सत्यमेव जयते

Office of the Principal Scientific Adviser
to the Government of India

TECHNICAL ROADMAP FOR DEPLOYMENT OF ZERO-EMISSION TRUCKING IN INDIA

March 2023

अजय के. सूद
भारत सरकार के प्रमुख वैज्ञानिक सलाहकार
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FOREWORD

India, during COP26, pledged to achieve net-zero greenhouse gas emissions by 2070. Road Transport (passenger and goods) currently contribute about 13% of the total emission, out of which long-distance heavy trucks contribute the largest, at about 35% to 40% of all road emissions, despite their low relative inventory on the roads. Therefore, India must focus on converting this sector into a Zero Emission Trucking (ZET) sector.

It is worth mentioning that NITI Aayog came out with a report on Transforming Trucking in India Pathways to Zero-Emission Truck Deployment, which broadly lays out pathways to ZET adoption in India, including policy, financing & business models, charging and technology & manufacturing. The document has set a good background for introducing ZET in India. Going forward a well deliberated and articulated Technical Roadmap for the effective Deployment of Zero Emission Trucking in India is important to draw a field research-based action plan.

I am pleased to introduce "Technical Roadmap on Deployment of Zero Emission Trucking in India". It highlights technical areas that require action specifically in the Indian context over a 5-year horizon. It consists of a master plan, timelines thereof, objective, justification, suggestive stakeholders, the task involved, methodology and indicative budget requirements for each activity.

I am hopeful that by expediting the workstreams outlined in this Roadmap, India shall be able to meet its national commitments and attain leadership in Zero Emission Trucking globally. This report carefully touches upon aspects such as regulations, standards, certifications, safety, field research, evaluation of technical applications and, most importantly, ZET pilots.

I thank all the working committee members for their valuable input and suggestions. I especially want to mention Dr Preeti Banzal, Scientist 'G', O/o PSA, Mr Karthick Athmanathan, O/o PSA Fellow and Sh. Abhijit Mulay, General Manager, ARAI, for their exceptional contributions to building this Roadmap document.

Ajay K Sood

(Ajay K. Sood)

Dated: 5th December 2022

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MESSAGE

The Office of the Principal Scientific Adviser to the Government of India, through its missions and programs, has supported and promoted R&D for Science and Technology in numerous areas of National importance. The Electric Vehicle Mission of the office was envisioned by the Prime Minister's Science, Technology Innovation and Advisory Council (PM-STIAC), with an aim of working towards reducing fossil fuel consumption, mitigating emissions, and facilitating the production of Electric Vehicles (EVs).

The Government of India has set an aggressive target of EV sales penetration of 30% for private automobiles, 70% for commercial vehicles, and 80% for two- and three-wheelers by 2030. The major policies and programs pertaining to the decarbonisation of road transport in India has so far been directed towards light duty vehicles. However, considering that heavy-duty trucks are responsible for most of the road transportation. The Zero Emissions Trucks (ZETs) provide a compelling alternative to the fossil fuel trucks as they have negligible tailpipe emissions and lower operating costs.

The Office of PSA has initiated the process of detailing the technical aspects required for the successful deployment of Zero Emission Trucks in India by constituting a panel titled as "Consultative Group on e-Mobility". This panel was tasked to prepare a well-researched and evidence-backed document to lay out the actions, tasks, and deliverables over five years as "Technical Roadmap for Deployment of Zero Emission Trucking in India".

The roadmap and the methodology adopted in the preparation are unique in nature, and it can be consciously said that it is the first of its kind. It has been a dynamic learning process for the Office of PSA. Upon comprehending this empowering exercise's value and usefulness, it is heartening to present this report to all the stakeholders working in the mobility sector.

I take this opportunity to thank the members of the Working Group who made this report a reality. I also urge the stakeholders to come forward and work towards the common goal of achieving Zero Emission Trucking in India.

PMaini

(Parvinder Maini)

Dated: 12 Dec, 2022

EXECUTIVE SUMMARY

India is committed to reducing the emissions intensity of its GDP by 45% by 2030 from its 2005 levels, as per the updated Nationally Determined Contribution. India is the world's third-largest net importer[1] of crude oil and petroleum products, importing over 80% of the crude oil consumed, and it is of strategic interest to reduce the country's dependence on imported fuel. Battery Electric Trucks (BETs) and Fuel Cell Electric Trucks (FCETs), operated at scale on electricity generated through renewable resources, can lead India to Zero Emission Trucking and address the country's high energy import bills. The trends indicate that BETs will be cost-competitive on a total cost of ownership per kilometre basis within the next few years. However, the technology transition from extant ICE-based trucks to ZET will require certain preparatory activities and due diligence.

The ZET sector is a performance-sensitive commercial sector, and the lack of preparedness during the technology transition may impact India's economic growth. It was realised that a well-designed Roadmap shall provide a clear pathway for the successful scaling up of the technology and may outline the suitable tools for conducting effective research, analysis, and technology development for ZET. Accordingly, for the preparation of such a Roadmap, the Office of the Principal Scientific Adviser (O/o PSA), in August 2022 has constituted the Consultative Group on eMobility (CGeM), a Panel of handpicked experts from Industry, academia, and another techno-commercial entity.

The Panel, after due diligence, collectively decided to bring about a Technical Roadmap for the deployment of ZET in India. The document has limited itself to listing the primary key next technical steps and immediate actions required for the successful deployment of ZET. The long-term technological measures shall be captured as part of a separate detailed eMobility Technology Roadmap. This Roadmap has stayed away from commenting on policy and other relevant commercial initiatives as it does not intend to repeat activities already undertaken by other Government of India (GoI) departments and ministries in this regard.

The Roadmap entails the following action items relevant to the ZET sector:

1. Devising enabling mechanisms for field data acquisition, data mining, analysis, and reporting for the trucks presently running across the country
2. Expediting product development and scaling up the ZET deployment work by rapidly adopting/developing national standards for vital technologies
3. Designing tools to enable the successful implementation of pilots and to track and improve the pilots on an ongoing basis
4. Identifying and modifying regulatory requirements and, in the future, drawing an emission mitigation Roadmap

The Panel identified the following activities to constitute the Roadmap and has prepared a Roadmap for each of the activities, with detailed scope and content and rough-cut timelines and budgets.

1. Update Regulations, Standards and Notifications for ZETs: Charging Standards, Battery and Relevant Standard Development in BETs and FCETs
2. Field Research–BETs and FCETs
3. Evaluate Rare Earth Magnet Free Motors for ZETs
4. Develop Finance, VGF, and Risk Products for BETs
5. Develop Overhead Automated Charging Device (OH-ACD)
6. Develop Onboard Hydrogen (H_2) Storage
7. Collect Drive Cycle Data (DCD) for Selected Field Corridors
8. Develop a Driver Rating Application (DRA)
9. Develop Safety Awareness, Training Methods, Manuals, and Guidelines for BETs and FCETs

Later in the document, in Section 2, a Masterplan constituting relevant activities and timelines has been incorporated. The tentative budget accompanying the yearly breakup has been included in Section 2.1. A budget of ≅ ₹850 Crores is required for the execution of all Roadmaps across 4 years. This also includes an estimated

[1] https://www.trade.gov/country-commercial-guides/india-energy#:~:text=India%20is%20the%20third%2Dlargest,percent%20of%20the%20crude%20consumed.

cost of ₹432 Crores for the development, homologation, and procurement of vehicles for BET pilots, certification and budget for the development of robust testing facilities relevant to ZET. It is to be noted that the technologies related to ZET are evolving continuously, so the cost estimates are dynamic in nature and will follow the techno-economic trajectory of technology adoption.

Currently, the activities regarding FCETs are intentionally kept limited to the regulatory framework, field research, onboard hydrogen storage and safety aspects. Based on the hydrogen ecosystem development, the pilots concerning FCETs are to be identified and executed in the next couple of years. The primary focus of this Roadmap is BETs. The emerging technologies such as Hydrogen ICE, Inductive Charging and others are not discussed in the Roadmap. The Panel has also refrained from commenting on the policy aspect of the deployment of ZET and drawing a deep, clean slate long-term R &D Plan.

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2W	2-Wheeler Vehicle
3W	3-Wheeler Vehicle
4W	4-Wheeler Vehicle
ACD	Automated Charging Device
AFR	Air Fuel Ratio
AIS	Automotive Industry Standards
AISC	Automotive Industry Standards Committee
ARAI	The Automotive Research Association of India
Auto-PLI	Automotive Production Linked Incentive Scheme
BET	Battery Electric Truck
BEV	Battery Electric Vehicle
BIS	Bureau of Indian Standards
BMEP	Brake Mean Effective Pressure
BMS	Battery Management System
BOM	Bill of Material
CaaS	Charging as a Service
CAN	Controller Area Network
CMVR	Central Motor Vehicle Rules
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
DCD	Drive Cycle Data
DI	Direct Injection
DISCOM	Electricity Distribution Company
DRA	Driver Rating Application
ECU	Electronic Control Unit
EGR	Exhaust Gas Recirculation
FC	Fuel Cell
FCET	Fuel Cell Electric Truck
FCEV	Fuel Cell Electric Vehicle
GVW	Gross Vehicle Weight
H_2	Hydrogen
H_2ICE	Hydron Fuel Internal Combustion Engine
ICE	Internal Combustion Engine
IITM	Indian Institute of Technology Madras
IM	Induction Motor

IPR	Intellectual Property Rights
IS	Indian Standard
IT	Information Technology
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas
NBFC	Non-Banking Financial Company
NHAI	National Highways Authority of India
NOx	Nitrogen Oxides
OEM	Original Equipment Manufacturer
OH-ACD	Over-Head Automated Charging Device
PESO	Petroleum and Explosives Safety Organisation
PMSM	Permanent Magnet Synchronous Motor
POC	Proof-of-Concept
PFI	Port Fuel Injection
SCR	Selective Catalytic Reduction
SI	Spark Ignition
SyRM	Synchronous Reluctance Motor
TCO	Total Cost of Ownership
TWC	Three-Way Catalytic Converter
TWNSC	Three-way NOx storage catalyst
VGF	Viability Gap Funding
ZET	Zero-Emission Truck/Zero-Emission Trucking

1. INTRODUCTION

1.1 INTRODUCTION AND JUSTIFICATION

India has formally committed to the international community to reducing the Emissions Intensity of its GDP by 45% by 2030, from the 2005 level and achieving about 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030[2]. More significantly, the dependence on imported fuel continues to be a priority concern for the country for both strategic and economic/forex criteria.

Road transport (passenger and goods) currently contributes about 20% of the total emissions[3]. In this, long-distance heavy trucks contribute the largest, at about 35%~40% [4] of all road emissions, despite their very low relative inventory on the roads.

In other words, by 2050, with no action on long-distance heavy trucking, the emissions from trucking in India may account for as much as 15% of the total country's emissions. It can also be expected that 15% or more of the fossil fuel imported will be towards heavy long-distance trucking.

It is, therefore, a priority for the country to focus on converting this sector into a Zero-Emission Trucking (ZET) sector with a judicious combination of Battery Electric Trucks (BETs) and Fuel Cell Electric Trucks (FCETs) along with good greening of the national grid.

A basic commercial assessment of cost trends over the next ten years indicates that ZET with BETs will be competitive on a Total Cost of Ownership (TCO) per kilometre basis within the next few years for those applications that cover about 320 km per day[5]. Therefore, given the long preparations, it is imperative to start activities with diligence soon.

1.2 THE CURRENT STATE OF ZET

In India, ZET is currently at the concept and POC stage with a few dozen vehicles running enabled by Startups and large corporates in partnership. While the relevant technical capability and supply chain options are available, more work is needed to develop the ecosystem and products. This document is prepared to meet the aforementioned preparatory requirements. In short, little, or no major data are available either in India or globally for long-distance ZET. Large-scale pilots are required to gather the data, study the India-centric criteria, and evolve different solutions

1.3 TECHNICAL PANEL FOR ZET

Implementing ZET will be a long-term process with distinct phases requiring preparations, pilots, policies, and technologies. This performance-sensitive commercial sector may likely impact the country's economic growth if ZET technologies are implemented without due diligence and practices. While other GoI Departments and Agencies are looking into policies and commercial aspects, the technical activities will require a Roadmap spread over the years, suitably enabling the overall GoI ZET Roadmaps and policies. Unlike commercial and policy initiatives, research, analysis, and development of suitable tools and technologies for ZET will require a Roadmap that provides the mission with a clear pathway for successfully ramping up and duly supporting the policy and commercial initiatives by the GoI.

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[2] https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1847812

[3] Ramachandra, T. V. (2009). Emissions from India's transport sector: statewise synthesis. Atmospheric Environment, 43(34), 5510-5517.

[4] Singh, Namita, Trupti Mishra, and Rangan Banerjee. "Emission inventory for road transport in India in 2020: Framework and post facto policy impact assessment." Environmental Science and Pollution Research 29.14 (2022): 20844-20863.

[5] NITI Aayog, RMI, Transforming Trucking In India: Pathways to Zero Emission Truck Deployment, September 2022.

Towards this, the O/o PSA in August 2022 has constituted a Panel of handpicked experts from Industry, academia, and other techno-commercial entities who can address the market and field requirements with suitable strategies on the technical and engineering fronts. This Panel, named Consultative Group on eMobility (CGeM), identified a set of urgent actions required on the ZET front and constituted a sub-Panel for ZET Technical Roadmaps.

The Consultative Group on Future Transportation (CGFT) was constituted by the O/o PSA in November 2018, to assess future transportation systems and technologies with a focus on identifying and addressing gaps in R &D, safety, data and regulatory frameworks. The CGeM members realised the merit in carrying forward the work done by CGFT, and after detailed deliberations, it was decided that an R & D Roadmap in the e-mobility sector is necessary to help India build capabilities in the next 3-5 years. The Roadmap is envisioned to address issues related to the technology adoption and assess the commercial and operational utilities of innovation and research projects. The Roadmap will help the various stakeholders review and adopt the document and make them aware of multiple stakeholders' flanking and supporting actions taken on other fronts.

1.4 METHODOLOGY AND APPROACH

The e-Mobility sector has been changing dynamically and rapidly over the last five years regarding technology, costs, supply chain, policies, and market trends. The ZET sector within this e-Mobility sector is relatively new, with no country other than China deploying at scale. The best efforts are currently limited to minor pilots in some North American and Western Europe locations.

It is, thus, prudent to conduct elaborate and well-prepared pilots with suitable solutions on the technical, policy, operational, and commercial fronts. Given the truck operator market and its significant and dominating fragmentation, it becomes imperative to conduct such a pilot on a larger scale and across different corridors in the country.

The Panel has stayed focused on the technical aspects of the Roadmap that are required for successful research, analysis, and identification and implementation of these pilots and respective corridors. It is also proposed to organize “BET Pilot Flag Off” events to create awareness among all stakeholders, boost confidence among stakeholders, and create public awareness and a positive environment to promote the ZET initiative. The Panel has stayed away from commenting on policy and commercial initiatives, which are also required and may need technical support.

Given that the costs of hydrogen and the infrastructure for the same are in the initial stages as part of another GoI mission, the Panel has currently limited FCET Roadmap actions to the basic field research and safety regulation levels. In the next couple of years, there will be a need to identify and execute more efforts on FCETs, including pilots, technology, and infrastructure. For now, the pilot is limited to the BET.

Given that other governments globally have started defining Zero-Emission (ZE) vehicles as those that are zero on carbon emissions, it is likely that the Indian classification shall also represent ZE vehicles the same way. There is, hence, a need and merit to discuss the fundamental aspects of Hydrogen ICE vehicles, which offer their advantages and disadvantages and can be implemented much faster. The topic of Hydrogen ICE has therefore been discussed in the Appendix without any Roadmap being drawn.

1.5 THE KEY ELEMENTS OF TECHNICAL ACTIONS

The ZET Panel has limited actions focused on the basic and primary key next technical steps, while the long-term technological measures are captured as part of the overall eMobility Technology Roadmap. This approach will enable quicker implementation of the ZET (BET) pilots while still ensuring that the key aspects of technology that are required are suitably covered.

The key elements are on the following fronts:

1. Field data acquisition, data mining, analysis, and reporting of trucks currently operating across the country
2. Product development work that is to be a part of National Standards, e.g., high-current chargers
3. Tools to enable successful implementation of pilots
4. Tools to track and improve the pilots on an ongoing basis
5. Regulatory requirements and possible emission mitigation Roadmaps

1.6 DELIVERABLES OF THE PANEL AS PART OF THIS ROADMAP

This ZET Panel has been asked to limit its deliverables and submit the same, with due peer review. It is to be noted that the Panel has refrained from identifying the agencies to carry out each work stream and has indicated only approximate estimates of the timelines and budgets for each action. As a Roadmap, the document focuses more on the content and scope rather than the operational aspects of carrying out the activity.

1. Identify the list of technical areas that require action, specifically in the Indian context.
2. A master plan for each of the above areas that shows the timelines and budgets thereof.
3. For each of these technical areas, a short and clear Roadmap will be prepared that will define the following:
    a. The Objective and Justification for the activity
    b. The Stakeholders for the activity
    c. The Tasks involved in the activity
    d. The Methodology for the activity
    e. An approximate Timeline for the activity displaying various tasks
    f. An approximate budget for the activity
4. For areas that are not directly part of a ZET Mission but will help mitigate truck emissions, the area of activity will be elaborated and explained only as Annexure, to stay focused on ZET

1.7 HOW IS THIS DOCUMENT TO BE USED?

1. This document identifies the various technical actions required for the successful implementation of ZET in India
2. For each of these actions, a Roadmap for executing the action is given in the form of a suggested methodology, the stakeholders to be dealt with, a rough-cut time plan for the various sub-actions that are to be carried out, and the overall budget for the action item
3. It is to be remembered that this is a Roadmap document and not a project plan or proposal. The experts have limited their suggestions to a broad level so that policymakers can take this up for further action
4. The individual Roadmaps can be read independently; while doing so, the user needs to refer to the specific Roadmap along with the introduction and conclusion
5. Some items, which are not yet entirely and clearly defined under ZET as of date, have been included as Annexures to avoid distraction from the core actions that are clearly within ZET's scope
6. As mentioned earlier, given the constant and rapid changes in the market, technology, supply chain, costs, and policies, this document is to be treated as a live document, and the latest updated version may be obtained from the O/o PSA if the reader is part of the approved list of recipients of this document
7. In those cases where a certain action item is dependent on the successful completion of a previous action, such dependencies are shown in the Roadmap of the dependent action item so that the reader and user of this document will be aware of the details that are being prepared in the previous action
8. The master plan, shown in this document, has been simplified for easy reading and contains sub-activities that are consolidated and built into a single line in the master plan. If the reader or user of this document so desires, further details and clarifications can be obtained from the O/o PSA

9. If the user of this document is looking for long-term R&D plans for ZET and not just the preliminary technical actions included in this document, then the same can be found in an overall R&D Roadmap for eMobility that the O/o PSA is preparing over the next few months. The O/o PSA can be informed regarding the details required, and the same can be arranged with due circulation approvals

2. MASTER PLAN FOR TECHNICAL ROADMAP

WBS	Activity	Period in Months									
		05	10	15	20	25	30	35	40	45	50
1	**Field Work**										
1.1	Field Research (Battery Electric Trucks–BET)										
1.2	Field Research (Fuel Cell Electric Trucks–FCET)										
1.3	Acquisition of Drive Cycle Data (DCD) for Selected Field Corridors										
1.4	Driver Rating Application (DRA) Development										
2	**Standards and Regulations**										
2.1	Updating CMVR to Incorporate OH–ACD Standards										
2.2	Updating CMVR Battery Electric Truck (BET)										
2.3	Updating CMVR Fuel Cell Electric Truck (FCET)										
2.4	Battery Standardisation for ZET										
3	**Technology Assessment and Development**										
3.1	Overhead Automated Charging Device (OH–ACD)										
3.2	Evaluation of Rare Earth Magnet Free Motors for Electric Trucks										
3.3	Regulation and Supply Chain to On-board Hydrogen Storage										
4	**Pilot Preparation and Running**										
4.1	Finance for Battery Electric Trucks										
4.2	Safety Awareness, Training, Manuals, Guidelines for BET										
4.3	BET Trial Flag-off Events										
4.4	Tender for Main Pilot–BET										
4.5	Development and Delivery of Vehicles and Equipment										
4.6	BET Pilot–Preparation										
4.7	Start of BET Pilot–In Sequence										
4.8	Pilot–Running										

*Work Breakdown Structure

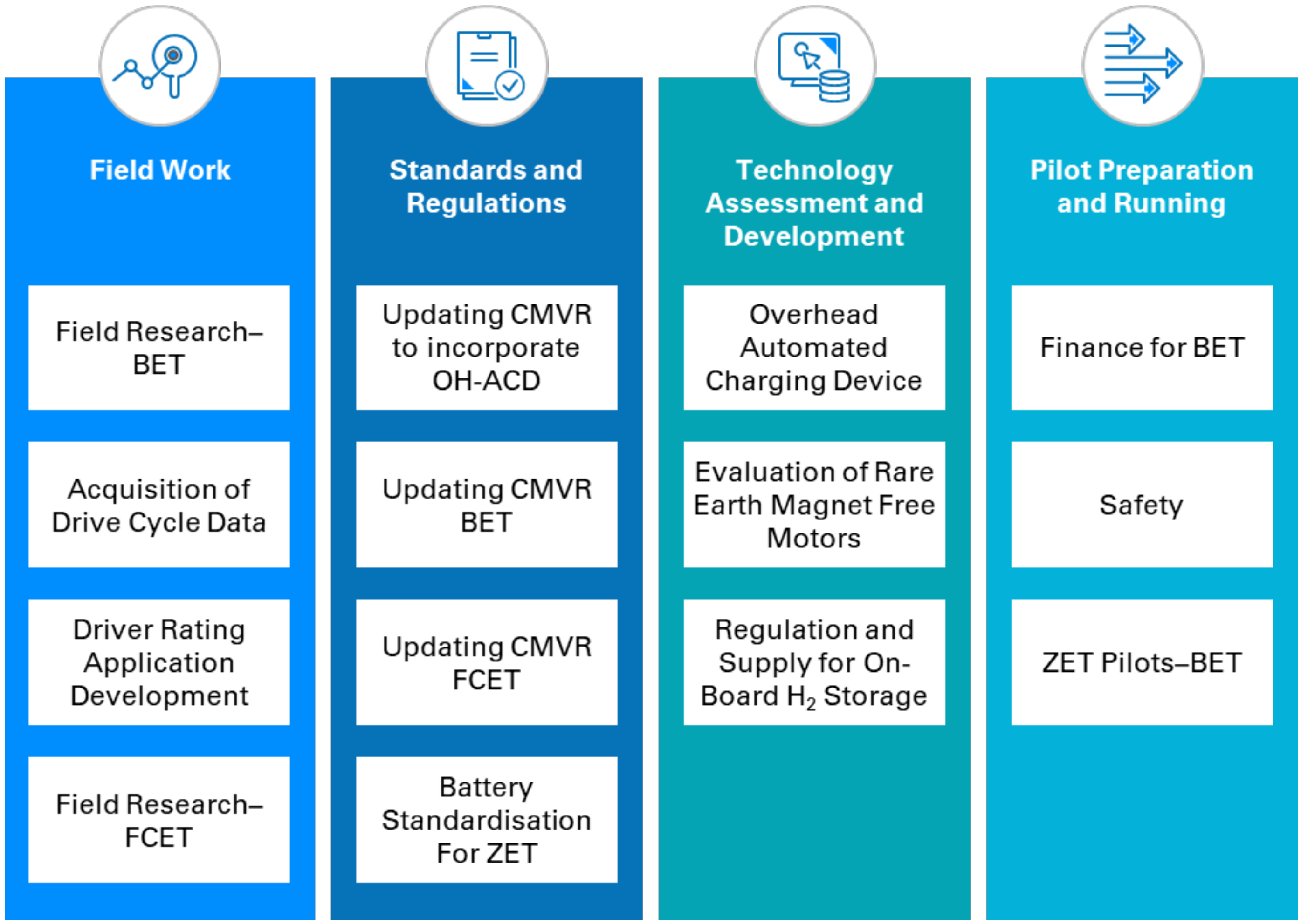
2.1 BUDGET FOR TECHNICAL ROADMAP

		Plan Duration (In months)	Yearly Budget Requirement (Rs. Crores)				Budget (Rs. Crores)
	Activity	05 10 15 20 25 30 35 40 45 50	Year 1	Year 2	Year 3	Year 4	
1	**Field Work**						
a	Field Research (Battery Electric Trucks–BET)		3.6	-	-	-	3.6
b	Field Research (Fuel Cell Electric Trucks–FCET)		-	3.6	-	-	3.6
c	Acquisition of Drive Cycle Data (DCD) for Selected Field Corridors		0.1	0.2	-	-	0.3
d	Driver Rating Application (DRA) Development		0.2	0.1	-	-	0.3
2	**Standards and Regulations**						
a	Updating CMVR to Incorporate OH–ACD Standards		-	-	-	-	-
b	Updating CMVR Battery Electric Truck (BET)		5.1	20.0	-	-	25.1
c	Updating CMVR Fuel Cell Electric Truck (FCET)		-	0.6	60.0	65.0	125.6
d	Battery Standardisation for ZET		1.0	-	-	-	1.0
3	**Technology Assessment and Development**						
a	Overhead Automated Charging Device (OH–ACD)		4.3	1.8	-	-	6.1
b	Evaluation of Rare Earth Magnet Free Motors for Electric Trucks		0.4	0.1	-	-	0.5
c	Regulation and Supply Chain to On-board Hydrogen Storage		-	2.0	20.8	-	22.8
4	**Pilot Preparation and Running**						
a	Finance for Battery Electric Trucks		0.7	-	-	-	0.7
b	Safety Awareness, Training, Manuals, Guidelines for BET		0.2	-	-	-	0.2
c	BET Trial Flag-off Events		-	1.8	-	-	1.8
d	Tender for Main Pilot–BET		-	-	-	-	-
e	BET Pilot–Preparation		36.3	86.7	82.8	23.8	229.6
f	Start of BET Pilot–In Sequence		-	-	-	-	-
g	Pilot–Running		-	-	-	-	-
	Total		**51.8**	**116.7**	**163.6**	**88.8**	**421.0**
5	**Development and Delivery of Vehicles and Equipment**		-	150	282	-	432.0
	Grand Total						**853.0**

3. ROADMAP

The **C**onsultative **G**roup **o**n **eM**obility (CGeM), constituted by the O/o PSA, has identified priority topics/areas for the deployment of **Z**ero **E**mission **T**rucking (ZET). The topics/areas identified by the CGeM, as categorised in distinct groups, are:

FIGURE 1: CLASSIFICATION OF PRIORITY AREAS FOR THE DEPLOYMENT OF ZET



The CGeM has prepared Roadmap documents for the above topics/areas after due deliberation and diligence. Each Roadmap document constitutes key aspects viz.

1. Background
2. Objective
3. Tasks
4. Stakeholders
5. Methodology
6. Deliverables
7. Exclusions (wherever applicable)
8. Timeline

Roadmap documents for topics/areas are detailed in the following sections.

3.1 FIELD RESEARCH – BATTERY ELECTRIC TRUCKS

OBJECTIVE

A pre-condition for the successful adoption of Battery Electric Trucks (BET) is the design of the right product. A product that does not meet the core requirements of the market can set back widespread adoption in a few years. The Indian trucking market has evolved over the years with several unique features, the multi-axle rigid haulage trucks being the prime example. The nature of Indian trucking is markedly different from the rest of the world. Due to the evolutionary nature of this sector, and its informal nature, it is difficult to capture all the requirements for a significantly different option, such as the BET, and their criticality without testing different design options in tightly controlled pilots.

However, given the varied nature of the geography, nature of cargo carried, road conditions, climate, driving patterns, loading patterns, vehicles used, and usage conditions across the country, it is important to conduct these pilots in multiple corridors that cover all these variations. Extensive field research is required to first identify the major freight corridors in India and then map out the variations across these corridors so that the candidates for the pilots can be shortlisted

This section details the Roadmap for the above-mentioned field research.

TASKS

The exercise to shortlist the candidate corridors for BET pilots will involve the following major tasks:

1. Identify the major corridors of freight in India
2. Shortlist about 30 specific corridors with up-and-down round trips for Commercial Vehicles (CVs) covering at least 300 km per day
3. Collect data for each of the 30+ corridors
4. Analyse the collected data
5. Shortlist at least ten candidate corridors for pilots; out of which the final six corridors will be taken up for pilots based on non-quantitative criteria

STAKEHOLDERS

1. Government and policymakers
2. End customers–freight users
3. Automotive Original Equipment Manufacturers (OEMs)
4. Spare dealers and service stations
5. Fleet owners/fleet operators/cargo aggregators
6. Drivers
7. NHAI
8. Infrastructure providers (DISCOMs, fuel stations, charging providers, etc.)

METHODOLOGY

The following steps are involved in completing the above tasks:

1. Identification of the research agency
2. Collection of data regarding freight movement (Trucks specifically) from multiple sources
3. Identification of around 30 corridors for extensive field research
4. Formulation of data to be collected during the field research

5. Formulation of data collection methodology
6. Field research in a few corridors
7. Data analysis, review of the results, and fine-tuning of the methodology
8. Completion of the field research in all the corridors
9. Collation and analysis of the data
10. Short-listing of six corridors, with an additional three as backup

DELIVERABLES

The following are the proposed deliverables of this field research:

1. To be done for a total of 30+ corridors.
2. To be split into four projects, each comprising about eight corridors in neighbouring regions. All four projects are to be carried out in parallel.
3. The following details are to be obtained for each corridor to help with the shortlisting of the ten corridors for pilot ZET runs:
    a. Traffic density, categorised by vehicle tonnages, nature of the cargo, and others
    b. Map of high-tension powerlines and substations (along with their existing ratings and capacities) near the corridor
    c. Map of fuel stations along the corridor, along with information such as sales, ownership, and others
    d. Map of the various truck parking lots, rest stations, and logistic centres.
    e. Map of major automotive servicing hubs along the corridor
    f. Map of fire stations along/near the corridor
    g. Map of non-highway-like areas (more mixed traffic, pedestrians, two-wheeler traffic and others) on the corridor
    h. For a statistically representative volume of vehicles:
        i. Vehicle–make, model and year
        ii. Driver–name, age, driving experience in years
        iii. Mobile number
        iv. Origin
        v. Destination
        vi. Driving pattern, speed vs time, wait/halt times, fuel consumed, and others
        vii. Payload nature (perishable, hazardous, and others), volume, and weight
        viii. GVW
        ix. Fuel
        x. Engine
        xi. Owner of the Vehicle
        xii. Vehicle financing
        xiii. Life Cycle of the Vehicle
        xiv. Fleet size
        xv. Driver-to-Vehicle relationship
        xvi. Predictable or fixed vs variable or random route and cargo
        xvii. Customer for the cargo
        xviii. Revenue vs expenses per trip
        xix. Telematics–yes/no
        xx. Driver monitoring system–yes/no
        xxi. Is the operator using any apps for maintenance, fuel, driving improvement, safety, and other parameters?
        xxii. Is the operator aware of electric vehicles - 2W/3W/4W/trucks?
        xxiii. Is the operator ready to embrace electric trucks?
        xxiv. Perceived advantages and issues with electric vehicles
        xxv. Preferred driving pattern–working time vs rest times

xxvi. Preference to change driving pattern for electric trucks–yes/no

4. Find out when drivers are willing to wait for charging during their day and night. Use special questioning/survey methods and tools in different applications and routes.
5. Measure and model actual energy consumption based on driving patterns and usage. This would enable better vehicle design along with planning recharging infrastructure.
6. Human/driver response to a BEV truck vis-à-vis an ICE truck.
7. Willingness to change driving habits; take a break of ~1 hour every 4 hours, a desire to use apps, reserve charging slots, and other mandatory activities
8. Identify the proportion of cargo limited by GVW vs limited by volume
9. Identify the proportion of hazardous goods carried vs non-hazardous goods

TIMELINE

The timeline for each task under this Roadmap is provided in Figure 2.

FIGURE 2: TIMELINES FOR CONDUCTING FIELD RESEARCH FOR BET

ACTIVITY	PERIOD (Months)									
	1	2	3	4	5	6	7	8	9	10
Identification of research agency	■									
Collection of data regarding freight movement from multiple sources		■	■							
Identification of around 30 corridors for extensive field research			■							
Formulation of data to be collected during field research		■	■							
Formulation of data collection methodology			■							
Field research in a few corridors				■						
Data analysis, review of results, and fine tuning of methodology					■					
Complete field research in all corridors						■	■	■		
Collate and analyse data									■	■
Shortlist six corridors with additional 3 as backup										■

The estimated budget for carrying out the above-mentioned activities is **₹360 lakhs**

3.2 ACQUISITION OF DRIVE CYCLE DATA (DCD) FOR SELECTED FIELD CORRIDORS

OBJECTIVE

This section presents a Roadmap for collecting real-life Drive Cycle Data (DCD) from selected field freight truck corridors that would contribute to the overarching objective of Zero-Emission Trucking (ZET). The DCD would include the time history of the truck's position, velocity, and altitude. The collected data would help in the following ways:

1. Estimating the energy consumption for BET
2. Sizing and optimisation of the powertrain of a Battery Electric Truck
3. Additionally, these data would help in the performance evaluation of a given BET at a later stage while the pilot is running
4. Evaluating the feasibility of other technologies such as H_2 Internal Combustion Engine (ICE) Driven Trucks and Fuel Cell Electric Truck

TASKS

The DCD process and evaluation involve the following tasks:

1. Identify the field corridors for data collection.
2. Make arrangements with drivers for mobile phone-based data.
3. Carry out preliminary testing of this system by revalidation using alternate mobile phones on a selected corridor before scaling up to all corridors.
4. Analyse collected data.
5. Use the DCD to assess pilot performance and evaluate powertrain choices such as battery electric, H_2-ICE, and fuel cell electric through appropriate simulation tools.

STAKEHOLDERS

1. Fleet operators
2. Academia
3. OEMs

METHODOLOGY

The following steps are involved in completing the above tasks:

1. The work in this Roadmap is dependent on the outcome of the following activity(s)/ Roadmap(s)
    a. Field Research (BET)
2. Conducting research and contact programs to identify at least 30 trucks currently plying with the drivers that will be used for collecting DCD
3. Obtaining DCD from the selected corridors
4. Analysis of data

DELIVERABLES

The following are the proposed deliverables of this activity:

1. DCD for each of the selected corridors obtained on a statistically valid number of currently plying ICE trucks along with the details of the sample Truck
2. Inputs for the development of DRA

TIMELINE

The timeline for each task under this Roadmap is provided in Figure 3.

FIGURE 3: TIMELINES FOR ACQUIRING DRIVE CYCLE DATA (DCD) FOR SELECTED FIELD CORRIDORS

ACTIVITY	PERIOD (Months)				
	1	2	3	4	5
Identification of field corridors	■				
Making arrangements with drivers for mobile phone-based data		■			
DCD collection from selected corridors		■	■	■	
Data analysis					■

The estimated budget for carrying out the activities mentioned above is **₹25 lakhs**

3.3 DRIVER RATING APPLICATION (DRA) DEVELOPMENT

OBJECTIVE

This section presents a Roadmap for developing a Driver Rating Application (DRA) based on data collected from freight trucks. This application aims to provide quantitative and qualitative feedback on driving behaviour to drivers of BETs, fleet operators, and other agencies as appropriate. This application would help in:

1. Evaluating the drivers for energy-efficient driving habits on BET
2. Comparing the driving patterns of various drivers on the same route
3. Linking the driving pattern to the energy consumed
4. Providing appropriate advice on modifying driving habits to reduce energy consumption
5. Granting rewards and recognition through the gaming app and encouraging competition in the community for safe and efficient driving

TASKS

The DRA process and evaluation involve the following tasks:

1. Identify variables to be collected that would reflect driving habits.
2. Develop rating metric(s) based on the collected data.
3. Develop the application for driver rating.
4. Develop a mechanism to provide the necessary advice and evaluate its impact through "before-after" analysis.

STAKEHOLDERS

1. Fleet operators
2. Drivers
3. Professional application developers
4. Academia
5. OEMs

METHODOLOGY

The following steps are involved in completing the above tasks:

1. The work in this Roadmap is dependent on the outcome of the following activity/Roadmap
    a. Acquisition of drive cycle data
2. Identification of variables to be collected
3. Evolution of metrics to characterise driver performance
4. Development of the DRA
5. Evaluation of DRA
6. Impact assessment of appropriate interventions
7. Deployment of the application on all pilot vehicles and their drivers

DELIVERABLES

The following are the proposed deliverables of this activity:

1. Variables to be collected (as per the methodology)
2. Preparing metrics for characterising driver performance
3. Development of the DRA
4. Launch and implementation of the Gaming and R&R schemes

TIMELINE

The timeline for each task under this Roadmap is provided in Figure 4.

FIGURE 4: TIMELINES FOR THE DEVELOPMENT OF DRIVER RATING APPLICATION (DRA)

ACTIVITY	PERIOD (Months)									
	1	2	3	4	5	6	7	8	9	10
Identification of variables to be collected										
Development of rating metric(s)										
Development of app for driver rating										
Maintaining DRA and DRA data on backend server										

The estimated budget for carrying out the above-mentioned activities is **₹30 lakhs**

3.4 FIELD RESEARCH – FUEL CELL ELECTRIC TRUCKS

OBJECTIVE

A precondition for the successful adoption of Fuel Cell Electric Trucks (FCET) is the design of the right product. A product that does not meet the core requirements of the market can set back widespread adoption in a few years. The Indian trucking market has evolved over the years with several unique features, the multi-axle rigid haulage trucks being the prime example. The nature of Indian trucking is markedly different from the rest of the world. Due to the evolutionary nature of this sector, and its informal nature, it is difficult to capture all the requirements for a significantly different option, such as the FCET, and their criticality without testing different design options in tightly controlled pilots.

However, given the varied nature of the geography, nature of cargo carried, road conditions, climate, driving patterns, loading patterns, vehicles used, and usage conditions across the country, it is important to conduct these pilots in multiple corridors that cover all these variations. Extensive field research is required to first identify the major freight corridors in India and then map out the variations across these corridors so that we can shortlist the candidates for the pilots.

This section details the Roadmap for this field research. The initial part of the field research—in terms of identification of major corridors and collection of data for each of these corridors—can be combined with the exercise being carried out for BETs to avoid duplication.

TASKS

The exercise to shortlist the candidate corridors for FCET pilots will involve the following major tasks:

1. Identify the major corridors of freight in India
2. Collect data for each corridor
3. Analyse the collected data
4. Shortlist candidate corridors for pilots

STAKEHOLDERS

1. Government and policymakers
2. End customers–freight users
3. Automotive Original Equipment Manufacturers (OEMs)
4. Spare dealers and service stations
5. Fleet owners/fleet operators/cargo aggregators
6. Drivers
7. NHAI
8. Infrastructure providers (DISCOMs, fuel stations, charging providers, etc.)

METHODOLOGY

The following steps are involved in completing the above tasks:

1. Identification of the research agency
2. Collection of data regarding freight movement from multiple sources
3. Identification of around 30 corridors for extensive field research, focusing on their suitability for FCETs. It is possible that the ideal corridors for BET pilots and FCET pilots may have different criteria, resulting in an altogether different set of corridors for each category of ZET
4. Formulation of data to be collected during the field research
5. Formulation of data collection methodology

6. Field research in a few corridors
7. Data analysis, review of the results, and fine-tuning of the methodology
8. Completion of field research in all the corridors
9. Collation and analysis of the data
10. Shortlisting of six corridors, with an additional three as backup

DELIVERABLES

The following are the proposed deliverables of this field research:

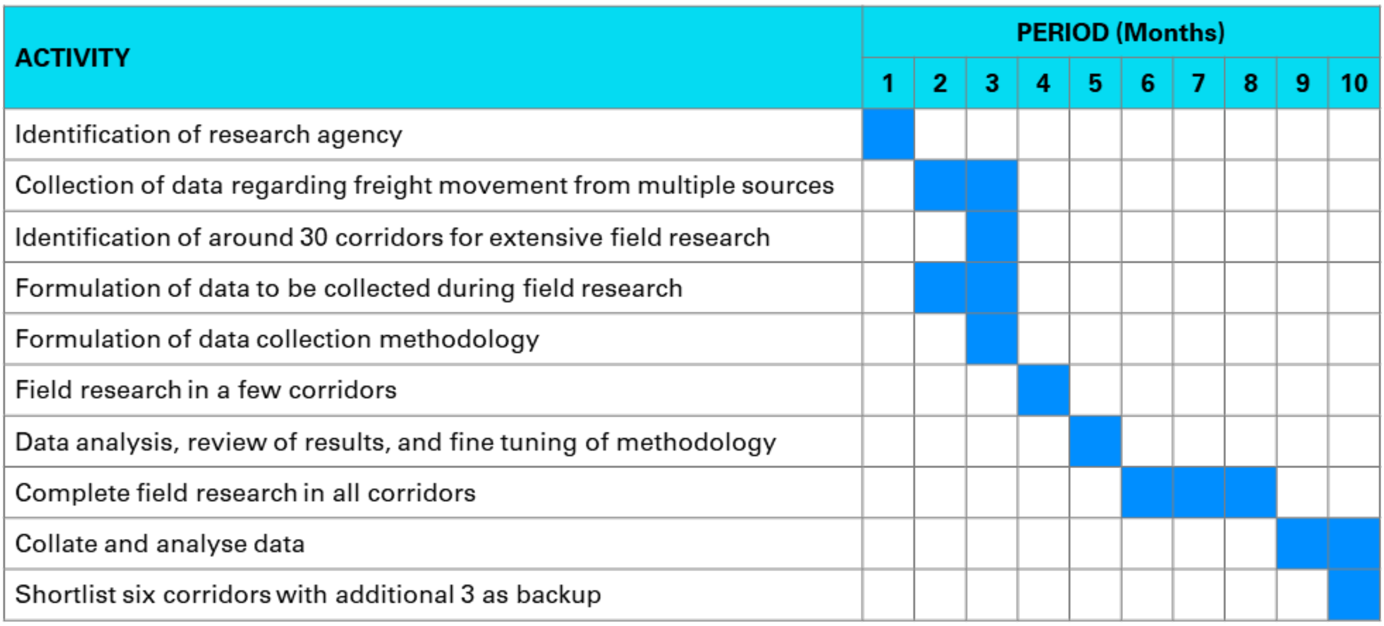
1. To be done for a total of 30+ corridors.
2. To be split into four projects, each comprising about eight corridors in neighbouring regions.
3. All four projects are to be carried out in parallel.
4. The following details are to be obtained for each corridor to help with the shortlisting of the ten corridors for pilot FCET runs:
    a. Traffic density, categorised by vehicle tonnages and nature of the cargo
    b. Map of high-tension powerlines and substations near the corridor
    c. Map of fuel stations along the corridor, along with information such as sales, ownership, etc.
    d. Map of major automotive servicing hubs along the corridor
    e. Map of fire stations along/near the corridor
    f. Map of non-highway-like areas (more mixed traffic, pedestrians or two-wheeler traffic, etc.) on the corridor
    g. For a statistically representative volume of vehicles:
        i. Vehicle–make, model, and year
        ii. Driver–name, age, driving experience in years
        iii. Mobile number
        iv. Origin
        v. Destination
        vi. Driving pattern, speed vs. time, including wait/halt times, fuel consumed, etc.
        vii. Payload nature (perishable, hazardous, etc.), volume, and weight
        viii. GVW
        ix. Fuel
        x. Engine
        xi. Owner of the Vehicle
        xii. Vehicle financing
        xiii. Life Cycle of the Vehicle
        xiv. Fleet size
        xv. Driver-to-vehicle relationship
        xvi. Predictable or fixed vs. variable or random route and cargo
        xvii. Customer for the cargo
        xviii. Revenue vs. expenses per trip
        xix. Telematics–yes/no
        xx. Driver monitoring system–yes/no
        xxi. Is the operator using any apps for maintenance, fuel, driving improvement, safety, and other parameters?
        xxii. Is the operator aware of electric vehicles (2W/3W/4W/trucks)?
        xxiii. Is the operator ready to embrace FCET?
        xxiv. Perceived advantages and issues with FCET
        xxv. Preferred driving pattern–working time vs. rest times
        xxvi. Preference to change driving pattern for fuel cell electric trucks–yes/no
5. Find out the time drivers are willing to wait for charging during their day and night in different applications and different routes.
6. Measure and model actual energy consumption based on driving patterns and usage, for better vehicle design along with planning recharging infrastructure.

7. Human/driver response to an FCET vis-à-vis an ICE truck.
8. Willingness to change driving habits, take requisite breaks in between, willing to use apps and other necessary modifications
9. Identify the proportion of cargo limited by GVW vs. limited by volume
10. Identify the proportion of hazardous goods carried vs. non-hazardous goods

TIMELINE

The timeline for each task under this Roadmap is provided in Figure 5.

FIGURE 5: TIMELINES FOR CONDUCTING FIELD RESEARCH FOR FCET



The estimated budget for carrying out the above-mentioned activities is **₹360 lakhs**

3.5 UPDATING CMVR TO INCORPORATE OH-ACD STANDARDS

OBJECTIVE

It is critical to provide the regulatory framework and required technical standards to enable the Industry to produce safe, reliable, and interoperable technologies for the effective implementation of the Zero Emission Trucking (ZET) initiative. An important task towards realising ZET is designing and developing robust battery recharging mechanisms by connecting to the electrical power grid. This section details the Roadmap for updating the vehicle side regulation and standards for an Overhead Automated Charging Device (OH-ACD) for Battery Electric Trucks. Existing standards need an update to include provisions required on the vehicle side.

TASKS

1. Identify requirements
2. Update Central Motor Vehicles Rules (CMVR) for BEV, vehicle side requirements
3. Communicate with concerned ministries for specific requirements
4. Enable existing Panels to deliberate and finalise updated standards and regulation
5. Obtain approval from the concerned ministry and notification

STAKEHOLDERS

1. Government and policymakers
2. OEMs
3. Charger manufacturers

METHODOLOGY

The following steps are involved in completing the above tasks:

1. Update Central Motor Vehicles Rules (CMVR) for BEV (vehicle side requirements)
    a. Update vehicle level requirements for construction, functional safety, electrical specifications (resistance/inductance), and communication protocols due to OH-ACD and other high-power charging methods
    b. Dimensional requirements for interoperability
    c. Location of OH-ACD on Vehicle
    d. Requirement for internal high voltage wiring connections

DELIVERABLES

The following are the proposed deliverables of this activity:

1. BEV vehicle side standard
2. Standard publishing and notification(s)

TIMELINE

The timeline for each task under this Roadmap is provided in Figure 6.

FIGURE 6: TIMELINES FOR UPDATING CMVR TO INCORPORATE OH-ACD STANDARDS

ACTIVITY	PERIOD (Months)							
	1	2	3	4	5	6	7	8
Global regulation research								
Roadmap requirement								
Communication to different requirements								
CMVR panel BEV vehicle side requirements								
Notification by concerned ministry								

There is no financial budget required for this activity as this would be part of the regular CMVR Committee activities.

3.6 UPDATING CMVR FOR BATTERY ELECTRIC TRUCK

OBJECTIVE

To propose suitable changes in the regulatory framework and the technical standards for safe, reliable, and interoperable technologies in BET. Focus areas to fulfil this objective are standardisation of battery communication protocol, proposing appropriate drive cycle for range/energy assessment, and assessment of gross vehicle weight (GVW). Other areas for regulations are not addressed in this Roadmap and are expected to be discussed as part of the established regulatory framework.

TASKS

1. Study international standards for battery communication if any
2. Finalise suitable communication protocol to offer interoperability for batteries
3. Finalise drive data and propose drive cycle
4. Collect data to understand the GVW considerations
5. Finalise regulatory framework alignment for GVW

STAKEHOLDERS

1. Government and Policymakers
2. Automotive Original Equipment Manufacturers (OEMs), component suppliers
3. CMVR-AISC committees
4. Electric Vehicle Charger OEMs

METHODOLOGY

The following steps are involved in completing the above tasks:

1. Determine technical requirements of battery communication protocol
2. Propose appropriate communication protocol, seek feedback from stakeholders, and update the standards
3. Analyse field data to propose the drive cycle, seek feedback from stakeholders, and update the standards
4. Analyse field data to propose the GVW, seek feedback from stakeholders, and update the standards
5. Ratify the standard by the concerned ministry
6. Identify a suitable Indian agency for the establishment of test facilities for testing of battery communication protocol
7. Augment a test facility for ZET

DELIVERABLES

The following are the proposed deliverables of this activity:

1. The standard for battery communication protocol
2. The standard for drive cycle
3. Standard for GVW

TIMELINE

The timeline for each task under this Roadmap is provided in Figure 7.

FIGURE 7: TIMELINES FOR UPDATING CMVR FOR BET

ACTIVITY	PERIOD (Months)								
	1	2	3	4	5	6	7	8	9
Study of battery communication protocol									
Prepare protocol document and review of stakeholders									
Update standards for battery communication Protocol									
Collect drive cycle data									
Study of drive cycle data (received from field research)									
Prepare drive cycle and review of stakeholders									
Update standards for battery communication protocol									
Notification									
Augmentation of test facility for ZET									

The estimated budget for carrying out the above-mentioned activities is **₹2512 lakhs**. This estimate also includes the estimated budget of **₹2500 lakhs** towards the upgradation of the existing test facilities for ZET.

3.7 UPDATING CMVR FOR FUEL CELL ELECTRIC TRUCK

OBJECTIVE

To support the ZET initiative, it is of utmost importance to provide a regulatory framework and required technical standards to enable the Industry to produce safe, reliable, and interoperable technologies. Existing standards need to be updated to include provisions required on the Vehicle, component, and infrastructure sides.

Fuel Cell Electric Vehicles (FCEV) are a potential candidate when it comes to ZET, and standard(s) for Fuel Cell (FC) in automotive applications and Fuel Cell Electric Vehicle (FCEV) need to be reviewed/updated accordingly.

TASKS

1. Benchmark FC and FCEV standards
2. Identify requirements for FC and FCEV standards
3. Update Central Motor Vehicles Rules (CMVR) for FCEV, vehicle side requirements
4. Communicate with different ministries for specific requirements
5. Enable existing Panels to deliberate and finalise updating standards and regulation
6. Formulate new standard(s)/update existing standard(s)–to be performed by concerned Panel(s)
7. Obtain approval from the concerned ministry and notification
8. Establish test facilities for testing and certification of FC and FCEV

STAKEHOLDERS

1. Concerned ministries
2. OEMs
3. Hydrogen generation and dispensation agencies
4. PESO
5. BIS committees
6. CMVR-AISC committees

METHODOLOGY

The following steps are involved in completing the above tasks:

1. Updating and harmonising vehicle level requirements with relevant, up-to-date international standard(s)
2. Updating and harmonising component-level requirements with relevant, up-to-date international standard(s)
3. Making arrangements for hydrogen storage and transportation
4. Finalisation of driving cycle for range and fuel consumption measurement
5. Finalising methodology for hydrogen fuel consumption measurement
6. Finalising H_2 fuelling protocol
7. Formulation of standards for fuel cell module/stack performance and safety testing
8. Ratification of the standard(s) by concerned ministry(s)
9. Identification of a suitable Indian agency for the establishment of test facility(s) for FC and FCEV testing

DELIVERABLES

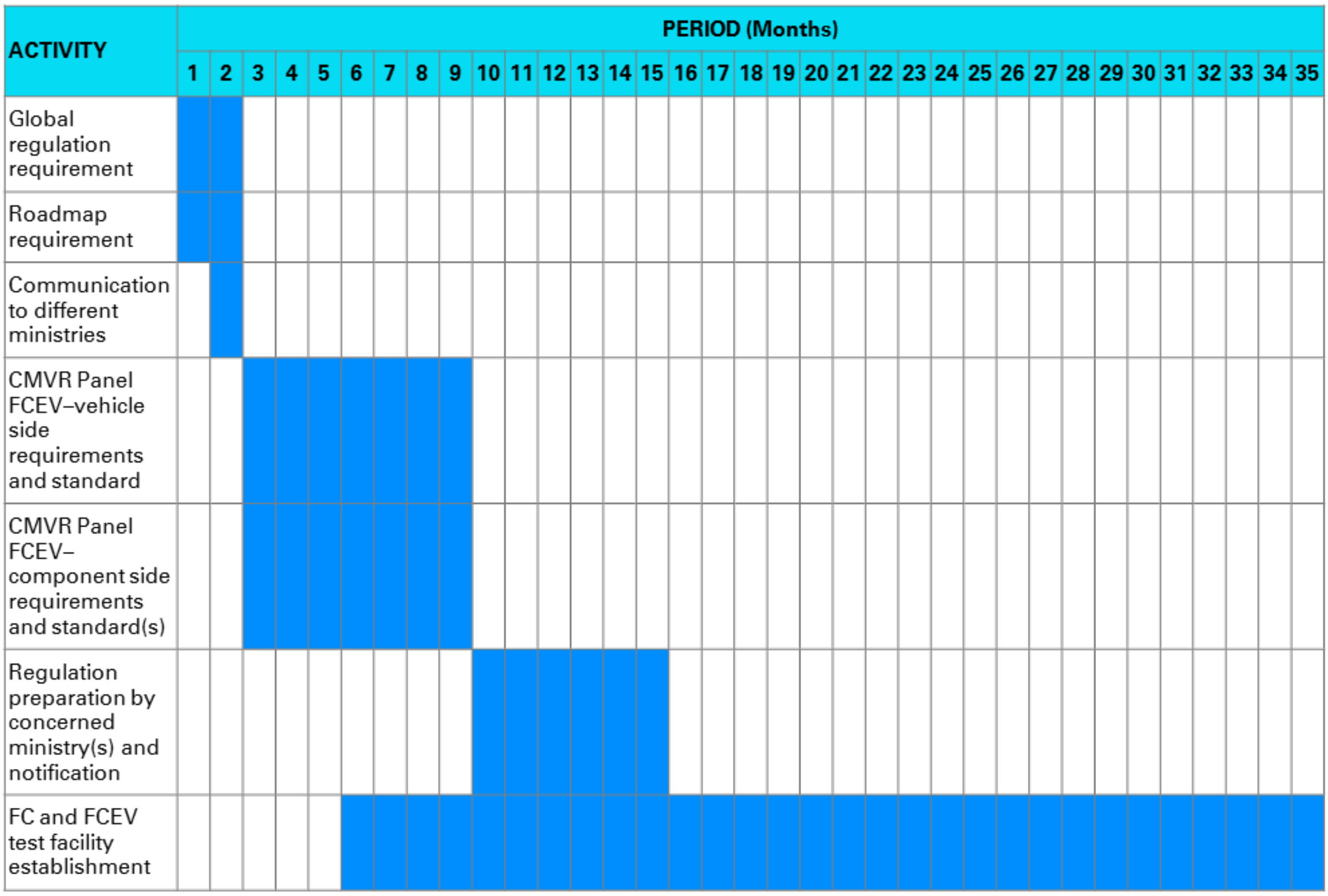
The following are the proposed deliverables of this activity:

1. FCEV vehicle side standard
2. FCEV component side standard(s)
3. Standard publishing and notification(s)
4. FC and FCEV test facility establishment

TIMELINE

The timeline for each task under this Roadmap is provided in Figure 8.

FIGURE 8: TIMELINES FOR UPDATING CMVR FOR FCET



The estimated budget for carrying out above mentioned activities is **₹12555 lakhs**. This Roadmap also includes the establishment of required test facilities for FC and FCEV as an important milestone and the estimated budget for the same is **₹12500 lakhs**

3.8 BATTERY STANDARDISATION FOR ZET AND RELATED VEHICLES

OBJECTIVE

Over the next couple of decades, the Battery Electric Truck (BET) and Fuel Cell Electric Truck (FCET) sale volumes are expected to steadily increase on account of superior economics as well as pressures on emission control. To get an idea of the scale, if 50,000 eTrucks are sold each year, with 200 kWHr of battery in each eTruck, then 10 gigawatt hours of battery packs will be put into eTrucks that year. It is important to protect end consumer interests and the interests of the other ecosystem players (such as vehicle OEMs, suppliers, recyclers, researchers, and others) with optimal and well-balanced standards that are evolved in consultation with stakeholders. It is to be noted that this activity is to be restricted to fixed batteries and not necessarily be extended to swappable batteries, which have their requirements, limitations, and complications for standardisation.

While the primary focus would be to increase protection to end consumers over the life of the Vehicle with replacement batteries, with a certain amount of interoperability, the following advantages are expected to accrue to the respective stakeholders:

CONSUMER/ PUBLIC/ NATION/ ECOSYSTEM

1. A security that the consumer will find a replacement battery whenever needed. Timely replacement of the battery is a concern in the eMobility sector, where there are many good start-ups with possible acquisitions or dissolutions.
2. The competition will drive costs down for the consumer.
3. Repurposing (2nd life) becomes far easier since similar batteries can be productised much faster and in a cheaper manner.
4. Easier safety metrics to adhere to
5. Rapid electrification of different sectors helps various aligned government missions

OEMs

1. eMobility is at an early stage and migrating to a standard now is far easier.
2. Supply chain options improve drastically for cost and quality, with a rapid change in suppliers when required, something like AUTOSAR for software.
3. Inventory and the cost of spare parts will decrease
4. Ample potential to innovate, differentiate, and offer value propositions
5. The possibility of making the standard optional for OEMs should be evaluated and enabled, with a long-term mandating plan for the standards with due diligence and concurrence

BATTERY SUPPLIERS

1. Much higher volumes and scale.
2. Direct access to the spare part market where value chains permit.
3. Enough opportunity to innovate within minimal constraints.

RECYCLING AND REPURPOSING PARTIES

1. Standardised format and interface specifications help reduce costs for repurposing, which is currently prohibitive
2. Improved level of automation, draining, handling, mechanicals, and others

In addition to all the above-mentioned advantages, one key and enabling advantage is that the lenders for these trucks will be able to identify the value of batteries separately in each truck and accordingly fund or estimate resale values, which in turn shall enable funding for the ZET ramp-up phase.

The above lists of advantages show that there is merit in limited standardisation to further the interests of various ecosystem players and doing this in a minimalistic manner to allow maximum space for innovation. It is also important to have these standards published for voluntary compliance if parties see merit, and not mandate it as regulation for at least the initial 3 or 5 years. The merits of standardisation will have to drive the market players, where relevant, to comply with these minimalist standards and they should be mandated, if at all, after another round of consultations after 3 or 5 years. Essentially, the trade-off between full freedom on all fronts and innovation and a larger interest in the Ecosystem will need to be evolved and finalised. Innovation and standardisation are not necessarily mutually exclusive, and standardisation has driven innovations in the past.

TASKS

The evolution and publishing of such a battery standard for ZETs will entail the following tasks:

1. Constitute a Panel that has subject matter experts, business stakeholders, user interest representatives, regulation makers like ARAI, and others
2. Hire, at extra cost, the scribers for these standards and the technical evaluators of the standards
3. The Panel must be given a clear brief by an appropriate authority regarding the minimum expectations and evolution of various aspects of interoperability and standardisation
4. Identify the technical, operational, and business constraints for OEMs and suppliers, so that these are suitably incorporated while making the standards. Items like packaging, cooling strategies (different for different vehicles and constantly evolving), supply chain security, and others are to be listed so that the standards are not rendered unimplementable.
5. In the context of ZET, identify the essential parameters (size, weight, mounting points, a couple of connector options, voltage, basic CAN signal, and others) that need to be standardised to permit user options and interoperability
6. Identify the number of standards, limited to three, that will be required to provide sufficient flexibility to OEMs and the supply chain
7. Discuss and evaluate the different options and variants, and finalise with technical due diligence by test agency(s)
8. Provide sufficient criteria for safety if required, in addition to what regulation already provides (repurposing or recycling)
9. Write out the entire standard(s) purely for the context of ZET and related vehicles
10. Ensure ratification of standard(s) by AISC
11. Obtain notification from the concerned ministry

STAKEHOLDERS

1. Concerned ministry(s), test agency(s), AISC
2. Automotive Original Equipment Manufacturers (OEMs) and their suppliers.
3. Technical experts in battery pack engineering and vehicle engineering, in the domain of ZETs.
4. Charger OEMs.

5. Battery pack recycling parties.
6. Battery repurposing parties.

METHODOLOGY

The following steps are involved in completing the above tasks:

1. A carefully constituted Panel will help in evolving optimal and realistic standards
2. The standards will be, to the realistically possible extent, applicable in a common manner to ZET and allied vehicles like buses
3. The end objective of the standard is to be consumer-focused and drive interoperability
4. The amount of energy, the cell chemistry, the cell form factor, and BMS capabilities should be left open so that vendors can innovate, differentiate, and offer different value propositions
5. Since this covers a wide variety of trucks and probably buses as well, it may be necessary to consider 3 different standards that will provide flexibility to OEMs and suppliers while still protecting the interests of the consumer and the Ecosystem
6. Engineering challenges and concerns need to be listed out and addressed with sufficient time for the development and discovery of alternate solutions
7. The connector specifications should not result in a monopoly for one single design. If that cannot be avoided, it should either be offered as free IPR or preferably developed from scratch for the Indian context but in partnership with different connector suppliers. At the end of the day, the specifications need to be vendor-agnostic and enable constant evolution by other vendors while still complying with the Interoperability Standards
8. Provision needs to be made for updates as technology evolves, which happens constantly and rapidly in the global battery field
9. Strong leadership in this effort, along with in-depth technical assessments, will be required to ensure relevance and success

DELIVERABLES

The following is the proposed deliverable of this activity:

1. Battery standard(s) for ZET

TIMELINE

The timeline for each task under this Roadmap is provided in Figure 9.

FIGURE 9: TIMELINES FOR DEVELOPING BATTERY STANDARDS FOR ZET AND RELATED VEHICLES

ACTIVITY	PERIOD (Months)									
	1	2	3	4	5	6	7	8	9	10
Panel Constitution and Brief										
Arrangements for Scribes										
Arrangements for Technical Consultant										
Listing out Consumer needs										
Listing out Vehicle OEM needs										
Listing out Battery Supplier needs										
Listing out Recycler's needs										
Listing out Repurposer needs										
Engineering assessment of the above										
Arrive at list of items that need to be standardised										
Calculate and prepare values for the items that are to be standardised										
Final report on issues, solutions and proposal on technical parameters by consultant										
Addition criteria for safety–apart from what is already addressed by CMVR on regular and ongoing basis										
Scribing of final draft Standard										
Review and concurrence of Panel Members										
AISC ratification										

The estimated budget for carrying out the above-mentioned activities is **₹100 lakhs**

3.9 DEVELOPMENT OF OVER-HEAD AUTOMATED CHARGING DEVICE FOR BET

OBJECTIVE

This section details the Roadmap for developing an OH-ACD for BETs. A few specific requirements are:

1. The charging device should be fully automatic and connect physically with the corresponding charging rails/receptacle present on the rooftop of the Vehicle
2. The design should be a "top-to-down" movement, i.e., the overhead connection mechanism fixed to a static pole/charging station should move downward and mate with the charging rails/receptacle on the Vehicle. This ensures that a movable connecting mechanism is avoided on vehicles, thereby decreasing overall costs, and improving reliability
3. The ACD should have a current rating of around 500–600 A
4. It should be safe
5. It should be interoperable in compliance with the relevant standards released by the Bureau of Indian Standards, Government of India, which is currently in the draft stage

TASKS

The development of the OH-ACD broadly involves the following tasks:

1. Mechanical design of the ACD mechanism
2. Sensing, control, and actuation design for the ACD mechanism
3. Electrical design to enable electrical energy transfer from the grid to the battery through the charger
4. Electronics design for the associated power electronic circuits
5. Communication design to enable the automatic coupling of the ACD to the Vehicle charging unit. This may also need appropriate communication needs with the power supply grid and cloud.
6. Software design that links and monitors the entire system
7. Prototyping, POC, and validation

STAKEHOLDERS

1. Government and policymakers
2. OEMs
3. Charger manufacturers
4. Distribution companies (DISCOM)
5. Academia

METHODOLOGY

The following steps are involved in completing the above tasks:

1. The work in this Roadmap is dependent on the outcome of the following activity(s)/ Roadmap(s)
    a. Updating CMVR to incorporate OH-ACD standards
2. Market and technology research to review requirements.
3. Finalisation of technical requirements.
4. Research and development on the above tasks to meet the corresponding requirements.
5. Validation of the developed prototypes.
6. Pilot field studies.
7. Delivery of OH-ACD Prototype to IITM and nominated test agencies (Total 4 Nos.).

DELIVERABLES

The following are the proposed deliverables of this activity:

1. Four OH-ACD prototypes that are validated over time with suitable modifications as required
2. Detailed designs for the same

TIMELINE

The timeline for each task under this Roadmap is provided in Figure 10.

FIGURE 10: TIMELINES FOR THE DEVELOPMENT OF OVER-HEAD AUTOMATED CHARGING DEVICE FOR BET

ACTIVITY	PERIOD (Months)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Market and technology research to review requirements																		
Finalisation of technical requirement																		
Research and Development on mechanical, Electronics, sensing, control and communication related components																		
Prototype validation and Proving																		
Pilot Field study																		
Prototype Finetuning and Delivery																		

The estimated budget for carrying out the above-mentioned activities is **₹605 lakhs**

3.10 EVALUATION OF RARE EARTH MAGNET-FREE MOTORS FOR ELECTRIC TRUCKS

BACKGROUND

In the recent past, induction Motors (IM) were being used for Electric Vehicle (EV) traction applications at the nascent stages of the EV revolution. However, with the advent of Permanent Magnet Synchronous Motors (PMSM) and the inherent advantages offered by PMSM, the use of IM as a prime mover in EVs has decreased considerably. However, with the extensive use of PMSM and with the ever-increasing number of EVs coming on Indian roads, dependency on other countries for raw materials used in PMSM, particularly rare-earth-based magnets, has come to the fore and is being widely debated. To address the concern of dependence on rare earth magnets, people have been working on IM design and performance improvement as well as Synchronized Reluctance Motor (SyRM). Both IM and SyRM can be cost-effective options with no dependency on any other countries.

However, when it comes to electric trucks, all available options viz.; PMSM, IM, and SyRM need to be evaluated for their suitability to meet application-specific requirements and their sensitivity to the supply chain dependence on other countries.

OBJECTIVE

An efficient, durable, and reliable cost-effective e-powertrain is the key to sustainable e-mobility and ZET. This section details the Roadmap for the assessment and comparison of suitable e-motor technology for electric trucks. Key requirements of e-motor for traction application can be summarised as:

1. Indigenous manufacturing with a robust supply chain
2. Should be competitive, reliable, and durable

TASKS

The assessment and comparison of suitable e-motor technology broadly involve the following tasks:

1. Explore, compare, and weigh existing e-motor technologies for performance, which can be used for traction applications in electric trucks such as:
    a. Permanent Magnet Synchronous Motor (PMSM)
    b. Induction Motor (IM)
    c. Synchronous Reluctance Motor (SyRM)
2. Assess BOM cost and overall TCO at a vehicle level
3. Assess supply chain risks
4. Prepare a report on the evaluation of different technologies pertaining to motors
5. Assessment and validation of the report to be performed by academia

STAKEHOLDERS

1. OEMs
2. E-motor manufacturers
3. Power electronics manufacturers
4. Test agency(s)
5. Academia

METHODOLOGY

The following steps are involved in completing the above tasks:

1. Market research to ascertain the needs
2. Techno-commercial research to review existing solutions and improvements required in existing technologies (if any)

DELIVERABLES

Report on evaluation of rare earth magnet-free motors containing:

1. Requirements of e-motor for e-trucks
2. The outcome of an evaluation of all available motor options viz.; PMSM, IM, SyRM etc.
3. Guidelines for the use of motor technology for ZET

TIMELINE

The timeline for each task under this Roadmap is provided in Figure 11.

FIGURE 11: TIMELINES FOR THE EVALUATION OF RARE EARTH MAGNET-FREE MOTORS FOR ELECTRIC TRUCKS

ACTIVITY	PERIOD (Months)							
	1	2	3	4	5	6	7	8
Market research								
Techno-commercial research								
Report on evaluation of e-motors of different technologies								
Report validation with academia								

The estimated budget for carrying out the above-mentioned activities is **₹40 lakhs**

3.11 REGULATION AND SUPPLY CHAIN FOR ON-BOARD HYDROGEN STORAGE

OBJECTIVE

A pre-condition for the successful adoption of FCETs is to have a localised supply chain for reliable, compact, safe, and cost-effective on-board hydrogen storage and use. Hydrogen is the lightest element, and it is difficult to store. It requires strong composite tanks to store hydrogen. The most mature and commonly used storage technology involves storing hydrogen in compressed gaseous form (350 bar or 700 bar). Different storage cylinders are used, ranging from Type 1 to Type 4, depending upon the pressure of the compressed hydrogen. Therefore, a key challenge is storing enough hydrogen on-board without sacrificing cargo space.

The first generation of FCETs used 350 to 700 bar pressure for Hydrogen with Type III or Type IV pressure cylinders to store hydrogen. At present, these technologies are imported by Indian OEMs. Given the Indian cost structures, the use of Type IV cylinders increases the cost of storing hydrogen due to the high cost of the carbon fibre composite material.

This section details the Roadmap for technology research and development for making India independent for such a critical FCET component.

TASKS

1. Identify organisations/institutes/extended work/reports for composite material research
2. Update standards and regulations related to storage tank

STAKEHOLDERS

1. Government and policymakers, including PESO
2. Automotive Original Equipment Manufacturers (OEMs)
3. Cylinder manufacturers
4. Academia

METHODOLOGY

The following steps are involved in completing the above tasks:

1. The work in this Roadmap is dependent on the outcome of the following activity(s)/ Roadmap(s)
    a. Updating CMVR for Fuel Cell Electric Truck
2. Identification of the research agencies
3. Identification of near-term and long-term research needs for on-board hydrogen
4. Evaluation of sub-ambient storage temperature technology
5. Evaluation of material-based hydrogen storage technologies.
6. Identification of interested Indian companies for local manufacturing
7. Establishment of a local manufacturing facility
8. Establishment/upgradation of a high-pressure cylinder test facility

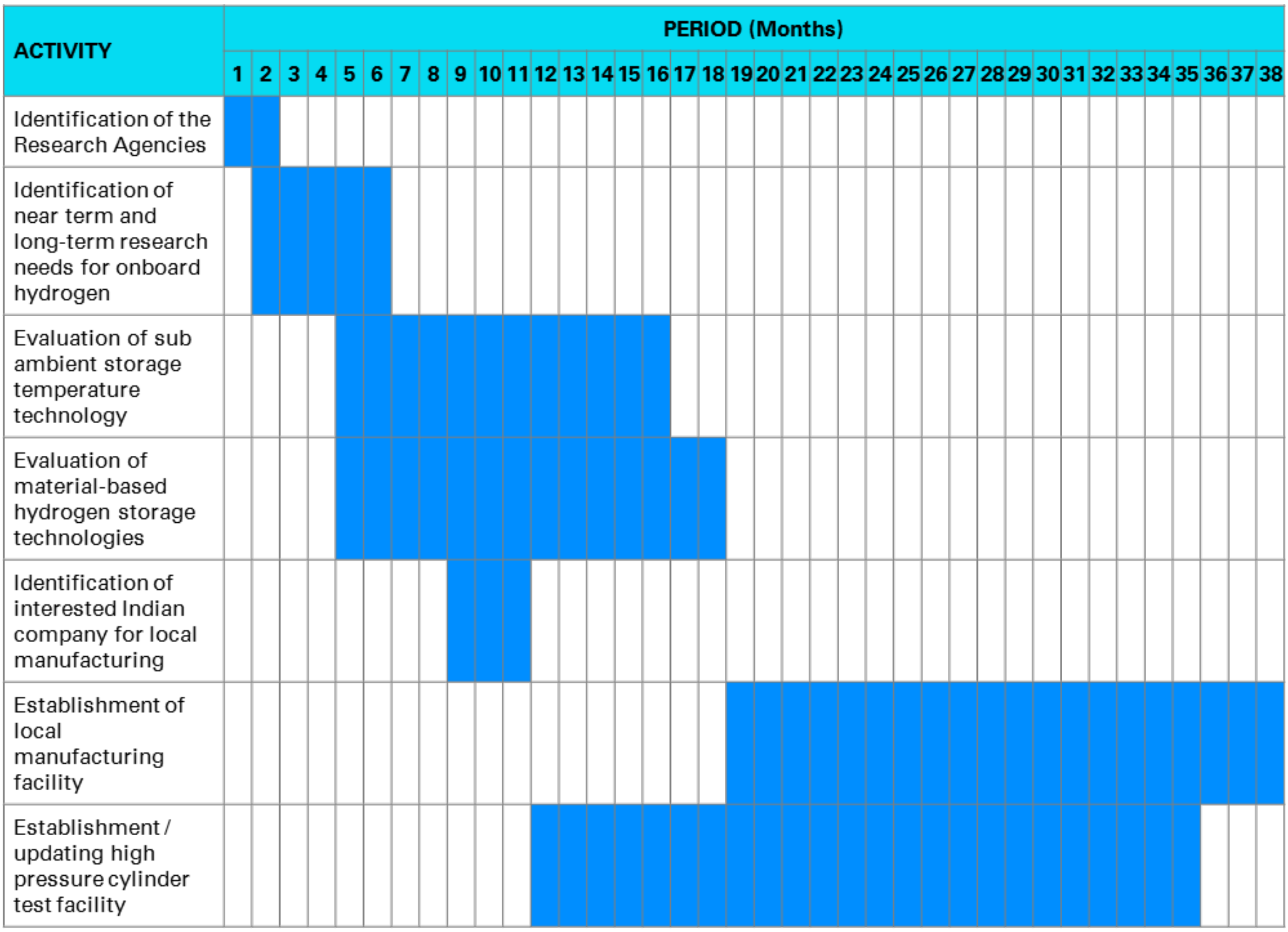
DELIVERABLES

1. National plan for design, development, and manufacturing of required technology for on-board hydrogen storage
2. Availability of relevant standards and testing facility for on-board hydrogen storage

TIMELINE

The timeline for each task under this Roadmap is provided in Figure 12

FIGURE 12: TIMELINES FOR FORMULATING REGULATION AND SUPPLY CHAIN FOR ON-BOARD HYDROGEN STORAGE



The estimated budget for carrying out the above-mentioned activities is **₹2275 lakhs**. This estimate also includes the estimated budget of **₹2000 lakhs** towards the establishment/up-gradation of existing test facilities for cylinder testing.

3.12 FINANCE FOR BATTERY ELECTRIC TRUCKS

OBJECTIVE

For commercial vehicles in general and long-distance, heavy-duty trucks, almost every new truck deployed requires carefully designed financial products. In future, BETs may have possibly lower total costs for certain applications. However, the higher upfront eTruck costs, the higher costs of new charging infrastructures, and the subsequent lower operating costs will require the development of a new set of financial products as per the revised cash flow requirements. Suitable financial products are required to ensure success, both for the pilot and ramp-up phase

Given that more than 90% of such trucks are owned and operated by very small fleet owners who own 20 trucks or less, financial products become much more important for the rapid growth of eTrucks [6]. The cash flows and costs that are generated over the period of financing will require careful design and productising.

There will need to be a set of specific financial products for the pilots, which will include viability gap funding for the pilots and the first loss risk coverage for the lenders and another similar set of products for the economic ramp-up phase. Therefore, two sets of financing products (which include loans, VGF, and risk loss cover) are to be designed and offered to the operators and CaaS (charging as a service) providers: one for the pilot phase and another for the regular economic ramp-up phase.

There is a certain mechanism by which drivers are compensated by the owners or operators of the trucks. These are primarily centred around the fuel allowances; such options do not exist for BETs and hence there is a need to come up with a suitable and innovative compensation model that the operator/owner can offer the driver.

This section details a Roadmap, consisting of the actions that are required to be taken to have such techno-commercial financing products ready.

TASKS

The design of the two financing products will entail the following major tasks:

1. An expert effort to assess the costs of assets and expenses of operations
2. Prepare cash flow and profitability statements to arrive at the specific requirements for Pilots
3. Design loan products for pilots
4. Design VGF products for pilots
5. Design risk loss products for pilot financiers
6. Prepare cash flow, profitability, and related trends over a period of 10 years as eTrucking become more competitive
7. Design loan products for economic ramp-up
8. Design VGF products for the economic ramp-up phase, with a limited period and quantity scope (based on the 10-year trend)
9. Design risk loss products for the economic ramp-up phase, with a diminishing cover over 10 years
10. Objectively establish the importance of battery standards to financiers to reduce their risk in offering loan products

[6] Sarkar, A., Jha, A., & Mukherjee, D. (2018). Rise in sales of multi axle trucks in India: Governmental initiatives, industrial development, and operator preferences. Indian Journal of Marketing, 48(7), 7-22.

STAKEHOLDERS

1. Government and policymakers
2. End customers–freight users
3. Automotive Original Equipment Manufacturers (OEMs)
4. Fleet owners/fleet operators/cargo aggregators
5. Infrastructure and/or CaaS providers (DISCOMs, fuel stations, charging providers, etc.)
6. Financing entities, preferably multi-lateral agencies like World Bank, Asian Development Bank, and others
7. Finance product retailers (NBFCs, banks, and others)
8. Risk cover agencies.

METHODOLOGY

The following steps are involved in completing the above tasks:

1. The work in this Roadmap is dependent on the outcome of the following activity(s)/ Roadmap(s)
    a. Field research–BET
    b. Acquisition of drive cycle data
2. Finalise the pilot plan–at least to the level of taking financing decisions.
3. Finalise the projected capital costs for pilots.
4. Draw up projected capital and running costs for pilots as well as for the ramp-up phase.
5. Prepare projected cash flows for the pilot as well as the ramp-up phase (with decreasing eTruck and infrastructure costs over the years).
6. Draw up VGF needs and options and reduction/phase-out plans.
7. Draw up loan requirements and channels.
8. Draw up risk coverage requirements and reduction/phase-out plans.
9. Interview finance product providers with well-designed questionnaires to establish the importance of battery standards for them to offer less risk-prone products for ZET.

DELIVERABLES

1. A set of finance, viability gap, and risk products for the pilot with options, recommendations, and sensitivity analyses
2. A set of finance, viability gap, and risk products for the ramp-up phase with options, recommendations, and sensitivity analyses
3. Phase out a plan for VGF in the ramp-up phase over the years
4. Phase out a plan for risk loss cover in the ramp-up phase over the years
5. The scale of loan, VGF, and risk loss cover required over 10 years (including pilots) to facilitate budgeting and funding

TIMELINE

The timeline for each task under this Roadmap is provided in Figure 13.

FIGURE 13: TIMELINES FOR DEVELOPING ENABLING FINANCIAL MEASURES FOR BATTERY ELECTRIC TRUCKS

ACTIVITY	PERIOD (Months)				
	1	2	3	4	5
Assess costs for pilots–industry experts					
Assess costs for ramp up phase- industry experts					
Cash flow and P&L preparations for pilots					
Loan products design & offer–pilots					
VGF products design & offer–pilots					
Risk products design & offer–pilots					
Cash flow & P&L preparations for ramp up phase					
Loan products design & offer–ramp up phase					
VGF products design & offer–ramp up phase					
Risk products design & offer–ramp up phase					
Current driver compensation research					
Design of BET driver compensation options					
Offer compensation schemes and supporting tools					

The estimated budget for carrying out the above-mentioned activities is **₹65 lakhs**

3.13 SAFETY AWARENESS, TRAINING, MANUALS, GUIDELINES FOR BET

BACKGROUND

For effective ZET penetration and sustained utilisation in the field, safety concerns, safety measures, and effective response in an emergency need to be addressed. This section details the actions for preparing and implementing effective safety measures and responses for BET.

A similar activity will need to be planned later for FCET, including that for hydrogen transportation, storage, and dispensing after the relevant regulations and standards have evolved globally.

OBJECTIVE

To design safety modules for effective field implementation of BETs.

TASKS

Major tasks involved:

1. Benchmark global practices
2. Understand possible safety hazards and failure modes expected to be encountered in the field
3. Identify areas/stakeholders to be targeted and covered. Major areas to be addressed include but are not limited to:
    a. Field breakdown of BETs
    b. Fire hazard
    c. Medical emergency and first aid
    d. Battery storage, transportation, and handling
    e. Charging infrastructure-related safety aspects and hazards
    f. General electrical safety aspects and hazards
4. Prepare safety-related manuals and awareness material (posters/fliers/videos) for different stakeholders, such as:
    a. Fleet owners, fleet operators, drivers, co-drivers
    b. Field service teams
    c. First responders
        i. Fire services
        ii. Hospitals, especially emergency wards
        iii. Traffic police
    d. Other road users and public
    e. Concerned govt. agencies and local bodies
5. Design training modules for all involved stakeholders listed above
6. Give training to trainers identified by local authorities

STAKEHOLDERS

1. OEMs
2. First responders
3. Concerned government ministries and agencies
4. Local bodies/local authorities
5. Medical practitioners
6. Service teams
7. Training agencies

8. Fleet owners and operators.
9. Drivers

METHODOLOGY

The following steps are involved in completing the above tasks:

1. The work in this Roadmap is dependent on the outcome of the following activity(s)/ Roadmap(s)
    a. Field research–BET
    b. Acquisition of drive cycle data
2. Benchmark global practices
3. Study and list down possible safety hazards, failure modes, and emergency conditions for BETs
4. Identify suitable agency(s)
5. Prepare a list of all involved stakeholders/interested parties
6. Prepare manuals and awareness material for all involved stakeholders/interested parties
7. Prepare training modules for all involved stakeholders/interested parties
8. Train the trainer as identified by local authorities
9. Provide training to stakeholders (sample batch in each corridor)

DELIVERABLES

1. Operation and safety manuals
2. Awareness material such as posters, flyers, and videos
3. Emergency response manuals
4. Training material and modules

It is to be noted that the aspects related to safety in CMVR, and component testing are not included in this section, as these are covered and administered through existing regulatory mechanisms.

TIMELINE

The timeline for each task under this Roadmap is provided in Figure 14.

FIGURE 14: TIMELINES FOR BUILDING SAFETY AWARENESS, TRAINING MANUALS, GUIDELINES FOR BET

ACTIVITY	PERIOD (Months)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Study and list down possible safety hazards, failure modes, emergency conditions for BETs and FCETs														
Identify suitable agency(s)														
Prepare list of all involved stakeholders/interested parties														
Prepare manuals for all involved stakeholders/interested parties														
Prepare training modules for all involved stakeholders/interested parties														
Training to identified trainers														
Training to stakeholders (1 no. sample batch from each corridor and for all 10 corridors)														

The estimated budget for carrying out the above-mentioned activities is **₹180 lakhs**

3.14 ZET PILOTS–BATTERY ELECTRIC TRUCKS

OBJECTIVE

The long-distance heavy-duty truck market in India is heavily fragmented, with more than 90% of the on-road inventory of trucks as well as the annual sales of new trucks being operated by single owner-drivers or, at best, small fleet owners who own 20 trucks or less. The preferences and criteria for decision-making for such owners, though primarily driven by cash flow and profitability, are varied across the country, with at least six different "zones" or "areas" amongst the high-volume locations. These buyers, typically, have been relying on word of mouth and trial to take decisions since they do not have a corporate structure to support new decisions; especially paradigm shifts like using BETs instead of Diesel Trucks.

Moreover, the different aspects of BET operations related to product performance as well as infrastructure performance and the reliability of power supply, require testing and validation. The Indian trucking market, extremely different from those in China, Europe, and North America, will need specific solutions that fit into the needs of this market, the practices, the preferences, and the ambient conditions across different seasons and corridors.

Financial viability and operational feasibility are typically established by these owners through trials/pilots run for a while before making decisions. Moreover, the vehicle manufacturers and CaaS (Charging as a Service) providers will also require statistically valid volumes to run for statistically accurate periods covering different terrains, duty cycles, products, and seasons.

No incentives and policy alone will enable rapid BET growth in India. There is a pressing need to design pilots carefully and technically in statistically relevant numbers in different corridors across the country almost simultaneously and then permit the market forces to take over but with due policy and fiscal support as required.

This document captures the Roadmap for such a pilot, starting from the field user research stage and going all the way to final proving, modification, and ramp-up readiness amongst all the stakeholders.

TASKS

The Pilots will entail the following tasks:

1. Detailed field research to identify corridor and application options and decide on the most suitable ones (a separate Roadmap for this activity is given in another document with full details)
2. In parallel, evolve Math Models, which will help assess upfront costs and total costs not only at a given point in time but as a trend over the years, with modifiable assumptions on costs for fuel, battery, foreign exchange, and others
3. Create another Math Model tool for feasibility studies on the operations of BET, with valid assumptions on weights, range, and energy management. For example, as of date, a BET that travels about 350 km every day has equal TCO w.r.t to a diesel truck. This can be done in several ways: 350 km one-way in a day and a return trip the next day or a full round trip in a day which is 350 km in total or 175 km one-way. Another option would be 1.5 trips totalling 350 km or two round trips totalling 350 km. Competitive battery sizing and suitable energy management, including charging time, will be required for a given application and segment
4. Based on the decision of the pilot corridors and applications, and using the above tools, design the solution for each corridor for eTrucks, chargers, power infrastructure, real estate, information technology, reporting of performance, and others. This will include detailed and competitive energy management calculations, including battery sizing and charger specifications
5. The business model required to operate these pilots will need to be evolved as the optimal balance between various conflicting criteria, such as ownership, service, revenues, and others

6. Based on these business models as well as specifications for vehicles, chargers, and duty cycles, prepare and tender for each corridor with specific qualification criteria by balancing the need for stable and mature players and innovative start-ups
7. Since the entire eTruck market will rely heavily on chargers that can supply about 500 A of current, it is important to have such India-centric chargers ready and developed for the pilots in time. The Roadmap for this is given as another separate document showing all details
8. There is a need to finance these pilots in terms of Loan, VGF, and risk cover products that will provide a clear and smooth transition of the pilot fleet from ICE to BETs. These finance products must be designed and offered well in time and in a manner that will address the needs of the owners and operators. This activity is captured in yet another Roadmap for the finance products, as a separate document showing all details
9. Well in advance of the pilot, the owner, operator, driver, and aggregator community need to be fully aware of and comfortable with the move to BETs. This will entail a series of engagements with the trucking community over at least one year that will include test drives of different BETs, test charging sessions, and performance in rain, high temperature, and dusty conditions. These events are to be conducted over one year before the operators order the BETs
10. The safety paradigm for BETs is very different from those for ICE vehicles. The drivers and operators of trucks as well as CaaS need to be trained before the pilots start and monitored at least for the first few months of the pilot. This will help avoid adverse events, reactions, and assessments of BETs
11. Since nearly 30% of the energy consumption is dependent on the driver's style of driving in BETs [7], it is important to provide enough training to the drivers before the pilots as well as during the initial three months of the pilot. Additionally, gaming incentives in the form of mobile apps and awards will increase the focus of the drivers towards optimal driving habits. Such training and gaming requirements are to be planned into the pilot implementation
12. There is a need to carefully monitor various aspects of this pilot and not all can come from the vehicle OEM and the CaaS providers. There is hence a need to specify and obtain data of the entire pilot continually over at least two season cycles/years so that there are sufficient data for analysis using modern data science tools and arriving at optimal solutions for the economic ramp-up phase after the initial two years of pilots
13. To ensure continuous engagement of the drivers with BETs over the years, a new ecosystem that can emotionally and successfully connect with the drivers is to be created with professional communications and engagement experts. This is also to be planned into the pilot
14. The OEMs, once the eTruck and other equipment details are finalised, require time to develop the products, debug them and then produce them on a pilot scale to reliable standards of quality and safety
15. DISCOMs will need to be given sufficient clarity on the location of chargers and the power/load in each of them
16. Real estate required for parking, charging, and relaxing/refreshing will need to be identified and secured
17. Tariff plans for charging in different locations are to be rationalised and finalised
18. eTruck and charger maintenance facilities will need to be arranged at the bare minimum in the corridors so that reliable operations are guaranteed to the owner/operator

[7] Donkers, A., Yang, D., & Viktorović, M. (2020). Influence of driving style, infrastructure, weather and traffic on electric vehicle performance. Transportation research part D: transport and environment, 88, 102569.

STAKEHOLDERS

1. Government and policymakers
2. End customers–freight users
3. Automotive Original Equipment Manufacturers (OEMs)
4. Fleet owners/fleet operators/cargo aggregators
5. Drivers
6. NHAI
7. Maintenance and spare parts service providers
8. Infrastructure and/or CaaS providers (DISCOMs, fuel stations, charging providers, and others)
9. Financing entities, preferably multi-lateral agencies like World Bank, Asian Development Bank, and others
10. Finance product retailers (NBFCs, banks, etc.)
11. Risk cover agencies
12. IT, data acquisition, and analytical experts
13. First responders for accidents–fire service, hospitals, police

METHODOLOGY

All the above-mentioned activities are to be planned in the correct order, with as much parallel activity as possible, to enable the earliest, safest, and most successful start of pilots. It is expected that about 60~70 eTrucks will be plied in about 7 corridors across the country with different models and different energy solutions (BETs covering not less than 300 km per day).

The work in this Roadmap is dependent on the outcome of the following activity(s)/Roadmap(s)

1. Finance for battery electric trucks
2. Safety awareness, training manuals, and guidelines for BETs
3. Tender for main pilot BET

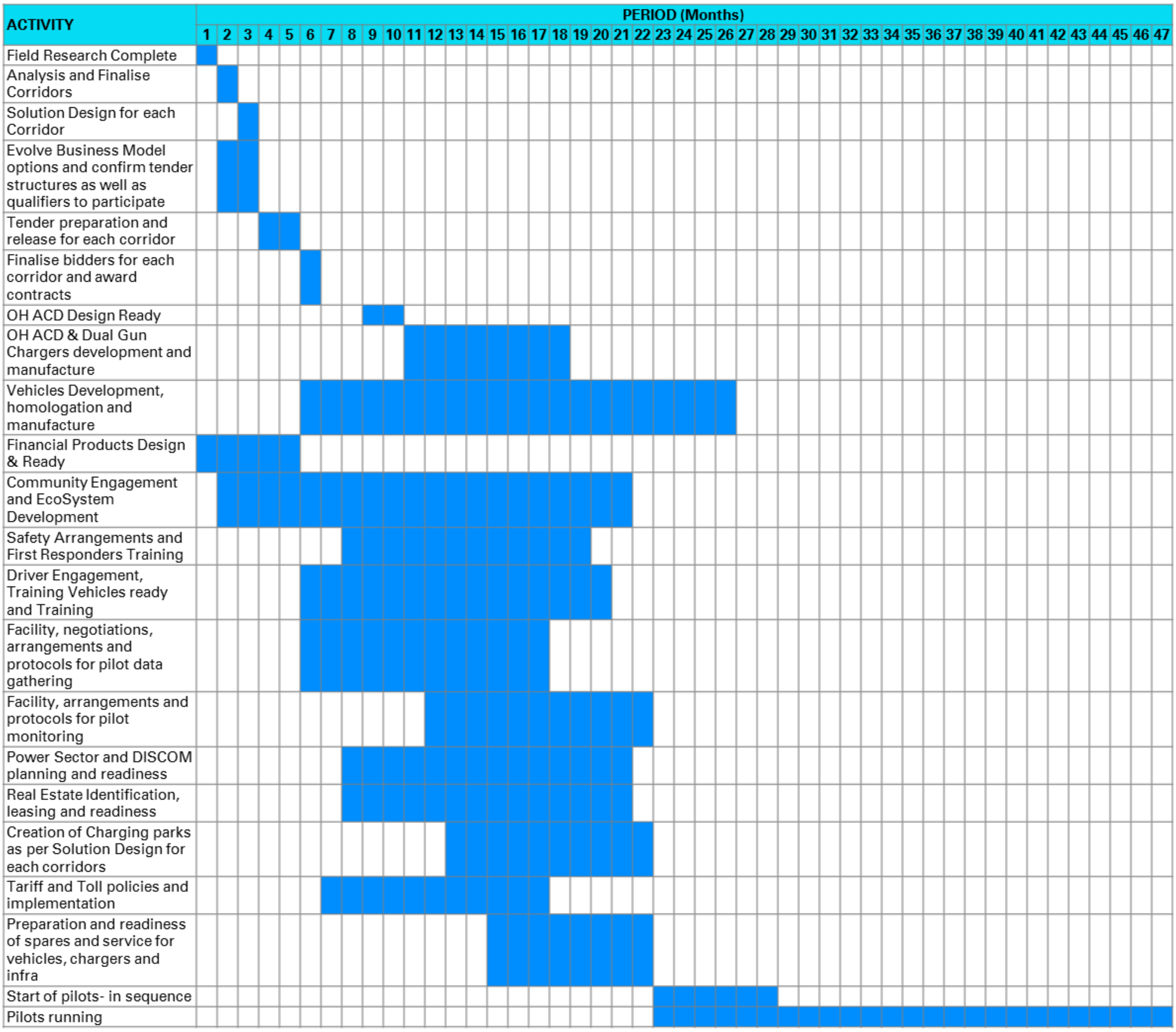
DELIVERABLES

A detailed activity plan, including all the aspects of the pilot preparations and operations, along with tentative costs for the capital and running.

TIMELINE

The timeline for each task under this Roadmap is provided in Figure 15.

FIGURE 15: TIMELINES FOR CONDUCTING ZET PILOTS – BATTERY ELECTRIC TRUCKS



The estimated budget for carrying out the above-mentioned activities is **₹22960 lakhs**; excluding the development, homologation, and manufacturing of vehicles required for BET pilots. An additional budget of **₹43200 lakhs** is estimated for the development, homologation, and procurement of vehicles for BET pilots

4. CONCLUSION & WAY FORWARD

A significant amount of preparatory and technical work must be done to successfully pilot BET, ZET, and subsequent ramp-up in the field. These activities will require planning, financial support, workforce support, and collaboration with multiple stakeholders.

The Panel of experts believes that if attempted without due technical preparations and the correct products and technologies, pilots will be counter-productive by making the operators and drivers reluctant to take up the ZET mission.

In addition to the above, multiple measures on policies, commercial, engagement and communication fronts are required to familiarise the trucking community with ZET.

To stay focused on the technical aspects, this expert Panel formed by the O/o PSA has refrained from providing details or recommendations on the following exclusions in this report:

a. Hydrogen ICE solutions are rapidly evolving across almost all countries with active trucking economies. This is primarily due to the focused interpretation of Zero-Emission Vehicles, where entities like California have classified a vehicle as Zero-Emission if it has zero or negligible carbon emissions.
b. Deep, clean slate, and long-term R&D actions are not reported in this Roadmap document from the CGeM; only some base product development is listed. The long-term R&D actions identified by the expert Panel are to be incorporated as a part of the overall eMobility R&D map for India. This Roadmap is expected to be released by the O/o PSA in the coming months.
c. Given that other GoI entities and ministries are working towards policy and commercial initiatives, inputs on the policy front are not provided in this technical Roadmap document.
d. Finally, the overall ZET Mandate Roadmap as a part of the regulatory mandate is not discussed in this document as it involves significant discussions with technical experts and stakeholders.
e. Inductive Charging is a relevant emerging technology for ZET, it has not been addressed in the Roadmap for any immediate action as the technology is at the nascent stage of the deployment level. If any rapid development is witnessed pertaining to inductive charging in the next 18 months, then the pilot plans can be suitably modified with revised charging strategies for one of the pilot corridors

The Roadmap in various sections emphasizes building relevant test facilities required for the successful deployment of ZET and the investments needed are also suitably highlighted. The expedited adoption of the Roadmap may help in the timely commissioning of these test facilities which may ensure market success and shall improve the country’s technical capabilities in this domain.

The accelerated adoption of the Roadmap shall aid in unlocking the full potential of the ZET sector and provide early-mover technical leadership, economic benefits and low emissions for the country while ensuring energy security. The Roadmap if used collectively as broad guidelines may create pathways for a systematic and effective deployment of ZET in India.

To take this Roadmap further, the O/o PSA will present the same to all relevant senior leadership members. However, specific actions will need to be evolved by a central entity in GoI with a detailed plan and probably a central ZET Program Management Office.

5. ACKNOWLEDGEMENTS

5.1 ADVISORY COMMITTEE

S. No.	Name, Designation, and Organisation	Role
1.	Prof. Ajay K. Sood, Principal Scientific Adviser, Government of India	Chairperson
2.	Dr. Parvinder Maini, Scientific Secretary, O/o PSA	Member
3.	Sh. Karthick Athmanathan, Honorary PSA Fellow and Professor of Practice, IIT Madras	Member
4.	Dr. Preeti Banzal, Adviser/Scientist 'G', O/o PSA	Member-Secretary
5.	Sh. Abhijit Mulay, General Manager, Automotive Research Association of India (ARAI)	Special Invitee

5.2 WORKING COMMITTEE

S. No.	Name, Designation, and Organisation	Role
1.	Dr. Preeti Banzal, Adviser/Scientist 'G', O/o PSA	Chair
2.	Sh. Karthick Athmanathan, Honorary PSA Fellow and Professor of Practice, IIT Madras	Vice-Chair
3.	Prof. C. S. Shankar Ram, V. Ramamurti Faculty Fellow, IIT Madras	Member
4.	Sh. S. A. Sundaresan, Vice President (EV and e-Mobility Solutions), M/s. Ashok Leyland Ltd.	Member
5.	Prof. Praveen Kumar, Professor, IIT Guwahati	Member
6.	Dr. Jabez Dhinagar, Senior Vice President–Vehicle, OLA Electric Technologies Pvt. Ltd.	Member
7.	Sh. Suresh Kumar Kunhikannan, Scientist 'F' (Retd.), O/o PSA	Member
8.	Prof. Sagar Mitra, Department of Energy Science and Engineering, IIT Bombay	Co-opted Member
9.	Prof. R. V. Ravi Krishna, Department of Mechanical Engineering, Indian Institute of Science Bangalore	Co-opted Member
10.	Prof. Kannan L., Centre for Battery Engineering and Electric Vehicles (C-BEEV)	Co-opted Member
11.	Dr. Malobika Karanjai, Scientist' F', International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI)	Co-opted Member
12.	Dr K. Balasubramanian, Director, Nonferrous Materials Technology Development Centre	Co-opted Member
13.	Sh. Panduranga Prabhu, Regional President, BOSCH India Limited	Co-opted Member
14.	Dr. Kaushal Kumar Jha, Centre for Battery Engineering and Electric Vehicles (C-BEEV)	Co-opted Member

S. No.	Name, Designation, and Organisation	Role
15.	Sh. Anil Kaushik, Additional General Manager (E-Mobility), NTPC Vidyut Vyapar Nigam Limited	Special Invitee
16.	Mr. Chandan Sawhney, Senior General Manager, Power Systems Engg, TML	Special Invitee
17.	Sh. Abhijit Mulay, General Manager, Automotive Research Association of India (ARAI)	Member- Secretary
18.	Sh. Himanshu Agrawal, Technical Staff, O/o PSA	Member-Convener

5.3 ZET PANEL

S. No.	Name, Designation, and Organisation	Role
1.	Dr. Preeti Banzal, Adviser/Scientist 'G', O/o PSA	Chair
2.	Sh. Karthick Athmanathan, Honorary PSA Fellow	Vice-Chair
3.	Prof. C. S. Shankar Ram, V. Ramamurti Faculty Fellow, IIT Madras	Member
4.	Sh. S. A. Sundaresan, Vice President (EV and e-Mobility Solutions), M/s. Ashok Leyland Ltd.	Member
5.	Prof. Praveen Kumar, Professor, IIT Guwahati	Member
6.	Sh. Anil Kaushik, Additional General Manager (E-Mobility), NTPC Vidyut Vyapar Nigam Limited	Special Invitee
7.	Mr. Chandan Sawhney, Senior General Manager, Power Systems Engg, TML	Special Invitee
8.	Sh. Abhijit Mulay, General Manager, Automotive Research Association of India (ARAI)	Member- Secretary
9.	Sh. Himanshu Agrawal, Technical Staff, O/o PSA	Member- Convenor

5.4 LIST OF CONTRIBUTORS

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2.	Sh. Sachin Pandit, Deputy General Manager, ARAI
3.	Dr. Sneha Malhotra, Chief technology Officer, O/o PSA

6. REFERENCES

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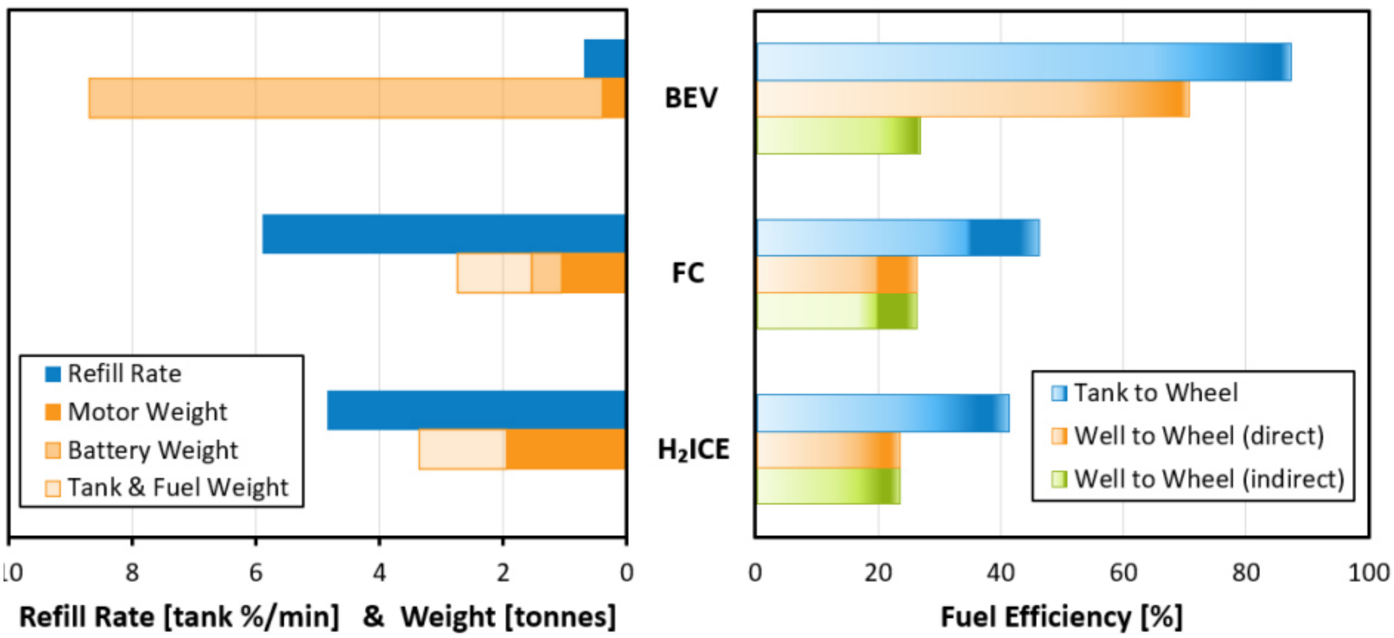
APPENDIX I – HYDROGEN INTERNAL COMBUSTION ENGINE

INTRODUCTION

Climate change, local pollution, and energy security vulnerabilities are coming together to transform the Transportation Industry from a diesel-powered present to a zero-carbon future. Among the technologies that have caught the attention of many are pure Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs). The discussion also goes on about the role of Hybrids, biofuels, and synthetic fuels as intermediate or bridge technologies.

In the recent past, entities such as the State of California have formally declared that a Vehicle will be treated as a Zero-Emission Vehicle if it has zero or negligible carbon emissions without mentioning any criteria yet for other emissions like NOx and particulate matter. This has been done to address the Climate Change issue, which is dependent almost entirely on carbon emissions. Because of this, a relatively new entrant to the debate is the Hydrogen Internal Combustion Engine (H_2ICE). H_2ICE has quickly leapfrogged into a leading option on the road to Zero-Carbon Transport due to its many advantages. It is recognised that H_2ICE does not offer zero-emission transport or zero-emission trucking–as nitric oxide and nitrogen dioxide (NOx) are the combustion by-products. However, it is a completely zero-carbon option, unlike biofuels or synthetic fuels, which may be net-zero, but still emit carbon dioxide at the vehicle tailpipe.

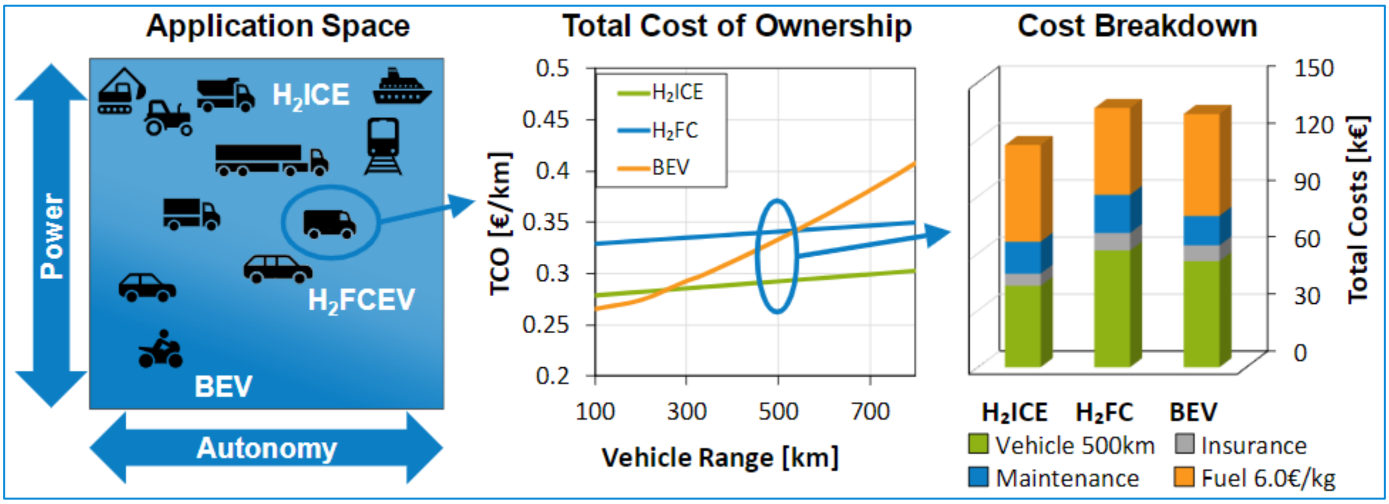
FIGURE 16: COMPARATIVE DATA FOR ZERO CARBON POWERTRAINS[8]



As can be seen in the above figure, H_2ICE falls between BEV and FCEVs in almost all parameters–both positive and negative.

[8] Decarbonizing The Automotive Sector With Hydrogen, BorgWarner Knowledge Library (accessed online on Nov 11, 2022)

FIGURE 17: RANGE AND TCO COMPARISON FOR ZERO-CARBON POWERTRAINS[9]



The above figure shows that while BEVs have a lower Total Cost of Ownership (TCO) when it comes to short ranges, at current prices of fuel cells and Hydrogen, H_2ICE has the lowest TCO for ranges beyond 300 km.

TECHNOLOGY OVERVIEW

H_2ICE is very similar to regular gas engines—LPG or CNG—a four-stroke reciprocating engine. Two options for fuel injection—either port fuel injection (PFI) or direct in-cylinder injection (DI). While PFI is proven, DI is still in development. In a PFI engine, air and Hydrogen mix in the port, and the mixture enters the cylinder during the intake stroke. The mixture of hydrogen and air is then compressed and ignited in the combustion chamber through a spark. The resulting high temperature and pressure gases power the piston through the expansion stroke. Exhaust is primarily composed of water vapour and nitrogen. Some NOx is generated during the combustion but can be controlled/treated using the traditional Exhaust Gas Recirculation (EGR) technology and/or Selective Catalytic Reduction (SCR) technology, presently used in fossil fuel-powered engines. The use of EGR and/or SCR brings down the tailpipe emissions below the levels allowed as per regulations. The performance is on par with existing engines. As more research goes into hydrogen combustion, efficiency gains are expected. The reported efficiency levels are already higher than diesel engines due to their wide flammability range.

Figure 19 shows the benefits and challenges of different injection technologies. While PFI is commercially available today, DI is still in the laboratory demonstration stage.

[9] Dr.-Ing. G. Dober, et-al, An Efficient Path to Zero CO2 Powertrains – BorgWarner's Hydrogen Injection Systems, 43rd International Vienna Motor Symposium, 27-29 April 2022.

FIGURE 18: SYSTEM ARCHITECTURE OPTIONS FOR GASEOUS FUELS[10]

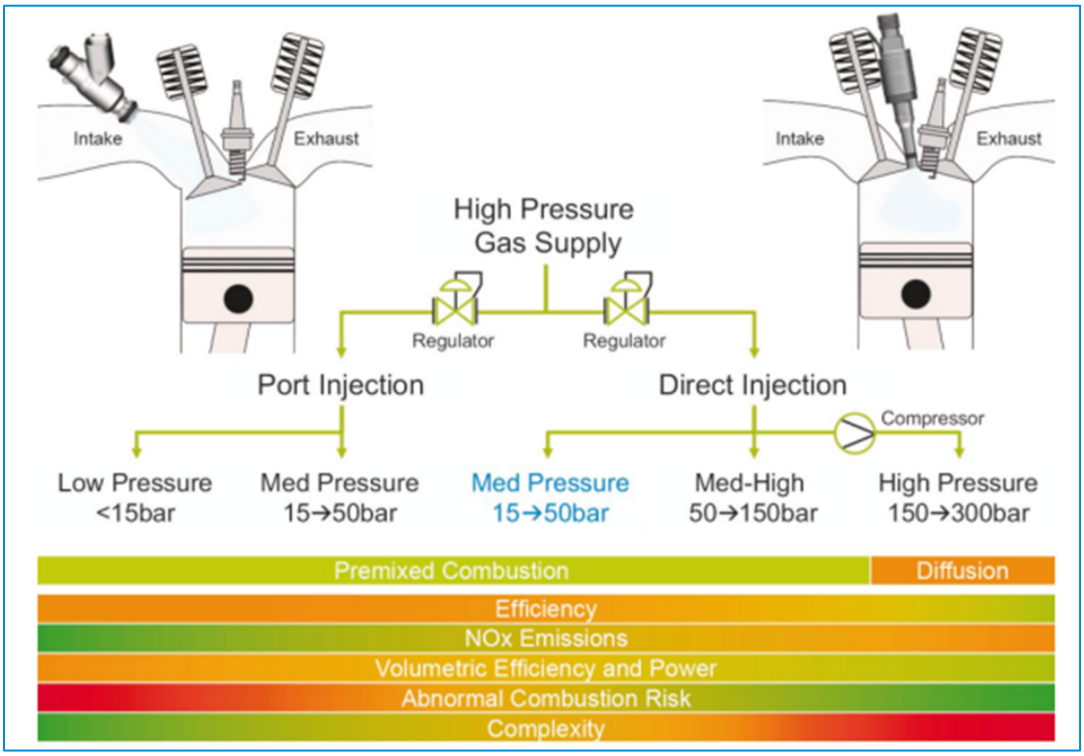


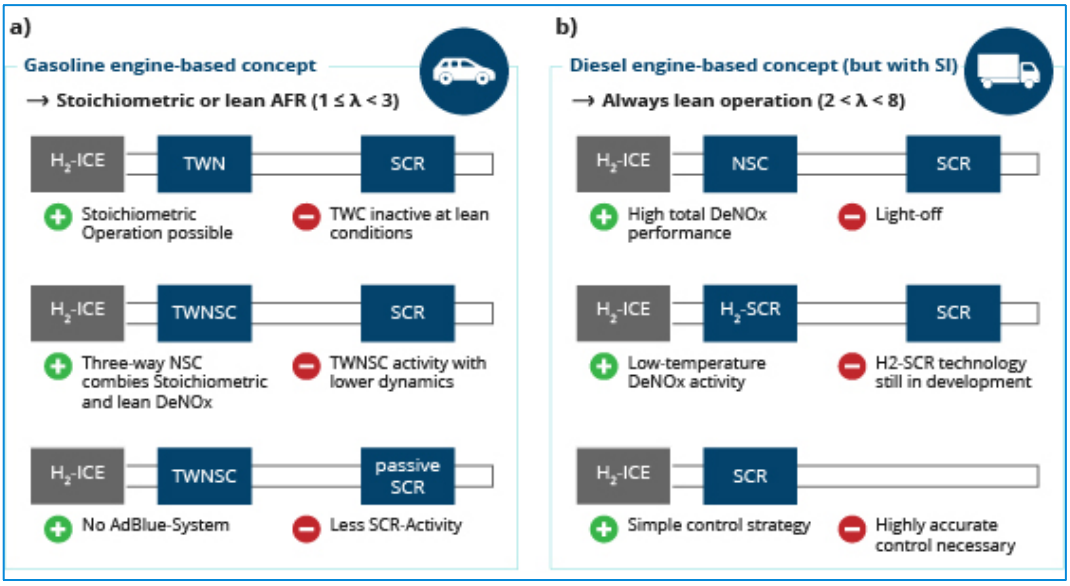
FIGURE 19: BENEFITS AND CHALLENGES OF DIFFERENT INJECTION OPTIONS[11]

	External mixture preparation	Space requirement cylinder head		
	Low pressure PFI	Low pressure DI	Mid pressure DI	High pressure DI
Fuel Injection	Port fuel injection ~5-10 bar	Direct injection ~15-30 bar	Direct injection ~40-60 bar	Direct injection ~300 bar
Specific Power (HD) Engine	<25 kW/l	>25 kW/l	>25 kW/l	~30 kW/l
Peak BMEP (HD) Engine	<20 bar	>20 bar	>20 bar	>25 bar
Combustion	Stoich/lean spark ignited	Lean spark ignited	Lean spark ignited	Lean Spark ignited -- Diffusive
Knock Tendency	↓	0	0	↑ (SI) -- Not existing (Dif.¹)
Boost Pressure Demand	↑↑	0	0	0
Transient Load Response	↑↑	0	0	↑
Main Benefits	• Easy to integrate • Hardware availability • Low failure risk	• Robust against backfire • Power density • Transient response	• Same as LP DI • Smaller packaging compare to low pressure • Potentially better mixture preparation	• Same as MP DI • Diffusive combustion possible
Main challenges	• Boosting • Safety (backfire)	• Integration DI injector • Uniform mixture preparation	• Integration DI injector • Range	• Integration DI injector • High pressure generation • For diffusive combustion high NOX raw emissions

[10] Decarbonizing The Automotive Sector With Hydrogen, BorgWarner Knowledge Library (accessed online on Nov 11, 2022)

[11] Dr.-Ing. L. Virnich, et-al, Powertrain Layout Optimization to Maximize Benefits of a H_2 Internal Combustion Engine, 43rd International Vienna Motor Symposium, 27–29 April 2022.

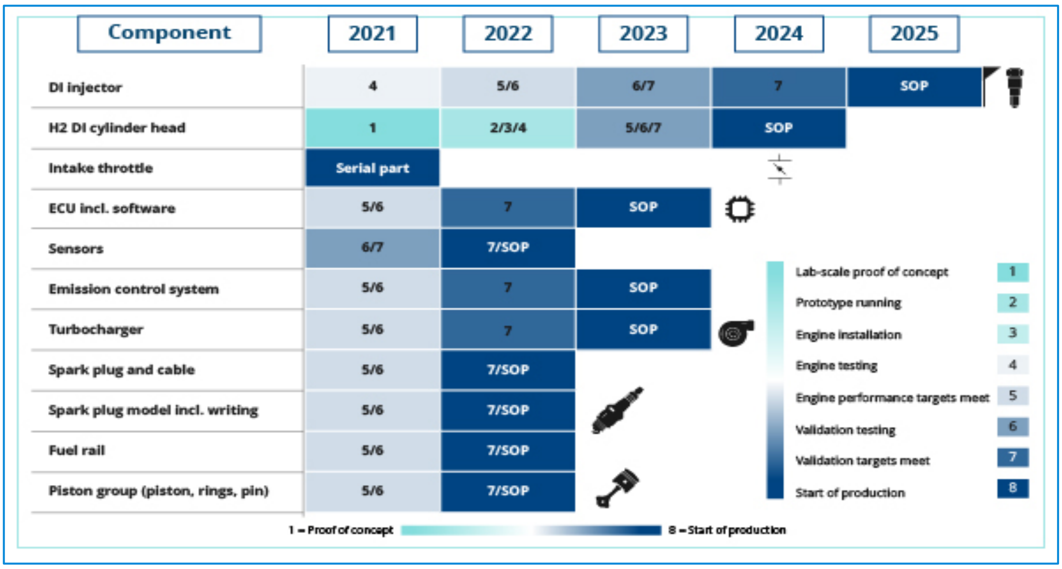
FIGURE 20: OPTIONS FOR EXHAUST AFTER TREATMENT FOR H_2ICE[12]



Along with injection technologies, the exhaust after-treatment technologies for H_2ICE are also under development. The above figure shows a few options with their relative merits and demerits. Already compliance with existing regulations has been achieved using multiple options, and further reductions in NOx emissions are promising.

WHY H_2ICE

FIGURE 21: ASSESSED TECHNOLOGY MATURITY LEVELS FOR H_2ICE COMPONENTS[13]



The above figure shows the relative maturity of H_2ICE components, demonstrating that H_2ICE is a technology ready for now; the fact that manufacturing and service infrastructure, competencies, and know-how exists for all these technologies and mostly in India is a compelling argument in favour of H_2ICE. Additional investments

[12] Sterlepper, S.; Fischer, M.; Claßen, J.; Huth, V.; Pischinger, S. Concepts for Hydrogen Internal Combustion Engines and Their Implications on the Exhaust Gas Aftertreatment System. Energies 2021, 14, 8166.

[13] "Industry Sources"

required for adopting H_2ICE are mostly in hydrogen generation and distribution. Hence, H_2ICE can act as a priming device for kickstarting the H_2 economy.

FIGURE 22: ADVANTAGES AND DISADVANTAGES OF DIFFERENT ZERO-CARBON POWERTRAINS[14]

Variations across categories: High performance | Medium-high | Medium-low | Low performance

Emissions	Bio/synfuel	Hydrogen internal combustion engines (H_2–ICE)	Hydrogen (H_2) fuel cell	Battery electric
CO_2 intensity	CO_2 intensity depends on source of biomass/carbon	Zero/minimal CO_2 if using green/blue H_2	Zero/minimal CO_2 if using green/blue H_2	CO_2 intensity depends on grid mix; zero CO_2 if using renewable power
Air quality	No$_x$[1] and particulate-matter emissions similar to diesel	No significant No$_x$[1] emissions with SCR[2] aftertreatment	Zero emissions	Zero emissions
Total cost of ownership				
Efficiency (well-to-wheel)	~20%	~30% for renewable H_2 production	~35% for renewable H_2 production	75–85%+ depending on transmission and charging losses
Powertrain capital expenditure	Same as today's combustion engines	H_2 engine with similar capex as diesel ICE, but H_2 tank required	High capex for fuel cells and batteries, but more scalable than BEV	High capex if large batteries required (medium for smaller/ lighter segments)
Constraints (space/ payload)	Same size and weight as today's combustion engines	Engine with same size as today, but H_2 tank needed	More space needed than combustion engine for fuel cell and H_2 tank	Higher weight than combustion engine; payload constraints subject to use case
Uptime/ refuelling	<15 minutes, depending on tank size	<15–30 minutes, depending on tank size	<15–30 minutes, depending on tank size	3+ hours, depending on ability for fast charging
Infrastructure costs	Can use existing infrastructure	H_2 distribution and refuelling infrastructure	H_2 distribution and refuelling infrastructure required	Charging infrastructure and grid upgrades required

The figures included in the earlier part of the document reflect that none of the Zero-carbon powertrain options is a clear winner at this point. Following are the arguments in favour of H_2ICE:

- Batteries and fuel-cell technology are not yet ready to meet the high-power requirements
- Internal combustion engines have met these requirements for decades, and switching from diesel to hydrogen could be a straightforward way to decarbonise these engines, with a relatively minor need for further technical innovation
- Low CAPEX requirements for combustion engines, decreasing hydrogen prices, and the relatively high efficiencies achieved by H_2ICEs at high loads create conditions in which hydrogen combustion can be a TCO-competitive solution.

[14] Heid, B.; How Hydrogen Combustion Engines Can Contribute To Zero Emissions. McKinsey Article, accessed online on Nov 11, 2022

- Since bi-fuel combustion engines can run on hydrogen, liquefied natural gas (LNG), or diesel (or hydrogen–gas blends), depending on availability, they can help decarbonise vehicle segments where hydrogen supply and infrastructure have not yet achieved full coverage
- H_2ICEs make use of current engineering know-how and jobs, draw on existing supply chains and production capacities in the automotive Industry, and do not create sustainability and integrity concerns around the supply and recycling of precious metals or rare earth metals
- Hydrogen combustion and hydrogen fuel cells are complementary, as they thrive in the same Ecosystem. Both can help grow hydrogen's share in the future powertrain mix and propel each other's success
    - Both together can drive the availability of hydrogen refuelling stations and the cost of hydrogen at the pump
    - Both share the same hydrogen-tank technology—a significant share of overall powertrain costs. Higher volumes help bring down the cost curve

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