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ROCKY MOUNTAIN INSTITUTE

INDIA'S ENERGY STORAGE MISSION:

A Make-in-India Opportunity for Globally Competitive Battery Manufacturing

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ABOUT NITI AAYOG

The National Institution for Transforming India, also called NITI Aayog, was formed via a resolution of the Union Cabinet on 1 January 2015. NITI Aayog is the premier policy 'Think Tank' of the Government of India, providing both directional and policy inputs. While designing strategic and long-term policies and programs for the Government of India, NITI Aayog also provides relevant technical advice to the Centre and States. The Government of India, in keeping with its reform agenda, constituted the NITI Aayog to replace the Planning Commission instituted in 1950. This was done in order to better serve the needs and aspirations of the people of India. An important evolutionary change from the past, NITI Aayog acts as the quintessential platform of the Government of India to bring States to act together in national interest, and thereby fosters Cooperative Federalism.

ABOUT ROCKY MOUNTAIN INSTITUTE

Rocky Mountain Institute (RMI) is an independent, apolitical, nonprofit think-and-do tank that transforms global energy use to create a clean, prosperous, and secure future. For more than three decades, RMI's work in the transportation sector has described and helped to concretely advance solutions that are both visionary and pragmatic, ranging from advanced vehicle designs to new mobility-services concepts. RMI's staff of scientists, engineers, and business leaders has helped governments, utilities, large corporations, innovative startups, and communities understand and benefit from the new energy economy with the imaginative application of rigorous technical and economic analysis. In recent years, RMI has developed electric vehicle (EV) deployment plans to reach 100 percent EV penetration for the U.S. and China. Cofounded by Amory Lovins in 1982, RMI has been a leader in energy efficiency and renewable energy for 35 years.

NITI Aayog

PREAMBLES FROM NITI AAYOG AND RMI'S LEADERSHIP

Shri Anil Srivastava, Advisor, NITI Aayog

India's urban population will nearly double in the next decade. More than half a billion people will live, work, and travel in Indian cities. This rapid growth poses many social, economic, and environmental challenges. To turn these challenges into opportunities, India must look to build new industries that can create jobs, strengthen energy security, and clean the air. Electric vehicle component manufacturing is one such industry that can help this ambitious and capable country to achieve these important objectives. Domestic manufacturing of Lithium-ion batteries, currently an electric vehicle's most expensive component, presents an enormous economic opportunity for India. Making batteries for electric vehicles in India can support automakers' efforts to produce an attractive fleet of clean vehicles at prices that Indian consumers can afford. India can become a net exporter of batteries, thereby enabling other countries' transitions to electric mobility and renewable energy, and I look forward to seeing how government and business leaders can collaboratively build a new economic engine for India.

Shri James Newcomb, Managing Director, India, Rocky Mountain Institute

The global energy transition is underway. Carbon-dioxide emissions have plateaued for the past three years. In 2015, 195 countries signed a legally binding climate agreement to limit global temperature rise to 1.5 Celsius-degrees. Nations are beginning to decouple greenhouse-gas emissions from economic growth. Renewable energy auctions continue to set record-breaking low prices around the world, while electric vehicles use this clean electricity to move growing numbers of passengers. Nowhere is there greater potential to accelerate the energy transition than India, the world's third-largest emitter and home to a growing, urbanizing population of more than 1 billion.

Steeply falling technology costs and business-model innovation are driving the world's transition to renewable energy and electric vehicles. A nearly 80% drop in Lithium-ion battery pack prices over the past 5 years has made high-mileage electric service vehicles cost competitive, in terms of total cost of ownership, in several geographies. Forecasts indicate that electric vehicles will reach price parity with conventional internal-combustion-engine vehicles on a first-cost basis by 2025. Against this backdrop, India's aspiration to achieve 100% electric vehicle sales by 2030 is adding further impetus for rapid change in the global automotive and battery manufacturing industries. We look forward to seeing how abundant, cheap batteries—made in India—can not only support the government's goals for vehicle electrification, renewable energy integration, and job growth, but also speed the world's transition to a clean energy economy.

1. INTRODUCTION

In line with its aspiration to achieve 100 percent electric vehicle (EV) sales by 2030, India can rise among the top countries in the world in manufacturing batteries. To do so, however, will require a strategy designed to overcome India's relatively weak initial position in battery manufacturing while claiming an increasing share of total battery value over time.

India's market for EV batteries alone could be worth as much as $300 billion from 2017 to 2030.[i] India could represent more than one-third of global EV battery demand by 2030 if the country meets its goals for a rapid transition to shared, connected, and electric mobility (Figure 1). Since the battery today accounts for about one-third of the total purchase price of an EV, driving down battery costs through rapidly scaling production and standardizing battery components could be a key element of long-term success for India's automotive sector. India's EV mission could drive down global better prices by as much as 16 percent to $60 per KWh. Given the projected scale of its domestic market, India could support global-scale manufacturing facilities and eventually become an export hub for battery production.

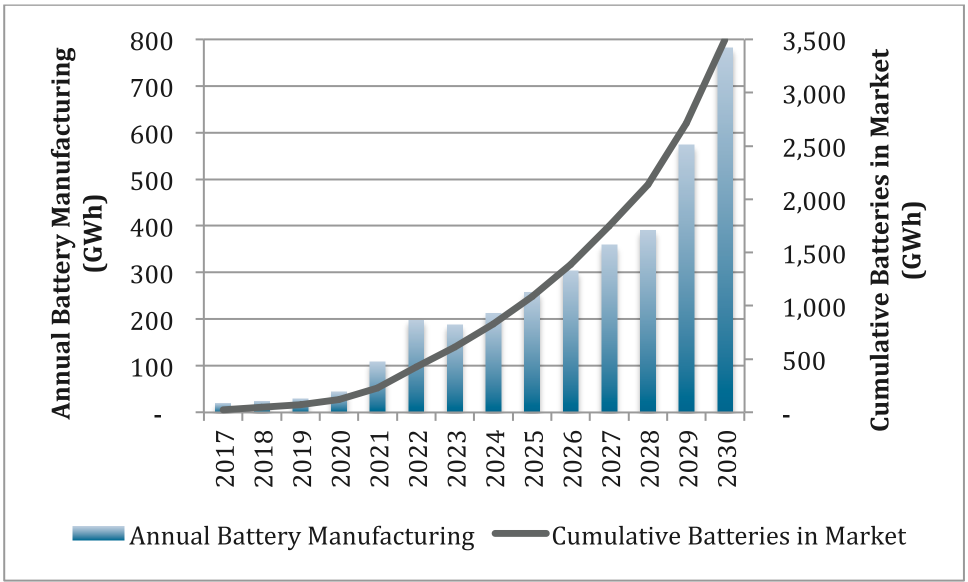

FIGURE 1: ANNUAL AND CUMULATIVE BATTERY REQUIREMENTS TO MEET INDIA'S EV AMBITIONS

Analysis by NITI Aayog and Rocky Mountain Institute (RMI) indicates that domestic battery manufacturing to supply the transition to EVs is an important market opportunity for the Indian economy. It would bring economic and social benefits from reduced oil imports, improved public health, and increased integration of renewable energy supplies into the electric grid. This analysis estimates that 25–40 percent of the total economic opportunity represented by battery manufacturing for India's EV ambitions can be captured in India even under the least favorable scenario, where India imports all lithium-ion cells and assembles these cells into battery packs. As India's battery manufacturing capabilities mature and supply chains are established, India will have the opportunity to produce both battery cells and packs, while importing only the cathode or its raw materials from mineral-rich regions. In this scenario, India stands to capture nearly 80 percent of the total economic opportunity.

Figure 2 shows the value contribution of different battery components from Tesla's gigafactory in the United States and the stages by which India could advance a make-in-India strategy for batteries that would capture progressively more value over time.

[i] Dollars are given in U.S. dollars throughout this document.

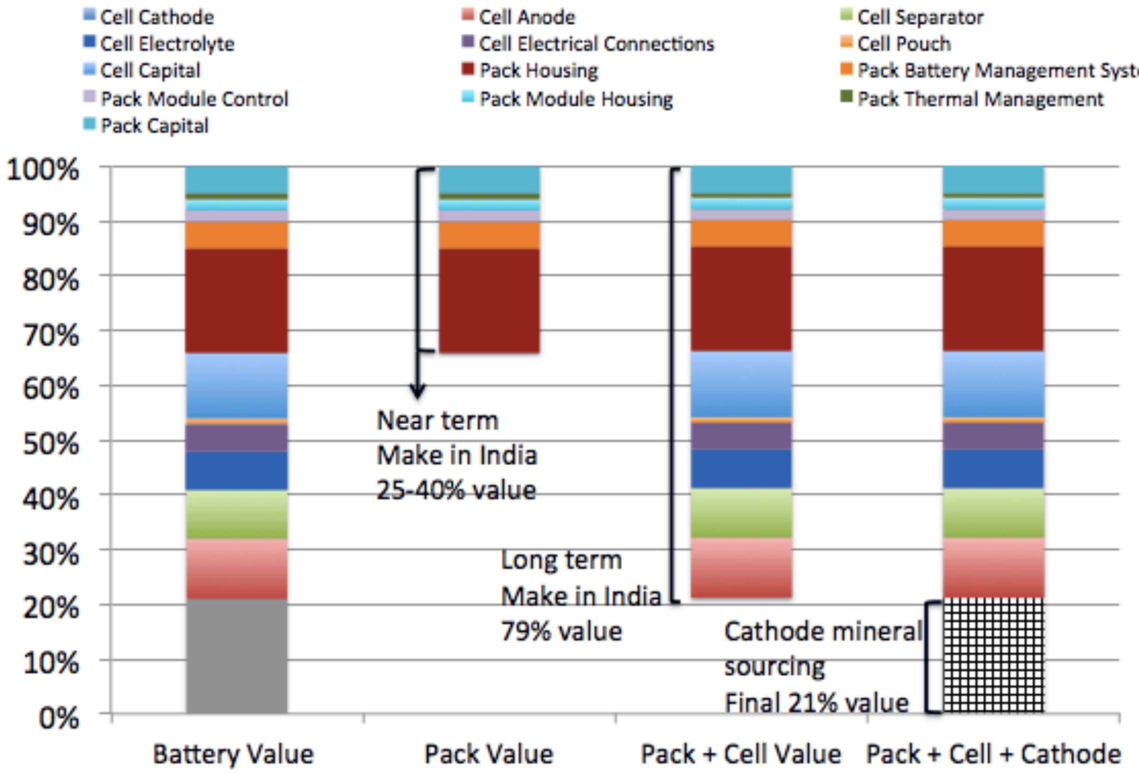

FIGURE 2: BATTERY COST BREAKDOWN AND OPPORTUNITIES FOR VALUE CAPTURE

We suggest that the development of India's battery manufacturing industry can proceed in three stages, with progressively larger economic value capture at each stage, as follows:

- Stage One – Developing battery pack manufacturing capacity and establishing a multistakeholder research and development consortium.
    - India's cumulative EV battery requirements between 2017 and 2020 will be at least 120 GWh on a trajectory to 100 percent EV sales by 2030.[ii] Assuming that India will be manufacturing primarily battery packs from imported cells during this period, India stands to capture 25–40 percent of the economic opportunity from battery sales, an economic value of between INR 0.4 lakh crore and INR 0.5 lakh crore.
- Stage Two – Scaling supply chain, capitalizing on research and development, and realizing the benefits of the consortium-led approach to set strategy and planning for battery cell manufacture.
    - India's cumulative EV battery requirements between 2021 and 2025 will be at least 970 GWh. Assuming that India will still be manufacturing only packs in this period, India continues to capture 25–40 percent of the total economic opportunity, an economic value of INR 2.0–2.9 lakh crore. If battery cell manufacturing scales too, this value will increase.
- Stage Three – Scaling end-to-end manufacturing capacity for batteries, particularly focusing on battery cell capacity.

[ii] This represents the cumulative battery needs for India on its path to 100% EV sales by 2030. Battery requirements are calculated using EV sales and anticipated battery size for each vehicle type. EV sales are based on estimates in NITI Aayog and RMI's May 2017 *India Leaps Ahead: Transformative Mobility Solutions for All*. This estimate does not consider replacement of older battery packs. Please refer to the appendix for details on pack costs.

- India's cumulative battery requirements between 2026 and 2030 will be at least 2,410 GWh. Assuming that India will be manufacturing both cells and packs while importing only cathodes (depending on technology used), India stands to capture nearly 80 percent of the total economic opportunity, an economic value of INR 9.3–13.7 lakh crore.

TABLE 1: ECONOMIC OPPORTUNITY FROM BATTERY MANUFACTURING TO MEET INDIA'S EV AMBITIONS IN DIFFERENT STAGES

	Cumulative battery requirements (GWh)	Total market size (INR lakh crore)	Imports	Domestic Manufacturing
Stage 1	120	1.3–1.4	Cells	Battery packs
Stage 2	970	6.1–8.9	Some cells, cathodes	Battery packs + limited cell production
Stage 3	2,410	11.7–17.1	Cathodes	End-to-end battery manufacturing

While these stages reflect progressively more challenging levels of manufacturing prowess and greater value capture, they could overlap in practice as India's battery manufacturers pursue different strategies. Some Indian manufacturers might move relatively quickly to full-scale battery production through partnerships with today's leading lithium-ion battery manufacturers, while others could adopt a more gradual approach, including developing new battery chemistries and production methods.

By developing battery manufacturing expertise and scaling its domestic production capacity, India can build durable economic advantage in this key sector. While securing raw materials will be critically important to India's battery manufacturing supply chain, recent analyses indicate that for most key constituents, sufficient supplies should be available to meet projected increases in demand. For example, a recent study by BNEF found no long-term issues with global supply of lithium. Under optimistic projections for lithium demand, only a very small share of extractable reserves of lithium will be required for global EV battery production through 2030. The lithium requirement to meet projected demand for EV batteries in 2030 is about 60,000 metric tons—just 0.7 percent of known global reserves.[1]

Temporary raw material supply shortages that may emerge as the industry ramps up could be addressed by opening new mines or expanding production by building additional evaporation pools to extract lithium from brine.[2] While India is not rich in domestic reserves of minerals such as lithium, manganese, and cobalt that many of today's common EV batteries require, India can build manufacturing capabilities that capture a significant portion of the value chain in this sector, as other countries are doing.[3]

But what might be the overall impact on India's balance of trade? Even though India's electric mobility policies are likely to necessitate significant imports of batteries, battery components, and/or raw materials as India scales up its domestic battery manufacturing capacity in the years ahead, the reduction in oil import costs is likely to more than offset the costs of these imports.

Under a business-as-usual scenario, India would need nearly 1.6 billion metric tons of oil equivalent of petrol and diesel to fuel its passenger mobility sector from 2017–2030. At a conservative crude-oil price estimate of $52/bbl (lower than today's prices), this oil import demand would cost nearly $670 billion or INR 44 lakh crore over the period 2017–2030.[iii] Assuming India continues to import 80

[iii] Total expenditure on petrol and diesel is calculated by multiplying total energy requirement for petrol and diesel in million short tons of oil equivalent (mtoe) by 7.33—the conversion factor for converting mtoe into million barrels of oil equivalent (mboe)—times 52, which is the current price of Western Texas Intermediate

percent of its oil, this could represent a total import bill of roughly $550 billion or INR 36 lakh crore.

In contrast, meeting India's EV ambitions through 100 percent domestic manufacturing of batteries would require at least 3,500 GWh of batteries at a wholesale cost of $300 billion (INR 20 lakh crore)[iv] from 2017–2030—less than half the cost of the avoided oil imports. In addition, battery manufacturers could seize 25-40 percent of the market's value at the onset by assembling battery packs in India and importing only battery cells. In this case, India's total value of imports for EVs would be between $180–225 billion or INR 12–15 lakh crore. Noting that India may still be consuming nearly INR 17 lakh crore worth of petrol and diesel, this would still represent an import saving opportunity of INR 4 lakh crore for India[v] (see Figure 3).

Batteries are a one-time upfront investment for EVs, serving as an asset (with potential for additional revenue streams through secondary use in stationary applications in India) and contrast with ongoing operating expenses for fuel needed for petrol or diesel vehicles. Every battery purchased will reduce oil imports for many years to come, improving future years' trade balance and reducing India's exposure to oil price shocks.

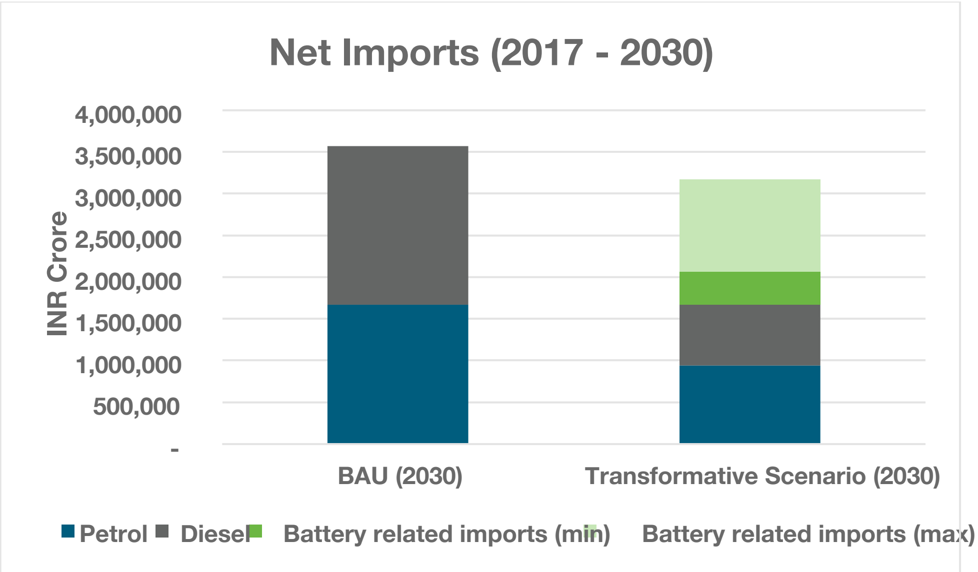

FIGURE 3: NET IMPACT ON INDIA'S BALANCE OF TRADE OF ELECTRIC MOBILITY STRATEGY. THE RANGE OF BATTERY IMPORTS DEPENDS ON INDIA'S CAPABILITIES TO CAPTURE VALUE IN THE BATTERY SUPPLY CHAIN. MINIMUM BATTERY IMPORTS CORRESPOND TO THE SCENARIO WHERE INDIA WILL BE MANUFACTURING BOTH CELLS AND PACKS WHILE IMPORTING ONLY CATHODES, WHILE THE MAXIMUM BATTERY IMPORTS CORRESPOND TO THE SCENARIO WHERE INDIA WILL ONLY ASSEMBLE BATTERY PACKS FROM IMPORTED CELLS.

To advance Make in India, shifting to electric vehicles and batteries allows India to become its own supplier of energy for transportation (electricity produced in India) and a leading manufacturer of the batteries used to store and transport that energy.

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crude oil in USD/bbl. This is a conservatism as it does not assume any change in crude costs, and does not include shipping, insurance, or refining costs to calculate wholesale costs of petrol or diesel.

[iv] This estimates the total outlay on batteries necessary to meet India's EV ambitions. This has been calculated using anticipated battery size for EVs in India and vehicles sales numbers calculated in NITI Aayog and RMI's May 2017 report *India Leaps Ahead: Transformative Mobility Solutions for All*. Please refer to the appendix for details.

[v] This analysis does not account for the potential costs of imported equipment for electricity supply chain or EV charging infrastructure. By 2030, transportation sector demand could account for as much as 15% of total electricity demand, but the marginal cost to the electricity system of meeting this demand is likely to be far less given the flexibility of EV charging loads. Further, we do not measure the economic costs and risks associated with volatility in oil and gas prices, but note the potential economy-wide impacts of oil price shocks in the BAU scenario.

2. GLOBAL CONTEXT AND IMPACT

India's target of 100 percent EV sales by 2030 is a game changer and its achievement could drive down costs and build production scale faster than anticipated in existing projections. Despite their relatively small share of global vehicle stocks, EV sales are experiencing extraordinary growth.

In 2016, the EV market passed the threshold of two million electric cars operating worldwide with 750,000 units sold in a single year—a 60 percent increase in stock compared to 2016.[4] Of 2016 global sales, 45 percent were in China, and 21 percent were in the U.S. China in 2016 sold more EVs than the world had sold two years earlier, on pace to a tenfold expansion from 2015–2020. Going forward, industry experts estimate that 7 percent of the global automotive (4-wheeler) fleet will be EVs by 2030, up from 0.2 percent currently. As India's EV ambitions, including EV 2-wheelers, auto-rickshaws, 4-wheelers and buses, become more widely known, they will help influence other countries to follow India's lead.

External industry experts predict that the initial purchase price of an electric car will be equivalent to that of a petrol car by 2025—a tipping point that will dramatically accelerate adoption. On a total-cost-per-km basis, this parity has already been reached for high-kilometer vehicles in some markets due to the favorable economics of high-utilization EVs and the steep learning curve and subsequent price reductions associated with EV batteries.

Batteries account for approximately one-third of the total purchase price of EVs today, and those battery packs' price fell by more than 70 percent over the last six years. Continuous innovation in battery technology and increased production scale are driving a steep ongoing decline in prices. Experts predict that prices could fall to $109 per kWh by 2025 and $73/kWh by 2030, from about $240 per kWh today,[vi] based on a 19 percent learning rate for current EV battery technology. If recent ambitions from countries including France, the UK (which aims to ban all petrol and diesel vehicles by 2040), Norway (which plans to do the same by 2025), China (which has targeted 7 million EV sales by 2025), and India, the aim of which to shift to an all-electric system continues to gain momentum, prices may fall even faster than current projections.[5]

Based on global EV projections (predating India's ambitions to achieve 100 percent EV sales by 2030), the global demand for EV batteries will require nearly 30 gigafactories by 2030, representing a $125 billion (INR 8 lakh crore) investment for battery manufacturing alone. A gigafactory is a factory that is representative of Tesla's battery manufacturing facility in Nevada, USA that will have a total manufacturing capacity of 35 GWh per annum and required an investment around $5 billion (INR 0.3 crore).

Social and economic factors, such as equity and public health needs, support the proliferation of shared electric mobility services. On-demand services are growing in market share, unlocking higher utilization of public transit. High utilization of shared vehicles, as just noted, quickly makes electrification of fleets cost-effective. Integrated data platforms can seamlessly connect multimodal transit options.

Car-sharing networks could provide transport four to ten times more cheaply than can driving individually owned cars. This trend, in turn, will drive rapid adoption of electric vehicles in high-usage service fleets. Already, mobility service providers around the world are testing EV solutions in pilot programs in anticipation of wider-scale deployment. For example, Uber deployed 50 EVs on the streets of London in the summer of 2016, working with OEMs Nissan and BYD to offer leasing options for Leafs and E6s to its drivers at below-market rates. Uber expects to increase this number and expand to other geographies in 2017, encouraging drivers to take advantage of EVs' low

[vi] According to published Bloomberg New Energy Finance data, this is the weighted average cost for lithium-ion batteries for EVs globally. Prices for lithium-ion batteries continue to drop dramatically and recent announcement from some companies including GM and Tesla suggest that battery production costs in some manufacturing facilities could be closer to $150/kWh.

operating costs, which offset their capital cost premium and can produce over $1,000 in annual savings per 4-wheeler by 2018 and over $4,000 by 2030.

The US, China, and Europe have introduced fuel economy standards that favor EVs, and policy frameworks are becoming more ambitious as EV technology becomes more mainstream. Norway has introduced extensive nonfiscal incentives, including road-toll exemption and bus-lane access, and offers incentives for company-owned EVs. These, along with other measures, have raised adoption to over 32 percent of sales in 2016. Additionally, Norway has established a target to phase out gasoline cars by 2025. India has announced that all new sales of cars will be electric by 2030, while Britain and France have announced plans to ban the sale of new gasoline and diesel cars by 2040.

India is poised to lead the world in the deployment of a shared, electric, and connected mobility system. The transportation sector is ready for disruption that can relieve many current constraints and create large and lasting national benefits.

Current situation: More than 80 percent of India's petroleum is imported. India spent $112 billion on crude oil imports in 2014–2015, and $64 billion in 2015–2016. Of India's 2008 national average mode share, 66 percent was nonmotorized transit—walking, biking, and public transit. This value was higher in Category 6 cities (>8 million people), where public transit, walking, and cycling made up 74 percent of the mode share (44 percent, 22 percent, and 8 percent respectively). India's per capita car ownership is quite low, with fewer than 20 vehicles per 1,000 citizens (as compared to 800 per 1,000 in the US and 85 per 1,000 in China). India's personal car ownership, however, is rising rapidly: vehicle registration has risen 10 percent annually for the past decade, with more than 60,000 new motor vehicles registered per day.[6]

Opportunity to leapfrog: India will need substantial upgrades and investments to provide transportation to its citizens in any scenario. Today, India has an opportunity to leapfrog ahead of the legacy model of individually owned, internal combustion engine (ICE) vehicles that are typically in use only about 5 percent of the time. India can avoid the "lock-in" effects of a system characterized by high costs, heavy pollution, inequitable access, and inefficiency. India's low per capita car ownership affords it the chance to pursue a different model. While other countries struggle to retire internal combustion engine vehicles and replace them with EVs, India's low share of vehicles (especially 4-wheelers) per capita can be turned to advantage, as India need not strand assets or prematurely retire a large fleet. Instead, India can design now a system that makes personal mobility accessible, affordable, clean, safe, quiet, and efficient in use of time and resources.

Emphasis on shared, electric, and connected transportation: Shared services are already ubiquitous in India, but could be enhanced to support greater adoption and even more effective access. Increased mobility is a positive economic force—citizens on the move enhance commerce and drive the economy. With 80 percent of all trips below 10 km in cities like Mumbai and Hyderabad, electric fleet vehicles and public buses can reduce private vehicle growth and emissions. Shared services can harness capital investments more productively, and could reduce the number of vehicles on the road in 2030 by 10 percent, relieving traffic congestion, bolstering economic growth, and reversing the rise of local air pollution.[7]

As battery costs continue to fall, total cost of ownership (a calculation of the costs of buying and using a vehicle over a period of time) of a privately operated electric car in India will be lower than that of an equivalent petrol car in 2020, a tipping point that will dramatically accelerate adoption.

The economics of a shared EV sedan, on the other hand, are already favorable in comparison to a shared ICE vehicle. Ola's pilot in collaboration with Mahindra Electric in Nagpur, consistent with the global interest of transportation network companies in shifting their fleets to EVs, affirms increasing momentum towards a shared and electric mobility future. These compelling economics are conservative, as they do not account for India's contribution to making global battery markets larger and hence driving battery prices lower.

Though economics for shared or service EVs (2-wheelers, 3-wheelers, and 4-wheelers) are already favorable on a per-km basis, policy support in the near- to mid-term will ensure that the balance is tilted unambiguously towards shared and electric mobility. Coordinated action and support from central and state governments, including targeted fiscal and nonfiscal incentives, will also be critical in increasing adoption. Increasing demand for electric vehicles will initiate self-reinforcing loops that can help to drive down costs as global manufacturing scale increases, creating virtuous cycles similar to the ones that have driven Moore's Law in the high-tech sector and plummeting solar power and LED costs in the electricity sector. A stable policy and regulatory environment, and sustained efforts by the private sector, will push ownership costs of electric vehicles to well below those of ICE vehicles, speeding adoption of shared and electric mobility services.

In addition, electric mobility services can be integrated to complement public transportation options seamlessly, with simplified trip planning tools for customers and cashless payment systems. India can lead the world in development and deployment of these systems. While it is important to set electrification targets by share of vehicle sales, the share of electric vehicle kilometers travelled (eVKTs) must also increase—a metric more indicative of India's progress towards shared and electrified mobility.

Manufacturing opportunity: According to analysis by NITI Aayog and RMI, a transition to a shared, electric, and connected mobility future could deliver Indians the same access as a business-as-usual scenario with nearly 6 crore fewer vehicles (a 10 percent decrease) in 2030.[8] Currently, only 2 percent of passenger kilometers travelled (PKT) are in shared vehicles. By 2030, this could grow to 23 percent of total PKT. Despite numbering fewer vehicles on the road, the high utilization and high turnover of service vehicles drive an increase in total vehicle sales in this transformative scenario. For instance, sales of buses in 2030 nearly double vs. business-as-usual.

Segment	Year		
	2020	2025	2030
Motorcycles & Scooters			
Non-EV	10,409,000	9,260,000	0
EV	7,352,000	14,035,000	26,514,000
Autorickshaws			
Non-EV	616,00	0	0
EV	646,000	2,364,000	4,072,000
Cars and Jeeps			
Non-EV	3,538,000	3,932,000	0
EV	26,000	1,592,000	15,911,000

TABLE 2: ANNUAL VEHICLE SALES BY VEHICLE TYPE IN A SHARED, ELECTRIC, AND CONNECTED SCENARIO (2017–2030 AVERAGE GDP GROWTH RATE @ 6.7%)

Global battery manufacturing capacity continues to soar, with many companies and nations announcing plans to build more Gigafactory-scale plants. Industry experts expect global battery manufacturing capacity to more than double from 2017–2021, rising from 119 GWh/y to 273 GWh/y over the period.

India's electric mobility ambitions could drive global battery demand and manufacturing capacity higher and prices even lower than has been projected in previous analyses.

NITI Aayog and RMI estimate that India would require a minimum of 20 Gigafactory-scale battery manufacturing plants, collectively producing approximately 800 GWh of batteries per year by 2030 to support 100 percent EV sales across all types of personal vehicles. This transformation would significantly increase global installed battery manufacturing capacity. In fact, India's 2030 requirement could represent 38 percent of global capacity by 2030. Given historic and projected learning rates for battery manufacturing, adding another 800 TWh/y could drive world battery prices down by 8–16 percent (relative to current forecasts that do not account for India's ambitions) to approximately $60/kWh–$67/kWh (see Figure 3).

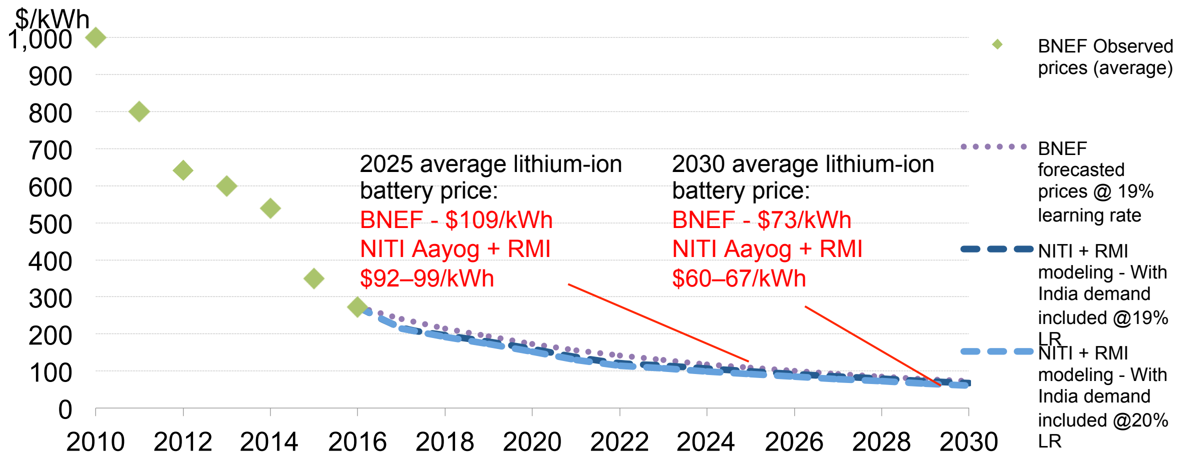


FIGURE 3: BNEF LI-ION BATTERY PRICE FORECASTS COMPARED TO NITI AAYOG AND RMI MODELING THAT ADDS BATTERY DEMAND FOR INDIA'S EV AMBITIONS. BOTH PRICE FORECASTS ARE BASED ON A 19% LEARNING RATE.[vii]

Domestic manufacturing of batteries and EV components could help India's OEMs and technology companies to capitalize on the nation's aggressive vehicle electrification goals, bolstering India's competitiveness on the global stage. Indigenously developed electric vehicle platforms and solutions that are readily adaptable to Indian use-cases could be applicable in other developing economies. In the long run, Indian OEMs and battery manufacturers could eventually grow to serve not just the domestic market but also a significant share of the global EV and EV-component market.

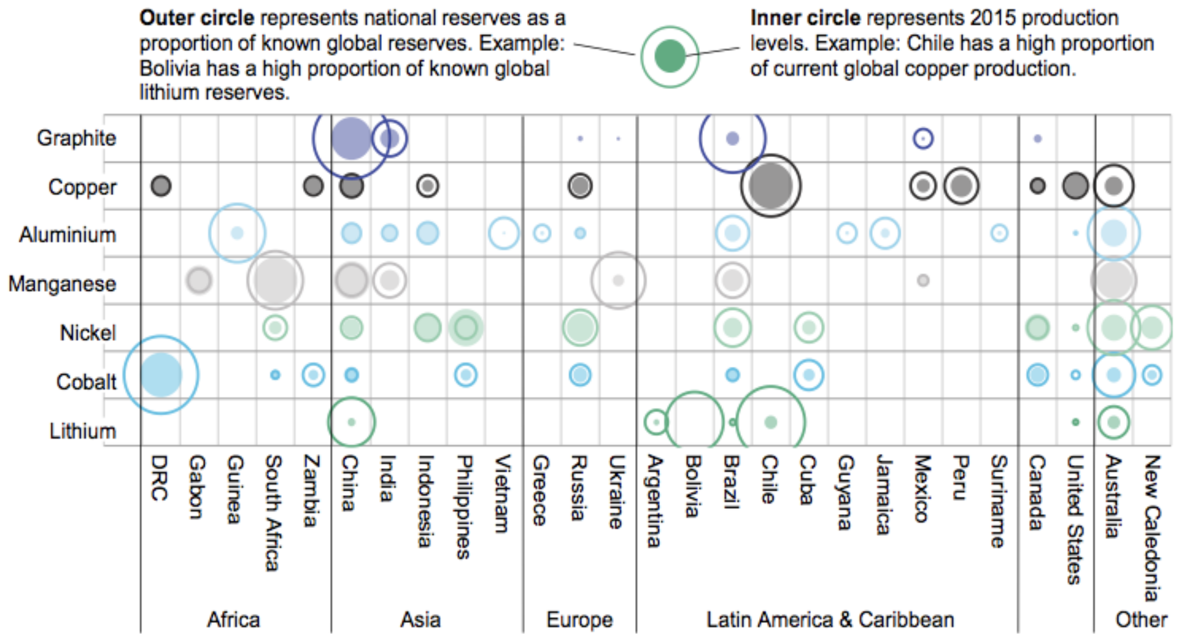
[vii] Please refer to the appendix for further details on calculations.

3. KEY CHALLENGES TO SCALING INDIA'S BATTERY INDUSTRY

India's 100 percent EV goal calls for building a robust and competitive battery manufacturing supply chain. To do so, however, India must overcome four challenges.

A. Low mineral reserves

India has small reserves of key minerals required for lithium-ion (Li-ion) batteries. In Li-ion batteries, cathode materials vary, but common formulations include minerals such as lithium, aluminium, cobalt, manganese, and nickel, while the anode is made of graphite. India does not have reserves of some of the most important Li-ion components including lithium, cobalt, nickel, nor, for that matter, of the copper used in conductors, cables, and busbars. (Figure 5 compares international declared reserves and production of the main relevant minerals.) Hence, reliable supply, not just of the raw materials but also of processed functional materials used in the anode and cathode, poses a challenge.



Note: Area of outer rings represent national reserves as a proportion of known global reserves, shaded circle represents 2015 production in that country x 20 as a proportion of known global reserves.

FIGURE 5: PRODUCTION AND RESERVES OF CRITICAL MATERIALS FOR NICKEL-MANGANESE-COBALT LITHIUM-ION BATTERIES IN SELECTED COUNTRIES, 2015[9]

Fortunately, global supplies of minerals for current battery chemistries are not considered to be resource constrained. A recent study led by researchers at MIT, University of California Berkeley, and Lawrence Berkeley National Laboratory concluded that supplies of most of the key constituent elements of the current generation of Li-ion batteries, including manganese, nickel, and natural graphite, are sufficient to meet the anticipated increase in demand.[10] With respect to lithium, most studies indicate that supply can outpace demand based on significant reserves and a diversity of extraction technologies. Meeting all expected global battery needs through 2030 would require just 2 percent of currently recoverable lithium reserves.[11]

Finally, cobalt may pose the most significant materials risk in the short term for Li-ion battery production, given its geographic concentration in a few areas and the associated geopolitical risks. Extensive research is being undertaken to find replacements for this as a cathode.

In order to achieve large-scale domestic production of EV batteries, India would likely need to forge international partnerships and ventures to secure access to key minerals in line with its battery technology and chemistry roadmap. Options for supply chain development will need to be considered based on assessments of battery chemistry and likely scaling of production.

B. Early-stage battery manufacturing industry

India has no major producers of EV batteries at present and lacks state-of-the-art facilities of both sufficient capacity and capability. Assembling battery packs from imported cells in India can reduce the cost and internalize more of the value of the battery, as well as build self-reliance to meet domestic pack demand as domestic cell manufacturing ramps up.[12]

India's market for lithium-ion EV batteries is projected to grow at a CAGR of 33 percent by volume from 2017–2030.[viii] Responding to anticipated increases in demand, Indian battery manufacturers and research institutes are gearing up to build domestic capacity. Indian Institute of Technology Madras has a research and development center devoted to new and advanced battery technology. Central Electrochemical Research Institute (CECRI) has also set up India's first indigenous Li-ion fabrication facility for batteries used in defense, solar-powered devices, railways, and other high-end uses. Additional research and development capacity will be required to meet India's rapidly growing battery market.[13]

C. Lack of coordination among stakeholders

Strong coordination between various stakeholder groups in cell manufacturing and battery assembly can support the development of a robust and competitive battery manufacturing supply chain in India. Key stakeholders in the battery manufacturing ecosystem include material suppliers, battery manufacturers, vehicle manufacturers, local and central governments, research institutes, and think tanks. Coordination among these parties can help to define technology pathways, align investment strategies and timing, and guide policies to help achieve India's 2030 EV target. The absence of this coordination amongst key stakeholder groups is a key barrier to streamlining efforts by different industries and organizations in building India's battery manufacturing supply chain.

D. High perceived risk

Due to the uncoordinated efforts by different stakeholder groups and the relatively nascent stage of battery manufacturing in India, investment risks in this sector are considered to be high. Due in part to the absence of clear long-term policies for manufacturing and uncertainty around future battery technology, battery and vehicle manufacturers hesitate to make significant investments. Consistent and transparent policies can help address this barrier.

The deployment of wind power in Denmark is an example of how long-term policy planning can enable the adoption of a new technology at a national scale.

[viii] This has been calculated using anticipated battery size for EVs in India and vehicles sales numbers calculated in NITI Aayog and RMI's May 2017 report *India Leaps Ahead: Transformative Mobility Solutions for All*. Please refer to the appendix for details.

Deployment of Wind Power in Denmark

Overview

- Denmark is a pioneer in commercial wind power with 42 percent of total electricity consumption based on wind power. Danish wind turbine manufacturers, like Vestas Wind Systems and Siemens Wind Power (headquarters in Brande, Denmark), are the largest in the world with a presence in over 74 countries and a total installed capacity of >90 GW.
- Denmark's energy targets include 100 percent renewable energy by 2050 and 50 percent of electricity demand met by wind by 2020.[14] Both look on or ahead of schedule.

Key strategies for success

- Citizen movements for the **development of renewable energy resources in response to the oil crisis,** and against nuclear power, started in 1974 and created favorable conditions for the growth of wind power[15]
- Taking advantage of this market opportunity, the Danish government **provided 40 percent of the initial capital investment** and offered **tax incentives** to Danish families for generating power. As a result of this effective policy, more and more wind-turbine cooperatives started investing in community-owned wind turbines,[16] which in recent years raised 86 percent of the onshore wind capacity.
- **A fixed feed-in tariff** was introduced in 1993 and decoupled the **power purchase price** from existing electricity prices. Meanwhile, by 2003 under the **renewable portfolio standard,** all wind generators were connected to the grid.
- Denmark's lack of major fuel reserves and industries reduced political pressure from incumbents to block windpower development as has occurred elsewhere.
- Denmark has also used **environment taxation** to reduce air pollution—incentivizing clean and efficient energy by attaching a premium to polluting energy sources.

Implementation Considerations for India's mobility vision

- Effective and transparent policies, favorable pricing structures, and industrial deployment strategies along with a functional financing sector could jumpstart India's battery manufacturing industry.

4. THREE-STAGE SOLUTION APPROACH

Three integrated development stages can address barriers that exist to growing a competitive battery manufacturing industry in India:

- **Stage 1**
    - Incentivize and encourage direct investment in the growth of a battery pack assembly industry.
    - Develop partnerships and a multistakeholder consortium for joint research, investment pooling, and development of battery technology and battery recycling.
    - Form a consortium to serve as a resource to government and industry on future action plans for recycling, battery standardization, and end-to-end strategy.
    - Individual companies selectively pursue battery cell manufacturing where a business case exists.
- **Stage 2**
    - Consortium leverages research results from battery cell research to advise and help develop cell manufacturing growth strategy.
    - Consortium establishes best-practice plans for end-to-end battery manufacturing (including cells) and recycling in India, considering investments in current and evolving battery chemistry.
    - Development of supply chain connected to consortium battery manufacturing strategy.
- **Stage 3**
    - Consortium-led coordination between battery manufacturing and countrywide infrastructure (charging, swapping, recycling, etc.).
    - Rapid scaling of battery cell manufacturing infrastructure through investment strategies, coordination with OEMs, incentives and policies, and coordination with existing battery assembly industry.

These stages are pathways to support the development and build-out of manufacturing capability over time. Each stage represents a key aspect of India's potential long-term battery manufacturing opportunity. Throughout these stages, government and industry actions will need to be coordinated to align strategic priorities, manage interconnections, and organize and prioritize research efforts for maximum benefit to India's economy and society.

In contrast to China, India can incentivize growth through smart policy and planning, coordinated public/private research, and incentives to reduce risk for private industry and encourage rapid market growth. In doing so, India can develop a robust battery manufacturing industry not just capable of meeting the demands from the domestic market as it scales up to meet the 2030 100 percent electric vehicle goal, but eventually capable of competing and exporting on the world market.

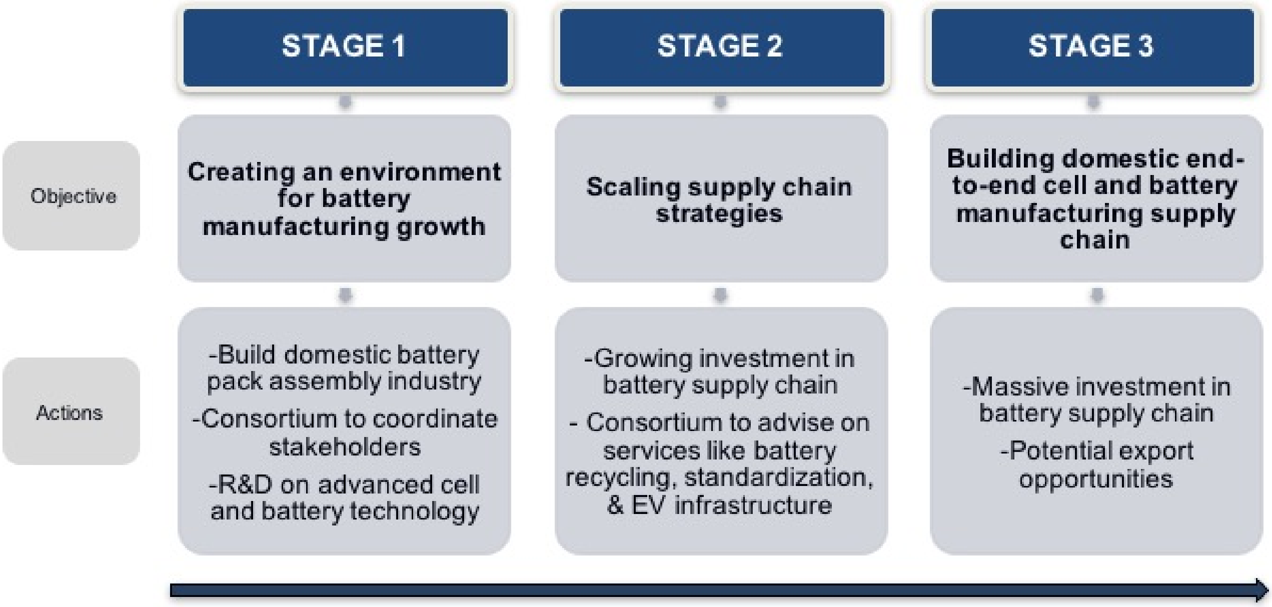


FIGURE 6: PATHWAY TO GLOBAL-SCALE BATTERY MANUFACTURING

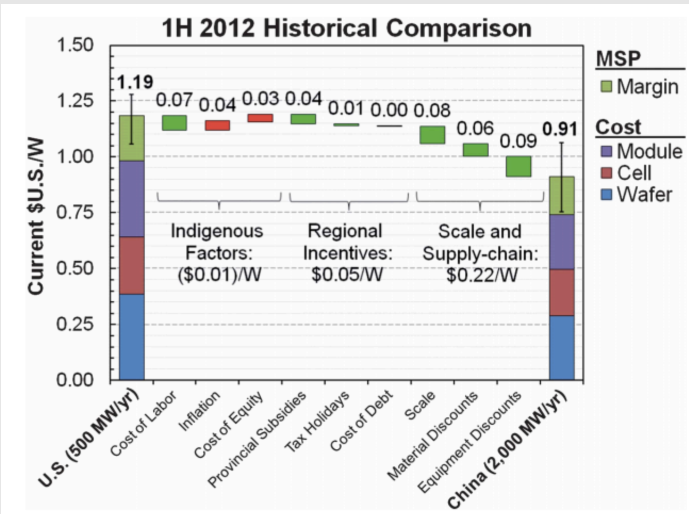
Expansion of Chinese Solar Manufacturing

Overview

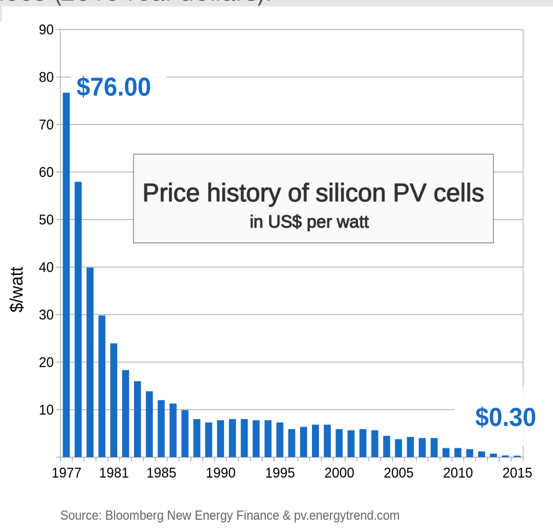
- China now manufactures 70 percent of global solar panels—over 70 GW per year.
- China is considered largely responsible for reducing the price of panels by 80 percent over the past decade due to growth in manufacturing volume.

Key strategies for success

- Growth in solar-panel demand created market opportunity for China in 1999; government invested $47 billion over five years in land grants, loans, and tax incentives to rapidly develop solar manufacturing capability and capacity.
- Government tax incentives, land grants, and loans to encourage rapid market growth.
- Trade restrictions reducing solar panel export led China to create incentives for internal utilization, China now has 70 GW of solar installed and added 24 GW in the first half of 2017
- Large existing demand—either from external or internal market.
- MIT-commissioned studies showed that, while China's lower labor costs and tax breaks had an impact, scale of manufacturing was also important. The "Swanson Effect" was observed, wherein every doubling in cumulative solar panel-manufacturing volume tended to decrease the real price by more than 20 percent. Increasing manufacturing volumes, familiarity with technology and industrial scaling mechanisms drove down prices (2015 real dollars).



China's solar manufacturing scale is its biggest asset



China has reduced solar prices by 80% since 2007

Implementation considerations for India's mobility vision

- India does not have access to inexpensive capital or large sums of public funds.
- China created many state owned enterprises to handle demand, often having them coordinate and work with government to rapidly grow capacity. India does not have the same luxury.
- Export market for batteries is still limited—India would need to rely on internal demand initially.
- By investing in research and development of new and advanced battery technology, India can build a sustainable battery manufacturing supply chain.
- India can take advantage of indirect subsidies offered by China to solar manufacturers as an example of supportive growth policies. Land grants, investment tax credits, streamlined permits, and foreign investment tax credits helped to rapidly develop the solar industry in China.

Stage One: Creating an Environment for Battery Manufacturing Growth

A modern electric-vehicle battery has many components beyond its lithium-ion cells. The battery cells (materials plus manufacturing) represent only 60–75 percent of a battery pack's total value, while the cells' assembly into a battery pack ready to insert into a vehicle represents 25–40 percent of the total value.[17]

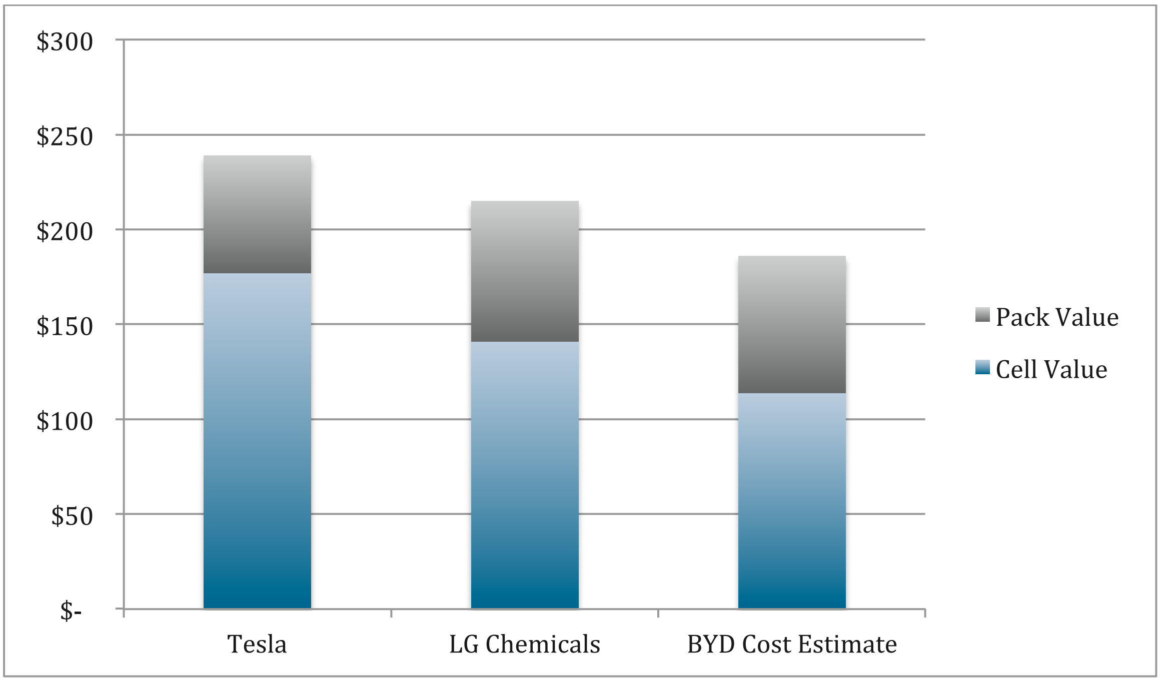


FIGURE 7: COST ESTIMATES FOR BATTERY CELLS AND PACKS[18]

While India does not have the capacity to begin mass-producing lithium-ion cells in the short term, it could take advantage of its strengths in manufacturing assembly to capture significant value in the battery supply chain. Lithium-ion cells could be imported from competing vendors, all subject to strict quality requirements to ensure durability and safety, while battery pack assembly and programming would take place domestically. Historically, cell value has decreased faster with volume than battery pack value, offering India a long-term, valuable industrial opportunity.

Investment in pack assembly would ensure that India develops domestic manufacturing capability for battery packs, which creates value for India regardless of whether cells are imported or created domestically. Individual companies can selectively pursue battery cell manufacturing as well where a business case exists.

Current Signs of Investment

Early electric vehicle contracts for India, like Tata's electric buses, imported fully assembled battery packs from foreign countries.[19] Yet companies have begun to recognize that importing a fully assembled battery pack is simply adding a "middle man" into the EV value chain. India has a very strong industrial labor market for technical assembly and programming—the two essential components of battery pack assembly. Importing a fully assembled battery pack (assumed at $200/kWh during initial stages) is forfeiting $50–80/kWh that could have otherwise been kept in India. Importing the lithium-ion cells, in which India does not yet have market advantage, and then assembling packs domestically is the best way to maximize revenue and minimize costs during initial stages. The estimated 120 GWh of cumulative demand during 2017–2020 would cost $24 billion in imported packs if a domestic industry were not developed, whereas assembling the packs in-country would require $15-18 billion in imported cells, while developing a $6–9 billion pack assembly industry in India.

In many ways, Stage 1 is already underway, and a need exists to continue investments in battery pack manufacturing, while establishing the conditions for coordination and collaborative research. Already, foreign and domestic companies have begun to construct battery pack assembly plants in India. In Gujarat, the Suzuki Motor Company is investing $530 million in a production facility for battery packs for the Indian market. This joint venture between Suzuki, Denso, and Toshiba showcases the value of foreign partnerships in bringing manufacturing and intellectual property to India.[20] Multiple other companies and partnerships, including Reliance, Foxconn, and Octilon, have announced multibillion dollar investments towards domestic battery manufacturing over the next decade.[21]

In Karnataka, Mahindra & Mahindra is discussing construction of a battery pack assembly facility. Mahindra already has such a facility in Bengaluru, taking advantage of imported nickel-manganese-cobalt (NMC) cells and assembling battery packs domestically.[22] JSW Group has also announced a plan to build battery pack assembly facilities in Gujarat as part of the utility's plan to diversify its holdings.[23] Battery pack assembly is an area Indian companies are already moving into as an economic opportunity. Support from the government and coordination by industry will only help scale this sector faster.

Preparing Capability

As India ramps up its manufacturing capabilities to support the 2030 100 percent EV goal, battery pack assembly will be a critical component in each stage. While domestic cell manufacture may not currently be a strong area for India compared to the global market, technology landscape, and resources constraints, battery assembly is well suited to India's domestic strengths.

During the initial stages of electric vehicle growth, as cells are imported to meet EV demand, battery pack assembly must accelerate as fast as EV manufacture, or internal value will be lost as India is forced to import fully assembled battery packs rather than capturing 25–40 percent of value domestically. As battery cell manufacturing scales, these same battery pack assemblers can scale and diversify.

Rapidly building out domestic battery pack assembly will allow India to pursue a unified strategy around battery cell manufacture to take advantage of bulk resource management of lithium and other necessary minerals. If the consortium finds it feasible to pursue other battery technologies than nickel-manganese-cobalt, these should be explored as well. Part of the purpose of the consortium will be aligning Indian battery cell manufacturing behind a singular strategy to reduce costs through mass manufacture and shared development, de-risking cell manufacturing investments and using market reconnaissance and alert R&D groups to guard against early factories' becoming stranded assets if battery chemistries shift.

No matter the cell technology used, the technology to monitor the battery pack and charge/discharge its energy can be retained. The battery pack assembly factories maintain value even as cell technology changes. As pack assembly is developed, these manufacturing groups can assist or help coordinate with EV and cell development in India to ensure cooperation and integrated manufacturing.

Consortium Building

SEMATECH - A model for competitive cooperation for battery manufacturers

Overview

SEMATECH – A U.S. government and industry partnership emerged in 1987 to help the U.S. reemerge as a leading manufacturer of semiconductors. SEMATECH was constituted as a nonprofit entity with a mandate to promote U.S. competitiveness in the semiconductor industry to help regain global leadership. Participating companies included 14 of the largest semiconductor companies, such as IBM, Intel, Motorola, and Compaq. These private members invested in SEMATECH a combined total of $100 million per year, matched by the federal government. This entity comprised engineers and scientists from the companies. SEMATECH's board also included government- and private-sector executives.

Over the years, SEMATECH played a role in helping the U.S. regain its share in the international market. Additionally, this collaboration enabled chipmakers to reduce R&D costs by nearly 30 percent for each subsequent generation of chips and reduce time to market from three to two years.

Key strategies for success

- **Identifying a common agenda for SEMATECH**: Through an evolutionary process, participants focused on the largest challenges that were too costly or too difficult for a single entity to overcome. SEMATECH helped coordinate standards for the semiconductor industry, and by bringing together chip manufacturers, technology companies, and equipment suppliers, it was able to move the industry on a coordinated path beneficial for all participants.
- **Role of the government:** Government participation was the critical catalyst in the creation of SEMATECH. Government involvement "provided a sense of both urgency and commitment, and made most of the companies feel as though they could not afford to be left out." Financing from the U.S. government raised expectations from the consortium, increased interest in participation, and encouraged private-sector members to contribute with equal zest. The government, in return, was able to develop low-cost designs for advanced military circuitry.
- By **focusing on basic research**, SEMATECH was able to address long-term opportunities too risky for private companies to pursue individually. Further, by collaborating on basic research, companies were able to avoid breach of antitrust rules and regulations that ensure fair competition. Lastly, since the benefits of basic research are universal, SEMATECH sought to benefit the whole industry and nation, not one company over another.
- SEMATECH enabled **open channels of communication on technology development and intellectual-property sharing** between all members. SEMATECH published and shared technology roadmaps that helped stakeholders—chipmakers, equipment manufacturers, and other vendors—by creating a forum where companies could openly communicate effectively about technological developments and share findings from joint R&D.
- SEMATECH also created **alliances with the equipment manufacturing industry and other vendors** to help improve quality control and address management issues. This was important when dealing with smaller and newer firms without sufficient resources or expertise to address every issue. These efforts enabled the creation of an ecosystem of suppliers and vendors that saw SEMATECH and other chipmakers as partners in their growth.

Implementation: Considerations for India's mobility vision

- India, too, could establish a domestic battery manufacturers' consortium or explore other international partnerships.
- The role of the government will be key. The government could contribute monetary resources, or provide non-monetary support such as land/labs/personnel to host the consortium, or both.
- The main objectives of this consortium in India could be:
    - Develop technological roadmaps for battery manufacturing in India. This should include detailed information on plans for the current state of R&D, battery technology evolution, and manufacturing processes relevant to OEMs and auto component manufacturers.
    - Conduct R&D on new and advanced battery technologies, including those that leverage innovative manufacturing technologies and alternative chemistries. Members could pool R&D resources to focus on basic research to enable the Indian battery industry to remain at the cutting edge of innovation.
    - Drive adoption of locally manufactured batteries in many other uses, e.g., off-grid applications, telecom towers, home or village energy storage, etc.
    - Conducting advanced research and pilot deployment on reusing and recycling batteries to reduce the need for scarce minerals to meet India's mobility goals.

New battery technologies are currently under development and include solid-state lithium batteries, lithium-air batteries, sodium-ion batteries, and silicon-based batteries. Solid-state polymer electrolytes are compatible with a wide range of chemistries ranging from inexpensive manganese-dioxide/aluminium to lightweight lithium-sulfur. Given that established battery manufacturing companies are aggressively pursuing research in these areas, a large-scale research and development-based consortium could succeed where individuals might fail, especially if it includes experts from government, industry, and academia, cross-pollinating Indian talent with foreign innovations.

Much as previous consortia built by the Technology Information Forecasting and Assessment Council (TIFAC) around vehicle lightweighting, vehicle system integration, and motor/power electronics helped speed and scale advances, this battery manufacturing consortium could look to pool resources and knowledge toward the advancement of an entire industrial sector in India. Other such consortia are emerging across the globe including one in the EU,[24] and a research consortium in the UK.[25] As the United States used the Manhattan Project as a massive public/private collaborative exercise for military advancement, so too can India create a collaboration of its best companies, government experts, organizations, and individual technologists and entrepreneurs to build durable economic advantage.

This organization would be responsible not just for collaborative research, but for coordinating an integrated manufacturing plan and advising policy makers and private actors on future incentives and goals. Though battery packs are typically proprietary and OEM-specific, battery cells are generally fungible. An exception to this could be a standardized battery pack for swapping operations. By creating a unified strategy around cell manufacture, India will assure its manufacturing is competitive globally. Without cooperation around cell manufacture, entering the market and sustaining advantage against high-volume fast movers like China will be difficult.

Research and Development

The most basic purpose of this consortium will be to coordinate research and development activities among battery manufacturers, governments, and other experts and to share information that could speed the development of battery technology. While the agenda and the role of the consortium should to be flexible to ensure that consortium members see sustained value in the face of evolving market needs and challenges, such a consortium could initially focus on battery cell chemistry and battery recycling, and could also include integrated IT, power electronics, and other battery applications, including those that could help monetize nonenergy benefits. The consortium could also conduct research on battery reuse, especially for grid applications including peak shaving, demand response, and other ancillary services.

Battery cell chemistry is a primary component of the forward-looking strategy. India will still be evaluating whether to pursue aggressive lithium-NMC build-out in the short term, while taking into consideration potential longer-term opportunities to be an innovator and leader in developing new electrolytes, battery chemistries, and morphologies (e.g., stacked, nanostructured, and thin-film formats). In order to achieve this goal, India must rapidly expand its knowledge of advanced battery technologies and be among the first actors to achieve the research base necessary for mass-scale deployment.

Battery recycling is a critical technology area for India due to the domestic shortage of certain scarce materials for today's lithium batteries. To ensure a level of resilience, India must be capable of reusing the majority of its scarce battery materials and limiting imports of costly, volatile-price ingredients. This has the added advantage of establishing the first generation of battery imports as a domestic resource, as the cells imported could have a second use by future generations of Indian batteries. Before that, they can enjoy a profitable "afterlife" in the secondary market of stationary applications for which they are well suited even after losing perhaps a fifth of their capacity, making them less fit for mobile uses.

De-risking for Success

Moving first in a new, highly competitive industry carries inherent risks. This is why new industries develop so slowly: most firms prefer to wait on the sidelines and see what barriers the first movers encounter, then invest later with the advantage of others' painfully learned lessons. Viable and economic technologies can take years or decades to mature and scale as private firms slowly test a new marketplace. First movers can easily fall at unexpected hurdles. Creating an environment where these first movers are supported by policy, resources, and incentives ensures there will be more first movers, they will be more likely to overcome difficulties and build a viable market, and others will follow to scale more quickly.

As this report has pointed out, battery pack assembly is already starting to scale in India. But faster growth is needed to reach the levels required for anticipated electric vehicle demand, and to ensure that India is assembling all or most batteries domestically and capturing as domestic value at least 25–40 percent of final battery cost in pack assembly.

The following approaches are options to help de-risk the system, encouraging investment and accelerating growth. Incentives and investments are most effective if transparent and explicit in their timing and support, with regard to both what they will incentivize and for how long, so firms can factor them into strategy and de-risk initial investments. These strategies could be pursued by a combination of state and central government actors, private companies, capital providers, and subject matter experts, but must be coordinated to deliver maximum impact.

Incentives	
Land grants	Direct awarding of land free of charge or at highly discounted cost encourages companies to develop manufacturing capacity (e.g., in Texas, USA).[26]
Tax Incentives	Mechanisms such as accelerated depreciation, deductions for investments in capacity, property tax reductions (such as those for Tesla's Nevada Gigafactory and for SolarCity's solar panel factory in New York, USA),[27] sales and use tax exemptions, or tax credits per job created (e.g., in Ohio, USA)[28] are popular for encouraging development. Generally, these are phased out over time, but encourage initial investment by boosting internal rate of return.
Streamlining Permit Systems	Often, companies in India must seek permitting approval from multiple agencies and ministries for construction, equipment, land acquisition, and other steps needed to build a manufacturing facility. Reducing this burden by lowering the number of permits required or making them available through just one or two "clearinghouse" agencies can accelerate growth by lowering bureaucratic hurdles.
Investments	
Encouraging Foreign Investment	Reducing taxes or penalties on foreign investment can allow easy partnerships, ventures, and investments with foreign companies. This takes advantage of foreign capital to develop Indian markets and jobs, as well as often attracting external expertise and intellectual property.
Direct Government Subsidy	Similar to China's rapid development of the solar industry, Indian central and state government may grant money directly to companies in order to rapidly scale growth. This can be through direct investment in a company, through low-cost loans, through coinvestments, or through loan guarantees or interest-rate buy-downs offered to Indian or foreign banks investing in Indian manufacturing. Modern financial engineering offers many opportunities to leverage limited government capital so it steers much larger private investments.
Consortium	
Pooling Research Funding	Creating a unified pool of research funding using private, government, and NGO groups will ensure rapid growth and innovation in the battery space and best help India compete in the global marketplace. This research can be also deployed to look at alternative uses of battery technologies, such as stationary applications.
Research into	No one can predict the exact battery technologies that will prevail in the

Battery Chemistry	future. The field's rapid flux is why research is necessary. The consortium will seek to rapidly expand knowledge on new battery chemistries, support pilot trials, and help scale and refine manufacturing and inform risk management.
Research into Battery Recycling	Battery recycling will help India deal with both the end-to-end manufacturing issues of batteries (ensuring less waste, avoiding environmental pollution, and reducing costs), while also dealing with the shortage of certain minerals in India by reusing them as much as possible to displace both imports and unwanted potential releases.
Coordination	
Partnership and Joint Venture Growth	Linking external foreign partners with domestic manufacturing can help pool resources and bring new experts and technology to India.
Electric-Vehicle Incentives/Growth	Battery pack manufacturers need a market. If India's EV market and domestic battery pack production get badly out of step, pack assemblers could risk bankruptcy. Structures for EV incentives are not covered in this report, however.[ix]

Stage Two: Scaling Supply Chain Strategies

The marketplace for the most common electric vehicle-battery cell technology, nickel-manganese-cobalt lithium-ion cells (lithium-NMC), is becoming increasingly crowded. As covered earlier in the report, companies like Tesla, Panasonic, and BYD have hundreds of gigawatt-hours in annual manufacturing capacity already planned or under construction. Industry experts expect battery manufacturing capacity to double by 2021 to 273 GWh/y, up from about 100 GWh/y now. By 2030, 1,300 GWh/y of total global capacity is anticipated.[29] India must carefully consider how to enter this marketplace, and a large part of the battery manufacturing consortium's role will be to advise on a collaborative strategy for development. This may involve direct entry into the NMC marketplace, a waiting period to pursue new battery technologies and seek a new-market advantage, or some combination of the two. India could invest early and heavily to seek domination of the NMC market, or could import NMC batteries for longer while aggressively positioning itself as the primary manufacturer of battery packs and next-generation batteries. Many options are possible, but India should pursue a unified strategy to assure maximum effectiveness at least risk. India's battery consortium, to be constituted in Stage 1, could help identify a least-risk strategy for battery investments.

Stage 2 will use the consortium created in Stage 1, building on its successes and its planning as the battery supply chain scales further, to create research and internal capacity. The consortium would help recommend incentives for the scaling of Stage 3—development of battery cell manufacturing technology. The research and development begun in Stage 1 will be capitalized on in Stage 2—establishing a strategy and path forward based on India's emerging knowledge and capabilities. Additionally, Stage 2 could eventually see the battery pack assembly industry become fully developed and India could start to scale back or eliminate subsidies.

In general, while Stage 1 will entail establishing the consortium, setting an initial task and research list, and beginning to build battery assembly capacity, Stage 2 will entail scaling these successes and the consortium's advisory role to prepare for a battery cell capacity build-out in Stage 3. By the end of Stage 2, the consortium will have to capitalize on previous successes in infrastructure and research, and create a coordinated plan and set of stakeholders ready for moving into Stage 3. This is especially important for battery cell manufacture, as the technology could be standardized and could create economies of scale

[ix] NITI Aayog and RMI's November 2017 paper *Putting Society First: Evaluating a Motor Vehicle Feebate Policy for India* discusses one such incentive structure

benefiting the entire ecosystem of Indian customers (pack manufacturers, OEMs, vendors and suppliers, etc.)

Capitalizing on Research and Development

The research and development investments launched in Stage 1 will deliver results in Stage 2. This will allow a greater understanding of the strategies India will pursue around battery chemistry, battery recycling, standardization, and electric-vehicle charging infrastructure deployment. The consortium will utilize this new knowledge in its advisory role to work out an action plan for developing an end-to-end battery manufacturing industry, scaling battery cell manufacturing in Stage 3, and integrating the battery cell manufacturing industry with battery assembly and the rest of the supply chain in India.

Consortium Coordination

As India scales up its battery manufacturing, it will be critical to ensure that battery charging/swapping infrastructure is designed to capitalize on standardization and on the battery monitoring systems in common use across a wide range of companies. As the battery cell manufacturing industry expands, it will be important to coordinate among consortium members to ensure that battery cells, charging infrastructure, and other elements are standardized across the full range of partners. At the same time, OEMs could differentiate offerings at the pack level based on vehicle types and needs. This will not only ensure a coordinated, open, vibrant, and competitive marketplace (not forcing customers to lock into one brand of charging station by using a certain vehicle type, for example), but will allow future research and development to be focused along common goals and products. This places a premium on using thoughtful standards to build volume and commonality where appropriate, such as the mechanical package and the electrical and IT/telecommunications connections of modular packs, while embracing rapid competitive evolution in chemistries and applications.

Given that the battery process has many dynamic elements, from mineral acquisition all the way to end-of-life recycling (or disposal—ideally designed out, or at least minimal), the consortium will also be in charge of logistical planning to make sure that India is prepared for each of these steps. In areas where the consortium has minimal power (such as mineral rights acquisition), it can recommend choices. The goal of the consortium will be to ensure a functioning system that maximizes domestic value capture and job creation in India while intelligently managing risk. It will provide advice and recommendations on standards, protocols, policy, and market interventions to that end.

Consortium Coordination	
Integration with Infrastructure	Batteries in electric vehicles require charging or swapping infrastructure to work. The consortium will coordinate with providers of infrastructure in order to ensure batteries and battery-monitoring systems are providing maximum value in their use. This includes potential utility in load balancing, grid ancillary services, or battery chemistries and designs to support ease of use, safety, versatility, and flexible evolution for the charging and swapping systems.
Standardization	Battery cells should be designed with standardization in mind, and in the case of swappable batteries, standardized wherever possible to ensure ease of swapping infrastructure. Ensure electric vehicles and battery manufacturers are coordinated in providing maximum fungibility of battery assets between vehicles and, where appropriate, with other uses.
End-to-End Coordination	The consortium will help ensure that, by 2030, processes are integrated as much as possible across the Indian economy to ensure maximum domestic value and jobs. This

	will involve coordination of companies along the entire supply chain—including materials acquisition and processing, cell manufacturing, pack assembly, battery component manufacturing, electric vehicle manufacturing, reuse, and recycling.
Cell Manufacturing Logistics	
Developing a Plan for Battery Cell Manufacture	It is difficult to give a set of recommendations for how to incentivize India's battery cell industry, as this report recommends no major ramp-up in cell manufacturing capability until new technology research is completed. Ideally this will be in the early 2020s. However, what the domestic and international market will look like at that time, what shifts in technology may mean for manufacturing, or what other industries and possibilities will exist in India make any incentives a moving target. The consortium will help track this target and ensure that as research creates opportunities, the Indian government and private actors have a solid set of recommendations about how this new sector can best be supported.
Developing an End-to-End Integration Plan	Though imports of battery cells are expected in the initial years of India's shift towards electric vehicles and battery manufacturing, the long-term goal is a fully integrated manufacturing system within India, manufacturing all necessary components for electric vehicles and batteries. This will require planning how to integrate these parts, so one job of the consortium will be drafting a plan for how companies will interact to maximize domestic activity and minimize net imports.
Subsidy Reduction	
Ending of Stage 1 Subsidies	It is unlikely that Stage 1 subsidies will end entirely during Stage 2. Battery pack assembly will likely continue to grow as an industry through 2030, as demand for electric vehicles continues to rise on the way to 100 percent deployment. As India looks toward the export market, demand may rise even further. But subsidies must be adjusted over time to best meet India's domestic needs—not the desires of manufacturers for indefinite incentive programs. Programs will be phased out on time, extended if absolutely necessary, or replaced with sensible alternatives.

Stage Three: Scaling of Battery Cell Manufacturing

While building battery packs in India can create substantial value, the crux of planning for India revolves around the ability to manufacture battery cells domestically. Otherwise India will depend on imports for a critical component of its transport infrastructure, just as it depends today on imported oil, with all the obvious risks such dependency entails.

This scaling of battery cell manufacturing would be coordinated by the consortium, and would account for any battery cell manufacturing pursued independently by Indian companies. The consortium will recommend incentives for rapid growth of battery cell manufacture during Stage 2, and will continue to make additions or changes to those incentives as necessary. The consortium will also help to plan the future of India's battery manufacturing sector after 2030.

Battery Cell Manufacturing Incentives

It is hard to estimate the incentive suite that would best promote the growth of battery cell manufacturing in five to seven years (ideally sooner if breakthroughs happen earlier). The future technology is unknown and the current technology is in rapid flux; the future state of both the world market and the Indian economy is uncertain. Part of the consortium's work will be to assess the future situation and create a list of tailored drivers most likely to promote rapid growth of battery cell manufacturing in India—similar to the options described in stage 1 for battery pack assembly.

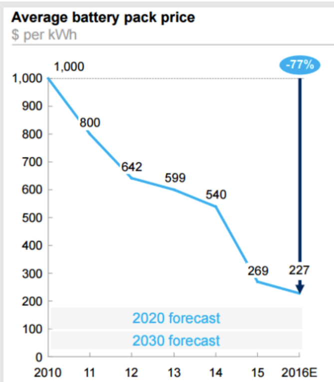
Previous experience in India has shown that government target setting and economic liberalization can lead to rapid growth in a market, as was the case with the uptake of LED and mobile telephone technology. This will emulate major growth areas in India previously, such as the rapid shift to LEDs.

SOLUTION CATEGORY	MOBILE TELEPHONY	LEDS
Overview	• Led mostly by the private sector, growth in mobile telephony leapfrogged the transition to landlines	• Nationwide replacement of incandescent lights with LEDs totaling 3.5 crore street lights and 77 crore household lights by 2019
Scaling mechanism	• In addition to technological improvements, liberalisation of the telecom sector (1991) • Competitive collaboration among telcos in the area of infrastructure development	• Aggregated demand and procurement lowered bulb costs 76% in 2014 alone • Outreach, turnkey implementation, and energy-savings monetization accelerated adoption
Impact	• 100 crore mobile phone subscribers and 22 crore smartphone users • High share of digital transactions with 63.8 lakh transactions valued at Rs 2,425 crore in the month of March 2017	• Reducing energy use by 114 TWh, peak load by 21.5 GW, and emissions by 85 $MTCO_2$/y in 2019, saving residential and municipal consumers Rs 455 crore per year

Expansion of Tesla Battery manufacturing

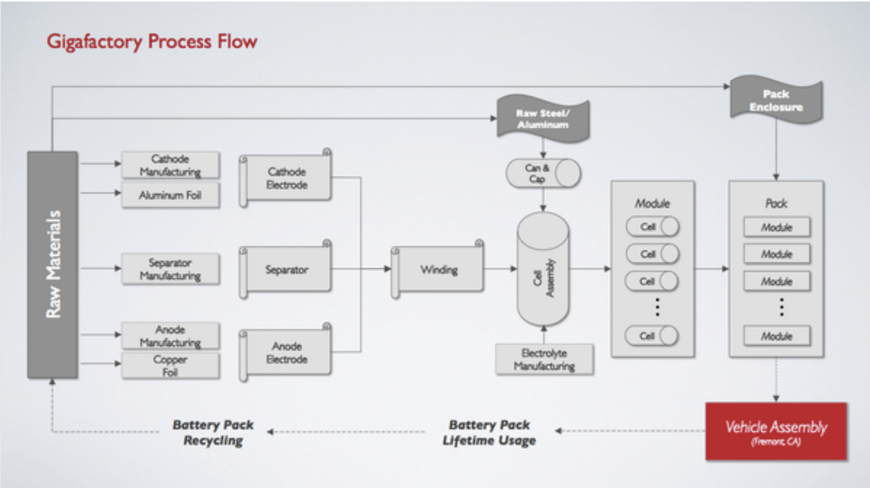
Overview

- Tesla invested in full vertical integration of the battery manufacturing process; combined with technology improvements, this led to an almost 80 percent decrease in its battery manufacturing costs from 2010 to 2016 ($1,000 to $227/kWh)
- It is estimated that after the Gigafactory is complete, there will be a further 30–40 percent decrease in its costs to $120–130/kWh
- Companies in China (e.g., BYD) building similar gigafactories are discussing similar costs



Key strategies for success

- Vertical integration
- Mass-scale production
- Natural resource control



Vertical integration in process leads to cost reduction

Implementation Considerations for India's mobility vision

- India's access to natural resources for Li-ion battery manufacture is limited
- Massive scale-up is made difficult by limited previous battery manufacturing experience
- Made in India initiative is already pushing for domestic energy growth
- High-tech manufacturing industry within India is very well developed, also software

Moving Forward on Batteries

By 2030, India aims to hit its 100 percent electric vehicle sales mark and battery manufacturing will scale to support domestic demand. It is an ambitious goal, but an achievable one with a supportive government and an active and involved consortium. As domestic battery manufacturing hits a critical point where subsidies are no longer required and it has met or exceeded the demand from the domestic EV market, the consortium's duty will shift to thinking about the future.

Will India continue expanding its battery manufacturing capacity and become an exporter? Will other segments of the Indian market be addressed (freight, rail, stationary energy storage, etc.)? What incentives might make further growth and development possible? How will further research and development happen, and how coordinated will this be in the future? These are just a few questions the consortium could address as India looks at the future of battery manufacturing after achieving this goal.

Battery Cell Manufacture Scaling	
Tailored Incentives for Cell Manufacturing Growth	The consortium will, over the course of Stages 2 and 3, provide recommendations on the best set of incentives to drive scaling in cell manufacturing. These will be based on the eventual battery chemistry and the market developing in India.
Streamline Permitting	Similar to battery pack manufacture, companies must be able to scale battery manufacturing with a minimum of bureaucratic red tape and through as few agencies as possible.
Foreign Partnerships	The consortium must decide to what extent foreign partners can be involved to gain greater access to external funding opportunities, while maintaining Indian control of initial technology access and an advantageous market position.

Future Planning	
Elimination of Subsidies	Some subsidies (particularly for battery pack manufacture, which will ideally be a well-developed industry by that point) will phase out during stage 3. They should be allowed to, maintaining a free market approach with open market entry and exit. The only exception will be if subsidies are determined to be necessary to maintain growth momentum.
Export Market or Other Potential	As India reaches its 2030 100 percent vehicle electrification goal (or exceeds it, if targets are hit prior to 2030), the decision must be made on how battery manufacture scaling will continue. This may involve an expansion to 100 percent electrification of other domestic markets (freight trucking, for example), or it may involve a focus on export to foreign countries. Whatever the plan is, the consortium will advise on it and the best way to move forward with it.

5. CONCLUSION AND NEXT STEPS

Battery manufacturing represents a huge economic opportunity for India. Ambitious goals, concerted strategies, and a collaborative approach could help India meet its EV ambitions while avoiding import dependency for battery packs and cells. This could help establish India as a hub for cutting-edge research and innovation, boost its manufacturing capabilities, create new jobs, and foster economic growth. India's strengths in IT and manufacturing, its entrepreneurial and dynamic private sector, and its visionary public and private sector leadership will be key factors in realizing these ambitions. Aggressive forward movement in battery manufacturing could cement India's opportunity for radical economic and industrial transformation in a critical and fast-growing global market.

Our analysis of India's battery manufacturing opportunity yields the following conclusions:

1. India's demand for batteries to meet its mobility transformation goals will support global-scale production that could place India among the world's leading battery manufacturers. **By 2030, India could account for more than one-third of the global market for batteries for electric vehicles.**
2. While India is starting from a relatively weak position in battery manufacturing globally, **the scale of its market opportunity is attracting strong interest from leading companies in India and globally**. Battery production in India could ramp quickly if manufacturers have confidence in future market growth.
3. **Clear and stable policies** to guide India's transition to EVs are fundamental to support investment in vehicle and battery manufacturing capacity in India.
4. Coordination among industry stakeholders and government can help to define a pathway to growth and competitiveness by establishing a shared technology roadmap, creating common standards, and aligning policies. Building on the recommendation from *India Leaps Ahead: Transformative Solutions for All* for an "India Platform for Vehicle Manufacturing," NITI Aayog and RMI recommend that **India create a consortium of battery manufacturers, OEMs, government officials, and subject experts to inform and coordinate the deployment of capital and intellectual resources and advance to a position of global leadership in battery manufacturing**.
    a. The government will play a key role in catalyzing, convening, and driving this consortium. The government's active engagement will not just infuse urgency and purpose; it will create an opportunity for open dialogue on the policies around battery manufacturing and technology development.
    b. The consortium could include key global battery R&D and manufacturing partners to bring India up to speed with global innovations, avoid past failures, and invest resources in areas that can help India build competitive advantage in battery manufacturing.
    c. This consortium will help key stakeholders coordinate and collaborate on a technological pathway for battery manufacturing in India. By focusing on joint R&D on long-term, high-risk opportunities, the consortium will support continuous innovation across the whole supply chain.
5. While the agenda and the role of the consortium should to be flexible to ensure that consortium members see sustained value in the face of evolving market needs and challenges, some initial objectives of such a consortium could include:
    a. **Developing a common technological roadmap** for the battery manufacturing industry
    b. **Coordinating R&D on new and advanced battery technologies**, including those that leverage innovative manufacturing technologies and alternative chemistries
    c. **Driving adoption of domestically manufactured batteries** in multiple additional use cases
    d. **Conducting advanced research on battery reuse and recycling** to reduce need for imported minerals
6. This consortium approach can also be extended to the vehicle design and manufacturing process, as an increasing number of vehicles will be utilized for service provision as opposed to personal ownership in the future. In such a future, many common parts will be indistinguishable to the end-user customer/rider, and many vehicles could share common components. **Common design and**

manufacturing of such parts could further reduce overall manufacturing and design costs and improve delivered quality.

7. **Start-up incentives can be used to de-risk early stage investments in battery manufacturing** and accelerate the development of India's domestic battery manufacturing industry. These incentives could include land grants, tax incentives, streamlined permitting, encouraging foreign investment, direct subsidies, and R&D support.
8. Scaling of battery production can be supported through **supply chain coordination and de-bottlenecking, infrastructure development, and end-to-end planning and coordination.**

6. APPENDIX

Gigafactory calculations

Electric vehicle population
- Global: BNEF projections from EV Outlook to 2040
- India: RMI analysis

Vehicle battery size

Vehicle Type	Scenario 1: Battery size (kWh)	Scenario 2: Battery size (kWh)
2-wheel	3	7
3-wheel	10	20
4-wheel	30	60
Public transit: buses	100	400

- Battery size is the same for personal or commercial use

Battery multiplier = 1.5
- Assuming a swappable infrastructure is available
- Multiplier only used for 2- and 3-wheel vehicles, and buses

RMI National-level road based-passenger mobility analysis

Modal Split (percent) with respect to billion passenger kilometers (BPKM)

Vehicle Type	Scenario and year		
	2016 All	2030 business as usual (BAU)	2030 Transformative
2-wheel	15.5	13.4	15
3-wheel	5.6	6.9	6
4-wheel	10.4	21.5	15
Public transit	68.5	58.1	64

Ownership mix

Vehicle Type	Notes
2-wheel	Personal: Commercial is 80:20 all years and all scenarios
3-wheel	Personal: Commercial is 20:80 all years and all scenarios
4-wheel	Personal: Commercial is 73:27 in BAU scenario for all years; 50:50 in Transformative scenario in 2030

Occupancy (# of occupants) for all scenarios

Vehicle Type	Year	
	2016	2030
2-wheel	1.6	Same
3-wheel	1.76	Same
4-wheel Personal Commercial*	 2.7 3.13	 2.14 3.07
Public transit Buses	 41	 40

* 4-wheel commercial vehicle occupancy in BAU scenario is the same as 4-wheel personal occupancy. Unless otherwise specified, occupancy is the same for all ownership.

NITI Aayog

Utilization (km/year) for all scenarios

Vehicle Type	Year	
	2016	2030
2-wheel	6,300	Same
3-wheel	33,500	Same
4-wheel		
Personal	12,600	Same
Commercial*	70,000	124,800
Public transit		
Buses	114,209	Same

* 4-wheel commercial vehicle utilization in BAU scenario does not exceed 70,000 km/year.
Unless otherwise specified, utilization is the same for all ownership.

Percent of electric vehicles (with respect to number of vehicles)

Vehicle Type	Year + Scenario		
	2016 All scenarios	2030 BAU	2030 Transformative
2-wheel	0	5	100
3-wheel	0	5	100
4-wheel			
Personal	0	1	40
Commercial*	0	5	100
Public transit	0	1	100

Interpolated Battery Cost Series

Manufacturer	2016	2030
Gigafactory-Based		
Cell	177	50
Pack	62	20
LG Chem-Based		
Cell	141	70
Pack	74	31
China-Based		
Cell	114	39
Pack	72	25

Energy Price Assumptions

Cost of Electricity	(INR/kWh)	6.5
Cost of CNG	(INR/kg)	38
Cost of Petrol/Diesel	(INR/bbl)	3380

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