GLOBAL INFRASTRUCTURE INITIATIVE
By McKinsey & Company

Voices on Infrastructure

Scaling EV infrastructure to meet net-zero targets

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Introduction

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The promise of electric vehicles (EVs) at scale seems increasingly tangible. Despite the disruption of the COVID-19 pandemic, EV adoption accelerated in 2020 as the industry began to develop the mobility systems of the future. For many private- and fleet-vehicle owners, the EV that will tip the scales away from internal combustion engines is already in development.

This rapid progress has highlighted two priorities that are critical to the future of the EV market: an adequate supply of tailored batteries and a scaled network of charging stations. Upstream investments include building sufficient battery production facilities to meet regional EV demand. For example, to meet Europe's 2030 targets, annual battery capacity will have to increase from the current 60 gigawatt hours (GWh) installed to 900 GWh. Downstream, charging infrastructure across multiple vehicle classes (such as passenger cars, trucks, and buses) and use cases (such as home, work, depot, or highway) will have to be ramped up fast. The upstream and downstream infrastructure is interdependent, and both face challenging bottlenecks due to the technology, capital, and commitment required to succeed.

With a global fleet of more than 11 million vehicles on the road today, there is potential to expand the market to seven times that number in less than a decade.[1] The enabling ecosystem of EVs will include myriad factors; in this issue, we cover the latest thinking on scaling battery manufacturing and publicly available charging. EVs will play a key role in reducing carbon emissions to remain on the 1.5 pathway. In service of this goal, it has never been more important to expand the availability of publicly accessible EV chargers and accelerate the production of high-quality, cost-efficient, low-carbon batteries.

[1] Julian Conzade, Andreas Cornet, Russell Hensley, Patrick Hertzke, Ruth Heuss, Timo Möller, Patrick Schaufuss, Stephanie Schenk, Andreas Tschiesner, and Karsten von Laufenberg, "Why the automotive future is electric," September 7, 2021, McKinsey.com.

News from the Global Infrastructure Initiative

Tony Hansen

Managing Director of the Global Infrastructure Initiative, McKinsey & Company

Welcome to the October edition of *Voices on Infrastructure*, where we explore what it will take to scale electric-vehicle (EV) infrastructure to meet net-zero targets.

Driven by policy, subsidies, and expanded consumer choice, the global EV market has seen incredible growth over the past decade. However, to meet the climate targets for zero-emission vehicles, attention is shifting from developing the EVs to scaling the infrastructure needed to support their operation and maintenance. This will entail significant innovation and investment from every player involved. The themes from this edition of *Voices* include the scaling of battery capacity and charging infrastructure, the role of regulation and incentives, and the collaboration required to succeed.

You can learn about the outcomes of our two latest GII roundtables, which focused on **charting net-zero emissions in transport** and **future-proofing transport infrastructure**, on our roundtable page. Sticking with the sustainability theme, GII is supporting a number of roundtables and a webinar being hosted by McKinsey at the forthcoming United Nations Climate Change conference (COP26) in Glasgow. For details on how to join these virtual sessions, please visit our roundtable page. We continue to gather momentum as we approach our eighth GII Summit, which will take place in Tokyo on October 19–21, 2022. Further details on the agenda can be found on our GII website.

We hope you enjoy this issue, and we welcome your thoughts on how GII can continue to be a catalyst for driving change toward sustainable infrastructure. If you have comments or would like to subscribe a colleague to *Voices*, please contact us at info@giiconnect.com.

The future of EV charging infrastructure: Executive perspectives

Frank Mühlon and Giovanni Palazzo offer their insights into today's and tomorrow's priorities for scaling EV charging infrastructure to meet demand.

Frank Mühlon

President, e-mobility division
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Giovanni Palazzo

President and CEO
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A few short years ago, the main questions customers had when purchasing electric vehicles (EVs) were about price and driving range.[1] Today, the number-one concern is different: adequate charging infrastructure. To keep pace with the rapidly growing interest in electric vehicles, vast networks of publicly accessible chargers will need to be built and put into operation in short order.[2] A failure to do so could stymie EV growth and slow progress on decarbonizing road transport.

To learn more about the future of EV charging infrastructure, McKinsey's Tony Hansen and Florian Nägele spoke with Frank Mühlon, president of the e-mobility division of ABB, and Giovanni Palazzo, president and CEO of Electrify America.

McKinsey: What are the biggest priorities in radically expanding electric-vehicle (EV) charging infrastructure and meeting or surpassing targets?

Frank Mühlon: If we are to meet the target of 290 million charging points by 2040, we'll need $500 billion in public–private investment.[3] These investments will likely be focused on high-impact segments—those that travel the most and carry large numbers of passengers or objects, such as commercial vehicles and public transport, as well as those that operate in highly dense environments.

Another priority is sustainability. To achieve global targets for emissions reductions as set out in the Paris Agreement, we need clear global standards for EVs, as well as credible solutions to abate emissions across the whole industry. Again, this can't be achieved in silos but requires public–private joint efforts to create a sustainable EV market.

Overcoming obstacles to expanding EV infrastructure will involve offering financial incentives and regulatory support to drive the transition from internal combustion engine (ICE) vehicles to EVs, including by favoring efficiencies through shared and autonomous EV rides.

Giovanni Palazzo: Real-estate access, local-government and regulatory support, and talent acquisition are crucial as the market grows and matures.

Public charging has a significant real-estate component. Charging should be conveniently located both on major interstates and in dense urban areas. Real estate also relates to power availability, especially for fast charging. A location could be great from a utilization perspective, but if there is no electrical-grid capacity, installation could be challenging regardless of the solutions and technology leveraged.

The second hurdle is policy support at the local and utility levels. For example, the state of California—the largest electric-vehicle market in the United States—has already suggested best practices to expedite permits for the installation of EV charging stations, potentially accelerating EV growth.[4] Continued updates to local permitting, as well as reassessments of utility demand, will be important in paving the way for EV infrastructure.

The final obstacle is talent. We have great people working at Electrify America—and, indeed, across EV-charging infrastructure. As the market grows, however, it will require additional talent that is determined to solve complex technological, operational, and consumer-acceptance challenges.

[1] Hauke Engel, Russell Hensley, Stefan Knupfer, and Shivika Sahdev, "Charging ahead: Electric-vehicle infrastructure demand," August 8, 2018, McKinsey.com.
[2] Sean Kane, Florian Manz, Florian Nägele, and Felix Richter, "EV fast charging: How to build and sustain competitive differentiation," June 4, 2021, McKinsey.com; Zealan Hoover, Florian Nägele, Evan Polymeneas, Shivika Sahdev, "How charging in buildings can power up the electric-vehicle industry," January 5, 2021, McKinsey.com.
[3] Jonathan Eckart and Frank Muehlon, "Here's how electric vehicles can keep us on the road to Paris," World Economic Forum, September 11, 2020, weforum.org.
[4] "Permitting electric vehicle charging stations: Best practices," California Governor's Office of Business and Economic Development, business.ca.gov.

McKinsey: How do dynamics differ in the public-charging sector across the European Union (the Nordic countries and Central, Eastern, Southern, and Western Europe) and the United States?

Frank Mühlon: The biggest difference in the charging landscapes of the US and the EU is the role of utilities. In most European countries, utilities have been engaged in deploying charging infrastructure for many years, with many more utility-owned, large public-charger networks. Meanwhile, with US utilities, the dominant charging companies are privately owned. Utilities are predominantly owned by investors, with more than 3,000 companies operating as regulated monopolies across 50 states with 50 different regulatory bodies. As such, it can be a long and complicated process to gain approval to invest in capital-intensive programs such as EV infrastructure, particularly on a regional or national scale.

While at present the United States trails the European Union in prevalence of charging infrastructure, its investor-owned model means the pressure is higher to achieve profitability faster. This push for faster profitability has created a culture among US charging companies of strong operational cost control and more experimentation with different business models.

McKinsey: What are your mid- and long-term views on how the charging-infrastructure sector is changing (for example, the role of software and services, new business models, consolidation, and competition)?

Frank Mühlon: The future of the market is full of opportunity for multiple disciplines. We will see the development of next-generation vehicles and supporting components, as well as an evolution of the collaborations among charging-technology providers, OEMs, operators, utilities, and players in renewable energy. Companies are already making bold moves, diversifying their portfolios to participate in the operation of charging stations. For example, IONITY—a joint venture of BMW Group, Daimler AG, Ford Motor Company, Hyundai, and the Volkswagen Group with Audi and Porsche—operates a network of approximately 400 fast-charging stations across 24 European countries.

New software solutions are also emerging that are shaping the future of the sector. One cloud-based digital solution aims to optimize the real-time fleet management of EVs and to speed up the electrification of transport fleets by helping operators maintain 100 percent business continuity as they make the transition to being fully electric.

Giovanni Palazzo: We expect more developments in the customer experience and the market as charging infrastructure continues to mature.

Studies have found that limited public charging and long charging times are now among the top barriers to further EV adoption. We've made progress, though: ten years ago, drivers of electric vehicles could usually charge only at home; then came public Level 2 chargers; and now we are starting to see widespread availability of fast-charging options. But there's still a lot more growth needed.

More dynamic systems will need to be developed in the medium to long term. Today, time-of-use tariffs for EV charging are emerging from utilities. As renewables on the grid increase, energy supply could fluctuate over the course of a day or a year. A more dynamic system could create value, requiring advances in smart energy and grid services and real-time pricing.

In the near term, I could see public fast-charging infrastructure remaining a fragmented market. Over time, though, as with many capital-intensive industries, companies will consolidate regionally or nationally. So in the medium to long term, you will see a structural change in fast charging.

McKinsey: What are the most exciting technology advancements that we will see in EV-charging infrastructure?

Giovanni Palazzo: Ultimately, charging will ideally become convenient, fast, and seamless. Of course, what might become routine to customers will require hard work from technology experts and a commitment to operational excellence.

When I say "convenient," it's not just a matter of location; it also means being available and online, which will require predictive maintenance enabled by data science and real-time diagnostics.

Second, I think the five-to-ten-minute charge will be game changing. With 800-volt architectures becoming more common in EVs, five-minute charge-ups may be a reality soon.

Finally, a seamless customer experience is about building on technologies like plug-and-charge solutions and ensuring that electric-vehicle charging is keeping pace as other mobility trends, such as autonomous vehicles, come to market.

Frank Mühlon: The development of vehicle to grid with bidirectional charging is really exciting. The chargers can smooth out each day's uneven generation of renewable electricity, such as through solar and wind, and enable EV drivers to transfer surplus power back to the grid—with the potential to earn money back.

Convenience is key to EV adoption, and plug-and-charge solutions represent the next significant evolution in fueling our vehicles. Plug-and-charge enables drivers to simply drive to the charger, plug in the connector, and start charging automatically, removing the need for credit cards or payments via a smartphone.

McKinsey: What are the most important or most impactful partnerships that you see or hope to see for accelerating the rollout of charging infrastructure?

Giovanni Palazzo: There are several key collaborations, such as coordination with utilities companies and technical integration with vehicle manufacturers. Strong collaboration with automotive companies will be necessary to offer a seamless customer experience, such as plug-and-charge solutions—the ability to plug in the vehicle and walk away with no credit-card or app interaction required in that moment.

Furthermore, government commitment at all levels is crucial to accelerating the rollout of charging infrastructure as the market continues to mature. Supporting access to funding, whether at the national level or through locally targeted incentives, could have a significant impact. Government can also reexamine complex permitting and site-development processes.

Frank Mühlon is the president of the e-mobility division of ABB. **Giovanni Palazzo** is the president and CEO of Electrify America.

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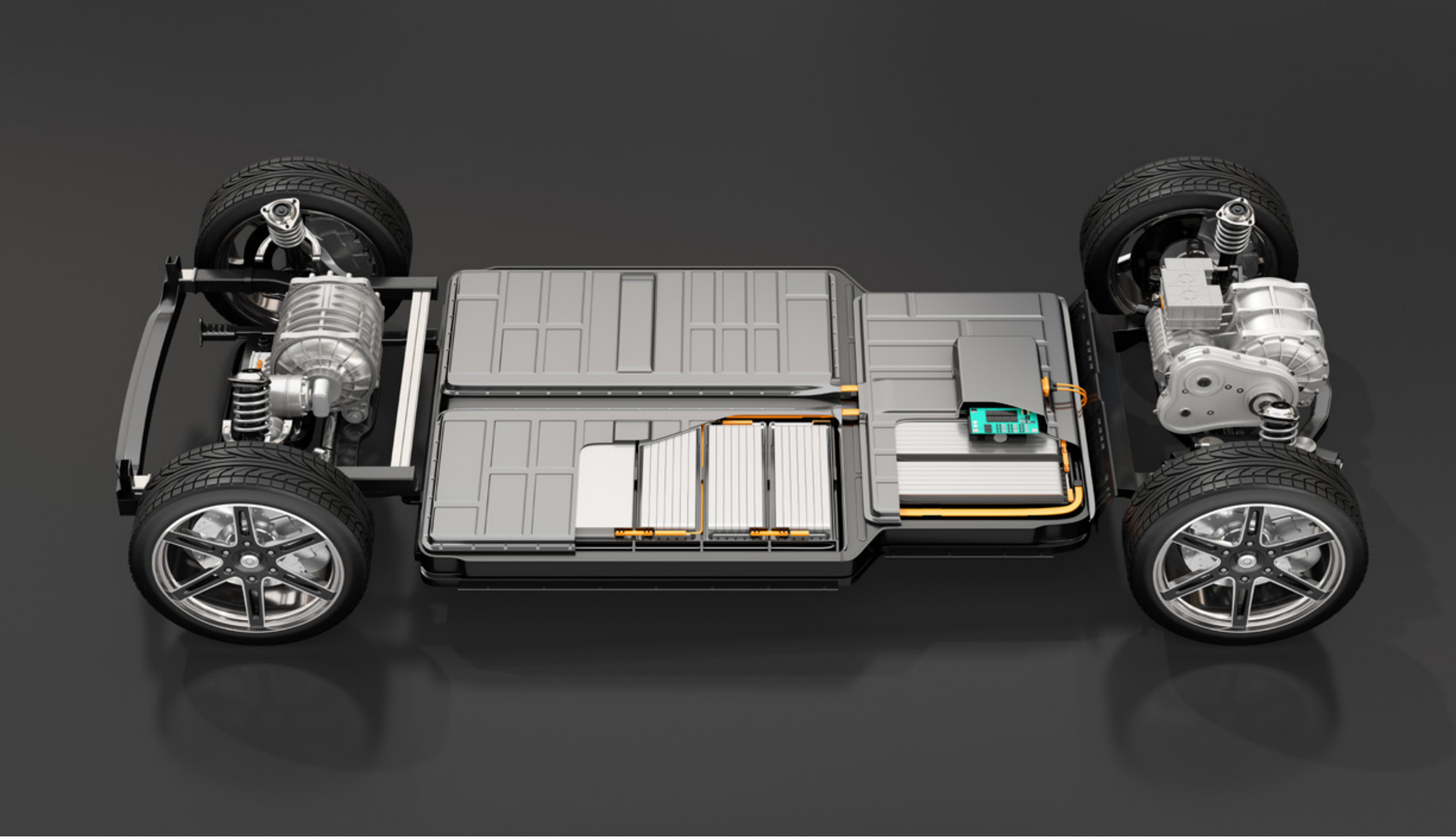

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Unlocking growth in battery cell manufacturing for electric vehicles

Demand for electric vehicles is soon expected to outpace the ramp-up of battery cell production. Accelerating the build-out of battery cell gigafactories can help the industry stay on course.

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As electric vehicle (EV)[1] sales continue to gain market share, the demand for batteries is ramping up with 30 percent year-over-year growth around the world, reaching 3,900 gigawatt hours (GWh)[2] in 2030. In some cases, supply cannot be scaled quickly enough to keep up. Established battery cell companies and emerging start-ups have announced combined plans to build production capacity of up to approximately 960 GWh in Europe alone by 2030, growing 20-fold from 2020 and accounting for 33 percent of global, announced battery cell production capacity of around 2,900 GWh in 2030. But as demand continues to accelerate, so too must supply. Building out the necessary manufacturing capabilities and capacities will require joint efforts across the entire industry—particularly by leading players in China, Europe, and the United States.

Electromobility demand is accelerating

In 2020, for the first time, the global number of EVs on the road surpassed ten million.[3] This milestone comes amid accelerating EV uptake driven by three key factors: evolving regulations, OEM sustainability targets, and increased customer pull as OEMs broaden their product portfolios.

Evolving regulations: To meet the targets of the Paris Agreement, governments around the world are announcing a growing number of net-zero and carbon-neutral commitments.[4] In addition to emissions and fuel-economy regulations, several countries have announced end dates for internal combustion engine (ICE) vehicle sales, with the earliest taking effect in Norway in 2025. Based on the regulations to date, ICE phaseout targets will affect almost 50 percent of global car sales by 2030.

OEM sustainability targets: OEMs have started announcing ICE phaseout dates of their own. To date, most of the largest OEMs have committed to increasing EV sales significantly over the coming years or have already defined phaseout dates for ICEs. As a result, at least 50 percent of global car sales will be affected by OEM targets for phasing out ICE vehicles by 2050.

Increased customer pull: Global EV sales rose by a record 43 percent in 2020, with 3.2 million EVs sold. This means the global market share of new EV sales increased from 2.5 percent of all new vehicle sales in 2019 to 4.6 percent in 2020.[5] That same year, the average driving range of new EVs increased to 380 kilometers from 230 kilometers in 2015. And in many countries the total cost of ownership of EVs became cheaper—for example, in the United States, driving electric can save a consumer $6,000 to $10,000 over the lifetime of the car.

The need for additional supply

The surge in demand for EVs is on pace to outstrip supply of battery cells in the coming years, based on the announced build-out capacity to date. A base-case EV uptake scenario requires more than 3,900 GWh of battery capacity globally by 2030 with passenger cars accounting for roughly 2,400 GWh, while an aggressive uptake scenario requires an additional 600 GWh. Geographically, the need varies; battery cell demand will remain highest in China, followed by Europe and the United States.

That said, additional cell capacity estimates based on the announcements of battery cell manufacturers sum to a global supply of approximately 2,900 GWh by 2030 (exhibit). Overall, 60 new gigafactories[6] with an average production capacity of 25 GWh are being planned for construction globally by 2030. There is a tendency for gigafactories to become larger on average, in some cases reaching up to 100 GWh.

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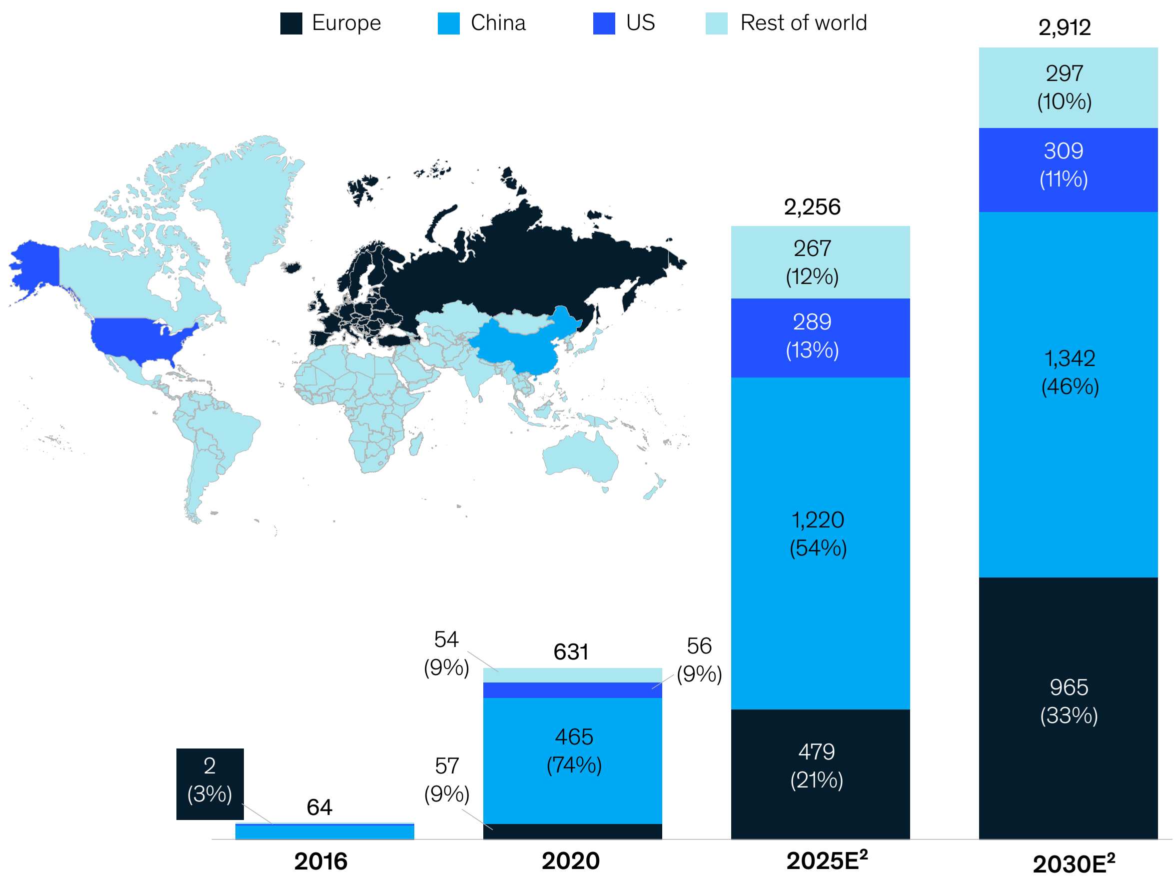
[1] Refers to battery electric vehicles, plug-in hybrid electric vehicles, and hybrid electric vehicles.
[2] Includes batteries for passenger cars, commercial vehicles, and nonmobility use.
[3] For more on the continued uptake of EVs, see Julian Conzade, Andreas Cornet, Patrick Hertzke, Russell Hensley, Ruth Heuss, Timo Möller, Patrick Schaufuss, Stephanie Schenk, Andreas Tschiesner, and Karsten von Laufenberg, “Why the automotive future is electric,” September 7, 2021, McKinsey.com.
[4] For more on the Paris Agreement, see “The Paris Agreement,” United Nations Framework Convention on Climate Change, 2021, unfccc.int.
[5] Global EV Data Explorer, IEA, April 2021, iea.org.
[6] A term originally coined by Tesla. Gigafactories bring together multiple companies, high-tech equipment, and specific business processes in a single location to create specialized products, such as lithium-ion batteries.

Exhibit

Battery production capacity is surging around the world.

Battery cell production capacity, GWh annually[1]



[1]Figures may not sum, because of rounding.
[2]Estimated based on announcements of battery cell manufacturers.
Source: McKinsey battery supply tracker (June 2021)

To meet overall demand in time (beyond passenger vehicles to include trucks and buses, among others), additional capacities to those already announced are needed from 2023 onward. A key challenge to anticipate will involve buildup of gigafactory-scale production lines and the typically delayed ramp-up as factories come online, given that most gigafactories require three to six years to ramp up to full capacity. Battery production will include a wider range of companies with different levels of experience; around 10 percent of the total 2030 supply target has been announced by start-ups with limited experience in battery production at scale. And automakers and battery producers and their supply chains will also need to get up to speed on technology diversification, particularly around evolving battery anode and cathode chemistries.

Overall capacity obscures certain regional differences in supply capacity and risks, with battery cell manufacturing footprints increasingly on a "regional for regional" model, with a strong focus on climate and Scope 3 decarbonization targets for OEMs and customers alike. The United States in particular is in need of additional capacity commitments, as current commitments will fail to meet projected demand by 2025. And while capacity in China and Europe appears to be better covered based on announcements already made, the implementation risk is highest in Europe, where 25 percent of cell capacity in 2030 has been announced by start-ups.

Joint efforts to activate the battery cell manufacturing industry

Today, a majority of companies that specialize in battery cell manufacturing equipment are in China, Japan, and South Korea. However, many Asian battery cell manufacturing suppliers are operating at more than 95 percent capacity, leaving little room to increase output, and might prioritize orders from their existing local customers over those from new European market entrants and those from other regions. This creates an opening for manufacturers from Europe, the United States, and other regions to join the effort to activate the battery cell manufacturing industry.

The strong build-out of battery gigafactories will likely require direct investments of more than €300 billion by 2030 alone (approximately €100 billion in Europe and €65 billion in North America). Gigafactory construction is complex, requiring the integration of numerous capital expenditures, such as building, infrastructure, energy, and different machine types, as well as specific areas for testing and dry rooms, among others.

The following targets and priorities can help jump-start progress:

— *Build battery production capacity*. Prior to start of production, on-time and on-quality battery cell manufacturing equipment supply will be crucial to achieve targeted yield or output performance. The supply of coating equipment is especially at risk of shortage or delay, given its high specificity to battery cell manufacturing, as well as the limited number of regional machinery players with the required expertise, high utilization of equipment production capacity, and full order books. Access to construction labor is also essential, and challenging in many markets.

— *Expand active material production capacity.* Additional active material production capacity—especially in Europe and the United States—is required to support or enable battery production in general and sustainable, local supply chains in particular.

— *Secure access to the most critical raw materials, especially nickel, lithium, and cobalt, but also graphite.* This might require direct investment or co-funding by downstream value-chain players to unlock new mining capacity.

— *Ensure circularity.* Closed-loop systems for the second life of batteries need to be established to mitigate raw-material supply risks, optimize the battery carbon footprint, and improve economics of the battery recollection obligation for OEMs.

Other investments will be needed not only to enable a truly sustainable and circular battery supply chain but also to meet net-zero targets set by auto OEMs. The electrification of equipment, operational-efficiency improvements, and use of green electricity will require further investment to supply low- or zero-emissions batteries so that the CO_2e[7] emissions of EVs are competitive with those of ICE vehicles.

Finally, the battery manufacturing workforce will need to be increased. On average, a 40 GWh gigafactory requires more than 2,000 full-time skilled employees. This means there is significant need for a new and skilled workforce. Filling these positions is critical to ensuring battery cell manufacturing meets demand, and will require strong efforts across the industry.

[7]Carbon dioxide equivalent.

Industry players that approach battery cell manufacturing thoughtfully and with an appropriate sense of urgency will likely reap the benefits of expanding into a lucrative new market. With emissions targets locked in place, the course is set to provide consumers with cleaner, greener transportation options.

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Scaling battery capacity in Europe: A conversation with Evan Horetsky

The Tesla gigafactory designer offers insights into what can be done to improve electric-vehicle battery manufacturing in Europe—a move that could drive the region into a cleaner future.

Evan Horetsky
Partner, Stockholm
McKinsey & Company

To many consumers, the decision to drive an electric vehicle (EV) will hinge on the promise of a high-quality, high-capacity battery powering the engine. As such, the large-scale arrival of EVs on the main stage of global vehicle sales will be predicated on significant acceleration of EV battery production and capacity.

In the European Union, total annual battery capacity will need to scale from the current 60 gigawatt hours (GWh) to 900 GWh to meet the European Union's 2030 decarbonization targets. McKinsey Partner Evan Horetsky helped plan and build all of Tesla's gigafactories in China, the United States, and most recently in Berlin, Germany, where he served as the director of engineering, procurement, and construction. He spoke with us about the role of gigafactories, breaking down organizational silos, and prioritizing decarbonization of the supply chain.

McKinsey: What are gigafactories, and what role will they play in achieving Europe's decarbonization targets?

Evan Horetsky: There are two definitions of gigafactories, both of which are relevant to Europe's decarbonization targets. The first is to think of a very large-volume factory as a hardware product itself—that is, applying all the technique and rigor normally found in product design and engineering to manufacturing and factory design. In this way, gigafactories will shape every area of future industrialization, prioritizing electrification, sustainability, and digital, as well as operative efficiency. The second definition is, more simply, a large battery factory—and battery production will be key to unlocking the energy storage, grid utilization, and future mobility strategies we need to achieve decarbonization.

McKinsey: What considerations are required to successfully expand Europe's annual battery capacity?

Evan Horetsky: The organizations building the more than 30 planned battery factories today need to think about several nuanced and difficult questions. These include what generation of cell technology to apply to their line planning, how to be flexible with changing customer specs and recipes, and how to carefully manage equipment, raw materials, and other long-lead items. All of these considerations will be crucial to ensure organizations do not get caught off guard with delays closer to launch. For example, Northvolt has invested heavily in lab and pilot-plant validation as well as in advanced simulation and process-validation techniques for both the product and the factory. These investments enabled the battery developer to roll out a new plant in Skellefteå, Sweden, very quickly.

McKinsey: Is there now a strong business case for investing in battery gigafactories, or are additional regulations and incentives required to attract investors?

Evan Horetsky: The margins are tight, and the scale needed to meet demand is intense, with some projecting that more than 3,000 GWh per year will be required by 2030 in order to displace the more than 70 million internal-combustion engine (ICE) vehicles produced annually. Because yield and scrap rate are such outsize factors in the probability of success—and ramping up cell manufacturing is so darn hard—government regulations and incentives could help support risk-taking in this period of ramp-up and scale.

McKinsey: What partnerships and commitments are required to scale battery capacity at the required pace?

Evan Horetsky: Products must be synthesized with manufacturing equipment, which must in turn be synthesized with factory decisions. Breaking down the walls between R&D, manufacturing, and building-construction data and efforts is crucial for a successful plan. Beyond this, precise forecasting and strategies are needed to secure long-lead materials and equipment. We also need to make a commitment to employees and talent, recognizing that they must sacrifice a lot to push through one of the most unforgiving production ramps in any industry.

McKinsey: How are car manufacturers collaborating with battery manufacturers and EV charging-infrastructure providers to collectively grow the market?

Evan Horetsky: Because there is a large and varied set of bottlenecks in the supply chain for electrification, OEMs and their suppliers are working in varied ways. With charging via either infrastructure or batteries, it is quite important to understand real estate, regional utility business, and power electronics. In some cases, like Volkswagen's Electrify America, OEMs are creating new businesses to serve this need. Others, like Tesla, are going their own way—and their developments could prove to be a key competitive advantage.

McKinsey: What key improvements can we expect from battery electric vehicle (BEV) batteries in the next three to five years, such as performance, cast, or carbon footprint?

Evan Horetsky: A zero-carbon supply chain is the first priority. After that, thermal efficiency and cell-to-pack density efficiency can do a lot to drive further improvements in EV architectures. Pack-density efficiencies must reach beyond 80 percent, and direct current internal resistance below 10 milliohms is needed to realize thermal-system efficiency. After this, cell chemistries with faster charge and power discharge will be developed. Solid-state products are very tricky to scale, but they could also double mass density of cells over the next few years.

McKinsey: What is the biggest sustainability challenge facing electric vehicles, and how do we mitigate it?

Evan Horetsky: Supply chains. All areas of the supply chain will present significant bottlenecks, so that will constitute the primary sustainability challenge for electric vehicles. Otherwise, the goal to advance to sustainable energy is incomplete. Decarbonization can be achieved through recycling and circular methods, as well as through agility in product bills of materials—swapping in more sustainable materials when possible. Safety and toxicity are also quite important, and there are alternative techniques for processing and selection that need to be employed, like direct lithium extraction, to improve manufacturing safety.

Evan Horetsky is a partner in McKinsey's Stockholm office. From 2015 to 2020, he worked at Tesla where he was on the leadership team for planning and building Tesla's factories around the world.

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Shaping the future of fast-charging EV charging infrastructure

To help electric vehicles reach ubiquity, governments and EV charging companies must ensure the availability of fast-charging infrastructure doesn't become a bottleneck for growth.

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Felix Richter
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In the past decade, electric vehicles (EVs) have gone from a rare sight on even the busiest road to an increasingly common, affordable option. In 2020, EV sales set new records that surpassed expectations, particularly in countries with an eager customer base and government policies supporting the transition to EVs. Much of this leadership has come from Europe, where EV adoption has surged; by July 2021, for example, two-thirds of Oslo's residents owned an EV.[1] According to McKinsey analysis, 45 percent of customers are considering buying an EV.

In addition to consumer enthusiasm and government regulations and incentives, the number of industry players committed to phasing out internal combustion engine (ICE) vehicles continues to grow. Such commitments are still in early stages, but by 2050 the bans OEMs have announced to date will account for more than half of today's passenger vehicle sales, and the EU is aiming for an ICE ban by 2035, likely pulling other countries' commitments forward as well.[2] All signs point to continued growth in the EV market, with Europe leading the charge: McKinsey projections suggest EVs will make up 75 percent of European new car sales by 2030.

All this growth means we need more places to charge EVs—now. Everywhere from homes and workplaces to retail sites, fleet depots, and on-the-go charging sites, the race is on to build enough public fast-charging stations to meet demand, remove perceived inconvenience for those still hesitating to transition to EVs, and ultimately help meet CO_2 emission reduction targets. Some actions governments and companies can take include offering incentives to build private chargers, subsidizing public charging, and investing in production capacity and a skilled workforce.

EV charging infrastructure could become a bottleneck for growth

As EVs have become increasingly affordable, one of the primary barriers for consumers is no longer cost but charging convenience. In McKinsey's 2020 ACES Consumer Survey, potential EV drivers put the lack of charging infrastructure at the top of the list of barriers to expanded EV adoption. Today, most EV charging is done at home, but the availability and convenience of publicly accessible chargers will be crucial for complete electrification of the vehicle fleet.

Although momentum in charging infrastructure has increased—Europe's public charger count increased fourfold between 2015 and 2020[3]—four risks could turn charging into a bottleneck:

— *Regulations.* In many geographies, securing permits to build chargers, construct sites, and connect to the electric grid can require months, or even years, of planning.

— *Grid.* Especially in areas with high charging demand, the electrical grid needs to be upgraded to expand power capacity—which include expensive and time-consuming updates.

— *Resources.* Several resources are in short supply, including skilled technicians, production capacity for fast-charging hardware, and enough green energy to make EVs fully environmentally friendly.

— *Cost.* EV charging infrastructure is not cheap; in the European Union, a typical 350-kilowatt (kW) charger can cost $150,000, including hardware, installation, and planning.

Actions to mitigate the threat of EV charging infrastructure shortages

Solution providers and owners and operators of charging networks play a key role in scaling EV-charging infrastructure, yet the broader ecosystem can help address a number of challenges. This includes, among others, OEMs, real estate providers, utilities and grid operators, and infrastructure funds.

[1] Julian Conzade, Andreas Cornet, Russell Hensley, Patrick Hertzke, Ruth Heuss, Timo Möller, Patrick Schaufuss, Stephanie Schenk, Andreas Tschiesner, and Karsten von Laufenberg, "Why the automotive future is electric," September 2021, McKinsey.com.
[2] Nick Carey and Christoph Steitz, "EU proposes effective ban for new fossil-fuel cars from 2035,"Reuters, July 2021, reuters.com.
[3] "Normal and high-power public recharging points (2020)," European Alternative Fuels Observatory, eafo.eu.

With this in mind, governments and companies can take several actions to address the leading risks facing EV charging infrastructure.

Governments

Offer more incentives and mandates for building private chargers. Many countries are finding success with establishing incentive schemes for consumers, such as refunds for installing a wall box. They are also increasingly introducing requirements and subsidies for apartment buildings and other multiunit dwellings to offer chargers, as well as for companies to install chargers at workplaces—indeed, chargers will eventually become a standard part of building design.[4] These inducements should be structured to direct money toward the biggest bottlenecks for EV growth in a given community—for example, earmarking more incentive funding for apartment buildings in dense areas with limited parking.

Subsidize public charging in necessary locations. Subsidies—for capital expenditure on chargers, installation, and power distribution, as well as ongoing costs for operation—can help draw EV charging to areas where it is most needed. Such subsidies can make it economically viable to build chargers in areas where long-term profitability can outweigh short-term costs. Some governments, such as New York City's, are funding installation costs to build chargers in high-demand areas; others, such as Germany's, are sponsoring an entire network to be operated by private companies. A successful effort will require modeling of demand, grid capacity, and other factors to determine priorities for investment.

Work with utilities to build out the electric grid. Electric grids will need to expand capacity to ensure they can cover the demand that will be created by a future of EV-covered roads. Governments might direct funding to grid operators earmarked to build capacity starting in areas with high local charging demand. They can also consider developing a new grid fee system that accounts for peak demand charging need, protects the grid from overutilization, and keeps charging economically viable at ultrafast charging locations.

Link incentives and subsidies to use of green energy. Achieving net-zero road emissions requires ensuring EV chargers are distributing 100 percent green energy. Where possible, governments can advance multiple sustainability agendas by requiring recipients of incentives and subsidies to commit to using green energy.

Simplify and standardize permitting. In extreme scenarios, securing a permit for a charger site, including installation and grid updates, can take two years. Streamlining permitting to accelerate throughput will take concerted action at a number of levels of government and in most geographies.

EV charging companies

Invest in production capacity and a skilled workforce. Now is the time for EV charging companies to scale, build out factories and supply chains in relevant regions to match demand, and develop a growth-minded talent strategy. These resources will form the foundation for successful rollouts of chargers in the coming years.

Partner to finance public chargers. Infrastructure funds and other potential investment partners offer alternative funding sources to help build, install, and operate public chargers. Beyond raising money, such partners may also be interested in other methods of funding capital, such as purchasing charging infrastructure assets in exchange for stable returns.

Use data and analytics for network planning. Sophisticated, data-driven planning will be required to identify the best sites for a successful, in-demand charging network. For example, geospatial analytics allow planners to optimize locations based on traffic flows, local grid status, and other relevant factors.

[4] Zealan Hoover, Florian Nägele, Evan Polymeneas, and Shivika Sahdev, "How charging in buildings can power up the electric-vehicle industry," January 2021, McKinsey.com.

Reduce "range anxiety" of potential EV drivers. Perception of potential issues with switching from ICE to EV needs to be proactively addressed. Ongoing consumer education efforts around helpful tools (such as integrated trip planning or charger reservations) and additional advantages of EVs (such as integration with a home solar system) is required.

In 2020, the EV rubber hit the road. Over the next decade, EVs will help redefine the intersection of mobility and infrastructure—and, in doing so, will, contribute significantly to achieving net-zero emissions targets.

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