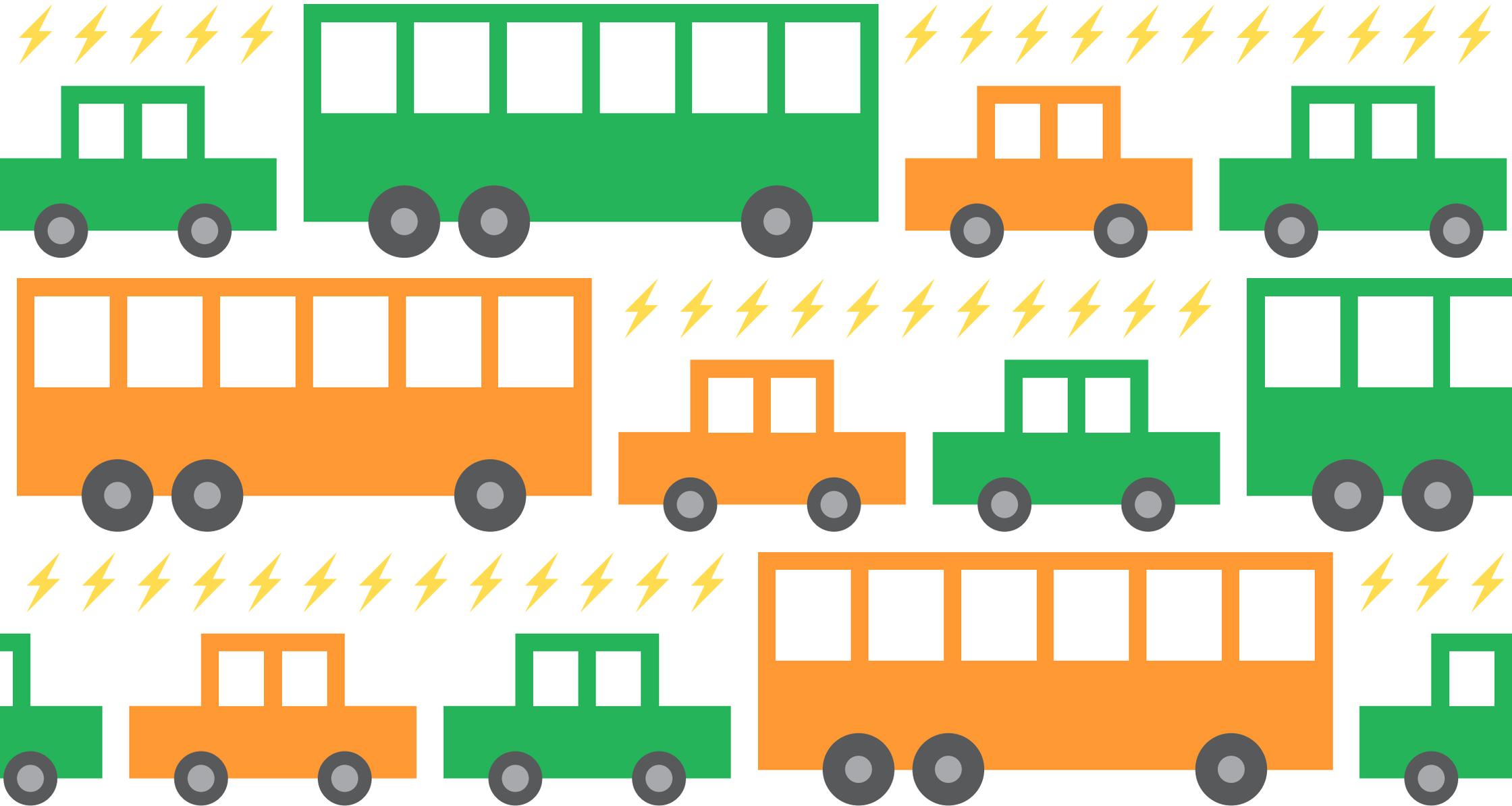


The case for
Electric Mobility in India



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Executive summary

India is the fifth largest car market in the world and has the potential to become one of the top three in the near future – with about 400 million customers in need of mobility solutions by the year 2030. That is one side of the coin. The other side is that the country needs a transportation revolution. The current trajectory of adding ever more cars running on expensive, imported fuel and cluttering already overcrowded cities suffering from infrastructure bottlenecks and intense air pollution is unfeasible. India's cities will choke. A transportation revolution will have many components – better 'walkability', public transportation, railways, roads – and better cars. Many of these 'better cars' will likely be electric.



India's government wants to accelerate the electric vehicle transition. The Minister of Road Transportation, Mr. Gadkari, is determined to 'bulldoze' India's shift to alternative fuels 'whether the industry likes it or not'. However, if the economics do not work – for the user/driver as well as for the business investor – that will be difficult to do.

Going 'electric' – as we see in many markets across the world – is a team effort. It requires governmental vision and goals (backed by legal and financial incentives), innovation from industry and start-ups (from battery technologies to mobility models), a push from car manufacturers to design affordable cars optimized for electric driving, and large-scale investment into charging infrastructure and the electricity supply behind it.

Changing a system as hardware-heavy and complex as road transportation is a huge opportunity. But how can a country, industry or company unlock it? Will being a pioneer pay? Or should one wait for a tipping point – for example, when battery costs have fallen to \$100/kWh and the country is dotted with fast charging stations? Where along this process will/should a strategically smart stakeholder make a move?

In this short report, we look at the key drivers for electric mobility in India, at the ecosystem and at emerging business models. We think that the early adopters will be agile businesses (rather than private users or government agencies) who see a robust business case emerging for certain types of mobility solutions and have the means and

incentives to set up their own charging infrastructure. They will break in the market, create new supply chains, drive down costs and change mindsets. In our conversations with large automotive players like Mahindra and Mahindra and agile start-ups like Sun Mobility or ION Energy, we found a wealth of new business ideas and excitement around electric mobility.

What makes us optimistic about a successful market growth story is that electric mobility can leverage India's strength as a place for agile digital and consumer product innovation, showing the way for an otherwise relatively conservative manufacturing industry and an often-underperforming infrastructure sector. Such digital business models work on providing mobility solutions and leveraging technology, and often rely on the monetization of data gathered from users.

India has the potential to become a very large electric mobility market. However, this will likely not be a top-down transition driven by the central government (as, for instance in China). Instead, it will be driven by pioneering companies and city governments. The push will come from specific use-cases and the improving economics of electric mobility, rather than from large infrastructure and incentive programs. Whether that will be enough to ensure that Indian companies will have a large share in this newly emerging value chain and create much-needed manufacturing jobs will depend not so much on battery manufacturers or infrastructure providers (where few jobs are created), but on the strategic positioning and investments of the Indian car industry.

» India has the potential to become a very large electric mobility market. «

5th

India's position as a global auto market

<0.1 %

of 21 million vehicles sold in India in 2017 were electric

40%

of cars sold in India in 2030 could be electric

up to 80%

reduction in operating cost for an electric car as compared to a diesel or petrol car in 2017

40% – 100%

higher capital cost of an electric car as compared to a diesel or petrol car in 2017

150 km

daily driven distance at which an electric car outcompeted a petrol car in 2017

220 – 250

operational charging stations in India in 2017 as compared to 56,000 petrol stations

10,000

largest tender for electric vehicles in India by EESL, a government organization in 2017



2 The case for electric mobility in India

India's roads are bursting at their seams with more than 210 million cars, motorcycles, 3-wheelers, and trucks. Over the past five years, the number of vehicles grew by as much as 23% cumulatively, just short of growth in China¹. Nonetheless, this is likely just the beginning as today only 4% of Indians have access to private motor vehicles compared to 80% in the US. By the year 2030, an estimated 600 million vehicles will be on Indian roads - thrice the current number. With all the major cities including New Delhi and Mumbai already plagued with severe traffic congestion and record-breaking pollution levels, India is in dire need of radically new mobility solutions. Electric mobility will be a part of that. It is attractive for a number of reasons:



© istock/ powerofforever

1 Oil imports

India is the third largest importer of crude oil in the world. In 2018, it will spend close to \$85bn on oil imports². Over 40% of this will be used to power the transportation sector.³

Between year 2017 and 2030, India is expected to spend \$550bn on imported fuel for passenger mobility. That is close to one-fourth of its current annual GDP.⁴



Long term
impact of
electric
mobility

+++

Assessment

Shifting to electric vehicles (EVs) would reduce India's dependence on oil imports. It would, at the same time, increase electricity demand. On balance, given the high energy efficiency of EVs and the increasing amount of local renewable energy in the energy mix, India's overall energy import bill will reduce sharply. India would need to import certain metals for battery packages.

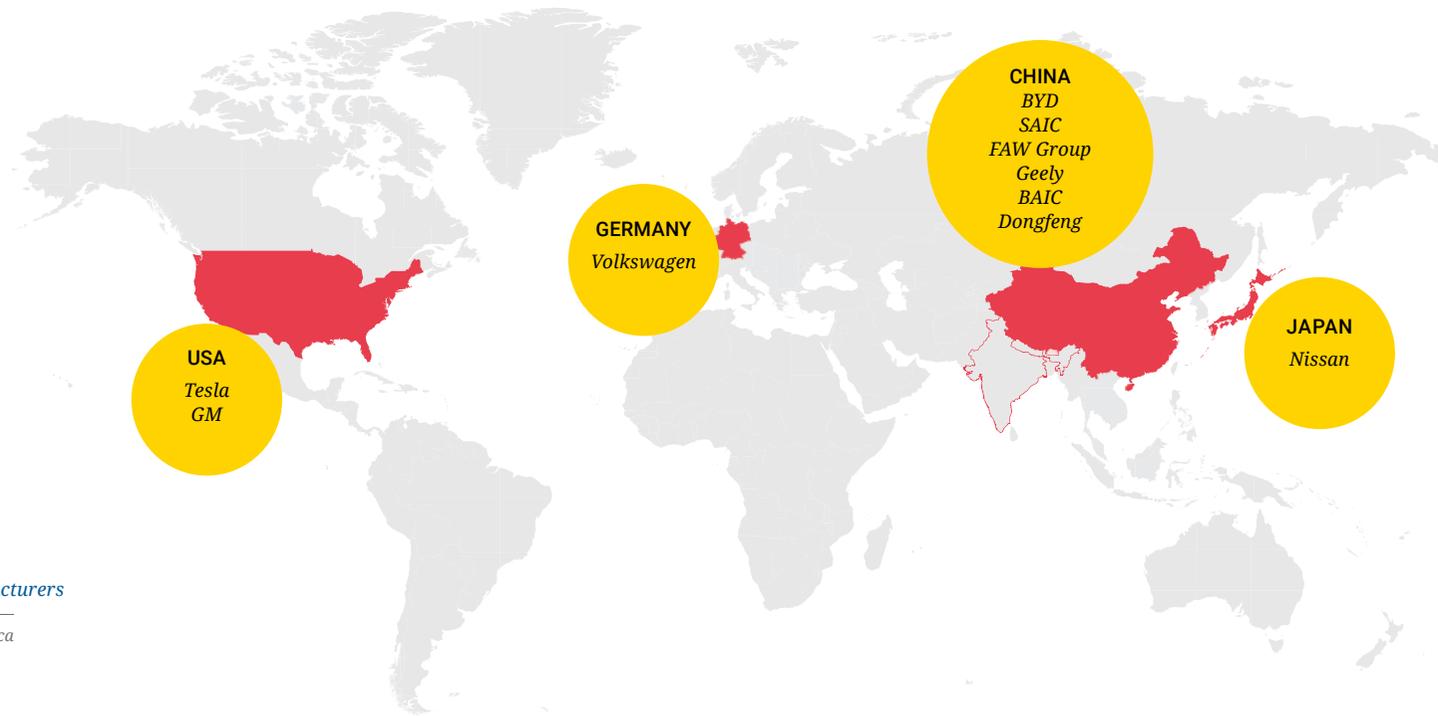


Figure 1:
Top 10 EV manufacturers

Source: Clean Technica

2 Technology leadership and job creation

India is the world's fifth largest producer of automobiles. As such, it is sound industrial strategy to be in the vanguard of a transition to EVs and support Indian manufacturing through a strong EV home market.

Today, Mahindra Electric is the only major Indian carmaker that offers electric vehicles. It expects to sell about 2,000 EVs in 2017⁵. Compare that to China, where more than 10 major manufacturers sold more than 50,000 EVs in a single month – December 2017⁶.

Six of the top 10 large EV manufacturers are from China. The rest are from the US, Japan and Germany⁷. These markets also already have advanced battery technologies and are experimenting with large-scale charging infrastructure.

Long term impact of electric mobility

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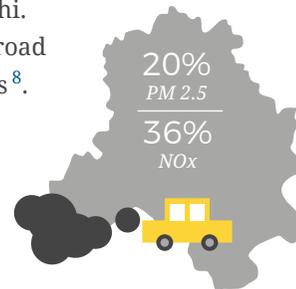
Assessment

The EV transition presents an opportunity for Indian manufacturers to leapfrog to the technological forefront of car manufacturing. This would create a large, highly-skilled and sustainable pool of Indian jobs.

3 Urban air pollution

Most cities in India have record-breaking pollution levels (particularly PM 2.5 and NOx). India's capital New Delhi is considered one of the most polluted cities in the world. A share of this pollution comes from vehicle engines.

A recent study found that vehicle emissions contribute to 20% of PM 2.5 and about 36% of NOx emissions in New Delhi. Other major contributors to urban air pollution were road and construction dust, industries and domestic sources⁸.



Long term impact of electric mobility
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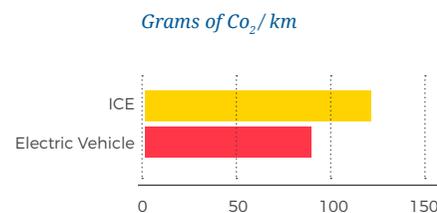
Assessment

Reducing tailpipe emissions is key to a long-term solution for India's pollution problem - especially given the expected growth in vehicles.

4 CO₂ emissions

India is already the fourth largest emitter of CO₂ (2.5 m kT in 2015). Given that India's per capita emissions are still only 25% of those in China and 12% of those in the US, as economy and population grow, overall emissions are set to grow too. From a global climate perspective, it is imperative that India takes a low carbon development path.

Globally, emissions from road transport contributed around 16% to annual CO₂ emissions in 2017⁹. Considering the current coal-heavy electricity mix in India, emissions per kilometer by EVs are around two thirds of emissions by internal combustion engines (ICE).¹⁰



Long term impact of electric mobility
++

Assessment

A large share of EVs would increase emissions from power plants in India but given the high tank-to-wheel efficiency of EVs, overall CO₂ emissions per vehicle will decrease by almost 30% when compared to ICEs. In addition, the trend towards a higher share of renewables in energy generation will make EVs even more CO₂ efficient.

The Indian government's current focus is, however, on local goals (local pollution, oil imports, etc.) more than on global climate goals, which are incidental to an economically attractive energy transition.

3 Growth scenario and ecosystem

Electric cars are in the news in India, but very few have so far hit the roads. Less than 0.01% of cars that were bought by Indian consumers in the year 2017 were electric. However, the transition from conventional internal combustion engine (ICE) based vehicles to electric vehicles could be very quick.

A recent study suggests that a significant share of consumers already consider electric cars as an option when choosing a new car.¹¹ Rapidly decreasing battery costs, technological advances in charging infrastructure, innovative business models, the influx of smart digital technologies, as well as green policies and subsidies are creating excitement around electric vehicles. As these trends continue, EVs could match the initial cost of conventional ICE vehicles by the early 2020's.

» *The future of India is definitely electric. Long term cost benefits, lowered pollution and a strong government thrust will drive the transition to EVs. And I think, India will see a large-scale transition to EVs as early as 2025.* «

*Kunwer Sachdev,
Managing Director of Su-Kam Power Systems Limited*

» **By 2030, there could be more EVs in India than the total number of vehicles today** «

By 2030, as many as 40% of new vehicles sold in India, approximately 24 million, could be battery powered. The number of EVs sold in India in 2030 would thus surpass the total number of vehicles sold in India in 2016, which was 22 million.

Figure 2:
Projected growth of EVs in India

Projection by TFE Consulting based on data from Society of Indian Automotive Manufacturers and Bloomberg New Energy Finance¹²

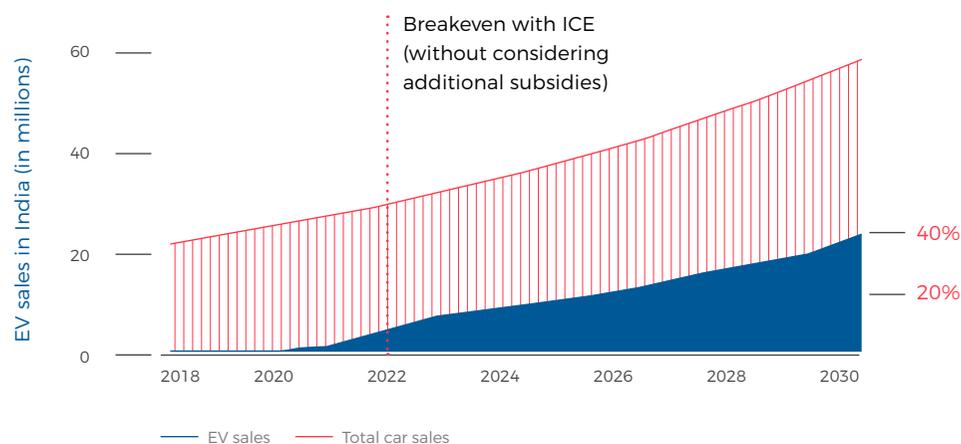
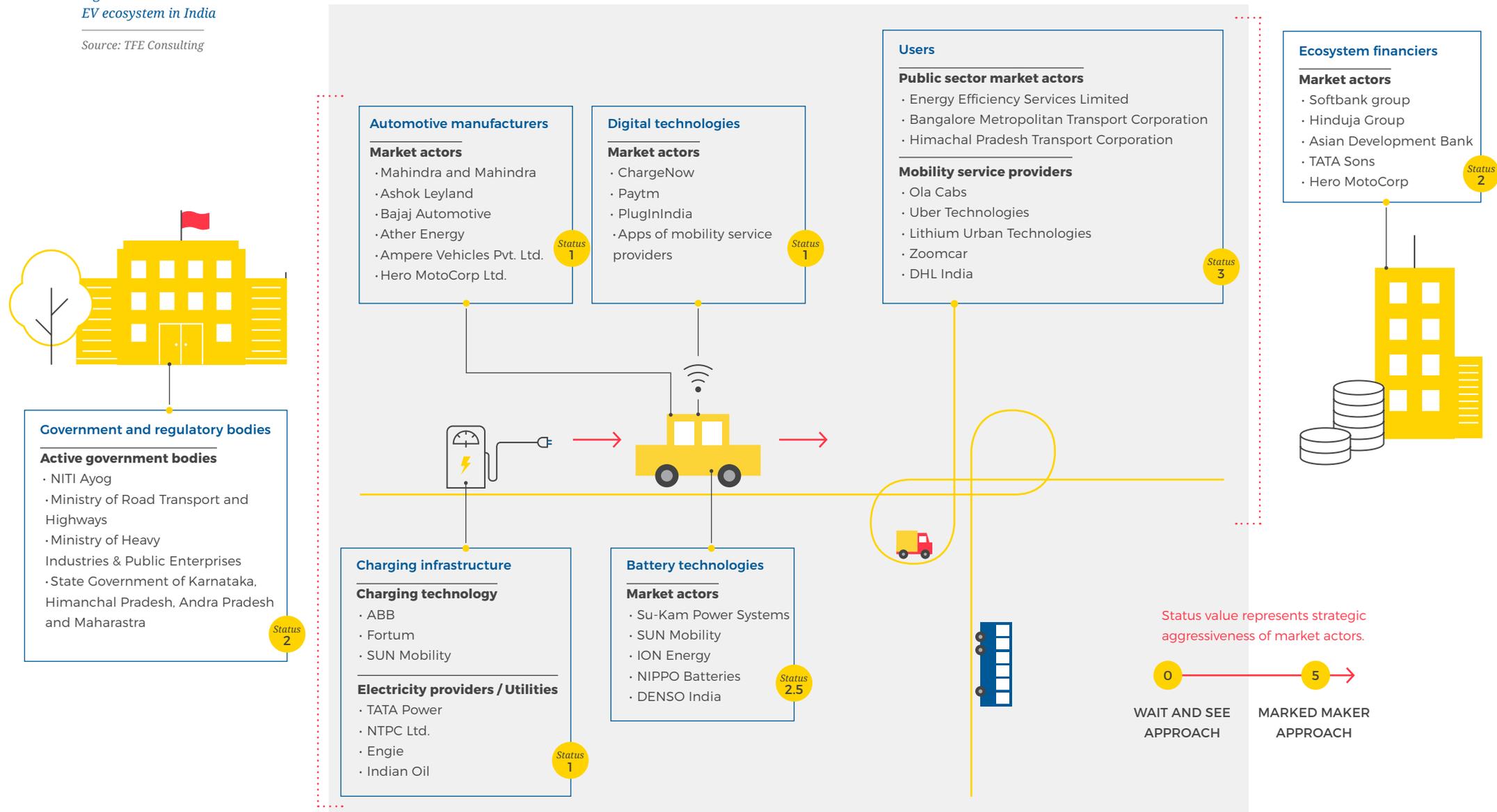


Figure 3:
EV ecosystem in India

Source: TFE Consulting



4 Drivers of electric vehicles in India

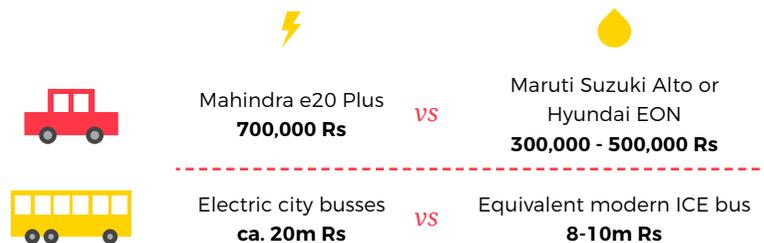
One of the key barriers for a fast adoption of electric vehicles is the upfront capital cost of an electric vehicle. In 2018, showroom prices of EVs – whether a car, bus, 3-wheeler or motor-cycle - were still 40-100% higher than those of conventional alternatives. The main drivers are the expensive batteries and peripheral electronics, which contribute about 50% of total EV cost.

While the upfront cost of EVs is higher, the cost of operating an electric powertrain is considerably lower than for a gasoline or diesel engine. This is due to higher powertrain efficiency (up to 80%¹³), lower cost of energy (especially when an EV is charged at off-peak hours), lower maintenance costs (fewer moving parts) and fewer sorties to the garage. However, given the current economics in India, owners of EVs would only see an overall economic benefit if their vehicle is driven for more than 150km a day. Such distances are typically not covered daily by private car owners.

A second key challenge is the development of the appropriate charging infrastructure. Moreover, given the very small size of the EV market, there are hardly any EV specific maintenance and servicing facilities, insurance policies or a second-hand EV market: these are features of particular importance for individual private users, who have limited market shaping powers.

Other vehicle users, however, already have an economic incentive to go electric and the means to structure the market. These include, for instance, mobility service providers or logistics companies. Their taxis, 3-wheelers, delivery vans or city buses often travel more than 150km a day – often within a specific city. At such distances covered, the total cost of ownership can be as much as 20% lower with an EV¹⁴.

Large-scale fleet operators like Ola, Uber, Lithium Urban, Zoom Cars, and door-to-door delivery/courier operators could become strategic drivers of the market. Since they often operate many vehicles across India, they have the right business incentives to develop strategic charging and digital infrastructures to



» India's auto market is going through rapid changes. This was evident at the Delhi Auto Expo 2018, where major car makers showcased 28 production-ready EVs and several concept EVs. India's carmakers, Mahindra Electric and Tata Motors, were leading the way with six electric cars each¹⁵. « Times of India

Chapter-highlights

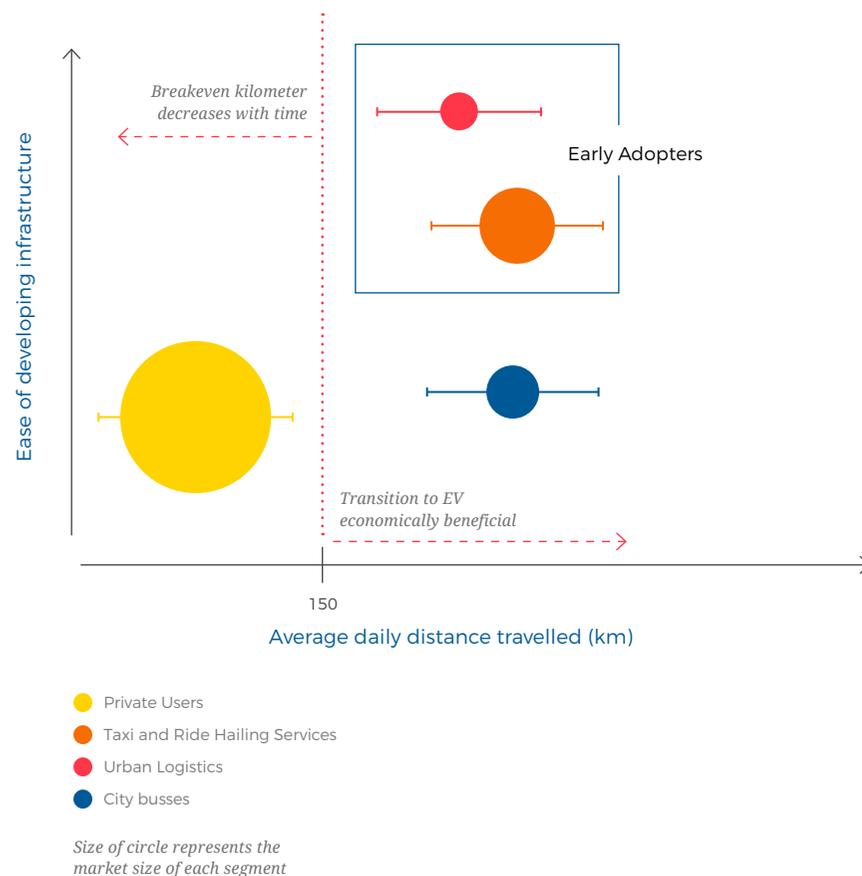
1. The business case for private EVs is still weak in India
2. Fleet operators, logistics companies and other professional players already have an economic case for EVs
3. Currently, the breakoff-point is still high at 150km/day of road driven. This will fall over time

support their own EV fleet. Add to that the existing digital technologies already widely used by these actors and the strong financial backing from investors, they also have the means to drive change.

City buses also have business incentives to switch to EVs, but there are larger organizational and market barriers that slow adoption. Close to 90% of the city bus market is privately owned, fragmented and unorganized¹⁶. As a result, this group will likely wait for the infrastructure to be built rather than take a lead. State transport corporations own 10% of city buses and often lack the required investment capital for a systematic transition to EVs, which includes the cost of EVs, the cost of developing charging infrastructure, the training of manpower for maintenance and service of vehicles. These transport corporations often also have a complex and largely bureaucratic organizational structure that makes them slow to innovate. As a result, city busses – whether privately or state owned – are likely to be followers.

Figure 4: Motivation to migrate to EVs

Source: TFE Consulting





Market voices

Karthika Nair

*Manager - Strategy and Business Planning
Mahindra Electric Mobility Limited*

What are the main challenges for adoption of EVs in India?

Karthika: There are four major challenges that we are working to solve. Firstly, the market is highly price sensitive. The higher capital cost of EVs as compared to an ICE is a challenge. Secondly, there is a lack of a fast charging infrastructure around the country. Thirdly, many of our customers like to travel long distances with a single charge, which is not feasible with the current battery technology installed in electric cars. This is particularly important for our customers because of the limited charging infrastructure in India. Lastly, customers are keen to charge as quickly as they can refuel a petrol tank, which is not feasible with the current charging technologies.

Who will likely be the early adopters of EVs in India?

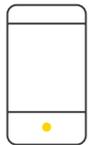
Karthika: Large fleet operators will likely be early adopters. We have also observed that mobility start-ups show a lot of interest in a transition to EVs. Apart from the business case, they seem to have a higher risk-appetite. Also, owning a fleet of green EVs can help them create brand value. Some of our largest customers are large start-ups, like Lithium Technologies, Uber, or Big Basket. We are also working on delivering the first batch of vehicles for Energy Efficiency Services Ltd. (EESL), a government organization that released a tender for 10,000 EVs. It is exciting to see that a public-sector company is taking a leading role in the transition to EVs.

What new technologies and business models is Mahindra Electric working on?

Karthika: Mahindra Electric is the first major auto manufacturer to bring EVs to the Indian market. We are leveraging our experience to expand our portfolio and be the largest provider of EVs in India. At the Auto Expo in New Delhi, we have unveiled several new models. We are working heavily on battery technology as well. We believe Li-ion batteries are the way to go, so we are expanding our research to enable their manufacturing in India. We are also working on technologies like swappable batteries, mostly for motorcycles and 3-wheelers.

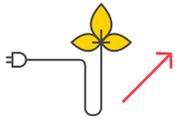


5 Strategic motivations for mobility service providers to adopt EVs



Utilization of existing digital infrastructure

Large fleet operators typically use digital and mobile technology for daily operations. These services can be extended to aid vehicles to communicate with charging infrastructure and support route planning. Coming from a different direction altogether, some Indian supermarket and wholesalers are thinking about providing charging infrastructure to attract customers to their business.



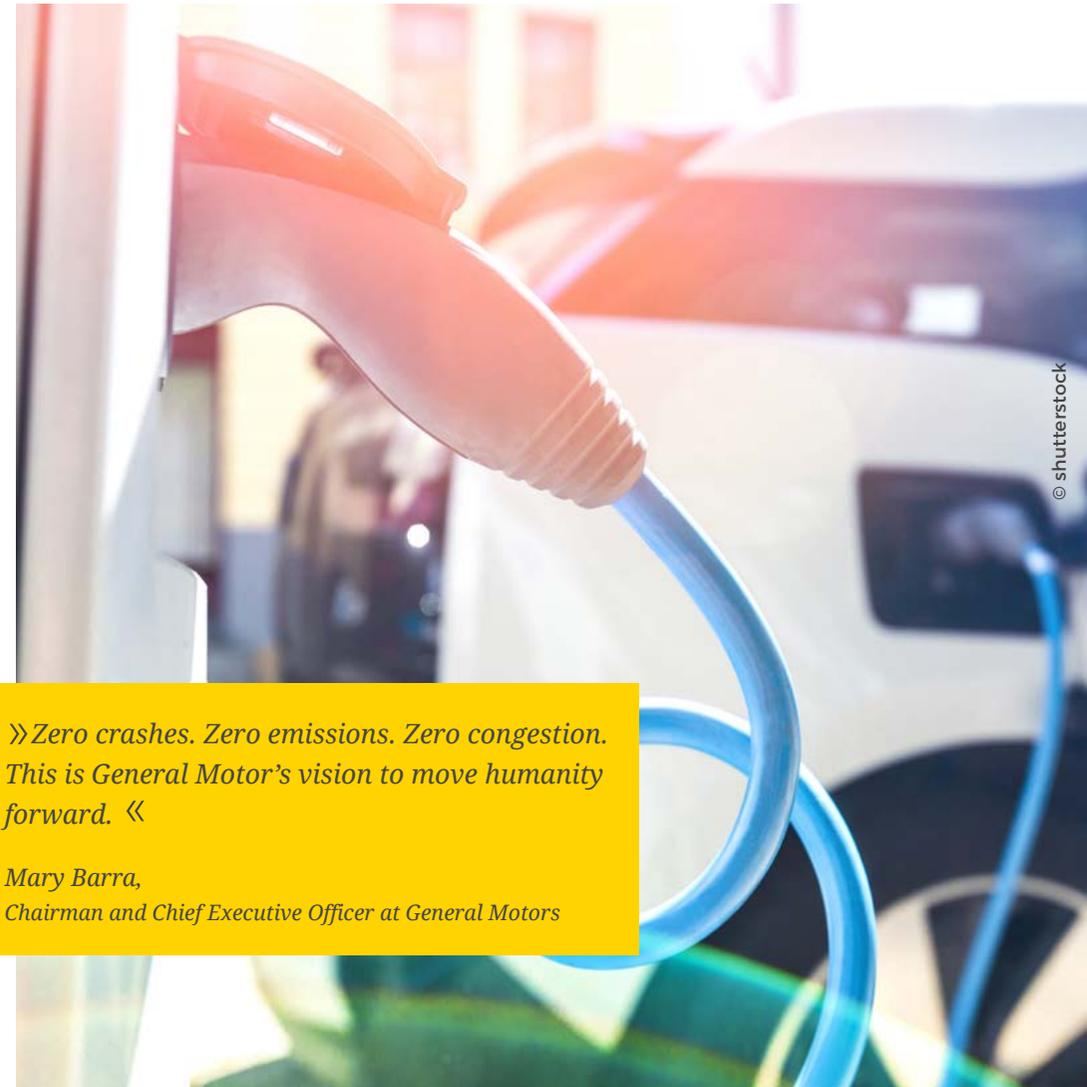
Step towards the future of mobility

There is a strong, global consensus that the future of mobility is green, connected and autonomous. Large fleet operators are also interested in EVs as it takes them a step closer to autonomous driving and a more efficient and reliable mobility future. Electric powertrains are simple and quick to control for an autonomous vehicle algorithm, and the control loop is considerably less complex with faster response time.

» Mahindra Electric, one of the most active market participants in India is collaborating with global companies like Ford Motors and LG Chemical to bring the latest technology to the Indian EV market. Ford Motors and Mahindra have set up a partnership on electric cars, connected cars and distribution in India. The collaboration with LG Chemicals focusses on developing better lithium ion batteries apt for Indian conditions¹⁷. «

»Zero crashes. Zero emissions. Zero congestion. This is General Motor's vision to move humanity forward. «

Mary Barra,
Chairman and Chief Executive Officer at General Motors



6 Business models

6.1 Charging infrastructure

Electric vehicles need an entirely new energy value chain developed around electricity generation and transmission. This creates large business opportunities for electricity providers or utilities, charging technology providers and charging space providers.

Charging technology: India needs a large number of fast charging spaces that utilize technically advanced and efficient technologies such as multi-site DC chargers. Demand for advanced charging technology has already seen growth, with the recent tender by EESL for the installation of 2,000 charging centers throughout India. Out of 2,000 charging stations, 200 will be fast DC chargers, making this the first sizeable installation of DC chargers in India¹⁸.

» Market actors can accelerate mass adoption through collaborations and partnerships. Ola, one of the largest mobility service providers in India has partnered with Indian Oil Corporation Limited (IOCL) to establish a fast charging facility in one of IOCL's petrol stations in the city of Nagpur, India. «

Globally, innovative new charging concepts are also being prototyped. An example is inductive charging on roads, that allows vehicles to continuously charge while being driven. Qualcomm, a US developer of this technology, suggests that in-road charging allows vehicle manufacturers to fit smaller batteries, which in turn drives down the capital and operating cost of the vehicles¹⁹.

Utilities: Electricity providers or utilities have the opportunity to replace many billion dollars' worth of fuel with electricity. However, utilities would need to manage electricity sourcing and supply carefully. A widespread adoption of EVs in the market will increase electricity demand – often at new points of consumption, with a potentially higher peak demand and demand volatility. Thus, investments are required along the entire value chain – from generation to transmission and distribution. Since India is already struggling to provide reliable and sufficient power to all its current consumers, this will be a challenge. However, it could also be an important opportunity to sell power at higher tariffs (as long as electricity is lower than fuel cost), and thereby improve the economic situation of the many loss-making public utilities.

» Newly developed fast-charging stations draw an enormous amount of power. 100 cars being charged using a fast-charging facility in a hyperlocal space can draw power in Megawatts. Imagine the impact on the existing grid, if India goes all electric. «

Akhil Aryan,
CEO of ION

Chapter-highlights

1. There is a vast business opportunity for building fast charging stations
2. Creating a stable supply of power to these charging stations will be a challenge
3. The EV transition would need to be managed together with a higher share of fluctuating wind and solar power in India's grid

An increase in the percentage of renewable energy in the energy mix would increase the operational complexity for utilities. Adoption of new technologies like energy storage, demand side management, smart grids, use of electric vehicles as a storage facility, and digital services could help flatten the demand curve. Utilities that invest in these technologies could have an upper hand over competitors as they drive the investment cost down.

Charging space providers: Unlike conventional petrol stations, providing charging services to EVs does not require businesses to be equipped with large inventories, tanks, pumps and a lot of real estate. This allows small businesses, malls, parking operators, grocery stores, hotels, fast-food chains and restaurants to provide their customers with charging services. These businesses can benefit from attracting customers to their stores, from gathering customer data, from improved customer satisfaction and by positioning themselves as green. Conventional petrol pumps could also start providing charging facilities to their customers as already seen in select Shell, Total and other gas stations in Europe and North America.



6.2 Battery technology

Battery pack and management system: The battery pack and its management contribute more than 50% to the cost of an electric vehicle²⁰. Today, most of these expensive battery packs are manufactured in countries like China and Japan and imported to India. India is well positioned to develop own manufacturing and technologies, although it will continue depending on China, Chile, Australia and other countries to source certain raw materials, such as metals. A mature manufacturing scenario in India has the potential to capture 80% of economic opportunity presented by the domestic EV market - by only importing raw metals and developing the entire battery pack inside India²¹.

India already is a global powerhouse in information, communication, digital and software technologies. This expertise combined with a booming start-up scene and ample engineering resources are an excellent foundation for the development of cutting-edge battery management systems and digital services for the Indian as well as for the global EV market.

Battery swapping technology: Selling EVs without a battery package (or a considerably smaller battery package) and having swappable batteries available through a pay-as-you-go model decreases the capital cost of EVs by a large factor. EVs sold without the batteries would today be at par in cost with a conventional vehicle. Add to that an innovative swapping solution which only takes 3-5 minutes²² for a vehicle to recharge and get back on the road and this innovative business model potentially solves two major barriers of EV adoption - large upfront capital cost and long charging time. A third party could invest into the batteries for swapping and offer them as a service to, for example, a fleet owner who can do without the higher initial costs for an overhaul of the existing fleet to EVs and does not have to take the fleet off the road to charge.

Swappable batteries could also accelerate the transition to EVs for private users, especially for motorcycles or 3-wheelers. Apart from lower capital cost and faster refueling, having a network of swappable batteries would allow consumers to buy or rent or lease batteries from small shops and manually switch batteries whenever and wherever required, much like refueling a petrol tank in conventional cars.

Battery swapping technology would help utilities and renewable energy producers, as batteries can be charged whenever

Chapter-highlights

1. India should seek to develop a domestic battery manufacturing industry
2. Battery swapping technologies can make small EVs competitive with ICE vehicles in terms of upfront costs
3. New battery technologies could offer a higher power density and therefore driving range

there is excess energy in the grid or when there is significant renewable energy generation. This might create alternative off-take opportunities for distributed solar or other renewable energy farms in India.

However, there would need to be a high degree of standardization of battery packages and its interface with the vehicle (a possible first mover advantage for battery companies). Swapping companies would need to develop a robust network of swapping stations throughout the country.

Market voices

Yuvraj Sarda

*Business Development and Strategy
Sun Mobility*



How does battery swapping technology solve the challenges EVs face?

Yuvraj: Battery swapping technology enables vehicles to be sold without batteries or with a very small battery. This brings the capital cost of EVs to almost the same level as ICEs and hence eliminates one of the largest barriers to adoption. Sun Mobility will set up a chain of battery swapping stations or kiosks in major cities across India. Batteries will be swapped by robotic arms. This would take only 3-5 minutes and makes EVs no different to a petrol or diesel car in terms of re-fuelling – so no range anxiety and long waits.

What are the focus segments for battery swapping technology?

Yuvraj: Battery swapping technology is suitable for public buses, 3-wheelers and motorbikes. We are focusing on providing services in these segments in urban areas of India and are already working with Ashok Leyland, one of the largest bus manufacturers in India, to introduce electric buses with swappable batteries.

Fast charging stations will grow in India. Can fast charging and battery swapping technology co-exist?

Yuvraj: Yes. Different battery charging technologies would be used in different use cases. Battery swapping is useful in urban settings, especially for fleet operators. No one would want their vehicle parked in a charging station for 30 minutes, the typical time required to fully charge a normal car using fast charging stations. However, this waiting period is acceptable on a long trip. So, chargers installed next to major highways would be fast-chargers. Also, private users would most likely charge their vehicles at home in the night for a day to day commute to the office. So, all the battery replenishment technologies would co-exist.



6.3 Digital and information technology

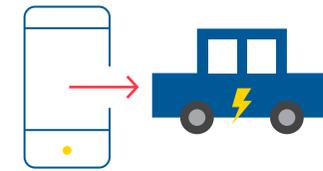
EVs already create an entirely new market for digital and information technology-based applications starting with charging location finders, online charging reservation platforms, IoT infrastructure for multiple cars and battery components to communicate with infrastructure, smart grid technologies, online payment platforms, autonomous driving and ride sharing.

Mobile technology to find a nearby charging location and reserve a charging slot has already been rolled out in Europe and the USA by companies like ChargePoint and ChargeNow. There is a business opportunity in India for a similar application. Online payment technology can be a part of the seamless charging experience as well. Already existing online payment companies like PayPal, Paytm and others could extend their services to EV drivers.

» **Electrical vehicles will create new business opportunities for digital technologies like charging location finders and reservation applications, online payments, ridesharing, smart grids, or autonomous driving.** «

Smart grid technologies can help integrate EVs into the existing energy supply system and help manage fluctuating renewable energy sources. Technologies that charge a car when electricity is in excess and use car batteries as distributed storage options create value for grid operators.

There is a sizable opportunity for companies to develop an efficient and smart battery management system, which improves battery performance and increases the efficiency of the car while enhancing the life of the battery pack; all of which will help drive the cost of operation down. Most EVs will also integrate sensors, communication hardware and software to allow mobile applications to access data from the car or the battery. Availability of such data from the car would allow a third-party application ecosystem to develop, including – for example – car or ride reservation applications, cashless payment applications, or predictive maintenance apps. Semi or fully autonomous driving technology can be developed with EVs as a foundation. EVs have much lower operating costs which make them ideal for semi or fully autonomous driving technologies whose early and major customers are likely to be large fleet operators. Although Indian roads offer a formidable challenge to autonomous driving, the large adoption of EVs in India can provide technology companies and start-ups with a strong business case, funding, subsidies and platform to work towards developing autonomous driving technology in India.



7 Looking ahead

India has enough reasons, business cases, technologies and resources to electrify its road transport. The government wishes to decrease oil imports and air pollution, businesses in India are trying to cut-down the operating cost of mobility services, carmakers are trying to get an upper hand on new automotive technologies and investors in the mobility space are looking for innovative technologies and business models to invest into. And yet, the needle still hardly moves. This is partially due to entrenched ecosystems, infrastructure shortcomings and customer expectations, and the cost of electric mobility. However, we believe that growth will be fast and will begin to make a real impact in the next 5 years. India's solar success story is a good measure to go by.

Businesses that benefit from lowered operating cost, like large feet operations, are already transitioning to EVs. They, as well as logistics companies, will likely be the early adopters. Public and private vehicles will likely follow their lead only later when the total cost of ownership as well as the capital cost of EVs will be further reduced. By 2030, TFE Consulting estimates that the total number of EVs sold in India will surpass the total number of vehicles sold in India in 2016.

Adopters of EVs in India are backed by a dynamic ecosystem of innovative start-ups and large market actors who are leading efforts in charging infrastructure, battery technology, digital technologies, or autonomous driving algorithms. Given India's strength in information and digital technologies, as well as manufacturing, coupled with a strong start-up scene and a large domestic market, the country could emerge as one of the global EV leaders.

To know more about how different business cases can help India capture domestic and global EV demand, write to us at inquire@tfeconsulting.com.

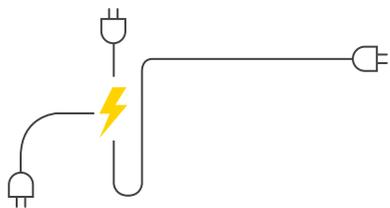


The digital and technological revolution in electric mobility



Communications and sensors

For example: TomTom; Siemens; ChargePoint; Qilu Transportation
Enables: Charge point route planning; IoT based communication; vehicle-to-infrastructure and vehicle-to-vehicle communication; traffic flow management; mobile communication; battery swapping information; software upgrades
Business case: Improved car safety; new mobility/communication based business models; reduced range anxiety



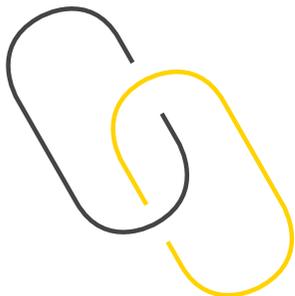
Smart grid

For example: ABB; UPS
Enables: Grid optimized charging; grid stabilization
Business case: Lower charging cost; grid balancing services from EVs; higher concentration of charging points



Autonomous driving

For example: Tesla; General Motors; Mahindra & Mahindra
Enables: Vehicle can self drive to charge points; optimized battery efficiency and lifetime; high usage of vehicle
Business case: User convenience; lower fuel/operating costs; lower repair/maintenance costs; reduced auto accidents; improved car safety



Blockchain

For example: eMotorWerks; Share & Charge; Xain
Enables: Efficient and secure vehicle charging and billing system; better integration into distributed energy generation networks; integration of charging economy with other market places (for example)
Business case: Peer-to-peer charging business models; tokenized charging infrastructure investment; incentivizing sharing of home charging stations; databased business models (for example)

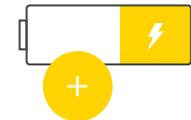
New charging technologies

For example: Qualcomm; Plugless; Ubitricity
Enables: Intelligent wireless charging, including inductive charging; faster charging
Business case: Convenient, everywhere charging (e.g. on a parking spot); car-to-car charging



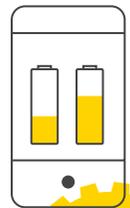
New battery technologies

For example: Panasonic; Fisker; Ionic Materials; solid-state batteries (and more)
Enables: Lower weight; higher power density; faster charging; inductive charging; faster charging
Business case: Lower vehicle costs; longer range; better charging and driving performance



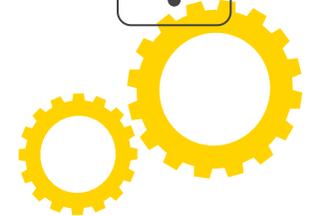
Battery management system (BMS)

For example: BYD; LG Chem; Maxim; Texas Instruments
Enables: Monitoring and control of voltage, current, state of charge for battery health and performance
Business case: Longer battery life; higher operational efficiency; lower manufacturing cost



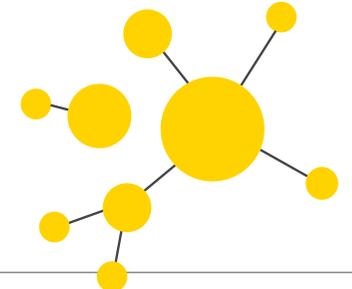
Additive manufacturing

For example: NRC; Porsche Engineering; UTRC; XEV
Enables: Use of cheaper more abundant materials; better designs and performance of motors; vehicle weight reduction
Business case: Lower vehicle cost; Less fuel usage



Nanotechnology

For example: Gold nanowire, graphene, and carbon nanotube batteries (all at the research level)
Enables: Faster battery charging; longer battery life; longer range
Business case: User convenience



Our electric mobility services

We assess and size market opportunities, develop and test business models, develop regulations for the sector and evaluate the intersection between electric mobility, energy consumers and electricity producers. Our clients are mobility service providers, OEMs, component suppliers, utilities, startups, investors and regulators.



End notes

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About TFE Consulting

TFE Consulting is a strategy consulting firm focusing on accelerating the clean energy transition in emerging markets. Headquartered in Munich, with additional teams in India and South Africa, we support clients to navigate the rapidly changing energy landscape in developing countries. Our strength is in our analytical and financial models, first hand project development experience and deep understanding of the interplay of government and markets. We utilize this to provide market assessment, risk analysis, business model adaptation and policy advisory to our clients.

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