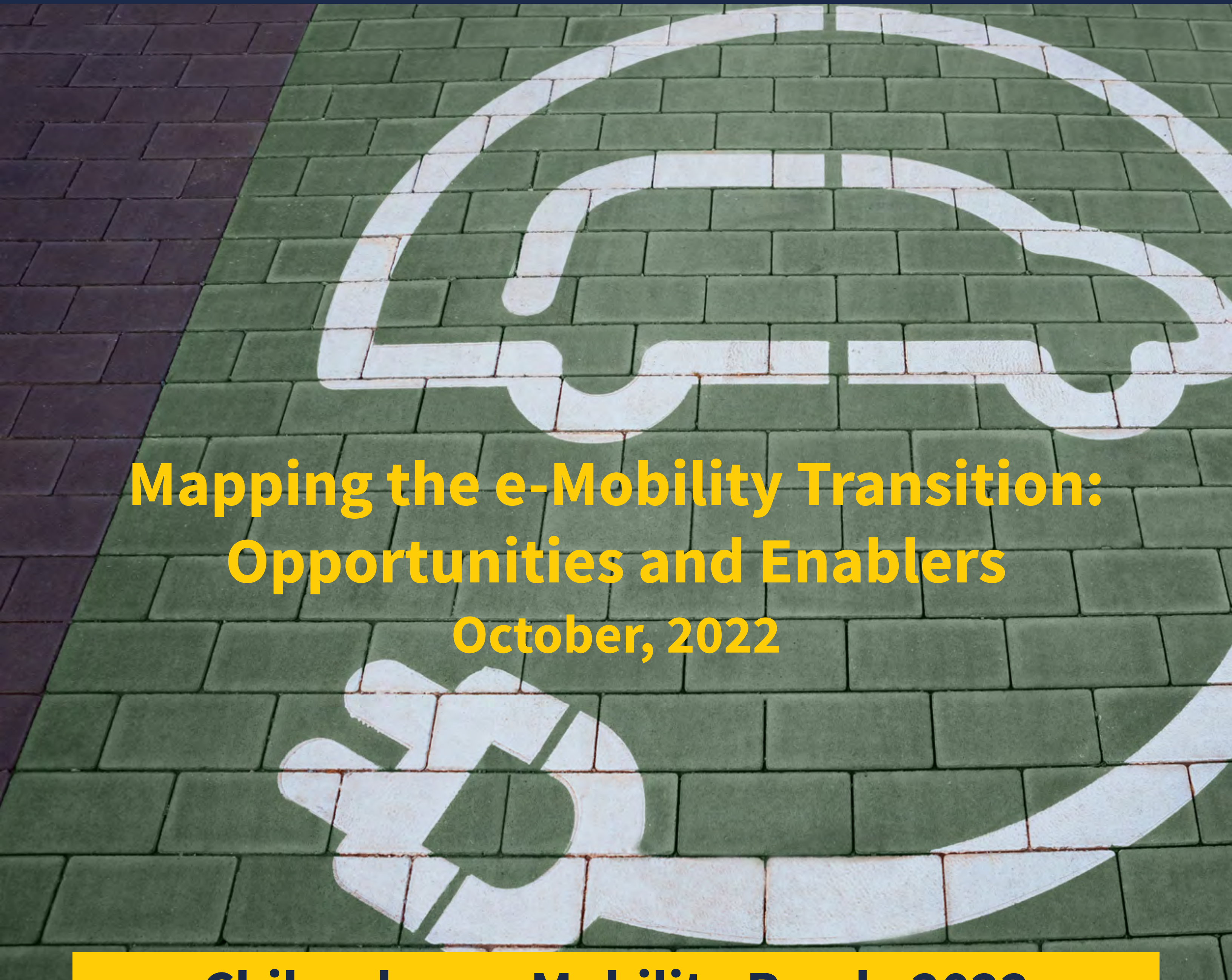
WILLIAM DAVIDSON INSTITUTE
AT THE UNIVERSITY OF MICHIGAN



Mapping the e-Mobility Transition: Opportunities and Enablers

October, 2022

Chihuahua e-Mobility Ready 2022

CHIHUAHUA
GOBIERNO DEL ESTADO
Juntos Sí podemos

SECRETARÍA
DE INNOVACIÓN
Y DESARROLLO ECONÓMICO

I²C
INSTITUTO DE INNOVACIÓN
Y COMPETITIVIDAD

INADET
INSTITUTO DE APOYO
AL DESARROLLO
TECNOLÓGICO

About this report

This report has been developed by the William Davidson Institute at the University of Michigan (WDI) within the context of an electric mobility (e-mobility) project involving the Secretary of Innovation and Economic Development (SIDE) and the Instituto de Innovación y Competitividad (I2C) in the state of Chihuahua in Mexico. WDI is working with the state of Chihuahua to prepare for the transition to e-mobility in the automotive industry by developing a statewide strategy to increase its competitiveness and tap into current and future business opportunities in this changing sector. Our work includes mapping out the opportunities and enablers of the e-mobility transition, represented by this report, and subsequent activities to assess Chihuahua's strengths and identify gaps and priority areas that will be central to the development of an e-mobility roadmap with actionable recommendations for the state.

The analysis in the following pages is global in scope, with special emphasis on lessons from certain U.S. states and key emerging markets, given the interests of SIDE, I2C and WDI. While this report has been developed with the goals of Chihuahua in mind, we hope it will serve as a valuable tool for anyone in the e-mobility ecosystem, in any market, to better understand and adapt to key trends, opportunities, and enabling strategies related to the major transition brought about by electrification of the transportation sector.

About WDI

At the William Davidson Institute (WDI) at the University of Michigan (U-M), unlocking the power of business to provide lasting economic and social prosperity in low- and middle-income countries (LMICs) is in our DNA. We gather the data, develop new models, test concepts and collaborate with partners to find real solutions that lead to new opportunities. This is what we mean by Solving for Business—our calling since the Institute was first founded as an independent nonprofit educational organization in 1992. We believe societies that empower individuals with the tools and skills to excel in business, in turn generate both economic growth and social freedom—or the agency necessary for people to thrive.

We endeavor to make this vision a reality by collaborating with local and multinational firms, University of Michigan scholars and enterprising students, as well as experts in a variety of fields. Our Consulting work focuses on developing, adapting and applying sound business principles in interrelated economic sectors that are essential for vibrant economies. Our Training programs incorporate the latest thinking in management education, consider the local context and help to shape learners into the global leaders of today and tomorrow.

Through our unique blend of field-based experience and academic rigor, we help to build both resilient leaders and stronger businesses in low- and middle-income countries.

Acknowledgments

WDI report authors: Diana E. Páez, Dana Gorodetsky

We would like to acknowledge several individuals who provided review, insights, and supporting research and content: Paul Clyde, Ari Shwayder, Sachin Nijhawan, Kristin Kelterborn, John Viera, Angela Flood, Cody Gallagher.

We would also like to thank the individuals who provided their time and expertise during key informant interviews, including: Brittany Affolter-Caine, Executive Director of Michigan's University Research Corridor (URC); Annika Berlin, Programme Management Officer, Sustainable Mobility Unit, United Nations Environment Programme; Komal Doshi, Director of Mobility Programs, Ann Arbor SPARK; Pramoda Gode, Senior Expert, Electric Mobility and Sustainable Transportation; Sarah Gregory, Director of Talent Solutions, Detroit Regional Partnership; Edward Hightower, CEO, Lordstown Motors Corporation; Nick Moroz, Director of Entrepreneurial Practice, University of Michigan Center for Entrepreneurship; Devon O'Reilly, Director of Entrepreneurship, Community Engagement, Mobility, Detroit Regional Chamber; Trevor Pawl, Chief Mobility Officer, State of Michigan; Alfonso Rodriguez, Interim Head of Purchasing, Canoo; Andrea Schuitman, Assistant Director, Nexus at College of Engineering, University of Michigan; John Walsh, President and CEO, Michigan Manufacturers Association; Steven Wilson, Executive Director, University of Michigan Economic Growth Institute.

Report design: Jesús Ramírez, Guillermo Ramírez, and Mariana Ramírez. All photos from freepik.es with permission.

Contact

For questions and/or feedback on this report, please reach out to Diana E. Páez (dianapc@umich.edu).

CHIHUAHUA GOBIERNO DEL ESTADO Juntos Sí podemos | SECRETARÍA DE INNOVACIÓN Y DESARROLLO ECONÓMICO

I²C INSTITUTO DE INNOVACIÓN Y COMPETITIVIDAD

INADET INSTITUTO DE APOYO AL DESARROLLO TECNOLÓGICO

WILLIAM DAVIDSON INSTITUTE AT THE UNIVERSITY OF MICHIGAN

Copyright © 2022 William Davidson Institute.

Table of contents

Executive summary

We are witnessing an inflection point in mobility that is radically changing established notions about the ways we move and the ways we power our vehicles. It is a time of profound change across the automotive industry, with a diverse mix of players emerging, evolving and interacting in different ways, challenging assumptions, and remaking the rules of the game.

Mobility – the movement of goods and people – is a key enabler of freedom and access, and has far-reaching effects in the social, economic, and environment domains. In any context, facilitating mobility is a key lever for enabling economic growth, inclusion, health, education, and more.

The ways in which we move impact our environment, in potentially irreversible ways. The transport sector is responsible for approximately one quarter of greenhouse gas emissions (GHG) globally, which brings serious consequences for climate change (United Nations, 2020). Globally, there is a trend toward decarbonization, which includes generating net zero emissions, so that we can harness the benefits of mobility without compromising the ability of future generations to do the same. Decarbonization requires a portfolio approach, and many tools and strategies are being deployed, aided by rapid innovation and technological advancements. This is allowing us to think outside the box in terms of how we move, which brings implications for consumers, businesses, government, and other stakeholders.

Four key trends are impacting mobility and ushering in far-reaching changes across society: autonomous, connected, electric, and shared (in combination, ACES). In addition to ACES, also challenging the automotive industry are supply chain disruptions exacerbated by the COVID pandemic, rising costs of materials and commodities, and acute labor shortages. Through all this, we are witnessing a shakeup in the relationship dynamics among traditional automotive players. Startups and tech companies are entering the market, dynamics between OEMs and suppliers are changing, and strategic partnerships are being formed between former competitors to gain competitive advantage. The landscape is shifting, resulting in blurred boundaries among industries and a broader, more fluid mobility ecosystem.

Along with challenges come opportunities. In this report, we delve into one of the ACES trends: electric mobility.

Electric mobility (e-mobility) is defined as the systems, services, and equipment that support the movement of passengers and freight by electric-powered means of transport – from electric scooters to e-rickshaws and electric cargo bikes, to cars, trucks, buses, and even aircraft. (Sustainable Mobility for All Initiative, 2021)

While the e-mobility landscape is broad, we focus on the specifics of electrification in the automotive industry, examining the implications and opportunities that this radical shift presents in the light-duty vehicle segment and related areas of high growth potential. We take a prospective approach, looking at trends that we expect will continue to play a role in the next 5-10 years. However, we acknowledge that this landscape will continue changing rapidly and – as the year 2020 taught us – unforeseen disruptions can materialize, changing the rules of the game again.

The rise of e-mobility

Electric vehicles (EVs) – and specifically battery-electric vehicles – are here to stay. Key drivers of EV adoption include government regulations, greater efficiency relative to internal combustion engine (ICE) vehicles, lack of tailpipe emissions, and growing consumer interest – all of which are interrelated. Barriers include a much higher price point than ICE vehicles, a situation driven by the current cost of batteries, availability and affordability of charging infrastructure, and limited models and supply. While ICE vehicles will remain globally the dominant vehicle type on the road for years to come, the industry is definitively shifting to EVs, and the foundations of an EV value chain are being built.

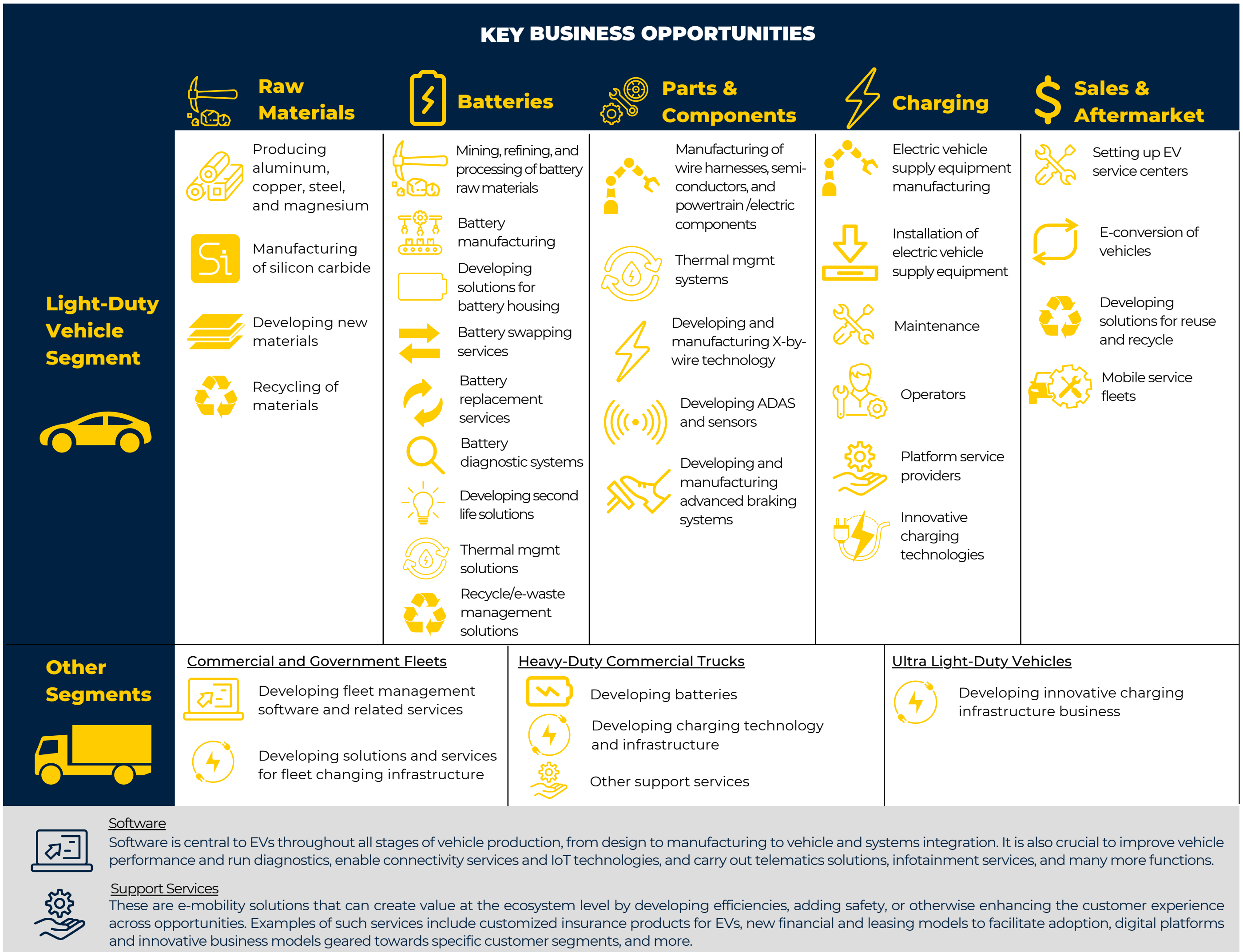
EV markets are expanding quickly. Globally, almost 20 million passenger EVs are on the road and electrification is growing in this and other segments of road transport (Bloomberg NEF, 2022). On the policy side, overall, we are seeing increasing government targets for phasing out sales of new ICE vehicles at a global scale. On the industry side, new goals and commitments by OEMs are regularly announced, confirming that the strategic direction of most is to embrace EV production at scale over the next decade. The 2020s will be a crucial decade for EV technology and the maturation of its value chain, as more companies move to capture market share.

The shift from ICE to EVs is not merely a change of one production step. The entire automotive industry was built around the internal combustion engine – a 120-year-old industry – and the transformation required will be profound. While we are in the early stages of this transition, it is already clear that adapting to it will require drastic changes to the automotive supply chain and will push the companies involved to reimagine their business models. This opens the door for companies to develop new products, services, and solutions – including many that have not even been conceived yet – that can create value in the market while helping the world reach critical climate goals.

Trends and opportunities

As the e-mobility value chain develops, new principles come into play. From designing vehicles around battery placement to selecting lightweight and sustainable materials for manufacturing, to improving battery technology and incorporating sustainable practices in their production and disposal – these many interconnected trends will dictate the type, feasibility, and size of the opportunities ahead. While EVs create new opportunities, they also eliminate others. With changes to the manufacturing and assembly processes, automotive suppliers whose portfolios are built around ICE-specific parts and components will face significant challenges and will need to pivot to stay relevant. The centrality of software to EV production, functioning, and performance underscores the shift in balance from hardware to software in terms of vehicle value and differentiation. This creates opportunities for tech-focused companies and weak spots for those that are not. There is a whole new set of players when it comes to developing the infrastructure to enable EV charging, and an opportunity to leverage clean energy in the process. Finally, broader trends such as digitization and consumer attitudes are impacting the way EVs are sold, and environmental concerns are central to ongoing debates about how they will be handled at end of life. And this is only the tip of the iceberg.

Across the value chain, opportunities abound. We have identified short- and medium-term opportunities and have organized them along each part of the value chain as illustrated below. We describe each opportunity and its potential in more detail throughout this report.



Enabling the transition

An enabling environment is needed to capitalize upon the opportunities that e-mobility brings. Business does not take place in a vacuum and there are broader conditions that need to be in place to support this shift. To understand the what, who, and how of these conditions, we examine six markets: the U.S. states of Michigan and California plus India, China, South Africa, and Brazil. We selected these markets based on two factors: a) their focus on e-mobility policies and practices, and b) their existing automotive manufacturing capacity and ongoing efforts to navigate the e-mobility transition. Below we present some key market features, with more comprehensive vignettes included later in this report.

Market	Key aspects and status of the e-mobility transition
 Michigan	• Global automotive manufacturing hub and headquarters to some of the largest automakers – birthplace of the assembly line in manufacturing automobiles. • Notable state government leadership in future mobility and electrification, with a dedicated cross-agency entity in charge of coordinating mobility initiatives and multiple signature projects. • Taking a broad view beyond electrification to focus on all mobility trends and across sectors, including aeronautical and maritime mobility.
 California	• State-level clean energy policy has played a major role in fast adoption of EVs and growth in EV-related manufacturing. • Access and equity have been a focus of policies related to infrastructure and financing. • Extensive investments in pilot projects, training programs, research and innovation.
 India	• Emissions-related pollution is a critical concern driving the push towards decarbonization. • Strong government commitment to e-mobility, with multiple national and state-level policies and incentive schemes. • Focus on both production and adoption; efforts to develop domestic manufacturing capacity are key given the existing automotive workforce.
 China	• Largest EV market in the world with the most extensive charging network. • Government has played a very strong role in promoting adoption and domestic manufacturing through strong policies, regulation, and investments at both national and local levels. • Global EV battery supply chain is concentrated in the country.
 South Africa	• A near-term goal is to prepare the auto manufacturing sector, a vital part of the economy, for the electrification transition. • Transition driven by shifts in E.U. and U.S. markets, as those are key export markets for the country. • Longer-term goals include supporting adoption through public transit and trucks and transitioning existing local battery production and recycling capacities to support Li-ion.
 Brazil	• Transition to e-mobility is in its early stages, primarily driven by national emissions reductions targets. • Ethanol from sugar cane plays a big role in the transport sector, driven by major government investments and policies for the past 20+ years. • Public transit (bus) and ultra-light-duty-vehicles are key target segments for electrification.

Players and roles

Various players make up the ecosystem of support necessary to enable the transition, including government, industry, entrepreneurs, investors, academia, and interest groups. Depending on the context, there may be players that operate across areas and work to add value by connecting the dots. In this report, we identify important features for each player in the context of navigating this shift. Further, the way these players interact is also important. Collaboration, competition, complementarity, and sharing of resources can lead to opportunities that would otherwise remain untapped. In the body of this report we examine the dynamic linkages among players to illuminate the types of relationships and value that can be created through their collaboration and describe key takeaways.

Strategies

We also identify emerging strategies across three transition enablers: policy framework, infrastructure, and workforce. The strategies we present illustrate a) some common patterns across contexts working towards the e-mobility transition, and b) innovative or unique features of a particular market that appear to have high potential. We include concrete examples for each strategy in this report.

1. Policy Framework

Policies are a powerful enabler of the transition to e-mobility. An agile and responsive policy framework helps to set the intention and strategic direction in any context. Policies can be an effective tool to help engage public opinion around a strong narrative, and the process of developing policies presents an opportunity to engage key stakeholders, including the broader community. E-mobility policies can focus on vehicle production and adoption, and a combination of both is most effective. Effective e-mobility policy frameworks should involve the different agencies and sectors that play a role in the transition to e-mobility – e.g., energy, transport infrastructure, urban planning, trade, climate and energy, labor, education, and more. From the markets we studied, we highlight these emerging policy strategies, describing their potential and offering specific examples in the report:

- **Develop an e-mobility roadmap/EV industry policy**
- **Form a dedicated entity focused on mobility policy**
- **Play at the regional level**
- **Develop and implement bold, multifaceted policy with a mix of mandates and incentives**
- **Engage business in policy development**

2. Infrastructure

There is much more than charging infrastructure when it comes to e-mobility. We consider both the physical and intangible infrastructure needed in the context of the transition. In the physical sense, having the right assets is mission-critical. Understanding what is available, and what can be leveraged or built out, is the first step in the process. A value chain asset map can assist in developing a clear picture of capabilities and gaps, and lead to thoughtful prioritization of infrastructure investments. Once these are prioritized, cross-sector partnerships and innovative financing mechanisms can help leverage the capital needed to make them a reality. Intangible infrastructure refers to the environment that is created by encouraging innovation, collaboration, and competitiveness. A crucial role can be played by an ecosystem orchestrator, understood as a cross-sectoral entity whose primary mission is to create value by connecting players, rallying support around specific initiatives, and unifying the e-mobility vision for a particular context. We include and describe, with details from the markets we studied, these infrastructure-related strategies:

- **Leverage public-private partnerships and other innovative cross-sectoral schemes**
- **Create a dedicated mobility entity that serves as primary orchestrator**
- **Establish a mobility hub**
- **Implement high-visibility signature projects**
- **Build around assets**
- **Develop pilot projects to test innovative approaches and innovative technologies**
- **Promote start-up development in future mobility areas**

3. Workforce

Getting the workforce piece right is critical to enable the transition to e-mobility. The task is two-fold: re-skilling the current automotive workforce so that they can take on EV-related functions, and developing the talent pipeline for a higher-tech workforce with the skills needed to enable electrification – and, sooner than we think, to support other ACES trends, too. Addressing these needs will require comprehensive training and support efforts across many aspects related to EVs – from assembly to servicing to recycling and training first-responders on how to handle fires and accidents involving EVs, and more. Industry, government, academia, and other players can all play a role, as training will need to occur at different levels and through diverse channels.

Also, ICE-specific businesses, especially lower-tier ones, will need special attention and tailored assistance to develop new capabilities or pivot as needed to adapt to the transition. We include, and describe with details, providing specific examples, these workforce strategies:

- **Centralize workforce development programs focused on e-mobility skills**
- **Develop dedicated support programs focused on the ICE-EV transition**
- **Develop and offer e-mobility certifications for industry**
- **Establish effective collaboration mechanisms between industry and academia to align curriculum and research with market needs**
- **Create dedicated EV training facilities**

We are currently in the midst of a transition that will have ripple effects throughout the industry, bringing challenges and opportunities to all players across the mobility ecosystem. In this report we outline in more detail the key trends, opportunities, players, and strategies that can help future-focused decision-makers propel this transition. Our hope is that this report will serve as a useful tool for those interested in understanding the implications of this change, and for those who are ready to create their own forward-looking strategy to take advantage of it.

I. Introduction

A. Trends in mobility

Mobility, defined as the movement of goods and people, is a key enabler of freedom and access. It is connected to everything, and it has far-reaching effects in the social, economic, and environmental domains, because it either provides or hinders access to services or destinations. The breakneck speed at which technology is advancing is leading to major changes in the way we move and the way our movement is powered, radically changing the mobility landscape.

There are four key trends when we consider the future of mobility: autonomous, connected, electric, and shared (ACES). The automotive industry's focus on ACES is prompting a profound industry shift, reshaping companies' portfolios, and setting in motion changes that will impact many aspects of society and communities around the world. The ACES combination is enabling new paradigms, companies, and business and revenue models in mobility that can bring sizable economic benefits. Because they represent a significant technology shift and way of thinking about mobility, thoughtfully preparing for the changes these trends will necessitate should be a priority for future-focused decision-makers.

Understanding the implications of these trends, and where they currently stand, is a good starting point for making sense of the future of mobility. In Table 1 below, we present definitions, implications, projections, "what to watch," and electrification aspects for each trend.

Table 1: ACES trends in mobility

Autonomous

Definition	Implications	Projections	What to watch	Intersection with electric
Autonomous vehicles transfer the role of driving from human to vehicle. Most new vehicles already incorporate at least some level of autonomy, including driver assist and safety features such as parking assist, cross-traffic warnings, self-adjusting cruise control and more. SAE defines six levels of driving automation, with level 0 providing limited warnings and assistance to a human driver, and on the other end of the spectrum a fully autonomous vehicle in all conditions at level 5. Broadly, levels 0-2 involve a vehicle supporting a human driver with various features, whereas levels 3-5 involve different degrees of human supervision of vehicle automated features.	As autonomous capabilities are developed and implemented, they pave the way for increased personal safety as human error and distraction are minimized; time savings for drivers as their attention is not needed for driving; reduced environmental impact as vehicles can be driven in more fuel-efficient ways; lower transport costs due to driving optimization and fewer accidents; range extension due to efficient vehicle management; and higher demands on batteries for autonomous EVs. There will also be different infrastructure needs (road markings, signs, etc.) for autonomous vehicles, and regulations will need to be developed.	Forecasts point to market entry of fully autonomous vehicles at earliest in 2030 (EY Belgium, 2021). Already, there is increasing demand for level 1 and level 2 vehicles in some markets, and growing investment in level 4 and 5 vehicles.	Moves toward autonomy open new opportunities for players in the auto value chain, including new focus on passenger comfort, new possibilities for mobility experience, and software/ computing innovations. More broadly, there will be a need for new regulations as this segment grows, and there are implications for urban planning with more autonomous vehicles on the road. While there are early adopters, a lack of broad consumer acceptance of autonomous features is currently a limiting factor, as well as appropriate infrastructure, especially in emerging markets.	EVs provide greater power and energy storage necessary for autonomous vehicles. Most autonomous vehicles will be electric, as there will be synergies in the development and deployment of automated technology and electric propulsion

Connected

Definition	Implications	Projections	What to watch	Intersection with electric
Vehicles can be connected in two main ways, Vehicle-to-X and Vehicle-to-Vehicle. Vehicle-to-X refers to people in a vehicle being able to connect with the world outside their vehicle, for instance via the internet. Vehicle-to-Vehicle refers to the exchange of information between different vehicles and connecting vehicles to transport infrastructure devices to control traffic lights and more. There are five levels of vehicle connectivity: (L1) general hardware connectivity, (L2) individual connectivity, (L3) preference-based personalization, (L4) multi-sensorial live interaction, and (L5) virtual chauffeur.	In connected vehicles, people are able to communicate, work, access multimedia services, and more while driving or riding. There will also be more data tracked and potentially shared (such as data on driving, location, behaviors, vehicle performance, etc.).	Connectivity services will really take off with adoption of autonomous vehicles. One forecast is for an increase in revenue from $4B in 2017 to $157B in 2035 (EY Belgium, 2021).	People are expected to highly value connected services, so connected vehicles can lead to many new monetization opportunities including in-vehicle ads and recommendations, digitally enabled services, feature unblocks, subscriptions, and B2B data brokerage (OEMs selling to third parties such as maintenance shops or insurance providers). All of this will have implications for data use and sharing, privacy, and cybersecurity.	Many aspects of vehicle redesign brought about by electrification will facilitate the adoption of connectivity technology, for instance remote monitoring and management of EV status, and remote connection to charging infrastructure.

Electric			
Definition	**Implications**	**Projections**	**What to watch**
Electric vehicles have electric motors powered by batteries, instead of internal combustion engines powered by gasoline or diesel. The batteries are recharged by plugging the vehicle into an electricity source. As described in detail in the Electrification section below, there are different types of electric vehicles.	EVs can reduce the total cost of vehicle ownership through lower fueling and maintenance costs, though upfront costs are often higher. There are also opportunities to drastically reduce transport sector pollution by transitioning to EVs, as these have no tailpipe emissions. However, overall emissions are reduced only when the source of energy to produce electricity and new aspects of the value chain such as battery production are clean as well.	Though EVs still represent a very small fraction of all vehicles on the road, global sales of EVs have been rising sharply in recent years. Global sales of electric vehicles reached a new record of 6.6 million in 2021, which was twice as high as sales in 2020, and the trend seems to be continuing in 2022. Currently, China is by far the largest and fastest growing market, followed by Europe	Globally, there are now over 450 EV models available to consumers and several markets have hit or are nearing the “tipping point” — 5% market share — where electric vehicles are poised to take off in an exponential way. In response, the entire auto industry and related sectors are poised for a major transition, from parts and components to new manufacturing and assembly processes, from the battery value chain to charging infrastructure, with new challenges and opportunities in energy as electrical grids are put to the test, and more.

Shared				
Definition	**Implications**	**Projections**	**What to watch**	**Intersection with electric**
Sharing is an alternative to ownership of a car/truck/bike/scooter/etc. and a complement to public transportation systems. This trend is relevant to vehicles for personal use as well as fleets. There are many different types of models such as car sharing, self-service bikes/scooters, e-hailing and more – also referred to as mobility as a service (MaaS). In addition to vehicles, a shared model can include charging infrastructure, software, and more aspects relevant to future mobility.	Through shared models, there is potential to reduce traffic, CO2 emissions, and other pollution with fewer vehicles on the road; increasingly cost-effective and convenient alternative to vehicle ownership for both personal use and fleet services, which might increase the number of people and businesses using vehicles while slowing ownership.	Major expansion in opportunities to share in terms of types of transportation modes, where sharing is available, and how sharing is done/business models in use.use.	New business models especially related to sharing of electric vehicles, such as fleet use and management, and consumers using shared services to try EVs.	Lower total cost of ownership and reduced emissions from EVs present a compelling economic and environmental case for adopting shared electric fleets. Sharing also presents an alternative to purchasing EVs, given higher upfront cost of ownership.

B. Electric mobility

While all these trends are important and are playing out in different ways, electric mobility is currently garnering the most attention for reasons that we discuss below – and is therefore the focus of this report.

Electric mobility (e-mobility) is defined as the systems, services, and equipment that support the movement of passengers and freight by electric-powered means of transport – from electric scooters to e-rickshaws and electric cargo bikes, to cars, trucks, buses, and even aircraft.

(Sustainable Mobility for All Initiative, 2021)

Globally, there is a trend toward decarbonization and net zero emissions in response to concerns about a changing climate. E-mobility is one of many approaches that will be needed to meet country-level emissions reduction goals and global temperature change targets, especially as the total number of vehicles in the world is expected to continue increasing as economies develop and incomes rise.

E-mobility entails a massive transition to move away from fossil fuels and toward net-zero carbon resources for all forms of transportation – and not just in vehicles themselves, but also along the entire value chain from energy sources to raw material production to manufacturing processes and more. Such a transition is underway and includes airplanes, ships, power plants, use of bikes, and more – certainly light-duty EVs, which are the main focus of this report. Though currently in an early stage, recent developments indicate that we are experiencing a trend toward e-mobility that is here to stay, which calls for the generation of knowledge and tools that can help stakeholders throughout the mobility ecosystem adapt to and benefit from this transition. This report aims to serve as such a tool.

C. Report overview

The subsequent portion of this report is organized as follows: First, in Section II, we discuss the specifics of the transition to e-mobility, including EV technologies, drivers, and barriers, as well as recent policy and market moves that reveal the scale of this shift. Next, in Section III, we delve into evolving trends and key business opportunities that the transition brings along the EV value chain, focusing primarily on the EV light-duty vehicle segment (Section III. A). We then highlight areas of current or potential growth outside this segment (Section III. B). These areas will be important for mobility stakeholders to keep in mind and, depending on existing capabilities and priorities, examine more deeply in the near future.

Of course, business does not take place in a vacuum, and the transition requires an enabling environment to take hold and succeed. In Section IV, we look at the broader conditions that can help navigate and accelerate this transition. First, we analyze the ecosystem of players and roles involved in developing and sustaining these conditions (Section IV. A), and then we examine their efforts across three key transition enablers: policy framework, infrastructure (physical and intangible) and workforce (Section IV. B). We describe noteworthy strategies used across these enablers, which can be a useful reference for interested mobility stakeholders. Our analysis in Section IV is based on preliminary lessons and insights derived from our examination of six diverse markets with different journeys to e-mobility: Michigan, California, India, China, South Africa, and Brazil. These markets were selected based on two factors: a) their focus on e-mobility policies and practices, and b) existing automotive manufacturing capacity and ongoing efforts to navigate the e-mobility transition. The Conclusion follows (Section V) and then details of supporting materials in the Appendices.

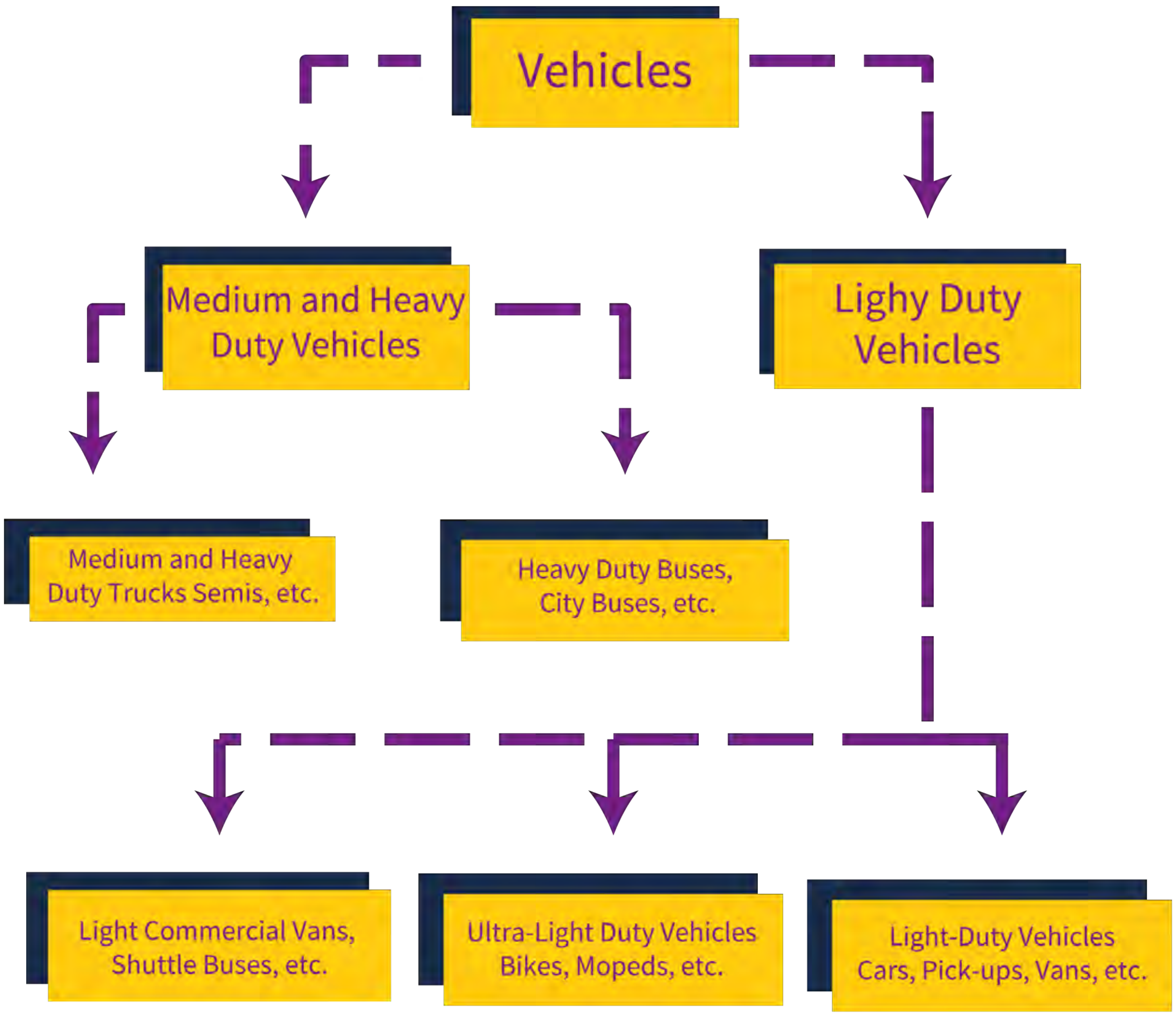
Let’s now examine in more detail the trends giving rise to e-mobility and its broader implications.

II. The rise of e-mobility

Internal combustion engines (ICEs) have been the dominant model of propulsion for terrestrial, air, and marine transportation for centuries. While there have always been vehicles that have demonstrated other technologies, those remained at the edges of consumer and industry preference. In recent years, though, the paradigm has been shifting; an ICE alternative is no longer just a “bleeding edge” technology.

Globally, there are almost 20 million passenger EVs on the road and electrification is growing in various segments **(Figure 1)** of road transport (Bloomberg NEF, 2022).

Figure 1: Vehicle segmentation



There are over 1.3 million commercial EVs including buses, delivery vans, and trucks, and over 280 million electric mopeds, scooters, motorcycles and three-wheelers on the road (Bloomberg NEF, 2022). With over 1.4 billion total cars in the world, EVs still amount to less than 2% of them, so the opportunity for further growth of this segment is huge (Hedges & Company, 2021).

EV markets are expanding quickly. Sales of electric cars reached another record high in 2021 despite the COVID-19 pandemic and supply chain challenges, including semiconductor chip shortages (see Parts and Components section below). Electric car sales accounted for 9% of the global car market in 2021 – four times their market share in 2019 (IEA Global EV Outlook, 2022).

Together, China and Europe accounted for more than 85% of global electric car sales in 2021 – as a result of comprehensive government policy and incentives, infrastructure investments and consumer interest – followed by the United States (10%), where they more than doubled from 2020 to reach 630,000 (IEA, 2022). The 2020s will be a crucial decade for EV technology and supply chain maturation, as more automakers move to capture market share and maintain a competitive edge by developing new models.

A. Electric vehicle technologies

“Alternative fuel vehicles” by the simplest definition are those vehicles that run on a non-exclusive ICE technology. Under the dominant ICE paradigm, incremental changes in technology, whether for better fuel-economy, more power and reliability, etc., have warranted incremental changes in production and adoption of technology by consumers. Now, however, the marketplace is undergoing a shift in technology driven by electrification that promises to deliver zero tailpipe emissions – a shift that will produce immense changes along the supply chain in every part of the vehicle design, manufacturing, and implementation.

The EV segment is made up of multiple sub-categories: hybrid electric vehicle, plug-in hybrid electric vehicle, fuel cell electric vehicle and battery electric vehicle. These are described in **Table 2.**

Table 2: EV segment categories

Vehicle	Description	Barriers
Hybrid Electric Vehicle - (HEV)	Uses the ICE as a primary driving power source with a small electric motor and battery that regenerate braking energy and extend fuel efficiency.	To a large degree, it has the drawbacks of a standard ICE vehicle. PHEVs and HEVs are a gateway technology to a full BEV market.
Plug-in hybrid electric vehicle (PHEV)	Can be plugged in to charge for electric-powered driving but also has an ICE for extending range. The battery capacity of a PHEV is usually around 50 miles, which is much smaller than for a BEV. The PHEV typically is able to drive in an all-electric mode while the battery power lasts. The battery range likely covers most urban driving needs. Once the energy in the battery is depleted, the ICE starts up and becomes the primary source of driving energy.	The biggest obstacles for the PHEV are the high cost of the vehicle and the lack of availability of models to choose from as carmakers have retired some models due to lack of profitability.
Fuel cell electric vehicle (FEV or FCEV)	Electric energy is generated by a fuel cell that uses hydrogen. A hydrogen tank is therefore the energy storage system in an FCEV instead of a battery.	Not very popular for passenger cars due to lack of infrastructure and availability of hydrogen. Fuel cells are considered more appropriate for long-distance trucks.
Battery Electric Vehicle (BEV)	**100% electric and able to recharge through a direct electrical connection, usually via a plug from a commercial charger or a home connection. Battery capacity of BEVs is typically around a 300-mile range for passenger cars.**	**Lack of charging infrastructure, time to charge, and upfront cost of the vehicle.**

Our analysis will focus on BEVs. We acknowledge that HEVs can be a transition vehicle for the market; hybrids have provided a technological proving ground and consumer introduction for a modern battery-based vehicle. However, HEVs and PHEVs do not represent a fundamental shift in fueling infrastructure, component lists or production processes. They remain fundamentally dependent on ICE technology. While many of the consumer attractions for purchasing HEVs are the same as for BEVs, such as environmental friendliness, fuel efficiency, and adoption of new technology, the shifts in the HEV supply chain are not as large as with BEVs.

On the other hand, FCEVs depend on new market factors and also demand a sea change in infrastructure and the supply chain. However, penetration of FCEVs in the light-duty space in North America is forecast to be over 30 years away and may never materialize. In North America, FCEVs are still an experimental and niche technology and when commercialized may relate only to the heavy-duty and commercial segment (see Other Opportunity Areas section below). While hydrogen may be ascendant in countries such as Japan and South Korea in the light-duty market, North America currently lacks the infrastructure to make a hydrogen transition for vehicle fueling. Hydrogen, it should be noted, is an energy carrier and not a fuel source on its own.

Even in a BEV market, vehicles could be powered by hydrogen if electricity generation is hydrogen-based. Many inroads are being made by hydrogen into multiple sectors, but at this time there is simply no production of hydrogen at scale to produce a full transition. Although FCEV cars have been commercially available for about a decade, registrations remain more than two orders of magnitude lower than EVs (IEA Global EV Outlook, 2022). This is due, in part, to the lack of widely available hydrogen refueling stations and the fact that FCEVs cannot be charged at home, unlike EVs.

Hydrogen

Increasing attention is being paid to hydrogen as an alternative method for carrying and storing energy as part of a broader push for lower-emission vehicles. While still in its early stage of development, hydrogen demand is projected to grow five-fold by 2050, driven by the transportation sector (road, maritime, and aviation) (McKinsey, 2022). On the supply side, hydrogen is expected to shift to 95% "clean" production by 2050, driven by policy and cost savings from technology advancements (McKinsey, 2022). Depending on its method of production, hydrogen can be more or less clean; see **Figure 2** for some of the most common types of hydrogen production (Pembina Institute, 2020).

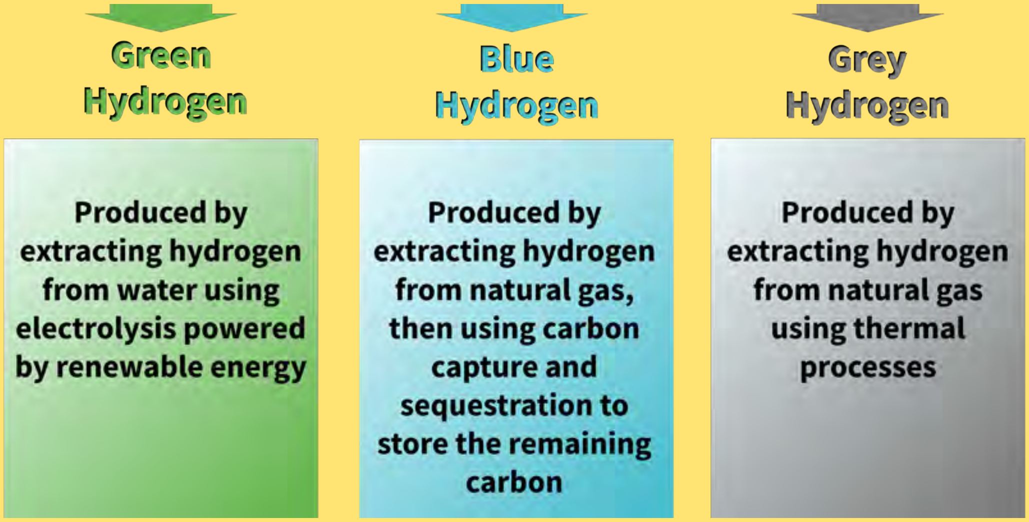


Figure 2: Common types of hydrogen production

After hydrogen is produced it must be delivered to its point of use. It is one of the lightest elements on earth and must be pressurized for transport, either as a compressed gas or liquid. Some of the necessary transport and storage infrastructure is already in place – such as pipelines, cryogenic liquid tanker trucks, gaseous tube trailers, storage facilities, compressors, etc. – as hydrogen has long been used in industrial applications. However, advancements in technology and expansions of supply chains will be needed to scale the infrastructure, and even then, there will be challenges in cost and efficiency depending on where and how much hydrogen is produced, where and how much hydrogen is needed and other factors (U.S. Department of Energy, n.d.).

As referenced, the heavy-duty commercial segment – specifically long-haul trucks – will likely be the most promising and commercially viable opportunity for hydrogen fuel cell vehicles. This segment has a large role to play in decarbonization goals, and hydrogen offers several cost and practicality benefits over batteries for these vehicles given their size and driving patterns. For instance, while neither technology produces tailpipe emissions, hydrogen fuel tanks weigh much less than batteries, and they can be refilled much faster than a battery recharges. A disadvantage is that while charging and other EV infrastructure and services are growing rapidly, a transition to hydrogen will require a completely different and no less significant investment in new infrastructure and means of operating (e.g., driver retraining, refueling stations, new types of maintenance, etc.). There are some indications that this segment is moving toward hydrogen, at least on a pilot basis. Daimler, the world's largest maker of heavy trucks, recently began testing a prototype hydrogen fuel cell truck (GenH2). They are also testing business model innovations to tackle infrastructure challenges, including a new partnership with Shell to build a corridor of hydrogen fueling stations in Europe, and a joint venture with rival Volvo Trucks to develop new fuel cell systems for power over long distances.

B. Drivers and barriers

Drivers of BEV dominance include the lack of tailpipe emissions (non-point source), consumer demand for pure EVs, and government incentives for the transition. Efficiency also plays a big role, as electric motors are much more efficient at converting energy to power a vehicle (90%) compared to internal combustion engines (25-50%), which significantly lowers the cost of operating EVs (NRDC, 2019).

Emissions are the number one driver of BEV promotion at the policy level. The carbon emissions from light-duty vehicles comprise a significant portion of the transport sector's greenhouse gas (GHG) emissions – 58% in the U.S. (Woody et al., 2022). Tailpipe emissions globally were estimated to cause approximately 38,000 deaths in 2015 from particulate matter emissions and the release of nitrous oxide (NOx) (ICCT, 2017).

Besides direct deaths, these pollutants, along with sulfur dioxide, leaded fuels, and smog are implicated in other serious health issues such as kidney disease, cognitive issues, and asthma.

BEVs eliminate these "non-point-source" pollutants and are classified as zero emission vehicles (ZEVs). Nevertheless, emissions are still created in the generation of electricity when the power plant's energy source is non-renewable (e.g., coal, etc.) and even to a lesser extent when the energy source is renewable (from the manufacturing of wind turbines, solar panels, batteries, etc.).
However, an opportunity presents itself with renewable electricity production and additional emissions measures applied at the "point-source" of electricity production. When coupled with renewable energy sources, transport electrification has the greatest potential to achieve climate-related goals.

Governments incentivize the use of these vehicles by either monetary credits for BEV purchase or via tariffs for use of non-BEV technologies. The toolbox available to policy makers includes tolls and license plate driving restrictions, incentives, and others.

Overall, governments are increasingly announcing targets for phasing out sales of new ICE vehicles (**Figure 3**). In Europe, for instance, lawmakers recently supported a proposal, made by the European Commission last year, to require a 100% reduction in CO_2 emissions from new cars by 2035, which would make it impossible to sell fossil fuel-powered vehicles in the E.U. from that date.

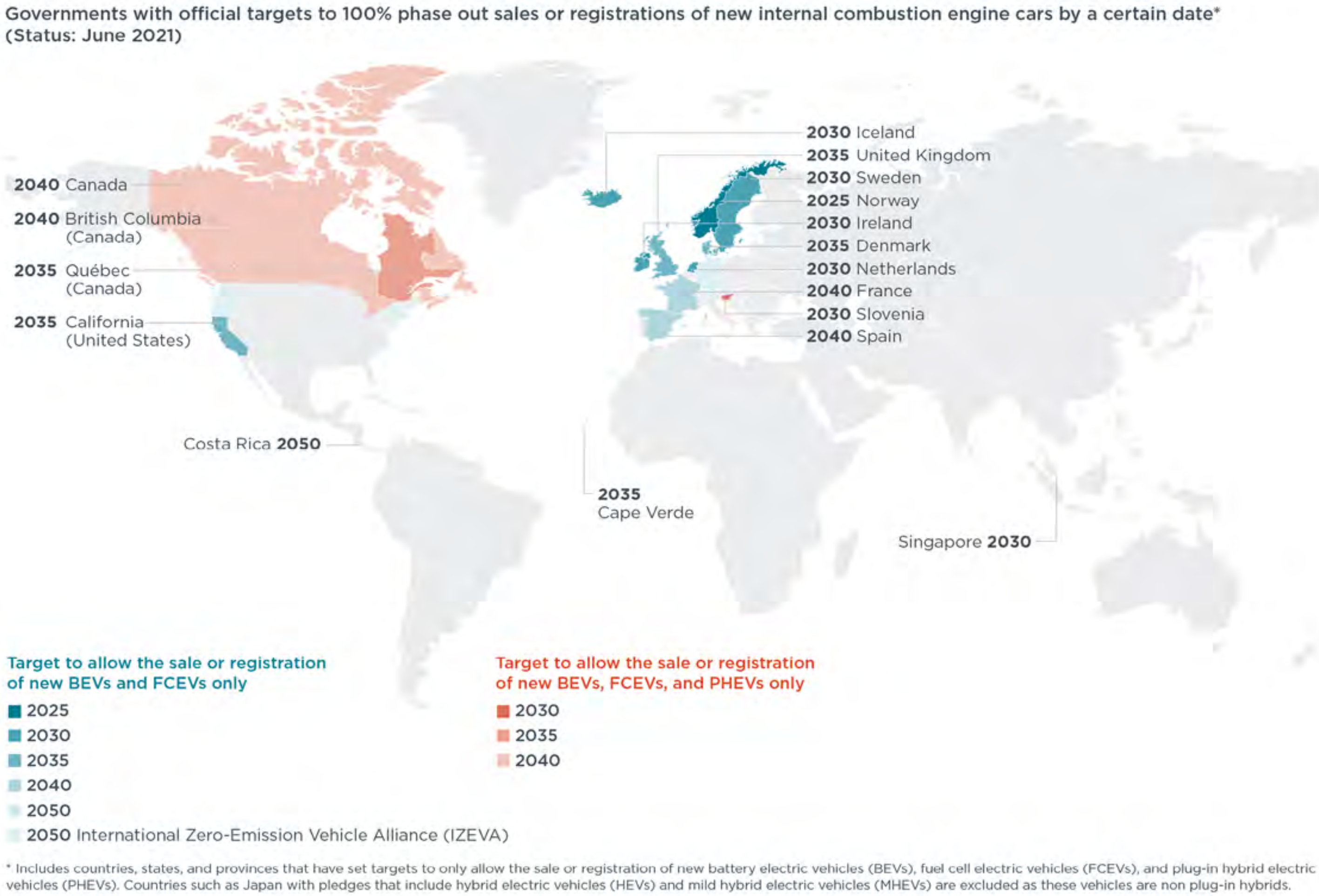


Figure 3: Government targets for ICE phase-outs
Source: International Council on Clean Transportation

In the U.S., the Biden administration has announced a 50% electrification target for 2030, more stringent fleet emissions targets, and strong investments in charging infrastructure, such as the $5 billion, 5-year National Electric Vehicle Infrastructure (NEVI) program to help states create a network of EV charging stations, supported by a newly created Joint Office of Energy and Transportation.

Further, in August 2022, a major bill devoting almost $370 billion to clean energy initiatives over the next decade, the Inflation Reduction Act (IRA), was signed into law. The IRA represents a substantial industrial policy to make clean energy cheaper in the U.S. and is expected to supercharge the transition to EVs through significant incentives designed to spur EV adoption and manufacturing. These are tied to specific, escalating content requirements for EV battery pack assembly, sourcing of critical minerals, and final assembly (must be exclusively from North America or its free trade partners, on all counts).

Along with government action – and often driven by it – the industry in North America has also reached a turning point regarding electrification, with ambitious goals by many original equipment manufacturers (OEMs) to begin producing EVs at scale. In the U.S., the Big Three automakers— Ford, General Motors, and Stellantis FCA (formerly Chrysler) — have made various commitments to convert more of their production lines to EVs, as outlined in **Table 3.**

Table 3: Big Three Electrification Goals

Company	Ford Motor Company[1]	General Motors[2]	Stellantis[3]
Goal	50% of sales to come from EVs by 2030.	100% of global sales to come from EVs by 2035.	100% of European sales and 50% of North American sales to come from EVs by 2030.
Strategy	Ford will focus first on electrifying its top-selling models, most notably the F-150 Lightning pickup, whose gas-powered version has been a top seller for four decades. Also, Ford has split its business into two lines: Ford Model e for its EVs and Ford Blue for ICE vehicles, recognizing that a different approach is needed for EV production.	GM plans to launch 30 new EVs globally by 2025, almost all of them new models rather than updates to older ones.	In North America, Stellantis has focused to date on plug-in hybrid versions of popular models, but it plans to launch at least 25 new EV nameplates.

Sources: [1]Fortune, 2022, Bloomberg 2022; [2]Fortune, 2022; [3]Fortune 2022

Similarly financial investments in battery and EV manufacturing by automakers in North America are also on the rise. (**Figure 4**).

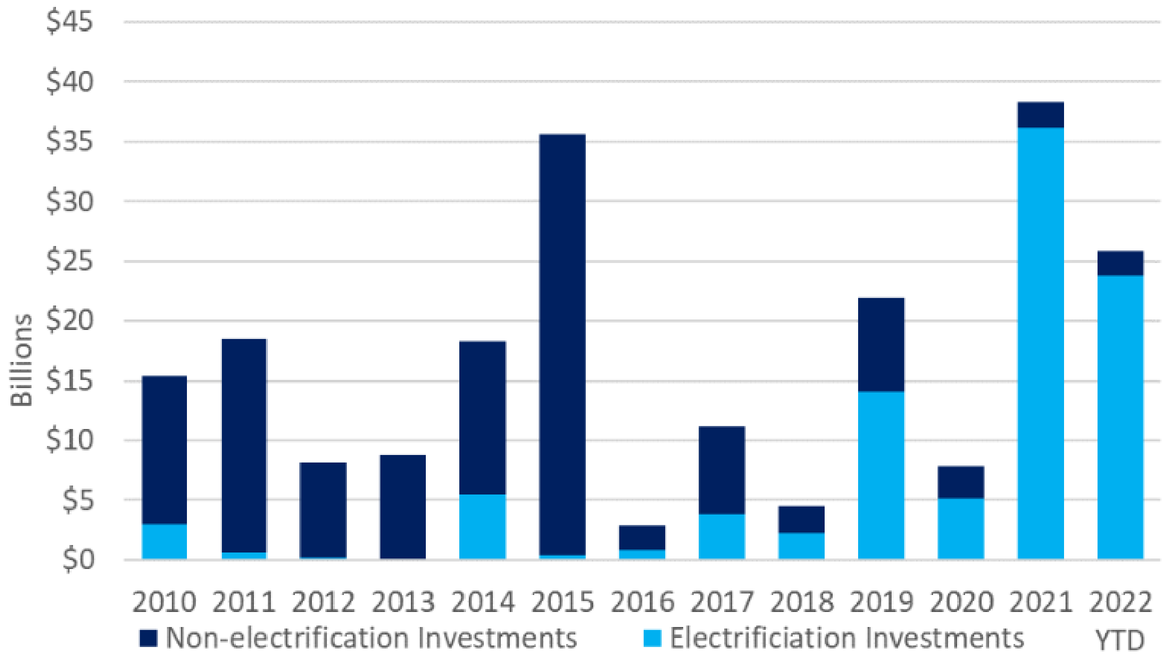


Figure 4: Announced EV, battery and related investments by automakers.
Source: Center for Automotive Research, 2022.

A key barrier for BEVs is their much higher price point. Currently, BEVs are generally not affordable for the mass market, even with incentives. The powertrain of a BEV is essentially the battery, and it is the most expensive component, making up ~50% of the cost of the vehicle. While batteries have improved significantly over the last 10 years – correspondingly, prices for lithium-ion batteries have decreased by nearly 90% over that period – major changes are still needed in battery technology to bring the cost down further while expanding range at the same time (Bloomberg NEF, 2022). Further, securing the raw materials necessary to satisfy expected demand will continue to be a challenge.

In addition to the battery, it is often necessary for the consumer to purchase faster-charging infrastructure separately and the cost to install it can average $5,000 in the U.S. The faster-charging infrastructure is almost the price of a used ICE vehicle. Related, the current lack of extensive public charging infrastructure is seen as an important barrier for mass adoption and is an area of increased focus and opportunity for companies. Despite these barriers, consumer interest in EVs is growing – in the U.S., EVs accounted for 5.6% of the total auto market in Q2 of 2022, crossing the 5% threshold, which is considered the tipping point in consumer adoption patterns – the S-curve – after which EVs are expected to go from niche into the mainstream (Bloomberg, 2022).

Technological advancements will continue to drive growth across all aspects of electrification, sending a strong signal to manufacturers to invest more into research and development. We can expect that these investments will drive ever greater technological innovation and improvements, leading to a virtuous cycle of vehicle proliferation, improved performance, and declining costs. Recent analysis indicates that further cost reductions will lead to price parity between EVs and ICE vehicles by 2025, without subsidies (Bloomberg NEF).

It should be noted that adoption will not occur consistently across regions – already there is an adoption gap between developed and emerging economies, and penetration will develop across different segments and at different times, as our examination of the various markets will illustrate.

C. Key implications

The shift from ICE to BEV technology (EVs for simplicity going forward in this report) is not merely a change of one production step. The entire automotive industry was built around the internal combustion engine – a 120-year-old industry undergoing a seismic technology shift. Some analyses indicate that, given the acceleration in EV adoption and related investments, combustion vehicle sales peaked globally in 2017 and are now in permanent decline (Bloomberg NEF, 2022).

This decline has far-reaching implications, and it requires automakers and all players throughout the mobility ecosystem – i.e., those involved in providing a myriad of services that move people and goods around the globe – to invest in and prepare for the future. This transition goes beyond moving from ICE powertrains to electric ones; it requires drastic changes to the automotive supply chain and will push the companies involved to reimagine their business models. Its scope also goes beyond the boundaries of the transportation industry and deeper into the energy industry, which brings its own set of implications (see sidebar: Energy Implications).

Energy Implications

Vehicles will be truly zero-emission only if the electricity used to produce and power them comes from clean sources. With decarbonization comes greater deployment of decentralized and variable renewable energy sources, as well as increased demand for electricity as transport moves toward electrification. These changes will make the management of the electricity grid more complex. Extensive updates to grid infrastructure and innovations in distribution will be required in the long term; given the investments required, pilot projects and other efforts are needed in the short term.

While many higher income markets have extensive existing, older grid infrastructure that will need to be updated, there are opportunities for countries without extensive existing grid infrastructure to leapfrog these challenges. Even without increased electrification and use of renewables, grid stability and congestion are already an issue in some parts of developed and emerging markets alike. Increased EV loads may exacerbate some of these challenges, but the type and degree of challenge will depend on location and the supply, demand, and state of infrastructure in each place.

Automakers' main concerns will be generating electric power and integrating fast-evolving digital technology, as well as securing access to critical inputs of the supply chain, whether that occurs via vertical integration moves that improve access to batteries or joint ventures and partnerships to ensure they can remain competitive in an increasingly crowded field. Because technology is at the center of this transition, companies outside the traditional automotive industry are able to enter the market more easily than before, and some have indeed reached scale faster than legacy companies.

The effects of this transition will be felt upstream and downstream, and the supply and value chains will look different as the industry moves to prioritize EV production over ICE vehicles, with manufacturers of ICE-specific parts running the risk of becoming obsolete, for example. Conversely, demand for electrified powertrains and related electronic components for EVs will grow exponentially. The transition also brings additions to the traditional automotive value chain, such as the battery, the charging infrastructure required for EV adoption, and a number of support services focused on improving the customer experience that are gaining prominence as digital technologies and innovative business models become the norm. We delve into the opportunities in these areas in the following section.

III. Trends and opportunities

While the transition to e-mobility brings a significant disruption and change to the way we power mobility, it also brings new opportunities for products, services, and solutions that can create value in the market while helping us reach critical climate goals.

And since the technology and parts that are involved in EV production are so different, it is not obvious that those who succeeded in the ICE world are best-suited to succeed as we transition to EVs – incumbency therefore does not guarantee success, even though many of the factors that have contributed to that success (high quality, low costs, etc.) are certainly applicable to building EVs. Ultimately, this shift requires a high degree of agility and flexibility from companies interested in capturing market share. This creates an opportunity for new companies to compete all along the EV value chain.

Therefore, identifying areas of potential growth and understanding the trends driving these opportunities can provide a competitive edge for mobility players seeking to navigate this transition. To that end, we present below a list of areas that are expected to grow significantly over the next 5-10 years. To develop this list, we analyzed the value chains involved in EV production and adoption (vehicles, batteries, charging, etc.), focusing on the links that present the most changes in the transition from ICE to EV (see **Figure 5**).

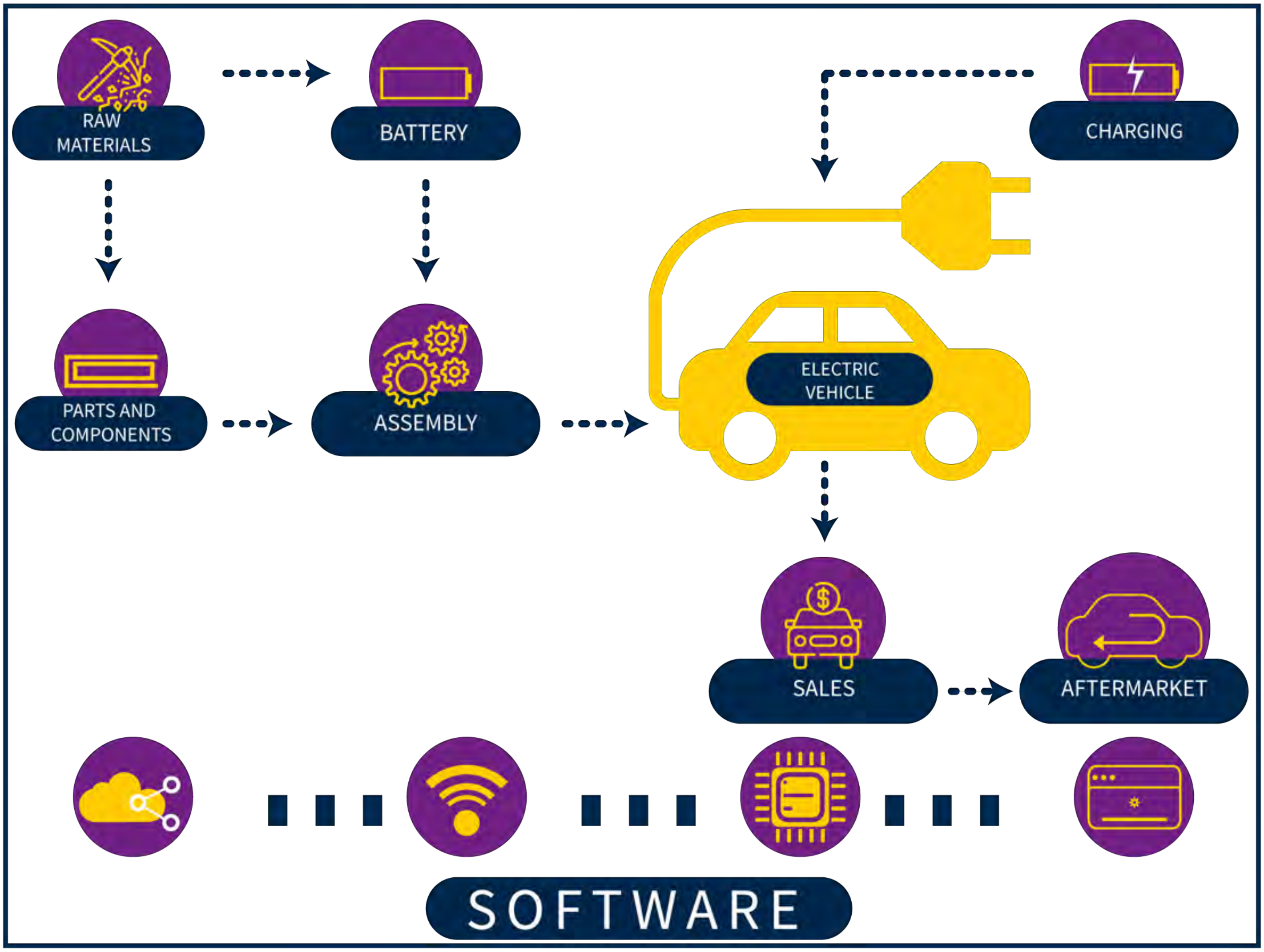


Figure 5: EV value chain

For each link in the value chain, we include prospective trends and related opportunities. It should be noted that the list of trends and opportunities is not exhaustive – we highlight the areas that we believe present the most obvious opportunities at this time and that offer the highest potential for growth. As the market matures, other opportunities will likely be uncovered. Because many of these opportunities are new, they require different or new skills and expertise. Therefore, for each area we include an illustrative list of skills and domains of expertise that will be needed to take advantage of these opportunities, with talent development considerations in mind.

Importantly, the primary focus of our analysis is the light-duty vehicles segment because of its market dominance and the significant manufacturing occurring in North America (and specifically in the U.S. and Mexico currently), which presents more immediate opportunities. Nevertheless, in Section B we also highlight a few opportunities outside this segment.

A. Light-duty vehicles

i. Raw materials

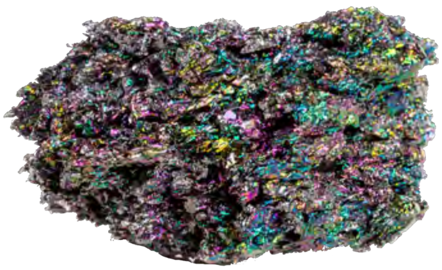
Raw materials are the primary inputs from which the parts and components necessary to build a vehicle are made. Traditionally, iron, steel, aluminum, glass, rubber, copper, petroleum products, and more have been used in vehicle manufacturing. There are key considerations in EV production that call for different materials. In EVs, the fuel tanks are replaced with large battery packs that make up as much as one-third of the total vehicle weight. Reducing vehicle mass becomes critical for extending the range of EVs because less weight increases energy efficiency.

To achieve these mass savings throughout the vehicle, the use of lighter materials that can reduce weight while maintaining strength and integrity is a key concern. This is known as “light weighting.” While light-weighting strategies have been used when manufacturing ICE vehicles as a way to improve fuel economy, the benefit of using them is much higher with EVs for the aforementioned reasons, and it will continue to be a focus going forward.

Material selection in EVs is driven by design optimization, durability, safety, light weighting, ride experience, and need for connectivity, among other factors. Some of the materials whose demand is expected to grow with increased EV production are aluminum, advanced plastics, composites (a mix of polypropylene, a polymer used to make plastics, and fiberglass), magnesium, steel, and copper. Copper, in particular, is a major component of EVs because of its high electrical conductivity, durability, and malleability, with the average EV containing almost four times as much copper as ICE vehicles. Considering its use in EVs and its applications on renewable energy technologies, demand for copper is expected to grow exponentially. Indeed, Goldman Sachs predicts that by 2030, copper demand will grow nearly 600% to 5.4 million tons (USGI, 2021). Lithium and other minerals are of course important for EV batteries; we discuss these in the Battery section below.

Copper

Steel



Silicon carbide

Another important material is silicon carbide (SiC), which is slowly replacing silicon use in power electronics for EVs. SiC is an extremely hard, synthetically produced crystalline compound of silicon and carbon, and is used in semiconductor chips for EV systems such as the inverter to enable power efficiency. It is well suited to high voltage applications, and it has higher thermal conductivity (Automotive World, 2019). While SiC still faces challenges in material production cost (it is notoriously difficult to produce), production capacity, and system integration, the industry seems to be moving toward SiC adoption. This trend, coupled with the rapidly accelerating push for electrification, is creating more opportunities for developing SiC supply chains to support EV production (Catapult, 2021).

Other key considerations when selecting raw materials are sustainability and cost effectiveness. Inflation and supply chain disruptions currently cause high prices for many raw materials. These constraints may hinder planned EV production and short-term market penetration. Related, the concept of circularity – to reuse and recycle materials as much as possible – is expected to take a more prominent role across the industry because it leads to reduced resource consumption, decreasing costs, and contribution to sustainability efforts.

Key opportunities	Description
Producing aluminum, copper, steel, magnesium	These are metals and alloy used in EV manufacturing because of their light weight and other properties. Demand for these materials is expected to grow hugely.
Manufacturing of SiC	Trends point toward increasing demand for SiC for use in EVs, in addition to applications in the energy sector, such as for solar. While the manufacturing process of SiC is complex, and the entry barriers are high, developing a supply chain for SiC represents an opportunity going forward.
Developing of new materials	These include advanced lightweight plastics and composites. A mixed-materials approach using metals and composites in EV design is likely to grow based on the need to reduce weight and costs.
Recycling of materials	Recycling processes for aluminum, copper, and other materials that help optimize resources will grow in importance as EV uptake increases.

Skills and expertise

- Materials science
- Materials selection in automotive design
- Lightweight automotive alloys
- Designing and manufacturing with lightweight automotive materials

ii. Batteries

Battery packs replace the fuel tank in EVs, making them one of the most important parts of the vehicle and a new addition relative to the traditional automotive value chain. As mentioned above, batteries account for approximately 50% of the vehicle cost, which is often cited as a key barrier to EV adoption. Prices for lithium-ion (Li-ion) batteries – the current dominant battery type – have decreased by 89% over the past decade, owing to technology advancements and increases in production volume (Bloomberg NEF, 2022). However, a continued decline is not guaranteed. The price of lithium has risen approximately 900% in the past year and a half (as of mid-2022) and recent reports indicate that battery cell prices may surge 22% from 2023-2026 before leveling out or declining again (CNBC, 2022). The cost of obtaining raw materials and current scarcity of key materials play a major role in driving prices up.

By some projections the market for EV batteries could increase to over $80 billion by 2025 (McKinsey, 2022). China currently produces approximately 75% of all Li-ion batteries, and global battery supply chains are concentrated in China (Bloomberg, 2022). Europe, the U.S., South Korea, and Japan also play roles in global battery supply chains, but they are more minor at present. There are opportunities along the entire battery value chain (**Figure 6**).

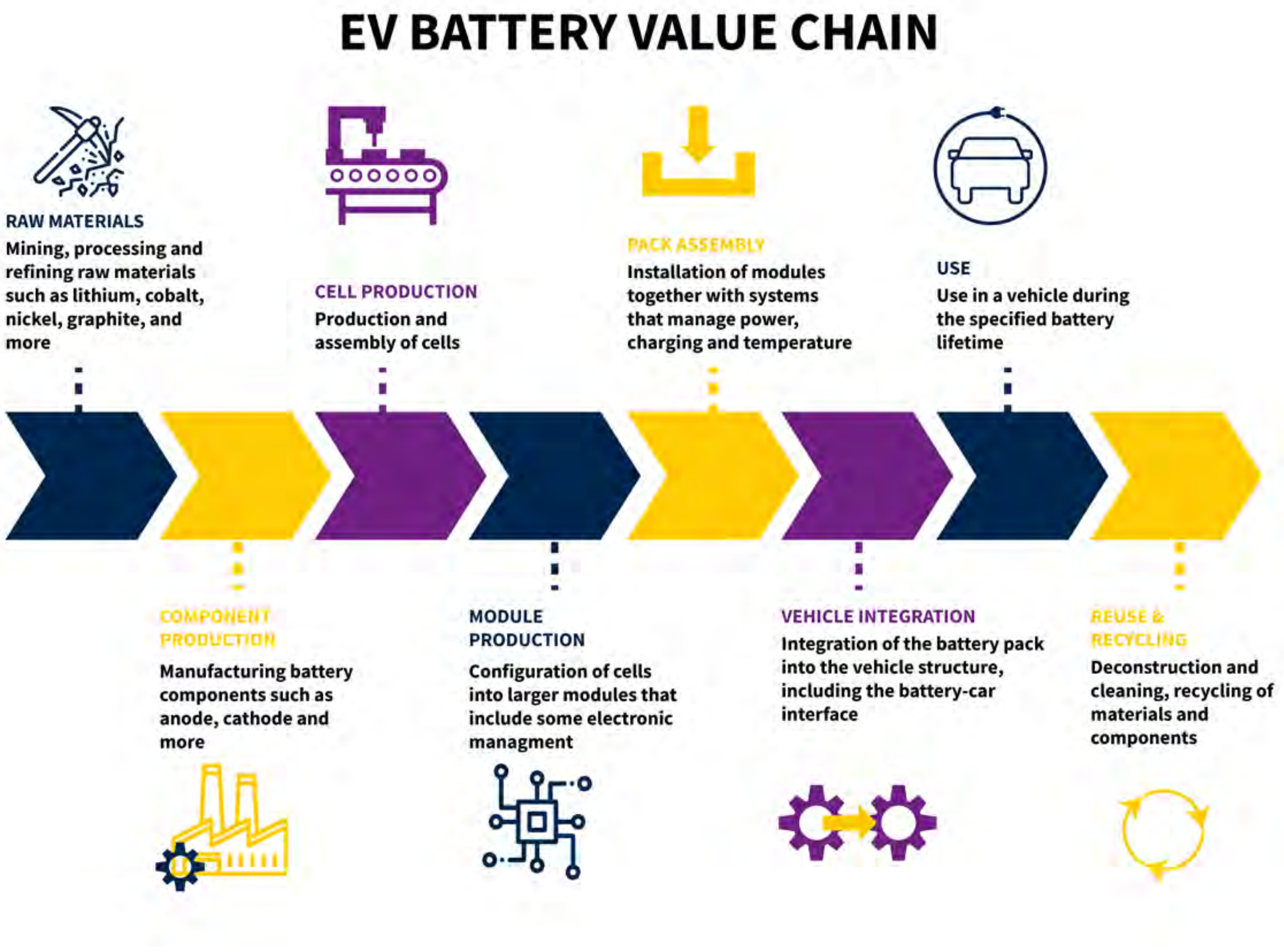


Figure 6: EV Battery Value Chain
Adapted from source: Jussani, Wright, Ibusuki, 2017.

Several critical minerals and other materials are required for battery production. There are currently a small number of major players involved in the extraction phase, some of which are new to the automotive sector. Different necessary raw materials are largely present in specific, limited locations, including regions of China, Africa, Australia, and South America. As with mining more generally, there are critical issues related to sustainability (such as energy use, water use, and pollution), displacement of populations (human, animal, and plant), and more that need to be addressed moving forward. Additionally, challenges are coming related to supply and demand. Companies will need to develop new production sites to meet increasing demand – demand for lithium, for example, is expected to grow by a compound annual growth rate (CAGR) of more than 25% through 2030 – which is challenging given the lead times and intensive processes needed to ramp up production (BCG, 2022).

After the raw materials are produced and processed, the battery's key components need to be built and assembled. This is a complex process that involves the battery module, the electronics, and the case/housing. Once installed and in use in a vehicle, batteries have specified operating parameters in terms of their charge and range. Over time batteries can hold less charge, resulting in shorter range and more frequent charging. Eventually they reach the end of their usable life in cars; the current prediction is 10-20 years of use before EV batteries require replacement (McKinsey, 2022).

As is the case with raw materials, circularity is a principle that is becoming increasingly important in battery life cycles to reduce negative environmental and social impacts and reduce costs. Circular economy strategies can take the form of second life applications and recycling and reusing battery materials and components. Opportunities in recycling involve dismantling batteries, sorting materials by chemistry, and selling different materials to different players. While there are promising initial efforts at these, the follow-through requires large commercial facilities and involves energy- and cost-intensive processes. Robotics, artificial intelligence, and other advanced technologies are expected to play a role in making battery recycling more effective and cost-efficient, given the large number of batteries that will need to be recycled.

Second life applications involve repurposing batteries for use in other energy storage applications such as storage for community level solar or other renewables. So far, these types of efforts are still in their infancy, and many predict they will not grow without regulation and dramatic scaling of EV production and adoption. At present there is not much clarity or consistency from a regulatory perspective about which players need to bear which costs in terms of responsible disposal or recycling/reuse of batteries, though there is some progress at global and local levels. For instance, the Global Battery Alliance was recently launched, convening over 70 organizations from across the battery value chain to create a battery "passport" framework that would promote circularity throughout the battery supply chain.

While much of the focus is on the now-dominant Li-ion batteries, researchers and manufacturers continue to explore innovations that would address current industry constraints such as raw material shortages, safety risks with flammable liquid electrolytes, human rights concerns with mining operations, and more. There are several different types of batteries under exploration and development (see **Table 4**), and there is much excitement about solid state batteries as a wave of the future. With these, the flammable liquid electrolytes that enable charging and discharging are replaced with ceramics, glass, or polymers to make batteries that are safer, smaller, and quicker to charge (The Washington Post, 2022).

Table 4: Key Battery Types for Electric Vehicles

Battery type	Use and status
Lithium-ion	Different types currently in use in BEVs and PHEVs; development of next-generation versions is under way.
Nickel-metal hydride	Currently in use in HEVs.
Lead-acid	Advanced high-power batteries in development for ancillary loads.
Ultracapacitors	Currently in use to provide additional power and as secondary energy-storage devices.
Lithium-sulfur	In development, approaching prototype stage.
Sodium-ion	In development.
Solid state	This is a category that may involve polymers, ceramics, or more; currently in development and testing phase.

Sources: U.S Department of Energy Alternative Fuels Data Center, Saft.

There is now a race to capture larger shares of the fast-growing battery market, and there are shifts in how different players are engaging in different parts of the value chain. Given resource constraints and the need to ramp up battery manufacturing, OEMs are shifting away from exclusive battery supply agreements and toward working with multiple players for battery cells and power electronics, as well as exploring in-house production of battery modules, battery packs, and electric motors (Automotive from UltimaMedia, 2021). While different players vie to increase their share of the pie, the size of the pie will also grow dramatically as supply chain, technology, and manufacturing improvements are made.

Key opportunities	Description
Mining, refining, processing of battery raw materials	A variety of raw materials is needed (as noted above) to produce batteries. There are opportunities to improve mining sustainability and expand operations to new locations to match increasing demand.
Battery manufacturing	Manufacturing high-power batteries for EVs is significantly more complex than making low-power batteries. This requires chemical engineering know-how. Li-ion battery manufacturing has the potential of creating jobs throughout the value chain because it is very labor-intensive.
Developing solutions for battery housing	Housing protects batteries from environmental hazards and aids in battery thermal management. Current solutions are at the early stage of development, and many are not yet commercially viable, so there is opportunity for technology innovation and new market entrants.
Battery swapping services	Battery swapping services involve renting a battery at one charging station and returning it to another. The manufacturer owns the battery, tracks its usage and location, and exchanges it between different vehicles. This reduces the upfront cost and usage cost for the EV owner. Because of these efficiencies, battery swapping could lead to greater adoption of EVs. This is being implemented in a limited way in China and Europe for passenger vehicles but is not widespread yet.
Battery replacement services	Current Li-ion battery technology will not last as long (5-6 years) as the rest of the EV parts and systems, so batteries can be replaced. This can be an opportunity for OEMs, battery manufacturers, service providers, and other businesses as EV adoption grows.
Battery diagnostics systems	The ability to accurately assess the battery “state of health” and “state of charge” is important for understanding and optimizing battery performance. Battery diagnostics systems will provide important data for OEMs determining which batteries to use in their EVs and all other players (e.g., battery manufacturers, second life solutions, etc.) to determine how to optimize the use and re-use of each battery.
Developing second-life solutions	Second-life solutions refers to take-back and recycling of Li-ion batteries, including pre-processing such as dismantling, sorting into chemistries, and selling to lead-acid or Li-ion battery recyclers (Siemens Stiftung, 2020). After the battery is no longer useful for an EV, it can be dismantled and different parts used in different ways or repurposed for other applications such as small community energy storage systems – each of which can be an opportunity for businesses.
Battery thermal management systems	Thermal management of battery and motor/electronics is crucial in EVs as the performance of the battery depends on the operating temperature. As more and different types of batteries are used in EVs, there are growing opportunities for optimizing these systems.
Developing solutions for reuse & recycle / e-waste management	Done to meet regulatory requirements in some places given sustainability concerns, e-waste management involves disposing of discarded electronics by suitable techniques to reduce their adverse impacts on the environment. California recently developed policy recommendations on how to handle electric vehicles at the end of their life, which will likely lead to the EV battery recycling market starting to scale in a meaningful way. The recommendations indicate that the OEM will bear ultimate responsibility for end-of-life treatment (California Environmental Protection Agency, 2022).

Skills and expertise

- Sustainable materials design
- Materials science
- Chemical engineering
- Integrated computational materials engineering
- Materials synthesis
- Integration and production at cell, module, and pack levels
- End-of-life management
- Techno-economic assessments

iii. Parts and components

EVs require fewer and different parts and components as compared to ICE vehicles. EVs have no need for the engine and traditional transmission, two of the most crucial components for internal combustion vehicles. EV powertrains are mechanically simpler than ICE powertrains, with fewer moving parts – a few hundred vs. more than 1,000 for ICE (BCG, 2020). Power electronics take a prominent place in EVs, which carry several key components: the electric motor (or motors), the battery, the on-board charger, and the electric power control unit. All are essential to achieve the conversion of the battery's electricity into the mechanical energy that puts the EV in motion. Other key EV components include the inverter (which plays a crucial role in the overall efficiency of the vehicle, converting DC to AC power), and the DC/DC converter, which converts the high voltage DC from the battery to the low voltage operations of the car (lights, infotainment, electric windows, mirrors, and so on). Also, EVs require a lengthier wire harness than ICE vehicles, and specifically high voltage harnesses, to send power and data throughout the vehicle.

Automotive Suppliers

· **Tier 1**: Specialize in making "automotive-grade" hardware directly supplied to OEMs.
· **Tier 2**: Produce smaller parts and components as inputs to T1 suppliers, but also serve non-automotive customers.
· **Tier 3**: Supply diverse companies with raw, or close-to-raw, materials like metal or plastic and other inputs.

Parts and components are provided by suppliers, whether they are Tier 1, 2 or 3 (see box). Suppliers play a critical role in the automotive value chain and are typically dependent on the strategies of the OEMs they serve. Suppliers that produce parts and components used in EVs will see their businesses grow, while those producing ICE-specific products will likely see their revenues shrink.

To name a few: combustion engines, transmissions, exhaust systems and fuel injection systems will phase out with the shift to EVs. In addition, because electric motor components (rotor hubs, stator hubs, magnets and bearings) can be manufactured using smaller and less complex machining methods, producers of machinery and automation equipment for engine-related parts will also be affected (BCG, 2020). Conversely, demand for electric motors, electronics, thermal systems, harnesses, critical safety systems, regenerative braking systems, and semiconductors (see box below) will grow.

Semiconductors

Semiconductors are vital to electric vehicles, which require about twice as many semiconductors as ICE counterparts given the criticality of power electronics to performance (IDTechX, 2021). The automotive industry continues to grapple with the lingering effects of global semiconductor shortages that began in 2020 at the start of the COVID-19 pandemic. Semiconductor chips are widely used in electronics and across various industries, which means that OEMs and Tier 1 suppliers compete with companies in other industries for chips.

Semiconductor manufacturing is largely concentrated in Asia, particularly in China and Taiwan, and efforts to ramp up production have been slow for many reasons, including the fact that substantial capital investment and time are required to build a semiconductor manufacturing facility ("fab"), and because there are long lead times for chip manufacture once the fab is up and running. At the peak of the chip crisis, this led some OEMs to delay, or even halt, vehicle production, while for others it meant not offering specific vehicle features and allocating available chips to their bestselling models. Another consequence is that OEMs have had to revisit their manufacturing strategies – from a just-in-time approach designed to increase efficiency and low inventory costs to one that prioritizes securing extra capacity to withstand possible supply chain disruptions.

This crisis has also led to increased attention being devoted to building supply as close as possible to the production location, which would reduce reliance on one particular player and diminish geopolitical risks. In the U.S, the passage of the Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act in August 2022 is expected to address this risk while fostering domestic high-tech innovation in manufacturing and R&D. CHIPS provides $52.7 billion for semiconductor research, development, manufacturing, and workforce development and is expected to spur the development of a strong domestic semiconductor supply chain over the next ten years.

As of October 2022, the chips shortage continues to disrupt automakers plans and as such further disruptions into 2023 could significantly hinder planned EV production.

Because T1 suppliers are often closely integrated with OEMs, they are locked into the strategic direction the OEM may be taking with regards to the EV transition, and many are evolving with the OEMs. Large T1 suppliers are likely to have greater capacity to plan around market shifts, and many are already providing EV parts and components (e.g., Bosch and Magna created divisions to produce parts and assemblies for EVs (Forbes, 2021)), which helps them retain their customer base.

Promoting inclusive transformation of lower tier suppliers, however, is expected to be a challenge, particularly in the case of smaller companies that typically have less capital, human resources, and resiliency to withstand such large market shifts. T2 and T3 suppliers that heavily rely on automotive customers and whose products are ICE-specific can consider two options: a) diversifying close to their core competencies by exploring opportunities in adjacent industries (e.g., heavy metals for defense industry or aerospace), or b) shifting to produce EV parts and components. The latter generally requires significant financial and human capital investments to convert their operations in order to continue to compete.

It will be crucial for these companies to be able to access support programs that can help them identify potential new markets and develop necessary capabilities – both at the management and the workforce levels – to keep pace with the transition. Two important actions that could help transition these suppliers at risk of obsolescence include a) conducting a more granular mapping of current capabilities relative to parts, components, and services associated with manufacturing of EVs, and b) providing sustained support so the most affected companies can transition and survive the shift.

There may be a learning curve for some suppliers of key EV electronic components, too. Some of these suppliers may be new to automotive and will therefore need to adapt to the intricate complexity of timing, standards, and processes inherent to the industry, which can pose challenges and disruptions for OEMs and related production goals.

Key opportunities	Description
Manufacturing of powertrain and electric components	As discussed above, inverter, DC/DC converter, battery management systems, turbochargers, and onboard chargers, along with other electronic components are central to EV manufacturing and their demand is expected to rise significantly by 2025.
Manufacturing of wire harnesses	The wire harness is an organized collection of cables and connectors that send power and data throughout the vehicle (TechBriefs, 2022). The length of the wire harness in an EV is three times as much as in an ICE vehicle, so demand will increase. Related, wire harness manufacturing is relatively labor-intensive, as different vehicles will require custom-made cable systems for numerous applications.
Manufacturing of semiconductors	Semiconductors are an essential component of vehicle manufacturing, and their importance increases in EVs. The need for a stable and diverse supply of semiconductors will continue and is crucial to enable mass production.
Developing and manufacturing of advanced braking systems	Regenerative braking recharges the battery by using the energy expended from slowing a vehicle. It also drives down maintenance costs by greatly reducing wear and tear on the regular mechanical brake system. The market for advanced braking systems is expected to grow significantly.
Thermal management systems	EVs need optimal temperatures to run efficiently, and thermal management impacts their performance, reliability, and robustness. Thermal management involves the cooling of power electronic systems and the motor, in addition to the battery.
Developing ADAS and sensors	Advanced driver-assistance systems (ADAS), which help with monitoring, warning, braking, and steering tasks, are expected to increase for all vehicles and are increasingly important for EVs.
Developing and manufacturing of X-by-wire technology	X-by-wire refers to the replacement of mechanical or hydraulic systems, such as braking or steering, with electronic ones. It aims to eliminate the physical connection between, for example, the steering wheel and the wheels of a car by using electrically controlled motors to change the direction of the wheels and provide feedback to the driver. Vehicle electrification is expected to boost the market, leading to a substantial increase in the demand for manufacturing of these systems. (Mordor Intelligence, 2022).

Skills and expertise

- Industrial engineering
- Electrical engineering
- Mechanical engineering

iv. Software

As vehicles become “smartphones on wheels,” and the industry moves from hardware to software-defined vehicles, there are increasing opportunities for software companies and other digital-technology players to supply products to automakers. Software allows for many of a vehicle’s features and functions to be enabled “over-the-air” (OTA), that is, wirelessly, as one might receive a wireless update on a smartphone. In EVs, such updates might allow manufacturers to remotely extend the range of EV batteries or enable EV owners to automatically pay for charging infrastructure through vehicle recognition technology, for example (BCG, 2020). In addition, OTA updates have become more prominent as the industry incorporates more sophisticated infotainment and user experience features in vehicles (Aptiv, 2022).

Software plays a critical role in EVs. Software’s complexity in current ICE vehicles is staggering, with many vehicles having 150 million lines or more of code. However, future EVs will likely have triple or more lines of code, as advanced autonomous driving features become available (IEEE Spectrum, 2021). Software allows for more connectivity, supports the increased reliance on data, and can enable numerous vehicle systems and applications, such as managing battery cooling and connecting the power source to vehicle applications. Software is seen as a key driver to profitability growth for automakers, especially in the early stages of EV market growth. Overall, software is expected to represent 50% of the value of the car by 2030 (BCG, 2020).

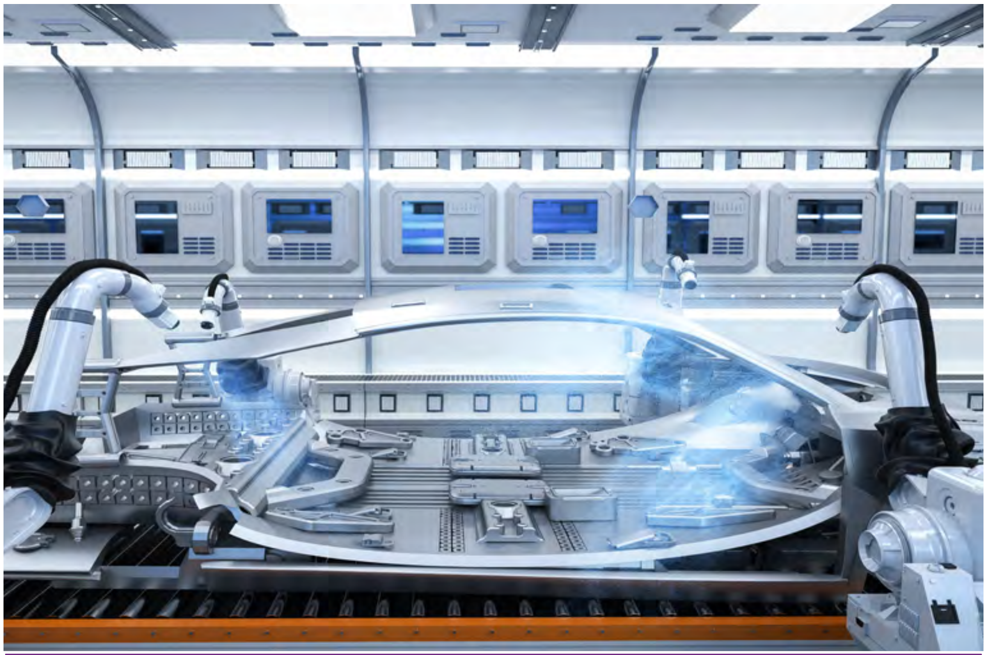
Importantly, as with conventional vehicles, increased connectivity is likely to give rise to cyber vulnerabilities, including the threat of malicious attacks, system outages, bugs, and glitches. There have already been product recalls in the automotive sector related to cyber security. Increasingly, companies and governments proactively identify remote and physical vulnerabilities and explore mitigation strategies, and this area will expand along with scale.

Opportunity	Description
Applications throughout the value chain	Software is central to EVs throughout all stages of vehicle production, from design to manufacturing to vehicle and systems integration. It is also crucial to improve vehicle performance and run diagnostics, enable connectivity services and IoT technologies, and carry out telematics solutions, infotainment services, and many more functions.

Skills and expertise

- Electrical engineering and computer science
- Software development
- Programming
- Cybersecurity

v. Assembly



EVs are generally easier to assemble than ICE vehicles, but key differences add some complexity and are important to highlight. Though EVs require no assembly of fuel piping or exhaust systems, they do require proper placement of high-voltage wiring converters and inverters, installing motor-charging units, and connecting battery cooling tubes, for example (BCG, 2020). The high-voltage systems in particular present new safety threats that OEMs need to account for in their processes. Some parts of the EV assembly process also require greater attention to quality control, and others pose different types of risk and are heavily dependent on reliable suppliers, such as in the case of the batteries.

Many of these differences impact assembly factory setup and operation at OEMs, which means there is a need to retool factory composition to adapt the manufacturing process, which necessitates a tremendous capital investment. Automakers are choosing different paths to produce EVs. Some are using brownfield sites (mixed production of EV with ICE vehicles, typically using flex-cell manufacturing) or greenfield sites (dedicated factories for EV production). Some new EV startups are choosing to build micro-factories instead that rely on automation and technology and can cost significantly less than building a traditional factory. Other startups are choosing an asset-light business model and partnering with contract manufacturers to produce their vehicles, such as Lordstown Motors and Fisker working with Foxconn.

As we move toward 2030, it is likely that more OEMs will leave ICE production behind to focus entirely on EVs, and in the process use original EV platforms rather than conversions from ICE vehicle platforms (Mitchell, 2022). Relevant to this trend, there is increasing interest in standalone modular EV platforms, with some new companies already focused on developing EV platforms from which OEMs can build customized, mission-specific vehicles across segments.

OEMs are also looking at vertically integrating other key parts of EV production to close current gaps, develop in-house capabilities, and reduce the impact of supply chain disruptions. The strategies they choose will create, shift, or eliminate business opportunities for some suppliers and service providers along the value chain, as detailed in other sections of this report.

vi. Sales and aftermarket

Advancements in digitalization and customer preferences are driving radical changes in the traditional model of car sales in general, and these changes are being amplified with EVs, with a trend to move from sales via dealerships toward a direct sales model. The rise of EVs and Tesla's leadership in the EV market – and its move to break the dealership model in the U.S. by selling directly to consumers from the beginning – signaled a shake-up of the traditional sales and distribution model for cars.

Other players, including legacy automakers, are following suit: Ford made its first sales for its electrified sports car, the Mustang Mach-E, online and took online reservations for its electric pickup truck. And the company has announced that it is moving toward 100% online sales (TechCrunch, 2022). Volvo Cars said last year that its electric vehicles – which the automaker says will account for 100 percent of sales by 2030 – will be sold exclusively online. And EV startup Lucid sells directly to consumers, with showrooms where customers can see the vehicles up close and customize them using virtual reality technology. Using digital channels for sales provides more opportunities for mass customization, specifically for EVs. Direct sales will enable automakers to develop closer relationships with customers, which can, in turn, be leveraged to create more products and services and sustain customer engagement after sales. It also gives OEMs better visibility to real demand.

The combination of direct-to-consumer automakers, the unique economics of EVs, and OTA software updates means that the dealership model will likely change, in favor of a leaner model, with physical assets strategically deployed, much less inventory sitting on dealership lots, and greater reliance on transparent online ordering and delivery of EVs. Some dealers are already starting to install charging infrastructure and other amenities catering to EVs as a way of utilizing their real estate and expanding their services, for example. The way this trend plays out will determine the extent to which the sales and distribution model for vehicles will evolve, and this will bring new opportunities.

Following the sale, other changes and opportunities are taking place in the aftermarket. Because EVs have fewer parts and do not require the regular maintenance that ICE vehicles are known for (such as filters, oils, and extensive lubricants), overall demand for servicing will decrease, further reducing a profit area for dealerships. Further, servicing will require more specialized EV capabilities, which is expected to give authorized service centers an edge over roadside mechanics and independent workshops without appropriate certifications. Hence, plans for re-skilling the workforce to handle EVs will be needed in the short term. Industry players are already investing in such efforts. For example, Volvo Cars plans a new EV service facility to train technicians and retailers to better serve their customers. Ford is expanding its training programs, some of which are designed as a pathway for students that may be sponsored at one of the 300+ dealers in the U.S. currently operating mobile service fleets – a service that is likely to grow as EVs become more popular.

Key opportunities	Description
Setting up EV service centers	These will be centers that are certified to provide EV maintenance.
E-conversion of vehicles	Many startups are specializing in the conversion of ICE vehicles by exchanging the fuel tank and combustion engine for Li-ion batteries and electric motors. This reduces investment costs and shows high potential in many contexts.
Developing solutions for reuse & recycle / e-waste management	Done to meet regulatory requirements in some places given sustainability concerns; e-waste management involves disposing of discarded electronics by suitable techniques to reduce their adverse impacts on the environment.
Mobile service fleets	An area of potential growth as EV market penetration increases. It involves traveling to the customers to fix their vehicles at their homes or offices, offering convenience to the customers and less expense for companies since it bypasses the need for retail space, etc. This service is easy to ramp up by adding vehicles to the service fleet.

Skills and expertise

- Mobile maintenance and light repair
- High voltage systems safety
- EV components and operation
- High voltage battery service

vii. Charging

Charging infrastructure is crucial for adoption of EVs at scale. The value chain of charging presents many opportunities for businesses, and involves the manufacture, assembly, installation, and maintenance of a charger; transfer of energy from an outlet to a vehicle; tracking of information about the energy provider and energy recipient; payment from recipient to provider; and maintenance and repair. Chargers must meet government regulations and carmaker requirements. Current technology supports slow charging (AC on-board) and fast charging (AC on-board or DC off-board) (UNIDO, 2020). Most EV charging takes place at home or at work using AC charging for ~8 hours. When on-the-go, public AC slow chargers and DC fast chargers may be available to drivers, depending on location and compatibility with vehicle type. Worldwide, there were approximately 1.8 million publicly accessible charging points in 2021 (IEA, 2022). One-third of these were fast chargers, which as a segment is growing faster than slow chargers (IEA, 2022). China has the most publicly available chargers globally, with ~85% of the world's fast chargers and 55% of slow chargers (IEA, 2022).

While charging infrastructure has experienced much innovation and growth in recent years, several key challenges remain to be addressed. In many countries, there is no single agreed charging standard; each OEM can produce a proprietary charger, resulting in lack of interoperability of charging stations. OEMs may move toward collaborating to create an industry standard. While this standardization would be helpful in some respects, it may also result in too-high charging station utilization in some areas, inconveniencing drivers and serving as a setback for EV adoption (Infosys, 2021). Range anxiety is also often cited as a barrier to EV adoption. It is not only the number of charging stations that is critical, but also their location, type of energy used, and time needed to complete a charge. There is also a wide range of potential charging segments/applications. While charging for homeowners in single-family homes is relatively straightforward, charging at multi-dwelling units and commercial and public properties represents a large segment and differs in terms of availability, accessibility, and affordability based on location.

Companies that own or develop property on which to place charging infrastructure can explore different partnership models with other players for the installation and operation of charging infrastructure. Equity in the deployment of charging infrastructure is a key consideration to ensure that this type of service is available across communities.

Innovations in charger technology and business models can address these challenges and other opportunities. Deployment of fast-charging networks is a major focus for scaling deployment of EVs. While DC fast chargers usually cost more than AC slow chargers, there is an overall higher return on investment for fast chargers due to their shorter charging time and ability to produce more power (UNIDO, 2020).

There are also opportunities to optimize the way chargers are networked to each other, to the grid, and to existing infrastructure, to minimize charging time and contribute to load management and energy distribution with the grid (UNIDO, 2020). As the charging market is relatively new, barriers to entry for newcomers are low and many players are experimenting with different business models.

Charging stations can be owned by a vendor, customer, third party, or a hybrid. Battery swapping is also an option in some cases, especially in markets with unreliable electricity supply. Charging stations can also generate additional revenue streams by providing additional products and services such as digital advertisements. These additional revenue streams can be important in building the business case for installing infrastructure due to current low utilization rates and high capital costs, and they also lend themselves to new types of partnerships. In some places, regulations limit which players can be involved in charging operations (i.e., utilities are not allowed to play an active role in the deployment of charging infrastructure in some countries), but there is a push to create forward-thinking strategies that will encourage the acceleration of charging infrastructure (UNIDO, 2020).

Key opportunities	Description
Manufacturing electric vehicle supply equipment (EVSE)	Companies involved in manufacturing the charging stations can specialize in certain technologies or manufacture a range of products to fit the needs of different vehicle types and markets.
Installation of EVSE	Companies involved in installing charging stations, including complying with property/building codes and connecting with energy sources, have a very large total addressable market with a variety of applications from commercial to public to residential (single family homes, apartment complexes, etc.).
Maintenance	Companies involved in providing preventive servicing and repair maintenance have potential for contracts with manufacturers, installers, operators, and/or owners of the variety of charging station technologies.
Operators	Companies that operate commercial or residential charging stations can also experiment with different partnership and contract types and explore offering supplementary products and services at charging stations.
Platform service providers	These companies manage technology systems for charging and energy management to deliver end-to-end EV charging. Their purview includes the driver experience and the charging operations. There is a need to develop systems and processes that can scale as EV charging scales and enable continuous operations and a seamless experience for drivers.
Innovative charging technologies	Currently, the predominant method of charging EVs is through stationary chargers located at homes, businesses, etc., with the EV attached to the charger via a cord. There are new technologies in the early development and pilot stages that would allow EVs to be charged on-the-go, for instance through wireless connection to another vehicle or through the road upon which the vehicle is traveling. There will be opportunities to invest in infrastructure and design new business models around these new charging technologies.

Skills and expertise

- Electrical engineering
- Mechanical engineering
- Civil engineering
- Installation and maintenance of charging stations
- Utility interconnect requirements
- EV battery types and charging characteristics
- Vehicle charging performance specifications
- First responder safety hazards and requirements

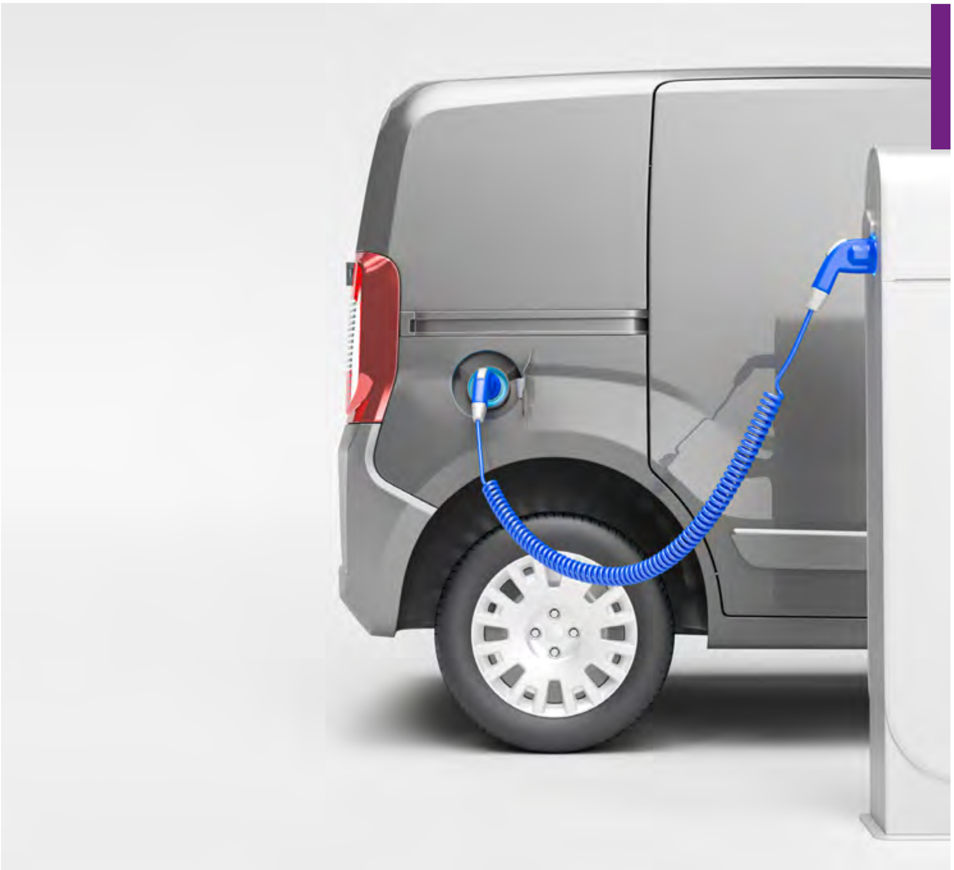
B. Other opportunity areas

In addition to the opportunities highlighted in the previous section, there is growing demand for companies to develop and offer support services around e-mobility solutions that can create value at the ecosystem level by developing efficiencies, adding safety, or otherwise enhancing the customer experience across opportunities. Examples of such services include customized insurance products for EVs, new financial and leasing models to facilitate adoption, digital platforms and innovative business models geared towards specific customer segments, and more. There are many examples of mobility start-ups innovating these types of solutions around the world.

Similarly, there are also opportunities in other segments that are experiencing accelerated electrification, namely fleets, heavy-duty commercial trucks, and ultra-light-duty vehicles. In this section, we present key trends and opportunities at a high level for these segments, relevant to both developed and emerging markets.

i. Commercial and government fleets

There is a strong case for fleet electrification, both from economic and emissions perspectives. Together, public and private fleets account for approximately 40% of energy use in the transport sector, so transitioning these to EVs could have a significant impact on emissions reduction (UNIDO, 2020). Additionally, fleet vehicles have high utilization rates, so they realize EV fuel and maintenance savings faster than vehicles for personal use. Last-mile delivery vehicles and school and public buses serve predictable routes that are well within current battery ranges and can charge overnight in central locations.



Fleets include government vehicles (police cars, public transport buses, school buses, etc.) and commercial vehicles (workforce passenger vehicles, delivery vans and trucks, taxis/ride hailing, and so on). Note that two- and three-wheelers and heavy-duty trucks may also be part of fleets but are discussed in later portions of this report.

Fleet electrification of taxis/ride hailing vehicles can bring opportunities for different ownership and operation models, which can involve partnerships with companies for bulk procurement or incentives for drivers in the network to transition their vehicles. Municipal public transportation is another opportunity for fleet electrification, through replacing older ICE vehicles and promoting local manufacturing of e-buses. Demand for public transit will also increase in areas experiencing rapid urbanization. There is a case for supporting this segment in emerging and developing economies because these vehicle types are most cost competitive. With government and company fleets, there is large potential to both replace and expand; delivery vehicles in particular are expected to grow.

Fleet electrification has major potential for scale and impact in the entire EV value chain. Some of the largest North American fleet operators have committed to transitioning to EVs. Many have joined EV100, a global initiative bringing together companies committed to making electric transport the new normal by 2030 (currently focused on vehicles under 7.5 tons but expanding to heavy-duty trucks soon). Bulk procurement of vehicles has an impact on vehicle manufacturers, charging infrastructure companies, fleet operators, and services providers, and can help create efficiencies of scale and lower costs (UNIDO, 2020). Public transport bus electrification may be an especially promising opportunity to spur local manufacturing and EV adoption in emerging markets where public transportation is a mobility solution for more of the population than are privately owned cars. E-buses have been growing at a faster rate than any other EV segment globally, with a CAGR of 100% since 2013, compared to 60% for passenger vehicles (IEA, 2020).

Key opportunities	Description
Developing fleet management software and related services	Software and other support services are needed to manage the operations of fleets, including gathering data and generating analyses to make decisions. Fleet operators are expected to be one of the largest customer segments and will need software and related services to optimize their fleet deployment.
Developing solutions and services for fleet charging infrastructure	Infrastructure will be needed to charge large numbers of the same types of EVs in the same or distributed locations based on specific schedule and space constraints. There is potential for new technologies and business models, and scale with different charging needs of fleets of EVs in centralized or distributed locations (e.g., scheduling charging, load balancing, accessing enough power, etc.).

ii. Heavy-duty commercial trucks

While there are some similarities in trends and opportunities for electrification across different vehicle segments, the heavy-duty truck segment has some unique features. Heavy-duty trucks are those weighing over 26,000 pounds, often used for freight transport over longer distances on highways. While these comprise a small overall percentage of vehicles on the road, they run frequently, and primarily on diesel fuel, and are responsible for an outsized percentage of global road transport emissions. In the U.S., they account for less than 5% of vehicles on the road but produce over 20% of emissions from the transport sector (U.S. Department of Energy, 2022).

As with other vehicle segments there is increasing attention being paid to electrification to reduce emissions, especially as trucking demand in many large markets (including China, Europe, India, and the U.S.) is expected to more than double by 2050 (Bloomberg, 2022). Hydrogen could also play a role in the future zero emissions strategy for this segment, as discussed earlier in this report. While regulations related to truck emissions are limited or lacking depending on location, early-movers toward truck electrification anticipate such regulations.

There is a range of sentiment on the feasibility of near-term versus long-term electrification of heavy-duty trucks. These trucks require higher-capacity batteries (targeting a range of up to 500 miles), more powerful chargers (including above 1MW) and different configurations of charging stations (in depots, along the highway) than other EV segments. As with other EV segments, the vehicles themselves have higher upfront cost (2-3 times as much as diesel trucks based on current models). Analysis suggests that total cost of ownership for electric trucks will be lower than for diesel, but upfront cost may still be a barrier to adoption, especially as very few long-haul electric trucks have been tested in real road conditions to establish estimated lower maintenance, fueling, and other costs (Autoweek, 2021).

On the infrastructure side there would be very large upfront capital costs needed to electrify highways for this segment, and low initial utilization rates may make it hard to justify the investment. There are similar challenges related to cost and technological advancement for batteries and infrastructure as with the other segments, though analysis suggests that electrification of these vehicles will be a longer-term endeavor given the current status and amount of investment needed.

Even so, major truck companies MAN and Scania have invested $2 billion into electric truck R&D, BYD and Volvo already have day-use heavy trucks on the road as of 2021, and Freightliner and Tesla plan to deliver electric heavy-duty models in 2022. None have yet achieved ideal range for long-haul trucks, but technological advancements are bringing those goals within reach in the medium term, according to some analyses.

Key opportunities	Description
Developing batteries for electric heavy-duty commercial trucks	These batteries will need to be higher capacity than batteries for other EV segments. Existing EV battery makers could expand their product lines or new companies could specialize in battery products to serve this segment.
Developing charging technology and infrastructure for electric heavy-duty commercial trucks	Different types will be needed for this segment. So-called megachargers will be needed for the larger capacity batteries, and infrastructure will need to be built in locations and with features that cater to the routes and schedules of long-haul transport.

iii. Ultra-light-duty vehicles

Ultra-light-duty vehicles (ULDVs), also referred to as micromobility, include a range of small, lightweight vehicles operating at speeds typically below 25 kilometers per hour. These vehicles (e.g., bikes, scooters, mopeds, motorcycles, etc.) can be two-wheelers (2W) and three-wheelers (3W) for personal or commercial use. 2W and 3W are very popular in Asia and Africa and are used as a primary form of transportation. In Africa these vehicles are more likely to be bought new compared to four-wheelers (4W) which are often purchased used; and nine out of 10 in sub-Saharan Africa are purchased for commercial use (Siemens Stiftung, 2020).

In these and other emerging markets, 2W and 3W are well-suited to capital-constrained consumers for personal use and entrepreneurs for commercial use (e.g., taxis, e-cargo bikes for delivery services); use in traffic-clogged urban areas; and use in rural or other areas with road infrastructure that is ill-suited for 4W. Given their prevalence in these markets, 2W and 3W are often seen as a great near-term opportunity in promoting e-mobility transitions.

2W and 3W are also used in more developed markets, and electrification of these vehicles has created opportunities for expanded applications and greater scale of use, for instance as first/last-mile transportation (e.g., e-scooters) and local delivery (e.g., e-bikes), which is booming in many places, propelled in part by COVID-19 restrictions.

2W and 3W are the most prevalent forms of taxis in emerging markets and are a key area for electrification. There are different business model opportunities for operation of taxi fleets or ride hailing in this segment, as well as opportunities to develop new vehicle types suited to this use. Also, most relevant to emerging markets, rural locations with roads that are not suited for 4W and/or lack a reliable grid connection are prime emerging areas for electric 2W and 3W. There is an opportunity to replace ICE or non-motorized ULDVs in these settings, and test different options for off-grid energy provision for charging. Relevant to urban settings in developed and emerging markets alike, last-mile delivery of goods and services to residences or businesses is a fast-growing area that is well-suited to electric 2W and 3W and brings potential for new types of partnerships between businesses in this space. Additionally, deployment of 2W and 3W in relatively centralized, planned and managed communities is suitable for electric 2W and 3W due to the high demand for moving people and goods over relatively short distances and predictable routes. There is an opportunity to use geofencing technology and shared ownership models here.

Electrification of 2W and 3W involves many of the same challenges and opportunities as electrification of 4W vehicles, with some differences worth highlighting. 2W and 3W have a smaller battery, so they can be charged faster and with less energy. This makes them suitable for battery swap models and charging via a mini-grid where electricity from the grid is not available and/or reliable. Geofencing (a technology that can restrict vehicle operations and limit speed based on virtual geographic boundaries), while also applicable to 4W, is already in use with 2W to limit safety hazards and comply with local laws/preferences. Many entrepreneurs and startups – in developed and emerging markets alike – are focusing on the micromobility space, including solar-powered e-bikes, battery swapping stations, 2/3W manufacturing, fleet management, and more.

Key opportunities	Description
Developing innovative charging infrastructure businesses	Charging stations, micro-grids, and their locations. Given the relatively small size of the vehicles and batteries and shorter charging times, there are a lot of opportunities for locating charging stations in different types of sites, offering battery swapping and other services, and more.

IV. Enabling the transition

The landscape of opportunity that the transition to e-mobility presents is rich and varied and is also rapidly evolving. An enabling environment is needed to capitalize upon the opportunities that e-mobility brings, as there are broader conditions that need to be in place to support this shift. To understand what these conditions are, and how they can enable the transition, we examined the experience of six markets, including Michigan and California in the United States, as well as India, China, South Africa and Brazil.

We selected these markets based on two factors: a) presence of or emerging focus on emobility policies and practices, and b) existing automotive manufacturing capacity and ongoing efforts to navigate the e-mobility transition. Below, in **Table 5**, we present a comparative summary of each market studied for additional context. **Appendix A** includes insights from each market in the form of vignettes presenting key features and insights into their approach to facilitating the e-mobility transition, for additional information.

Table 5: Comparative summary of e-mobility in key markets

Market	Key aspects and status of the e-mobility transition
Michigan	■ Global automotive manufacturing hub and headquarters to some of the largest automakers - birthplace of the Model T, the first mass-producer car. ■ Notable state government leadership in future mobility and electrification, with a dedicated cross-agency entity in charge of coordinating mobility initiatives and multiple signature projects. ■ Takes a broad, proactive view beyond electrification to focus on all mobility trends and across sectors, including aeronautical and maritime mobility. ■ Strong, long-standing industry-academia collaboration that drives innovation, R&D, and joint investments in infrastructure and talent. ■ EV adoption is still limited but is picking up: Michigan had approximately 10,500 EVs registered in 2021, which grew to over 16,000 by early 2022 (MiBiz, 2022).
California	■ State-level clean energy policy has played a major role in fast adoption of EVs and growth in EV-related manufacturing. 250,000 EVs were sold in the state in 2021; California has now surpassed 1 million EVs sold there (CA Office of Governor, 2022). ■ Access and equity have been a focus of policies related to infrastructure and financing. ■ Extensive investments in pilot projects, training programs, research, and innovation.
India	■ Emissions-related pollution is a critical concern driving the push towards decarbonization. ■ Strong government commitment to e-mobility, with multiple national and state-level policies and incentive schemes. ■ Focus on both production and adoption; efforts to develop domestic manufacturing capacity are key given the existing automotive workforce. ■ Adoption of electric 2W and 3W is taking place much faster than 4W EVs: in FY2022 (ending March 2022), 17,000 four-wheel EVs were sold in India (compared to 231,000 electric 2W and 3W) (AutoCar India, 2022).

China	■ China is the largest EV market in the world and has the most extensive charging network in the world. In 2021, ~2.9 million BEVs were sold in China (CAAM, 2021) and 1.15 million public charging stations were available (EVCIPA, 2022). ■ Government has played a very strong role in promoting adoption and local businesses involved in manufacturing and more through strong policies, regulations and investments at both national and local levels. ■ Global EV battery supply chain is concentrated in the country. ■ Decarbonization is a challenge while coal continues to be the predominant energy source.
South Africa	■ A near term goal is to prepare the auto manufacturing sector, a vital part of the economy, for the electrification transition. ■ Transition driven by shifts in E.U. and U.S. markets, as those are key export markets for the country. ■ Country-level transport-related strategies have recently been developed, but the country is currently lacking a comprehensive, supportive policy framework for the transition. ■ Longer term goals include supporting adoption through public transit and trucks and transitioning existing local battery production and recycling capacities to support Li-ion. ■ Adoption of EVs in the country is an even longer-term goal: in 2021, 896 EVs were sold in South Africa accounting for 0.19% of the total newvehicle market (Naamsa, 2022).
Brazil	■ Transition to e-mobility is in its early stages, primarily driven by national emissions reductions targets. ■ Ethanol from sugar cane plays a major role in the transport sector in the country driven by major government investments and policies for the past 20+ years. ■ Public transit (bus) and ultra-light-duty-vehicles are key target segments for electrification. ■ Adoption of EVs will be more relevant in the longer term, though it is picking up pace: in 2021, nearly 35,000 EVs were sold in the country, representing an increase of 77% from 2020. Since 2006, ~77,500 EVs have been sold in Brazil (RENAVAM, 2022).

As we analyzed these markets, we worked to identify two main areas. First, we identified the players who have a role in the e-mobility transition, because they are well positioned to create and sustain the conditions needed for this transition by working together with other players. Further, we examined those roles and the dynamic linkages between players to illuminate the different types of relationships and value that can be created through collaboration. And second, we analyzed key transition enablers – and emerging strategies – that some of these players have deployed to accelerate the transition.

Our analysis of these markets, in addition to the interviews we conducted with key experts and mobility stakeholders for this research (see Methodology section for more details), serve as the basis for the insights and early lessons contained in the following sections.

A. Players and roles

Adapting to a technology shift of this magnitude necessitates an enabling environment and ecosystem of support that can make it possible for players to capitalize on the emerging business opportunities. Ecosystems involve a complex web of relationships that create complementarities and interdependencies between players. A business ecosystem is composed of different types of actors from multiple sectors and industries that are needed to create and sustain mutual value. When it comes to facilitating the transition to e-mobility, adopting an ecosystem view can help us identify the complementarities and interdependencies with other actors, and build catalytic linkages to capitalize on the combination of strengths and complementarities to fill gaps.

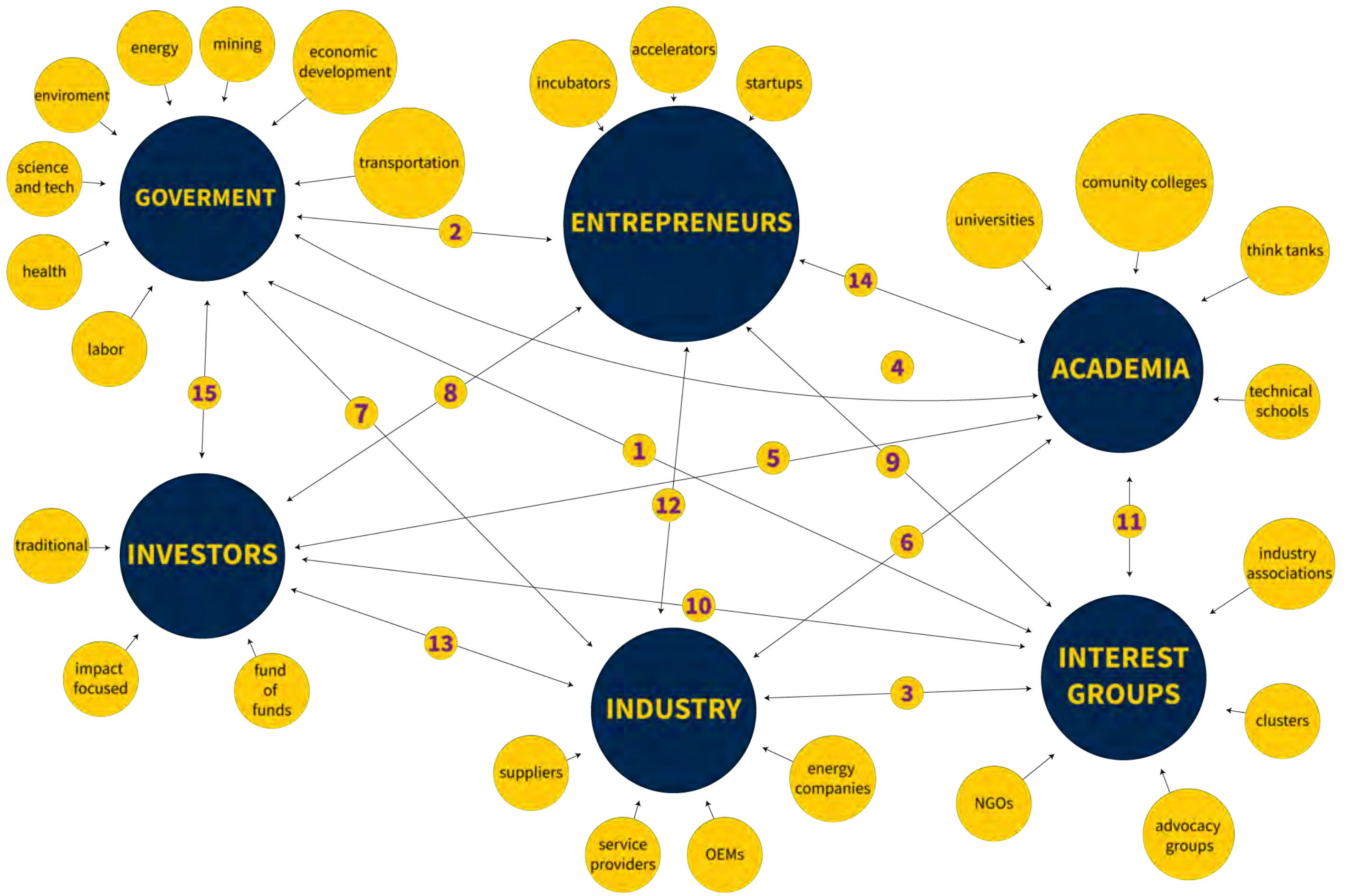
Through our comparative analysis of the selected markets, we identified a list of key players and their roles, in addition to features that surfaced as important in the context of navigating this shift **(Table 6)**. As we consider these features, three important principles related to the interactions between these players should be emphasized: 1) developing and maintaining trust among players is crucial and, in itself, an enabler for effective collaboration; 2) ensuring alignment of priorities and goals, so that resources can be properly allocated should be a priority; and 3) it is crucial to put the needs of the ultimate users, i.e., the local community, at the center of policy action.

Table 6: Players, roles and key features for success

Player	Role	Key features for success
Government	Sets the policy framework that will drive the transition, which spans various government levels, and involves cross-sector government agencies.	■ Multi-agency, cross-sectoral engagement ■ Centers policy on local needs by understanding those first and engaging citizens ■ Develops innovative funding schemes and strategically allocates funding ■ Engages in storytelling to facilitate understanding by the community and drive public opinion
Industry	Includes businesses across industries related to e-mobility: automotive manufacturers, suppliers, service providers, energy companies, etc. They contribute to creating the market for e-mobility solutions, drive innovation forward through both competition and collaboration and provide leadership and share insights on the direction of the market.	■ Laser-focused on innovation ■ Cultivates and maintains strong ties to the community ■ Is willing to make capital investment and able to manage risk
Entrepreneurs	Develop new businesses based on innovation to satisfy market needs. Tech-focused, in a position to disrupt and create new markets.	■ Can rely on an innovation focused ecosystem, resources and tools ■ Leverages connections to industry ■ Can access support programs to launch and scale
Investors	Help develop processes, products, and demonstration projects by new businesses. Guide priorities and growth through targeted allocation of resources.	■ Provides seed funding to help catalyze projects ■ Provides mentorship and expertise to entrepreneurs ■ Mobilizes capital for key investments
Academia	Provides training and education in relevant areas as mobility evolves; develops scientific and other knowledge through R&D that feeds into innovation and strengthens the broader ecosystem; provides a forum for the free exchange of ideas on emerging mobility topics; offers a platform for connecting people and sharing information about innovations.	■ Develops strong linkages to and alignment with industry; uses a variety of channels to engage industry partners ■ Offers diversity of trainings through a variety of modes and for different demographics ■ Leverages resources to engage cross-sector stakeholders and provide opportunities to students, graduates and other players
Interest groups	Industry associations, coalitions, clusters, advocacy groups and other organizations from civil society that have an interest in promoting future mobility in general and e-mobility in particular.	■ Specialize on a particular area or issue; can provide expertise to other players Clearly articulate priorities and promote alignment across their constituents ■ Build a visible platform that enables them to educate the community and increase public awareness

Figure 7 below illustrates different types of linkages between players in the e-mobility ecosystem. While not exhaustive, these highlight specific ways in which players collaborate, compete and coordinate activities and work related to e-mobility. In some cases, the type of interaction is one-directional (i.e., one player providing funding to another) and in other cases the type of interaction is two-way (i.e., sharing information). For simplicity, different interaction types are presented together.

Figure 7: E-mobility ecosystem players and relationship types



RELATIONSHIP KEY

1. Together they collaborate to increase public awareness of issues; interest groups lobby for specific agendas.

2. Entrepreneurs provide information and feedback to improve policies; government creates measures to enable business launch and growth.

3. Together they share information, inform agendas, amplify messages and grow networks.

4. Together they collaborate on education and workforce training; government provides funding for early-stage research; academia provides technical input to policies.

5. Investors provide funding and access to expertise; academia provides access to expertise and other resources for investors and entrepreneurs in their network.

6. Together they collaborate on talent development and engagement; industry also sponsors research, shares data, and commercializes research; academia provides expertise and serves as a platform for exchange of ideas.

7. Together they collaborate on attracting, training and retaining workforce; government sets regulations and policy that governs businesses; industry provides government with input through task forces, etc.

8. Investors provide funding, technical assistance, and access to networks and expertise; entrepreneurs provide new ideas, and financial returns and impact.

9. Together they exchange information and collaborate to move a shared agenda forward.

10. Together they exchange information and resources to move a shared agenda forward.

11. Together they exchange information and collaborate to move a shared agenda forward.

12.Entrepreneurs develop IP / innovations and supply products and services; industry also develops and licenses IP, scales ideas, and provides investment mentorship, expertise, and access to networks.

13. Together they collaborate and/or compete to identify and invest in promising ideas.

14. Academia provides expertise and other resources (e.g. facilities for testing technologies), develops talent; entrepreneurs commercialize research and enable ideas to have impact, and provide employment and engagement opportunities for students, graduates, alumni, faculty, etc.

15. Together they co-fund pilots and programs; government establishes policy and regulations; investors provide input and feedback through task forces, etc.

B. Key enablers & strategies

As illustrated in the previous section, many different players are involved in supporting the transition to e-mobility, and they can interact in many mutually beneficial ways. As we examined the various areas that this transition is impacting, we identified three key enablers of the transition: policy framework, infrastructure and workforce.

We describe each of these enablers below, presenting noteworthy strategies from the markets we studied. It should be noted that we did not assess the strategies included in terms of their effectiveness; indeed, while attention to the transition is growing overall as we have highlighted in this report, it is still early to evaluate impact and results. Instead, we include these takeaways and strategies because they illustrate a) some patterns that were common across contexts and that seemed to be gaining traction to accelerate the transition; and b) innovative or unique features of a particular market that appear to have high potential.

i. Policy framework

Policies are a powerful enabler of the transition to e-mobility. A responsive policy framework helps to set the intention and strategic direction at various levels of policy (subnational, national, etc.); sends a clear signal to market actors about requirements and regulations, and associated timelines; and provides a platform around which other stakeholders can align.

This framework can – and often should – evolve as conditions change and desired results are achieved. Policy typically lags innovation, so efforts to develop policy in a responsive and agile way are key. Many of the policies we reviewed take the form of e-mobility roadmaps; specific EV policies tailored to a state, city, or region; or broad industrial policies intended to support industry development. In some places, a national or state level roadmap/strategy is developed, followed by local and/or sub-sector plans (e.g., specific to EVs and grid infrastructure, battery technology, etc.).

Many are developed for a 3-, 5-year, or longer period; others envision much longer-term planning and might be in place for 10 years or more. And other places choose to develop and revisit policy recommendations annually – approaches vary and depend on context, goals and government priorities. Policies can be an effective tool for engaging public opinion around a strong narrative.

Additionally, the process of developing them presents an opportunity to engage key stakeholders, including the broader community. Policies also play a role in attracting and retaining businesses and investment – a clear framework sends a readiness signal and increases investors' confidence in a market and regulatory environment, which can lead to more available capital to drive growth. Government actions are therefore crucial to determining the direction to follow in the immediate term. E-mobility policies can focus on vehicle production and adoption. Policies designed to encourage local manufacturing of EVs include issuing mandates to require manufacturers to produce a certain number of EVs (or in some cases ban the manufacturing of new ICE vehicles as we have seen recently in Europe); imposing tariffs on imports; providing incentives to attract manufacturing investments, and funding to promote R&D.

They can also be designed to foster innovation and support homegrown startups, as well as to develop the local talent and capacities to support production. Policies related to EV adoption include efforts such as: developing mandatory standards and regulations (including for emissions), offering tax incentives or subsidies for consumers to help with affordability, developing necessary infrastructure, and offering exclusive benefits for adopters (e.g., EV-only lanes, parking spots, free charging, etc.). These efforts must consider the importance of ensuring equitable access to these benefits – particularly by underserved and disadvantaged communities.

Research shows that policies and regulations related to adoption can have a positive effect on production, and vice versa. Moreover, different types of policy tools can work in conjunction with one another, and indeed combining well thought-out policy, regulations, incentives and funding will be most effective in realizing change. Related, effective policy frameworks will likely involve many different agencies and sectors that play a role in the transition to e-mobility – e.g., energy, transport infrastructure, urban planning, trade, public health, climate and energy, labor, education, and more – hence the importance of adopting an ecosystem lens to bring all relevant agencies to the table when developing and implementing policy solutions.

Across all policy types, it is important to describe a clear vision, to include concrete targets and timeframes to achieve them, and to set up monitoring mechanisms to ensure they are implemented.

Of course, public funding is crucial to enabling many of these initiatives, particularly in the early years of the transition, and government players need to identify and allocate resources strategically to pull key levers that can help move the needle in their specific contexts. Working across agencies, and even partnering with other stakeholders across local or state boundaries can help maximize resources and take key steps in the e-mobility journey.

As the ecosystem develops or matures, early wins can help catalyze additional resources from other sectors to support the next stages of the transition – see **Table 7**.

Table 7: Policy strategies

Strategy	Potential	Select examples
Develop an e-mobility roadmap/ EV industry strategy	A roadmap or strategy is a common first step towards emobility readiness. The process involved is useful for stakeholder engagement, communication, metric setting, participation and accountability. A roadmap should include a clear vision statement and ambitious, yet realistic targets with associated timelines.	• Michigan Council on Future Mobility and Electrification Annual Report • The South African Roadmap to Production of Electric Vehicles • India's Faster Adoption and Manufacturing of EVs II • China's 14th Five-Year Plan • California
Form a dedicated entity focused on mobility policy	A dedicated entity in charge of reviewing evolving trends across industry and society and tasked with developing policy recommendations on an annual basis can help engage stakeholders from across sectors in the strategic direction that should be followed, and course correct as conditions change.	The Michigan Council on Future Mobility and Electrification (CFME) serves in an advisory capacity to the Labor and Economic Office, the Office of Future Mobility and Electrification (OFME), the governor, and the legislature, providing annual recommendations on changes in state policy. CFME is composed of members from industry and government organized in thematic workgroups.
Play at the regional level	Forming regional alliances can help make former competitors into allies in implementing bold projects. It can also provide access to resources and capabilities beyond our own.	Michigan, Illinois, Indiana, Minnesota, and Wisconsin collaborate on EV charging infrastructure across the Midwest region, through the Regional Electric Vehicle for the Midwest Memorandum of Understanding. The goal of this initiative is to collectively accelerate vehicle electrification in the Midwest Region.
Develop and implement bold, multifaceted policy with a mix of mandates and incentives	A bold policy agenda sets the tone and drives the market forward - this leadership can translate into job growth and economic development.	In 2015, China released 'Made in China 2025', the country's first ten-year plan focused on promoting manufacturing. The plan uses a mix of subsidies, resources for state-owned enterprises, and strategies to acquire intellectual property with a goal of developing China into a global power in manufacturing. Electric and new energy vehicles are identified as priority sectors.
Engage business in policy development	Engaging business when designing policy actions through dedicated platforms enables early industry input and can help foster buy-in	Moving India is a network of government and business leaders facilitated by the World Economic Forum with the goal to accelerate the transition to shared, connected and emobility solutions in the country. Within it, the Strengthening EV Supply Policies Taskforce was set up to develop policy frameworks that can help states implement effective local policy action to attract and accelerate investments in EV supply chains.

ii. Infrastructure

Infrastructure is another enabler of the e-mobility transition. We consider two types of infrastructure that are equally necessary to support this transition: physical infrastructure and intangible infrastructure. Physical infrastructure involves the physical assets, facilities and structures available to a specific location and that can be used to enable the transition to emobility, both from a production standpoint (when relevant) and from an adoption point of view. Intangible infrastructure refers to the value that is created (e.g., knowledge, innovation, etc.) through the interactions, relationships and networks among players in all their social, economic and cultural dimensions.

Investing in the development of new physical infrastructure, especially for large mobility-related projects, necessitates significant capital. Leveraging existing infrastructure and utilizing it in new ways can be a way to build out new assets without such a substantial investment. Physical assets can serve as an anchor and focal point for fostering the development of an e-mobility ecosystem in a particular place. For example, workshops or innovation labs can be located on university campuses, co-working spaces can be made available to startups developing new technologies or services to support e-mobility, or a city can prioritize the development of EV clusters and industrial parks offering a range of services to e-mobility companies. Stakeholders can be brought together around assets to promote collaboration and generate new services, develop new products and engage the community.

When large investments are required to build a new asset or repurpose an existing one, cross-sector partnerships are particularly well-suited to help with viability and manage risk. These partnerships can also lead to efficiencies and a diversity of perspectives.

Pilot projects are a good way to start when funding is limited – they help test different approaches and identify possible quick wins, which can tell us about the direction in which these interventions could be scaled up in the next stage. Investing in large, highly visible "signature projects," while costly, can help elevate the importance of the transition, educate the public and contribute to the future vision of a particular context.

From a production perspective, having the right assets is mission critical. Understanding what is available, and what can be leveraged or built out is the first step in the process. For example, developing a value chain asset map that plots existing assets that can play a role in accelerating the transition can assist in developing a clear picture of capabilities and gaps. Similarly, infrastructure that supports adoption should also be developed as the market scales. This can include working with utilities, energy companies and planning agencies to develop charging infrastructure, using assets to engage in consumer education activities, and more. As mentioned above, maintaining an ecosystem perspective will help engage the relevant players at the right time, which will facilitate the task.

Intangible infrastructure can be intentionally cultivated by building an environment that is conducive to innovation, collaboration and competitiveness. Services, convenings, shared spaces, place-making activities and other means that allow ecosystem players to interact, understand each other better, and collaborate all contribute to the intangible value and features that distinguish a particular place from others. For example, supporting idea development, encouraging failure and elevating problem-solving through grant competitions and challenges can help foster an innovation culture that leads to the creation of homegrown startups. In time, technology products or services created by the startups can be adopted and scaled by established local businesses, leading to more growth.

A powerful figure that can help further develop the ecosystem is that of the orchestrator, understood as a cross-sectoral entity whose primary mission is to create value by mapping out assets, connecting players, rallying support around specific initiatives and unifying the e-mobility vision for a particular context. Given the multi-sector, cross-functional nature of the transition, having an entity that can play this role can be beneficial. See **Table 8** for infrastructure related strategies.

Table 8: Infrastructure strategies

Strategy	Potential	Select examples
Leverage Public-Private Partnerships (PPP) and other innovative crosssector schemes	Collaboration between the public and private sector is more critical than ever. Leveraging public funding to spark private investment can help the transition move faster.	In Michigan, Mcity is a collaboration between industry, government and academia to advance transportation safety, sustainability, equity and accessibility for the benefit of society. Mcity enables early-stage testing in their labs, funds a wide-range of research and has a commitment to education and outreach. Mcity is a leading voice in mobility innovation related to connected and automated vehicles (CAVs). In China, there are many examples of public-private initiatives and investment. For instance, in Beijing, the approach has been to establish industrial campuses to promote R&D in EV technologies and attract leading industry actors such as automakers battery makers and others.
Create a dedicated mobility entity that serves as primary orchestrator	A dedicated entity can help rally stakeholders around key initiatives and make progress more quickly. It can serve as a central hub and strategic planner of related initiatives, leveraging resources from various sectors and connecting players to create more value.	In Michigan, OFME leads the coordination of all auto and mobility-related initiatives across state government to secure Michigan's status as a global leader in ACES future mobility. Led by a Chief Mobility Officer, OFME sits between four key state agencies that are critical for mobility: transportation, energy, labor and economic development.
Establish a mobility hub	A mobility hub can provide an all-in-one solution for mobility innovations, serve as a platform to engage industry, and attract investors and entrepreneurs.	Michigan Central (under construction, expected 2023) is a mobility innovation hub in Detroit where innovators can develop, test and launch technology around autonomous vehicles, public transit, smart roads, and EV infrastructure. A collaboration between the City of Detroit, Ford and Google, the complex will include "landing pads" for other companies. About half of the 5,000 employees on the campus will come from Ford's workforce—creating a pipeline from the innovation frontier back to the parent company. The hub will be anchored on the restored train station in Corktown, Detroit's oldest neighborhood. The California Mobility Center (CMC) is a membership organization of corporations, education and other institutions and government agencies interested in innovation and commercialization in future mobility. CMC facilitates connections between members and entrepreneurs and innovators with the goals of knowledge sharing, partnership, investment and workforce training. Given its unique position, CMC identifies areas of need for training and workforce development and collaborates with partner institutions to implement training programs.

Implement high visibility signature projects	Signature projects can rally support from various sectors and create more awareness among the public, which helps advance the narrative.	In Michigan, the Detroit Smart Parking Lab helps businesses test innovations related to parking, EV charging and logistics. Also, beyond electrification, a firstof-its-kind corridor for connected and autonomous vehicles is in its early development stage between Ann Arbor and Detroit.
Build around assets	Existing infrastructure can be made available for companies to test and validate their products or technologies, and a variety of services can be created to expand opportunities for growth.	Also in Michigan, the American Center for Mobility (ACM) is a collaborative effort of government, industry and academic organizations focused on accelerating the mobility transportation industry. In addition to having testing facilities, ACM offers an innovation and technology campus for the co-location and incubation of mobility companies as well as event and demonstration facilities.
Develop pilot projects to test innovative approaches and technologies	Pilot projects provide an opportunity to assess the viability or outcomes of a product, service or technology. They also offer a learning and engagement opportunity for various players and help highlight an innovation mindset and culture.	In Michigan, the Inductive Vehicle Charging Pilot will create an electrified roadway system that allows electric buses, shuttles and vehicles to charge while driving, enabling electric vehicles to operate continuously without stopping to charge. In China, Shanghai set up an EV demonstration zone (EVZONE) to test and pilot innovations in vehicle performance, route design and charging facility distribution. A related pilot project is the establishment of leasing stations in busy areas where consumers can use memberships to lease EVs.
Promote startup development in future mobility areas	Initiatives to support startup development can help accelerate investments in specific mobility areas of importance to a particular context, such as equity, sustainability, and more. They can catalyze innovation and help increase awareness of mobility related challenges.	The Michigan Mobility Funding Platform provides grants to mobility and electrification companies looking to deploy their technology solutions in the state of Michigan. The platform will also enable Michigan-based organizations (public and private) to launch their own mobility and electrification funding initiatives.

iii. Workforce

As we have highlighted in previous sections, the transition to e-mobility will cause workforce demands to shift in response to the specific skills that EVs and the broader mobility trends require. Workforce retraining and new talent development is a prominent topic across geographies, with players working to identify and satisfy training needs. In **Appendix B**, we include a summary of the major skills and domains of expertise identified through our analysis, for illustrative purposes.

Low entry barriers and growing momentum for EVs means that, in addition to the established OEMs that are electrifying their fleets, new startups will continue to enter the market, with the associated labor needs. Current labor shortages plaguing many industries combined with growing demand for EV-related jobs make the need to have a highly trained and available workforce with the right skills for the transition an urgent priority.

Workforce concerns associated with the transition to e-mobility are relevant at two levels: on one hand, there is the need for reskilling the current automotive workforce, so that they can take on different functions associated with e-mobility. In some communities, the impact of this transition will be acutely felt. Stakeholders involved in related workforce development should ensure that the transition from ICE to EV is just – in that it considers the people whose livelihoods depend on their jobs – and that players can plan for and minimize the impact of job losses. On the other hand, there is a need to develop the talent pipeline for a new higher-tech workforce with the skills needed to enable electrification and other future mobility trends (autonomous, connected, shared). The task is therefore two–fold for many of the players in the markets we studied: a) building the knowledge economy of the future and b) seeking to compete in a bigger way and in new markets while bolstering and revitalizing their manufacturing base.

Without a cadre of highly trained workers, the industry cannot grow and be sustained. Without reskilling those whose jobs will eventually radically change or disappear, the transition will have a devastating effect on many communities. Getting the workforce piece right is therefore a critical enabler of the transition.

Reskilling the existing workforce will require comprehensive training and support efforts across a wide range of aspects related to EVs – from assembly to servicing to recycling; and training first-responders on how to handle fires and accidents involving EVs, and more. Training these workers is seen as a shared responsibility – industry, government, academia and other ecosystem players can all play a role, as training will need to occur at different levels and through diverse channels.

On the industry side, automakers are scaling existing training programs to include EV skills and are also dedicating new infrastructure to establish training centers that can house large numbers of workers. Moreover, OEMs are emphasizing that having the right skills for the job is more important than having an academic degree, opening the door to a broader pool of skilled workers with less traditional paths. Other public and private stakeholders are also engaging in educational and training efforts around EV skills to ready the talent pipeline. These programs, though small at first, will have to scale rapidly to meet demand.

In addition, targeted and tailored programs will be needed to work directly with companies upstream in the supply chain whose ICE-specific businesses will eventually shrink or disappear altogether – identifying these players early is equally important, so that there is time to roll out dedicated efforts to help them develop relevant capabilities or pivot as needed to minimize the impact.

Table 9: Workforce strategies

Strategy	Potential	Select examples
Centralize workforce development programs focused on e-mobility skills	A centralized program can facilitate identification of workforce needs and create a consolidated platform or structure that helps both workers and employers match up.	In Michigan, the EV Jobs Academy is a new initiative that partners with employers to build customizable training academies for the mobility and electrification industry. This includes determining projected job openings, identifying competencies, credentials and other hiring requirements, reskilling, and upskilling incumbent workers, identifying training opportunities for job seekers interested in industry and conducting career awareness and promotion of EV-related industries and its occupations with Michigan's future workforce.
Develop dedicated support programs focused on ICE-EV transition	Support programs designed to identify ICE-specific manufacturers, particularly small and medium size, and help them diversify or develop EV capabilities can help avert job losses and related economic impact.	The Economic Growth Institute at the University of Michigan provides technical assistance to companies affected by the energy transition and is planning to create a $5.3 million advanced mobility supply chain transformation center to support small and medium-sized manufacturers as they transition to the electric vehicle market.
Develop and offer e-mobility certifications for industry	Universities can help close the skill gap by providing customized mobility solutions for industry as part of the transition.	Nexus Engineering at the University of Michigan offers professional education certificates and custom programs for industry that are practical, grounded in research, and taught by faculty and lecturers from the College of Engineering and beyond. Offerings include Vehicle Electrification, Foundations of Mobility and Current and Emerging Technologies. Mobility Academy by Wayne State University in Detroit offers customized professional development courses for vehicle electrification and mobility, which can range from professional training to graduate-level certificates and degrees, short courses to full-semester curriculum covering a broad range of relevant topics.
Establish collaboration mechanisms between industry and academia to align curriculum and research with market needs	Well-designed collaboration mechanisms can provide inputs and guidance on industrial development trends, joint project opportunities and impacts of research and education outcomes.	At the Industrial Advisory Board at the Center for Electric Drive Transportation, U-M Dearborn College of Engineering. Board members include managers and supervisors from OEMs, suppliers and national laboratories in related technical areas.
Create dedicated EV training facilities	A dedicated, flagship training center can concentrate EV training and expertise and serve as a springboard for innovation and collaboration.	A new training center, the Michigan Electric Vehicle Center, will be built and operated by the University of Michigan in Ann Arbor (expected to begin in 2023).

V. Conclusion

We are entering an era of great change in mobility, including transformations in the ways in which people and goods move and how that movement is powered. We are currently in the midst of an early wave of change, which will have ripple effects throughout the industry, bringing challenges and opportunities alike to all players throughout the mobility ecosystem. The trend toward electrification is causing automotive industry incumbents such as OEMs, suppliers, dealers and more to take a hard look at their business models and their future direction, and adapt – in some cases gradually, and in some more drastically. It is also bringing new entrants to the industry, including those related to batteries, charging, software, services and more. All actors in the broader mobility ecosystem – including government, industry, academia, entrepreneurs, investors and interest groups – have important roles to play in enabling this emobility transition and ensuring it plays out in beneficial ways for companies, communities and the environment.

In this report we have outlined key trends, opportunities, players and strategies to enable this transition. The analysis is intended to be global, with special attention on lessons from the U.S. and several key emerging markets. While we drew from the most recent information available with an eye toward outlining opportunities for the next 5-10 years, as we have seen, this space is fast-evolving and not immune from unexpected disruptions. Given the intended use of this report, we did not include the entire breadth and depth of possible topics related to mobility. Further investigation of certain topics would be valuable as resources allow. These include, for instance: additional examination of trends and opportunities outside of the light-duty vehicle segment; deeper exploration of changes in energy demand and production as they relate to mobility; and a closer look at the other ACES trends (autonomous, connected, shared) including recent developments, projections, implications and areas of intersection.

With all this in mind, we hope that this report will serve as a useful tool for any player interested in better understanding the e-mobility transition and creating their own forward-looking strategy to tap into the wealth of opportunities it brings.

VI. Methodology

For this global analysis, we defined and refined the scope of research in collaboration with Chihuahua stakeholders, prioritizing the greatest areas of opportunity and the key emerging topics in this fast-evolving sector. Much of the information included in this report was gathered via desk research (with sources including industry publications, peer-reviewed articles, recent reports and analyses, news articles, company websites, and more – see full bibliography). We analyzed and synthesized this information and complemented the desk research with key informant interviews. Interviewees provided targeted information based on their areas of expertise to validate information, fill gaps, and provide additional insight and nuance. Beyond these interviews we also consulted with experts in WDI's network who helped to refine the research framework and reviewed the report.

Appendix A: Insights from other markets

Table 9: Select key features* of countries and states included in the research

	Michigan	California	United States	India	China	South Africa	Brazil
GDP	$592B (BEA, 2021)	$3.4T (BEA, 2021)	$23T (World Bank, 2020)	$3.17T (World Bank, 2020)	$17.73T (World Bank, 2020)	$335B (World Bank, 2020)	$1.61T (World Bank, 2020)
GDP per capita ($)	$47,448 (BEA, 2021)	$70,662 (BEA, 2021)	$69,287 (World Bank, 2020)	$2,277 (World Bank, 2020)	$12,556 (World Bank, 2020)	$5,655 (World Bank, 2020)	$7,518 (World Bank, 2020)
Economic impact of auto sector	$225B contribution to state economy (MICHAuto, 2021)	$5 billion market size (IBIS World)	3% of GDP (CAR)	~7% of GDP (McKinsey, 2018)	9.6% of total retail sales of consumer goods (WEF, 2020) P	6.4% of GDP (NAAMSA, 2019)	5.5% of GDP (WEF)
# of jobs in auto sector (directly employed)	~570,000 (MICHAuto, 2021)	~26,000 (BLS, 2021)	~1,700,000 (CAR)	~1,360,000 (Ministry of Road Transport and Hi-ghways, 2018)	~1,300,000 (IBIS World, 2022)	~110,000 (GreenCape, 2021)	~119,000 (PNME, 2020)
Primary/ near-term e-mobility focus	Production and adoption	Adoption and production	Adoption and production	Production	Production and adoption	Production	Production

*Note that data for different states and countries come from several different sources and in some cases different timeframes (i.e., 2019 vs. 2021) so they are not directly comparable. These data points are included for general illustrative purposes only.

Michigan

Manufacturing is at the core of the Michigan economy, and automotive is the state's signature industry. Currently, Michigan is home to 26 OEMs, including the "Big 3" — Ford, GM, and Stellantis FCA. Ninety-six of the top 100 automotive suppliers have a presence in Michigan and 60 are headquartered in the state, according to the state Office of Future Mobility and Electrification (OFME, 2021). OFME was created in 2020 to lead the coordination of all auto and mobility-related initiatives across state government. It is situated between state agencies involved with labor, energy, transportation, and economic development.

The state has indicated 2030 as a year of demarcation to become an established hub for EVs, emerging technology, and automation. Mobility stakeholders in Michigan take a broad approach to focus on future mobility technologies, of which electrification is one, and to look at their evolution across different forms of transportation, including drones, maritime, and trucking, for example. The state has invested in smart infrastructure and test sites for next-generation mobility, which it combines with responsive policy: Michigan has the most extensive network of autonomous vehicle and mobility testing infrastructure in the United States, and the nation's friendliest laws for testing autonomous cars and related technologies (MEDC, 2021).

Michigan leverages PPPs as collaborative mechanisms to catalyze innovation, conduct demonstration projects, and leverage funding from various sources. Highly visible "signature" projects help rally support from various sectors and create more awareness among the public. They include the country's first public electrified roadway, expected to be operational by 2023, which will allow for wirelessly recharging EVs while they drive, park, or wait in traffic; the Lake Michigan EV Circuit, an EV route with reliable charging options along Lake Michigan as part of a wider EV infrastructure network; and Michigan Central, a mobility innovation hub in Detroit where innovators will develop, test, and launch technology around autonomous vehicles, public transit, smart roads, and EV infrastructure, among others.

Preparing the workforce that future mobility, and electrification in the more immediate term, will need is a key concern for the state, given the number of workers employed by the mobility industry – in 2019, nearly 570,000 workers statewide, which supported an additional 526,000 jobs, for a total of almost 1.1 million jobs (MICHAuto, 2021). Many of these will be affected by the EV shift. The state has set the goal of growing Michigan's advanced mobility workforce by 15,000 by 2030 and is rolling out multiple training efforts (OFME, 2021). For example, the new EV Jobs Academy program (2022-2027) combines multiple employer-led collaboratives composed of cross-sector partners working together to scale existing EV mobility curriculum and make it accessible across the state through a single, dedicated online platform. Many other organizations are also working to develop EV training programs to address this industry need.

Helping to develop the talent pipeline, Michigan's universities are deeply involved in mobility research, development, and training. The state has long-standing linkages between academia and industry, with collaboration ranging from addressing training needs to co-funding mobility assets such as Mcity and developing cutting-edge, co-located research and educational facilities such as the Kettering University's GM Mobility Research Center, the only autonomous vehicle testing track on a college campus in the country. Most recently, the state announced that it will build a new center for EV teaching, training, and development, the Michigan Electric Vehicle Center, to be operated by the University of Michigan in Ann Arbor. These assets, along with tax and policy incentives, serve as the basis for a wide variety of efforts to attract investment by OEMs looking to expand their EV and battery manufacturing capacity, train and retrain the talent that will be needed to sustain the industry, and foster innovation and entrepreneurship that can help design the mobility solutions of tomorrow.

California

California has been a leader in the interrelated areas of clean energy policy, EV adoption, and EV manufacturing. The state has a history of strong environmental and economic development policies, which have expanded and accelerated in recent years. There has been much faster EV adoption in California than in other parts of the United States and most other parts of the world.

Enabling that, California has implemented a set of laws, regulations, incentives, and funding programs to promote e-mobility. Among these are a recent gubernatorial executive order that all new vehicles in the state should be emission-free by 2035; increasingly strict standards that control smog-causing pollutants and GHG-emissions from passenger vehicles; regulations requiring manufacturers to produce an increasing proportion of electric commercial vehicles from 2024 on; requirements for all California public transportation buses to be electric by 2029; working with utility companies to install an expansive network of charging stations throughout the state; and more.

On the demand side, California has implemented consumer rebates, EV access to carpool lanes on congested highways, and charging infrastructure, and has also promoted EV marketing and greater model availability. Access and equity have been key considerations in many of these measures, for instance targeting placement of 50% of new charging stations in state-designated disadvantaged communities (defined as those suffering most from the effects of air pollution) and providing an additional EV financing rebate for low-income households (CA Business Portal, 2021).

California has also had success in building an ecosystem to support research, design, and manufacturing of EVs in the state. There are efforts related to new job quality standards, vocational training, and ecosystem building through the Energy Innovation Ecosystem program, and grants to support commercialization of new clean energy technologies. As of 2018 California had 119,200 workers in the EV industry and related jobs, and southern California accounted for 43% of these jobs (Orange County Register, 2021). Analysis suggests that the state's clean energy leadership has had a direct impact on the growth of this industry through a cause-effect relationship between growth of a domestic market and greater likelihood of export success (Forbes, 2020). This leadership involves investment too: One of the most recent government measures is a $15-billion investment package that includes $3.9 billion for e-mobility projects. The e-mobility funds will go toward zero-emission transportation vehicles, school buses and public transit buses, new road infrastructure, and additional EV purchase incentives.

In all, California serves as a model in leveraging its resources to design and implement clean energy policies that promote both adoption and production of EVs and the development of other clean energy technologies.

India

India is the third-biggest emitter of greenhouse gasses on the planet and the fourth-largest automotive producer in the world (WRI India, 2021). Its automotive industry represents 49% of the country's manufacturing sector output, contributing 7.1% of India's GDP (DPIIT, 2022). India is also the world's largest market for 2- and 3-wheelers (2W and 3W, such as scooters, bikes, and rickshaws) (WEForum, 2022). Emission-related pollution is a major concern for the country and has driven strong policy efforts to move toward adoption of EVs to support decarbonization goals. India has set an ambitious target to achieve new vehicle sales of 30% EVs by 2030, primarily led by the 2W and 3W, bus, and commercial vehicle segments (WRI India, 2022). Almost 40% of India's three-wheeler fleet is already electric, though many are powered with natural gas (Bloomberg, 2022).

Many state and central government policy tools have been developed to spur both adoption and manufacturing of EVs. At the national level, driven by energy security concerns, a National Electric Mobility Mission Plan (NEMMP) was launched in 2013, providing a roadmap for the faster adoption of electric vehicles and their manufacturing. Subsequently, the government launched the Faster Adoption and Manufacturing of Electric Vehicles (FAME) program in April 2015 to encourage electric and hybrid vehicle purchase by providing financial support, and then FAME II in 2019, a subsidy program to support the electrification of public and shared transportation and financing charging infrastructure. FAME II was recently extended through 2024.

In addition, the government has deployed a number of production-linked incentives (PLI) in recent years to spur domestic manufacturing of e-mobility-related products, including advanced automotive technology, advanced chemistry cells for batteries, electronics, and metals and mining. These efforts seek to create economies of scale and build a robust supply chain while generating employment, ultimately helping move India up the value chain to develop higher value-added products (Invest India, 2020).

The states play a major role in implementing e-mobility initiatives and policies. As many as 20 states have proposed or adopted their own EV policies since 2017, with more in the works (Transport Policy, n.d.). For instance, Telangana, in the southern region, developed a comprehensive, forward-looking "Electric Vehicle & Energy Storage Policy ‘’ in 2020 to position itself in the EV manufacturing and battery storage market. The policy includes strong incentives for consumers, manufacturers, charging providers, and the EV ecosystem. Some examples are capital incentives for plants and machinery as well as for projects that employ over 1,000 people; power subsidies for EV and EV component manufacturing; open access renewable energy systems; skill development training assistance; and developing an "EV cluster" (NRDC, Telangana Government, 2022).

Transitioning the workforce and developing new talent are also major priorities for India. The Ministry of Skill Development and Entrepreneurship estimates that the EV industry alone will create employment for 10 million people by 2030 across the country, and that for every single direct job, five indirect jobs will be created, leading to a total of 50 million jobs created by the EV ecosystem (AFT Media, 2022). There are calls for regulating and standardizing the quality of skill training, and to skilling the workforce at the right time to mitigate the possibility of job loss due to the transition, using tools such as vocational training and apprenticeship programs, as well as on-the-job skilling certifications.

China

China is one of the largest countries in the world in terms of geography, population, size of economy, and GHG emissions – and since 2015, the largest EV market in the world (UNIDO, 2020). In recent years, China has made a concerted effort to become a leader both in terms of EV manufacturing and adoption, investing an enormous amount of capital and implementing multiple national and local policies and practices to reinforce these goals. Key to this was the launch in 2015 of its government-led industrial policy Made in China 2025. This policy put in place mechanisms such as subsidies, intellectual property acquisition, and mobilization of state-owned enterprises to promote China's dominance in global high-tech manufacturing. The program includes EV-related targets such as sales of 1 million BEVs and PHEVs in 2020 and 3 million in 2025; 80% global market share in EV batteries and electric motors by 2020; and two Chinese OEMs in top 10 in global sales by 2025 (UNIDO, 2020). In the last decade, China produced 44% of the world's EVs (Pew Research, 2021). Chinese companies have captured a large share of the global EV battery market, producing ~60% of all EV batteries in 2019, with top companies CATL and BYD controlling ~32% and ~9% of the global market, respectively, in 2021 (The Guardian, 2021).

In line with the Made in China 2025 goals, the government uses a variety of tools to stimulate demand for EVs, including purchase subsidies, tax breaks, in-kind benefits, emissions regulations, government procurement policies mandating a portion of vehicle purchases be EVs, and supporting the development of a fast DC charging infrastructure network in the country. On the supply side, the government promotes domestic manufacturing of EVs and EV components in several ways, including by providing consumer incentives only for government-approved (domestic) vehicles, government purchasing of domestic vehicles, requiring foreign OEMs seeking to enter their market to create joint ventures with domestic OEMs, and setting EV production mandates for automakers. These actions have resulted in domestic OEMs having an 85% share of sales volume in 2019, with foreign automakers seeking ways to enter and grow in this market (McKinsey, 2019).

The government has also focused on building the capacity of Chinese companies to dominate global battery production. China controls 80% of the world's raw material refining, 77% of the world's cell capacity, and 60% of the world's component manufacturing for lithium-ion batteries (Bloomberg NEF, 2020). Beyond lithium, Chinese companies also play a major role in producing and refining cobalt, nickel, and graphite. In 2021 China was the world's largest producer of natural graphite, with a global market share of 79% (AutomotiveWorld, 2022). China also invests in operations in key countries (such as Australia and Argentina and more, including in Africa) where critical materials exist, and builds supply chains on which EV companies depend. For instance, CATL, a Chinese company, is the world's largest battery producer and key supplier for Tesla, Kia, BMW, and others.

China's dominance in EV and battery supply chains can have downsides, both globally and locally. While COVID-19 disrupted supply chains around the world, China's strict lockdown policies, stretching into 2022, have had outsized and lasting implications on many industries in terms of reduced production, including automotive. Further, there are important geopolitical concerns, particularly in the U.S., associated with relying on China so heavily for supply chains that are considered critical. This is leading companies to focus on diversifying their suppliers away from China, to hedge against such risks in the future.

Also, while the electrification push is tied to decarbonization goals as discussed throughout this report, emissions reductions as a result of electrification in China will be limited while over 60% of China's electricity is generated from coal (IEA, 2022).

South Africa

Automotive manufacturing, assembly, and exporting is a key aspect of South Africa's economy. South Africa is a net exporter of vehicles (more than 60%), primarily to Europe and secondarily to the U.S. (GreenCape, 2021). With the EU not allowing importation of ICE vehicles as of 2030 and the U.S. moving toward low-emissions vehicles, South Africa has a very clear impetus to build its EV manufacturing capacity.

Policies and regulations that could support this transition are currently lacking. The ICE-focused automotive sector has benefited from government support and longstanding policy certainty in the form of the Automotive Production and Development Programme. While the government has sent signals of support for an e-mobility transition through the development of the South African Automotive Masterplan (2021-2035) and the Green Transport Strategy for South Africa (2018-2050), there are calls for more to be done to create an enabling policy framework for established OEMs and local entrepreneurs. Meanwhile, OEMs in South Africa (including Toyota, Volkswagen, BMW, Mercedes-Benz, Mazda, Nissan, and Volvo Cars) are developing local EV manufacturing capacity. In addition to a policy framework, there is also a need to up-skill workers in the automotive market and related services. This is a focus moving forward for many players in the country.

Interest in developing the wider workforce is growing, too, and a new fund supported by the United Kingdom will be established to support new skills development across South Africa for EV jobs. The fund will conduct research on the skills needed in the EV sector, and develop new online training content and programs.

While the near-term focus is on transitioning production, there are also efforts to build an ecosystem to support local adoption of EVs in a way that is complementary to local manufacturing. For instance, local manufacturing can eliminate or reduce taxes that South Africans currently pay to import EVs (25%, compared to 18% import tax that applies to ICE vehicles). Additionally, some players have identified opportunities for local manufacturing and electrification of public transport (primarily buses); local lithium-ion battery production, which would build on an existing battery assembly and recycling industry and South Africa's availability of raw materials and highly developed mining industry; and local production of EVs for use in construction and underground mining (GreenCape, 2021).

Brazil

The e-mobility market in Brazil is in its early stage, but some unique features make it an interesting market for investigation. Brazil has committed to reducing its GHG emissions by 37% below 2005 levels by 2025 and achieving 45% of renewables in the energy mix by 2030, and biofuels play an important role in achieving these goals (Plataforma Nacional de Mobilidade Eléctrica (PNME), 2020). Brazil started investing in biofuels – specifically sugarcane ethanol fuel – in a big way starting in 2003. By 2019 more than 67% of all light-duty passenger vehicles ran on ethanol fuel (PNME, 2020). Vehicles running on ethanol play a major role in future mobility in Brazil, in addition to BEVs. As of 2022 there are 24 automakers in the country, providing nearly 103,000 direct jobs (Anfavea, 2022). Nearly all of these automakers have been positioning themselves to produce and sell low-emissions vehicles.

Just as investments have been made in building a strong industrial base for ethanol, BEVs are now becoming a bigger part of a transition away from ICE vehicles. Government programs such as RenovaBio help with promotion and investment, and on the regulatory side the Motor Vehicle Emission Control Program (Proconve) has set emissions targets since 1986 (PNME, 2020). The energy sector also plays a key role in e-mobility; Aneel (the National Electric Energy Agency) provides the majority of the investment in R&D e-mobility projects (PNME, 2020). The e-mobility ecosystem also involves local governments, universities, R&D centers, automakers and components makers, vehicle fleet operators, energy companies, and others who are exploring different types of partnerships aimed at expanding low emissions technologies. The e-mobility market is mainly concentrated in the state of São Paulo.

Targeting public transportation is a strategy many local governments in Brazil are employing, for instance through the Bus Rapid Transit electrification initiative in Salvador and e-bus pilot project in Belo Horizonte. There are 247 e-buses operating in Brazil (the majority of which are trolleybuses). There is also growth in the ultra-light-duty vehicle sector, with increases in sales in e-bikes and e-mopeds (PNME, 2020).

Appendix B: Summary of skills and expertise*

Opportunity area	Key skills and areas of expertise
Raw materials	■ Materials science ■ Materials selection in automotive design ■ Lightweight automotive alloys ■ Designing and manufacturing with lightweight automotive materials
Batteries	■ Sustainable materials design ■ Materials science ■ Chemical engineering ■ Integrated computational materials engineering ■ Materials synthesis ■ Electrolytes ■ Integration and production at cell, module, and pack levels ■ End-of-life management ■ Techno-economic assessments
Parts and components	■ Industrial engineering ■ Electrical engineering ■ Mechanical engineering
Software	■ Electrical engineering and computer science ■ Software development ■ Programming ■ Cybersecurity
Sales and aftermarket	■ Mobile maintenance and light repair ■ High voltage systems safety ■ EV components and operation ■ High voltage battery service ■ EV operation and diagnosis
Charging	■ Electrical engineering ■ Mechanical engineering ■ Civil engineering ■ Installation and maintenance of charging stations ■ Utility interconnect requirements ■ EV battery types and charging characteristics ■ Vehicle charging performance specifications ■ First responder safety hazards and requirements

* Sources : OFME 2021 and review of mobility related curricula at U-M and other institutions.

Appendix C: Bibliography

2022 Megatrends in Power. (2022). Black & Veatch.
AB 2832 Advisory Group. (2022). Lithium-ion Car Battery Recyling Advisory Group Final Report. California Environmental Protection Agency. https://calepa.ca.gov/wp-content/uploads/sites/6/2022/05/2022_AB-2832_Lithium-Ion-Car-Battery-RecyclingAdvisory-Goup-Final-Report.pdf
An Ecosystem Approach for EV Adoption. (2021). Infosys Knowledge Institute.
Argonne National Laboratory. (2022). Light Duty Electric Drive Vehicles Monthly Sales Updates. https://www.anl.gov/es/light-duty-electric-drive-vehicles-monthly-sales-updates
As Electric Car Makers Ante Up Billions, Software Is Ace in the Hole. (2021, October 1). IEEE Spectrum. https://spectrum.ieee.org/electric-cars
Association for Electric Mobility and Development in Africa (AEMDA) Strategic Plan. (2022).
August 07, & Alum, 2020 Anjali Jaiswal-. (n.d.). Moving Forward with Electric Vehicles in India – Telangana. NRDC. Retrieved July 10, 2022, from https://www.nrdc.org/experts/anjalijaiswal/moving-forward-electric-vehicles-india-telangana
Austin, J., & Zielinski, S. (n.d.). Building the New Mobility Economy. UM-SMART.
Auto Green Paper: Advancement of New Energy Vehicles in South Africa. (2021). Department of Trade, Industry and Competition, Republic of South Africa.
Auto OEMs must transform manufacturing mindset to survive EV industry disruption. (2021, December 28). Automotive World. https://www.automotiveworld.com/articles/auto-oemsmust-transform-manufacturing-mindset-to-survive-ev-industry-disruption/
Autocar India. (2022, April 10). Retail EV sales cross 4 lakh units since April 2021. https://www.autocarindia.com/industry/retail-ev-sales-cross-4-lakh-units-since-april-2021-424073#:~:text=Retail%20sales%20of%20electric%20vehicles,of%20Automobile%20De alers%20Association%20said.
Autoweek. (2021, May 24). Electric Big Rigs are Coming—And We Drive Four of Them. https://www.autoweek.com/news/green-cars/a36506185/electric-big-rig-semi-trucks/
Azevedo, M., Baczynska, M., Hoffman, K., & Krauze, A. (2022). Lithium Mining: How New Production Technologies Could Fuel the Global EV Revolution. McKinsey & Company.
Balaskovitz, A. (2022, February 27). Michigan EV registrations climb as state prepares millions for charging stations. MiBiz. https://mibiz.com/sections/energy/michigan-ev-registrationsclimb-as-state-prepares-millions-for-charging-stations
Baltic, T., Hensley, R., & Salazar, J. (2019). The Trends Transforming Mobility's Future. McKinsey & Company.
Barassa, E., Ferreira, R. da C., & Moraes, H. B. (2020). First Brazilian Electric Mobility Annual Report. Platforma Nacional de Mobilidade Eléctrica.
"Battery arms race": How China has monopolised the electric vehicle industry. (2021, November 25). The Guardian. https://www.theguardian.com/globaldevelopment/2021/nov/25/battery-arms-race-how-china-has-monopolised-the-electricvehicle-industry
Battery global value chain and its technological challenges for electric vehicle mobility | Elsevier Enhanced Reader. (n.d.). https://doi.org/10.1016/j.rai.2017.07.001
Behrendt, A., Gomez, R. M.-Q., Rettig, R., & Soubien, F. (2022). Admid Disruption, Automotive Suppliers Must Reimagine their Footprints. McKinsey & Company.
Best Practices in Electric Mobility. (2020). United Nations Industrial Development Organization.
Bloomberg NEF. (2020, September 16). China Dominates the Lithium-ion Battery Supply Chain, but Europe is on the Rise. https://about.bnef.com/blog/china-dominates-the-lithium-ionbattery-supply-chain-but-europe-is-on-the-rise/
Boloor, M., Valderrama, P., Statler, A., & Garcia, S. (n.d.). Electric Vehicle Basics. NRDC. https://www.nrdc.org/

experts/madhur-boloor/electric-vehicles-101
boxcar-admin. (2017, May 15). New study quantifies global health, environmental impacts of excess nitrogen oxide emissions from diesel vehicles. International Council on Clean Transportation. https://theicct.org/new-study-quantifies-global-health-environmentalimpacts-of-excess-nitrogen-oxide-emissions-from-diesel-vehicles/
Bozer, S. (2022, July 21). Automakers Invest Billions in North American EV and Battery Manufacturing Facilities. Center for Automotive Research. https://www.cargroup.org/automakers-invest-billions-in-north-american-ev-and-batterymanufacturing-facilities/
Breiter, A., Hackert, P., Han, W., Hensley, R., & Schwedhelm, D. (2020). Improving Battery-Electric-Vehicle Profitability through Reduced Structural Costs. McKinsey & Company.
Bubear, R. (2022, May 13). How Fast Are EV and Hybrid Sales Growing in South Africa? Cars.Co.Za. https://www.cars.co.za/motoring-news/how-fast-are-ev-and-hybrid-sales-growing-in-south-africa/123652/
Bureau of Economic Analysis, U.S. Department of Commerce. (2022, March 31). Gross Domestic Product by State, 4th Quarter 2021 and Year 2021. https://www.bea.gov/sites/default/files/2022-03/qgdpstate0322.pdf
CAAM. (2022). Annual sales volume of new energy vehicles in China from 2011 to 2021, by type. Statista. https://www.statista.com/statistics/425466/china-annual-new-energyvehicle-sales-by-type/#:~:text=In%202021%2C%20around%202.9%20million,162%20percent%20compar ed%20to%20 2020
California Leads the Nation's ZEV Market, Surpassing 1 Million Electric Vehicles Sold. (2022, February 25). CA Office of Governor. https://www.gov.ca.gov/2022/02/25/californialeads-the-nations-zev-market-surpassing-1-million-electric-vehicles-sold/
Campagnol, N., Pfeiffer, A., & Tryggestad, C. (2022). Capturing the Battery Value-Chain Opportunity. McKinsey & Company.
Capturing growth in Asia's emerging EV ecosystem | McKinsey. (n.d.). Retrieved July 12, 2022, from https://www.mckinsey.com/featured-insights/future-of-asia/capturing-growth-inasias-emerging-ev-ecosystem?cid=other-eml-alt-mip-mck&hdpid=5277dc3f-01e7-402f-9806-7e6dc87d087b&hctky=11752436&hlkid=9ff28c899b614f13bde04e2114da4b75
Center for Automotive Research. (n.d.). Contribution of the Automotive Industry to the Economies of All Fifty States and the United States. https://www.cargroup.org/publication/contribution-of-the-automotive-industry-to-theeconomies-of-all-fifty-state-and-the-unitedstates/#:~:text=The%20auto%20 industry%20is%20one,Gross%20Domestic%20Product%20(GDP).https://www.autosinnovate.org/resources/insights/ca
Chege, W. (2021). Electric Vehicles Market Intelligence Report (J. Radmore, C. Pienaar, L. Basson, & N. Fordyce, Eds.). GreenCape.
China strengthens lead in global EV battery market. (2022, February 7). Just Auto. https://www.just-auto.com/news/china-strengthens-lead-in-global-ev-battery-market/ City
EV Readiness: Bottom-Up Approach to Scale EVs. (2019). Manifold Business Solutions.
Cleary, K. (2019). Electrification 101. Resources for the Future.
Conzade, J., Engel, H., Kendall, A., & Pais, G. (2022). Power to Move: Accelerating the Electric Transport Transition in Sub-Saharan Africa. McKinsey & Company.
Council on Future Mobility and Electrification 2021 Report. (n.d.).
Desilver, D. (2021, June 7). Today's electric vehicle market: Slow growth in U.S., faster in China, Europe. Pew Research Center. https://www.pewresearch.org/facttank/2021/06/07/todays-electric-vehicle-market-slow-growth-in-u-s-faster-in-chinaeurope/
DOE Projects Zero Emissions Medium- and Heavy-Duty Electric Trucks Will Be Cheaper than Diesel-Powered Trucks by 2035. (2022, March 7). Department of Energy. https://www.energy.gov/articles/doe-projects-zero-emissions-medium-and-heavy-dutyelectric-trucks-will-be-cheaper-diesel
Doshi, K. (2021). Ann Arbor SPARK Sector Report: Automotive Technology and Mobility.

Doshi, R. (2020). The Future of Mobility—On the Cusp of the Electrification Revolution. Everest Group Research.

Driivz. (2022, June 24). Four Major Trends in the eMobility Industry in 2022. https://driivz.com/blog/ev-industry-trends/

Electric Mobility Barriers in Kenya: Market Survey Report. (2021). Association for Electric Mobility and Development in Africa.

Electrifying Fleets One Solution to World's Car Obesity Problem. (2022, June 13). Bloomberg.Com. https://www.bloomberg.com/news/articles/2022-06-13/electrifyingfleets-one-solution-to-world-s-car-obesity-problem

Estrategia Nacional de Electromovilidad. (n.d.). Gobierno de Chile: Ministerio de Energia, Ministerio de Transporte y Telecomunicaciones, Ministerio del Medio Ambiente.

EV vs. ICE: How Does Wire Harness Design Differ? - Tech Briefs. (n.d.). Retrieved July 22, 2022, from https://www.techbriefs.com/component/content/article/tb/stories/blog/45485

Fine, C., St. Clair, R., Lafrance, J. C., & Hillebrand, D. (1996). Meeting the Challenge: U.S. Industry Faces the 21st Centure: The U.S. Automobile Manufacturing Industry. U.S. Department of Commerce Office of Technology Policy.

Ford and GM are going all in on electric cars, and thousands of jobs hang in the balance. (n.d.). Fortune. Retrieved June 17, 2022, from https://fortune.com/2022/06/01/ford-generalmotors-electric-vehicles-jobs-fortune-500/

Fostering Effective Energy Transition Insight Report. (2022). World Economic Forum and Accenture.

Fournier, G., Hinderer, H., Schmid, D., Seign, R., & Baumann, M. (2011). The New Mobility Paradigm: Transformation of Value Chain and Business Models. Enterprise and Work Innovation Studies, 8, 9–40.

From No Mobility to Future Mobility: Where COVID-19 Has Accelerated Change, Compendium. (2020). McKinsey & Company.

Giesecke, R. (2014). The Electric Mobility Business Ecosystem: An Initial Agenda for Future Research Needs Based on Organisation Theory. IEEE Ninth International Conference on Ecological Vehicles and Renewable Energies.

Global Commercial Vehicle Drive to Zero. (n.d.). https://globaldrivetozero.org/

Global Energy Perspective 2022 | McKinsey. (n.d.). Retrieved July 14, 2022, from https://www.mckinsey.com/industries/oil-and-gas/our-insights/global-energy-perspective-2022?cid=other-eml-alt-mip-mck&hdpid=e0385461-7213-427c-9e4dfc208f36420c&hctky=11752436&hlkid=1536e3c859ba429dbba621e05997147b

Gohlke, D., & Zhou, Y. (2020). Assessment of Light-Duty Plug-in Electric Vehicles in the United States, 2010-2019. https://doi.org/10.2172/1642114

Hagerty, M., Sergici, S., & Lam, L. (2020). Getting to 20 Million EVs by 2030: Opportunities for the Electricity Industry in Preparing for an EV Future. The Brattle Group.

Han, W., Husain, A., Inampudi, S., Loh, B., Malik, Y., & Stone, S. (2022). ICE Businesses: Navigating the Energy-Transition Trend Within Mobility. McKinsey & Company.

Hannon, E., Krishnan, M., Patel, J., & Sahdev, S. (2022). Mobility's Net-Zero Transition: A Look at Opportunities and Risks. McKinsey & Company.

Harrison, D. (2021). Electric Vehicle Battery Supply Chain Analysis (C. Ludwig, Ed.). Automotive UltimaMedia.

Hedges & Company. (2021, June). How Many Cars are there in the World in 2022? https://hedgescompany.com/blog/2021/06/how-many-cars-are-there-in-the-world/

Heineke, K., Hornik, T., Schwedhelm, D., & Szilvacsku, I. (2021). Defining and Seizing the Mobility Ecosystem Opportunity. McKinsey & Company.

Hughes-Cromwick, E. (2021). Mapping Jobs and the Transition to Electric Vehicle Assembly in the US. Third Way.

Hyde, C. K. (2001). "Detroit the dynamic": The industrial history of Detroit from cigars to cars. Michigan Historical Review, 27(1), 57–74.

Hydrogen Delivery. (n.d.). Energy.Gov. Retrieved July 14, 2022, from https://www.energy.gov/eere/fuelcells/hydrogen-delivery
IBIS World. (n.d.). Automobile Manufacturing Industry in China—Market Research Report. https://www.ibisworld.com/china/market-research-reports/automobile-manufacturingindustry/
India needs to reskill its workforce for the electric vehicle industry. How to do that? | AFT Media. (2022, June 14). https://autofintechs.com/india-needs-to-reskill-its-workforce-for-theelectric-vehicle-industry-how-to-do-that/
India: State Level EV Policies | Transport Policy. (n.d.). Retrieved July 20, 2022, from https://www.transportpolicy.net/standard/india-state-level-ev-policies/
Inside the race for a car battery that charges fast—And won't catch fire. (n.d.). Washington Post. Retrieved July 14, 2022, from https://www.washingtonpost.com/technology/2022/05/18/solid-state-batteries-electricvehicles-race/
Institute, P. (n.d.). Hydrogen on the path to net-zero emissions. Pembina Institute. Retrieved July 14, 2022, from //www.pembina.org/pub/hydrogen-primer
Issues in Excel. (n.d.). Anfavea. Retrieved July 14, 2022, from https://anfavea.com.br/site/issues-in-excel/?lang=en
Jha, S., & Kanuri, C. (n.d.). Tracking India's Evolving E-Mobility Startup Landscape. WRI India.
Jordan, P., & Hunt, N. (2021). Building an Electric Transportation Supply Chain in the United States: Companies, Jobs, Growth Rates, and Economic Opportunities in Vehicle Electrification. BW Research Partnership.
July 31, & Alum, 2019 Madhur Boloor-Alum Patricia Valderrama- Alum Ada Statler- Alum Samuel Garcia-. (n.d.). Electric Vehicle Basics. NRDC. Retrieved July 14, 2022, from https://www.nrdc.org/experts/madhur-boloor/electric-vehicles-101
Jussani, A. C., Wright, J. T. C., & Ibusuki, U. (2017). Battery global value chain and its technological challenges for electric vehicle mobility. RAI Revista de Administracao e Inovacao, 14(4).
Kane, M. (2022, March 9). US: Three Tesla Models On Top of BEV Sales Chart in January 2022. Inside EVs. https://insideevs.com/news/572470/us-tesla-bev-sales-january2022/
Karnataka Electric Vehicle and Energy Storage Policy. (2017). Commerce and Industries Department, Government of Karnataka.
Key Factors Defining the E-Mobility of Tomorrow. (2019). Capgemini.
Köberle, M. (2020). E-Mobility Solutions for Rural Sub-Saharan Africa: Leveraging Economic, Social and Environmental Change (E. Biber & A. Kovanetz, Eds.). Siemens Stiftung.
Kuhlmann, K., Küpper, D., Schmidt, M., Wree, K., Strack, R., & Kolo, P. (2021). Is E-Mobility a Green Boost for European Automotive Jobs? BCG.
Küpper, D., Kuhlmann, K., Tominaga, K., Arora, A., & Schlageter, J. (2020). Shifting Gears in Auto Manufacturing. BCG.
LeBeau, P. (2022, May 18). EV battery costs could spike 22% by 2026 as raw material shortages drag on. CNBC. https://www.cnbc.com/2022/05/18/ev-battery-costs-set-tospike-as-raw-material-shortages-drags-on.html
Lipman, T. E., & Maier, P. (2021). Advanced materials supply considerations for electric vehicle applications. MRS Bulletin, 46(12), 1164–1175. https://doi.org/10.1557/s43577-02200263-z
McKinsey & Company. (2018, July 18). The future of mobility in India's passenger-vehicle market. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/thefuture-of-mobility-in-indias-passenger-vehicle-market
Merge Ahead: Electric vehicles and the impact on the automotive supply chain. (n.d.). PwC.
Michigan: At the Intersection of Mobility and Innovation. (2021). Michigan Economic Development Corporation.
Michigan's University Research Corridor Powers Mobility Innovation. (2021). Public Sector Consultants.
Ministry of Road Transport and Highways. (2018). Employment in the automotive sector across India from

financial year 2013 to 2018. https://www.statista.com/statistics/581257/projected-automotive-sector-directemployment-in-india/
Mitchell, A. (2022a, February 20). Su$tainable Mobility, Volume 22 [Substack newsletter]. Su$tainable Mobility. https://alexmitchell.substack.com/p/-sutainable-mobility-volume-22
Mitchell, A. (2022b, June 12). Su$tainable Mobility: Ford Just Killed the Dealership Model [Substack newsletter]. Su$tainable Mobility. https://alexmitchell.substack.com/p/sutainable-mobility-ford-just-killed
Mobility Industry's Economic Contribution to Michigan. (2021). Public Sector Consultants.
Montmasson-Clair, G., Dane, A., & Moshikaro, L. (2020). Harnessing Electric Vehicles for Industrial Development in South Africa. Trade and Industrial Policy Strategies.
Moving India & Emerging Markets. (n.d.). World Economic Forum. Retrieved July 20, 2022, from https://www.weforum.org/projects/moving-india-emerging-markets/
Opsahl, D. (n.d.). Council Post: The Shift To Electric Vehicles Means Training New Auto Suppliers. Forbes. Retrieved July 19, 2022, from https://www.forbes.com/sites/forbesbusinesscouncil/2021/07/19/the-shift-to-electricvehicles-means-training-new-auto-suppliers/
Pais, G. (2022). Potential for Electric Vehicles in Africa. McKinsey & Company.
Paliscanova, J. (2022). Why Europe Can Secure Enough Critical Raw Materials. Transport and Environment.
Raman, A., Sahay, R., & Samantray, S. (2019). EV-Ready India Part 1: Value Chain Analysis of State EV Policies. World Economic Forum and Ola Mobility Institute.
Reboost: A comprehensive view on the changing powertrain component market and how suppliers can succeed. (n.d.). 79.
RENAVAM. (2021). Electric and hybrid motor vehicle registrations in Brazil from 2006 to 2021. https://www.statista.com/statistics/620654/electric-car-and-light-commercial-vehiclesales-brazil/
Saft. (n.d.). Three battery technologies that could power the future. https://www.saftbatteries.com/media-resources/our-stories/three-battery-technologiescould-power-future
Schmidt, A., Lio, T., Reers, J., & Regalia, A. (2021). The Electric Vehicle: Why manufacturers need to rethink their ecosystems, the customer journey, and the entire value chain. Accenture.
Self-Driving Cars Market Global Forecast to 2030: Increasing Demand for Level 1 and Level 2 Cars and Rising Investment in Development of Level 4 and Level 5 Cars Will Propel Markets. (2022, February 15). Business Wire. https://www.businesswire.com/news/home/20220215005655/en/Self-Driving-CarsMarket-Global-Forecast-to-2030-Increasing-Demand-for-Level-1-and-Level-2-Cars-andRising-Investment-in-Development-of-Level-4-and-Level-5-Cars-Will-Propel-Market--ResearchAndMarkets.com
Silicon carbide shows clear benefits for electric vehicle efficiency. (2019, May 10). Automotive World. https://www.automotiveworld.com/articles/silicon-carbide-shows-clear-benefitsfor-electric-vehicle-efficiency/
Silicon carbide (SiC) devices for the next-generation of electric vehicles | News. (n.d.). CORDIS | European Commission. Retrieved July 20, 2022, from https://cordis.europa.eu/article/id/429487-silicon-carbide-sic-devices-for-the-nextgeneration-of-electric-vehicles/fr
Singhai, S., & Saran, S. (2020). Future of Mobility in India: Envisioning the Future of the Indian Mobility Ecosystem. Deloitte Touche Tohmatsu India LLP.
Slavin, T., & Luckhurst, K. (Eds.). (2021). Sustainable Transport Briefing: Why the Future of Transport is Electric. Reuters.
Soman, A., Ganesan, K., & Kaur, H. (2019). India's Electric Vehicle Transition: Impact on Auto Industry and Building the EV Ecosystem. CEEW, Shakti Sustainable Energy Foundation.
Strengthening electric vehicle supply policies.pdf | Powered by Box. (n.d.). Retrieved July 20, 2022, from https://weforum.ent.box.com/s/9669u27zkf9bng8arxukjk240whhx4fg
Sustainable Electric Mobility: Building Blocks and Policy Recommendations. (2021). Sustainable Mobility for All.

Taking the High Road: Strategies for a Fair EV Future. (2020). UAW Research Department.
Tamil Nadu Electric Vehicle Policy. (2019). Government of Tamil Nadu.
The-road-ahead-auto-suppliers-navigate-new-terrain.pdf—Dianapc@umich.edu—University of Michigan Mail. (n.d.). Retrieved July 17, 2022, from https://mail.google.com/mail/u/0/#inbox/FMfcgzGpGwnlssDsdWLDGvGkqTsfXLKr?proje ctor=1&messagePartId=0.1
Trends and developments in electric vehicle markets. (2022). IEA. https://www.iea.org/reports/global-ev-outlook-2021/trends-and-developments-in-electricvehicle-markets
Trends in charging infrastructure – Global EV Outlook 2022 – Analysis. (n.d.). IEA. Retrieved July 14, 2022, from https://www.iea.org/reports/global-ev-outlook-2022/trends-incharging-infrastructure
UNIDO Low Carbon Transport Project in South Africa. (2021).
U.S. Bureau of Labor Statistics. (n.d.). Automotive Industry: Employment, Earnings, and Hours. https://www.bls.gov/iag/tgs/iagauto.htm#emp_state
U.S. Department of Energy Alternative Fuels Data Center. (n.d.). Batteries for Electric Vehicles. https://afdc.energy.gov/vehicles/electric_batteries.html
Verkehrswende, A. (2022). Powering the Automotive Jobs of the Future: How the Electrification of Transport and Other Trends Will Change Jobs in the Automotive Sector up to 2030— And What this Means for Policymakers. BCG.
Why an Electric Car Battery Is So Expensive, For Now. (2021, September 16). Bloomberg.Com. https://www.bloomberg.com/news/articles/2021-09-16/why-an-electric-car-battery-is-soexpensive-for-now-quicktake
Why Electric Vehicles Will Likely Emerge as California's Top Manufacturing Export in 2020. (2020, September 30). Forbes. https://www.forbes.com/sites/energyinnovation/2020/09/30/why-electric-vehicles-willlikely-emerge-as-californias-top-manufacturing-export-in-2020/?sh=7cb53477351c
Wissell, F., Speetles, B., Townley, M., Harris, D., & Noblet, S. (2022). The Impact of Electric Vehicles on Climate Change. ICF Climate Center.
World Economic Forum. (n.d.). Enabling Trade: Reducing Import and Export Costs in the Automotive Sector. https://reports.weforum.org/enabling-trade-increasing-the-potentialof-trade-reforms/enabling-trade-reducing-import-and-export-costs-in-the-automotivesector/?doing_wp_cron=1658345161.2065699100494384765625
World Economic Forum. (2020, May 28). How China is strengthening its electric vehicle market during the pandemic. https://www.weforum.org/agenda/2020/05/how-china-isstrengthening-its-electric-vehicle-market-during-thepandemic/#:~:text=The%20automotive%20sector%20is%20one,entire%20value%20chai n%20is%20considered
www.ETAuto.com. (n.d.). FAQs: A comprehensive roundup on Indian EV Policies - ET Auto. ETAuto.Com. Retrieved July 10, 2022, from https://auto.economictimes.indiatimes.com/news/policy/faqs-a-comprehensive-roundupon-indian-ev-policies/89290126
X-by-wire System Market Size, Growth, Trends 2022—27. (n.d.). Retrieved July 22, 2022, from https://www.mordorintelligence.com/industry-reports/x-by-wire-systems-market
Yadav, N., & Mulukutla, P. (n.d.). Tracking India's Industrial Evolution with Electric Mobility. WRI India.
Zero Emission Vehicle Program Path to 2030. (2021). CA Business Portal. https://businessportal.ca.gov/zero-emission-vehicle-program/path-to-2030/
Zhou, Y., Gohlke, D., Rush, L., Kelly, J., & Dai, Q. (2021). Lithium-Ion Battery Supply Chain for E-Drive Vehicles in the United States: 2010-2020. https://doi.org/10.2174/1778934

WILLIAM DAVIDSON INSTITUTE
AT THE UNIVERSITY OF MICHIGAN

CHIHUAHUA
GOBIERNO DEL ESTADO
Juntos Sí podemos

SECRETARÍA
DE INNOVACIÓN
Y DESARROLLO ECONÓMICO

I²C
INSTITUTO DE INNOVACIÓN
Y COMPETITIVIDAD

INADET
INSTITUTO DE APOYO
AL DESARROLLO
TECNOLÓGICO