure managerial responsibility:

- To establish and enhance a long-term mechanism for investigating and managing hidden risks in production safety, promote the investigation and management of hidden hazards, and prevent occupational health and safety accidents, these management measures are formulated.
- Hidden danger refers to the unsafe behavior of people, unsafe state of things, and management defects of people, items, and management that may lead to environmental pollution, work-related injuries, occupational health accidents, or the expansion of accident consequences due to other factors in production and operation.
- Hidden danger investigation: Organize safety production management personnel, engineering and technical personnel, employees in other positions, and other relevant personnel following national laws and regulations, standards, and the company's management system, adopt specific ways and methods, and check the work process of the accident hazards of the unit according to the effective implementation of risk classification control measures.
- Hazard management: The activity or process of eliminating or controlling the hidden danger.

*"The General Management Department is the supervision department for investigating and managing hidden dangers. Organize and implement regular and irregular safety supervision and inspection, and supervise and inspect the investigation and management of hidden dangers. Establish hidden danger information files, organize and carry out special investigation and management activities promptly for common accident hidden dangers, and summarize, analyze and evaluate the hidden danger investigation and management work". (Source: Owner of the station).*

### 9.8.1. Clear management responsibilities:

- The General Management Department is the supervision department for investigating and managing hidden dangers. Organize and implement regular and irregular safety supervision and inspection and supervise and inspect the investigation and management of hidden dangers. Establish hidden danger information files, organize and carry out particular investigation and management activities promptly for common accident hidden risks, and summarize, analyze, and evaluate the hidden danger investigation and management work.
- The person in charge of each department shall organize the investigation of hidden dangers in their departments, register hidden dangers found, establish information files on hidden hazards, and rectify them. Do a good job summarizing, analyzing, and reporting the department's confidential danger investigation work.
- Personnel at all company levels should report promptly when they discover hidden dangers and report to legal compliance and safety management leaders in charge immediately if they find hidden dangers of significant accidents.

*The primary way of the company's hidden danger investigation is self-inspection and supervision and inspection. The self-inspection of the production site is mainly based on daily and monthly inspections, and special inspections are carried out on personal protective equipment, electrical equipment, firefighting equipment and facilities, emergency materials, etc. We are following the requirements of the "Occupational Health, Safety, and Environmental Protection Guidance Manual for Charging and Swapping Stations. The office site is mainly self-inspection, carried out by the "Office Monthly Inspection Form". (Source: Owner of the station)*

## 9.9. Measures for the Administration of Personal Labor Protective Equipment

The primary purpose of this package is to prevent, eliminate, and control occupational hazards in the construction and operation of charging and swapping stations, protect the life, health, and safety of employees, and ensure the implementation of measures such as the purchase, distribution, management, use, and scrapping of labor protection equipment, and this operation guide is specially formulated in combination with the actual situation of the company.

- Personal labor protective equipment (from now on referred to as PPE): all equipment or clothing worn or owned by workers at work to protect them from one or more occupational hazards. PPE is designed to cover multiple body parts, including the eyes, face, head, ears, hands and feet, limbs, and torso.
- PPE includes (but is not limited to): goggles, hard hats, seat belts, insulated shoes/boots, insulated gloves, safety shoes, protective gloves, work clothes, noise-proof earplugs, etc.
- Key PPE: safety helmets, safety belts, insulated boots/shoes, gloves, etc.

### 9.9.1. To clarify management responsibilities:

- The Production Management Department is responsible for formulating and updating these operational guidelines, formulating and updating PPE selection criteria and personal protective equipment matrix, monitoring monthly inspections of key PPE, and supervising PPE procurement, application, and use.
- The production management department is centralized for managing personal labor protection equipment. It shall promptly purchase PPE that meets qualified suppliers' standards promptly according to the PPE procurement application. Establish a PPE spare parts library according to

the application process, issue PPE on time, and do an excellent job in inventory management and early warning.

- The production management department determines the selection of work clothes, safety helmets, safety shoes, and other styles, and the production management department determines that the performance and standards of each PPE meet the national standards. The PPE use department is responsible for supervising the department's application, storage and correct use of PPE.

Other clarifications include personnel protection equipment, fall protection, foot protection, hand protection, respiratory protection, hearing protection, physical protection, winter safety, and specific work requirements.

## 9.10. Measures for the management of work - Job skill and training requirements for work of involved personnel

The main purpose of this package is to

- Standardize the company's charging and swapping station work management. These management measures are formulated by the "Work Safety Law of the People's Republic of China", "Electric Power Safety Work Regulations" (thermal and mechanical parts), (electrical parts of power plants and substations) and other laws and regulations, combined with the actual situation of the company. ¨
- To ensure the implementation of safety technical measures for maintenance operations, aiming to strengthen operation management and equipment management, standardize equipment shutdown and maintenance procedures, eliminate all kinds of maloperations, and ensure personal and equipment safety.
- When installation, transformation, overhaul, maintenance, defect elimination, testing, and other productive work are carried out in the distribution room and box transformer area, the work ticket must be used, and other areas shall be implemented with reference.

The personnel involved in the work ticket should be qualified.

- The issuer of the work ticket, the person in charge of the work, and the work permit shall be approved by the relevant responsible person of the business department after passing the examination organized by the business department to which they belong. It shall be announced in the form of a document.
- Suppose the issuer and person in charge of the work ticket for the outsourced maintenance work are the maintenance units within the system. In that case, they shall have the qualification certificates of the above personnel issued by the unit and store them at the operation site after review as the basis for issuing the work ticket.
- Suppose done by an external maintenance provider. An external maintenance provider does the outsourced maintenance work. In that case, the person in charge of the work must be organized by the relevant person responsible for the subordinate business department to conduct the electrical safety work procedure examination. After passing the inspection, the subordinate business department shall approve it and issue a written notice to be stored at the operation site as the basis for giving work orders.

## 9.11. Measures for the safety management of the maintenance of charging and swapping equipment

The main purpose of this package is to

- Standardize and strengthen the safety management of the company's charging and swapping station equipment maintenance and ensure the safety and health of equipment maintenance personnel; these management measures are formulated by relevant national laws and regulations, industry, and superior unit systems.
- The equipment maintenance work implements the safety production policy of "safety first, prevention first, and comprehensive management", adheres to the principle of "must be repaired, and must be repaired", and provides reliable safety measures for the equipment maintenance period through effective methods such as equipment status monitoring, operation evaluation, risk assessment, and safety measures layout.
- These management measures apply to the daily maintenance and periodic preventive maintenance of charging and swapping stations, guide each charging and swapping station to improve the equipment maintenance management system documents, improve the safety work procedures of equipment maintenance, improve the technical quality and skill level of the maintenance team, and actively improve the safety and quality level of care.
- Ensure that the technical activities that maintain and improve the technical status of the equipment or restore its specified functional objectives using inspection, adjustment, replacement, and repair for the overhead machine system of the charging and swapping station, the intelligent battery-swapping robot system, the battery box mobile system, the battery bottom bracket and connector, the dustproof and warm system, the security system, the vehicle positioning and detection system, the monitoring system, the communication system and the auxiliary facilities.

One of the main tasks is to ensure clear division and distribution of responsibilities among different management levels:

*!The comprehensive management department is responsible for organizing and improving the company's safety management measures for the maintenance of charging and swapping station equipment, supervising and inspecting the implementation of the maintenance management system documents of charging and swapping station equipment, coordinating and guiding the significant hidden dangers found in the maintenance process, and has the right to stop violations in maintenance operations and assess violations.*

*Each department is responsible for implementing the relevant systems and regulations of maintenance management, responsible for the management of maintenance operations of their own departments and outsourced projects, and for inspecting the implementation of safety measures for the maintenance of charging and swapping station equipment within their jurisdiction.*

*The main person in charge of each department is fully responsible for the safety of the equipment maintenance operation. The person in charge of operation and maintenance is responsible for managing the whole process of equipment maintenance and the approval of the operation permit application and organizes the implementation of the rectification of non-conformities in the maintenance process".  (Source: Station manager).*

## 9.12. Conclusions

The primary training efforts are directed to staff that work in motoring and supervise the daily operations of battery-swapping stations.

The main area of training concerns content and requirements by the national law and environmental and safety regulations.

One key area is the personal safety and health conditions of staff. Personal safety is a high priority in staff training. The second most critical is environmental risk and exposure to accidents that can impact air, earth, groundwater, etc. The third critical training area concerns the station's safety and firefighting.

The second area is directed at managing the battery-swapping stations, where the emphasis is on responsibility related to supervisors and operators. The administration system points out the responsibilities for each role and how those responsibilities are transformed into key performance indicators to be documented, followed up on, and evaluated regularly.

Every year, all staff are evaluated based on following the regulations and rules, avoiding mistakes and accidents.

During a particular part of the year, exceptional support must be given to station monitoring related to snow, storms, and heavy rain to ensure continuous operations even under severe conditions. There are limitations regarding the wind in the storm to ensure that the battery being swapped is not torn down and hurting the vehicle falling from the swapping robot.

There is ongoing technological development toward increasing automation of the battery-swapping stations. So far, the entire process of registering incoming vehicles, changing batteries, checking out, documenting the swapping procedure, and evaluating the exchanged battery is fully automated. However, supervising and monitoring work is still needed and is conducted by people. The automation development is ongoing, and it is reasonable to expect that the supervising and monitoring work might be fully automated in the future. Still, the entire technology will also be changed, enabling full station automation.

The education of truck drivers to operate the swapping of batteries is related to managing smartphone apps, which is conducted in one day per driver.

The primary concern for training the staff in the Swedish context is to relate the training program based on the Swedish regulations to personal safety, environmental safety, and firefighting according to existing regulations to ensure the safety of people, vehicles, batteries, and station property.

## 9.13. Recommendations

If battery-swapping stations are to be established in Sweden, the entire training package must be transformed (not only translated) to the Swedish laws and regulations and follow the policy.

Those training packages are based on the Chinese context and can only be seen as inspiration and indicators of relevant areas.

Environmental laws and regulations, safety regulations, and personal safety and selection of personal safety equipment are related to specific contexts and conditions of place of operations.

The training also needs to consider the management system, supervising entire battery-swapping station operations, and the specific security operation preventing fire in the high voltage equipment and firefighting if such an accident might happen.

We can learn from the Chinese experiences to train daily operating staff and to have access to on-demand trained staff in high voltage technology, firefighting etc., areas that are specific for battery-swapping operating in high voltage areas and sensitive lithium-based batteries.

## 9.14. References

EVCIPA, 2023

The following laws and regulations are underlying the training packages we explored and summarized in this report.

All documents are only available in Chinese language.

Training packages as described in the report:

1) Work Safety Law of the People's Republic of China
2) Environmental Protection Law of the People's Republic of China
3) DL/T5027 "Typical Fire Protection Regulations for Power Equipment"
4) GB50140 "Code for Design of Building Fire Extinguisher Configuration"
5) GB50444 Code for Acceptance and Inspection of Building Fire Extinguisher Configuration
6) GB/T 51007 Code for Design of Battery Swapping Stations for Electric Vehicles
7) GB 2894 "Safety Signs and Guidelines for Their Use"
8) Regulations on Fire Protection Management of Organs, Groups, Enterprises and Institutions.

# 10. Modelling and simulations of electrified transports – benefits and needs

Authors: Svetla Käck, David Daniels.

## 10.1. Background

Modelling and simulations can give important insights when it comes to achieving a well-functioning and optimized electrified transport system which simultaneously fulfils its logistic purposes, connects well with the energy sector via its charging infrastructure, and contributes to other societal goals such as smart resource usage, system flexibility, and resilience. Apart from estimating the optimal uses of resources, such methods also allow visualization and quantification of trade-offs. By comparing different scenarios and performing sensitivity analyses over uncertain input parameters, model outputs can quantify which factors are the most influential on outcomes, helping users focus on the most important decision criteria for their circumstance. In addition to projecting the end state of a system, models may also be used to illustrate the pathways to get there.

This chapter addresses the needs for and benefits of modelling and simulation for electrified transportation in general and for evaluating different charging alternatives such as battery-swapping.

### 10.1.1. What models provide, and what they do not

Models may be used for decision support when the business environment encounters change. In these times, operators and planners may not be able to rely fully on their intuition and experience; yet many aspects of the system hold even under changes elsewhere, such as engineering principles or the basics of economics. Models allow a decision-maker to hold some relationships constant while making changes elsewhere, so see how the situation would evolve under such a set of assumptions.

Models are simply calculators; they do not predict the future. While models are often used to project a known system into a hypothetical future stage where some aspects of that system are believed to change, models cannot determine how the future will unfold. Instead, they simply represent the accepted dynamics (i.e., values of key parameters, physical or economic principles, and relationships between system variables) of the system, and maintain internal system consistency as some of those aspects are changed. Models cannot determine whether the changes introduced to the system are likely or not, but they can project how the system might evolve under a coordinated set of changes.

There is a huge amount of uncertainty in the evolution of any models' input parameters as they are projected into the future. Economic growth, demand for services, the evolution of techno-economic characteristics of existing technologies and the emergence of new breakthrough technologies, consumer behaviours, the development of new infrastructure, and the introduction or modification of laws and regulations are all highly uncertain. The probability that any model predicts the evolution of any complex system far into the future is extremely small. But models are very good at determining how that future evolution could change if one of the input assumptions changes. This allows models to perform sensitivity analyses, running the model a number of times with varying input parameters to quantify how these input parameter uncertainties impact the outputs. Modelers can also employ other techniques using deterministic models to characterise uncertainty, such as modelling to generate alternatives (MGA). (DeCarolis, 2011)

Models are less commonly used for uncertainty analysis, though, than for decision support. If one compared a model's outputs in a base case with those of a modified case in which one input parameter were changed by a small amount, one would find that the inherent uncertainties in the two cases were very similar (i.e., their covariance matrices would be almost identical). Thus, the difference in model outputs between the two cases would have much less uncertainty than the outputs from either case themselves. This implies that a key value of models is to perform delta analysis: compare two different cases to see what the impact might be from making small changes in the inputs. In the rest of this section, it is implied that there is a baseline in which the system is not modified, against which a modified case is compared to determine the impact of making that modification. The modified case could be the case of battery-swapping, and sometimes the base case could be the same transport sector under the assumption of diesel truck operation, and sometimes the baseline could be the transport sector with BEV trucks and fast charging.

### 10.1.2. Model scope and granularity

Several different types of modelling approaches are outlined below. In general, models can be characterized according to the scope (i.e., system breadth) and granularity (i.e., system detail) of the simulation, which can collectively be called the model domain. Most modelling approaches try to match the scope and granularity with the perspective of one or more agents (i.e., decisionmakers) in the system, so that model inputs correspond to agents' decision criteria and model outputs correspond to agents' objectives. For example, a model of the movements of a single truck throughout a day may correspond to the truck operator's perspective; a model of a set of trucks whose movements could be coordinated might correspond to a fleet owner's perspective; and a model of all trucks on the road could match the perspective of an urban planner or national regulator.

As there are many different agents in an electrified transport system, each with different perspectives, so there is no single model domain that can realistically capture that system. Outside the model domain, (i.e., at the system boundaries), model parameters and assumptions are usually held fixed (or on a constant trajectory), either explicitly or implicitly. (This is sometimes referred to as ceteris paribus, Latin for "other things being equal.") Inside the model domain, the dynamics governing the system, and thus the equations driving the model behaviour, depend on the domain itself. For example, a model that describes a truck owner/operator will be sensitive to the economics of the truck purchase price, with discounts for any financial incentives that might apply, and the economics of operating the truck over a set of routes, with a discount factor that might reflect the typical cost of capital of a small business. On the other hand, a model of the entire freight transport system would consider shared system costs, including the costs of building infrastructure and providing purchase incentives, as well as the costs of purchasing and operating trucks. If these system costs are properly captured in the single-truck model (via higher taxes and energy prices, for instance), then both models should yield similar results. But ceteris paribus assumptions can make it difficult to reflect effects outside the model domain caused by decisions taken within it. Still, it can be enlightening to view the same system from different agents' perspectives, and a collection of models can accomplish that.

Intuitively, a model is specified to represent the perspective of a representative agent and a decision that agent needs to make. Structurally, though, a model is specified in terms of scope and granularity along a number of different dimensions. Figure 67 illustrates the time and space dimensions for a selection of electric power system models, which shows the general trend that the greater the scope, the less the granularity on the same dimension; this generally holds for all system models. A limited model domain is often a result of resource trade-offs and desire for a more tractable model, but it can also represent a design choice based on the research question. Figure 68 suggests different types of transport issues can be addressed with models of different spatio-temporal domains.

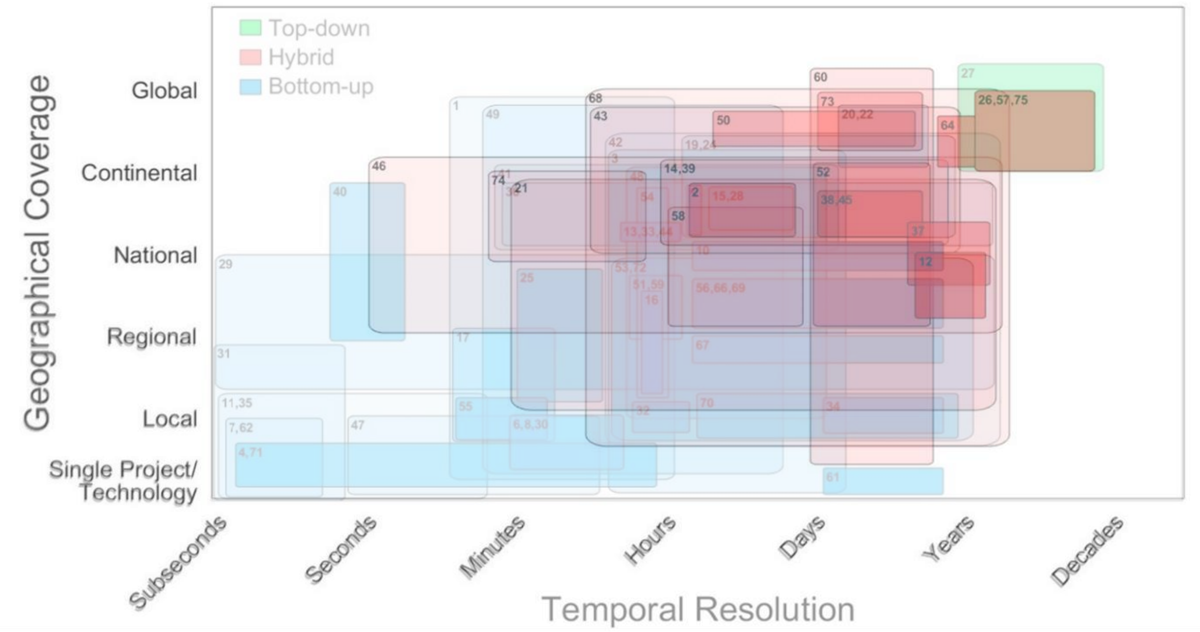


*Figure 67. Spatio-temporal scope and granularity from a review of 75 electric power system models, showing different, but overlapping model domains. Figure adapted from Ringkjøb, Haugan & Solbrekke, 2018, p. 452.*

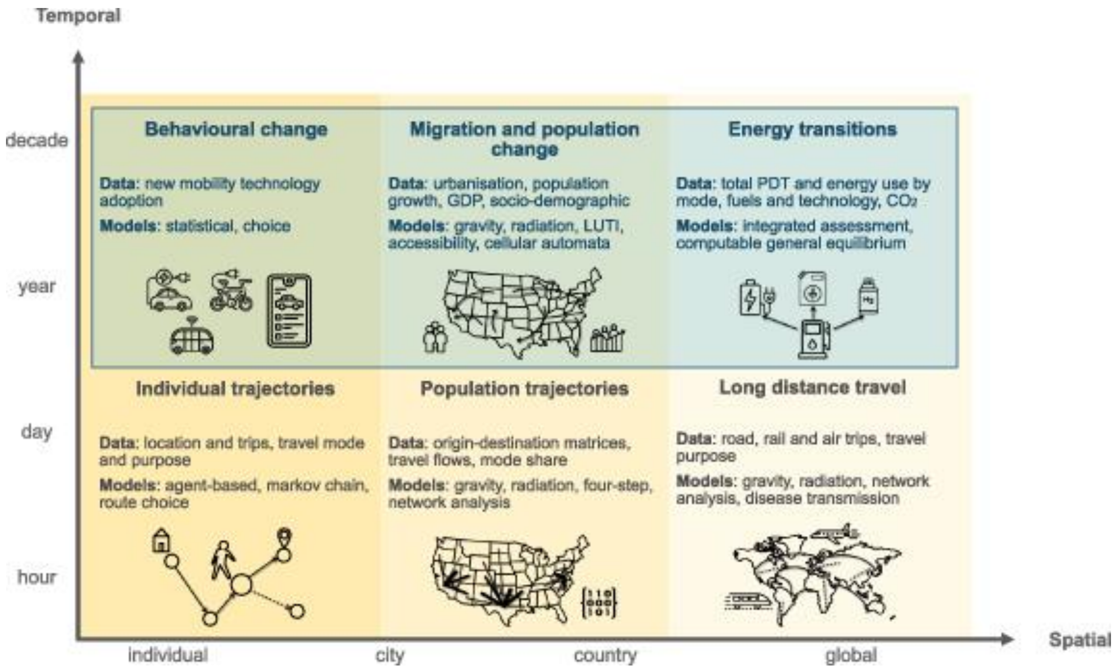


*Figure 68. Different levels of spatio-temporal aggregation are used to address different issues within human mobility. Figure from Yeh et al., 2022, p.8.*

Transportation models can be characterized by their scope and granularity across the following four dimensions:

1. Time
    - Scope, how far into the future the model projects the system. Can be as little as a day (i.e., projection-less) to show traffic flows during a representative day under different

infrastructure or regulatory adjustments, or can be multidecadal (e.g., for infrastructure planning). A model with a short temporal scope implies a focus on operational decisions (e.g., route planning), while infrastructure and the legal/regulatory environment often remain fixed. A model with a long time horizon implies the incorporation of changes to infrastructure or vehicle stocks as investment decisions evolve.

- Granularity, the minimum time increment included in the model. Though vehicle models can operate on shorter timescales, transport system models often operate on time scales of minutes to hours, although some models only represent aggregate data at the annual level.

2. Space
    - Scope, the maximum geographic extent of the model. This can be defined as, e.g., Europe, Sweden, Region Västra Götaland, or Gothenburg, but it can also be included implicitly, as in "a single truck" or "the daily trips made by trucks stationed at a certain depot," which implicitly limits their spatial extent.
    - Granularity, the minimum geographic increment in the model. This can be different depending on the mathematical formulation of the model. For "regional" models, in which the transportation activities in different regions are parameterized, the spatial granularity is the region size (e.g., country, region, municipality). For spatial models of the physical transport, this is the smallest artifact that drives model behaviour (e.g., lane on a road, road segment, origin-destination pair).
3. Mode/Vehicle
    - Scope, the types of transport modes and vehicle types considered in the model. This is often either a single mode, such as on-road vehicles or air travel or shipping, or all transport modes. The choice of mode in transport models is closely related to the portion of the value chain considered. One class of modes that is often either included or excluded as a group are non-motorized/personal mobility, such as walking, biking, scooters, etc. While these are often important modes for urban mobility, they can be less important in other model domains.
    - Granularity, the number of modes and their differentiation from each other. For instance, on-road vehicles could be classified by size class, function (passenger vs. freight), ownership (personal vs. corporate), drive train and fuel options, efficiency, and age or vintage. One could even track individual makes and models by model year.
4. Value chain/Activity/Process/Commodity
    - Scope, the portion of all possible transportation activities that are considered in the model, potentially including upstream or downstream determinants of transportation activities (such as warehousing, industrial gross output, economic growth, employment, vehicle manufacturing, or connection with the electric power system). Value chain is often connected with mode; for instance, freight is strongly connected with heavy-duty vehicles. The value chain may also be defined implicitly by the commodity being modelled; for example, a logistics model may track individual shipments from origin to destination, including inter-modal transfers and warehousing, while a long-haul transport model may restrict itself to that part of the value chain where goods are transferred between cities. Common segments of the value chain included in transportation models are goods transport or personal mobility, public and private transport, and long-distance transport or last-mile/urban

transport. With vehicle electrification, including aspects of the energy system in the scope of a transportation model becomes increasingly important.

- Granularity, the level of detail with which each segment of the value chain is modelled. This can also depend on the model purpose; for example, transportation models whose goals are to estimate the sector's energy consumption can avoid explicit representations of much of the transport value chain, while models of public transit may require a much more detailed depiction of different urban mobility options and their trade-offs. However, transport models that focus on vehicle electrification may need to include more detail within the energy value chain.

### 10.1.3. Model mathematical formulations

There are multiple mathematical formulations that a transport model can take. A detailed description of the mathematical formulations of these models is beyond the scope of this report, but an overview of the major types of transport models is given in this section. Although some of these model formulations are associated with specific model domains and agents' perspectives, often because of data availability reasons, there is enough overlap across these model formulation for several different model types to be applicable in most model domains.

Transportation models can broadly be divided into two classes, optimization models and system dynamics models. Optimization models define a system-wide objective function, such as total travel time or total system cost, and change variable parameters (i.e., decision criteria) until the value of the objective function is minimized (usually). This is meant to represent the optimal possible system state, subject to constraints built into the model by the user, and it may be used as a target to which an infrastructure planner might aim, for example. Some infrastructure and traffic flow models are designed as optimization models with travel time (or time in traffic) as their objective functions. Economic models, including partial-equilibrium models and computable general equilibrium models (CGE), are examples of optimization models that use system cost as their objective function. Although optimization models appear to represent the decisions of a single central planner, which is not how most transportation systems are structured, the model formulation is meant to represent the solution that a frictionless free market (i.e., perfect competition, perfect knowledge by all market participants) composed of welfare-seeking agents would achieve, through different market mechanisms.

System dynamics models are built with systems of equations that describe the structures and influences of observable components of the system. They tend to rely less on theoretical mechanisms and more on historical relationships among variables. Within system dynamics models are those that describe commodity flows (e.g., input-output models) and those that describe financial flows (e.g., econometric models).

Many transportation models fall within the class of system dynamics models. Stock-flow models keep track of an evolving inventory of vehicles to be used for transportation, retiring older vehicles and replacing them with newer ones according to decision rules pursuant to each model. At any time step in the model an existing stock of vehicles is available, with its own ensemble average of performance characteristics, for the model to perform necessary transportation services with. A four-step model is another type of system dynamics model, in which an inventory trips is 1) assigned to origin locations (trip generation), 2) assigned to destination locations (trip distribution), 3) allocated among applicable transport modes (mode choice), and 4) given a routing from origin to destination, given its mode (route choice). While the four-step models are based on statistical trip distributions (trip-based models), other system dynamics models use a series of activities that require various transportation services to accomplish (activity-based models). Both activity-based models and trip-based models imply the existence of semi-autonomous and heterogeneous agents, and agent-based models leverage this heterogeneity to provide a different model-based dynamic that is also consistent with observed historical distributions.

Some model formulations are associated with different system perspectives. For instance, mobility models focus on trips or flows of passengers, regardless of the vehicle they may be in, and they imply an active agent making choices about their transportation services. Logistics models tend to focus on the flow of physical goods, whether they are in transit or not, and the goods themselves do not make their own transportation choices. Transportation energy models may not even represent passengers or goods at all, but only the energy consumed by vehicles that are moving, presumably in the transport of people and goods. And economic models tend to emphasize the flows of financial value, which may be distinct from physical measures of cargo such as mass and volume.

It is important to note that all model formulations are designed to capture aspects of the same real transportation system. Model formulations differ based on the simplifications they make and the basic organizing principles they adopt. Each of these model formulations has advantages and disadvantages, and none represents a complete description of every transportation problem. But, since they all aim to capture the way the transportation system operates, analysing the same transport system issue using models of different mathematical structures can be a powerful validation technique.

### 10.1.4. Operational and planning perspectives

One of the factors discussed earlier (Chapter 6 and 7) is that the slow transition to a fossil-free freight transport system is related to the expectation that the transition will be primarily driven bottom-up by the logistic actors. This has not proven sufficiently quick in the heavy-duty segment due to the currently low market demand for electrified truck transport. Two reasons for this can be put forward, firstly, that the industry has very small margins and consists of many small and medium-sized companies with an average of only a few vehicles each, and furthermore, that it is quite difficult to assess and analyse risks and benefits. Clearly, then, some clarity can be gained by modelling from the hauliers’ and logistics companies’ perspective. By looking in detail at a particular truck operation or a cluster of truck operations one can identify the determinants for and hindrances to truck electrification, with and without battery-swapping. Questions like how specific operations are affected by battery sizes and charging solutions, or where charging points should be placed to be of best use, can be addressed by operational models of a representative logistics agent. One can supplement this understanding by also modelling from the perspective of the swapping station owners, which may or may not be the same as the logistics actors. Since the choices of individual agents or battery station owners have limited impact on the larger transport system, the models that represent their perspectives often have limited scope (i.e., short-term time horizons, limited geographic extent) and high granularity, and they treat system-level parameters as constants (e.g., infrastructure, demand, costs/prices), unaffected by individual agents’ decisions. It is worth noting, however, that the decisions suggested by individual representative agent models, such as optimal swapping station usage and total battery capacity in a swapping station, will influence business models that, once aggregated across all agents, can create indirect feedback loops in larger-scale simulations of the transport system.

At the other extreme, one must use a very broad model domain to capture the perspectives of transport system planners, such as government regulators or public infrastructure owners. For example, when simulating the effect of transport system electrification on the electric power grid, one must include the energy system and at least regional geographic scope in the model domain. As discussed earlier, the connection to the grid is central in the context of battery-swapping, as it is there that several of the advantages can be seen. It is also on this level that resilience effects and lifecycle assessment (LCA) analyses can be applied.

Finally, in all the approaches it is of great importance to understand the exact assumptions made, both within the model domain and outside of its boundaries (i.e., ceteris paribus). For instance, are techno-economic parameters held at current/historical measured values, or are they projected forward using historical trends or expected developments, such as via learning curves, new battery technologies, and future charging infrastructure deployment targets. All approaches introduce their own sources of uncertainty, but making the assumptions explicit is important for interpreting model outputs.

An example of such an assumption that could be critically important to modelling battery-swapping is the representation of battery charge times. If the process of charging an electric vehicle battery is represented approximately (or implicitly) in a model, then it may be appropriate to neglect that charging the top percentages of a vehicle battery will take somewhat longer than the same percentages in the middle region of a vehicle's battery, while a more detailed charging process representation may be needed when the exact number of charging minutes are of interest. Such assumption discussions are also exemplified in the sections below.

## 10.2. Battery-swapping and regulations: AFIR

### 10.2.1. Description of the alternative fuels infrastructure regulation (AFIR)

Recent political initiatives shape the landscape for electrification of the transport system. The alternative fuels infrastructure regulation (AFIR) is part of the "Fit for 55" package put forward by the European Commission aiming to reduce EU greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels and to achieve climate neutrality in 2050. The regulation has been developed concurrently with this project, with a provisional agreement on the regulation on 28 March 2023.

AFIR describes requirements for recharging and refuelling stations for alternative fuels in the coming years across Europe. This will inevitably have a major effect for scaling up and planning of charging infrastructure. The regulation applies to the roads in the Trans-European Transport Network (TEN-T), with different requirements for the core road network and the broader comprehensive road network. For heavy vehicles the regulation states that by the end of 2030 there should be a pool of charging stations:

- At most every 60 (100) km along the TEN-T core (comprehensive) road network, with at least 7200 (3000) kW total charging capacity in each direction
- in each urban node, at safe and secure parking areas, etc.

There are exceptions given for low traffic flows – for roads with annual average daily traffic (AADT) less than 2000 vehicles, the required capacity is reduced by half, and for AADTs less than 800, the minimum distance is increased from 60 km to 100 km.

AFIR is generally open to new technologies, but it also describes specific standards that the charging points must meet, for which it is not clear how battery-swapping solutions contribution should be interpreted.

### 10.2.2. Suggestion how battery-swapping could be potentially included in AFIR

Battery-swapping has not been explicitly planned in but is mentioned as an option "if applicable"; however, battery-swapping could be included directly or indirectly under the AFIR requirements. The current AFIR requirements call for a number of stations at certain distances along the TEN-T core and a total capacity of charging power. Since no power is delivered to a vehicle when a battery is swapped, battery-swapping stations do not contribute to this requirement as written and are thus effectively discouraged in the AFIR.

In many cases battery-swapping stations are deployed in conjunction with DC fast chargers for non-swapping EVs. As mentioned before, there are currently no swapping stations for trucks in Sweden yet, but for cars just in the last year, the number of swapping stations in Sweden has grown from zero to eight, all owned by Nio, and half of these are combined with fast charger options. The inclusion of fast chargers would qualify such station configurations under the AFIR definition of a charging station. The inclusion of battery-swapping does not, by itself, qualify the station as an AFIR charging station, but the inclusion of battery storage to support fast charging would potentially allow a greater power capacity than the grid connection alone would imply (i.e., buffered charging), making the swapping station contribute indirectly.

Though not included in the AFIR language, one could also consider battery-swapping as an effective charging station with an effective charging power capacity. The effective power capacity of a battery-swapping station would be the transferred energy per time unit for a swap, which depends on the capacity of the battery being swapped and the time required to swap a discharged battery for a charged one. For example, if a 282 kWh battery is swapped in 5 minutes, this swap would transfer the same energy as a 3384 kW charge, which is a megawatt-class charger. A typical station with 12 slots could maintain this high capacity for an hour. The equivalent charging capacity for the swapping station would then go down again until the batteries in the station are charged again. Even higher equivalent temporary capacity can be achieved just by increasing the battery capacity. AFIRs requirement of 7200kW capacity connection, would roughly correspond to having 2 stations with 12 slots each and 300kW-batteries charged at C-rate of 1. Figure 69 provides a symbolic illustration of how adding a battery-swapping station can partially decouple the power drawn from the grid from the power provided to the vehicle through a battery swap. The peak power capability $P_2$ [kW] provided by the swapping station can be temporarily higher than the power provided by the grid $P_1$ [kW] as it is only limited by the battery capacity and the swapping time. This could better utilize the power available from the grid especially if peak battery swap hours are less frequent and charging can be slower during waiting times between peak hours. This can be compared to regular cable-charging where the peak powers $P_1$ and $P_2$ are always equal unless the charging station has its own energy storage.

In summary, it is possible to assign a certain factor for the stations that count this kind of capacity contributions in the AFIR regulations.

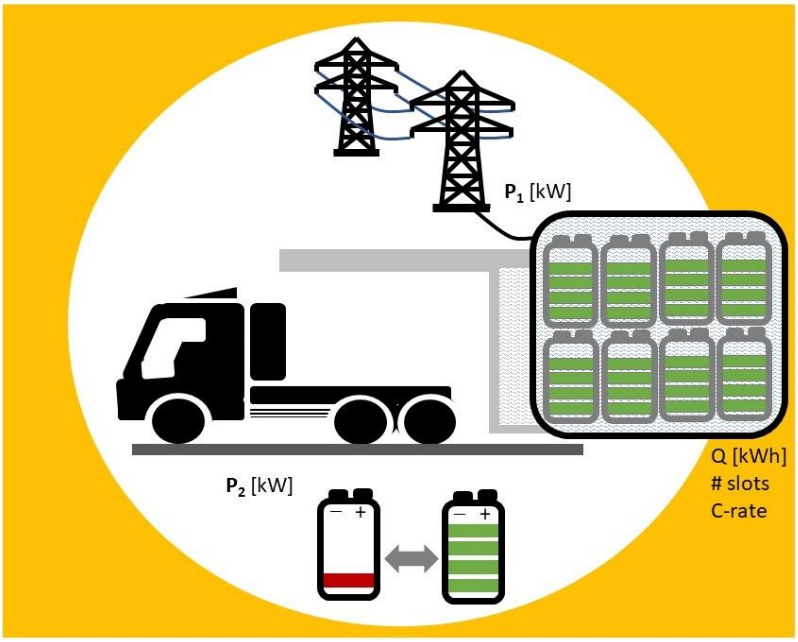


*Figure 69. A symbolic illustration of a battery-swapping station for heavy duty vehicles. The station is charging with power from the grid $P_1$[kW] which depends on the number of battery slots, the battery capacities Q [kWh], and how fast these are charged, described by the chosen C-rate. It partially decouples the power from the grid and the equivalent effective power $P_2$[kW] as seen from the vehicle.*

## 10.3. Modelling operators' perspectives

This section concerns modelling approaches that reflect the perspectives of actors within the transport sector [*See chapter 6*], and in these contexts modelling and simulation can be used both for optimizing their operations. Models contain a great deal of operational realism within a narrow, but detailed domain within the transport sector, while the broad boundaries of the system are held constant. It is a decentralized approach, and decisions taken by individual actors are not assumed to substantially change the system.

These types of specific operational analysis are those that can inform important business decisions, such as needed battery capacities and charging times. In optimization models, decisions are often taken (input variables are changed) to minimize an operator's costs, subject to a fixed demand and fixed prices; in simulation models, costs may be only indirectly addressed, with other efficiency parameters, such as vehicle loading, delivery times, or throughput measures taking greater precedence. Model outputs may be used to develop business models for actors.

Models commonly illustrate either the operational constraints placed on an actor or the costs required to manage the business despite the constraints. The latter includes cost models, such as total cost of ownership (TCO) models for owner/operators of heavy trucks with different drivetrain technologies that was used in a recently released study by The International Council on Clean Transportation (ICCT). (Basma & Rodriguez, 2023) That analysis considered the TCO for a truck owner for trucks of different size classes operating with several different drivetrains. It did not include the possibility of battery-swapping, however, which could significantly affect a BEV owner's TCO.

The next several sections illustrate the operation of models of the first type, which illustrate operational constraints and trade-offs from the viewpoints of different actors.

### 10.3.1. Operational level - Hauliers' perspective – Basic example

A simple example to illustrate modelling battery-swapping from an operator's perspective is that of a haulier with a single truck and the representative operation during a typical day. The operational baseline is that of today's diesel-powered truck, but if the haulier wishes to decarbonise its operations in the future, it may consider purchasing a battery electric truck as a replacement. The decision variables, then, would be around the purchase and operation of the new truck, including the size of the truck's battery and whether it could swap batteries. These decisions become modelled cases to be compared with one another.

For the model, we can assume that the haulier operates an electric heavy-duty truck in the current infrastructure landscape of Sweden. Typical electric trucks can operate over 200-300 km but then require charging. The dominant charging solution for electric trucks today is via cable at a private charging station at the depot or at a limited but expanding infrastructure of public chargers [chapter 10.2]. Typically, the trucks can be slow charged (i.e., at 50 kW or lower charging power) overnight at their depot but often this would not be enough for fulfilling operations without additional charging during the day as well.

Today's heavy-duty electric trucks have between 250 and 600 kWh of battery capacity and are equipped with CCS (Combined Charging System) – the most common charging standard for electric vehicles, including passenger cars and trucks in Europe. Most CCS chargers have a maximum power output of between 50 and 400 kW. In the future, MCS are planned (Megawatt Charging systems) with powers above that, but these are not commercially available yet.

The operation of any truck in the European Union is governed by Council Regulation (EC) 561/2006, which requires truck drivers to rest for at least 45 minutes after driving for 4.5 hours, and it prohibits them from driving more than 9 hours before taking a longer 9-hour rest (i.e., overnight). If a truck drives at an average speed of 80 km/hr, then this limits the operation of the truck to 360 km of driving, followed by a 45-minute break, and another 360 km of driving in a single day.

With these assumptions, a simple model of the haulier's best operational decisions under a number of use cases with different types of electric charging options can illustrate the trade-offs between charging options. For the cases below, we assume a loaded truck on typical highways and traffic averages 80 km/h speed and consumes 1.86 kWh/km of energy (Fulton and Burke, 2019).

*Case 1:* Mission: one-day round-trip reaching a destination 240 km away to be operated with a truck with usable battery capacity of 400 kWh and equipped for CCS charging of up to 375 kW. This means that overnight charging is possible, as 400 kWh can be charged in 8 hours even with a relatively low-power, 50 kW charger, and we can assume that the truck begins with a fully charged battery in the morning. At 80 km/h, the truck would reach its destination in 3 hours, but the battery capacity will only allow a range of 215 km; it will need to stop to charge within 25 km of its destination. It wouldn't need to stop long – a CCS charger delivering an average 350 kW of charging power could provide enough energy to complete the remaining journey in 8 minutes – but it would arrive with a fully-discharged battery. If the battery were charged again at 350 kW during a 45-minute driver rest period, while the truck was unloaded and reloaded again, the truck could begin the return journey with a partially charged battery with 262 kWh of energy. A charge time of slightly more than an hour would allow the truck to begin the return journey with a fully charged battery. In either case, whether the battery is fully charged or only partially charged, the truck would need to stop again to charge on the return journey.

While there are different options in this case for when and where to charge the truck, because the 240 km trip length exceeds the range of the battery, the truck will need to stop to charge at least once on each leg of the journey, even if it also fully charges at the destination. The total round-trip distance of 480 km would consume 893 kWh of energy, so a 400 kWh battery will need to be charged more than once to make the entire trip. If the battery begins fully charged and returns completely discharged, it will still need to add 493 kWh of energy at CCS fast chargers along the route. At 350 kW, this would add 1.4 hrs to the otherwise 6-hour trip, although up to 1.1 hours of charging could be done at the destination while the truck is being turned around and the driver is resting.

There is no particular operational advantage to the haulier in this case for battery-swapping with 400 kWh batteries. The truck would need to swap batteries at least twice on this journey, and the additional time needed for swapping batteries would be roughly equivalent to the additional time spent charging in a non-swappable truck. Depending on prices for fast charging and battery-swapping, there may be an economic reason for favouring one solution over the other, but there are minimal scheduling reasons to favour one over the other.

It is also worth noting that in this example, the BEV truck arrives back at its home depot with a discharged battery, but only after a 7.4-hour day. It would need to charge first before becoming available for other missions. The equivalent battery swap truck would take the same amount of time, but it would arrive with a nearly full, recently swapped battery and would be available immediately for additional operations.

This case illustrates the advantage of sizing a truck's battery to the length of the trip. A truck with a larger 500 kWh battery would be able to make this 240 km trip on a single charge. Fully charging the truck at the destination for 1.3 hours would allow it to make the return journey without stopping as well. However, most hauliers do not travel the exact same route day after day. If one has a fixed capacity battery in a truck, trips that exceed the effective range of the battery will require stops to charge.

*Case 2:* Mission: two-day round-trip reaching a destination 600 km away (approximately Stockholm – Malmö) with the same truck as in Case 1 (400 kWh battery, 1.86 kWh/km efficiency). With a range of only 215 km, the truck would need to stop at least twice to fully charge on each leg of the journey (outward and return). Though the travel time at 80 km/h is only 7.5 hrs each way, the truck would take almost 10 hours to complete the journey, including stops for charging of slightly more than an hour each.

Figure 70 shows the time periods when the truck in Case 2 is in motion (green) or stopped (red) for various reasons along one direction of the 600 km route. Each horizontal bar denotes a different truck technology and charging behaviours that were modelled under otherwise identical case assumptions. All 8 modelled options assume that the truck begins its journey fully charged/fuelled at 7:00 in the morning. The top bar, option a, shows the diesel truck baseline. It is assumed that the diesel truck does not need to stop to refuel, but after 4.5 hours it must stop for 45 minutes to give the driver a chance to rest. It arrives at its destination at 15:15 in the afternoon. The next two options show a BEV truck with a 400 kWh battery under two different charging schemes. In option b, the truck stops when its battery needs to be recharged, and each time it charges for 45 minutes while the driver has a chance to rest. The battery is not fully recharged in these periods, and so the truck must stop to charge three times during the day, and it arrives at its destination around 16:45, an hour and a half later than the diesel truck would have. Option c is an identical truck to option b, but the driver fully charges the battery when it becomes discharged. Under this assumption, only two charging events are needed, but they are of slightly longer than an hour each. The option c truck arrives slightly earlier than the truck in option b, only because it shortens the second charging time and arrives completely discharged.

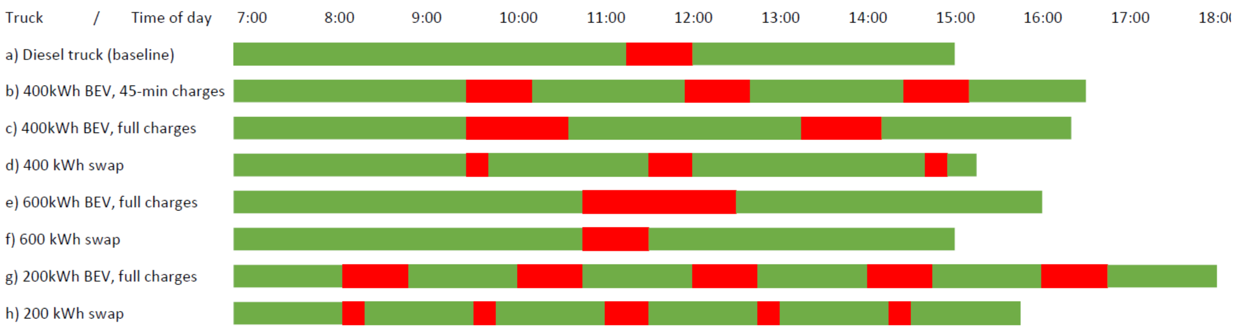


*Figure 70. Results from simple model of truck operations over a one-way 600 km route. Vehicle assumed to begin the trip at 7:00 fully fuelled or charged. Periods with vehicle in motion (green) or at rest (red) are indicated.*

Option d in the table demonstrates the operational benefit of battery-swapping quantitatively. Option d shows a truck identical to those in options b and c, except that the truck in option d can swap its discharged battery for a charged one at a battery swap station. This shortens the time required to "charge" its battery compared with the BEV examples in options b and c. The driver still needs to rest, though. Council Regulation (EC) 561/2006 allows the 45-minute rest period a driver must be given every 4.5 hours of driving to be split into one 15-minute and one 30-minute period. In option d, each rest period includes a battery swap; but while the first event just before 10.00 occurs because the battery has become discharged, the second event, 30 minutes from 11:45 to 12:15, is timed to meet the driver rest requirement. The battery is swapped for a fully charged one at this point, even though the battery in use is not fully discharged. The timing of this rest period corresponds exactly with the end of the 45-minute rest period for the diesel truck (a). Option d requires one more battery swap event to complete the trip, and that extra swap causes the truck in option d to arrive at 15:30, 15 minutes behind the diesel truck.

The truck owner could also change the size of the battery in the truck, and this changes the operational constraints, which can be illustrated using the same model. Options e and f show a BEV and a battery swap truck with a 600 kWh battery, and options g and h show the same for a smaller 200 kWh battery. With a larger battery, the 600 km trip can be made on two charges. Since the truck needs to stop for the driver rest period, anyway, a 600 kWh battery allows the battery swap truck to complete the journey in the same amount of time as the diesel truck (option a). The BEV truck (option e) must wait for almost 2 hours for the battery to fully charge before continuing, and this causes it to arrive 45 minutes after the diesel and battery swap truck would have arrived. Faster charging (i.e., MCS) could eliminate this time penalty. These options demonstrate the value of large batteries and fast charging. However, it must be stressed again that MCS is not a currently available option as the standard is being still developed, which makes the comparison with the available at present battery-swapping variants not entirely fair.

Conversely, options g and h show the performance penalty incurred when a smaller battery is chosen, but it also shows how this penalty is minimized under battery-swapping. With a 200 kWh battery, the truck must recharge its battery 5 times to make it to its destination. With a 350 kW CCS charger, each charging event would last around 35 minutes, but if startup times are included, each event could reasonably be rounded up to 45 minutes. The frequent, long pauses along this route cause the truck in option g to arrive after 18:00. Conversely, if the batteries can be swapped at stations along the way, and if these stops can be limited to the minimum time needed to give the driver their regulated rest periods, then the truck would still arrive before 16:00.

Modelling this case demonstrates the trade-offs between charging speed and battery capacity for a long-haul truck. Without battery-swapping, a haulier’s incentives would be to choose the largest battery and fastest charging rate to minimize their travel time. Battery capacity and charging power both come at a cost, which is not modelled here. High charging powers also place a disproportionate load on the electricity grid, which raises societal concerns; this can be modelled with a system planning model, but it is outside the scope of the operational model in this example. Battery-swapping allows the haulier to choose smaller truck batteries and forego MCS charging and still minimize or eliminate the time penalty of charging compared with diesel trucks. Note that in this basic example it is assumed that there is always a charging station or battery swap station where needed, there no queues or other difficulties, and the truck operation is not connected to ownership of chargers or swapping stations.

### 10.3.2. Operational level - Hauliers’ perspective – Operating a truck fleet

This section illustrates how an operational model may also be constructed to reflect the fleet owners’ perspective. The model and analysis illustrate the kind of questions that can be answered and the data needed to do so. The model and analysis in this section uses data from an ongoing case study at VTI, ”Laddinfrastrukturlösningar”, financed by Energimyndigheten over the period from 2021 to 2023, which aims to provide electrification decision support for goods transport by investigating possible electrification pathways. That project is a collaboration between VTI, TRB Sverige, and Halmstad University and considers only cable charging options, i.e., no battery-swapping options. The study analyses vehicle data from the transport company Göteborgs lastbilscentral (GLC), a part-owner in TRB, a branch organization in the transport industry, and discusses which vehicle battery sizes are needed, and how many and where the charging points should be situated. The premises are keeping the same operation as current fossil powered. It assumes that charging is available at home depot stations, at some customers’ depos, and at public/semi-public stations. Some study results are published in Nåbo et al., 2023.

The data that this simulation is based on includes time stamped trips, defined as traveling from a start point to a stop, destination coordinates, and fuel consumption for all vehicles in a fleet of 61 (non-electric) trucks over a period of sixth months. 110,000 trips were recorded, and these may be used to simulate the operational impacts of different electrification options. Figures for an example vehicle and a few insights related to the haulier's perspective are presented below.

Figure 71 shows the trip duration profile for one of the vehicles in the fleet (Vehicle 20). This vehicle is used for both short trips (less than one hour) and long trips (represented by a secondary peak at 200 minutes). Without regard to range, a vehicle’s payload characteristics can be matched to the load to be delivered. If this fleet were electrified with fixed batteries, then all trucks with a similar distribution of trips would need batteries with sufficient range for the longest trips, even though many trips are shorter. However, if battery-swapping allows changing battery capacity when swapping, then a truck can be chosen to match the load and its battery can be chosen to match the trip distance, independently. In this case, modelling can simulate the need for batteries of different sizes for each truck in the fleet and calculate the total battery capacity needed across the fleet of trucks. Since some trucks can operate some of the time with smaller than the maximum battery size needed for the longest trips, the total battery capacity needed across the fleet of battery-swapping trucks would likely be less than the total battery capacity across the equivalent fleet with fixed batteries.

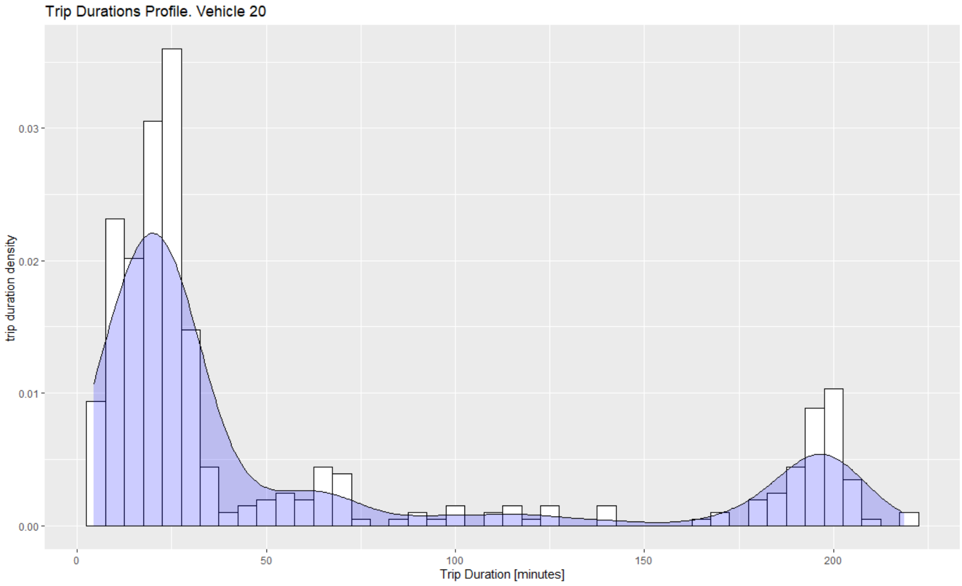


*Figure 71. Trip duration profile for an example vehicle.*

Figure 72 shows the start and end times for the same vehicle's trips, which are primarily during the daytime. If other vehicles in this haulier's fleet have similar operating schedules, then nighttime charging when the vehicles are stationary would be a convenient option, and most vehicles could begin most days with a fully charged battery. (A model of each vehicle in the fleet could quantify the required nighttime power for charging or calculate the amount uncharged battery capacity remaining by morning for fixed nighttime chargers.) This operational profile could decrease the value of a battery-swapping solution compared with one in which vehicles are used throughout the day and night. However, if the battery capacity were not sufficient for this truck to complete its daily mission on a single charge, then it could become difficult to find sufficient time of vehicle inactivity during the day to recharge a cable-charging truck, while a battery swap truck would have lower downtime. One option for charging a truck with a fixed battery during the day could be while the driver was stopped for lunch. However, this could create a maximum power issue for the fleet if many of them chose to fast charge at the same time in the same place (i.e., the vehicle depot or a popular lunch spot). It could even strain circuits within the local distribution grid. A fleet model could simulate this charging behaviour for each vehicle and report the charging and operational implications for the fleet, such as failed missions within the operational schedule, which would help the haulier explore options to provide operational flexibilities. These could include equipping some or all trucks in the fleet with larger batteries, choosing a mix of fast and slow charging, altering routes and/or charging strategies of individual vehicles to distribute more evenly the charging load for the fleet, or exploring battery-swapping solutions for some or all the fleet vehicles.

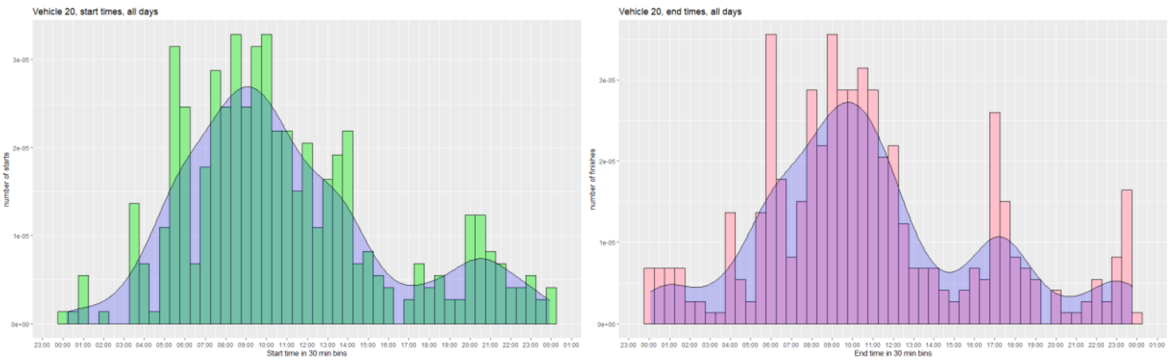


*Figure 72. Start times (left panel) and end mission times (right panel) over a 24 hour-period for an example vehicle showing that it is difficult to synchronize charging times with lunch or other rest times.*

In the above analysis, it was assumed that the logistics operations are independent of the owners of vehicle charging infrastructure (i.e., the charging stations or the battery-swapping stations), and that the charging infrastructure functions well without capacity limits. No considerations were given to making sure that there is always a charging point or a fully charged battery available for swaps when needed by the fleet operator.

### 10.3.3. Operational level – Swapping station owner considerations

The important parameters to determine from a swapping station owners' perspective, apart from the physical placement of the station and its connection to the power grid, are choosing the number of places (slots) for batteries, the ideal distribution of sizes of batteries, if applicable, and controlling the charging power to each battery so that the station can meet expected battery demand from trucks arriving with discharged batteries. The station capacity questions are investment decisions to be made when the station is built or expanded; how batteries are charged is an operational question involving trade-offs between charging cost, battery degradation, and customer demand.

In general, the faster the charging rate (charging power), the more it degrades the battery and the more disruptive it is to the grid; but slower charging prevents the battery from being available for swapping for a longer period of time, reducing its potential capacity utilisation factor. Battery charging rates are expressed as a C-rate, which is the ratio of the average realized charging power in kW to the battery capacity in kWh. A C-rate of 1 means that it takes one hour to fully charge the battery, and C-rate of one half means that it takes two hours. The maximum number of possible swaps performed in an hour for a station with a single swap bay is dependent on the time needed per swap; existing stations with battery swap times of 3-5 minutes could in principle handle a dozen or more swaps per hour. Future swapping station designs may be able to reduce the time needed to swap a battery.

It should be noted that while the C-rate for cable-charging depends on the capacity of the battery and the power delivered by the charger; larger batteries need chargers with greater charging speeds to maintain a constant C-rate. By contrast, battery-swapping yields an effective C-rate, $C_{swap}$, which is independent of the battery capacity and only depends on the swapping time, $t_{swap}$. If $t_{swap}$ is given in minutes then $C_{swap} = 60/t_{swap}$. Thus, a 5-minute battery swap, which is typical of existing battery-swapping stations, has an effective $C_{swap}$ of 12. Unlike with cable-charging, larger batteries automatically yield higher effective C-rates.

Modelling the arrival of trucks and their battery needs is key to the efficient operation of a battery-swapping station. A battery-swapping station could potentially maintain a stockpile of batteries with different capacities, which makes it possible to optimize battery sizes as well. However, for simplicity in the following analysis we consider all batteries in the station are of the same size of usable capacity Qu (kWh). (The usable capacity of the battery can be estimated to be differ by a factor ***f*** of about 0.7-

0.8 of the total capacity, as it is a rule of thumb that the batteries avoid having state of charges below 15% depletion, and function best when not charged completely, say to 95%.)

If a swapping station with charging rate C receives vehicles at constant time intervals separated by $t$ with discharged batteries needing to charge then the number of batteries, N, needed to maintain continuous operation of the station can be descried by the following:

$$N = f/(C \cdot t)$$

The maximum number of batteries to maintain continuous operation occurs when the trucks arrive at intervals that equal the swap time $t = t_{swap}$. (To handle faster arrival rates, one could envision a swap station with multiple vehicle bays and/or multiple swapping stations in close proximity.) This assumes vehicles arrive at a steady rate and would need to be adjusted for actual vehicle flows. Some over-dimensioning of the station is to be expected in order to cover the top demand hours and/or accepting some queue times at the peak hours.

The above considerations address only the transport side. It is also possible that some extra capacity of the swapping station may be planned if it is to serve as an actor in the electricity flexibility market *[see chapter 7]*. It should be noted that different grid services require different amounts of standby capacity, so the ability for a swapping station to bid into different ancillary services markets depends on its expectations for future spare battery capacity.

Unique to battery-swapping is the concept of managing a stockpile of EV batteries independently of the vehicles, and this is modelled from the swapping station owner persecutive. The owner of the battery stockpile decides how many batteries to maintain, of which capacities, and how to price their usage to satisfy demands from both transport and energy sectors; they decide how fast and when to charge them to balance battery lifetime and availability; and they decide when to retire batteries from the stockpile once their useful life is over. Each of these decisions can be modelled, and the perspective of the battery stockpile manager may differ significantly from that of a BEV owner with a fixed vehicle battery.

Having an independent battery stockpile manager can lead to different system outcomes than if the vehicle owner makes decisions about the battery. As mentioned previously, battery-swapping introduces the idea of matching battery capacities to trip distance (or typical daily use), which could result in less total battery capacity in vehicles at any point in time than with fixed-battery BEVs. Although the battery stockpile owner will certainly need more batteries than there are vehicles in the system, the total capacity of batteries may or may not be larger than if all trucks have large, fixed batteries. With fixed-battery BEVs, the owner of a single truck or small fleet of trucks will likely not invest in additional spare BEVs to allow for the slow charging that would preserve the vehicles' battery health. But, a battery stockpile owner, with more battery turnover and smaller unit costs (i.e., only the battery, not the entire BEV) might be better able to manage the charging rates of the batteries to lengthen their lifetimes. The system-level effects of these differences between fixed and battery swappable BEVs, due to the different perspectives of the actors operating vehicles and batteries, can be calculated using the broad domain system models discussed in the next section.

### 10.3.4. Operational level – Harbor Transport Case

A previous chapter of this report, (*chapter 8)* includes another example of a model-based analysis of battery-swapping at the operational level. This simulation explores drayage trucks moving containers along a known route between a harbour and warehouse facilities.

## 10.4. Modelling the system planning perspective

System planners take a more high-level view beyond individual vehicles or fleets of vehicles, to include multiple, interacting vehicles and usually long-term time horizons. Accordingly, models that take this perspective capture a broader part of the space-time-mode-process domain, but they usually do so with less operational detail. Actors at this level include municipalities, regional and national infrastructure planners and policymakers, etc. [*see chapter 6*] As with the operational perspectives, models and simulations of the system planning perspectives can be useful to provide insights for planning purposes.

It is important to note that the system is a conglomerate of its components, so even if a system model does not model its components in as much detail as an operations model would, both models should have mutually-consistent representations of the dynamics involved. For example, a system model needs to assume the size of a battery in a fixed-battery BEV truck in order to calculate the optimal places to place charging stations, while an operations model might use trip distances to calculate the optimal size of battery in a truck. Ideally, where possible, the calculated outputs from both types of models can be used to inform the non-calculated inputs to the other.

System models are designed to address research topics such as the following:

- Modelling the battery capacities and placement of charging networks needed at higher-than-haulier levels, and optimizing these, e.g., for as low total capacity as possible while still supporting Swedish transport electrification,
- Electrification and charging impact on the electrical grid, which means modelling and being able to optimize, e.g., to minimize the peak power draw from the grid.
- Land use considerations for scaling up vehicle electrification and associated charging infrastructure.
- Battery aging and degradation aspects, possibility to optimize resources and battery lifetimes.

### 10.4.1. Total battery capacity and land usage in the system

It may initially seem like battery-swapping is connected to a higher amount of battery usage in the transport system. Compared to a case with cable charging when the only batteries are the ones in the vehicles, battery-swapping implies the need for a greater number of batteries in the system, both those in the vehicles and those charging in swapping stations. The number of batteries needed in the whole transport system in a battery swap case, $n_{swap}$, is larger than the number of batteries needed for the cable charging option, $n_{cc}$, by a factor $k$:

$$n_{swap} = n_{cc} * k; \qquad 1 < k < 2$$

The factor $k$ is certainly greater than one and likely less than two. A factor of two would mean having exactly two batteries for every vehicle and always charging one with the same rate as using the other one. This is not a probable scenario, as vehicles are sometimes stationary, synergies exist between different truck missions, etc. It should be noted, however, that regions with irregular or sparse traffic flows may have higher $k$ factors than those with more predictable battery-swapping demands.

However, from a system planning standpoint the number of batteries is not the most relevant quantity, unless all batteries have the same capacity. From a system perspective the total amount of battery capacity corresponds more closely to cost, critical minerals, etc. The system battery capacities for swapping and cable charging are given by:

$$Q_{swap\_}^{tot} = n_{swap} * Q_{swap}^{mean}$$

$$Q_{cc\_}^{tot} = n_{cc} * Q_{cc}^{mean}$$

Where $Q^{tot}$ is the total capacity (in kWh), n is the number of batteries in the system, and $Q^{mean}$ is the average capacity of a battery (in kWh). The subscripts cc and swap denote a system with only cable charging BEVs or battery-swapping BEVs in the system, respectively. As has been argued, using battery-swapping allows for a smaller average battery capacity, so it is unclear without further analysis which system has greater total battery capacity. One analysis (as yet unreviewed) of truck operations in Sweden, using an agent based simulation model, estimated this factor k to be around 1.08. (Lai Jakobsson, 2023) The same study makes a quick estimate of the land usage for battery-swapping stations based on Chinese suppliers' information comparing it to the land needed for a fast-charging station for trucks, finding the difference of about a factor three.

Even in a cable charging environment, fixed batteries may be needed to supplement charging during periods of extraordinary charging demand in locations that have limited grid connectivity. A recent example of this need was when Scania electrical truck fast chargers needed extra battery capacity when operating in Åre during winter vacation in early 2023: a mobile battery unit with truck chargers was installed temporarily to handle the surge in demand, as reported by Elfordon.se, February 2023. The mobile unit contained two CCS2 fast chargers connected to a battery storage of 560kWh. As vehicle electrification increases, such mobile battery units may become part of the charging system resilience strategy, and a demand model with grid capacity and charger installations could help identify the need for these solutions.

While BEVs with fixed batteries may be able to support electric grid stability via V2G or smart charging, the grid support function may be easier to coordinate with batteries in a battery-swapping system. Agent-based models of BEV vehicle operations could identify times when those vehicles could be connected to a charger and available for V2G support to the grid. In a battery-swapping context, a battery stock management model could quantify similar potential for grid support. As the perspectives of the vehicle owner or battery-swapping station owner are different, comparing the potential for grid support between fixed-battery and swappable-battery systems likely requires different models.

Finally, a model that simulates the operation and disposition of a stockpile of batteries for use in battery-swapping may be able to quantify the amount of battery capacity degraded over time compared with a system with cable charging. With batteries fixed in vehicles, the lifetime of the battery is connected to the lifetime of a vehicle. Although a depleted battery may be replaced with a new one, the replacement is costly in vehicles not designed for easy battery-swapping. Fast charging fixed batteries degrades their health faster than in the controlled charging environment of a battery-swapping station, which means that the BEV may face early replacement due to degraded battery performance and the high replacement cost. Upon vehicle retirement, the depleted battery may find a second life in stationary grid applications, for example. Conversely, in a battery-swapping system, batteries are routinely replaced in vehicles at negligible incremental cost and time. Over time, degraded batteries in a battery-swapping stockpile can be replaced with newer batteries. As cost and performance characteristics of battery technologies continue to advance, these improvements can be deployed to existing vehicles without waiting for vehicle replacement. Depleted batteries can be offered (at reduced prices) to vehicle owners as lower-capacity vehicle batteries or used for grid support; and the decision to use a battery for vehicle operations or grid support services can be made on a continuous basis with all batteries in the stockpile. The value of this flexibility in battery usage may be modelled with a vehicle and battery stock-flow model. One output of such a model would be the total amount of new battery capacity added to the system – including both the transportation and electricity systems – over time.

### 10.4.2. Modelling the connection to the electric grid

From the type of models used in the previous section spatial allocation of consumed energy at charger locations and their time profile from the charging can be deduced. The parameters of importance are the charging rates and battery capacities needed in the system as well as the charging in time and place.

For cable-charging, there have been such studies that present calculations on maps of Sweden with predictions of aggregated consumed energy, see for instance the Electric Sweden model reported by

Bischoff et al, 2019. This particular study uses a so-called MATSim tool, a multiagent transport model simulation where a synthetic population is created and analysed. (Horni, Nagel & Axhausen, 2016) Similar studies can be done including battery-swapping as a charging option. One such study which included swapping but however did not calculate profiles was the one previously mentioned by Lai Jakobsson, 2023.

Modelling the connection to the electricity grid becomes increasingly important as the number of EVs and the charging rates both increase over time. The demand for more electrical energy for transportation will lead to more generating capacity being built, and that energy is likely to come from variable (nondispatchable) renewable sources such as wind. Balancing the future grid with more variability on the supply side and greater peak loads from BEV charging on the demand side will present an unprecedented grid management problem. The future evolution of the energy system as transportation electrifies can be projected using an energy system optimisation model such as TIMES (Loulou, Goldstein, Kanudia, Lettila & Remme, 2016) or in a power system capacity planning and dispatch model, such as PyPSA. (Brown, Hörsch & Schlachtberger, 2018)

Perhaps more pervasive, though, than managing the evolving grid will be the challenges of distributing enough power to the individual low-voltage circuits that supply power to charging stations without overloading those circuits or disrupting power in the rest of the local power distribution networks. (Unterluggauer, 2021; Sudha Letha & Bollen, 2021) Although the grid capacity can be increased, modelling the most vulnerable circuits in a power flow model, as was done in the two studies referenced above, will help target capacity investments to where they are most needed and most effective. As with obtaining data to estimate battery SoH, obtaining data about local distribution networks is often an impediment to conducting non-proprietary modelling of these networks.

### 10.4.3. Battery lifetimes: modelling degradation and aging: the effects of battery-swapping

Optimizing the system for maximum battery lifetimes is a key to a sustainable electrification transformation of the transport segment. Understanding the degradation effects of charging and discharging over the lifetime of a battery is an important enabler to the use of vehicle batteries to support electricity grid services, in either a cable-charging or battery-swapping environment. Being able to estimate a battery's state of health (SoH) independent of a vehicle is critical to managing the stockpile of batteries in a battery-swapping environment.

Validated battery degradation and aging models are specific to the exact cell chemistries and how the batteries are used and stored. For the most reliable models one needs extensive data from both battery suppliers and vehicle manufacturers, which are rarely made available due to the perceived commercial value. The factors and practices that are important to prolong battery lifetimes are generally accepted, though. Fast charging, for instance, is understood to reduce a battery's useful capacity, and repeated fast charging cycles results in a diminished battery lifespan. Temperature also plays an important role in the aging process.

There are several freely available degradation models found in the literature, for example in Fioriti et al., 2023 and Loew, Anand & Szabo, 2021. In these models the aging mechanisms can be separated into two types: calendar aging, when the battery ages over time due to chemical processes taking place unrelated to whether the battery is being used or not, and cycling aging, which has to do with how the battery is charged and discharged. A battery's capacity Q (kWh) is diminished from its nominal capacity when new by the combined effects of the two types of capacity losses,

$$Q = Q_{nominal} - (Q_{calender} + Q_{cyclic})$$

The rate of change for the calendric component is a function of the time, t, since the battery was manufactured and complicated functions of the history of the battery's state of charge, SoC, and temperature exposure, T. The incremental change in $Q_{calender}$, though, $dQ_{calender}/dt$ can be parameterized as a function of T, SoC, and t. For constant SoC and temperature this rate of change exhibits a square root behaviour of the lifetime t. Thus, if $Q_{calender}$ is known at one point in time, the incremental degradation may be able to be estimated using a degradation model and knowledge about the battery's SoC and temperature history since last estimated.

In order to evaluate the cyclic component $Q_{cyclic}$ one can use the so-called Rainflow algorithm, which identifies cycles from charging and discharging data, where the depth of discharge is the major factor. This algorithm is however simplified and does not explicitly account for the rate of charging or discharging, though, which can be of importance depending on exact battery cell chemistry, etc.

The introduction of battery-swapping would affect both aging types. Batteries managed in the controlled temperature of a swapping station can be charged more slowly, avoiding some of the lifetime reduction effects of fast charging and extreme temperatures. Intelligent demand predictions for batteries could allow the station owner to keep some of the batteries at a moderate SoC during periods of low demand (i.e., at night), only fully charging the batteries prior to expected demand increases. While time affects all batteries, whether fixed in a vehicle or managed in a battery-swapping station, the other determinants of battery degradation are more controllable in a battery swap environment than fixed in a vehicle.

For fixed-battery vehicles, the vehicle manufacturers can provide estimates of a battery's SoH using proprietary battery degradation models. As this can be considered to be a source of market differentiation for them, though, they may be naturally reluctant to share these algorithms or the data they rely upon. To facilitate battery stockpile management in a battery-swapping environment for trucks, however, battery standardization across vehicle makes will be necessary, along with standards for battery health estimates and battery data sharing. Coordination across vehicle manufacturers on battery standards and digitalisation has been an impediment to battery-swapping in light-duty passenger cars. (Ulrich, 2021)

## 10.5. Summary for modelling and simulation aspects

This work package addressed the question of what methods, models and simulations can be used to adequately analyse the possibilities and effects of an upscaling of battery-swapping for heavy vehicles. Several simple and more advanced cases were provided, along with listing some different simulations tools available. The benefits of including both current and future logistic solutions and their energy needs were discussed, as well as a discussion about how calculations can help compare different charging solutions and help include these in future regulations such as AFIR. Modelling and simulation are about identification of the key factors, and visualization and optimization.

To support electrification of truck transport, electrification solutions are needed that hauliers and logistics companies can afford and that provide vehicle utilization that is on par with today's diesel-powered trucks. Battery-swapping technology for heavy vehicles has the potential to deliver electrified transport solutions with less operational constraints than cable-charging, and with potentially lower and more flexible costs. However, it introduces a new business (the battery-swapping station owner and battery stockpile manager) which does not exist with either diesel trucks nor with cable-charging BEVs. Understanding the role and motivations of this new actor as the business environment evolves will be key to fostering battery-swapping. The advantages are clear: the potential for rapid heavy vehicle electrification on commercially advantageous grounds, which can also contribute to other societal goals such as sustainability and smart use of resources.

It is important to optimize battery usage in society for the most sustainable solution, which means choosing the best trade-offs. Modelling and simulation tools can help different actors within the space understand the trade-offs and opportunities from their perspectives, and system planning models can show how individual actors' decisions can either moderate or exacerbate decisions by other actors.

## 10.6. References


Basma, H. & Rodriguez, F. (2023) *A total cost of ownership comparison of truck decarbonization pathways in Europe* (working paper 2023-28). November 2023, The International Council on Clean Transportation (ICCT). https://theicct.org/wp-content/uploads/2023/11/ID-54-%E2%80%93-EU-HDV-TCO-paper-working-paper-28-A4-50145-v2.pdf [2023-12-05]

Bischoff, J., Márquez-Fernández, F.J., Domingues-Olavarría, G., Maciejewski, M. & Nagel, K. (2019). Impacts of vehicle fleet electrification in Sweden – a simulation-based assessment of long-distance trips. *6th International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS)*, Cracow, Poland, 2019, pp. 1-7. https://doi.org/10.1109/MTITS.2019.8883384

Brown, T., Hörsch, J. & Schlachtberger, D. (2018) PyPSA: python for power system analysis. *J. Open Res. Software* 6(1). https://doi.org/10.5334/jors.188

Council Regulation (EC) 561/2006 of the European Parliament and of the Council of 15 March 2006 on the harmonisation of certain social legislation relating to road transport and amending Council Regulations (EEC) No 3821/85 and (EC) No 2135/98 and repealing Council Regulation (EEC) No 3820/85 (Text with EEA relevance), *Official Journal L* 102/1, arts. 6-7. http://data.europa.eu/eli/reg/2006/561/oj

DeCarolis, J.F. (2011). Using modeling to generate alternatives (MGA) to expand our thinking on energy futures. *Energy Econ.* 33(2), pp. 145-152. https://doi.org/10.1016/j.eneco.2010.05.002

Fioriti, D., Scarpelli, C., Pellergrino, L., Lutzemberger , G. & Micolano, E. (2023). Battery lifetime of electric vehicles by novel rainflow-counting algorithm with temperature and C-rate dynamics: Effects of fast charging, user habits, vehicle-to-grid and climate zones. *J. Energy Storage* 59, art. 106458. https://doi.org/10.1016/j.est.2022.106458

Fulton, L. & Burke, A. (2019) *Analysis of advanced battery-electric long haul trucks*. OmEV guest article, 2019-09-26. https://omev.se/2019/09/26/analysis-of-advanced-battery-electric-long-haul-trucks/ [2023-12-01]

Horni, A., Nagel, K. & Axhausen, K.W. (eds.) (2016). *The multi-agent transport simulation MATSim*. London: Ubiquity Press. http://dx.doi.org/10.5334/baw

Lai Jakobsson, J. (2023). *Energy in the Transportation System - A comparison of charging infrastructure scenarios*. Master thesis, Industrial Electrical Engineering and Automation, Lund University. https://lup.lub.lu.se/student-papers/search/publication/9140611

Loew, S., Anand, A. & Szabo A. (2021). Economic model predictive control of Li-ion battery cyclic aging via online rainflow-analysis. *Energy Storage* 3, e228. https://doi.org/10.1002/est2.228

ElFordon.se (2023). *Varuleveranser med Scanias ellastbil under sportlovsveckorna i Åre* (news article), 7 February. https://elfordon.se/varuleveranser-med-scanias-ellastbil-under-sportlovsveckorna-i-are/ [2023-12-01]

Nåbo, A., Nordin, L., Andersson, J., Berglund, M., Bhatti, H. J., Brunner, S., … & Wehner, J. (2023). *Regeringsuppdrag om elektrifieringen av transporter: rekommendationer för att underlätta datadelning och nyttiggörande av data för planering, utveckling och drift av laddinfrastruktur och affärsmodeller* (VTI rapport 1158). Retrieved from Statens väg- och transportforskningsinstitut website: https://urn.kb.se/resolve?urn=urn:nbn:se:vti:diva-19335

Ringkjøb, H.K., Haugan, P.M. & Solbrekke, I.M. (2018). A review of modelling tools for energy and electricity systems with large shares of variable renewables. *Renew. Sust. Energy Rev.* 96, pp. 440–459. https://doi.org/10.1016/j.rser.2018.08.002

Sudha Letha, S. & Bollen, M. (2021) *Impact of Electric Vehicle Charging on The Power Grid*. Luleå University of Technology, Sweden. https://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-83040

Loulou, R., Goldstein, G., Kanudia, A., Lettila, A. & Remme, U. (2016) *Documentation for the TIMES model*. Energy Technology Systems Analysis Programme (ETSAP). https://iea-etsap.org/docs/Documentation_for_the_TIMES_Model-Part-I_July-2016.pdf

Ulrich, L. (2021) How Is This A Good Idea?: EV Battery Swapping. *IEEE Spectrum*, 2021-05-13. https://spectrum.ieee.org/ev-battery-swapping-how-is-this-a-good-idea

Unterluggauer, T., Hipolito, F., Klyapovskiy, S. & Andersen, P.B. (2022). Impact of Electric Vehicle Charging Synchronization on the Urban Medium Voltage Power Distribution Network of Frederiksberg. *World Electric Vehicle Journal* 13(10) 182. https://doi.org/10.3390/wevj13100182

Yeh, S., Gil, J., Kyle, P., Kishimoto, P., Cazzola, P., Craglia, M., Edelenbosch, O., Fragkos, P., Fulton, L., Liao, Y., Martinez, L., McCollum, D.L., Miller, J., Pereira, R.H.M. & Teter, J. (2022). Improving future travel demand projections: a pathway with an open science interdisciplinary approach. *Prog. Energy* 4, 043002. https://doi.org/10.1088/2516-1083/ac86b5

# 11. Social sustainability perspectives on electrification and battery-swapping

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## 11.1. Summary & key insights

The ongoing shift to electrification of heavy trucks is changing the transport sector and presenting both companies and workers with both opportunities and risks. This chapter analyses perceptions about electrification in general, and battery-swapping specifically, understanding them through a lens of *socio-technical imaginaries*. Using interviews and focus groups with managers at haulier companies, researchers and experts involved in this feasibility study, and teachers and students at a high school program for truck drivers, the study explores how different principles of social sustainability in transportation may or may not be affected by electrification and battery-swapping technologies. The social sustainability principles included are 1) health, 2) influence, 3) competence, 4) impartiality, and 5) meaning making.

The results present complex and in-coherent imaginaries which are influenced by the positions held by the different interviewees. Specifically, the inclusion of both experts and non-experts in the interviews and focus groups also provide insight into how different actors relate to ongoing and future socio-technical transformations. The results thus highlight that there is no *single* imaginary about neither electrification nor battery-swapping, but *multiple* imaginar*ies.*

Incorporating workers' and users' imaginaries may assist in developing technological solutions and business models that are more easily adopted. Developing structures that encourage active involvement by workers and users would also address several of the social sustainability perspectives. The material and findings also point to that there are several social sustainability principles that may not be best addressed through the employment of electrification and battery-swapping technologies, for example gender equality and working conditions related to surveillance of workers.

A key recommendation from the chapter is to invite those affected by ongoing changes in economic and technological structures to also contribute to the creation of alternative imaginaries. This may open trajectories that make such transitions better adapted to their situation, thereby both democratising the transition within the industry and improving the likelihood of acceptance of it.

## 11.2. Introduction

This chapter contributes with an analysis of sociotechnical imaginaries about electrification and battery-swapping technologies for heavy trucks and their impacts on social sustainability. Understanding imaginations and expectations around the implementation of new technologies is of interests as they may help identifying both possibilities and risks associated with these.

The work has been conducted as the main output in a work package on equality, in the project "A feasibility study for upscaling of battery-swapping for heavy vehicles". Early in the project we identified both that equality, understood in Swedish policy as gender equality between men and women, was too narrow, but also that only discussing battery-swapping was too narrow a focus. Therefore, to allow for a better analysis, the focus was broadened both empirically and analytically. Empirically, the study focuses both on electrification of heavy trucks in general, but with specific attention to battery-swapping. Analytically, the study is concerned with social sustainability, which includes gender equality but also analyses other aspects, such as work environment, health, possibilities to influence decisions, and so on. The analytical focus will be described in further detail in section four.

The chapter is structured as follows: after the introduction the theoretical framework of socio-technical imaginaries is introduced. In section three, the material and methods employed is presented, after which the analytical framework of social sustainability perspectives in the transport sector is introduced. Section five provides a background discussion about social sustainability issues in the transport sector. Section six covers the main results from the interviews and focus groups, structured both around general perceptions about electrification and battery-swapping for heavy trucks and specific issues related to the five social sustainability principles. Lastly, in section seven, findings are discussed, and in section eight a concluding discussion and recommendations based on the study are presented.

The work in the work package has been carried out mainly by Jens Portinson Hylander, VTI, who has framed the study, conducted interviews and focus groups, analysis and writing text. Per Lindahl, Logistikia, has contributed with initial framing of the study and assisting in providing relevant interview contacts.

## 11.3. Sociotechnical imaginaries

*Sociotechnical imaginaries* (STI) is a concept used within the field of science and technology studies (STS). STS departs from the recognition that developments in science and technology are intrinsically bound together with social, political and cultural systems (Jasanoff, 2015). As a subfield within the STS literature, STI studies how visions about technological futures figure in and shape social action. With Jasanoff (2015, p. 4), STIs are defined as "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology."

In STS terminology STIs are performative, i.e., the fact that certain technologies are seen as desirable (or undesirable, for that matter) make them part and parcel of shaping present actions to attain the imagined future that can be bestowed upon a certain technology. As Jasanoff (2015, p. 12) state, from this point of view technologies "operate as performative scripts that combine values and interests, materializing and making tangible the invisible components of social imaginaries."

The reason for choosing to employ an STI perspective in the study is that the empirical material and the analysis of it rests on second-tier speculations about the future, i.e. speculating about social impacts from technology based on speculation about a certain sociotechnical system, i.e., battery-swapping systems for heavy duty vehicles. While there are certainly many challenges concerning speculating about the electrification of transport systems, it is a process that is – at least to some extent – already ongoing. The implementation of battery-swapping systems for heavy trucks in Sweden is, on the other hand, virtually non-existent at the moment. Therefore, one must speculate about the implementation of such a technical system, and after that speculate about the social impacts of such a system. Considering such an analytical challenge, adopting an STI perspective is fruitful, as this allows for those 'meta-speculations' becoming an enriching material in and of themselves, whether the imagined futures are realistic or reasonable at all.

The literature on STI originally developed around a focus on the national level, with examples ranging from diverging technological trajectories around nuclear (Jasanoff and Kim, 2009) and negative emissions (Christiansen and Carton, 2021) and energy transitions (Carvalho, Riquito and Ferreira, 2022), to COVID-19 (Leonel Da Silva and Au, 2022). However, in recent years more attention has been given also to differences in imaginaries within nations, providing a more nuanced perspective on the multiplicity of sociotechnical imaginaries. Compared to grand national narratives, Mutter (2019, p. 3) argues that local imaginaries can help uncover "multiple, competing idea and visions" within a nation, and thus shed light on imaginaries that "emerge from non-expert visions at a local level but that lack the political power to influence the national imaginary" (ibid.).

Given that battery-swapping is an emerging and not yet adopted as coherent national policy in Sweden, it is deemed fitting to explore STIs around battery-swapping on this level. Analysing the material from a STI perspective allows an exploration into whether battery-swapping is seen by different actors as something providing change or stability, and offering a future that transforms or stabilizes existing social, economic, and geographic patterns.

### 11.3.1. Sociotechnical imaginaries and transport systems

A lot of the STI literature has focused on large scale energy systems, with less attention to transport systems. In the last few years, however, several studies have been published where an STI perspective on the development of the transport system has been employed. In this section this research is briefly reviewed. The identification of literature was done using the Lund University LUBsearch engine, using the search term “sociotechnical imaginar*” AND (transport* OR mobilit*).

**Public transport.** There are a number of studies focusing on socio-technical imaginaries related to public transport, both the choice of transport technologies such as light rail (Olesen, 2020) and the choice of fossil free energy alternatives (Mutter, 2019; Mutter and Rohracher, 2022). In their study, Mutter and Rohracher (2022) highlight four dimensions that shape the differing imaginaries of biogas vs. electric vehicles in public transport in Sweden: spatial boundedness, temporality, coherence and contestation and sociomaterial relations, which figure differently in imaginaries of different energy solutions. Olesen (2020), on the other hand, highlights how technological solutions are embedded in different political and urban development trajectories: light rail as technological systems appeal to notions of technological advancement and globally attractiveness, which also ties into ideas of light rail as attracting investments and raising land values.

**Automation.** Several studies have analysed imaginaries of futures with automated vehicles. For example, Sovacool et al. (2020) have studied imaginaries of sustainable energy and mobility systems, in which automation and EVs figure as part of the mobility imaginaries. Mladenovic (2019), Olin & Mladenovic (2022) have analysed discourses around self-driving vehicles in Finland, and Mladenovic et al. (2020) have conducted a comparative analysis of policy discourses around self-driving vehicles in Finland, the UK and Germany. Haugland (2020) and Haugland and Skjösvold (2020) have also analysed the role of experimentation and pilots in the development of self-driving vehicles in Norway.

**Adoption of electric automobility**. Finally, a number of studies can be found focusing on the adoption of electric automobility, for example studies about the role of user imaginaries in the adoption of electric vehicles in Norway (Ryghaug and Toftaker, 2016), imaginaries about electric vehicles in Sweden (Mutter, 2021) and the content of companies’ visions of automated urban futures (Martin, 2021). Martin (2021) suggests that leading ‘regime actors’ deploy material that visualizes the future as a way of stabilizing existing automobility regimes. In an STI framing, the future is created through visualizations in the present, and can be more or less radical in comparison to existing transport systems. As we shall see, this is of relevance for this study as plug-in charging and battery-swapping can be thought of as providing different degrees of disruptiveness to the heavy trucking sector as it is currently configured.

Taken together, this literature points to the importance and weight assigned to electrification, automation, and technology in the various imaginaries of future (sustainable) transport systems. The research provides insights into how policy actors, citizens (or consumers as they are more often referred to by other actors (Mladenovic 2019), and companies partake in the creation of multiple and conflicting imaginaries of the future of transport. In line with the socio-technical imaginaries perspective, the literature also argues for the necessity of sensitizing analyses of future technologies to the social, political, and cultural contexts in which they are both imagined and realised. Although important in themselves, it is not enough to conduct analyses of market potentials or technical feasibility: the success (or failure) of technologies to break through or solve problems owes perhaps not so much to the inherent qualities of specific technologies, but equally to how they are adopted and put to use by individuals and collective actors driving or resisting change.

One thing of note is that there is little literature that exclusively addresses the heavy trucking industry. However, the socio-technical imaginaries perspective has been used in studies of the development of energy systems, smart cities, carbon neutral technologies, etc., which all have relations to and repercussion for the electrification of the transport system in general, as well as heavy trucks specifically (cf. Rudek, 2022). Another thing to note from this brief review of the STI literature on imagined future transport systems is that the literature seems to be dominated by a firstly European, and secondly Nordic perspectives. Norway, Sweden, and Finland all feature heavily in the studies, although examples from Germany, the UK., and the United States are also evident. What this situation owes to is unclear.

## 11.4. Material and methods

The study has been conducted employing a qualitative, interpretative approach. With a focus on the interrelation between the structural dimension of technological infrastructures and the subjective dimensions of agency, an interpretative approach to STI allow for probing “the nature of structure-agency relationships through inquiries into meaning making” (Jasanoff, 2015, p. 24).

The methods used in the study has been semi-structured interviews and focus groups, chosen for their suitability in exploring indiviudals’ perceptions and opinions about a specific topic (Wibeck, 2010; Kvale and Brinkmann, 2014). Seven interviews and two focus groups were conducted with a total of 19 persons, 5 women and 12 men, between May and November 2023. In the results section the interviewees and focus groups are denoted by an “I” or “FG” followed by a number. Wanting to explore the width of potential opinions around electrification and battery-swapping, we sought to interview a broad sample of people that work with or have a relation with the heavy trucking industry. We have interviewed employer interest groups, researchers, consultants, representatives from logistics companies, and teachers and students at truck driver education (see Table 19 for a description of the interviewees and focus groups).

*Table 19. Interviews and focus groups conducted in the project. Individuals working in or tied to the battery-swapping project in some capacity are denoted by (*).*

| **Interview / focus group** | **Organization** | **Role of interviewee(s)** | **Gender** |
|---|---|---|---|
| Interview 1 | Transport business organisation | Business developer | Female |
| Interview 2 | Research institute | Researcher* | Male |
| Interview 3 | University | Researcher* | Female |
| Interview 4 | Haulier company 1 | Manager, purchases and customer | Male |
| Interview 5 | Electric truck company | Consultant* | Male |
| Interview 6 | Haulier company 2 | Manager, logistics | Male |
| Interview 7 | Haulier company 3 | CEO | Male |
| Focus group 1 | High school | Five teachers | One female, four male |
| Focus group 2 | High school | Seven last-year students | Two female, five male |

Since battery-swapping for heavy trucks is a technology under development with no implementation in Sweden so far, we also interviewed researchers and experts enrolled in the project. This also brings an auto-reflective aspect to the interview study, highlighting that the project itself plays a role in shaping the sociotechnical imaginaries of battery-swapping technologies.

Focus groups were chosen as a method to engage teachers and students as it was deemed suitable to engage in a joint discussion about the topic of battery-swapping for teachers and students. Distinct from a research interview situation, the purpose of focus groups is to facilitate a discussion not only between the researcher and one or more interviewees, but also to stimulate interaction between the participating individuals. (Wibeck, 2010). The use of focus group methodology also more easily facilitates the formulation of a broader set of ideas (ibid.), which was deemed suitable, as teachers' and students' daily activities are further removed from discussions about technology development than those of managers at logistics companies or researchers engaged in the battery-swapping feasibility study, and therefore may not have as readily formulated ideas and concepts related to battery-swapping.

## 11.5. Analytical framework: social sustainability and the trucking industry in Sweden

### 11.5.1. Social sustainability

As mentioned in the introduction, the study was broadened from only focusing on (gender) equality aspects to include a wider perspective of social sustainability. Together with economic and ecological sustainability, social sustainability is one of the three pillars included in the now classical definition of sustainable development by the Brundtland commission (World Commission on Environment and Development, 1987). Compared to the other two, social sustainability for long remained underemphasised and lacking in definitional clarity. Over the last decade, however, more attention has been given to social sustainability in both policy and research literature, not least through the adoption of Agenda 2030 sustainable development goals (De Fine Licht and Folland, 2019). Several of the Agenda 2030 goals are related to social sustainability, e.g., Gender equality (SDG 5), Good health and well-being (SDG 3), Decent work and economic growth (SDG 8), Reduced inequalities (SDG 10), Sustainable cities and communities (SDG 11), and Responsible consumption and production (SDG 12) (United Nations, 2023).

The chapter draws inspiration from an exploration of social sustainability in relation to electrified roads by Balkmar et al. (2022). In their study, they draw upon a definition of social sustainability by Missimer et al. (2017, p. 44), in which they state that "in a socially sustainable society, people are not subject to structural obstacles to: (1) health, (2) influence, (3) competence, (4) impartiality and (5) meaning-making." These social sustainability principles subsume various other aspects of socially sustainable systems, such as diversity, trust, learning, and so forth. Missimer et al. (2017) describe the principles in more detail:

*Health* means "that people are not exposed to social conditions that systematically undermine their possibilities to avoid injury and illness; physically, mentally or emotionally, e.g., dangerous working conditions or insufficient wages" (ibid., p. 47)

*Influence* refers to that people are not systematically hindered from participating in shaping the social systems they are part of, e.g., by suppression of free speech or neglect of opinions (ibid.).

*Competence* means that people are not systematically hindered from learning and developing competence individually and together, e.g., by obstacles for education or insufficient possibilities for personal development. (Missimer et al. 2017, p. 47)

*Impartiality* means that people are not systematically exposed to partial treatment, e.g., by discrimination or unfair selection to job positions (ibid.).

*Meaning making* means that people are not systematically hindered from creating individual meaning and co-creating common meaning, e.g., by suppression of cultural expression or obstacles to cocreation of purposeful conditions (ibid.).

Importantly, these principles are expressed in the *negative*, i.e. that a socially sustainable society or sub-system of society does not impose structurally determined obstacles to either of those aspects. As the authors expresses it:

The term ‘no structural obstacles’ in each of the principle is key to understanding the approach. The focus is intentionally not on, e.g., health or influence per se, but about whether there are structural obstacles in the way of achieving them. There can still be sick and un-influential people in a very solid and vital social system for as long as their misery is not being caused by structural obstacles. (Missimer, Robèrt and Broman, 2017, p. 49)

To exemplify with relevance for the transport sector, in a socially sustainable transport system truck drivers may still be subject to accidents or ill health, but such conditions must not be caused by *structural* deficiencies, limitations or oppression.

### 11.5.2. Analysing social sustainability in the heavy trucking industry

The principles described above are general; they can be applied to any context of relevance. To sensitize the framework for the transport sector, and heavy trucking industry specifically, I draw on Balkmar et al. (2022), who have translated these general principles for social sustainability to the transport sector by applying them to the case of electric roads in Sweden. This translation implies identifying what each of the overarching principles can mean when applied to the heavy trucking industry. For example, for the category of health, Balkmar et al. identify *safety and security*, *noise and emissions*, and *universal design in vehicles and facilities* as important aspects to highlight for electric roads; all of which can readily be applied also to electrified vehicles and battery-swapping systems. See Table 20 for a description of the five social sustainability principles applied to the transport sector.

*Table 20. The five principles of social sustainability, based on Balkmar et al. (2022). The items described in the “areas of relevance” are aspects that are used in the analysis. Note that all areas are not necessarily applicable or will be addressed in the material.*

| **Principle** | **1. Health** | **2. Influence** | **3. Competence** | **4. Impartiality** | **5. Meaning-making** |
|---|---|---|---|---|---|
| **Overarching question** | How can well-being be promoted in organisations and among individuals? | How can people´s influence and participation in decision-making be promoted? | How can people´s need for education, training, and learning be promoted? | How can non-discrimination and equality be promoted in society and organisations? | How can people´s sense of meaning-making and concreation be promoted? |
| **Areas of relevance** | 1.1 Working conditions<br>1.2 Safety and security<br>1.3 Exposure to noise and emissions<br>1.4 Universal design of instruments and machinery | 2.1 User influence<br>2.2 Represenation<br>2.3 Inclusion of people´s quality of life in assessment and evaluations | 3.1 Promoting broad recruitment<br>3.2 Securing equal access to competence development that makes new technologies available and usable within organizations and wider society. | 4.1 Non-discrimination<br>4.2 Equal rights to work, education and services | 5.1 Inclusive innovation<br>5.2 Promoting the inclusion of new ideas from all<br>5.3 Awareness of exclusionary practice and norms<br>5.4 Participation and diversity in decision-making<br>5.5 Cultural heritage and promotion of social values |

## 11.6. Social sustainability issues in the transport sector

### 11.6.1. Gender aspects in the transport sector

The trucking industry is a historically male dominated sector. Truck drivers has been dubbed the ‘last cowboys’ of the US (Layne et al. 2009); also, in Sweden there are deep historical and cultural connections to the lone and freestanding carters from the agrarian society (Nehls 1993). Deeply rooted conceptions and structures made the trucking job a male-coded occupation. In an ethnographic study of long-distance truckers, Eddy Nehls (1993, 54) points to a self-perception of low-class status and an underdog position as something that strengthens the group's outward boundaries and partly may explain the poor diversity and gender equality in the sector. Understanding gender-inequality in the transport sector theoretically, Andersson et al. (REF 2022) have proposed using the concept of *firewalls* (as opposed to the more common term *glass ceilings*) to conceptualize gendered organizational norms. The notion of firewalls speaks to that access to certain spaces or areas are granted only if you can supply the right 'code', understood here as conforming to specific norms. If a certain person does not comply with these norms, they are not granted access.

Another way of understanding the barriers to gender equality in the transport workforce is understanding the structural mismatch between supply and demand factors in the sector (Scott and Davis-Sramek, 2023). *Supply* factors concern the situation and preferences among potential employees, including how reproductive work is divided between genders and how this affects availability and willingness to take a certain job. Scott and Davis-Sramek point to the bigger role women take in household labour and that this often leads to women taking up employment in jobs that allow for more flexibility, working from home, and shorter commuting distances. Specifically for the trucking industry Scott and Davis-Sramek (2023) cite studies that point to women valuing both time at home and predictable working hours and upholding a 'work life balance' more than men. Demand factors are derived from the situation and preferences of employers. It is well established that corporate culture and structures affect the gender division in the transport sector (Stave, Levin and Henriksson, 2023). This can be a question both of that truck companies disfavour employees who display preferences that are gendered as female, and, echoing the concept of firewalls mentioned above, that in businesses traditionally dominated by men female gendered persons may find it harder to gain access to some parts of the organization, leading to difficulties in women establishing and attaining more attractive positions.

While the trucking industry has historically been relatively 'firewall proof' in terms of granting access to women, in recent years, however, a need to secure competence in the sector has contributed to a heightened awareness of the need to recruit and retain women in the workforce, in Sweden as well as abroad (Turnbull, 2013; TYA, 2014; Godfrey and Bertini, 2019; Ng and Acker, 2020). In the US there are estimations of the female workforce among truck drivers range from an optimistic 12 % to more modest 3,2% (Scott & Davis-Sramek 2023). However, even assuming the lower number, the amount of female truck drivers has risen by 23 % between 2010 and 2019 (ibid.).

In Sweden, the recruitment of women to the transport industry has been forefronted in the last decade. *TYA*, the Swedish Occupation and Work Environment board, released a report in 2014 discussing the conditions for joining, staying in, and leaving the truck logistics sector. They identify five areas of importance: the truck sector, technology, work roles, recruitment, and attitudes. The transport sector was considered by respondents as a sector that too easily becomes a transitory occupation, where women only stay briefly before moving on to other sectors. The work environment was also seen as a barrier, where women have to act uncomfortable by pointing out deficiencies in the organization. Assistive technologies that make work easier (for both women and men) were seen as important for the retainment of women, which was also seen as an important factor for the relative increase of women in the sector. The women in the study also saw that they, more often than men, entered administrative work, which without the necessary qualifications may close career paths for women. The report states that "many [women] feel that they are stuck in their gender roles" (TYA, 2014, p. 7). Furthermore, better gender-neutral recruitment in the form of recruitments adverts were seen as a potential for improving the gender balance in the sector. Lastly, a work culture with jargon that diminishes or excludes women was identified as a barrier to keeping women in the workforce.

Drawing on such experiences, and in light of the great need for broadening recruitment in the transport, the business organization *Transportföretagen* has launched a series on improving gender perspectives in the sector (Transportföretagen, 2023). Projects focusing on recruitment and retention of women in the maritime transport sector have also been carried out, where similar structures and barriers have been identified as across the transport sector in general (see e.g., REDO, 2021).

### 11.6.2. Gender, transport, and electrification

Although the literature on equality and electrification of the transport sector is sparse, there are insights to be drawn from previous research. To do so we must venture beyond the truck industry and look at electrification and transport in general.

In a study of gender and electrified transport in the Nordic countries, Sovacool et al. (2019) identify four general aspects related to gender and transport: 1) a gender divide in travel patterns, i.e., that women in general both travel less and travel shorter distances than men; 2) feminized values about and towards transport; 3) gender-based preferences, which indicate that women value and prefer sustainable and safe travel options more than men, and; 4) gender norms, identities and roles, which affect which attributes are, generally, preferred by women and men, respectively. Based on surveys, interviews and focus groups the researchers show how use of and attitudes toward cars generally, and electric cars specifically, are coded in accordance with existing norms about males and females. However, an ongoing and substantial shift in the Nordic transport systems are also both affected by and affecting existing norms and practices (p. 201).

Related to specific technologies, a study by Adu-Gyamfi et al. (2022) surveyed attitudes and intentions regarding battery-swapping technology among Chinese households. The study suggests that female respondents show a greater inclination among female respondents to adopt battery-swapping than among men. The interpretation induced by the researchers is that women to a higher degree prefer the simplicity that battery-swapping affords compared to plug-in charging technologies.

### 11.6.3. Safety and accidents in the transport industry

Another statistic where the transport industry stands out is workplace accidents. While not the most accident-prone sector in absolute numbers, in terms of accidents relative to the number of employees in the sector transport is overrepresented with the most accidents that lead to sick leave (including deaths), with 16,7 accidents per 1000 employees in 2022 compared to a mean of 6,9 accidents per 1000 persons employed across all sectors in Sweden (Arbetsmiljöverket, 2023, p. 6). Accidents involving heavy trucks incur larger consequences on the degree of injury and are relatively more often involved in serious accidents (WSP, 2019). Of the 325 persons who were killed in road accidents in 2017, 70 fatalities are attributed to heavy trucks (ibid.)

### 11.6.4. Summarizing the section

From the reviewed literature we can summarize that there are several social sustainability issues in the transport sector. Connecting it to the theory of social sustainability by Missimer et al. (2017), we can identify structural obstacles both to gender equality and health and safety aspects. We will return to these in the discussion sections.

## 11.7. Results

In this section the main findings from the interviews and focus groups are presented. The section begins with results regarding general perceptions about electrification and battery-swapping in the heavy trucking industry among the respondents, to then move on to results related to the five principles of social sustainability.

### 11.7.1. General perceptions about electrification and battery-swapping

#### Attitudes to electrification

While this study is not primarily about electrification in general, it is useful to present some of the attitudes to electrification of heavy trucks, to set the stage for a discussion about the relative merits and drawbacks of battery-swapping to conventional plug-in charging. The empirical material shows quite well the spectrum of attitudes to electrification, from an optimistic future-oriented embracing of electrification to a sceptical rejection of it.

One of the logistics companies has fully embraced electrification and invested in electrified trucks and even its own charging infrastructure and renewable energy production, with the ambition to be entirely energy-independent by 2030 (I7). A manager at a second logistics company says that “I am very optimistic [about electrification]. If I weren’t, I wouldn’t have believed in the future, because there must be some kind of change for our whole world. We must be part of it and drive this together with companies and we need to do it now, as fast as possible.” (I6) The representative from the third logistics company represents a more sceptical attitude, focusing on the time it takes to transition, the high costs associated with it, lack of public support, lack of electricity in the grid and a sense of punishment of conventional trucks. As he states, “they have just decided that this is the way to go.” (I4) And while both representatives from the other logistics companies also mentioned high costs of purchasing vehicles as a main barrier, there was a difference in entering the discussion of electrification of one filled with problems or opportunities.

A sceptical attitude toward electrification is even more present in the focus groups conducted with teachers and students, and especially the latter. “I don’t believe in that stuff” says one of the students, receiving confirmation from fellow students. “Is it even environmentally friendly to produce all those batteries?” asks a third. “And they’re produced under poor conditions” someone adds. A concern for lack of charging infrastructure, electricity in the grid and operating conditions of electric trucks is also expressed: “how is the electricity going to be enough? We barely have enough to heat homes now,” says one student. “I’ve ridden an electric truck, as soon as you use the machine equipment the battery drops really quickly”. A third person relates to his friend who drives a truck between southern and northern Sweden and states that “he would never be able to drive an electric truck, it wouldn’t work in winter. Stopping say ten times on the way up just to charge. And the more batteries are strained by the load, the more beating they take.” The teacher group also focus more on the problems with electrification than their opportunities: “the reach is poor”; “batteries are heavy, we can load less”; “there is a lack of electricity”; “it will take time”, are statements that pervade the discussion.

Among the researchers and consultant involved in the feasibility study there is more optimism, and the discussions revolve more around the opportunities afforded both by electrification of heavy trucks and battery-swapping as a complement. “I can get excited about battery-swapping as a technology from a purely technical perspective, but that’s not what’s important here, but it’s what business model it comes with,” says one researcher (I2).

One aspect that most persons we talked to agree on was that electrification can, and already does work, in many urban areas. Two of the logistics companies are already running several electric trucks in urban logistics and plan on expanding. The manager at the third company states that “we’re approaching electrification because it’s popular, but it’s extremely hard to execute.” (I4) Both teachers and students also highlight the possibility of electrification of logistics in urban areas, especially for trucks that run “A to B” services, where one can charge batteries while loading or unloading at each station.

#### Knowledge and attitudes toward battery-swapping

A first thing to note is that while electrification is something that every interviewee has a conception and considerations about, there is much less consideration of battery-swapping among the interviewees, except for experts and researchers working in the battery-swapping project. This can reasonably be explained by the lack of concrete policies and pilots for battery-swapping in Sweden, which means that persons working within logistics companies or teachers and students in schools so far has had little need to take a stance on the issue. Conversely, the researchers and consultants engaged in the battery-swapping feasibility study are more knowledgeable and have more developed conceptions of battery-swapping. Some persons outside the research project were familiar with the new battery-swapping for passenger cars, NIO, that currently has eight battery-swapping stations in Sweden.

With regards to battery-swapping for heavy trucks, we will go into more detail about different pros and cons perceived by the participants. But in general, there is a lack of clear opinions about the role of battery-swapping in a future zero-carbon transport system. As one person from a logistics company said, “the idea is splendid, but I don’t think that’s what we’re going to see in 5 to 10 years.” (I4). Asking the same person whether battery-swapping is something that exists in the company’s planning, he said “No. And there’s one simple reason for that: it’s great in theory, but how many private cars do you see in Sweden with battery-swapping?” (I4)

A consultant involved in the feasibility study states that “I don’t believe in battery-swapping for city trucks, those that drive in urban environments and are often home in the evening or have proximity to the home base. As opposed to those that drive long-haul” (I5). Likewise, the CEO at the company that has come the furthest with electrification states that for their city logistics, battery-swapping is not a relevant alternative, as their fixed battery pack are enough to conduct urban logistics operations. However, as you go further away from the urban centres, battery-swapping technologies becomes more relevant to their company (I7.)

### 11.7.2. Social sustainability principles

#### Health

**Working conditions**

An important aspect of health is the working conditions for drivers and other staff. The most common concern that arises in discussions is the *ability and necessity to take breaks* during driving. This was not perceived as a big problem in urban or short-distance logistics where routes are planned with many stops and little need for on-route charging. For long-distance driving it was however seen as a major issue by many. Many respondents brought up the regulations regarding driving times and rest periods that act as framework conditions for when and how hauling can be done. One student complains that “there are hardly any places in Sweden where you can park to take breaks or mandatory breaks in the trucking industry. Which is a matter of life and death because you could lose your job [if you don’t take mandatory breaks].” A manager sees the possibility that you reach a popular charging stop but “there’s no charging pole for me, so then I have to stay in Ödeshög much longer, maybe the double or triple time, which makes that I won’t be able to reach Stockholm within the regulations” (I4). Discussing with teachers, they also think drivers will become more steered by the availability of charging stations, for example that drivers must plan nightly rest places according to where charging stations are. The availability of charging station relates also to health aspects on the road: “Perhaps fast-food chains will invest in charging stations, then you can only eat at McDonalds,” muses one teacher.

In this regard, the notion of battery-swapping is welcomed by most as a more positive alternative to plug-in charging. Electrification is good “if you can make it work like a petrol car … If it can be fully charged in ten minutes so you can drive like a normal car.” (student, FG2). One researcher posits that other driving times and rest periods may develop depending on how charging takes places (I3). However, the ‘charging freedom’ that battery-swapping promises is not self-evident. One manager of a company states that “you need to know that [when you arrive] you can swap a battery there and not have to stand in line for two hours" (I7). As one student says, "there's thing whole thing about supply. It must be developed first" (FG2).

### Safety and security

Safety and security are not a major topic that was brought up in the interviews. One teacher express concern about the potential effects of increased magnetic fields when large batteries are involved, citing effects on train staff (FG1). If this is a common concern, battery-swapping could potentially offset some of it, as batteries would not have to be as big in a battery-swapping system. One researcher also reflected on the possibility of battery theft and robberies with a battery-swapping system (I3). If the batteries are not fixed the same way as they are in plug-in solutions, perhaps there will be opportunities to assault drivers and steal their batteries. Safety situations related to potential fire in battery packs were also mentioned by some interviewees.

Lastly, the question of speed is brought up by one logistics manager, where electrification is seen as a potential remedy to speeding issues: "It's not unusual that you drive along the E6 […] and you can be passed by trucks there and they keep a speed that's not ok. But if you drive electric you can see clearly that you must keep the speed down a bit, to save battery life. So, there should be a positive effect regarding the speed on roads as well." (I6)

### Exposure to noise and emissions

Regarding positive health aspects from electrification, two items stand out in the interviews: less noise and less vibrations:

> *"Driving an electric car is fantastic, it is quiet, it's powerful, there are only upsides to it" (I4)*
>
> *"It's quieter, less vibrations" (I4)*
>
> *"Guys and girls driving electric trucks are less tired. You have no vibrations in an electric truck, the way you do in a diesel truck, they always move and shake" (I5)*
>
> *"And then you can think that in society at large maybe it will affect noise pollution in urban environments. … And it's not just noise pollution but also particle emissions and those aspects" (I3)*
>
> *"I only think that the driver's work environment is better. It's quieter if I say so." (I6)*
>
> *It is also "more humane to society at large if you don't have as many cars driving around. There's less noise in the urban environment." (I6)*
>
> *"The work environment is a hundred times better, fantastic really. All drivers love it, I have never met anyone who has jumped into an electric truck that want go back to a diesel truck, so it's enormously positive" (I7).*
>
> *"it's very quiet. I thought it was creepy in the beginning, because it didn't make a sound. It was really, we left and backed out of the charging station and all you can hear is a tiny whining. It was really gross. But then of course the quiet is probably great in the long run, because there's a lot of noise in some trucks as well. So, it's probably very good for the work environment" (S).*
>
> *"I think that the driver booth environment is a little better. It's quieter" (I5).*

The quotes above show a broad agreement that is shared between all categories of interviewees (researchers, consultants, company managers, teachers, and students) about an imaginary of electrified transport as being better for health, both of people working in and people being exposed to heavy trucks in their environment.

**Universal design**

The question of universal design in relation to electric trucks was mentioned in a few interviews. One manager at a company argues that "they think more about the driver's booth environment in the new offers on the market. I think that it will enhance and make the occupation more attractive" (I6).

"There is a work environment aspect that with electric traction you can have a different design on a car, it's exciting that you remove the engine that's in the way really" (I6).

### Influence

The principle of influence covers aspects of i) user influence, ii) representation and iii) inclusion of people's quality of life in assessment and evaluation. The main aspect address in the interviews relate to the first, user influence but also touches upon inclusion of people's quality of life. Here there is a potential difference between plug-in and battery-swapping.

Related to the possibility of influencing decision-making, the *heightened need for planning* when driving electric vehicles comes up in most discussions. Electrification of trucks and associated infrastructure is considered by teachers and students as limiting the freedom of truck drivers (FG1, FG2). They will become more tied to where plug-in stations are located and not as free in their choice as individuals. Electrification is perceived (or experienced) by most participants as something that requires more planning. As one company manager puts it "Driving electric vehicles requires a bit more planning than other vehicles. Because you have a limited amount [of energy] as it is right now, so you must stick to a plan for the energy to go all the way" (I6).

And if breaks need to be taken while charging your truck, the location of charging stations determines where breaks can be taken. Thus, the level of autonomy of drivers is seen as being negatively affected by electrified trucks. Both teachers and students are concerned about the level of planning and what this does to the autonomy of drivers. On teacher says that he thinks that drivers will become even more controlled, there will be "more surveillance" as one person puts it (FG1).

Battery-swapping may to some extent be a remedy to this, as it would not necessarily tie drivers down as much, if one could swap a battery at one place and then continue to another location for lunch, for example. In this respect, battery-swapping is perceived by most to promise more freedom:

> *"If you can make it work like a petrol car it can become pretty good. If it is fully charged in ten minutes so you can drive it like a normal car." (Student, FG2)*
>
> *"The principle is good," says one teacher. "It reduces the stop time compared to plug-in charging." (teacher, FG1)*
>
> *"If I can roll in to Ödeshög, do a battery swap in ten minutes, have my lunch, and then continue toward Stockholm, that's fantastic. But we're a long way from that." (I4)*
>
> *"He [the driver] gets more freedom in a battery-swapping system. He can plan better himself than if you have to charge, because then you need a route plan for that, clearly." (I5)*

However, several interviewees argue that the controlling of drivers is not something that comes with electrification but is part of a larger structural development of the trucking industry but also society at large:

*"I think that drivers have had to accept the lay of the land. They don't think much about the drivers when they make these systems… if you're part of a larger logistics company, then you're surveilled too, I'm thinking about the map at the control hub. So, they see you if you take that extra round to stop by mom and have a coffee. It takes 2 extra minutes but then the boss is sitting there watching you, so those opportunities have already been vanquished" I3*

*"If you think about eco-driving, then the companies were competing around fuel statistics and who's best at driving and so on. And it could be the same trend starting here, who's killing their battery the fastest…" I3*

*"But unfortunately, that's how society is built today. There's a lot of pressure on delivery times … and you can follow a car when you order things. As a customer you can follow the car and know when he's driving and exactly when he'll show up. We also have those systems. … In the best of worlds, it wouldn't be that way, and you could drive the way you want. … It's the market and us people who demand that kind of delivery." I6*

The question what markets and customers can accept is of relevance to electrification in general: "if you just get the end customer to accept that there is an added cost that quite much higher, then there's no problem. If everyone agrees that we'll electrify and it will take longer time to drive this route or that the workday will require longer breaks, I see no problem at all." (I4) Thus, if there was to be a shift in mindset away from cheap and instant delivery at all levels of the chain, electrification would be a more feasible option.

### Competence

This section covers three aspects: i) promoting broad recruitment; 2) gender equality, and 3) new competence needs.

**Promoting broad recruitment**

One aspect of competence is the promotion of broad recruitment. This entails two aspects, both whether electrification and battery-swapping will attract more people overall to the business, and specifically whether electrification and battery-swapping will attract more women to the business.

The overall sentiment in the interviews are that electrification and battery-swapping will not make a deep impact on the attractiveness of truck driving. While one logistics manager thinks that "It could be attractive, definitely. That you know you will be allowed to drive an electric truck here and you've tried it before. It could even be that you promote [electric trucks] in an advert" (I7), another manager argues that "Maybe there are a few [needles] in the haystack, there are drivers who dream of driving an electric truck … but that it would attract people from other sectors to this industry, I find that hard to see" (I4).

Teachers however didn't think that electrification would change anything substantially in terms of recruitment. More important has been e.g. the introduction of technical assistance with loading/unloading and so forth, which is already in place. Turning to the students, electric vehicles is not something that seems to attract them to the sector; in fact, the opposite seems to be the case. Asking whether they think they will use electric trucks in 25 years, one student says, "I'm hoping for diesel", and another states that "I will refuse anything but diesel". A third student who wants to drive a crane truck thinks that it will "surely be diesel". The prospect of electric vehicles seems more like a resignation to the fact of the evolution of the sector than something exciting or promising (FG2).

**Electrification and battery-swapping as a route to gender equality**

Battery-swapping was not considered by anyone as a definitive barrier to people of different genders being attracted to (or repelled from) the trucking industry. One researcher thought that "maybe it can attract both more women and other parts of the labour force if it is perceived as 'now I'm working with something clean and not as environmentally damaging" (I2) Another researcher however ponders that "I don't think that the refuelling being cleaner would attract a specific group … there are probably many traditional in the business who want it to be a little dirty" (I3). The romantic view of diesel trucks among the students may speak to this latter point.

Other comments reiterate similar opinions: "I think that if I as a driver come, guy or girl is whatever, there's no huge difference between if you swap a battery or if you charge it, from a working point of view." (I5) "I wouldn't say it has to do with gender equality, but I think that it can help because people think [electric trucks] are nice to drive, so you go for that. But nothing to do with gender equality" (I7).

If anything is considered to promote better gender division in the labour force, it is two different aspects: a *gender inclusive work environment,* and the impact of *role models*. One person working with gender issues in the transport sector claims that simple "hygiene factors" are hugely important: "say that a girl comes to a workplace and [people are] like 'oh, so great that you're here, we're happy to have you'. And she's the only girl on site and asks where she should change clothes. [they answer] 'but we don't have any dressing rooms for women, because we have no women here. So, you can take the accessible toilet as your dressing room'. How welcomed do you feel by that?" (I1)

With regards to role models, it was noteworthy that, independent of each other, several interviewees (I5, I6, FG1) cited the impact of trucking television shows in which female truck drivers figure on high school girls being choosing to become truck drivers. This speaks to the function role models that girls can identify with in creating and promoting desires and ideals about a future work life. However, while the teachers also acknowledge the impact of such television shows for both boys and girls coming into truck driver education, they also mused that the students were likely in for an awakening when they enter working life: "the students watch these tv shows and think that's what reality is like. They're going to drive log trucks, but after six months they realize it's not that glamorous." (Teacher, FG1)

**New competence needs**

It is expected that there will be a need for competence development, both by drivers but also auxiliary services – mechanics, charging stations, teachers, etc. One aspect that is mentioned by several interviewees is that the driver's relation to their engines will become simplified with electrification: "On an electric car you're not supposed to touch anything because it's high voltage cables, you're not supposed to do anything. So maybe there's a positive change from that, that a driver drives the truck, that it, and the competence will be more about loading, unloading, driving the car correctly. Maybe more like being a pilot." (I4) "You can't tinker, and you don't have to tinker. There are few moving part in an electric engine" (I5).

However, if the competence concerning engines is lowered for drivers, then car mechanics need new and more competence in handling electric engines instead. One researcher ponders that the development of battery-swappingcould lead to the development of a whole new sector, 'swap operators' (I2). The electric car company NIO has taken a first mover position on this for passenger cars, whether they or some other actor will develop swapping stations for heavy trucks remains to be seen. Another researcher points to experiences from plug-in charging and the need for competence development to integrate electric trucks in operations, including improved computer and digital skills for booking battery charging or swapping (I3). The ongoing electrification thus co-evolves with an ever-increasing digitalisation of society in general as well as the transport industry.

In general, the need for improved skills in *planning routes and trips*, among drivers as well as logistics managers and other office staff is widely recognized by the interviewees.

> *[there's a need for competence in] planning before, how to charge, where charging stations are, how to plan the shifts. Can the car run multiple shifts, can you stop and charge overnight, can you stop on the way?" (Teacher, FG1)*

> *"You would need to plan. It's not the same thing, you can make it on a full diesel tank for a few days. With an electric truck you must plan your stops." (Student, FG2)*

> *"You need to know where all the charging stations are and how much time it takes to charge at certain stations, so there's a lot of that. This competence doesn't exist today in the way it will be needed going forward." (I6)*

And while several interviewees sees that the need for planning may be reduced in a future system with extensive battery-swapping opportunities, it seems that also in a battery-swapping future a different planning competence will be needed.

### Impartiality

#### Non-discrimination

Regarding the question on non-discrimination, the topic of an inclusive work environment comes up again. The need to provide facilities that make workplaces more accessible, and thereby promote non-discrimination toward women, is of relevance. Another aspect mentioned by the interviewee working at the transport industry's business association is the need for non-discriminatory leadership. "If there's a lot of men the jargon can become quite rough, sexist and so on, and that has to go" (I1). A solution that the person sees is the inclusion of women: "but if two or three women enter, they can stand up to the men in a way, and it becomes more shameful to have that [attitude]. … There must be more women to change workplaces, or a clear leadership that is about not accepting these jargons that exist in the workplace" (I1). Here a potential problem arises, because if more women in a workplace are required to change the workplace culture, but that current workplace cultures exclude women, it may demand a lot of those women who enter to change the culture; both in terms of ability to stand up to the jargon, and the labour required to make such cultural changes. This actualizes the question if it is the women's responsibility to change men's behaviour at a workplace and in society?

#### Equal rights to work, education and services

Sorted under this item are spatial and distributional dimensions of the effects of electrification and battery-swapping. The motivation for this is that, during interviews, the topic of spatial distribution of charging stations and battery-swapping stations came up frequently. The interviews reflect a concern that the electrification of the trucking sector will lead to a spatial concentration of accessibility and services:

> *"You will become much more tied to the large infrastructure corridors with electrification. The towns along those routes will maybe flourish. They build the corridors along the power grid and there are surely … overlaps. Before, with the diesel car, it was all of Sweden." I3*

> *"Are we going to spread battery-charging to northern Småland and Östergötland? … You can't afford to leave the E4 too long to go charging." (I4)*

*A driver will think ”no, I’ll only stick to the E4, well everybody wants to do that. Nobody wants to go over Småland just to charge. So, i think it will bring a whole lot of problems.” (I4)*

*”Sure, there’s more acceptance that it takes longer to receive a pair of shoes bought online if you live in the inner parts of Norrland than if you live in central Stockholm, but … we’re going to have to serve all of Sweden even though we run on electricity. And the problem with electric cars is that they will be concentrated to the large cities, so there it will be a problem getting enough power.” I4*

With respect to geographical accessibility for electrified trucks, battery-swapping is considered by some as promising a remedy to such tendencies of concentration. If super-fast battery charging is the way to go along the heavily trafficked corridors, other areas can experience a “darkness” as one interviewee states. “And that where battery-swapping comes in as a smarter option. Instead of putting charging poles everywhere you can have depots, it will be like refuelling [a petrol car] in another way” (I5). Battery-swapping would even be an option for temporary sites, according to the same person: “If there’s a huge construction site, you could have portable swap stations. Or if you have logging in the forest, you could swap trucks and tractors” (I5).

However, the promise of spatially evenness of battery charging is also met with scepticism by some: “It’ll be the big cities that gets it to begin with. Which company would want a charging station in Arjeplog [northern Sweden] where two batteries are swapped each day? So, there’s no profitability… the companies will invest where there are the most trucks, and that’s between the big cities” (Teacher, FG1).

### Meaning making

For this principle there are less direct references in the interviews. Some items already mentioned can be repeated here, for example:

- The potential for innovation around electrification and battery-swapping could allow for inclusion of drivers’ perspectives in the design and layout of trucks (I5, I6).
- The inclusion of more women in the workforce could help both promoting inclusion of new or other ideas from all and an increased awareness of exclusionary practices and norms, and participation and diversity in decision-making (I1).
- The development and roll-out of electrification and battery-swapping presents a challenge to existing cultures and social values in the trucking industry, as exemplified primarily by teachers and students but also one of the managers. This relates especially to the way that long-distance hauling will be affected by electrification, but also to the status of truck drivers in society.

## 11.8. Findings

In this section the findings will be discussed before some recommendations for the continued developments in the sector are presented. First, some general reflections on the findings are presented before each social sustainability principle is discussed in turn. One thing to be aware of is that the results and analysis are based on discussions with a limited number of people. Hence, the analysis does not purport to be a representation of general attitudes toward or imaginaries of a future with plug-in or battery-swapping trucks. On the other hand, statements in interviews and focus group talk stem from the experiences of people involved in the sector under study and they thus represent beliefs, ideas and perspectives that exist within this sector, which are characterised by the ongoing technology development.

### 11.8.1. General findings

Regarding the perceptions of people who work, or will work, with truck hauling, it seems that there is a difference between those who have direct experience of electric trucks and those who don't. Persons who have tried or are actively working with electrification express more positive views. It is for example clear that the two managers of companies that have already electrified parts of their fleet are much more optimistic about electrification in general than the manager of the third company, and the difference is even greater between them and the high school teachers and students.

Coupled to the previous point, there seems to be a difference in how the respondents think and talk about electrification. The people involved in the feasibility study – researchers as well as consultant – present ideas and reflection at the level of a systems perspective and generally talk about a future where battery-swapping is in place. Managers, students, and teachers – i.e. people closer to the actual business of truck driving – talk more about the near term and express more concerns about the effects on existing conditions and the problems associated with the transition of the industry.

### 11.8.2. Reflections on the principles of social sustainability

Below, each principle of social sustainability is discussed. The main findings are also summarised in Table 21.

**Health**. Electrification and battery-swapping will likely create better working conditions in terms of reduction of noise and emission pollution, both for drivers and local environments. However, the possibility for drivers to control their working conditions, including taking breaks, risks being diminished by electrification – at last in the initial phases of system deployment. Taking drivers' concerns and opinions into account is important in the future development of the system.

**Influence.** Under this principle, the question of control over working conditions is raised again. The greater need for planning that comes with electrification is a potential barrier to acceptance by drivers. Battery-swapping can alleviate some of these effects, but it requires that it is developed in conjunction with drivers' and other persons working in the sector.

**Competence**. It is clear that the roll-out of electrification will require new competences, some of which are already being developed among companies lying at the front of development. Specifically, competence to plan routes in accordance with the need and availability of charging and/or swapping stations needs to be raised, both among drivers and other staff in the sector. Regarding the question of gender equality and the promotion of broad recruitment, interview responses show that few persons think that electrification in and of itself – whether plug-in charging or battery-swapping – will provide a more gender-equal sector. Some respondents ponder the possibility that a less 'dirty' job would attract more people, including women, to the sector. However, such reasoning could as much reflect those persons' perceptions about differences between women and men than a true depiction of the world.

**Impartiality**. Regarding the relation between plug-in charging and battery-swapping it seems that, although scepticism does exist, the imaginaries around battery-swapping can be interpreted as promising to be less disruptive than plug-in charging for the trucking industry. If rolled out extensively, battery-swapping could provide a mode of existence for current distribution of trucks and logistics services. However, if driven by the market both plug-in charging and battery-swapping stations will likely be provided where it is profitable, which probably would lead to a spatial concentration of electrified infrastructure.

With regards to aspects of non-discrimination, issues of impartiality between women and men in the sector seems to be about other things than electrification. A continued strive toward inclusive workplaces and work cultures are not seen as directly related to electrification or battery-swapping.

**Meaning making**. This aspect was the least present in the interviews and few conclusions can be drawn from the material.

*Table 21. Main results related to the five principles of social sustainability. '+' indicates potential positive effects, '-' negative effects, and '=' denotes ambiguous and/or no direct effects.*

| **Principle** | **1. Health** | **2. Influence** | **3. Competence** | **4. Impartiality** | **5. Meaning-making** |
|---|---|---|---|---|---|
| **Overarching question** | How can well-being be promoted in organisations and among individuals? | How can people´s influence and participation in decision-making be promoted? | How can people´s need for education, training, and learning be promoted? | How can non-discrimination and equality be promoted in society and organisations? | How can people´s sense of meaning-making and concreation be promoted? |
| **Areas of relevance** | 1.1 Working conditions<br>*- ability and nedeccity for breaks*<br>1.2 Safety and security<br>*+ better speed control*<br>*- exposure to magnetic fields*<br>*- increased risk of robbery*<br>1.3 Exposure to noise and emissions<br>*+ less noise & vibrations*<br>*+ less particle emissions*<br>1.4 Universal design of instruments and machinery<br>*+ possibilities to improve vehicle booth design & driver environment.* | 2.1 User influence<br>*-less autonomy due to increased need for planning & boundedness*<br>*+ battery swapping can potentially alleviate (some of) this*<br>2.2 Representation<br>*= no direct results*<br>2.3 Inclusion of people´s quality of life in assessment and evaluations | 3.1 Promoting broad recruitment<br>*= unclear connection btw electrification/battery swapping and a more attractive job*<br>*= few respondents believe electrification/battery swapping will attract more women*<br>3.2 Securing equal access to competence development that makes new technologies available and usable within organizations and wider society.<br>*= there is a need for improved competence regarding planning routes for electric vehicles* | 4.1 Non-discrimination<br>*= electrification/battery swapping not seen as a barrier to non-distrimination*<br>4.2 Equal rights to work, education and services<br>*- a perceived risk of spatial concentration of the physical infrastructure needed for electrification.*<br>*+ Battery swapping could alleviate some of this but won´t happen on the market´s own terms.* | 5.1 Inclusive innovation<br>*No direct results*<br>5.2 Promoting the inclusion of new ideas from all<br>*No direct results*<br>5.3 Awareness of exclusionary practice and norms<br>*No direct results*<br>5.4 Participation and diversity in decision-making<br>*No direct results*<br>5.5 Cultural heritage and promotion of social values<br>*No direct results* |

## 11.9. Discussion and conclusions

The findings can help us understand the development and establishment of socio-technical imaginaries about electrification and battery-swapping in the heavy trucking industry. While the results are not possible to generalise to an overall discourse about electrification and battery-swapping, they highlight what Mutter (2019, 3) call ‘local imaginaries’ that show multiple, competing ideas and visions within a nation. Specifically, the inclusion of both experts and non-experts in the interviews and focus groups also provide insight into how different actors relate to ongoing and future socio-technical transformations. The results thus highlight that there is no *single* imaginary about neither electrification nor battery-swapping, but *multiple* imagina*ries.* These multiple imaginaries are evident in the different ways in which the interviewees relate to electrification and battery-swapping; these developments are perceived as opportunities or threats depending on the vantage point. Especially interesting is the rejection of electrification at large that was displayed by several students studying to become truck drivers. And if a rejection of electrification would, in the end, be impossible a sense of *resignation* before the eventual electrification of the heavy trucking sector is evident in some of the responses. At the other end of the spectrum is the imaginaries presented by the people involved in the feasibility study for battery-swapping. While not naïve about the challenges involved in employing battery-swapping, the potentials for untying several knots in the difficult issue of electrification of the trucking industry is much more prominent in these individuals' reasoning. This can, at least partly, be attributed to the potential role of the project in establishing an imaginary for battery-swapping that can be incorporated into public policy and other actors' attitudes towards the transition of the sector.

Given the urgent need for decarbonization of all societal and industrial sectors, the reluctance among some of the respondents – especially from those who work with or will work in the heavy trucking industry – is imperative to understand and incorporate in analyses and future developments. The socio-technical imaginaries of researchers and other experts may often become too abstract and systems-oriented and lack connection to the experiences and needs of workers and users who, in the end, are the ones expected to employ new technologies. Incorporating workers' and users' perspectives may therefore assist in developing technological solutions and business models that are more easily adopted. Developing structures that encourage active involvement by workers and users would also address several of the social sustainability perspectives identified by Balkmar et al. (2022), including universal design of instruments and machinery (item 1.4.), User influence (item 2.1.), Inclusive innovation (item 5.1.), Promoting the inclusion of new ideas from all (item 5.2.) and Participation and diversity in decision-making (item 5.4.). In this respect, securing relevant competence development (principle 3) is also imperative to ensure that workers and users can turn these changes from abstract ideas into practical experience.

The material and findings also point to that there are several social sustainability principles that may not be best addressed through the employment of electrification and battery-swapping technologies. This is most clearly visible in relation to gender equality in the heavy trucking industry, which few interviewees saw as likely to be affected by the adoption of fossil free technologies. However, given the potential structural change the industry is going through by adopting and innovating new technologies and business models, there may be opportunities to simultaneously address other issues, such as gender equality. However, the results from this study point to that addressing structural deficits in gender equality requires a different set of change practices than simply adopting new technologies.

Another challenge to social sustainability is whether new technologies can and will improve or worsen the working conditions for truck drivers and other workers in the sector (item 1.1.). Just as with gender equality, there are other structural issues that likely exert bigger influence over truck drivers' working conditions – digitalisation, the economic logic of just-in-time, and an increasing influence from customers both enable and shape a culture of surveillance of truck drivers that may have detrimental effects, and electrification and battery-swapping are unlikely to change these, at least without intention and intervention.

Of course, the inclusion of workers' and users' perspectives is not a guarantee for people embracing low-carbon solutions as attitudes to these are formed also by other factors, such as ideology, identity, and habit. Imaginaries around electrification and battery-swapping are also affected by preexisting conceptions, experiences, and practices, and while they change over time, there is inertia to how worldviews change. During rapid technological and other societal transformations established preconceptions are challenged, and existing norms are destabilised. Therefore, inviting those affected by ongoing changes in economic and technological structures to also contribute to the creation of alternative imaginaries could open trajectories that make such transitions better adapted to their situation, thereby both democratising the transition within the industry and improving the likelihood of acceptance of it.

## 11.10. References

Adu-Gyamfi, G. *et al.* (2022) 'Towards sustainable vehicular transport: Empirical assessment of battery swap technology adoption in China', *Technological Forecasting and Social Change*. Elsevier Inc., 184(August), p. 121995. doi: 10.1016/j.techfore.2022.121995.

Arbetsmiljöverket (2023) *Arbetsskador 2022 – län och kommun*. Arbetsmiljöstatistik Rapport 2023:01. Solna.

Balkmar, D., Callerstig, A. and Lövstål, E. (2022) 'Hur kan elvägar bli socialt hållbara ? Ett ramverk för social hållbarhet vid teknik- och miljöomställningar'.

Carvalho, A., Riquito, M. and Ferreira, V. (2022) 'Sociotechnical imaginaries of energy transition: The case of the Portuguese Roadmap for Carbon Neutrality 2050', *Energy Reports*, 8, pp. 2413–2423. doi: https://doi.org/10.1016/j.egyr.2022.01.138.

Christiansen, K. L. and Carton, W. (2021) 'What "climate positive future" ? Emerging sociotechnical imaginaries of negative emissions in Sweden', *Energy Research & Social Science*. Elsevier Ltd, 76(December 2020), p. 102086. doi: 10.1016/j.erss.2021.102086.

De Fine Licht, K. and Folland, A. (2019) 'Defining "social sustainability": Towards a sustainable solution to the conceptual confusion', *Etikk i Praksis*, 13(2), pp. 21–39. doi: 10.5324/eip.v13i2.2913.

Godfrey, J. and Bertini, R. L. (2019) *Attracting and Retaining Women in the Transportation Industry Attracting and Retaining Women in the Transportation Industry*.

Haugland, B. T. (2020) 'Changing oil : self-driving vehicles and the', *Humanities and Social Sciences Communications*. Springer US, 7(180), pp. 1–10. doi: 10.1057/s41599-020-00667-9.

Haugland, B. T., Skjølsvold, T. M. and Skjølsvold, T. M. (2020) 'Promise of the obsolete : expectations for and experiments with self-driving vehicles in Norway', *Sustainability: Science, Practice and Policy*. Taylor & Francis, 16(1), pp. 37–47. doi: 10.1080/15487733.2020.1765677.

Jasanoff, S. (2015) 'Future Imperfect : Science , Technology , and the Imaginations of Modernity', pp. 1–33.

Jasanoff, S. and Kim, S.-H. (2009) 'Containing the Atom : Sociotechnical Imaginaries and Nuclear Power in the United States and South Korea', *Minerva*, 47, pp. 119–146. doi: 10.1007/s11024-009-9124-4.

Kvale, S. and Brinkmann, S. (2014) *Den kvalitativa forskningsintervjun*. Lund: Studentlitteratur.

Leonel Da Silva, R. G. and Au, L. (2022) 'The Blind Spots of Sociotechnical Imaginaries: COVID-19 Scepticism in Brazil, the United Kingdom and the United States', *SCIENCE TECHNOLOGY AND SOCIETY*, 27(4), pp. 611–629. doi: 10.1177/09717218221125217.

Martin, R. (2021) 'AV futures or futures with AVs? Bridging sociotechnical imaginaries and a multi-level perspective of autonomous vehicle visualisations in praxis', *Humanities and Social Sciences Communications*. Springer US, 8(1), pp. 1–15. doi: 10.1057/s41599-021-00739-4.

Missimer, M., Robèrt, K. H. and Broman, G. (2017) 'A strategic approach to social sustainability - Part 2: a principle-based definition', *Journal of Cleaner Production*, 140, pp. 42–52. doi: 10.1016/j.jclepro.2016.04.059.

Mladenović, M. N. (2019) 'How Should We Drive Self-driving Vehicles? Anticipation and Collective Imagination in Planning Mobility Futures', in Finger, M. and Audouin, M. (eds) *The Governance of Smart Transportation Systems. Towards New Organizational Structures for the Development of Shared, Automated, Electric and Integrated Mobility*. Cham: Springer, pp. 103–122.

Mladenović, M. N. *et al.* (2020) *Governance cultures and sociotechnical imaginaries of self-driving vehicle technology: Comparative analysis of Finland, UK and Germany*. 1st edn, *Advances in Transport Policy and Planning*. 1st edn. Elsevier Inc. doi: 10.1016/bs.atpp.2020.01.001.

Mutter, A. (2019) 'Mobilizing sociotechnical imaginaries of fossil-free futures – Electricity and biogas in public transport in Linköping, Sweden', *Energy Research and Social Science*, 49, pp. 1–9. doi: 10.1016/j.erss.2018.10.025.

Mutter, A. (2021) ‘Embedding imaginaries- electric vehicles in Sweden’s fossil fuel free future’, *Futures*. Elsevier Ltd, 129(January 2020), p. 102742. doi: 10.1016/j.futures.2021.102742.

Mutter, A. and Rohracher, H. (2022) ‘Competing Transport Futures: Tensions between Imaginaries of Electrification and Biogas Fuel in Sweden’, *Science Technology and Human Values*, 47(1), pp. 85–111. doi: 10.1177/0162243921996052.

Ng, W.-S. and Acker, A. (2020) *The Gender Dimension of the Transport Workforce*. International Transport Forum Discussion Paper, No. 2020/11. Paris.

Olesen, K. (2020) ‘Infrastructure imaginaries: The politics of light rail projects in the age of neoliberalism’, *Urban Studies*, 57(9), pp. 1811–1826. doi: 10.1177/0042098019853502.

Olin, J. J. and Mladenović, M. N. (2022) ‘Imaginaries of Road Transport Automation in Finnish Governance Culture—A Critical Discourse Analysis’, *Sustainability (Switzerland)*, 14(3). doi: 10.3390/su14031437.

REDO (2021) *Recruitment Equality and Diversity Opportunities*.

Rudek, T. J. (2022) ‘Capturing the invisible. Sociotechnical imaginaries of energy. The critical overview’, *Science and Public Policy*, 49(2), pp. 219–245. doi: 10.1093/scipol/scab076.

Ryghaug, M. and Toftaker, M. (2016) ‘Creating transitions to electric road transport in Norway : The role of user imaginaries’, *Energy Research & Social Science*. Elsevier Ltd, 17, pp. 119–126. doi: 10.1016/j.erss.2016.04.017.

Scott, A. and Davis-Sramek, B. (2023) ‘Driving in a man’s world: examining gender disparity in the trucking industry’, *International Journal of Physical Distribution and Logistics Management*, 2021. doi: 10.1108/IJPDLM-03-2022-0073.

Sovacool, B. K. *et al.* (2019) ‘Are electric vehicles masculinized? Gender, identity, and environmental values in Nordic transport practices and vehicle-to-grid (V2G)preferences’, *Transportation Research Part D: Transport and Environment*. Elsevier, 72(May), pp. 187–202. doi: 10.1016/j.trd.2019.04.013.

Sovacool, B. K. *et al.* (2020) ‘Imagining sustainable energy and mobility transitions: Valence, temporality, and radicalism in 38 visions of a low-carbon future’, *Social Studies of Science*, 50(4), pp. 642–679. doi: 10.1177/0306312720915283.

Stave, C., Levin, L. and Henriksson, P. (2023) ‘Gender Equality Culture: Measuring Attitudes Towards Gender Equality in the Transport Sector’, *Proceedings of the Global Conference on Women’s Studies*, 2, pp. 1–12.

Transportföretagen (2023) *Framfart*. Available at: https://www.transportforetagen.se/kompetensforsorjning/for-dig-som-medlemsforetag/framfart/ (Accessed: 30 November 2023).

Turnbull, P. (2013) *Promoting the emloyment of women in the transport sector - Obstacles and policy options*. Working Paper No . 298. Geneva.

TYA (2014) *Kvinnor i transportbranschen*. Stockholm.

United Nations (2023) ‘SDGs Report 2023’, *The Sustainable development Goals Report 2023: Special Edition*, p. 80. Available at: https://unstats.un.org/sdgs/report/2023/.

Wibeck, V. (2010) *Fokusgrupper : om fokuserade gruppintervjuer som undersökningsmetod*. Lund: Studentlitteratur.

World Commission on Environment and Development (1987) *Our Common Future*.

WSP (2019) *Olyckor med dödlig utgång, Tung lastbil inblandad, år 2018*. Available at: https://www.transportforetagen.se/globalassets/rapporter/ba/190520_dodsolyckor-med-tung-lastbil-2018.pdf?ts=8d8483bbdf2c700.

# Appendix 1. Battery-Swapping Explorative Trip to China

Report from an exploratory trip, 20–24 November 2023

Authors: Per Lindahl, Logistikia, Mike Danilovic, Halmstad University, Arne Nåbo, VTI

## Summary

> *"Of the 10 largest manufacturers of electric heavy trucks, nine are Chinese! China is leading the electrification in the transportation sector, with battery-swapping for heavy trucks now becoming the dominant recharging infrastructure solution, expected to reach 70% in a few years' time" (Liu & Danilovic, 2021).*

This study tour was arranged to give a unique insight into Chinese electrification with a specific interest in battery-swapping.  The study trip was conducted 18-25 November 2023. It was made possible due to extensive long-lasting collaboration between the Sweden-China Bridge project (SCB), financed by Trafikverket (Swedish Transportation Administration) led by Professor Mike Danilovic and Dr. Jasmine Lihua Liu, Halmstad and Lund University, and the Shanghai Dianji University.

The SCB project has studied Chinese renewable energy since 2013 and the electrification of transportation since 2018, including battery-swapping. This has led to vast knowledge, a broad industrial, business, and academic network of collaborative contacts, and a unique possibility for on-site observation and exchange of experience. SCB, in collaboration with the regional logistics cluster Logistikia and VTI (Swedish National Road and Transport Research Institute) has worked to increase Sweden's knowledge of battery-swapping as a complementary solution to cable charging. We advocate battery-swapping because it has a potential to be an important enabler in scaling up the electrification of heavy transports, responding to major obstacles identified for transportation companies and challenges regarding power capacity in local grids. From a Swedish perspective, we consider it remarkable that battery-swapping is unknown and not discussed on the national Swedish scene and that public financing is biased towards cable charging as the only solution!

The explorative study program in China covered several electrifications of transportation hot spots. It gave participants a broad and deep understanding of the electrification of transport in China and particularly about the status of battery-swapping as a concept and how it is organized and developed in the Chinese context.

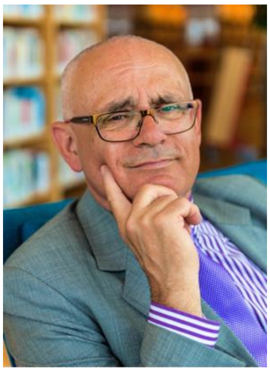
**In short, we conclude the following experience from the trip:**

- Chinese electrification, regarding technological development and implementation in the real life, is many years ahead of Europe in all fields of electrification of transport.
- The technology development and implementation speed is very fast, and the speed to full-scale implementation is remarkably fast.
- China's official climate goals set the direction, but in practice, the electrification, including the battery-swapping, is business-driven. What is not business-wise successful is not moving to large-scale implementation.
- There is a close, almost seamless cooperation between academia/research and companies, enabling high speed in development, innovation and implementation.
- Battery-swapping is an essential solution for electrifying heavy electric trucks, dominating sales of heavy trucks in China since 2022.
- The technical development is extremely fast, with several (three) generations of battery-swapping on the market.
- There are battery-swapping solutions for all types of vehicles and trucks, with the dominating areas seemingly being mining, construction/dumpster trucks, and trailer transportation.
- The dominating battery-swapping solution for heavy trucks is by placing the battery on top of the chassis, behind the cabin.
- Several companies are developing solutions where batteries are swapped from the side or from below, mounted under the chassis, between front and rear axles (as common with fixed batteries).
- Grid power capacity is not an issue; companies do not consider battery-swapping as an enabler in that perspective. Instead, the business value is the number one issue, and physical space utilization is also considered necessary, as well as the time for "recharging" the truck, i.e., swapping the battery.
- The efficiency and effectiveness of operations are two major concerns for Chinese transportation companies when they choose solutions for the electrification of transportation solutions.

# About Sweden-China Bridge

Sweden-China Bridge started researching the electrification of transportation systems in China in 2017-2018. In 2018, a VIP team from the Swedish Transport Administration (Trafikverket, TRV) visited China and explored its development.

## Researchers on the development of electrification of transport in China



*Professor Mike Danilovic.*

Professor at Halmstad University, Industrial Management focusing on Innovation and Technology Management. Distinguished overseas professor at Shanghai DianJi University since 2011. Project leader Sweden-China Bridge.

*Dr. Jasmine Lihua Liu.*

Lund University, Affiliated with Jönköping International Business School. Has been working as a researcher in Sweden since 2012. Received Ph-D. in Innovation Sciences in 2019 on extensive action-based research in business model innovation of the wind power industry.

Other Swedish researchers in the projects are: Tech. lic., Arne Nåbo (VTI), Dr. Harrison John Bhatti (VTI), and Dr. Philip Linné (VTI).

## Sweden-China Bridge 1.0, 2020-2023

In 2020, we started the Sweden-China Bridge 1.0 project, focusing on a deeper exploration of the development of electrification of transportation in China. Battery-swapping was discovered as an exciting and rapidly growing solution for all transportation systems.

## Sweden-China Bridge 2.0, 2023-2026

In 2023, SCB started a three-year project, Sweden-China Bridge 2.0 focusing on the system approach to electrification and the Inteligentization of transportation systems. SCB intend to explore and understand how different technologies are developed and integrated on different system levels to achieve larger-scale electrification of electrified vehicles integrated with intelligent roads, and smart cities, all the way along the value chain and across system levels.

The SCB have three perspectives on exploring electrification in China:

- the holistic system approach,
- the symbiotic collaboration between decision makers, institutions, regulatory, and industry, and

- the experimental approach in developing electrification of transport.

All those three characterize the Chinese way of approaching renewable energy and the electrification of transportation.

The SCB project is exploratory and includes a step-by-step approach to knowledge development. The project spans different areas of knowledge, technology, business, and society, where we will shed light on what technologies are being developed for the electrification of the transport system, from critical technologies such as minerals and batteries to complete intelligent vehicle systems, to integration with intelligent roads and smart cities.

## The 2023 battery-swapping explorative trip-delegation

17 people constituted the delegation, broadly representing the Swedish transport and heavy-truck industry, transportation companies, transportation buyers, industrial networks, and research and innovation clusters from Sweden and Finland. Competencies in the group stretched from truck operation to battery expertise, truck engineering, business and market, and others. The different profiles and experiences in the group contributed to interesting discussions and different perspectives being put forward.

## Program and visits

The study week featured an intensive program covering major hotspots in Chinese electrification, looking at battery-swapping in practice, vehicles, swapping stations, research and development of artificial intelligence and autonomous technologies, full-scale test road capabilities, and manufacturing. The program also covered a lot of meetings with presentations, discussions, and mutual Q&As. Our hosts received the delegation well at all stops, for which we are very grateful! We are impressed by the openness and willingness to share experiences and practice in all those areas we explored.

The trip was made possible thanks to massive and thorough preparation by Dr. Jasmine Lihua Liu and prof Mike Danilovic

## Exploring many places

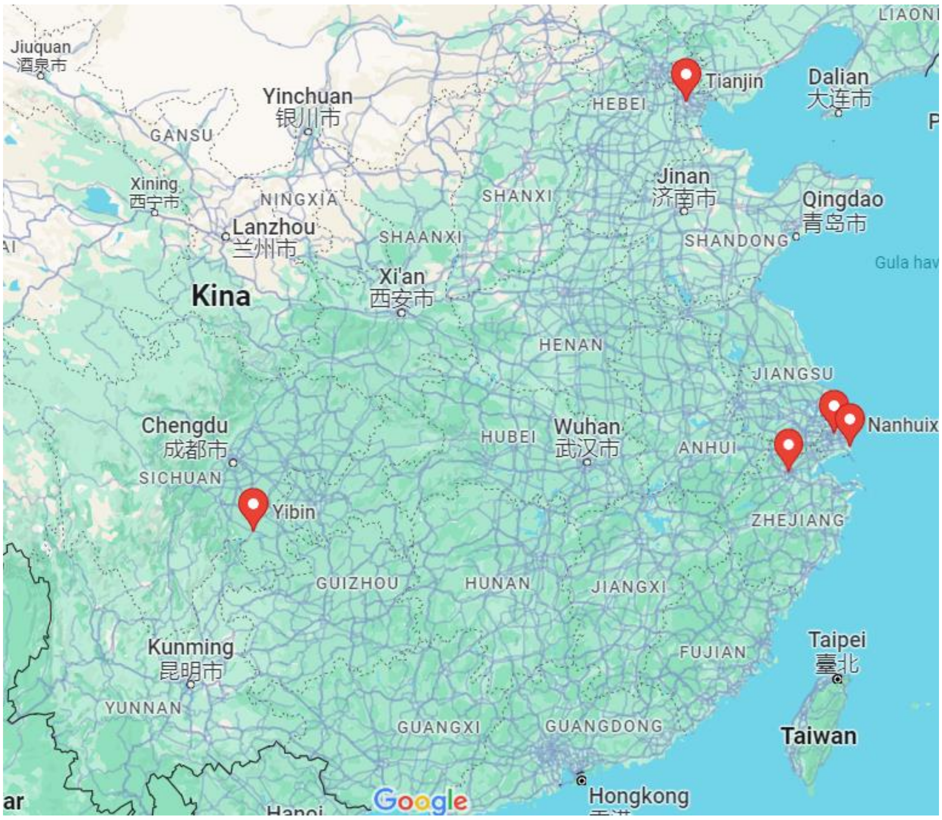



*Figure 73. Destinations in China visited by the team.*

During the week we explored Shanghai, Lingang as one of the major development areas in China, Hangzhou, Yibin, Beijing and Tianjin.

We visited University, research centers, test drive facilities, vehicle manufacturers, battery manufacturers, battery-swapping system developers and manufacturers, and got close experiences of intelligent heavy trucks.

## Explorative schedule of the week

**Sunday November 19, Shanghai City**

Walking tour in Shanghai. An appreciated first glance of Shanghai and introduction to China. Stunning experience with close to 100% electrified 2-wheelers and taxis.

*Shanghai, Bund in the night.*

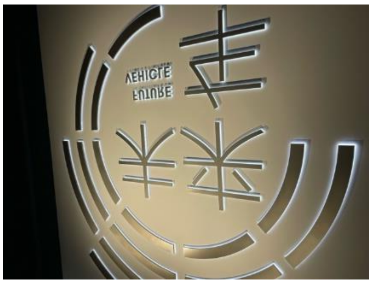
**Monday November 20, Lingang (Shanghai)**

Shanghai Dianji University (SDJU) & Lingang municipality. President SDJU Siyi Gong, Director Yimin Bian.

Opening conference at SDJU, Chinese counterpart in the SCB project, enabling contacts with research centers and companies in China. Presentation and visit to Lingang, 800 km2 development area with intense activities, new companies moving in, including Teslas new factory. Shanghai DianJi University (SDJU) welcoming ceremony.

*President Professor Gong.*

We visited 3 development nodes – Centers. Visit Artificial Intelligent Center. Visit Autonomous Driving Center. AI Center (planned to house 30-50,000 people working with AI). Visit Test Center for autonomous driving and battery-swapping.



*Innovation Center – Future Vehicle.*

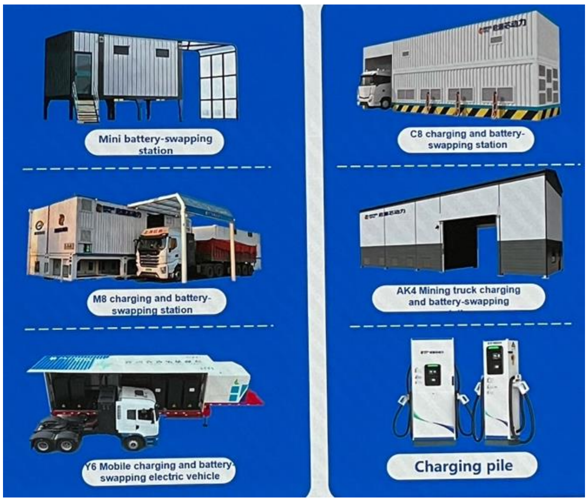
Autonomous driving center, Test-range for autonomous driving and battery-swapping. Battery-swapping practice, test site and autonomous driving to port of Shanghai.


*Intelligent chassis.*

*Battery-swapping practice, test site and autonomous driving to port of Shanghai).*

Visit Aulton, 3rd party battery-swapping system developer. Swapping from side (battery between axles. No photos.)

Presentation from SPIC, developed the first swapping systems. Today 500.




*SPIC Batter-swapping solutions.*

Seminar from SPIC, world’s largest producer of green power.

**Tuesday November 21, Hangzhou**

Geely, Farizon, meet and study BS station in operations. Test driving.

Visit swapping station developed and operated by Geely. This station supports 20+ concrete trucks at a concrete industry. Station supplied with 2,5MW performs max. 168 swaps/24h with 7 batteries. Station can be relocated in 48 hrs. Footprint 60m2. Time for swapping 3 min.

Meeting with Geely discussing technical development, marketing strategies and differences in the Chinese and Swedish transportation market.

*Geely swapping station at a concrete industry.*

Presentation of the Farizon Homtruck (brand owned by Geely) for long haul transports with convoying features, L4 autonomous ability, build.in battery-swapping as standard solution, and a fully equipped "home like" cabin. Farizon also develops a cables truck for closed environment operations. The Homtruck is set to be on the market by 2025.


*Farizon Homtruck.*

**Wednesday 22 November, Yibin**

We started with exploring the Prof Ouyang Minggao Academician Workstation, Sichuan New Energy Vehicle innovation center. First visit Zhi Li Wu Lian. We also visited CATL battery manufacturing in Yibin. Visit exhibition area. Integration research and technical development including battery research.

"in 2022 CATL was ranked n:o 1 globally in EV battery consumption for 6 consecutive years"

https://www.catl.com/en/about/profile/

The stand-alone EV-platform in the picture is a product of Zhi Li Wu Lian and CATL. Zhi Li Wu Lian conduct research and develops batteries, vehicle mounting fixture, swapping robots and two generations of swapping stations.

*EV-platform.*

**Thursday 23 November**

Zhi Li Wu Lian, factory, swapping test sites, swapping operational site, test driving. Visit Zhi Li Wu Lian manufacturing and test site. We explored the new generation with a linear robot that swaps a battery in a few minutes.

*Visit Zhi Li Wu Lian operational swapping station.*

**Friday 25 November, Tianjin (Beijing area)**

DeepWay trucks and battery-swapping station, development, test drive area.

Study and test drive the DeepWay newly developed Intelligent truck. The truck is already on the market.

As of December 2023 DeepWay will start real traffic tests with autonomous L4 (vehicle performs all driving tasks, with only human monitoring).

*Battery-swapping as standard solution, placement between axles, swap from below.*

## Reflections on the Chinese electrification

### From 2-wheelers to taxis and trucks

In Shanghai, all mopeds and scooters are electric, as well as most taxis. Hence, traffic is silent and almost emission-free. Heavy trucks spotted in the city and on highways are still normally fossil-based. Several electric trucks, especially in construction, are electric in areas visited during the trip. Most electric trucks spotted were with battery-swapping. The impression is that the electrification of heavy trucks emerges out of clusters with large concentrations of electric trucks rather than equally distributed throughout the country.

### Autonomous driving

Electrification in China is closely related to digitalization and the development of autonomous driving. Even in low-salary developing economies, the cost of the truck driver is significant. In addition, the Chinese market, as well as the European, suffers from a lack of drivers, especially for long-haul transport. Modern trucks for long-haul are equipped comfortably, some even with showers, washing machines, and toilets. Autonomous driving on level L4 is anticipated to be an important selling feature of modern trucks, already from 2024.

### Speed in innovation and application

Companies visited showed an impressive speed in their development. DeepWay, as mentioned above, was founded in December 2020, and already has several hundreds of new intelligent electric trucks on the market. New prototypes have been developed and tested with only months apart, indicating a different, seamless, approach to the traditional sequential process. Speed may often be prioritized above perfection, “put new products on the market and correct faults as you go!”.

### Integration between research and companies

As a foreigner it is not easy to understand all different relations between state, companies and academia, but a frequent, fast and close cooperation, many times symbiotic, is evident. The Sichuan New Energy Vehicle innovation center and Zhi li Wu Lian that we visited, was one example of this. Led by professor Minggao (with a PhD from Denmark) the institution has incubated many companies, that cooperates and stay connected to the center. The close cooperation between actors seems to be an important factor to explain the speed of which Chinese electrification is moving forward.

### Vehicle standard

Compared to premium brands as Scania and Volvo, Chinese trucks are plain and from a Swedish driver perspective of lower standards (suspension, quality of materials etc). This version of trucks would not be accepted by Swedish drivers. However, this should not be interpreted as a lack of quality, Chinese manufacturers may supply also higher standards if asked for, it is a matter of cost.

## Battery development and battery-swapping, lessons learned

### Battery development

There are numerous manufacturers of electric vehicles, passenger cars and trucks. Battery suppliers are fewer and more dominating. World leading CATL is said to represent about one fifth of all vehicle batteries presently on the market, heavy trucks and passenger cars, including VW and Tesla. Research is intense and focused towards several areas such as energy density (kWh/kg), capacity (kW), battery management, cost and safety. The bulk of $1^{st}$ generation batteries are based on Silicon which has a theoretical maximum energy density around 400Wh/kg. Next generation batteries may be Na-based (lower energy density) or Fe-based, significantly higher energy density, around 600Wh/kg. Seemingly battery manufacturers may take a pole position in the electrification, controlling the most strategic component!

### Battery-swapping

Battery-swapping is rather new (about 5 years on the market) but well established on the Chinese markets with thousands of vehicles in operation and several generations and different solutions for swapping stations. Battery-swapping has become one crucial complementary technology for recharging heavy trucks. Battery-swapping based trucks have about 50% of the electric heavy truck market in China. Today, it is a proven and robust technology, scalable and flexible with very little footprint compared with cable charging. SPIC who started the development, has 21 000+ vehicles with BS on the market and 500+ swapping stations of different design.

By November 2023, 3,394 battery-swapping stations have been installed in China (source: EVCIPA). Among the 3,394 battery-swapping stations, about 400 are for heavy trucks. The acceleration is rapid, and almost all heavy truck OEMs offer vehicles with battery-swapping solutions.

The first and most popular solution for battery-swapping is a battery mounted on the frame behind the cabin. The benefit is a simple technical solution for mounting vehicles and swapping stations. It is also a verified and robust solution for challenging environments such as bad roads, etc. The downside is the space occupied by the battery intruding on load (length). The high mounting could be a disadvantage regarding the centre of gravity, but no such effects have been reported and could not be confirmed during our discussions. Currently there are several manufacturers of heavy trucks that are developing a solution where batteries are mounted in the chassis frame, as is common in traditional cable-charged vehicles. For swapping the three manufacturers we visited have chosen different solutions, two swapping from below and one from the side. Currently, the placement of the battery behind the cabin, swapping upwards is the dominant solution.


*Figure 74. A battery-swapping heavy truck with the battery mounted behind the cabin.*

## Applications

There is battery-swapping for two-wheelers, passenger cars, boats, and all sorts of heavy machinery. Heavy trucks have a lot of different applications. However, the main applications are in construction (dump trucks, concrete trucks) and mining with short distances and high delivery frequency.

*Figure 75. Swapping station DeepWay trucks, swapping from below.*

The development of swapping stations has gone through three phases, the last is presently being rolled out:

1. Stand-alone - One swapping station provides several local trucks with service. Trucks operating in the area use the same station. This model can “stand-alone” without a general market penetration. With some 20 trucks using the station, the utilization rate is at break-even.
2. Local grid – Several swapping stations in one area where trucks can use one or the other to swap batteries.
3. Connecting cities – Swapping stations along highways enabling trucks to go a longer distance between remote destinations.

We also witnessed several battery-swapping trucks parked and charging by cable at charging stations, which is always possible.

## The Chinese business case versus a Swedish/European perspective

China has set out national goals about CO2 emissions, which sets the direction towards electrification. From there, the development is totally business-driven; transportation companies buy battery-swapping trucks when they get better revenue (also compared to diesel). Swapping station operators' primary earnings come from energy sold.

The grid-capacity problems in Sweden with insufficient power, emerging as a bottleneck in Swedish electrification, seems irrelevant in China! We discussed this with several companies, and no one could relate to limitations in power for charging. Still, "vehicle 2 grid"-function is under development in China, also for battery-swapping stations.

### Standardization

Standardization in electrification is a prioritized subject in China, as in Europe. There is a national battery-swapping organization promoting this. Companies may choose to join a standard or stay outside; there is no mandatory regulations regarding standards. Chinese organizations have a long tradition of dialogue, which seems to enable the process of standardization.

Today, there are two standards regarding frame-mounted batteries, one of which is an accepted national standard. The main manufacturer of this is Zhi Li Wu Lian, which company also manufactures an "adapter" for when the battery and vehicle are of different standards.

Regarding batteries mounted between axles, there is not yet any one standard accepted, and companies developing this concept have chosen to go with their individual solutions.

## Final words

Remarkably, the awareness of battery-swapping in Sweden and in Europe still is very low, despite it being the dominating solution in Chinese electrification, being many years ahead of Europe. The main reason for this, we argue, is the reluctance of European manufacturers to discuss and test the concept on the European market. Also, the public funding promoting electrification is biased towards cable charging, further obstructing a test of the battery-swapping concept. To our knowledge, there is not one battery-swapping station or -truck in Europe, making it challenging to evaluate the solution under our market conditions.

*Hence, it is not a lack of interest from transportation companies and transportation buyers that holds the process back; on the contrary, transportation companies line up to try a solution as soon as it is available.*

The consortium behind the trip (Sweden China Bridge, VTI, and Logistikia) intends to continue work to place battery-swapping on the Swedish national agenda, spreading knowledge and interest. The main immediate target is to get a battery-swapping system tested on the Swedish market.

## Suggested continued reading

We have collected some information of battery-swapping on the Logistikia homepage, https://logistikia.se/battery-swapping/. The page will be updated with further documentation from the trip as well as other news on the topic.

The SCB project is housed by Halmstad University where you can find project information and all project reports: https://www.hh.se/forskning/var-forskning/forskning-vid-akademin-for-foretagande-innovation-och-hallbarhet/forskningsprojekt-vid-akademin-for-foretagande-innovation-och-hallbarhet/sweden-china-bridge.html

Several new reports from the project will be published in the beginning of 2024.

VTI together with LiU, Logistikia, Scandinavian Executive Education and Research (SEER), and Intuizio has during 2023 conducted a feasibility study on implementing battery-swapping in Sweden. The report will be available as of Q1-24 on the VTI homepage (www.vti.se ).

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