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The New Forces Research of New Energy Vehicle Development Strategy in India

Tran Thu Hien[1], Nova Mardiana[2]

[1,2] *Telfer School of Management, University of Ottawa.*

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Abstract

India stands at a pivotal transitional phase in its clean mobility journey, and recognizes the demand for clean mobility options given the synergy that exists between new energy vehicles (NEVs) as an industrial opportunity, and an environmental imperative. The country's rapidly accelerating urbanization, worsening air pollution, heavy dependence on foreign crude oil and international obligations on climate change have converged as powerful pushes for electric and alternative-energy vehicles. By examining the relationships amongst policy, technology, business, infrastructure, consumer behaviour and global competitiveness – this paper nuances the emerging drivers of change that are propelling India's New Energy Vehicle Development Strategy forward. Contrast the previous waves of motorised industrialisation, the new phase is less about some fresh engineering tweaks and more about systemic gestalt shift across energy systems, manufacturing ecosystems, collaboration polities, digital platforms; retooling not just what we thing a 'car' is, but what it means for a 'vehicle' to be a vehicle, and how it means to operate within a society.

The first big driving force is policy innovation and mechanism docking, and India has adopted a multi-level approach such as PLI, FSS, green financial market to promote the NEV market and have fitted coordination with ministries and state. In the context of targeted public procurement programs, such as the purchase of electric buses, they reduce costs and create anchor demand. A second force is that of the domestic manufacturing ecosystems, where the country is striving to localise the entire supply chain of batteries, motors and power electronics, for example, moving from just assembly to fully developed local capabilities. It is not just about import substitution, this industrial strategy is to make India a credible exporter of New Energy Vehicle (NEV) technologies and components.

A third dimension is in battery innovation and material strategy, where India is playing with a number of chemistries such as lithium iron phosphate (LFP), nickel rich cathodes and even fledgling sodium-ion tech. These are the avenues for balancing between economy, performance, secure supplies and India's lack of domestic reserves of critical minerals." Topping these hurdles is the challenge of charging infrastructure and grid integration, where India has to build out modern, interoperable and renewable energy-friendly systems which can also take care of urban and intercity requirements without disturbing its stretched thin power distribution networks.

On the demand side, India's unique mobility landscape primarily consisting of two- and three-wheelers and buses, and the potential that comes with it, is also due to challenges. These two sectors enjoy faster COE and higher mileage indexes. It means a lower threshold to true mass adoption of NEVs. It is also helped by new financing arrangements, like battery renting and fleet electrification. At the same time, sustainability and circularity is the strategy and NEV benefits are realized through the whole life cycle with responsible sourcing, second life of the battery and ever more important end-of-life recycling. The focus is as much on software-defined vehicles and data governance and India, leveraging this to court its strong IT expertise, will hard-code digital brain power, cyber security, mobility-as-a-service integration into the NEV ecosystem.

Finally, the paper argues that India's NEV strategy can be best perceived as a mission-oriented change, which goes beyond transport policy and centers around industrial development, energy transition and digital leadership. Balancing

short-term mandates for cost cutting with long-term strategic aspirations, not only does India have the chance to decarbonize domestic mobility, but also to be a global hub for new energy solutions which are affordable and replicable. This method will also depend, not on how well these "new forces" are organised, leveraged and adapted to India's own specific social and economic and infrastructural oddities.

Keywords

New Energy Vehicle, New Forces, Strategy, Production-Linked Incentive, NEV vision

Introduction

The Indian transportation sector is going through its biggest transition ever, driven by the pressing needs to control air pollution, rising fossil fuel imports and demands for modern day mobility. Smoggy capital cities on the verge of crisis, year-on-year growth of greenhouse gas emissions, an oil import dependency that undermines the economic stability of the country and New Energy Vehicles (NEVs) have even reached the level of national strategy. NEVs — battery electric vehicles, plug-in hybrids and hydrogen fuel-cell vehicles combined — are not just an adjunct to traditional petrol- and diesel-based internal-combustion engines; they represent a broader transformation of India's energy, industrial and technological complex. Indian auto in the era of sustainability As the world moves to the era of sustainable mobility, India has raised its stakes, adding not just a participation, but also taking it off with beaming on charting the global blueprint of a sustainable, affordable, scalable and clean transportation.

India's NEV vision is based on policy priority, business opportunity and social imperatives. On the policy front, ambitious government programs such as in FAME (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles) scheme, the Production-Linked Incentive (PLI) for advanced chemistry cells and auto components, and various regional measures to catalyze demand and supply are deployed, all meant to elevate e-vehicles in the country. All deliberate reversals of history, from reactive rather than orchestrated industrial strategy, to back-room rather than front-running investment, innovation and ecosystems. And what we focus on isn't only subsidizing adoption; it's creating local manufacturing capability to produce it, supply-chain resiliency, and global competitiveness.

From the perspective of industry structure, the automotive industry in India, the world's largest two- and three-wheeler manufacturer, would offer a unique platform for the establishment of the NEV market penetration. Unlike in western markets, where personal vehicles continue to rule the roost in the transportation space, India's transportation ecosystem is more diverse, with small vehicles as well as public buses and shared mobility constituting an important part of the mix. This variety offers opportunities for fast track electrification, especially in segments like electric rickshaws, scooters and buses where high utilisation and cost sensitive end customers offer positive economics for electrification. There is also a concerted effort to indigenize battery manufacturing, motor and power electronics production to reduce import dependence and create jobs besides laying the foundation of a competitive export led sector.

Not least in this context is technology and production side aspect. India's NEV focus is on battery, charging infrastructure and grid integration. Despite near zero reserves of crucial battery minerals in Australia, India will have to strive to diversify battery chemistries and their safe supply chain It must also invest in recycling (of old batteries) and in the second-life procurements of batteries. There is also a need to deploy charging infrastructure smartly in urban and rural areas, making it both interoperable and affordable as well as linked to renewable energies. The goal is to develop a symbiotic relationship in which electric vehicles not only reduce emissions but help to stabilize and add flexibility to the power grid.

From a more conceptual perspective, the move by India towards NEV should be considered in terms of mission-led sectoral transformation as opposed to sectoral reform. It is a proposition about both industrial development and job creation and about digital innovation and clean mobility. Software-based vehicles, data governance, and cyber-security—all of them crisscross to layer a digital veneer on the transition that IT and telecommunication-dependent India can take lead on).In a piecemeal, these new forces — policy, industry, technology, infrastructure design and digital systems are plotting a course toward a sustainable, self-reliant, globally competitive NEV future for India.

Two Substantive Reform Policy Catalysts and Institutional Alignment 1.

The trajectory of electric vehicles in India was determined to a large extent by the influence of policies and institutional convergence over the years as key change agents. In fact, unlike developed automotive markets, which are able to leverage demand pull characteristics and existing infrastructure, the trajectory of clean mobility in India will need to be significantly premised on a government led push on account of structural issues such as high initial costs, fragmented infrastructure and low consumer understanding. Thus, policy has not only emerged as an enabler, but a sine qua non for India's NEV strategy, determining the pace, direction, and inclusiveness of the transition.

Indian government has deployed a diversified cocktail of policy – a fusing of the supply-side with the demand-side. At National level, Access to vehicles under the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME) scheme will remain a lead driver for demand through consumer subsidies, in particular for two-wheelers, three-wheelers and busses. By reducing the purchase price of FAME, the gap between electric and ICE vehicles has been bridged and this is crucial for India as it remains a price sensitive market. This has been further supplemented by PLI (Production-Linked Incentive) aimed at creating efficiencies in the domestic manufacturing by promoting (investment in large scale) advanced chemistry cells and NEV components. The supply-side intervention is a key element of India's policy push to reduce its dependency on imports for strategic technologies and develop a competitive indigenous industry value chain.

The government's sync with the ministries and state government is another dimension to this strategy. NOWCPP initiative will be steered by the Ministry of Heavy Industries, Ministry of Power (charging infrastructure), and NITI Aayog (policy direction). State administrations have also come out with EV policies that offer incentives such as road tax, registration fee, and additional purchase subsidy. A few states, such as Delhi, Tamil Nadu and Maharashtra, have gone a step further by setting out specific penetration targets for EVs, investing in charging infrastructure and extending incentives to local players to set up or expand factories. In this multi-level governance, the NEV agenda, therefore, is not a patchwork quilt of projects, provinces and policies, but a national project.

Policy initiatives are also extended to public procurement and institutional demand aggregation. Schemes such as electric buses in urban public transport system and electric government fleets create anchor demand which brings production volumes to a level that is sustainable for manufacturers. The interventions are especially important during early-stage market development to guarantee off take, and build trust among investors and suppliers. In addition, local clean air requirements and state-regulatory climate policies are aligned with local environmental and public health priorities by accelerating transportation electrification.

Just as important to the advocacy of policy is finance and investment. The Indian government has already started pushing for the development of green finance frameworks, viability gap funding for charging infrastructure, as well as to scale up through a mixture of public and private partnerships that will catalyze capital. There are plans afoot to encourage banks to include EV lending on their books and give such lending perhaps priority sector status in the effort to bring the cost of finance to consumers and fleet operators down.

At a macro level, policy regime in India appears to be slowly moving from direct subsidies towards ecosystem building and institutional convergence. Temporary early stage relief is being replaced by longer term structural reform to manufacturing competitiveness, supply chain resilience, and financial sustainability. This two-tiered, phased approach will allow the policy response to accommodate market maturity — fostering competition and incentives for the private sector to participate, rather than subsidies. Lastly, policy- and institution- level coherence is the core of India's NEV development path (Gouldson et al., 2014), which helps transform the systemic bottlenecks into opportunities for industrial development, energy self-reliance and environmental closed-looping.

Manufacture Ecosystem and Localize the Supply Chain

The NEVs market will be a success story in India when the manufacturing ecosystem has been localised in any instance to minimize the imports and add muscle to the domestic industrial community in the country. India is already the fourth largest automobile market in the world and it has significant capabilities in ICE vehicles. But going electric requires an entirely new set of skills — for battery cell manufacturing, to electric motor production, for battery pack assembly, to power electronics, to lightweight materials, to deep software integration. Localizing a supply chain that has

these components is valuable for cost reduction as well as to structure a resilience against global raw material supply disruptions and global trade flow.

The GoI has recognized this demand and already introduced the announcement of Production Linked Incentive (PLI) for Advance Chemistry Cell (ACC) and Auto components, to dole out financial support to manufacturers to create domestic production capacities. These are themed to attract international players too To build in some local firms to develop part of the production capacities. India will also develop technology for lithium-ion cells, cathodes and anodes, eliminating its dependence on imports from countries, including China, South Korea and Japan, as it looks to localize all critical technologies.

The third point of supply-chain localization is the construction of industrial agglomerations and industrial chain vendors. Already, states such as Tamil Nadu, Maharashtra and Gujarat have turned into hubs for manufacturing of EVs with the infusion of funds from both domestic and foreign players. The hubs are surrounded by Original Equipment Manufacturers (OEMs), Tier-1 manufacturers, components suppliers, research and testing facilities within a cluster environment, producing a very ripe environment for synergy, knowledge exchange and economies of scale and overall cost-down for the supply chain. India should promote related industry clusters to reduce production costs, accelerate technology diffusion as well as establishing regional NVE production centers.

And of course, there is a battery making and battery recycling capability as a part of localization. Currently, we import battery cells and that sits at about 40-50% of the cost of an electric vehicle. One way of overcoming this problem is large gigafactories for cell production, a solution being explored by some companies. At the same time, recycling capacity is being developed to recycle valuable materials (e.g.., lithium, cobalt and nickel) from spent batteries to reduce dependence on imports and create a closed-loop for critical materials. Eventually, less hard counter-measures will become economically and ecologically more sound with NEVs.

Localization is also being pushed for motors, controllers and power electronics, for which we are dependent on high imports today. For competition, forex outflow reduction and local build-up, we also need to produce local items such as assemblies. Indian Companies are also entering into joint ventures and technical collaborations with foreign companies to bridge the technology gap and adopt modern plant and machinery. We're also seeing startups with nimble solutions in battery management systems (BMS), telematics, and software integration, all of which are crucial for NEVs to function.

The success of manufacturing ecosystems does not depend only on infrastructure, but also on talent availability and research strength. A training specific for engineers, technicians and working staff at special courses is necessary to ensure high-quality production. They will need, however, to take in research institutions and universities to innovate in materials, design and process efficiencies. It would be beneficial if academia-industry-government linkages are tightened, which will help in positioning India as the hub for clean mobility technology innovation."

In all, manufacturing ecosystems and localisation of supply chains are key to India's growth story for NEVs. India can achieve its cost-competitiveness, industrial development, and technology self-reliance, by reducing its import-dependency and increasing its domestic competence, and partnership of global and local players. This will be a key to boost the domestic NEV (New Electric Vehicles) market and turn India into an export hub for cost-effective electric vehicles (EVs) and components which will lead to increasing the Chinese factor, amidst the continuously changing dynamics in the backdrop of the global shift to cleaner mobility."

Routes and Pathways for Batteries and Materials$results Strategy

The battery is a house of cards in New Energy Vehicle (NEV) development, and is the most difficult link to control within the four-key factors: cost, performance, safety, and sustainability. In the case of India, battery tech isn't just an engineering efficiency issue, but also an issue of strategic autonomy. With batteries being almost 40–50% in cost of an electric vehicle, the battery chemistry India selects, its battery manufacturing and choice of material sourcing will decide how affordable and scale-able India's NEV journey can be. And, with low reserves of the key critical minerals such as lithium, cobalt and nickel which are critical to the growth of India's industry and technological needs, India needs a much richer materials strategy that encompasses diversification, recycling and international engagement.

Lithium Iron Phosphate (LFP) batteries is one such major battery technology change that India has received. LFP has been of interest due to its lower cost, increased cycle life, and better thermal stability compared to nickel-rich chemistries. For two wheelers, three wheelers and buses – which dominate the Indian transport eco-system, LFP is low cost, high performance, disobeys a lower energy density. On the other hand, NMC and NCA are best applied to passenger vehicles, which require a wider driving range and superior driving performance. So on the one with LFP in mass market and the other with NMC/NCA in premium, then India can consider also on cost vs performance both.

It is likely for the future as well as there are new emerging technologies such as Na-Ion batteries which may be advantageous in terms of resources and costs. Sodium is more plentiful and more widely dispersed than lithium which makes the sodium-ion technology interesting from the perspective of resource security. Pioneering pilots and some experimental projects are already under way that may change things enough to see India becoming a marginally less victim to the whims of the planet's lithium market. Solid state batteries are also under research for their superior energy density and safety characteristics, but also those are years away from coming to market. India is preparing for technology leadership over the long term by focusing on developing these future chemistries while fulfilling near-term market needs with mature technologies.

But any robust battery innovation agenda motivates an aggressive materials strategy. Since India does not have large domestic reserves across most of the critical minerals, it is imperative that these are secured through participation in production through engagement in international projects, making long-term agreements for off-take and also participating in overseas mines. There have been talks on setting up deals with the resource-rich countries of Africa, Latin America and even Australia. At the same time, India is also looking to bolster domestic capacity on intermediate products of cathode-active materials, anodes, electrolytes and separators in a bid to wean off the dependence on global supply chains.

Recycling and circular economy are equally promoted. Recycling old batteries helps to reduce the impact on the environment as well as carry less of a demand on the earth's natural resources — both of which can impose potential harm on habitats and humankind alike — in both saving these chemicals (lithium, cobalt, nickel and manganese) for future usage in other batteries. An integrated approach by India in introducing recycling will enable to build a closed loop recycling infrastructure and over time, India will be able to reduce dependency on imports of virgin materials & become self-sufficient on natural resources. End-of-life use cases like recycling retired EV batteries for stationary energy storage also help to extend the value chain and create new business opportunities.

Like the business models, this one is also backed up by R, D and T facilities. There is a need to work closely between universities, startup companies, and research laboratories and address next generation: advanced battery chemistries, battery management systems (BMS) and safety protocols. Similar test facilities need to be established for thermal runaway, fast charging and life-cycle performance to ensure that Indian batteries meet global safety and performance benchmarks.

Ultimately, the Key of India's NEV development is the battery technology routes and materials strategy. By combining the low cost, near-term deployment of well-established chemistries like LFP and NMC with the long-term investment in chemistry such as sodium-ion and solid state, access to critical raw materials and robust recycling processes, India can achieve both low-cost and sustainable technologies. The extent to which these gambles will pay off will not just dictate the rate of electrification in India; it will also influence India's potential to emerge as a global hub for next-generation, low-cost battery technologies and electric mobility.

Charging and Integration of Infrastructure and Grid

It also can promote the implementation of India NEV development strategy -- the construction of charging infrastructure and the interactive with the grid constitute the foundation of the Strategy. The most sophisticated EV is as good as dead, without ubiquitous reliable and affordable charging infrastructure. Especially in the case of a country like India which is already so densely populated and chaotic, and with varied routes and terrains, not only does charging infrastructure have to be strategically placed to cater to the city dweller, but also for the road tripper gunning across the city periphery. At the same time, this growth has to work with a stable and efficient national grid if EVs are to act as an enabler of the proliferation of renewables rather than being another straw on the camel's back.

The charging infrastructure in India is being developed based on a mixed system with slow, medium, and fast-charging being deployed through out grid depending on the vehicle types and use cases. After all, for the multitude of two- and three-wheelers – which rule India's urban mobility roost - affordable slow chargers as also battery swapping stations are turning out to be practical options. Urban passenger cars can benefit from a mix of home, work and fast charging stations at public locations but long distance travel between cities needs to be served with fast-charging corridors across highways. Electric buses (and some commercial fleets) that require depot-based charging, though, demand megawatt-level charging capacity in order to stay on schedule. This kind of segmented policy recognizes that there is no one-size-fits all policy -- from both the economics and politics of a country as diverse as India.

The Indian government itself has taken few steps to promote the charging infrastructure development, such as FAME, National Electric Mobility Mission Plan and Guidelines for EV Charging Infrastructure from Ministry of Power. These are policies that encourage participation by the private sector, but include for connector type and the possibility of use of different standard since we are not looking for fragmentation. Government-owned companies — from Energy Efficiency Services Ltd (EESL) and Power Grid Corporation of India to startups and private sector newcomers — are creating the infrastructure needed for the big charging grids also for the new business models — swapping of the battery, charging on a subscription basis and mobile units, such as that of BPCL. Together, the efforts are beginning to build confidence with both consumers and fleet drivers, who worry about getting left high and dry in the middle of a trip.

But vehicle-charging infrastructure can't be divorced from the grid. When you've got mass proliferation of EVs, you've got such a huge surge of demand for electricity, particularly at time. Done poorly, it might overwhelm the distribution system, raise costs and wreck the grid. To tackle these, India is considering the adoption of smart charging approaches to encourage vehicle to charge at off peak hours, TOU tariffs and demand response. AMI and communication technologies, as an example, provide utilities with the means of viewing the online charging loads and of managing the energy supply accordingly. In the future, Vehicle- to-Grid (V2G) technology as a long-lasting remedy might allow EVs to feedback power into the grid to support grid frequency regulation and as a backup power, making EVs to be not only a passive load but a mobile energy resource.

Yet another key is co-locating it with charging infrastructure of renewable power. Since India is barely beginning to pick up the pace on raising the installation of solar and wind capacity, there is a flexible demand sink in the form of EVs, which can soak up the excess renewable energy during evening and day peaks. WEplan chargers are equipped with solar panels and batteries on the chargers to minimize grid reliance, enhance energy resiliency and at the same time save operating costs. This accord allows for a vision that transcends tailpipe emissions and for the environmental implications of NEVs to extend to the overall energy ecosystem.

Lastly, charging infrastructure and 'grid integration strategy' is also a challenge and opportunity for India's NEV strategy. India can build back better charging infrastructure, by providing a combinatorial suite of charging solution for various vehicle segments, promote interoperability and SMART grid readiness & Charging demand for with renewable energy available. As it paves the way for a new era of electric mobility, the solution is set to reshape the kingdom's fundamental energy and mobility sectors with electrification as the pivotal point to determine where Saudi Arabia goes on the greenhouse-gas reduction route.

Demand Generation and Market Segmentation

Demand Creation for NEV is the Key The demand side has to be built up as strong as the supply side has to have deployment capability in India's NEV strategy. Unlike in developed countries where EV demand is driven by consumer mindset with a mix of environmental consideration and deep discretionary spending, EV demand creation in India is predicated on keeping it in sync with economics, usage pattern and affordability if demand has to be created. In addition, market segmentation is indeed a key to learning which groups of the vehicle owners will be most likely to accept NEV during the coming years and what kind of policy, business model, and financing provision may be provided to help the adoption.

The three-wheeler space, especially the electric rickshaw (e-rickshaw) and cargo loader categories are the most attractive to adopt NEVs in India. These vehicles already constitute a significant part of India's urban and peri-urban

mobility, moving millions of passengers on a very low cost-per-trip to-date. Due to their fixed routes and high utilization, the TCO benefit offered by electric three wheelers accrues much earlier compared to passenger cars. Operators can also opt for a battery swapping model to help cut out non-productive periods and fleet owner financing options also enable a lower cost of entry. Therefore, three-wheelers are also expected to remain the first big(volume) success story of NEV strategy India.

The other major segment for electrification is two-wheelers, the most popular form of mobility in India. And with almost 200 million two-wheelers on the road today, even relatively small amounts of electrification translate into game-changing reductions in fuel use and emissions. Electric scooters and motorcycles make it to the domain of the common commuter or delivery workers due to their cheaper cost of running, cheaper maintenance, and the constantly increasing distance it can cover. Government subsidies under the FAME scheme as well as an increase in petrol prices are also pushing cost-conscious buyers to look at electric two-wheelers. But the barriers — a small charging infrastructure, public skepticism about battery life — demand a warranty guarantee, a strong service network and transparent range certification.

There is another, very important sector for the introduction NEV which is the bus and the Bus Lines. It is also easy to electrify the city bus systems which are state owned as they operate on fixed circuits, unlike the private buses. GCC models are also eroding obstacles to widespread adoption, which involves buses being owned and operated by private operators but governments paying fees per kilometres traveled. The application of electric buses in the clean air actions at city-level, will, save the emission value of pollutants at least, represent some public benefits directly, and increase the social approval of NEV obviously.

And there are the passenger cars, which yield little exponential. While luxury electric vehicles have found a niche among wealthy customers, mass-market adoption has been restrained by initial higher costs and worries about the charging conveniences. But urban dwellings will be more likely to adopt EVs sooner – especially as city charging infrastructure grows and financial products get better and better at lowering barriers to entry. The prices of batteries are falling and production has gone local and over time, EV car ownership will be real for middle income consumers, especially those living in cities.

New models of financing and ownership are being designed to help bolster demand at those planes. BaaS, rental or residual value guarantee are all financial risk management tools for the customer. There is also demand aggregation in fleet electrification in ecommerce and last mile delivery end markets which leads to economies of scale for the manufacturers enterprises" said the report. Additional non-financial incentives such as free parking, green plates and access to restricted zones go some way to providing the motivation for consumers to look at NEVs.

To sum up, NEV demand induction in India will necessarily have to be through multiple segments and rationally address consumer behaviors, economics and infrastructure. By prioritizing three-wheelers, two-wheelers and buses — where electrification is already viable — India can also create the critical mass that is required to multiply the penetration we have achieved in passenger vehicles and commercial fleets. Thus, market segmentations can also be considered a relevant factor for the uptake of NEVs in India in some rational manner with ease of access and acceptance among the Indian even in the socio-economic contexts.

Export Orientation and GVCs

Now, for India's NEV plan to become a world scale export-led growth strategy from a domestic/designed-for-domestic adoption plan, (being) export-oriented and (being) connected in the GVC are sine qua non. Even as India has been trying to position itself as an emerging large consumption centre for electric mobility, the actual long-term opportunity to become a global manufacturing and innovation hub cuts in the other direction. This requires robust industrial policies, cooperation with other countries and targeted investments to align India's NEV ecosystem with global experience and demand patterns.

India already possesses a few advantages of comparison that may offer it a competitive position as a NEV and related component exporter. An Industrial Base : With a huge number of trained engineers, long term investment into automotive industry, manufacturing cost advantage are what makes the country an ideal choice for automobile

manufacturing. Just as importantly, large scale Government initiatives like Make in India and the Production-Linked Incentives (PLI) for Advanced Chemistry Cells (ACC) as well as automobile components would provide a wider push for creating an export capable ecosystem with focus on scale, local value addition and global competitiveness. It is trying to ensure the domestic demand is met and the country becomes part of the global supply chain for batteries, power electronics and vehicle platform.

In the near-term, India's surge of exports could be targeted at its two and three-wheeler NEVs OEMs, which also constitute as one of the dominant categories in its domestic market. These urban transportation trends and price sensitivities are replicated in AoT in SEA, Africa, LatAm SoMEA making them a natural home ground for the Indian electric 2Ws and e-rickshaws. Cheaper and better models from India, utilising (identity of) scale to cope with an expanding demand within the developing world, and so taking us into a robust export-lead path growth. And, by making vehicles that are tailor made to local conditions — whether they are the terrible roads on which many Indian drivers must steer or bad weather — Indian firms can differentiate themselves from say, China, where products often are a code term for being cheap rather than of the highest quality.

There is another tactical export play involving zigzagging around the battery and component supply chain. India is an importer of advanced cells from places like China, South Korea and Japan today mostly but with investment in gigafactories and local production of cathodes, anodes etc., India can be a exporter of intermediates instead in the future. Working with an existing global champions as they try to diversify their supply chains away from a China-centric strategy can provide India an opportunity to break-in to the battery and NEV component GVCs.

Besides this there is the export potential of digital and software content solutions for NEV from India. With its strong points in IT services, artificial intelligence (AI) and data-centric mobility platforms, India can build competitive advantages for itself in connected vehicle software, fleet management systems, and algorithms for charging optimisation. The world going towards software defined vehicles, and India is great at scalable digital solutions to be married with hardware exporting to have integrated mibility.

And yet, this outward orientation needs to be supported by policy. With the opening of trading policy, India and bilateral cooperation agreements for technology transfer, and conformity to international standards, the Indian NEVs and parasitical items would be competing across the world. Simultaneously, India needs to preempt against being caught in low-value segments by creating industry and R&D capabilities to capture higher value drivers of innovation – battery chemistry, autonomous driving technologies, recycling solutions perhaps.

In fact in the long run the more export driven is the NEV strategy, we can really be able to kill 3 birds with one stone – growth (by earning forex), independence (by reducing our dependence) and leadership (by leading the world in sustainable mobility for the developing world. Through its active participation in GVCs and use in developing domestic capabilities, India has the potential to evolve from a passive observer to an active participant in shaping the global NEV domain.

Technological Innovation and R&D

Innovation and R&D is the foundation for the development of NEV in India. Policy support, infrastructure and developing a market is what we have so far, game changers which would ensure long-term competitiveness and self-reliance are innovations. 907 However, in the case of India, which aims not only to become a prime adopter of NEVs but also to become the largest producer & exporter of it, indigenous investments in R&D is vital to cut its dependence on imports & improve its product effectiveness & also be ahead in the game of sustainable mobility solutions.

The key R&D is battery. Expressing similar views, Assocham had pointed out that India is predominantly reliant on lithium-ion cells from China, Japan and South Korea and manufacturing the cells for power banks is need of the hour in India. Such dependence exposes the sector to supply-chain risk, and price famine. In response, India was ushered into the National Programme on Advanced Chemistry Cell (ACC) Battery Storage, which seeks to drive indigenous research on high-density, low-cost and safer batteries. Indian startups and research institutions are also developing technologies for solid-state, sodium-ion and zinc-air systems that will reduce the reliance on imports and leverage locally available

materials. By excelling in these areas, India could potentially jump forward technologically to be an innovation leader in the world than a follower.

Another segment in which we will see innovations are electric powertrain and power electrics. While the global auto giants focus upon luxury high-performance EVs, Indian R&D is poised to deliver affordable, efficient, and long-life technologies to the masses. Flow battery efforts to look at researching lightweight materials, developing regenerative braking systems, thermal management and more efficient motors to help increase vehicle range and cut costs. Collaborations between industry giants like Tata Motors and Mahindra Electric and technology institutions such as IITs are beginning to bear fruit in terms of prototyping and testing these futuristic components.

Hardware-wise, India does not stack up, but it has a convincing argument in software-driven innovation. What would also bring a difference will be India's prowess in IT and AI when NEVs will integrate digital platforms for performance optimization, energy management and connectivity (all of which are currently being negotiated to be included in the specs of NEVs). Already startups are taking on use cases such as predictive maintenance algorithms, smart charging platforms and AI driven fleet management solutions. The addition of Internet-of-Things (IoT) in electric vehicles (EVs) and charging infrastructures system enhance the efficiency with scalable solutions in to urban as well as in rural aspects. This means, India is not only producing hardware, it has also launched global-first MaaS (mobility-as-a-service) solutions that can be reproduced anywhere.

There are several government funded R&D institutes like ARAI, CSIR and IITs which should foster innovation. These institutions are focused on testing, certification and application research in between of R&D and application. Long-term sustained NEV innovation needs ingredients like public-private partnerships, which are quickly becoming the unsung hero in the journey of NEV innovation in India, pooling together resources, reducing risks, and ensuring quicker commercialisation.

However, challenges persist. India’s research and development (R&D) expenditure as a percentage of GDP remains low with slower pace of technological breakthroughs compared to other large economies. The absence of a good migration of brains, lack of patent generators and dependence on technology alliances with foreign firms are also some of the challenges for self-reliance. It will need resources, to stop technologically with its people of its potential and international capabilities capable of transferring technology while they develop their base.

But in the long run, where technology and R&D are concerned, "To be or not to be [is] not a luxury. Without it, India risks becoming an assembly-hub country relying on imports. In this way, the nation can blaze its own path of independent development, bringing forth inexpensive, high-performance, and environmentally friendly NEVs with both domestic and overseas markets. If it integrates R&D with its ambition for sustainable development, energy security and global competitiveness, India can become a global leader in the new era of mobility.

NEVs: Sustainable, Recycled and Circular Economy

Sustainability is as well the cornerstone of India’s new energy vehicle (NEV) growth narrative, since the ultimate objective to make a shift towards clean mobility is not only about cutting tailpipe emissions. The more difficult task is thus to secure the environmental friendliness of the whole NEV industry chain from upstream original manufacturing to downstream usage, scrapping, and recycling. The transition to electric mobility, if not accompanied by integrating recycling and circular economy principles, might merely be moving from one environmental challenge to another (battery waste, raw material extraction, and energy-intensive manufacturing).

The treatment of EoL batteries is one of the critical problems for NEVs in the aspect of sustainability. Lithium ion battery is not completely safe even after useless NEVs. They’re full of valuable but nonrenewable resources like lithium, cobalt and nickel, which exist on the earth only at significant cost to mine and are often, elsewhere on the planet, associated with locally ruinous environmental and social extraction practices. Otherwise, used batteries might become hazardous waste in which chemicals can seep into the soil and water. In order to address this, India has recently notified the Battery Waste Management Rules (2022) that require battery producers to manage the collection and recycling of all waste batteries under EPR. Regulators like this are driving automakers and battery builders to think about a circular economy, recycling and then upcycling and recycling yet again.

And since Japan now seeks to be more self-reliant, recycling technologies are being developed in home country to reduce dependency on imported raw material through export abroad. A handful of start-ups and research groups are experimenting with hydrometallurgical — and pyrometallurgical — processes to extract critical metals from spent batteries. Attero Recycling and Lohum are already piloting huge recycling centres in India to generate a secondary resource pool. It could do more in averting the environmental risks and in reducing the cost of NEV production while achieving resource security. Ultimately, a robust battery recycling ecosystem can generate thousands of jobs, and also make India self-dependant in the world electric vehicle supply chain.

NEV circular economy does not focus solely on batteries. Second life of EV drive units (electric motors, controllers, chargers) is also a concern. For example, secondary use of retired EV battery in stationary energy storage systems can give them a second life of a decade or more and drive the adoption of renewable energy in the grid. Similarly, modularity in vehicle design, with ease of repair, replacement, and remanufacturing of parts, decreases the total material requirement.

Moreover, the sustainable development of NEV cannot be separated from green manufacturing. The automotive producers are resorting to the use of eco–friendly energy during the implementation stages of NEV manufacture, as well as adopting water preservation procedures and life-cycle assessment tools for determining the environmental impact of the production of the NEVs. Industry-academy cooperation is pushing research into biodegradable composites, the use of lightweight green materials and low-carbon production processes, which are expected to secure a cleaner and greener supply chain.

Yet the project of building a sustainable circular economy is filled with difficulties. Recycling in India is at a pauci-formation stage for the lack of adequate infrastructure and the non-affordability of advanced recycling technologies. Battery recycling The public's awareness regarding the disposal of batteries is not good, and system of collecting used batteries is in the early stage. These problems have to be solved by policy carrots, by investments in recycling R&D, and by a public education campaign that promotes a culture of responsibility and participation.

Finally, when sustainability, recycling and circular economy become not add-ons but the internal moorings of India's NEV policy, domestic manufacture can take on flesh." They serve to help ensure that the country's clean-mobility push does not exact a cost in new environmental hazards and that the nation retains some lasting economic resilience. By pursuing an ecology-centric system where resource loops are closed, and viewing value and life cycles in their entirety, India can create an environmentally-friendly NEV ecosystem that is truly sustainable — aligned to climate obligations, enhances resource security, and makes India a global leader in responsible green mobility.

Conclusion

India moving to NEVs is not just technological leap but a structural shift in our economic understanding and environmental obligations towards mobility. As evidenced in this study, the development path of India's NEV is influenced by multiple factors such as government policy, industrial innovation and infrastructure, consumer demand, environmental considerations, and international trends. Together, these forces are shaping a mobility revolution in a city with the potential to reshape the way India travels, uses energy and works to curb climate change around the world.

The Indian government is actively encouraging this through policies such as the FAME (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles) scheme, PLI incentives, and the Battery Waste Management Rules to help create an enabling policy ecosystem. These moves encapsulate the two-faced impulses behind India's energy choices: to reduce dependence on coal in order to meet its commitments under the Paris Agreement, the international pact to fight climate change. But policy alone can't endure transformation, it requires an industry, technological breakthroughs and end use consumer sectors to make it happen.

The industry is responding with increasing force. Local and foreign manufacturers all attach much importance to R&D, design and construction of facilities. From tiny startups designing two-wheelers to giant conglomerates making electric SUVs and buses, the industrial map of India Inc. is being redrawn in a fashion that is extremely hard to keep pace with. At the same time, supply chain localisation remains an important task in order to reduce dependence on

imports, especially for battery manufacturing and raw material processing, and to enhance resilience. The gigafactories, recycling plants and strategic partnerships with global tech leaders prove the industry is looking ahead toward scale in the long term.

Just as important is the infrastructure challenge — and opportunity. Adequate infrastructure for charging is the lifeline for the adoption of NEVs, and India is creating networks in urban clusters, along highways and semi-urban locations. Challenges of grid connectivity can be addressed with creative solutions such as battery swap and mobile charging models. However, the reliable, affordable and wide delivery of charging capacity is a long way off.

The dimension of the consumer, we must also add, is fundamental. Awareness, cost and range anxiety are all barriers to mainstream adoption, but the tide is slowly turning with the cost of fuel rising, government incentives and the ever-improving range and safety features of EVs. NEVs are attractive to new generations, as they are contemporary and environmentally friendly, while in "a city of limited financial resources," their affordability makes them even more appealing and could push the cultural acceptance of clean mobility forward.

The sustainability and circular economy model In the long term, the most important thing for the health of a business is likely to be sustainability and the transition to a circular economy model. Battery waste, recycling and resource security must not be afterthoughts as India fast-tracks NEVs. The report suggests establishing recycling industries, second-life applications of batteries and green manufacturing processes as part of the India's clean mobility revolution to prevent negative outcomes on the environment.

At its core, India's NEV narrative is one of change on many fronts — a mix of government vision, business dynamism, technology leap, consumer shift and environmental stewardship. The pendulum has swung and, though it isn't all smooth sailing in the price tag, in infrastructure and for the supply chain, nothing is going to stop it now. If the powers that be in India can translate these Into action through a better policy framework and continuous innovation and PPP, then we stand a good chance towards developing these and becoming a global leader in clean mobility and a NEV Industry leader tomorrow.

Thus the development of NEVs in India is more than a transport revolution — it is a blueprint for economic growth, environmental stewardship and social progress. By linking its mobility revolution with other development objectives, India can chart a course that is not only cleaner, but also more attractive in the eyes of the world, such that other developing countries feel they have no choice but to follow suit.

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