In Collaboration With

Shaping the Future of Mobility

Charging Ahead:
Global Insights and India's Roadmap for Electric Road Systems (ERS)

Futures Report | September 2025

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FOREWORD

India's transport and energy systems are undergoing a tectonic shift, driven by a confluence of national imperatives - decarbonisation, energy security, technological sovereignty, and *Atmanirbhar Bharat.* Nowhere is this transformation more critical than in the road freight and public transport sectors, which together account for a substantial share of our fossil fuel consumption, logistics costs, and emissions.

Over the past two decades, I have had the opportunity to work closely on India's journey of technological self-reliance - whether through defence innovation, indigenous propulsion systems, or the articulation of national missions for clean energy, semiconductors, and mobility. Today, as India emerges as a global voice on sustainability and technology-led development, our ability to leapfrog legacy systems and create new models for the world assumes even greater importance.

In this context, Electric Road Systems (ERS) offer a powerful and timely pathway to reimagine surface transport for the 21st century. The ability to dynamically charge electric vehicles while in motion addresses several constraints inherent to conventional EV adoption - by reducing battery size, enabling longer range, improving vehicle uptime, and cutting dependence on imported critical minerals. Critically, ERS reinforces India's long-term goal of reducing strategic dependence on external supply chains, while building domestic capabilities in emerging mobility technologies.

Importantly, ERS aligns well with India's goals of distributed renewable integration, smart grid development, and digital public infrastructure. By intelligently coupling infrastructure with energy and data systems, ERS can play a transformative role in building not just cleaner transport, but also more resilient and sovereign infrastructure ecosystems.

NITI Aayog has consistently championed electric mobility - from pioneering EV adoption frameworks and charging policies to convening expert groups on advanced battery chemistries, energy innovation, and clean logistics. The time

स्वच्छ भारत
एक कदम स्वच्छता की ओर

is now ripe to begin serious consideration of ERS as a strategic complement to India's broader e-mobility ambitions - particularly on high-utilisation freight corridors, multimodal hubs, and urban logistics routes.

I commend the ITS India Forum and the OMI Foundation for bringing clarity, evidence, and global perspective to this emerging domain. Their *Futures Report*, titled, ***Charging Ahead: Global Insights and India's Roadmap for Electric Road Systems (ERS)***, provides a valuable knowledge base for stakeholders across government, industry, and research. These insights must now feed into carefully chosen pilot projects - backed by clear regulatory signals, public-private collaboration, and outcome-driven evaluations.

As we move toward building the transport systems of the future, we must prioritise technologies that not only reduce emissions and costs but also strengthen India's sovereignty, industrial competitiveness, and economic resilience. Electric Road Systems, if developed with foresight and adapted to Indian conditions, can be a cornerstone of that vision.

Let this work be the starting point of a broader dialogue - one that brings together ministries, state governments, technology providers, utilities, OEMs, and public institutions to shape India's roadmap for dynamic electric mobility.

(Dr. V. K. Saraswat)

PRESIDENT'S MESSAGE

Akhilesh Srivastava
President
ITS India Forum

As President of the ITS India Forum, I extend my deepest gratitude to our partners - the OMI Foundation, NATRAX, NHEV, and the many experts, policymakers, and industry leaders - who contributed to shaping this landmark Futures Report on Electric Road Systems (ERS). Over the past six months, through intensive deliberations, expert consultations, and global benchmarking, we have collectively charted a forward-looking roadmap for India.

This is more than a report - it is the outcome of rigorous research, dialogue, and collaboration. More than 15 expert consultations, desk research on 10 global pilots across Europe, the US, Israel, Japan, Korea, UAE, and Australia, and comparative assessments of all three leading ERS technologies have informed our recommendations. The working group applied a multidimensional framework - technical readiness, cost-benefit analysis, policy feasibility, and contextual fit for India - to ensure this is not just a vision document, but a practical playbook for action.

The findings are compelling. Dynamic charging - Charge As You Drive (CAYD) directly addresses the barriers holding back EV adoption, particularly in the commercial vehicle sector - high battery costs, limited range, and operational downtime.

By enabling continuous in-motion charging, ERS can: Cut logistics costs by 5-7%; Reduce reliance on diesel imports by billions of dollars annually; Lower national demand for critical minerals by nearly 35%, thanks to smaller, right-sized batteries; Achieve up to 97% energy transfer efficiency (conductive ERS), delivering a 10% gain in overall efficiency compared to conventional EV pathways; Reduce CO_2 emissions by 30-87% compared to diesel, and an additional 10-20% over large-battery BEVs.

For India, the opportunity is immense. With 70% of freight dependent on diesel trucks, ERS can enable electric trucks to match diesel on payload and range, reshaping logistics economics. Integrated with Bharatmala, PM Gati Shakti, and Smart Cities, ERS can redefine infrastructure by aligning roads with renewables, smart grids, and digital systems.

The Futures Report calls for phased pilots in India - beginning with high-density freight and urban logistics corridors, leveraging PPP models like those pioneered under NHEV Tech Trials, and anchored by national institutions such as NATRAX.

At ITS India Forum, we see ERS not just as a technology, but as a systems opportunity - to decarbonise transport, enhance energy security, reduce logistics costs, and empower Indian industry across automotive, energy, and infrastructure. With strategic partnerships and bold pilots, India can lead the world in dynamic electric mobility.

I once again thank all stakeholders for their vision, contributions, and commitment. Together, we are charging ahead - building the foundation of a cleaner, smarter, and more self-reliant mobility future for India.

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Foreword

India is at the cusp of mobility disruption. At this transformative juncture we are resolute in our pursuit of sustainable, self-reliant, and innovative transportation systems. Electric Road Systems (ERS) is a disruptive technology that offers a ground-breaking opportunity to reimagine surface transport, particularly in high-impact sectors such as freight logistics and public transit, which are critical to reducing emissions and optimizing energy use. It can play a central role in our national mobility strategy and can compliment the national flagship initiatives as PM e-DRIVE, PM e-BUS SEWA and Smart City projects.

Electric Road Systems, by enabling dynamic charging of electric vehicles, address critical barriers to widespread EV adoption, including high battery costs, limited range, and operational downtime. By integrating with renewable energy sources and smart grid systems, it can further reduce reliance on imported critical minerals and strengthens India's energy and technological sovereignty. This aligns seamlessly with national priorities of fostering innovation, enhancing domestic manufacturing, and building efficient, future-ready logistics networks.

Development of ERS will require appropriate standards, prototyping and state-of-the-art testing infrastructure. The role of BIS in development of standards and National Automotive Test Tracks (NATRAX) for developing testing infrastructure is logically visualised. Such initiatives would enable rigorous evaluation of ERS technologies under Indian conditions, fostering confidence among stakeholders and paving the way for scalable deployment.

I congratulate the ITS India Forum and the OMI Foundation for their insightful and forward-looking Report – '***Charging Ahead: Global Insights and India's Roadmap for Electric Road Systems***'. It can serve as a compass to all the stakeholders—policymakers, industry leaders, researchers, and testing agencies like NATRAX—to collaborate on pilot projects, regulatory frameworks, and technological advancements. It is imperative that we unite to translate these insights into practical, India-specific solutions that drive impactful change.

I also compliment all other partners - industry leaders, researchers, policymakers, testing agencies and innovators - who have contributed to the development of this Report. Let this Report serve as a catalyst for a collaborative journey—one that harnesses ERS to build a transport ecosystem that is sustainable, efficient, and a testament to India's technological and economic prowess. With strategic partnerships and innovative implementations, we can position India as a global leader in dynamic charging infrastructure for Electric Mobility.

(Sudhendu J. Sinha)

FOREWORD

FOUNDATION

Ambassador (Retd.)
Gautam Bambawale
Managing Trustee,
OMI Foundation

Harish Abichandani
First Trustee,
OMI Foundation

India stands at the cusp of a new mobility revolution - one that must serve our people, secure our energy future, and assert our technological sovereignty. The stakes are clear. Road transport - lifelines of India's economic engine - must now transition rapidly towards clean, electric alternatives. While battery-electric vehicles and charging infrastructure are advancing with speed and scale, it is equally vital to explore complementary solutions that enhance system efficiency, grid alignment, and strategic resource planning. Electric Road Systems offer one such pathway - helping reduce reliance on large battery packs, optimising fleet uptime, and strengthening energy security. Unlike incremental change, ERS invites us to reimagine surface transport from the ground up, powered by smart infrastructure and strategic foresight.

Importantly, ERS integrates mobility with energy. It provides us with a live opportunity to align our transportation corridors with renewable energy generation, dynamic grid balancing, and digital infrastructure. This is a future where vehicles charge as they move, cities breathe cleaner air, and Indian industry owns the technology stack - from power electronics and vehicle integration to software and safety standards.

This is why the OMI Foundation, in collaboration with the ITS India Forum, has authored the Futures Report, titled, Charging Ahead: Global Insights and India's Roadmap for Electric Road Systems (ERS). This report is a product of the extensive research and deliberations undertaken by the members of the Working Group on ERS constituted by the ITS India Forum. The report effectively provides a foundation for action, rooted in evidence, global benchmarking, and India's unique transport and energy realities. We believe this is not merely a question of what is technically possible. It is about what is institutionally feasible and nationally desirable. If we can connect the dots among our national infrastructure initiatives, EV ambitions, energy transition targets, and industrial vision, India can lead the world in designing, manufacturing, and operating ERS solutions at scale. We do not see ERS as one technology among many. We see it as a systems opportunity - to align transport with our grid, to reduce dependence on imported minerals, and to empower Indian industry across automotive, energy, and infrastructure sectors. It is a chance to lead. We urge policymakers, state governments, public and private operators, and technology innovators to come together and launch focused ERS pilots. Let us move from vision to execution - with the same boldness that powered our space missions, digital public infrastructure, and renewable energy leap. The time to act is now.

FOREWORD

Dr. Manish Jaiswal
Director,
National Automotive
Test Tracks (NATRAX)

India is at a transformative juncture in its pursuit of sustainable, self-reliant, and innovative transportation systems. The pressing imperatives of combating climate change, ensuring energy security, and advancing the vision of Atmanirbhar Bharat have elevated technologies like Electric Road Systems (ERS) to a central role in our National Mobility Strategy. ERS offers a groundbreaking opportunity to reimagine surface transport, particularly in high-impact sectors such as freight logistics and public transit, which are critical to in reducing emissions and optimizing energy use, hence protecting the environment.

Electric Road Systems, by enabling dynamic charging of electric vehicles in motion, address critical barriers to widespread EV adoption, including high battery costs, limited range, and operational downtime. By integrating with renewable energy sources and smart grid systems, ERS reduces reliance on imported critical minerals, used in batteries, and strengthens India's energy and technological sovereignty. This aligns seamlessly with National priorities of fostering innovation, enhancing domestic manufacturing, and building efficient, future-ready logistics networks, under controlled conditions.

Organisations like the National Automotive Test Tracks (NATRAX), under Ministry of Heavy Industries, being the largest proving ground in South Asia, can play a pivotal role in accelerating ERS adoption by providing the space for developing state-of-the-art testing infrastructure. Such initiatives would enable rigorous evaluation of ERS technologies and compatible vehicles, under specific to Indian conditions, fostering confidence among stakeholders and paving the way for scalable deployment.

As NATRAX is one of the key member in Automotive policymaker and has the best facility and technical know how for all research and development (R&D) activity concerned with Automobile and associated infrastructure, I firmly believe ERS can be a cornerstone of India's sustainable mobility ambitions, complementing initiatives like the FAME scheme, National Electric Mobility Mission, and smart city projects.

I commend the ITS India Forum and the OMI Foundation for their insightful and forward-looking report, Charging Ahead: Global Insights and India's Roadmap for Electric Road Systems (ERS). This report provides a robust foundation for stakeholders - policymakers, industry leaders, researchers, and testing agencies like NATRAX - to collaborate on pilot projects, regulatory frameworks, and technological advancements. It is imperative that we unite to translate these insights into practical, India-specific solutions that drive impactful change.

Let this report serve as a catalyst for a collaborative journey - one that harnesses ERS to build a transport ecosystem that is sustainable, efficient, and a testament to India's technological and economic resilience. I am confident that through strategic partnerships and innovative implementations, we can position India as a global leader in dynamic electric mobility.

FOREWORD

Masakazu Sakai
MD, CEO, Aisin India

Katsuhisa Yamada
VP R&D, Aisin India

Krishna Chaitanya Reddy
DGM - Advanced Technologies, Aisin India

The launch of the Electric Road Systems (ERS) report by the National Automotive Board, Ministry of Heavy Industries, at NATRAX is a landmark moment in India's journey towards sustainable mobility. ERS represents one of the most promising future mobility solutions, particularly considering India's diverse energy mix requirements and the urgent need for sustainable, low-carbon transportation systems.

At Aisin, sustainability is at the core of our vision for the future. We believe technologies such as ERS can accelerate the transition towards cleaner mobility by enabling up to 50% reduction in battery material usage, lowering dependency on high-power charging infrastructure, and reducing vehicle downtime for charging by almost 80%. Together, these benefits improve efficiency, extend vehicle utilization, and shorten the return-on-investment cycle - critical factors for sustainable adoption of electric vehicles in India.

Globally, Aisin has been proactive in advancing ERS technology, with a strong focus on the conductive type. Our first ERS demonstration was established on a dedicated test track at our Mons, Belgium facility, and we continue to collaborate with leading research institutions to integrate regional requirements into a robust, adaptable system. For India, this is the right time to leapfrog into sustainable technology adoption by building solutions that balance innovation with local relevance.

We commend the ITS Forum, OMI Foundation, Telangana Government, IIT Hyderabad, University of Lund, University of Cambridge, ASCI, NHEV, and NATRAX for their collective efforts in shaping this report. It reflects the collaborative spirit needed to build a sustainable mobility ecosystem, where government, academia, and industry come together to accelerate ERS development in India.

Aisin India is proud to contribute to this global movement and remains committed to driving sustainability through future-ready mobility solutions for India and the world.

FOREWORD

Abhijeet Sinha
National Program Director, Ease of Doing Business (EODB) & National Highways for EV (NHEV)

As India accelerates towards its vision of Viksit Bharat@2047, the vision of Common, Connected, Convenient, Congestion-free, Charged, Clean, and Cutting-edge mobility given by our Hon'ble Prime Minister is no longer a distant dream - it is becoming an urgent necessity. The urgency to mitigate climate change, secure our energy future, and advance the vision of Atmanirbhar Bharat calls for transformative mobility solutions. Among these, Electric Road Systems (ERS) represent a breakthrough with the potential to revolutionise surface transport in both freight logistics and public transit.

By enabling dynamic charging of electric vehicles while in motion, Electric Roads System (ERS) directly addresses critical adoption challenges such as high battery costs, limited range, and downtime in operations. More importantly, when integrated with renewable energy and smart grids, ERS reduces dependence on imported critical minerals, enhances energy sovereignty, and strengthens India's position as a leader in future-ready mobility solutions.

As India's premier tech piloting agency, Ease of Doing Business (EoDB) has consistently demonstrated how innovative technologies can move from concept to large-scale adoption through real-world pilots. Our initiatives, like building E-Highways under the National Highway for EV (NHEV), have shown that policy, technology, and industry can converge effectively when supported by evidence-based pilots. ERS, in this continuum, is a natural next step that can transform how freight and passenger mobility is powered across India.

The report, Charging Ahead: Global Insights and India's Roadmap for Electric Road Systems (ERS), offers timely insights and a roadmap for collaborative action across policymakers, industry leaders, and testing agencies. It lays the groundwork for pilot deployments, regulatory frameworks, and technology validation that will be crucial for scaling ERS in India.

Let this report serve as more than just a vision document; let it be a call to action. Through collective will, strategic partnerships, and technology pilots, India can position itself as a global leader in dynamic electric mobility, building a transport ecosystem that is cleaner, more efficient, and resilient for generations to come.

FOREWORD

Professor David Cebon
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India is at cross-roads in developing sustainable, self-reliant, and innovative transportation systems. Road freight is central to India's economy, carrying more than 70% of domestic goods movement. India's public transport system relies heavily on buses, especially in cities. They provide affordable mobility for millions. However, transport of goods and passengers by road with diesel vehicles are major contributors to greenhouse gas emissions, to air pollution in cities and to the national demand for imported oil.

The need to address climate change, ensure energy security, and advance the vision of Atmanirbhar Bharat has brought electrification of road freight and buses into focus within the national mobility strategy. This poses particular challenges. Heavy batteries reduce the payload capacity of trucks, cutting into logistics efficiency, while also limiting passenger numbers and the range of buses. The need for regular charging during operations creates costly delays; while supplying large amounts of electricity at depots, logistics facilities, and along highways raises major infrastructure and investment hurdles.

Electric Road Systems (ERS) have the potential to reshape surface transport, for heavy vehicles, public transit and potentially for cars: unlocking the path to lowering emissions and improving energy efficiency. By enabling vehicles to charge while in motion, ERS can ease key barriers to electrification such as high battery costs, limited range, and downtime. It also reduces reliance on large static charging systems. When integrated with renewable energy and smart grids, ERS can lessen dependence on imported oil and critical minerals while supporting national priorities of innovation, domestic manufacturing, and efficient logistics networks. ERS is potentially an important element of India's sustainable mobility strategy, complementing initiatives like the FAME scheme (for Faster Adoption and Manufacturing of Hybrid and Electric Vehicles), the National Electric Mobility Mission, and smart city projects.

Indian technology companies, research and development organisations like the National Automotive Test Tracks (NATRAX) and universities can support adoption of ERS through rigorous evaluation of the technologies under Indian conditions, providing evidence for policy makers, helping to build stakeholder confidence, and supporting wider deployment.

I commend the ITS India Forum and the OMI Foundation for their report, Charging Ahead: Global Insights and India's Roadmap for Electric Road Systems (ERS). It provides an important reference point for policymakers, industry leaders, and researchers to collaborate on pilot projects, regulatory frameworks, and technology development. Turning these insights into practical, India-specific solutions will be key to making progress.

Let this report serve as a catalyst for a collaborative journey - one that harnesses ERS to build a transport ecosystem that is sustainable, efficient, and a testament to India's technological and economic resilience. Through strategic partnerships and innovative implementations, India can become a global leader in dynamic electric mobility and decarbonizing road transportation.

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Executive Summary

1. Context and Vision

India's transportation sector urgently requires innovative, sustainable solutions to address rising emissions, dependency on fossil fuels, and increasing logistics costs. Electric Road Systems (ERS) enables electric vehicles (EVs) to charge dynamically while in motion, thereby emerging as a powerful tool to electrify road transport efficiently.

India's road freight sector, responsible for transporting over 70% of domestic freight, heavily relies on diesel, contributing significantly to national emissions and dependence on imported oil. ERS technologies promise substantial reductions in carbon intensity, operational costs, and battery sizes, potentially overcoming current limitations of stationary charging infrastructure and grid constraints. Ultimately, ERS can enhance national energy security through decentralised energy distribution, and reducing reliance on imports.

2. Why ERS Matters for India

1. **Sovereignty and Global Leadership:** Reduces reliance on imported oil, critical minerals, and large batteries, while enabling technological leapfrogging and positioning India as a global leader in next-generation electric mobility solutions.
2. **Efficient Electrification:** Minimises battery size, extends vehicle uptime, and lowers lifecycle costs for electric vehicle fleets.
3. **Energy Resilience:**
    a. Functions as a flexible load, enabling smart charging, peak shaving, and renewable energy integration.
    b. Reduces the need for large individual grid connections at logistics depots and highways.
    c. Optimises energy distribution by decreasing the number of required charging nodes for electric freight.
4. **Vehicle Efficiency:**
    a. Enables electric trucks to match diesel vehicles in payload and range.
    b. Enhances vehicle range beyond conventional battery-electric designs.
    c. Facilitates integration of simple autonomous vehicle technologies,

significantly lowering logistics costs.

5. **Infrastructure Synergies:** Aligns seamlessly with India's major infrastructure initiatives such as Bharatmala Pariyojana, PM Gati Shakti, and Smart Cities Mission.

2.1. Why ERS Stands Apart: A Comparative Snapshot

Electric Road Systems (ERS) offer a distinct advantage when compared with other leading electrification technologies - including hydrogen fuel cell vehicles (FCEVs), battery electric vehicles (with static charging), and battery swapping. The table below summarises key parameters across these technologies and highlights how dynamic charging via ERS delivers superior outcomes on cost, energy efficiency, emissions, and logistics performance.

Table 1:

Comparative Assessment of EV Power Delivery Models; ***Source:*** *Deshpande, 2025*

Criterion	Hydrogen[1] FCEV	Static Charging BEV (big battery)	Dynamic Charging BEV (small battery)	Battery Swapping
Vehicle CAPEX	Very high CAPEX due to complex fuel cell + hydrogen storage system [1, 14]	High CAPEX due to large batteries [1, 2, 7]	Lowest CAPEX due to small batteries [2, 13]	High CAPEX due to large batteries [1, 8, 15]
Vehicle OPEX	Very high OPEX - at least 3x electricity cost due to energy efficiency [3. 4, 7, 16]	Low OPEX due to low energy and maintenance costs [2, 6, 7, 16, 20]	Lowest OPEX - most efficient energy utilisation [1, 4, 5, 16]	Moderate OPEX due to extra batteries in the system and cost of battery swapping service [8, 16]
Energy Infrastructure Cost	High: Making, transporting distributing hydrogen are costly [11]	High: Electricity connections for logistics facilities is a major blocker [16]	Lowest overall cost option, Privately financeable [4, 13, 21]	Moderate: Electricity connections needed at swapping points (same as chargers) [15, 16]
Emissions Reduction	Poor: 3x the emissions of BEVs due to low energy efficiency [4, 7]	Good: Depending on grid carbon emissions factor [4, 7, 20]	Best: +10% efficiency vs. BEVs; fewer grid links ease renewables integration [4, 16]	Good: Depending on grid carbon emissions factor [7, 16]
Standards	Infrastructure standards relatively advanced [17]	Charging standards exist [8]	Industry standardisation is needed [9, 13]	Significant interoperability issues: system, comms, cooling mismatches, etc. [15]
Logistics Penalty: Weight	Logistics as per today [7, 18]	Reduced payload capacity due to battery mass [10]	Logistics as per today [2, 5]	Reduced payload capacity due to battery mass [15]
Logistics Penalty: Time	Logistics as per today [11, 12, 18]	Up to 20% additional logistics time needed for charging [12, 19]	Logistics as per today [2, 5, 9]	Logistics essentially as per today, depending on queueing [15]

Note: Reference numbers in brackets (e.g., [1, 14]) correspond to sources listed in the References section at the end of this report, where full citations and weblinks are provided for further reading.

[1] *Assumes hydrogen made by electrolysis.*

3. Research Objective

This report, ***Charging Ahead: Global Insights and India's Roadmap for Electric Road Systems (ERS)***, synthesises global learnings to inform strategic piloting and scaling of Electric Road Systems (ERS) across select corridors in India. Subsequent sections present a structured comparative analysis of ERS technologies, guiding policymakers and industry stakeholders in making informed decisions about technology suitability, implementation feasibility, and strategic investments.

4. ERS Technologies

1. **In-Road Conductive Systems:** Ground-level conductive rails providing direct electrical contact charging.
2. **Inductive (Wireless) Systems:** Road-embedded coils enabling wireless energy transfer through electromagnetic fields.
3. **Catenary Systems:** Overhead Contact Lines (OCL) delivering power through vehicle-mounted pantographs.

5. Global Insights

A comprehensive analysis of global ERS pilots - spanning Germany, France, Sweden, USA, Japan, Australia, UAE, Israel, and South Korea - highlights successful technical deployments and economic models. These global experiences underscore several critical insights:

1. **Technology Maturity:** Electric Road Systems, including ground-based conductive and wireless inductive technologies, have demonstrated operational viability, with Technology Readiness Levels (TRL) ranging from 6 to 8.
2. **Energy Efficiency:** ERS solutions deliver high energy transfer efficiency - up to 97% for conductive and around 91% for inductive systems. Unlike conventional battery-electric vehicles (BEVs), ERS allows direct power transfer to the traction motor, reducing conversion losses. This results in a 10% or more gain in overall efficiency and proportionate emissions reduction.
3. **Economic Viability:** Successful pilots have adopted Public-Private Partnership (PPP) models that combine government support with private-sector innovation. These models facilitate scalable deployments and encourage ecosystem development.
4. **Environmental Benefits:** ERS can reduce greenhouse gas emissions by 30-87% compared to diesel-based transport. Moreover, dynamic charging helps eliminate the need for oversized batteries and frequent fast charging, further cutting CO_2 emissions by 10-20% compared to current BEVs. These benefits will

approach 100% emissions reduction as the electricity grid decarbonises.

5. **Critical Mineral Efficiency & Sovereignty**: ERS technologies significantly lower reliance on critical minerals by enabling smaller, right-sized batteries. Compared to conventional EV pathways, total material demand can drop by about 35%, even after accounting for ERS infrastructure such as embedded coils and conductive rails. In France, for instance, projected cumulative mineral needs between 2030 and 2050 fall from 16,600 kilotonnes to 10,800 kilotonnes under the ERS scenario - yielding material savings of 5.7 megatonnes, including 94 kilotonnes for heavy goods vehicles (HGVs) and 5,600 kilotonnes for light vehicles (LVs).
6. **Regulatory & Institutional Alignment:** Countries with successful ERS pilots have implemented clear policy mandates, dedicated regulatory frameworks, and strong institutional coordination - all of which are essential for mainstreaming ERS into national transport and energy systems.

6. Comparative Assessment of ERS Technologies

6.1. In-Road Conductive Systems

In-road conductive systems use conductive rails embedded in the road surface to deliver mid-to-high-power charging (up to ~300 kW) for both heavy-duty and light-duty vehicles. Installation is relatively quick and non-intrusive, often limited to shallow milling of the road's top wearing layer. This enables integration during routine resurfacing, avoiding deep excavation or structural road alterations, and minimising labour requirements.

A key advantage is the modularity of the rail segments, which can be replaced in under 30 minutes without halting traffic or damaging the road - significantly lowering maintenance costs and ensuring operational continuity.

Given their adaptability to India's road geometry, vehicle diversity, and mixed-traffic conditions, in-road conductive systems are well-suited for pilot deployment, particularly along high-density freight and urban logistics corridors.

6.2. Inductive (Wireless) System

Inductive systems enable wireless energy transfer via electromagnetic fields generated by coils embedded beneath the road surface. With a visually unobtrusive profile and minimal above-ground infrastructure, this technology is particularly suited for dense urban environments, pedestrian zones, and smart-city applications. Typical energy efficiency ranges from 85% to 91%, with individual coil outputs between 50 and 90 kW.

However, several technical and regulatory challenges remain. Embedded components are difficult to access and replace, potentially increasing system downtime and lifecycle costs. Many deployments also require a high density of roadside electrical cabinets, adding to spatial and infrastructure constraints. Installation and scaling costs remain high, and critical standards - particularly those governing electromagnetic interference (EMI) - are yet to be developed. The long-term health and safety implications of exposure to strong magnetic fields for vehicle occupants also require further study.

Despite these concerns, inductive ERS holds strong potential for dynamic charging in constrained urban settings, especially for public transport, municipal fleets, and short-haul logistics, among others. Addressing the cost, maintenance, and regulatory issues will be essential to unlocking its scalability in India.

6.3. Catenary Systems

Catenary Systems are among the most mature ERS technologies globally, offering high energy efficiency (95-97%) and proven reliability for heavy-duty freight applications. They deliver continuous power via overhead cables to vehicles equipped with pantographs and have seen successful deployment in several dedicated freight corridors, especially in Europe.

While technically robust, Overhead Contact Lines (OCL) systems face notable integration challenges in the Indian context. The infrastructure demands - such as poles, cables, and clearances - may be difficult to accommodate along diverse urban and intercity road networks. Visual intrusion remains a debated issue; although often cited as a limitation, some governments are actively assessing whether it is an objective constraint or a perceived one.

Retrofitting requirements for OCL are comparable to other ERS technologies and should not be viewed as uniquely burdensome. However, broader implementation could be constrained by India's right-of-way limitations and climatic variability, which may impact infrastructure durability and uptime.

Given these considerations, OCL may have limited applicability in mixed-traffic environments or dense urban zones, but could still be considered for evaluation in dedicated highway freight corridors.

Table 2: *Comparative Assessment of ERS Technologies;* ***Source:*** *Deshpande, 2025*

Criterion	In-Road Conductive System	Inductive (Wireless) System	Catenary System (Overhead Contact Lines)
Technology Readiness	Medium (TRL 6-7) [a, 1, 3, 6, 7]	Low (TRL4-5) [a, 1, 3, 6, 7]	High (TRL 8-9) [a, 1, 3, 6, 7]
Vehicle Classes Supported	Cars, LDVs, HDVs [2]	Cars, LDVs, HDVs [3]	HDVs only [3, 8]
Energy Transfer Efficiency[2]	High (95-97%) [2, 3, 9]	Medium (85-91%) [3, 9]	High (95-97%) [3, 8]
Power Delivery	300+ kW [2, 3, 4]	50-100 kW [3]	500+ kW [3, 4]
Cost/km[3]	Lowest: ~ £1.5-2m/km [3]	Highest [3, 9]	Middle: ~ £2-3m/km [4, 8]
Infrastructure Impact: Installation	Medium (slot cut along road centerline) [3, 10]	High (cut rectangular slots or resurface road) [3, 10]	Medium (poles at 60m intervals + overhead lines) [3, 10]
Infrastructure Impact: Maintenance	Low (straightforward to replace active sections) [3]	High (cut damaged loops out of road surface) [3, 10]	Medium (contact lines accessible above road) [3, 8, 11]
Infrastructure Impact: Longevity	Unknown (long-term effects of thermal cycles) [3, 10]	Unknown (regular weak spots along road surface) [3, 10]	High (proven in long-duration tests) [3, 4, 8]
Infrastructure Impact: Visual Intrusion[4]	Low (contact strip along road centerline) [3, 10]	High (roadside boxes every 40m) [10]	Medium (overhead lines) [12]
Vehicle Retrofitting Capability/ Cost[5]	Medium [6]	Difficult (multiple pickups needed for each HGV) [5, 7]	Medium [8]

Note: Reference numbers in brackets (e.g., [2, 3, 4]) correspond to sources listed in the References section at the end of this report, where full citations and weblinks are provided for further reading.

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[2] *Pickup/ Pantograph transfer efficiency only.*

[3] *Difficult to estimate cost per km for the inductive solution as there are none for HGVs.*

[4] *Subjective: While the inductive coils may not be visible, the solution needs power boxes every 40 m unlike the conductive solutions that only need a power unit every km or two.*

[5] *Subjective: Detailed cost data is not available.*

Table 2 presents a snapshot comparison of Electric Road System (ERS) technologies as of today, highlighting their technical readiness, efficiency, cost, and infrastructure implications. While each system has strengths and trade-offs, it is important to note that these technologies are continuously evolving. With sustained R&D, pilot deployments, and global learning, their performance, costs, and adaptability will improve - offering even greater benefits for India's transport electrification journey in the coming years.

7. Indian Context and Challenges

While global benchmarks provide essential guidance, ERS deployment in India must address local complexities, including diverse road typologies, mixed-traffic conditions, extreme climatic conditions (heat, monsoons, dust), and unique energy distribution dynamics. These factors demand comprehensive localisation efforts, robust technical validations, and context-specific adaptations.

8. Strategic Recommendations for ERS Piloting in India

The following strategic framework is proposed to pilot ERS effectively within the Indian context.

1. **Technology Suitability and Agnostic Support:** All ERS technologies - including conductive ground-based, inductive wireless, and overhead systems - should be encouraged for pilot deployment across varied use cases such as urban freight corridors, intercity logistics routes, Bus Rapid Transit (BRT) systems as well as public transport in general, and other emerging mobility formats. Government support should remain technology-neutral, focused on outcomes such as cost-efficiency, operational performance, and emissions reduction. Phased pilots can help identify the most suitable technologies for India’s diverse contexts.
2. **Grid Integration & Flexibility:** ERS infrastructure can serve as a flexible grid load, modulating energy demand spatially and temporally. Thus, ERS technologies can be strategically integrated with distributed solar generation, Battery Energy Storage Systems (BESS), and smart grid architecture, thereby enhancing grid stability, supporting renewable energy absorption, and optimising peak load management.
3. **Detailed Economic and Route Analysis:** A comprehensive techno-economic analysis should be undertaken to assess ERS feasibility across potential routes. This includes capital and operational cost modelling, comparisons with conventional and battery electric vehicles, lifecycle benefits, and an evaluation of corridors where ERS yields maximum economic and environmental impact.
4. **Safety & Standards:** Establish robust protocols for safety - including

electromagnetic interference (EMI), pedestrian and cyclist interaction, and cyber-physical system security.

5. **Institutional Collaboration Models:** Formulate Public-Private Partnerships (PPPs) and Special Purpose Vehicles (SPVs) bringing together central and state governments, private ERS technology providers, utilities, regulators, and academic institutions. These institutional frameworks can accelerate technology development, pilot execution, and long-term scaling. Specialised national institutions such as NATRAX (under the Ministry of Heavy Industries) can play a critical role in testing, validating, and standardising ERS technologies by offering controlled environments for pilot-scale demonstrations and vehicle - infrastructure integration.
6. **User-Centric and Operational Assessments:** Invest in primary studies to evaluate real-world fleet performance, driver experience, operational improvements, and maintenance efficiencies. These insights are essential for tailoring ERS strategies to India's complex transport and logistics ecosystems.

9. Accelerating ERS Adoption in India

To rapidly advance Electric Road Systems (ERS), collaboration among policymakers, industry stakeholders, and academic institutions is essential. Immediate actions should include:

1. **Dedicated Funding Streams:** Leverage existing R&D allocations from the Science & Technology Ministry to support pilot-scale ERS projects.
2. **Pilot Implementation Support:** Select strategic corridors, such as key urban routes, PM Gati Shakti logistics hubs, and Bharatmala Pariyojana expressways, etc., for targeted ERS deployments. NATRAX's high-speed test tracks and vehicle certification facilities can also serve as initial ERS testbeds, enabling rigorous, low-risk evaluation of system performance before full-scale deployment.
3. **Regulatory Frameworks:** Fast-track clear regulatory and approval pathways tailored specifically to ERS, addressing land acquisition, grid integration, and operational permits.

Integrating ERS into India's active infrastructure development will swiftly transform the country from technology importer to strategic innovator, securing leadership in sustainable and economically competitive transport electrification.

Introduction

01

1. Introduction

As countries worldwide accelerate their transition to clean mobility, Electric Road Systems (ERS) are emerging as an innovative solution to address some of the limitations of conventional battery electric vehicles (BEVs). ERS are commonly referred to as eRoads, eHighways, or Charge-as-You-Drive infrastructure. By enabling electric vehicles to charge dynamically while in motion, ERS reduces dependence on large battery capacities, minimises vehicle downtime due to charging, and optimises energy use over long distances.

1.1. ERS in the Broader Electrification Landscape: A Strategic Comparison

India's transition to zero-emission mobility is progressing along **multiple technology pathways**. Each pathway offers unique advantages and poses distinct challenges across cost structures, energy efficiency, emissions reduction, infrastructure needs, and operational feasibility. These include:

1. Hydrogen Fuel Cell Electric Vehicles (FCEVs),
2. Battery Electric Vehicles (BEVs) using static charging,
3. BEVs with dynamic charging through Electric Road Systems (ERS), and
4. Battery swapping models.

All four approaches are undergoing active exploration, and each holds relevance for specific use cases, vehicle segments, and geographies. However, for India's cost-sensitive, high-utilisation ecosystem - where uptime, grid capacity, and total cost of ownership are key considerations - some technologies offer more near-term alignment than others.

To support a strategic policy and industry response, the comparative matrix in *Table 1* presents a snapshot of how these technologies perform against key criteria

Among these, **dynamic charging through ERS presents a compelling blend of benefits**. It offers high energy efficiency, lower vehicle and infrastructure costs over the long term, and limited disruption to operations. ERS also mitigates the need for oversized batteries and helps reduce dependence on imported critical minerals - strengthening India's pathway to energy and technology sovereignty.

Table 1: *Comparative Assessment of EV Power Delivery Models;* ***Source:*** *Deshpande, 2025*

Criterion	Hydrogen[6] FCEV	Static Charging BEV (big battery)	Dynamic Charging BEV (small battery)	Battery Swapping
Vehicle CAPEX	Very high CAPEX due to complex fuel cell + hydrogen storage system [1, 14]	High CAPEX due to large batteries [1, 2, 7]	Lowest CAPEX due to small batteries [2, 13]	High CAPEX due to large batteries [1, 8, 15]
Vehicle OPEX	Very high OPEX - at least 3x electricity cost due to energy efficiency [3. 4, 7, 16]	Low OPEX due to low energy and maintenance costs [2, 6, 7, 16, 20]	Lowest OPEX - most efficient energy utilisation [1, 4, 5, 16]	Moderate OPEX due to extra batteries in the system and cost of battery swapping service [8, 16]
Energy Infrastructure Cost	High: Making, transporting distributing hydrogen are costly [11]	High: Electricity connections for logistics facilities is a major blocker [16]	Lowest overall cost option, Privately financeable [4, 13, 21]	Moderate: Electricity connections needed at swapping points (same as chargers) [15, 16]
Emissions Reduction	Poor: 3x the emissions of BEVs due to low energy efficiency [4, 7]	Good: Depending on grid carbon emissions factor [4, 7, 20]	Best: +10% efficiency vs. BEVs; fewer grid links ease renewables integration [4, 16]	Good: Depending on grid carbon emissions factor [7, 16]
Standards	Infrastructure standards relatively advanced [17]	Charging standards exist [8]	Industry standardisation is needed [9, 13]	Significant interoperability issues: system, comms, cooling mismatches, etc. [15]
Logistics Penalty: Weight	Logistics as per today [7, 18]	Reduced payload capacity due to battery mass [10]	Logistics as per today [2, 5]	Reduced payload capacity due to battery mass [15]
Logistics Penalty: Time	Logistics as per today [11, 12, 18]	Up to 20% additional logistics time needed for charging [12, 19]	Logistics as per today [2, 5, 9]	Logistics essentially as per today, depending on queueing [15]

Note: Reference numbers in brackets (e.g., [1, 14]) correspond to sources listed in the References section at the end of this report, where full citations and weblinks are provided for further reading.

[6] Assumes hydrogen made by electrolysis

As India charts its course toward inclusive and self-reliant freight decarbonisation, well-designed ERS pilots can play a catalytic role. They offer an opportunity to test real-world performance, inform cost-benefit assessments, and align investments with national infrastructure, energy, and industrial policy goals.

1.2. Objective and Scope of Research

This Futures Report assesses the feasibility of ERS in India. It examines a selection of global ERS pilot projects to extract practical insights and lessons learned. Through a structured comparative lens, the analysis captures the design, implementation strategies, technical challenges, policy frameworks, and operational outcomes of these projects. The selected pilots span geographies and technology types, offering a rich diversity of approaches, from conductive rail and inductive wireless systems embedded in urban roads to overhead conductive systems deployed on freight corridors.

The analysis specifically focuses on the following dimensions.

1. Technical Feasibility

The analysis evaluates the engineering and infrastructural foundations of each project. This includes the type of ERS technology deployed - be it conductive rail embedded in road surfaces, inductive wireless charging pads, or overhead contact lines (OCL). Further, it reviews aspects such as vehicle compatibility (retrofitting vs. purpose-built vehicles), charging efficiency, grid integration, and interoperability with existing road and transport systems. The Technology Readiness Level (TRL) of each solution is also assessed to determine maturity and scalability.

2. Economic Viability

Cost-effectiveness remains a pivotal criterion for ERS adoption. The projects are analysed for their capital expenditure (construction, technology deployment), operational and maintenance costs, and associated revenue models (e.g., electricity sales, tolling systems, public-private funding mechanisms). Special attention is given to business models that ensure sustainability beyond the pilot phase and reduce dependence on public subsidies.

3. Environmental Impact

ERS presents a unique opportunity to decarbonise freight and long-distance travel. The review explores each project's contribution to emissions reduction, energy efficiency, and modal shift potential. It also addresses concerns around energy losses, construction-related environmental impacts, and the lifecycle emissions of embedded components. Projects that demonstrate measurable carbon savings and successful environmental audits are highlighted.

4. Pilot Project Exploration

Drawing from international case studies, the analysis identifies criteria for selecting a potential pilot corridor in India. Factors considered include traffic density, vehicle mix, logistical connectivity, availability of renewable energy, and regional industrial readiness. Comparative insights are used to inform corridor typologies most suitable for Indian conditions, such as urban freight routes, inter-city highways, industrial logistics zones, or intra-city roads.

5. Institutional and Regulatory Frameworks

Effective ERS deployment requires strong multi-stakeholder collaboration. Each pilot is studied for the institutional mechanisms and partnerships that supported implementation, including roles played by government ministries, utilities, automotive OEMs, research institutions, and private infrastructure firms. Particular emphasis is placed on models where stakeholder alignment led to successful regulatory clearances, funding approvals, and public buy-in.

This report, ***Charging Ahead: Global Insights and India's Roadmap for Electric Road Systems (ERS)***, synthesises global experiences from these initiatives. It will inform not only technical recommendations but also strategic decisions around regulatory design, investment planning, and pilot execution for India's potential ERS journey.

Methodology

02

2. Methodology

This report employs a structured, multi-method research design that integrates global evidence, expert insights, and a comparative analytical framework to assess the feasibility and strategic relevance of Electric Road Systems (ERS) for India. The methodology rests on two pillars: (1) extensive desk research on global ERS pilots, and (2) in-depth interviews with practitioners, innovators, and policy experts from India and abroad.

2.1. Research Design and Theoretical Foundations

The research design is grounded in a comparative, multi-dimensional framework informed by transition studies, infrastructure governance, and technology assessment. We adopted the **Technology-Policy-Market (TPM) triangle** (Hekkert et al., 2007) to conceptualise ERS not just as a technical intervention, but as part of a broader socio-technical system. This framework enables the identification of alignment (or misalignment) among technological maturity, policy support, and market dynamics - crucial for guiding successful pilot deployment in India.

To evaluate the maturity and scalability of ERS technologies, we incorporated **Technology Readiness Levels (TRLs)**, a tool widely used by NASA and later adapted by the European Commission for energy technologies (Mankins, 1995; European Commission, 2009). This allowed us to compare ERS variants on a spectrum from laboratory validation to real-world deployment readiness.

The study also draws on **principles from responsible innovation and infrastructure transitions theory** (Stirling, 2008; Loorbach et al., 2017), emphasising that technological adoption must be context-sensitive, inclusive, and adaptable to long-term systemic change. These theories highlight the importance of social legitimacy, governance structures, and institutional alignment when designing pilots for public infrastructure systems like ERS.

Additionally, to ensure practical feasibility, our framework integrates elements from **public-private partnership (PPP) analysis and lifecycle cost assessment (LCCA) methods** (Yescombe, 2007; Delmon, 2015), commonly applied in infrastructure finance and transport policy. These methodologies help unpack the investment risks, cost distribution, and value-for-money metrics necessary for large-scale ERS adoption.

Overall, this research design brings together technical assessment, socio-institutional mapping, and market feasibility analysis to present a well-rounded evaluation of ERS technologies for India's clean mobility transition.

2.2. Desk Research and Global Case Analysis

We conducted detailed desk research on ten ERS pilot projects across Europe, Asia, North America, and the Middle East. Primary data sources included peer-reviewed publications, technical white papers, project documentation, policy reports, and regulatory filings. Secondary sources included industry databases, news media, and public presentations from key stakeholders involved in ERS development.

Each project was analysed across six core dimensions:

1. Technical feasibility (TRL, vehicle compatibility, grid integration)
2. Economic viability (CAPEX/OPEX, cost-benefit analysis)
3. Environmental impact (emissions impact, energy efficiency)
4. Pilot project exploration
    a. Use-case relevance (urban vs. highway settings, mixed traffic)
    b. Operational reliability and user adoption (uptime, throughput, safety)
5. Institutional and regulatory frameworks (policy, permitting, PPP models)

These dimensions formed the basis of a cross-pilot comparative matrix, enabling us to evaluate the performance, maturity, and contextual applicability of three leading ERS technologies: in-road conductive systems, inductive (wireless) systems, and overhead catenary systems.

2.3. Expert Consultations and Practitioner Insights

To complement desk research and contextualise global learnings, we conducted semi-structured interviews with over 15 stakeholders. These included:

1. ERS technology providers and OEMs
2. Indian public infrastructure experts
3. Government advisors and policy experts on energy, transport, and innovation
4. Global ERS researchers from India, the UK, and others
5. Urban planners and logistics operators in India

These interviews helped validate our analytical assumptions, surface real-world deployment challenges, and identify promising corridors and use cases for India.

2.4. Development of the Analytical Framework

The framework of analysis evolved iteratively based on literature review, pilot evaluations, and expert feedback. Unlike traditional cost-benefit-only models, our framework is multidimensional, balancing:

1. Performance criteria (energy transfer efficiency, interoperability)
2. Scalability metrics (retrofitting ease, capex per km, pilot-to-scale pathway)
3. Contextual relevance (traffic density, mixed-use compatibility, climatic durability)
4. Governance feasibility (institutional ownership, PPP structures, stakeholder alignment)

This framework allowed us to differentiate between technologies not only by technical parameters but also by their fit within India's infrastructure typologies, governance systems, and policy trajectories.

2.5. Application to Indian Context

All global insights were filtered through a localisation lens. India's transport and energy systems differ markedly from Europe's structured highways or East Asia's smart city zones. Our methodology emphasised "glocalisation" - adapting global ERS strategies to India's climate, road design, vehicle mix, and renewable energy potential.

We identified potential Indian corridors based on secondary datasets (freight flow maps, Smart Cities mission plans, PM Gati Shakti zones), and mapped them against suitability factors such as:

1. Road ownership and governance models
2. Urban vs. inter-city vehicle composition
3. Renewable energy capacity and grid readiness
4. Land acquisition and regulatory complexity

This contextual tailoring is key to ensuring ERS pilots are not just technically demonstrable but also institutionally viable and socioeconomically scalable.

ERS Pilot Projects: Global Scan

3. ERS Pilot Projects: Global Scan

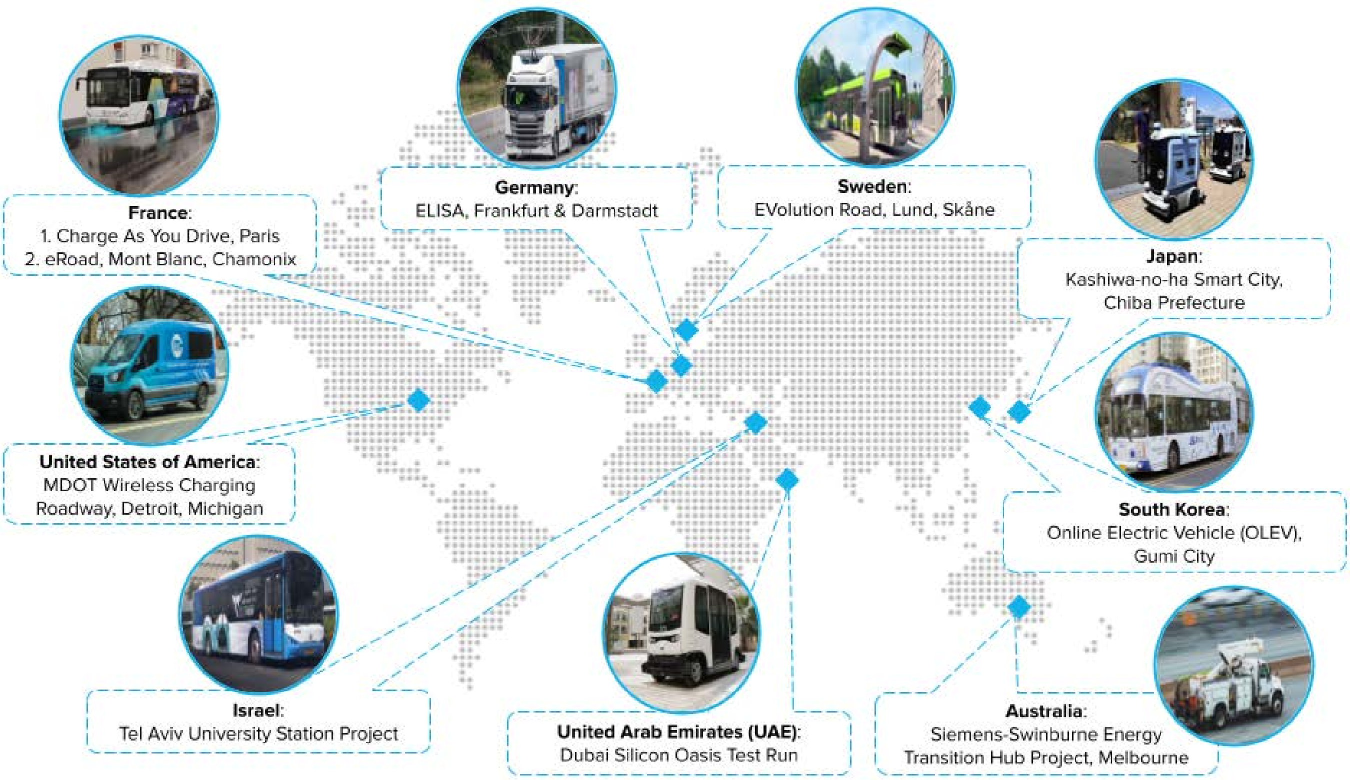
This study draws upon a diverse set of ERS pilot projects from around the world, each representing a unique approach to dynamic electric charging infrastructure:

1. **Charge-as-You-Drive (CAYD) - France:** Implemented approximately 40-50 kilometres southwest of central Paris along the A10 Motorway in the Essonne region, this project evaluates the feasibility of long distance highway electrification for electric vehicles. It serves as a comparative testbed for two technologies: dynamic inductive wireless charging (already deployed on a 1.5 km stretch) and ground-based conductive rail charging (currently under testing at a closed site and scheduled for highway deployment in 2026).
2. **EVolution Road - Sweden:** Situated in Lund, Skåne, this pilot deploys a conductive ground-based system embedded in public roads to test dynamic charging for buses and light commercial vehicles.
3. **eRoad Mont Blanc - France:** Developed along the RN 205 highway near Chamonix at the base of Mont Blanc, this initiative explores ERS application for heavy goods transport in mountainous terrain. The project specifically tests ground-based conductive systems.
4. **Wireless Charging Roadway - United States of America (USA):** Located in Detroit, Michigan, adjacent to the historic Michigan Central Station, this inductive charging pilot is a collaboration between MDOT and wireless ERS developers, aiming to revitalise urban mobility infrastructure.
5. **Kashiwa-no-ha Smart City - Japan:** Part of a smart city initiative in Kashiwa-no-ha, Chiba Prefecture, this project integrates ERS within a broader sustainable urban mobility ecosystem.
6. **Siemens-Swinburne Energy Transition Hub Project - Australia:** Conducted in Melbourne, this research-focused initiative explores ERS applications through simulation and laboratory testing, providing a theoretical foundation for deployment in Australia's freight corridors.
7. **Dubai Silicon Oasis Test Run - United Arab Emirates (UAE):** This pilot tests wireless ERS technology in controlled urban environments as part of Dubai's vision for smart, electric mobility.
8. **Tel Aviv University Station Project - Israel:** This live demonstration runs between Tel Aviv University Station and Klatzkin Bus Terminal in Ramat Aviv, showcasing wireless in-road charging for electric buses.

9. **Online Electric Vehicle (OLEV) - South Korea:** One of the earliest ERS demonstrations, this project operates in Gumi City, using inductive power transfer from road-embedded coils to public buses.
10. **ELISA - Germany:** Located along the A5 Autobahn between Frankfurt and Darmstadt, this project is Germany's flagship ERS pilot, deploying overhead contact lines (OCL) for hybrid freight trucks.

The pilots span diverse geographies and ERS technologies, from urban to intercity settings. This variety offers key insights for assessing India's feasibility.

Figure 1: *Global Distribution of Selected ERS Pilot Projects*



Note: Map not to scale.

Technical Feasibility

04

4. Technical Feasibility & Operational Analytics

4.1. Technical Feasibility

The technical feasibility of ERS hinges on a nuanced interplay of **infrastructure deployment, technology maturity, vehicle compatibility, and integration with existing transportation systems**. A comparative analysis of global ERS pilot projects reveals diverse approaches in terms of technology types, deployment scale, and operational readiness, offering valuable lessons for future implementation.

4.1.1. Technology Types

ERS projects can be broadly categorised into three types: in-road conductive, inductive systems, and overhead conductive each with distinct technology readiness levels, power capabilities, and vehicle compatibility.

1. **In-road conductive systems**, such as Sweden's EVolution Road, and France's eRoad MontBlanc, and the Charge As You Drive (CAYD) project, feature conductive rails or segmented elements embedded in the road surface. Power is transferred to the vehicle through a physical connector, or "pick-up," mounted underneath. These systems are designed for compatibility with a wide range of vehicles, from passenger cars to heavy-duty vehicles (HDVs), and support both dynamic and static charging. Several configurations exist, including parallel rails and alternating live segments. In-road conductive ERS can currently deliver up to 300 kW (150 kW for direct propulsion and 150 kW for battery charging), enabling high-performance charging and significant reductions in on-board battery size.
2. **Inductive (wireless) systems**, such as those tested in Detroit, USA, and parts of the CAYD project in France, use coils buried beneath the road to transmit energy via electromagnetic fields. While wireless systems offer visual advantages, they face notable technical limitations. Power losses due to heat reduce overall efficiency, and alignment between the vehicle and road coils must be precise. Currently, individual inductive coils can provide only about 50 kW, meaning vehicles must span multiple coils, typically six or more, to achieve the power levels needed for heavy-duty use.

3. **Overhead catenary systems**, such as those deployed in Germany's ELISA project, utilise catenary lines and pantograph-equipped trucks to draw electricity while in motion. Adapted from railway and tram technologies, these systems are technologically mature and can reliably deliver high power, making them well-suited for heavy-duty vehicles (HDVs). However, their infrastructure is limited to taller vehicles and is not compatible with light-duty vehicles (LDVs) or passenger cars.

4.1.2. Electric Road Systems (ERS): Static, Dynamic, and Hybrid Modes

ERS can support both static (charging while stationary) and dynamic (charging while in motion) applications, regardless of whether the underlying technology is inductive (wireless) or conductive (via physical contact).

1. **Dynamic conductive systems**, such as Elonroad's technology, and **dynamic inductive systems**, as tested in Tel Aviv and Detroit, both enable vehicles to charge while moving, helping reduce battery size requirements and downtime.
2. Several pilots, including those in Dubai and Israel, demonstrate **hybrid applications that combine static and dynamic charging** to improve operational flexibility, especially in urban environments.
3. Even **static deployments**, such as those at bus stops, intersections, or logistics hubs, can benefit from ERS integration when designed to complement dynamic segments, optimising total cost of ownership (TCO) across local, regional, or national networks.

4.1.3. Deployment Lengths

Some projects involve **short test tracks**, such as those in Dubai or Detroit, designed primarily for technology validation in controlled environments. Others extend to **more advanced demonstrations**, including France, with 1.5 km of inductive and 2 km of conductive ERS, and Germany, where three highway sections collectively span 17 km.

4.1.4. Road Types

ERS technologies have been tested across varied road conditions:

1. **Highways:** Germany (ELISA), France (CAYD), and Australia (Swinburne Hub)
2. **Urban and mixed-use roads:** Sweden (EVolution Road), Japan (Kashiwa), and South Korea (OLEV)
3. **Mountain terrain:** France (eRoad MontBlanc)
4. **Dedicated public transport routes:** Israel and South Korea

4.1.5. Vehicle Compatibility and Use-Case Suitability

1. **Ground-based conductive systems** can support a broad range of vehicles, from light-duty vehicles (LDVs) to HDVs, and are well-suited for both static and dynamic charging. These systems are also designed for retrofit compatibility, often with a lower cost and material footprint than inductive alternatives. Moreover, preliminary findings suggest they may be cheaper and quicker to install and maintain than overhead catenary systems.
2. **Inductive (Wireless) ERS** has been successfully demonstrated with light vehicles like electric vans and buses (e.g., in Tel Aviv, Detroit). Current limitations in power delivery make it less suitable for heavier vehicles such as long-haul trucks. Inductive systems also allow retrofitting, but typically with higher cost and complexity.
3. **Catenary systems**, which rely on **overhead conductive lines and pantographs**, are primarily limited to heavy-duty vehicles (HDVs) like trucks due to height and clearance requirements. These systems have already been widely adopted in railway applications, including in India, and are considered highly reliable in diverse operating conditions such as high temperatures and exposure to elements like salt water.

4.1.6. Standards and Interoperability

1. Europe is actively advancing **interoperability through standardisation** efforts for both conductive and inductive systems (e.g., IEC 61980 series for WPT, ISO 5474 for inductive EV charging).
2. Projects led by Electreon, Elonroad, Siemens, and Alstom contribute to **industry-wide standardisation**, while others like South Korea's OLEV remain **proprietary** and incompatible with global standards.

4.1.7. Technology Readiness Levels (TRL)

1. Most projects are at **TRL 6-7**, indicating demonstration in relevant or operational environments, with some reaching **TRL 8 (partial commercial readiness)**.
2. Electreon's pilots in Israel and the US have achieved TRL 7-8 for low-speed projects and some specific vehicles.
3. Germany's ELISA and Sweden's EVolution Road have demonstrated TRL 7 maturity
4. Japan's Smart City testbed remains at TRL 4, focused on design and simulation

4.1.8. Ownership and Intellectual Property

ERS innovation is being driven by a dynamic mix of startups and established corporations. As global pilot deployments expand, a growing number of players are developing and securing patents for core ERS technologies - such as in-road coils, conductive rail systems, vehicle retrofit kits, and smart interfaces. The IP landscape continues to evolve rapidly, reflecting the sector's commercial momentum. Select players include:

1. Alstom: Ground-level APS (Alimentation Par le Sol) systems for trams and buses
2. Electra: French ERS consortium partner collaborating with VINCI and Electreon on technology integration and rollout
3. Electreon: Inductive in-road coils and retrofit kits; a leading innovator in dynamic wireless charging
4. Elonroad: Rail-based ground conductive systems and retrofit kits
5. Siemens: Overhead conductive systems for freight; IP drawn from railway electrification
6. VINCI: Infrastructure development and deployment partner for inductive ERS pilots in France
7. WiPowerOne: Developer of SMFIR (Shaped Magnetic Field in Resonance) systems, active in Dubai and South Korea, with patents in multiple jurisdictions

4.2. Operational Performance

4.2.1. Energy Transfer Efficiency

1. **Varied** across the studied ERS pilots, ranging from over **80%** for the ELISA project in Germany to as high as **97%** for the conductive Elonroad and Alstom APS systems in Sweden and France, respectively.
2. Electreon's inductive technology reported around 91% efficiency in France and approximately 85-90% in its Detroit project, with Dubai's Silicon Oasis claiming up to 90±2%.
3. **Conductive ERS systems have demonstrated higher efficiency levels** due to their ability to power vehicles directly, bypassing the energy losses associated with battery charging and discharging. This direct power transfer avoids losses caused by internal battery resistance and results in an estimated 10% gain in overall energy efficiency compared to systems that route energy through the battery.
4. However, several pilots did not publicly disclose efficiency metrics, highlighting the need for more transparent reporting standards.

4.2.2. System Reliability and Uptime

1. While specific figures are absent for most pilots, the Detroit pilot did offer **partial metrics**, recording a total operational time of 38.1 hours over 11 days, with a system downtime of 7.43 hours and 101.5 kWh wirelessly charged across 202 miles.
2. Other pilots only disclosed limited or no information on reliability. Similarly, data on daily operational hours, vehicle utilisation rates, maintenance frequency, and downtime due to failures or planned maintenance remain largely undisclosed or anecdotal across pilots.
3. The ELISA project stands out slightly, reporting a 2.5% annual investment earmarked for system maintenance.

4.2.3. Utilisation

1. The ELISA project in Germany reported **regular operation** with five heavy-duty trucks, each completing seven trips daily, offering valuable insights into commercial-scale logistics electrification.
2. The CAYD project in France, which tests both inductive and ground-based conductive systems, includes **projections for significantly higher daily vehicle throughput**. The projections suggest a daily operation of beyond 200 vehicles per day, in its future deployment plans. However, these figures refer to anticipated use in full-scale implementation and not the current pilot phase.
3. Most other global pilots, such as those in Dubai, Tel Aviv, and Detroit, remain at limited scales or have not published detailed usage data, making comparative assessments of vehicle throughput difficult at this stage.

4.2.4. Environmental Benefits

1. **CO_2 emission reductions ranged from 8.8-22.1%** for ELISA (when operating at full capacity with 365 trucks) to a **projected 87% reduction** from road freight for the CAYD project in France.
2. The CAYD project conducted an independent comparative study, which found that **ERS can reduce total CO_2 emissions by approximately 30%** compared to conventional battery electric vehicles (BEVs), due to smaller battery sizes and more efficient energy usage. In France, where the grid is relatively low-carbon, the Carbone 4 study within CAYD estimated an additional 10 to 20 percent CO_2 savings over BEVs. These savings are attributed to lighter vehicles, smaller batteries, and the elimination of fast charging. The study also compared inductive and ground-based conductive technologies, identifying further

environmental advantages, with conductive ERS performing better than inductive systems on these metrics.

3. Elonroad's Swedish pilot claimed a **potential reduction** of **1.53 million tonnes of CO_2 annually by 2026** and a long-term reduction of up to **7.66 million tonnes by 2050**.
4. The eRoad MontBlanc project also reported lifecycle emissions reductions compared to other technologies, though without specific numerical disclosure.
5. Finally, while most pilots have not publicly released detailed findings on reductions in particulate matter (PM), nitrogen oxides (NOx), or noise pollution, general expectations across inductive dynamic charging projects point to substantial benefits. These include reductions in PM and NOx due to fewer combustion engine vehicles and less brake/tire wear, and lower noise pollution from electrified drivetrains, especially in urban contexts with frequent stops and dense pedestrian movement. However, robust empirical data on these secondary benefits remains limited and should be prioritised in future reporting.

4.2.5. Scalability and Replicability

1. Electric Road Systems (ERS) demonstrate strong potential for modular, phased deployment across diverse geographies and vehicle fleets. Projects such as Germany's ELISA and France's CAYD have adopted modular infrastructure approaches, with ELISA expanding from an initial 5 km pilot to 12 km, and France planning ERS deployment over 5,000 km by 2030. Technologies like Electreon and Elonroad feature prefabricated or embedded modules that enable incremental installation with minimal disruption, making them suitable for integration into existing roads and scalable across urban and intercity corridors. Many systems also support both dynamic and static charging, enhancing flexibility.
2. Installation speed and infrastructure requirements significantly influence ERS deployment costs and scalability. In the CAYD project in France, VINCI installed 912 inductive coils over a 1.5 km stretch using 38 Electric Management Units (EMUs) and a team of 10 workers, completing 150 meters per day. By comparison, conductive ERS systems have shown up to 10 times faster installation speeds, 7 times less road milling volume, and up to 40 times fewer roadside power cabinets, significantly reducing disruption and infrastructure burden.
3. Fleet compatibility varies, while projects like CAYD and Electreon support a wide range of vehicle types, others like WiPowerOne remain proprietary and require specific retrofitting.
4. Climatic adaptability remains underreported, though pilots in Dubai and eRoad

MontBlanc indicate performance in extreme heat and mountainous terrain respectively.

5. Regulatory adaptability is an emerging focus, with few projects actively engaging in international standardisation efforts. The ability to retrofit existing infrastructure, minimise land requirements, and align with fleet electrification goals enhances the replicability of ERS in varying Indian contexts.

4.3. Sovereignty

4.3.1. Reliance on Critical Minerals

By enabling smaller battery sizes and reducing the need for high-capacity fast charging, ERS systems significantly lower the demand for critical raw materials such as lithium, nickel, cobalt, graphite, and copper. These materials form the backbone of conventional EV battery packs and charging infrastructure. Some projections estimate that ERS can reduce the overall requirement for these materials by approximately 35% compared to standard battery-electric vehicle (BEV) pathways.

For example, in France, the total critical metal requirement for powering the national electric vehicle fleet and associated infrastructure between 2030 and 2050 is estimated at 16,600 kilotonnes under a conventional BEV scenario. With ERS deployment, this figure drops to 10,800 kilotonnes, resulting in a material savings of 5.7 megatonnes. This includes 94 kilotonnes saved in the heavy goods vehicle (HGV) segment and 5,600 kilotonnes in the light vehicle (LV) segment. These savings not only ease supply chain pressures and reduce import dependence but also contribute to making EV adoption more sustainable and geopolitically secure.

4.4. Social Acceptance and Impact

The successful implementation of ERS technologies hinges not only on technical feasibility and economic viability but also on the willingness of communities, drivers, operators, and local institutions to adopt and support such infrastructure. Social acceptance becomes especially critical when infrastructure is integrated into public spaces or road networks, potentially disrupting existing traffic patterns, local businesses, or community landscapes. In this context, deliberate and well-planned community engagement efforts can act as enablers of trust, transparency, and smoother project execution.

4.4.1. Community Engagement

The EVolution Road project in Lund, Sweden, established a dedicated visitor center near the test site on Getingevägen, offering members of the public the opportunity to learn about the project every Thursday, with advance registration. It served as a key platform to raise awareness, foster transparency, and invite local participation in the ERS demonstration.

Similarly, the ELISA project in Germany implemented public outreach campaigns and developed a visitor centre near the pilot track. These efforts were designed to inform and engage nearby communities, supporting greater acceptance and public trust in the emerging technology.

Economic Viability

5. Economic Viability and Implementation Strategies

5.1. Economic Viability Analysis

The economic transparency of ERS projects remains limited, particularly around long-term operational viability.

5.1.1. Capital Expenditure (CAPEX)

1. Germany's ELISA reported €2.2 million per kilometre (approximately USD 2.37 million or ₹198 crore) for infrastructure and €50,000 per vehicle retrofit (approximately USD 54,000 or ₹45 lakh), expected to fall to €19,000 (approximately USD 20,500 or ₹17 lakh) by 2050.
2. Sweden's Elonroad pilot required €9.3 million (approximately USD 10 million or ₹83.5 crore), while France's APS system investment exceeded €20 million (approximately USD 21.6 million or ₹180 crore).
3. The Michigan pilot cost approximately USD 5.9 million (about €5.46 million or ₹49 crore), and Australia's trial required A$8.2 million (approximately USD 5.4 million or ₹45 crore) with a government grant of A$3 million (approximately USD 2 million or ₹17 crore).
4. It is also important to account for offsetting benefits as ERS deployment can reduce battery size by at least 50%, substantially lowering vehicle capital costs over time.

5.1.2. Operational Expenditure (OPEX)

OPEX, including energy costs, system maintenance, and administrative overheads, has not been publicly disclosed for any pilot.

5.1.3. LCCA/ CBA Estimates

Not many countries have released a Lifecycle Cost Analysis (LCCA) detailing the total cost of ownership per kilometre, vehicle type, or charging modality. Only Australia has tentatively outlined a broader cost-benefit (CBA) estimate, suggesting potential national savings of A$324 billion (approximately USD 212 billion or ₹17.7 lakh crore) by 2050 from improvements in safety and transport efficiency due to smart road electrification. France stands out with a study published in 2021 that included LCCA components, offering one of the earliest attempts to model the long-term economics of ERS deployment. The CAYD project is currently expanding on this work through updated analyses conducted in collaboration with independent economists from the French government.

Nonetheless, no pilot has yet presented a comprehensive economic evaluation including externalities such as reductions in carbon emissions, public health improvements, or traffic congestion mitigation. As these pilots transition from demonstration to scale, detailed public economic analyses will be critical for informed policy decisions and market replication. While international benchmarks often cite high grid connection costs as a major CAPEX driver, India's regulated grid connection charges may reduce this significantly. Conversely, land acquisition could pose a higher cost in India. Unlike in Europe, where public road authorities often own adjacent land for ERS components (poles, substations), Indian highways are frequently flanked by private land, necessitating a separate cost evaluation for land access and acquisition.

5.2. Implementation and Funding Mechanisms

5.2.1. PPP Models

ERS pilots across the globe have largely adopted **Public-Private Partnership (PPP) models**, leveraging the strengths of government funding and private sector innovation.

1. Countries such as Germany, France, Sweden, and the United States have structured their pilots with **direct support from national or regional governments**, often under targeted green mobility or infrastructure investment programs.
2. In Japan and Australia, the ERS pilots have received **government backing in collaboration with private industry leaders** such as Mitsui Fudosan.
3. South Korea's deployment adds an **academic dimension**, showcasing a Public-Academic-Private Partnership led by the Ministry of Science and ICT.

While the PPP model dominates, the exact structure varies: some follow **competitive bidding processes** (e.g., Michigan's pilot awarded via an RFP), while others are based on **consortium agreements or direct assignments**, particularly when innovation leadership or regional economic development is a goal.

5.2.2. Reliant on Government Grants

In terms of funding mechanisms, nearly all pilots rely on **government grants and public investment banks**, often supplemented by **industry co-financing**.

1. Germany's ELISA project, for instance, utilised the "Erneuerbar mobil" programme, while France's pilots are funded through Bpifrance under the France 2030 and France Relance plans.
2. Sweden's Elonroad pilot saw significant investment from Trafikverket, with additional contributions from a private consortium.
3. The US and Australian pilots also demonstrate mixed funding, with specific allocations by state or federal governments and co-investment by private ERS providers such as Electreon.
4. South Korea's pilot is primarily government-funded, with support from national R&D agencies.

5.2.3. Non-commercial Deployments

Despite the promising deployment models, most pilots remain non-commercial demonstrations. The business models are evolving, with some pilots experimenting with Charging-as-a-Service (CaaS) frameworks based on usage-based fees, though explicit tariff structures, toll models, or subscription schemes remain undisclosed or under development. Public transit and municipal use cases have typically not involved fare-based monetisation, focusing instead on technical validation. Revenue frameworks for eventual scaling are still speculative, dependent on technology maturity, regulatory clarity, and adoption readiness.

Policy Framework

6. Policy, Regulatory and Institutional Framework

The global landscape for ERS is gradually evolving, marked by a growing number of **supportive policy frameworks**, emerging **regulatory clarity**, and varied levels of **institutional involvement** across countries. Several leading nations and regional blocs have begun **integrating ERS into their strategic roadmaps for transport electrification**, although gaps remain in legal frameworks, liability provisions, and insurance protocols.

6.1. National and Regional Policies

1. Europe leads in establishing **policy direction for ERS**. The CollERS Project (Sweden, Germany, France) has played a pivotal role in identifying regulatory and standardisation gaps, while national-level strategies like Sweden's 2017 Roadmap for ERS and France's 2030 Plan provide targeted funding and strategic backing. The European Commission's AFIR proposal also includes ERS definitions and mandates, positioning the EU as a frontrunner in cross-border ERS infrastructure standardisation.
2. In the US, Michigan stands out with its MI Future Mobility Plan and a **dedicated public-private partnership** between MDOT and Electreon, signalling serious policy-level support.
3. Japan's pilot in Kashiwa-no-ha benefits from **ministerial oversight**, while Australia's National EV Strategy (2023) and funding under the CRC-P scheme point to early-stage but **positive governmental receptivity** toward ERS.
4. Other countries like the UAE and Israel have **embedded transport electrification into broader clean energy or public transport strategies**, but without ERS-specific policies yet. Korea's ERS trials are aligned with its longstanding Low Carbon, Green Growth policy and benefit from dedicated R&D funding.

6.2. Standards and Certifications

1. **Standardisation** is **advancing steadily**, particularly in Europe and North America. The EU's EN50119 and CENELEC TS 50717, as well as ongoing work in CENELEC TC9x WG27, cover technical elements for overhead and rail-based ERS systems.
2. **Global wireless ERS** efforts are backed by key standards such as:

   a. SAE J2954/2 and J2954/3 for heavy-duty and dynamic wireless power transfer (WPT)
   b. IEC 61980 series for various WPT systems, including dynamic and high-power transfer
   c. ISO 19363, ISO 5474, and ISO 15118 for safety and communication
   d. Broader management system standards (ISO 9001, ISO 14001, ISO 27001, ISO 45001) for quality, environmental, cybersecurity, and occupational safety management
3. Countries like Japan and Australia apply national **adaptations of these international standards for wireless charging**, while the UAE and Israel enforce **EV-related certifications without yet defining ERS-specific protocols**.
4. Korea's OLEV trials, however, operated without harmonisation to these global standards, a gap that limits interoperability and global scalability.

6.3. Legal and Liability Frameworks

Legal treatment of ERS infrastructure remains **inconsistent**.

1. Germany’s A5 eHighway project is a rare example where **legal status, building permissions, liability, and safety protocols** were **clearly defined**. The system was classified as a “road accessory,” simplifying the permitting process, while safety mandates and infrastructure integration were addressed proactively.
2. Other countries have yet to develop clear legal frameworks for ERS, particularly in terms of:
   a. Liability in case of malfunction or accidents
   b. Insurance coverage models tailored to dynamic charging systems
   c. Coordination with existing road safety laws and electrical safety norms
3. Some **existing public-private partnership frameworks** (e.g., Dubai’s Law No. 22 of 2015 on PPPs) or **city-level transport regulations** may serve as **starting points** for embedding ERS-related provisions, but these remain underutilised.

6.4. Permitting and Approval Processes

1. Germany again provides a notable case where **regulatory classification facilitated faster approval**. By designating the ERS as a road accessory, delays were minimised.
2. However, **most countries currently lack specific ERS permitting pathways**, which could become a major bottleneck as pilot projects transition to scale.

Leveraging PPP Models for ERS in India

07

7. Leveraging PPP Models for ERS in India

The development of large-scale infrastructure in India has often been constrained by limited public finance, uncertain returns, and execution inefficiencies. The Public-Private Partnership (PPP) model has emerged as a powerful tool to address these challenges, combining public sector support with private sector innovation and efficiency. Nowhere has its success been more visible than in the road and highway sector, where PPP frameworks such as Build-Operate-Transfer (BOT), Build-Own-Operate-Transfer (BOOT), and the Hybrid Annuity Model (HAM) have transformed India's transport landscape.

As India aims to pioneer Electric Road Systems (ERS) capital-intensive and next-generation mobility infrastructure, PPP models can once again provide the financial and operational foundation to scale this innovation. This chapter explores PPP lessons from highways and EV charging infrastructure to illustrate how they can be adapted to ERS corridors, offering policy makers a structured pathway for deployment.

7.1. Scope of the Chapter

This chapter focuses exclusively on the PPP models in highways and EV charging networks, as these represent the closest parallels to ERS deployment:

1. Both involve large upfront capital expenditure (CAPEX).
2. Both require long-term operation and maintenance (O&M) commitments.
3. Both depend on steady revenue streams from users and associated assets.

By analysing these models, we aim to identify how ERS projects can be structured to cover CAPEX and O&M costs while attracting private participation.

The choice of highways as a reference for PPP evaluation is deliberate. **Highways and ERS corridors share several common features**:

1. **Linear infrastructure networks** with long concession periods.
2. **Demand certainty** tied to freight and passenger movement.
3. **Bundling potential with monetisable assets** (tolls, logistics hubs, charging infra).
4. **Proven PPP track record** in overcoming funding and efficiency barriers.

Charging networks, though more recent, provide important insights into clean mobility infrastructure development. They illustrate:

1. **De-risking early investment** through targeted government support, including subsidies, concessional land allocation, and viability gap funding
2. **Defined private sector roles** in infrastructure installation, operations, maintenance, and technology deployment
3. **Commercial viability strategies** that leverage blended financing and bundled monetisation to attract investment in emerging infrastructure markets

7.2. Evaluation Framework

This chapter evaluates PPP models based on four core criteria:

1. **Revenue Sharing Mechanisms:** How were returns structured between public and private partners?
2. **Sustainability of Financing:** Did revenues alone sustain CAPEX and O&M?
3. **Scalability:** Could the model be expanded corridor-by-corridor?
4. **Transferability to ERS:** How can lessons be applied to electrified highways and freight corridors?

7.3. Spotlight on PPP Models in Practice

India's PPP experience in the EV sector offers strong parallels for ERS corridors. Each model reflects different approaches to land use, financing, revenue-sharing, and stakeholder alignment, all critical elements for capital-intensive infrastructure like ERS. Below, we examine four cases that provide relevant lessons.

6.3.1. National Highways for Electric Vehicles (NHEV), Pan India

The National Highways for Electric Vehicles (NHEV)[7] initiative has been designed to test the viability of electric highway corridors in India. Conceptualised as a public-private testbed, NHEV aims to de-risk investment in EV infrastructure by offering government support for land access and policy clarity, while inviting private operators to participate in charging solutions. The NHEV Tech-Trials began in 2020.

1. **Model Structure:**
    a. Operated under the Annuity Hybrid E-Mobility (AHEM) model, adapted from HAM.
    b. A ₹500 crore blended finance pool was created to cover Viability Gap Funding (VGF).

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[7] *While NHEV remains in the trial and demonstration phase, it nonetheless provides a valuable proof-of-concept for structuring PPPs in high-capex mobility infrastructure, offering lessons that can be directly adapted for ERS corridors.*

c. Stakeholder mapping included fleet operators, utilities, OEMs, asset owners, financiers, and regulators.

d. Real-world TechTrials tested for energy efficiency, interoperability, and cost structures before commercial rollout.

2. **Revenue & Risk Sharing:**

The Annuity Hybrid E-Mobility (AHEM) model applies a multi-layered investment safety framework to balance revenue potential with risk mitigation for ERS-like infrastructure.

a. Revenue Assurance Measures:

i. Market-Driven Demand Models: Business cases are anchored in strong demand projections and targeted market share, ensuring predictable revenue streams.

ii. Advance Annuity Contracts (Minimum Guarantee): Fixed annuity payments provide baseline cash flows regardless of utilisation fluctuations.

iii. Bundled Revenue Streams: Income is diversified across charging fees, logistics services, retail spaces, and carbon credits.

b. Risk Mitigation Measures:

i. Conservative Utilisation Matrix: Break-even schedules are based on conservative demand estimates to avoid over-projection risks.

ii. Securities & Warranties: Operational performance is backed by warranties and contractual guarantees to ensure accountability.

iii. Land Access Flexibility:

- *Public:* Land made available via NHAI to PSUs for station development.
- *Private:* Private developers purchase land directly.
- *People:* Individuals can offer land as collateral for bank financing.

3. **Sustainability**: By diversifying revenue streams and proving bankability through trials, NHEV demonstrated how EV corridors can scale without an indefinite subsidy reliance.

4. **Relevance to ERS**: By combining guaranteed annuity payments with diversified revenue sources and layered risk protections, the model aligns the interests of public agencies, private investors, and community stakeholders, ensuring bankable and sustainable project execution.

a. Closest precedent to ERS because it targets electrification of highways and freight corridors.
b. Demonstrates the use of blended finance and escrow-backed annuities for de-risking.
c. Validates the importance of trial-based de-risking before scaling.

7.3.2. Tata Power - NAREDCO, Maharashtra

Tata Power, one of India's largest power utilities, signed an MoU with the National Real Estate Development Council (NAREDCO) in 2022 to deploy 5,000 EV charging stations across Maharashtra. This PPP leveraged Tata's technical capacity and NAREDCO's access to real estate assets.

1. **Model Structure:**
    a. Public-private-industry partnership: Government facilitated approvals, NAREDCO provided land and integration with residential/commercial projects, Tata Power handled installation and O&M.
    b. Chargers were renewable-powered, integrating sustainability into the business model.
2. **Revenue & Risk Sharing:**
    a. Tata Power captured charging revenue, while NAREDCO benefitted from increased property value and service revenue.
    b. The government's role was to enable land use and supportive policy.
    c. Investment risk was spread across multiple stakeholders (utility, developers, property owners).
3. **Sustainability:**
    a. Revenue was sustained through steady demand in residential societies, malls, and petrol pumps.
    b. Scale (5,000 chargers) helped Tata Power reduce costs per unit.
4. **Relevance to ERS:**
    a. Illustrates how multi-stakeholder partnerships (infra developers, utilities, and private operators) can co-invest in corridors.
    b. For ERS, similar consortia of logistics firms, infra developers, and utilities can share risk and capture value.

7.3.3. Ahmedabad Municipal Corporation (AMC) PPP Model, Gujarat

AMC initiated one of India's earliest city-level PPPs for EV charging in 2024, aiming to deploy 25 charging stations in the first phase, with tenders floated for 81 sites.

1. **Model Structure:**
    a. AMC leased land at ₹10 per sqm for 10-year contracts, with a mid-term review at year 5.
    b. Private bidders were responsible for installing and operating stations within 6 months of allotment.
    c. AMC aligned its efforts with the Gujarat EV Policy 2021, which offered subsidies of ₹20,000 to ₹1.5 lakh per EV and charging point.
2. **Revenue & Risk Sharing:**
    a. Concessionaires earned from charging fees, while AMC collected lease revenue and concession fees.
    b. State government incentives reduced upfront CAPEX risk.
    c. Contracts included flexibility AMC extended lease periods from 5 to 10 years after initial lukewarm investor interest.
3. **Sustainability:**
    a. Early financing sustained by subsidies; long-term ensured through lease payments and growing demand.
    b. Integration with regulatory amendments (mandating charging infra in new buildings) created long-term certainty.
4. **Relevance to ERS:**
    a. Land-lease based PPPs can be a starting point for ERS pilots, where concessional land access reduces CAPEX.
    b. Shows that policy alignment + flexible concessions are key to attracting private players in early-stage markets.

7.3.4. Delhi PPP Model

Delhi implemented one of the most ambitious PPP models for EV charging in 2021, targeting 900 charging points at 100 sites. It aimed to ensure affordability, expand infra quickly, and attract private partners.

1. **Model Structure:**
    a. Unique PPP design that linked land lease to revenue.
    b. The government provided land parcels from public agencies and covered upstream electrical infra costs (100 kW/site).
    c. Land lease fees were deferred until revenue generation.

2. **Revenue & Risk Sharing:**
    a. Charging tariffs capped at ₹2/unit (world's lowest, ~USD 0.03).
    b. Operators paid a fixed revenue share of ₹0.70/kWh sold to the land-owning agency.
    c. Risk-sharing ensured that private bidders had low initial burden while the government retained long-term revenue participation.
3. **Sustainability:**
    a. Subsidies and deferred leases made the early phase viable. It was later sustained through low tariffs and high utilisation.
    b. The revenue-sharing model created aligned incentives between public and private sectors.
4. **Relevance to ERS:**
    a. Demonstrates how affordability and revenue sharing can expand adoption.
    b. For ERS, similar dynamic charging fee and revenue-share models can balance financial sustainability and accessibility.

7.4 Financing Models

The successful deployment of Electric Road Systems (ERS) will depend as much on robust financing mechanisms as on technological readiness. ERS corridors are inherently capital-intensive, require long concession periods, and demand early-stage de-risking before they can achieve commercial viability. This makes financing models central to their success. India's experience with highways, urban infrastructure, and electric mobility provides a strong foundation to build upon. A combination of **public investment, private sector participation, and blended financing instruments** can be leveraged to structure bankable projects. Existing frameworks ranging from national incentive schemes and risk-sharing annuity models to urban challenge funds and asset monetisation plans demonstrate that when government support is combined with private innovation, even high-risk infrastructure can be scaled sustainably. For ERS, adapting these proven models into a coherent financing ecosystem will be critical to move from pilots to large-scale implementation.

7.4.1. Prime Minister's Electric Drive Incentive for Vehicles

1. **Implementing Authority:** Ministry of Heavy Industries (MHI)
2. **When Announced:** 2024
3. **Expiry Date:** 2026 (2-year scheme)

4. **Type of Projects it Funds:** Demand incentives for electric trucks (N2 & N3 category) and charging infrastructure
5. **Funding Allocation:**
    a. Total Outlay: ₹10,900 crore (2024-26).
    b. E-Truck Support: ₹500 crore earmarked to incentivise the purchase of 5,643 electric trucks in FY 2026.
    c. Charging Infrastructure: Separate allocation to provide subsidies for upstream EV charging networks.
6. **Demand Incentives for Electric Trucks:**
    a. Maximum Incentive: Up to ₹9.6 lakh per vehicle.
    b. Conditions:
        i. Incentives linked to gross vehicle weight (GVW).
        ii. OEMs must provide a 5-year warranty (battery: 5 years/5 lakh km; vehicle/motor: 5 years/2.5 lakh km).
        iii. Mandatory scrappage of old, polluting trucks to qualify.
7. **Charging Infrastructure Support:**
    a. Subsidy: Up to 80% of the cost of upstream infrastructure for EV charging stations (grid augmentation, transformers, and feeder lines).
    b. Implementation: Funds to be disbursed via the PM E-DRIVE portal on a first-come, first-served basis.
8. **Key Features:**
    a. Targets large freight vehicles, which are among the highest emitters in the transport sector.
    b. Encourages fleet operators and logistics companies to transition to electric trucks by lowering upfront costs.
    c. Integrates vehicle incentives with infra support, ensuring both demand and supply-side readiness.
    d. Complements national programs like FAME II and aligns with India's 2030 EV adoption targets.

7.4.2. Hybrid Annuity Model (HAM), 2016

1. **Implementing Authority:** Ministry of Road Transport & Highways (MoRTH), executed by the National Highways Authority of India (NHAI)
2. **Announcement:** 2016

3. **Duration:** Ongoing
4. **Scope:** Financing of national highway and road projects under a risk-balanced PPP framework
5. **Funding Size:**
    a. 40:60 cost-sharing structure (40% government upfront contribution, 60% private sector equity/debt)
    b. **Annuity Payments:**
        i. The private developer is repaid through semi-annual annuity payments by NHAI over a period of 10-15 years post-construction.
        ii. Payments are performance-linked (e.g., tied to road quality, maintenance, and availability standards).
6. **O&M Responsibility:**
    a. The developer retains responsibility for operations and maintenance throughout the concession period, ensuring quality standards are met.
7. **Revenue Risk:**
    a. NHAI retains control over toll collection and traffic revenue.
    b. Developers are insulated from traffic risk, unlike in BOT models.
8. **Key Features of HAM:**
    a. **Risk Balancing:** Reduces financial risk for developers by eliminating traffic risk while ensuring the government does not shoulder 100% of costs.
    b. **Performance-Based Payments:** Links annuity payments to measurable performance indicators such as road availability, safety standards, and service levels.
    c. **Liquidity Support:** Reduces upfront financing requirements for private players, making projects more attractive for investors and lenders.
    d. **Government Oversight:** By retaining tolling rights, the government ensures revenue flows back into public accounts while guaranteeing stable returns to developers.
9. **Impact of HAM:**
    a. By FY22, nearly 51% of the 1,900 km of highway projects awarded under Bharatmala were structured through HAM.
    b. HAM accelerated project execution, reduced stalled projects, and restored private sector confidence in road development.
    c. It contributed significantly to India's target of expanding the national

highway network to 200,000 km by 2025.

d. HAM is now regarded as the preferred PPP model in India's highway sector, bridging the financing gap between EPC and BOT.

7.4.3. Annuity Hybrid E-Mobility (AHEM), 2021

The Annuity Hybrid E-Mobility (AHEM) model was launched in 2021 by Ease of Doing Business for Government of India, with implementation support from PSUs, State Transport Undertakings (STUs), and private concessionaires. It builds on the Hybrid Annuity Model (HAM) used for highways and adapts it to the needs of India's electric mobility ecosystem, particularly for EV charging networks, e-bus and e-truck fleets, and electric highways.

1. **Implementing Authority:** Ease of Doing Business, Climate Finance Division
2. **Announcement**: 2021
3. **Duration:** Ongoing (currently piloted, scaling to broader adoption)
4. **Scope:** Financing of EV charging infrastructure, e-highways, and fleet electrification through blended finance PPP structures
5. **Funding and Incentives:**
    a. Dedicated Climate Finance Pool: A ₹500 crore blended finance corpus was announced under the AHEM pilot framework to support early projects, including corridor electrification (NHEV).
    b. Fixed Annuity Payments: Developers receive guaranteed annuity disbursements from government agencies/PSUs over 8-12 years.
    c. Variable Incentives: Linked to performance indicators such as fleet expansion, station utilisation, and uptime standards.
    d. Insurance and Guarantees: Risk protection offered through insurance-backed guarantees and escrow-secured annuity accounts, making projects creditworthy for banks and NBFCs.
6. **Structure of AHEM:**
    a. **Government Role:**
        i. Provides VGF support up to 40% during construction to lower upfront risk and annuity guarantees.
        ii. Facilitates concessional land allocation through state agencies.
        iii. Ensures policy alignment with FAME-II, PM E-DRIVE, and state EV policies.

b. **Private Developer Role:**
   i. Invests 60% of project CapEx (equity + debt).
   ii. Responsible for installation, O&M, technology deployment, and fleet integration.

c. **Payment Mechanism:**
   i. Fixed annuities ensure baseline revenue security.
   ii. Variable payments incentivise higher utilisation and expansion.

d. **Revenue Sources:**
   i. EV charging fees, fleet leasing, battery-as-a-service, V2G integration, logistics services, and carbon credit monetisation.

7. **Operational Model:**
   a. **Self-Sustaining Opex:** Charging and e-highway stations generate recurring revenue from electricity sales, grid-balancing services, retail/amenity rentals, and advertising rights.
   b. **Revenue Reinvestment:** Surpluses reinvested into expanding charging networks or used to shorten project breakeven.
   c. **Multi-Stakeholder Alignment:** Six key groups fleet operators, OEMs, utilities, concessionaires, financing partners, and asset owners share both risks and benefits, making projects more resilient.

8. **Key Features of AHEM:**
   a. **Risk Mitigation:** Escrow-based annuities and insurance-backed guarantees lower financing risks.
   b. **Blended Finance:** Mobilises domestic banks, NBFCs, FDI, and climate-linked funds.
   c. **Performance Incentives:** Variable payments tied to operational KPIs ensure quality and efficiency.
   d. **Commercial Viability:** Bundling monetisable assets (charging stations, logistics hubs, EV fleets, carbon credits) creates diversified revenue streams.

9. **Impact and Relevance:**
   a. AHEM has been piloted in the NHEV corridor program, financing 830 km of electrified highways (Delhi-Agra, Delhi-Jaipur, Chennai-Trichy).
   b. The model demonstrated 72% utilisation at prototype stations and potential for 36-month breakeven at corridor level.

c. By FY23-24, projects under AHEM had mobilised ₹3,600+ crore in financing agreements from private banks and investors, backed by annuity guarantees.

d. It has become a flagship financing structure for India's clean mobility transition, reducing dependence on upfront subsidies and moving toward market-driven sustainability.

7.4.4. Union Budget 2025

In the Union Budget 2025, the Hon'ble Finance Minister, Smt. Nirmala Sitharaman, announced a series of measures to accelerate infrastructure development in India by mobilising Public-Private Partnerships (PPP). These initiatives are designed to spur private investment, enhance project execution, and strengthen economic growth across housing, power, energy infrastructure, transport, and urban development.

1. **Announcement:** 2025 (Union Budget)
2. **Duration:** PPP pipeline until 2027; Asset Monetisation Plan until 2030
3. **Scope:** Supports PPP projects across housing, power, energy infrastructure, transport, and urban development
4. **Three-Year PPP Pipeline:**
    a. All infrastructure-related central ministries (housing, roads, railways, power, renewable energy, urban development, etc.) will prepare a pipeline of projects that can be executed under the PPP model by 2027.
    b. States and UTs are encouraged to prepare similar pipelines.
5. **Support to States through IIPDF:**
    a. States may access the India Infrastructure Project Development Fund (IIPDF) to finance feasibility studies, DPRs, and bid preparation for PPP projects.
    b. This ensures state-level projects are investment-ready and bankable.
6. **Capital Expenditure Support:**
    a. A special interest-free loan facility of ₹1.5 lakh crore will be provided to states for 50 years.
    b. Funds to be used for capital expenditure and infrastructure reforms, encouraging states to undertake large-scale PPP-based projects.
7. **Asset Monetisation Plan (2025-2030):**
    a. A second phase of the National Asset Monetisation Pipeline was launched with a target of ₹10 lakh crore to be unlocked between 2025-

2030.

b. Revenues generated from monetisation of existing public assets will be reinvested into new infrastructure projects.

8. **Financing Structure:**

    a. The emphasis is on blended financing, where government support (Urban Challenge Fund, IIPDF, long-term loans) is combined with private equity, debt, and bond markets.

    b. This approach reduces reliance on public funds and makes projects more financially sustainable.

The evolution of financing frameworks in India from highway PPP models like HAM, to sector-specific innovations such as AHEM, and more recent instruments like PM E-DRIVE, offers critical lessons for ERS deployment. These mechanisms demonstrate how early-stage viability gap funding, risk-sharing annuities, concessional land, and blended finance can attract private investment into capital-intensive projects, while long-term concessions and asset monetisation ensure sustainability. For ERS, the relevance is clear: it must combine the predictability of highway PPPs with the de-risking and innovative support of e-mobility schemes. By aligning existing funding sources with ERS-specific needs, India can create a bankable, scalable, and globally replicable financing model that accelerates the transition to clean freight and urban mobility.

ERS Roadmap for India

08

8. Roadmap for Testing ERS in India

8.1. The Promise of ERS for India

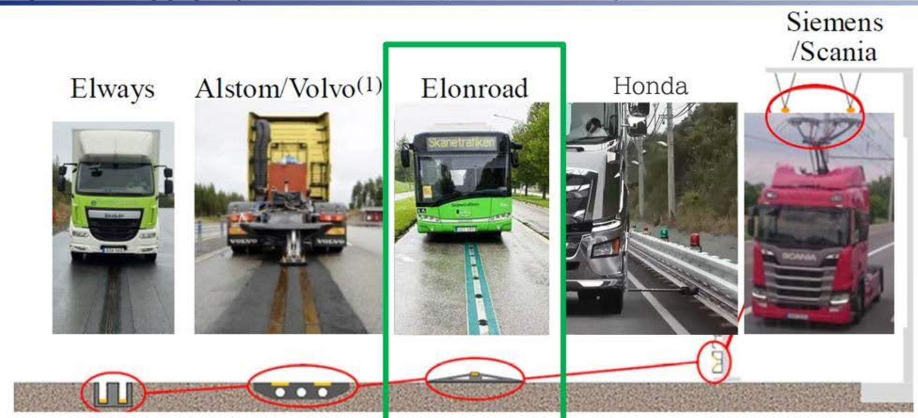
The global pilot landscape for ERS demonstrates a rich diversity of technologies, deployment models, and policy frameworks. Several countries around the world have taken bold steps to trial ERS technologies in both urban and highway contexts, testing inductive road-based, conductive ground-based, and overhead catenary solutions to assess technical feasibility, commercial models, and ecosystem readiness. These pilots serve not only as proof-of-concept demonstrations but also as real-world testbeds for long-term viability, policy alignment, and stakeholder coordination.

For India, the relevance of ERSs lies in their **ability to enable uninterrupted electric mobility across a broad spectrum of vehicle types**, including both heavy-duty and light-duty vehicles, without overloading the grid or requiring large, land-intensive charging stations. While heavy-duty freight and public transport fleets provide an effective entry point for early pilots due to high utilisation rates, the **long-term societal and economic benefits of ERS** will come from **reducing battery size requirements** and **minimising dependence on fast-charging infrastructure** across all vehicle categories. It is important to clarify that, at a system level, the total electric load on the grid remains comparable whether energy is delivered via ERS or through fast-charging stations, since the overall energy demand and usage timeframes are similar. However, ERS allows for **more distributed energy feed-in points** (e.g., every 2 km), in contrast to concentrated fast-charging stations placed every 40 km or more, potentially **easing local grid stress** and improving load balancing.

A notable advantage of ERS is its **modular infrastructure**. Unlike centralised fast-charging stations, ERS networks can localise and isolate faults without disrupting the broader system. If a power unit or segment fails, only that section can be temporarily shut down, allowing the remainder of the roadway to remain operational. This modularity **enhances system resilience and offers greater reliability** in the face of technical disruptions. Moreover, by enabling **in-motion energy transfer**, ERS can reduce dependence on high-capacity, grid-intensive fast chargers, potentially **easing stress on local grid infrastructure** and **improving overall system stability**. Another key aspect lies in their **ability to eliminate the need for large-scale grid connections** at remote logistics hubs and warehouses. For instance, in the UK, it is estimated that conventional electrification would require up to 20,000 individual grid connections at warehouse sites, whereas an ERS solution could achieve the same objective with as few as 64 connections. This dramatic reduction stems from **ERS distributing energy usage both spatially and temporally**, thereby avoiding peak loads at specific locations or times, such as the surge in demand from overnight depot charging.

Furthermore, ERS enables the use of **smaller onboard batteries** in electric trucks, helping to mitigate key operational penalties. While longer charging times may be less critical given existing inefficiencies in loading and unloading, the **impact on payload** is **substantial**. Many freight operations are mass-limited, meaning that larger batteries would directly reduce payload capacity. By minimising battery size, ERS helps preserve cargo volume and weight capacity, enhancing both efficiency and profitability for logistics operators. Given India's push toward decarbonising transport, improving logistics efficiency, and ensuring energy security, ERS presents a transformative opportunity, especially along high-density freight corridors and urban expressways, if designed with a long-term vision that includes wide-scale deployment for LDVs as well.

Conductive power supply (overhead / side / road surface)



	Elways	Alstom/Volvo	Elonroad	Honda	Simens/Scania
Advantage	-Less risk of electrocution -Easy to trace	-Simple shape	**-Less risk of electrocution -Vehicle recognition**	-Easy to install and repair (just replace)	-Less risk of electrocution -Train technology can be diverted
Disadvantage	-Water/trash enter -Dig deep to reinforcement	-Electrocution/leak -Dig wide	-Cost of IGBT	-Safety belt disappears -Left and right installation difference	-Large impact on landscape and high cost -Impossible to install in PV

8.2. Comparative Assessment of Electric Road System (ERS) Technologies: Current Capabilities

Table 2: *Comparative Assessment of ERS Technologies;* ***Source:*** *Deshpande, 2025*

Criterion	In-Road Conductive System	Inductive (Wireless) System	Catenary System (Overhead Contact Lines)
Technology Readiness	Medium (TRL 6-7) [a, 1, 3, 6, 7]	Low (TRL4-5) [a, 1, 3, 6, 7]	High (TRL 8-9) [a, 1, 3, 6, 7]
Vehicle Classes Supported	Cars, LDVs, HDVs [2]	Cars, LDVs, HDVs [3]	HDVs only [3, 8]
Energy Transfer Efficiency[8]	High (95-97%) [2, 3, 9]	Medium (85-91%) [3, 9]	High (95-97%) [3, 8]
Power Delivery	300+ kW [2, 3, 4]	50-100 kW [3]	500+ kW [3, 4]
Cost/km[9]	Lowest: ~ £1.5-2m/km [3]	Highest [3, 9]	Middle: ~ £2-3m/km [4, 8]
Infrastructure Impact: Installation	Medium (slot cut along road centerline) [3, 10]	High (cut rectangular slots or resurface road) [3, 10]	Medium (poles at 60m intervals + overhead lines) [3, 10]
Infrastructure Impact: Maintenance	Low (straightforward to replace active sections) [3]	High (cut damaged loops out of road surface) [3, 10]	Medium (contact lines accessible above road) [3, 8, 11]
Infrastructure Impact: Longevity	Unknown (long-term effects of thermal cycles) [3, 10]	Unknown (regular weak spots along road surface) [3, 10]	High (proven in long-duration tests) [3, 4, 8]
Infrastructure Impact: Visual Intrusion[10]	Low (contact strip along road centerline) [3, 10]	High (roadside boxes every 40m) [10]	Medium (overhead lines) [12]
Vehicle Retrofitting Capability/ Cost[11]	Medium [6]	Difficult (multiple pickups needed for each HGV) [5, 7]	Medium [8]

Note: Reference numbers in brackets (e.g., [2, 3, 4]) correspond to sources listed in the References section at the end of this report, where full citations and weblinks are provided for further reading.

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[8] *Pickup/ Pantograph transfer efficiency only.*

[9] *Difficult to estimate cost per km for the inductive solution as there are none for HGVs.*

[10] *Subjective: While the inductive coils may not be visible, the solution needs power boxes every 40 m unlike the conductive solutions that only need a power unit every km or two.*

[11] *Subjective: Detailed cost data is not available.*

The comparative assessment presented in *Table 2* provides a current-state analysis of three principal Electric Road System (ERS) technologies - in-road conductive, inductive (wireless), and catenary (overhead contact line) systems - across key criteria such as technology readiness, vehicle compatibility, energy efficiency, infrastructure cost, and maintenance requirements. These insights are drawn from global pilot deployments, industry reports, and published technical literature, and are intended to support informed decision-making by Indian policymakers, regulators, and infrastructure developers.

[a] *Current Technology Maturity Levels of ERS Systems;* ***Source:*** *Deshpande, 2025*

Technology Readiness Definitions	System	Explanation
TRL 1. Basic principles observed and reported.		
TRL 2. Technology concept and/or application formulated.		
TRL 3. Analytical and experimental critical function and/or characteristic proof of concept.		
TRL 4. Component and/or breadboard validation in laboratory environment.		
TRL 5. Component and/or breadboard validation in a relevant environment.	Inductive (Wireless) System	Components validated but entire system not demonstrated.
TRL 6. System/subsystem model or prototype demonstration in a relevant environment.		
TRL 7. System prototype demonstration in an operational environment.	In-Road Conductive System	Prototype demonstrated on the road.
TRL 8. Actual system completed and qualified through test and demonstration.	Catenary System (Overhead Contact Lines)	Completed system demonstrated and tested in Germany.
TRL 9. Actual system proven through successful mission operations.		

It is important to underscore that these tables reflect the present level of technological maturity and real-world experience. As pilot projects scale, interoperability standards mature, and local ecosystem capabilities strengthen, we can expect notable improvements across several parameters - particularly cost-efficiency, vehicle retrofitting ease, and infrastructure longevity. Advancements in materials science, grid integration, and modular system design will further enhance the suitability of ERS technologies for Indian conditions.

In short, while the current comparison is instructive, it should be viewed as a dynamic reference point. With targeted investments in R&D and carefully designed pilot programs, ERS technologies are poised to evolve rapidly, positioning India to lead in shaping and deploying the next generation of transport electrification systems.

8.3. What Should Be Tested in the Indian Context?

To adapt global learnings meaningfully, India must frame ERS pilots that respond to local infrastructural, climatic, and operational realities. Key elements for testing include:

8.3.1. Technology Suitability Across Use Cases

1. Compare the performance of inductive wireless, conductive rail, and overhead catenary systems on:
    a. Urban last-mile freight routes (e.g., Delhi NCR)
    b. Inter-city logistics corridors (e.g, Delhi-Mumbai Expressway)
    c. Bus Rapid Transit (BRT) corridors or metro feeder roads
2. Evaluate systems under extreme weather conditions (heat, dust, monsoons), mixed-traffic environments, and varied pavement types.

8.3.2. Grid Integration and Renewable Alignment

1. Prioritise grid connection strategies and substation sizing as a foundational step.
2. Test integration of ERS with distributed solar, Battery Energy Storage Systems (BESS), and smart metering systems.
3. Examine vehicle-to-grid (V2G) readiness and dynamic energy balancing for peak shaving and load management.

8.3.3. Cost-Benefit Metrics for Policy Benchmarking

1. Establish localised CAPEX and OPEX estimates per km, including civil works, hardware, and utility relocation costs.
2. Assess potential cost recovery through fleet operator tariffs, green logistics incentives, or carbon finance.

3. Compare with baseline diesel and electric fleet TCOs to justify commercial scalability.
4. Develop a sizing strategy based on expected utilisation and create a comprehensive utilisation model that accounts not just for traffic density but also for vehicle origin-destination patterns. Utilisation rates are influenced by how many vehicles can meaningfully engage with ERS over their typical route lengths.
5. Factoring in future shifts in public revenue as diesel vehicles are phased out, government excise revenues from fuel duty will decline. A margin on electricity supplied through ERS infrastructure could serve as a replacement revenue stream.

8.3.4. Standards and Safety Validation

1. Evaluate interoperability across ERS hardware, vehicle interfaces, and metering systems.
2. Test for electromagnetic safety, data security, and pedestrian/ cyclist impact in dense zones.

8.3.5. Institutional and PPP Models

1. Pilot business models where private technology firms, fleet operators, state utilities, public transport/ mass transit authorities, and public road authorities co-own and operate ERS infrastructure.
2. Consider Special Purpose Vehicles (SPVs) for shared O&M responsibilities and transparent cost recovery.
3. Structure ERS pilots as public-private partnerships involving technology providers, fleet operators, utilities, public transport authorities, and road agencies.
4. Integrate ERS corridors into existing PPP project pipelines and freight electrification schemes like PM E-DRIVE. Adopt risk-sharing frameworks similar to AHEM, where the government provides Viability Gap Funding (VGF) and guarantees annuity-based returns, while private partners manage installation, operations, and technology integration.
5. Mobilise blended financing pools combining public funds, private equity, green bonds, and international climate finance. Use escrow-secured annuities to attract institutional investors and lower cost of capital.
6. Bundle ERS lanes with toll revenues, dynamic charging fees, logistics hub operations, and carbon credits to diversify income sources. Position ERS corridors within national asset monetisation pipelines to access long-term

reinvestment funding.

8.3.6. User Behaviour and Operational Efficiency

1. Study driver behaviour, vehicle lane discipline, the effect of ERS on traffic flow, and the effectiveness of driver-assist systems for ERS alignment.
2. Monitor operational efficiency in fleet scheduling, charging reliability, and downtime reduction.

8.4. Charging Ahead

A **national roadmap for the Electric Road System (ERS)** in India should be anchored in the principle of **'localisation with global learning'**. This means not just importing technology, but adapting it to India's unique traffic, road, climate, and energy conditions, while learning from international experiences. Equally important is leveraging local learnings from within India.

For instance, the rapid construction of the national highway network by the Ministry of Road Transport and Highways (MoRTH) offers valuable lessons in planning and executing large-scale infrastructure rollouts, which can inform ERS deployment strategies. Similarly, India's achievement in electrifying a large portion of its railway network, one of the highest globally, can guide ERS grid connection planning, substation placement, and cost management, given the striking similarities in power supply infrastructure between electrified rail and electric roads.

A particularly critical enabler in this journey is the **National Automotive Test Tracks (NATRAX)**, India's premier proving ground under the Ministry of Heavy Industries. Located near Indore, NATRAX provides world-class facilities for vehicle testing and homologation across all powertrains - including electric and next-generation mobility systems. Recognising the importance of ERS in India's freight and public transport future, **NATRAX has proposed a dedicated 3,600+ metre ERS testing track with varied surface conditions** (bitumen, concrete), **simulated real-world infrastructure features** (bridges, curves, crossings), and **capability to support both inductive and conductive charging systems**. This facility, as shown in *Figures 2 and 3*, will play a vital role in validating ERS technologies under Indian conditions, refining standards, and accelerating pilot readiness.

To establish the feasibility of ERS in India, **access to robust and granular data from the government** will be critical. Key datasets include **'freight flow information'**, potentially sourced from e-way bills, which can help map high-density logistics corridors and identify priority segments for ERS deployment. **'Traffic flow data'**, including vehicle type, volume, and peak hour usage, will enable accurate modeling of energy demand and system sizing. Additionally, integrating **toll data** with **vehicle registration** information can help distinguish between different classes of vehicles: private, commercial, and public transport, along specific routes. Together, these datasets can support detailed techno-economic analyses, utilisation modelling, and selection of optimal corridors for pilot implementation, while also informing broader infrastructure planning and regulatory coordination.

Strategic ERS pilots could be co-designed and co-executed by key central ministries, including:

1. **Ministry of Road Transport and Highways (MoRTH):** For identifying, preparing, and approving ERS-compatible highway and urban road segments.
2. **Ministry of New and Renewable Energy (MNRE):** To align ERS with decentralised renewable generation (especially solar) and energy storage systems.
3. **Ministry of Heavy Industries (MHI):** Through its testing agency NATRAX, MHI can enable early-stage prototyping, testing, and certification of ERS components and vehicles. MHI can also support industrial scaling and indigenous manufacturing of ERS-related systems.
4. **National Automotive Test Tracks (NATRAX):** To support the development, validation, and certification of ERS technologies in a controlled test environment. NATRAX's proposed ERS track will be instrumental in assessing energy transfer efficiency, component durability, electromagnetic interference, and vehicle-infrastructure integration before public deployment.
5. **Ministry of Power (MoP):** To facilitate grid readiness, smart metering, and dynamic pricing mechanisms for energy use by ERS.
6. **Ministry of Science and Technology (DST, MST):** To support R&D, innovation grants, and pilot-scale trials of ERS technologies under national science missions.
7. **Ministry of Electronics and Information Technology (MeitY):** To enable secure communication protocols, data interoperability, and intelligent transport systems (ITS) integration.
8. **NITI Aayog:** For overarching policy coordination, inter-ministerial alignment, and long-term investment frameworks.
9. **State-level Nodal Agencies for Charging Infrastructure:** To coordinate with Transport and Energy Departments for site selection, regulatory support, and facilitate local public-private collaboration. It is equally important to engage land-owning agencies at both the state and municipal levels, as they play a critical role in site allocation, permitting, and infrastructure planning for ERS deployment.

The **ideal testbeds for ERS pilots** include:

1. **Urban freight corridors**, where shared mobility (public transport and intermediate public transport or popular mobility), e-commerce delivery fleets, and municipal vehicles offer high utilisation potential.
2. **Multimodal transport hubs** are being developed under the PM Gati Shakti National Master Plan, which integrates road, rail, ports, and warehousing into seamless logistics zones.
3. **High-density expressways and freight routes** like the Delhi-Mumbai Expressway, Mumbai-Pune Expressway, and sections of the Golden Quadrilateral, under programmes like Bharatmala Pariyojana, which aim to improve national freight movement efficiency.

By embedding ERS into these infrastructure ecosystems and leveraging NATRAX's testbeds, India can become a global co-creator of the next generation of electric mobility infrastructure. This path can enable the country to **leapfrog conventional charging constraints, localise technology innovation, and strengthen energy and transport sovereignty** - thereby shaping a cleaner, more efficient, and digitally integrated future for road-based mobility.

8.4.1. NATRAX's Proposed ERS Tracks

NATRAX is a State-of-the-Art Testing and Certification Centre, under National Automotive Board (NAB), Ministry of Heavy Industries, Government of India. It is a one of a kind Proving Ground in India, catering to all the requirements of the Automotive Industry. The Centre was planned under the Automotive Mission Plan 2006-2016, launched by the Government of India. NATRAX serves as a comprehensive test facility for the entire Automobile Industry, and provides a one stop solution for the development, Certification and R&D Projects, be it for National or Global automotive, auto component or tyre Industry. NATRAX is designated to be the Center of Excellence in Vehicle Dynamics. The Center is also planning to impart various training programs for the Skill India Mission in association with the Industry and Academia.

NATRAX is notified under CMVR Rule-126 as a Homologation and certification agency. The special tracks, like High-Speed Track, Dynamic platform, Braking, Noise and Gradient track are being used for all Vehicle type approval. All the mentioned tracks are certified by M/s TUV, Rhineland, as per ISO norms. Keeping abreast with the requirements of the Development in the Industry, NATRAX is also establishing infrastructure and facilities for the development, testing and certification of the Electric

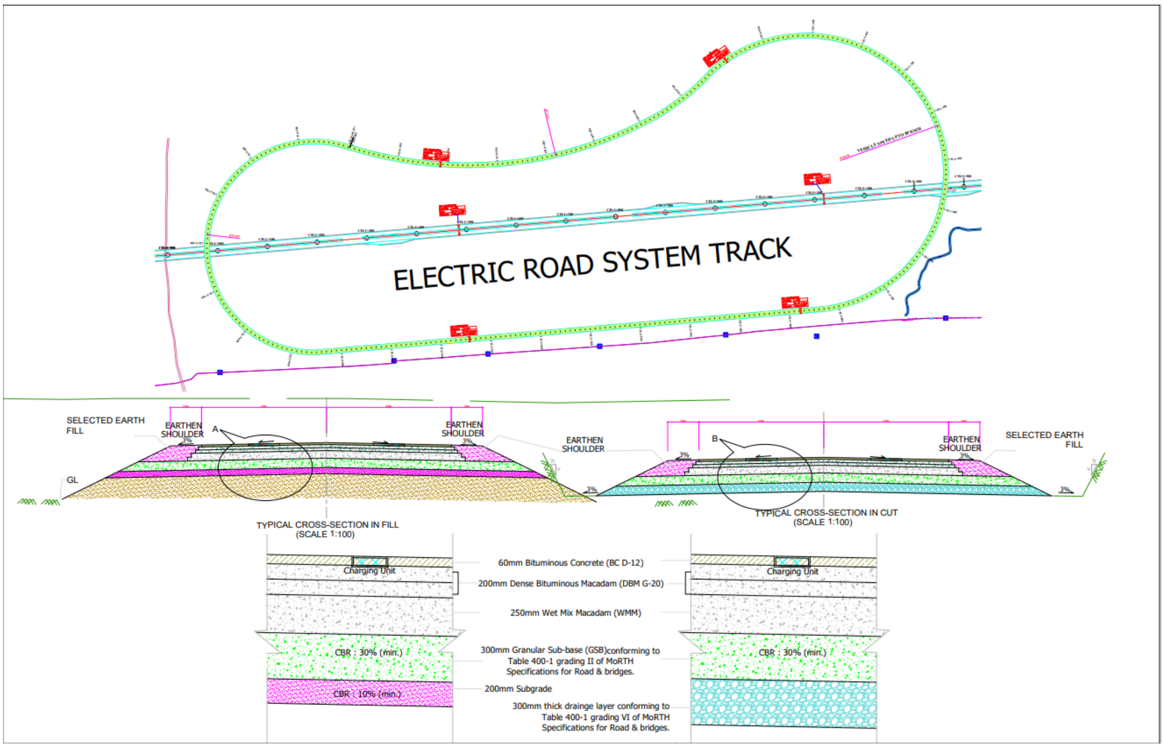
Vehicles and Components and other upcoming technologies related to Automobile and associated infrastructure.

NATRAX is also accredited under ISO 17025:2017 for Certification tests including Crash Barrier certification (EN-1317).

NATRAX is situated approx. 50 km from the commercial capital of Madhya Pradesh i.e., Indore. The Center has been developed in 2960 acres of land, and falls on NH-3 bypass road (Indore - Mumbai). The place is well connected by rail, road and air with Metros like New Delhi, Mumbai, Chennai, Pune, Bangalore, Hyderabad, Ahmedabad, Jaipur, and Dubai.

Recognising the importance of ERS in India's freight and public transport future, **NATRAX has proposed a dedicated 3,600+ metre ERS testing track with varied surface conditions** (bitumen, concrete), **simulated real-world infrastructure features** (bridges, curves, crossings), and **capability to support both inductive and conductive charging systems**. This facility, as shown in *Figures 2 and 3*, will play a vital role in validating ERS technologies under Indian conditions, refining standards, and accelerating pilot readiness.

Figure 2: *Details of the ERS Track for Testing by NATRAX*



Details of the Tracks - Consideration:

Total Length: 3,603.30 m

Straight Length: 1x1,025 m

Width: 8.0 m (2 Lane)

Radius at Curve: Varying from 215 m to 770 m

Speed at Curve: 70 kmph to 100+ kmph

ERS system shall be embedded in the centre or centre of lane as applicable.

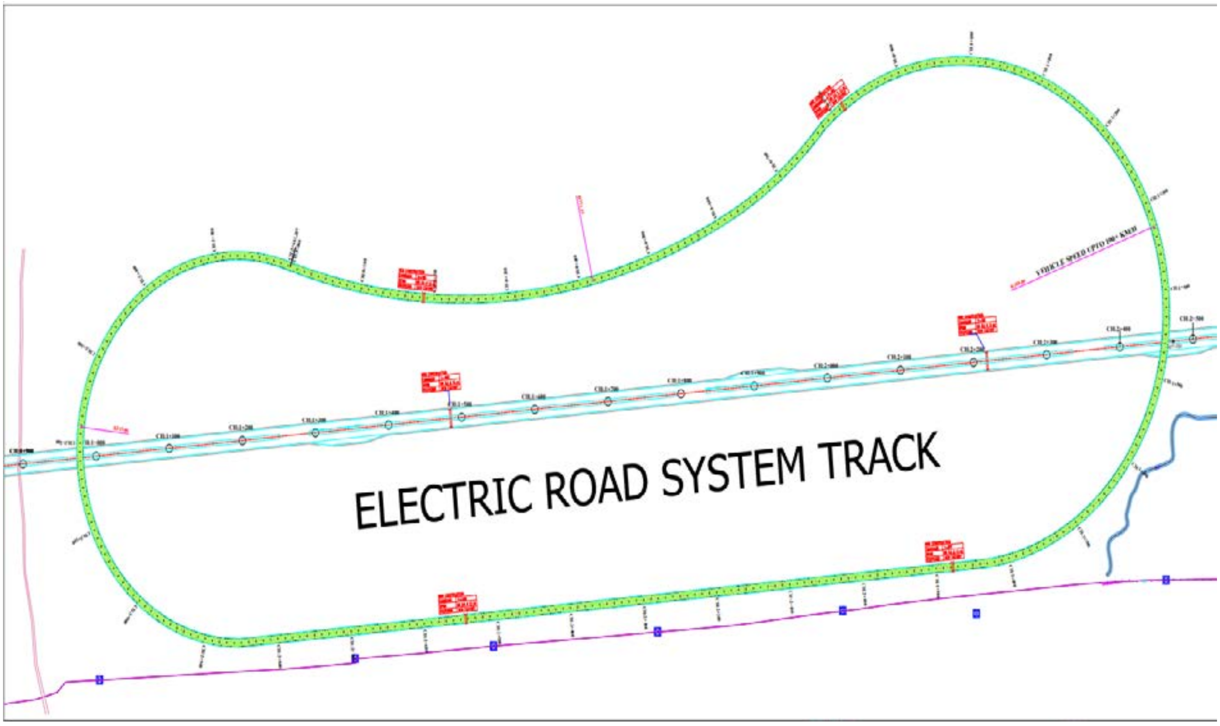
Both side driving shall be applicable .

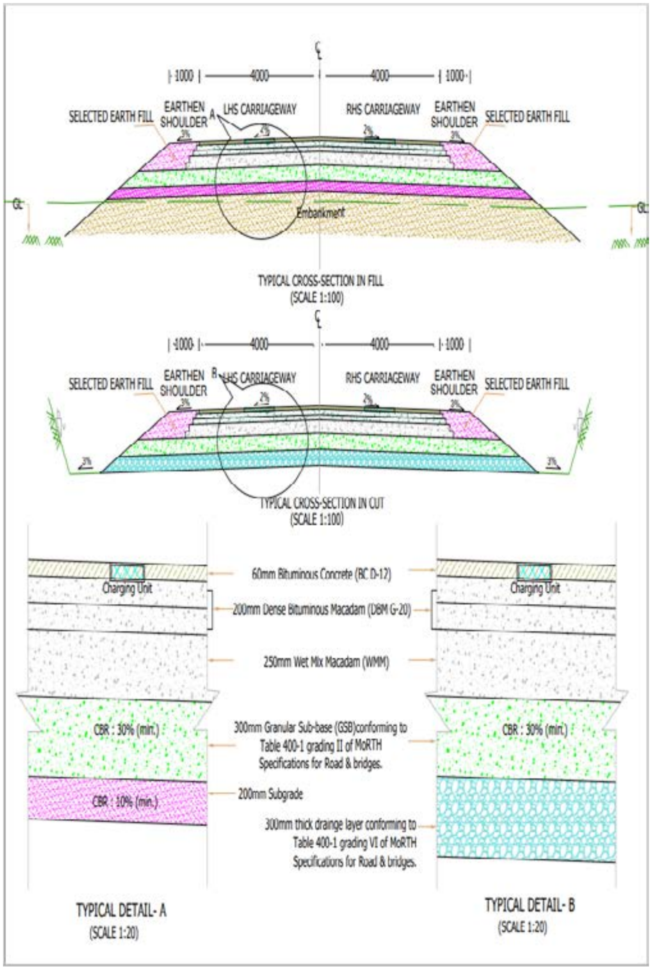
RCC Box Culvert: 04 nos.

Crossing NATRAX approach road at 2places to simulate condition.

Source: NATRAX

Figure 3: *Layout and Cross-Section of ERS Tracks by NATRAX*





Source: NATRAX

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About The Futures Report

This brief was prepared by the Working Group on Electric Road Systems (ERS), constituted under the aegis of the ITS India Industry Growth Forum, to assess the feasibility of implementing Electric Road Systems (ERS), also known as eRoads, eHighways, or Charge-as-You-Drive systems, in India.

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The Working Group brought together experts from diverse fields:

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Scope

The Working Group conducted:

1. **Global Scenario Analysis** of ERS implementations in Europe, Asia, Australia, and North America.

2. **Technical Assessments** focusing on infrastructure needs, vehicle compatibility, energy integration, and technological maturity.
3. **Economic Evaluations** of capital costs, operational viability, and revenue models.
4. **Environmental Impact Studies** emphasising ERS's contribution to emission reduction and sustainability.

Regular weekly meetings, iterative reviews, and active stakeholder consultations informed the findings presented in this report, ensuring robust analysis and practical recommendations tailored specifically for India.

Credits

About ITS India Forum

ITS India Forum unites industry leaders, policymakers, academia, and domain experts to foster collaboration and innovation in Intelligent Transportation Systems for driving advancements in safer and sustainable mobility solutions, optimise transportation networks, and reduce logistics costs to forge a path toward India's transformation into a developed nation by 2047. ITS India Forum aims to provide a platform for transport experts, researchers, industry leaders, and policymakers to collaborate and evolve the best policies, standards, and technologies for an efficient transport system in the country. It further promotes large-scale adoption of ITS solutions, and facilitates the highest-quality implementation by bridging gaps in skill, standards, funds, and quality assurance.

About OMI Foundation Trust

OMI Foundation Trust is a new-age policy research and social innovation think tank operating at the intersection of mobility innovation, governance, and public good. Mobility is a cornerstone of inclusive growth providing the necessary medium and opportunities for every citizen to unlock their true potential. OMI Foundation endeavours to play a small but impactful role in ushering meaningful change as cities move towards sustainable, resilient, and equitable mobility systems, which meet the needs of not just today or tomorrow, but the day after.

OMI Foundation houses four interconnected centres that conduct cutting-edge evidence-based policy research on all things mobility:

1) The Centre for Clean Mobility catalyses the adoption of electric vehicles, future fuels, and renewable energy within the mobility ecosystem as a key climate strategy of cities.

2) The Centre for Future Mobility supports the leapfrog of cities to a sustainable future anchored in the paradigms of active, shared, connected, clean, and AI-powered mobility.

3) The Centre for Inclusive Mobility promotes safe, accessible, reliable, and affordable mobility for all. It paves the road for the future of work and platform economy to fulfil the modern promise of labour.

4) The Centre for Technology Transitions is dedicated to transforming India's innovation ecosystem through a systems approach. It aims to position India as a global leader in ethical, inclusive, and sustainable technological innovation.

About National Automotive Test Tracks (NATRAX)

NATRAX is a State-of-the-Art Testing and Certification Centre, under National Automotive Board (NAB), Ministry of Heavy Industries, Government of India. It is a one of a kind Proving Ground in India, catering to all the requirements of the Automotive Industry. The Centre was planned under the Automotive Mission Plan 2006-2016, launched by the Government of India. NATRAX serves as a comprehensive test facility for the entire Automobile Industry, and provides a one stop solution for the development, Certification and R&D Projects, be it for National or Global automotive, auto component or tyre Industry. NATRAX is designated to be the Center of Excellence in Vehicle Dynamics. The Center is also planning to impart various training programs for Skill India mission in association with the Industry and Academia.

NATRAX is notified under CMVR Rule-126 as a Homologation and certification agency. The special tracks, like High-Speed Track, Dynamic platform, Braking, Noise and Gradient track are being used for all Vehicle type approval. All the mentioned tracks are certified by M/s TUV, Rhineland, as per ISO norms. Keeping abreast with the requirements of the Development in the Industry, NATRAX is also establishing infrastructure and facilities for the development, testing and certification of the Electric Vehicles and Components and other upcoming technologies related to Automobile and associated infrastructure.

NATRAX is also accredited under ISO 17025:2017 for Certification tests including Crash Barrier certification (EN-1317). NATRAX is situated approx. 50 Km from the commercial capital of Madhya Pradesh i.e., Indore. The Center has been developed in 2960 acres of land, and falls on NH-3 bypass road (Indore - Mumbai). The place is well connected by rail, road and air with Metros like New Delhi, Mumbai, Chennai, Pune, Bangalore, Hyderabad, Ahmedabad, Jaipur, and Dubai.

About Aisin

Aisin Corporation is a Japanese multinational company and a leading global supplier of automotive components and systems. Founded in 1965 and a member of the Toyota Group, the company is headquartered in Kariya City, Aichi, Japan, and operates more than 200 consolidated companies in over 20 countries. Aisin develops advanced technologies for electric vehicles, clean energy, and safe mobility, with a focus on achieving carbon neutrality.

Aisin India is the Indian arm of the global auto parts manufacturer Aisin Corporation, focusing on producing and supplying automotive components like transmissions, brake-related products, and electrification systems such as eAxles for electric vehicles. Aisin's presence in India includes subsidiaries like Aisin Automotive Haryana Private Ltd., which contribute to the global production of Suzuki's electric vehicles and serve the Indian market.

Ease of Doing Business

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About Ease of Doing Business (EoDB)

EODB is a Special Purpose OPC (SPC); currently India's premier emerging Tech-Piloting agency, privately held and based at New Delhi contributing with its pilot projects in micro-level tech-economies across the states and sectors in the macro tech-o-nomic Bharat vision of PM Modi.

EODB is providing advanced-level technical and commercial piloting services to facilitate reforms with evidence-based tech-pilot programs for the private sector since 2014, exclusively contributing to our emerging and deep tech national ambitions, going on ground beyond bureaucratic boundaries to deliver actual Ease of Doing Business at grassroot levels as envisaged by PM Modi, through footprint ecosystem pilots for commercialization of emerging technologies like AI, IoT, Blockchain, Electric Mobility, Health Tech, Drones, Cloud Computing, 3D Printing, Robotics, Automation, Machine Learning, Geospatial, Big Data Centres etc.

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