EXPLORING OPTIONS AND FEASIBILITY FOR INDUCTION OF ALTERNATE FUEL VEHICLES IN THE INDIAN ARMY WITH SPECIAL EMPHASIS ON ZERO / VERY LOW EMISSION TRUCKS

A Dissertation submitted to the Panjab University, Chandigarh for the award of the degree of Master of Philosophy in Social Sciences, in partial fulfillment of the requirement for the Advanced Professional Programme in Public Administration

by

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under the guidance and supervision of

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Certificate

I have the pleasure to certify that Brigadier Bharat Huria has pursued his research work and prepared the present dissertation titled '**Exploring Options for Induction of Alternate Fuel Vehicles in the Indian Army with special emphasis on zero/ very low emission Trucks**' under my guidance and supervision. The dissertation is the result of his own research and to the best of my knowledge, no part of it has earlier comprised any other monograph, dissertation, or book. This is being submitted to the Panjab University, Chandigarh, for the purpose of Master of Philosophy in Social Sciences in partial fulfillment of the requirement for the 48th Advanced Professional Programme in Public Administration (APPPA) of the Indian Institute of Public Administration (IIPA), New Delhi.

I recommend that the dissertation of Brigadier Bharat Huria is worthy of the award of M.Phil. degree of Panjab University, Chandigarh.

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Declaration

I, the undersigned, hereby declare that the dissertation titled '**Exploring Options for Induction of Alternate Fuel Vehicles in the Indian Army with special reference to Medium and Heavy-duty Trucks**' is my own work and that all the sources I have accessed or quoted have been indicated or acknowledged by means of completed references and bibliography. The dissertation has not been submitted for any other degree of this university or elsewhere.

New Delhi	Brigadier Bharat Huria
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List of Abbreviations

S No	Abbreviation	Full Form
1.	AAT	Advanced Automotive Technology
2.	AC	Alternating Current
3.	ACC	Advanced Chemistry Cells
4.	ADB	Army Design Bureau
5.	AEV	Alternate Energy Vehicles
6.	AFV	Alternate Fuel Vehicles
7.	ALS	Ashok Leyland Stallion
8.	ALSV	Armoured Light Specialist Vehicle
9.	AR	Assam Rifles
10.	ARAI	Automotive Research Association of India
11.	ASC	Army Service Corps
12.	ATW	Assault Track Way
13.	BEE	Bureau of Energy Efficiency
14.	BEV	Battery Electric Vehicle or Pure EV
15.	BMIS	Battery Management Information System
16.	BMS	Battery Management/ Monitoring System
17.	BPL	Bulk Petroleum Lorry
18.	BS	Bharat Stage (Emission Standards)
19.	BTM	Beyond-The-Meter
20.	CAPF	Central Armed Police Force
21.	CDS	Chief of Defence Staff

22.	CISF	Central Industrial Security Force
23.	CKD	Complete knock down
24.	CNG	Compressed Natural Gas
25.	Cr	Crore
26.	DAD	Defence Accounts Department
27.	DC	Direct Current
28.	DMA	Department of Military Affairs
29.	DPM	Defence Procurement Manual
30.	DPP	Defence Procurement Procedure
31.	DPR	Detailed Project Report
32.	DR	Dispatch Rider
33.	E&Y	Ernst & Young
34.	e2W, 3W, 4W	Electric Two, three, four wheelers
35.	ECM	Electronic Control Module
36.	eCPC	electric Common Powertrain Controller
37.	EESL	Energy Efficiency Services Limited
38.	eHMMWV	Electric High Mobility Multipurpose Wheeled Vehicle
39.	EPR	Extended Producer Responsibility
40.	EV	Electric Vehicle
41.	EVCS	Electric Vehicle Charging Stations
42.	FAME	Faster Adoption & Manufacturing of Hybrid
43.	FCEV	Fuel Cell EV
44.	FCH	Fuel Cell and Hydrogen
45.	GeM	Government e-Marketplace
46.	GeM	Govt e-Marketplace

47.	GHCO	Green Hydrogen Consumption Obligation
48.	GHG	Green House Gas
49.	GSI	Geological Survey of India
50.	GSQR	General Staff Qualitative Requirement
51.	HDT	Heavy Duty Trucks
52.	HEMTT	Heavy Expanded Mobility Tactical Truck
53.	HEV	Hybrid EV
54.	HMV	High Mobility Vehicle
55.	HRS	Hydrogen Refueling Stations
56.	IA	Indian Army
57.	IAF	Indian Air Force
58.	ICE	Internal Combustion Engine
59.	iDEX	Innovations for Defence Excellence
60.	IIT	Indian Institute of Technology
61.	IN	Indian Navy
62.	IRNSS	Indian Regional Navigation Satellite System
63.	ITBP	Indo Tibetan Border Force
64.	JLN	Joint Logistics Nodes
65.	JLTV	Joint Light Tactical Vehicle
66.	LAMV	Light Armoured Multi-role Vehicle
67.	LCO	Lithium Cobalt Oxide
68.	LFP	Lithium Iron Phosphate
69.	LiB	Lithium Iron Battery
70.	LMO	Lithium Manganese Oxide
71.	LNG	Liquid Natural Gas

72.	LTO	Lithium Titanium Oxide
73.	MDT	Medium- Duty Trucks
74.	MHI	Ministry of Heavy Industries
75.	MNRE	Ministry of New and Renewable Energy
76.	MoD	Ministry of Defence
77.	MoRTH	Ministry of Road Transport and Highway
78.	MPV	Mine Protected Vehicle
79.	MTVR	Medium Tactical Vehicle Replacement
80.	NCA	Nickel Cobalt Aluminium
81.	NGV	Natural Gas Vehicles
82.	NHAI	National Highways Authority of India
83.	NITI Aayog	National Institution for Transforming India *Aayog*
84.	NMC	Nickel Manganese Cobalt
85.	NOx	Nitrous Oxide
86.	NSG	National Security Guards
87.	PEM	Polymer Electrolyte Membrane
88.	PHEV	Plugin Hybrid EV
89.	PLI	Production Linked Incentive
90.	PM	Particular Matter
91.	PMO	Prime Minister’s office
92.	PMSM	Permanent Magnet Synchronous Motor
93.	PSU	Public Sector Undertaking
94.	QRFV	Quick Response Fighting Vehicle
95.	R&D	Research & development
96.	RDE	Real Driving Emission

97.	RMI	Roackey Mountain Institute
98.	RNG	Renewable Natural Gas
99.	RPO	Renewable Purchase Obligations
100.	RR	Rashtriya Rifles
101.	SDG	Sustainable Development Goal
102.	SKD	Semi knock down
103.	TaCV-E	Tactical and Combat Vehicle Electrification
104.	TCO	Total Cost of Ownership
105.	TLV	Tactical Light Vehicle
106.	TMS	Thermal Management System
107.	TTM	To-The-Meter
108.	UAV	Unmanned Aerial Vehicle
109.	VLET	Very Low Emitting Trucks
110.	WhAP	Wheeled Armoured Protection
111.	WOLF	Wheel On-Lightweight-Folding
112.	WRI	World Resource Institute
113.	ZET	Zero Emission Trucks

ABSTRACT

Abstract

India, as a responsible nation and COP27 signatory, stands by its commitments to reduction in pollution and achieve net zero emission targets by 2070. EV-ization plays an important role towards transition to zero-emission. e-2W, e-3W and e-4W passenger car segments, and buses have been at the forefront of this change. The government's think tank NITI Aayog in conjunction with RMI, laid down guidelines and way ahead for electrification of the country's 4 million strong freight vehicles carrying 70% of freight, which is likely to grow 4x by 2050. This is likely to reduce carbon emissions by 46% by 2050.

The Indian Army is a liberal contributor to carbon emissions, given its transport fleet is completely fossil fuel based and mainstay vehicles work on BS-III engine technology. It has 1% of national civil trucks on its inventory, approx one lakh medium and heavy load carriers. Electrification of its fleet will contribute 82.5 mega tons CO_2, 25k tons of PM and 0.77 million tons of NOx reduction by 2050. De-carbonisation of military vehicles is therefore justified. However, it has serious operational considerations.

The study aims to explore the feasibility, extent and scope of induction of AFVs in the IA and give recommendations for its implementation, with special emphasis on zero/ very low emission trucks. The research endeavours to answer questions as to which type and class technology of AFVs, with special focus on ZETs, are best suited for IA and to what extent. It also attempts to identify locations fro induction. Finally the study endeavours to draw a road map through recommendations to include the entire system of alternate fuels and associated issue.

The research was exploratory to a very large extent, especially in the Indian context and furthermore within the military perspective. Focussed interviews were conducted with governmental bodies, institutes, think tanks, experts and the automobile and battery manufacturing industry players. A survey questionnaire was used to obtain views of the stakeholders on various aspects of the study and to arrive at cogent and pragmatic direction for the way ahead.

During peacetime, army units alongwith their vehicle inventory may be located in the hinterland, these will mobilise to forward areas on self-power, during training, war or when heightened operational preparedness levels are declared, over long hauls. The areas where these vehicles ply have difficult terrain and severe weather challenges. They are far-flung and have extremely poor connectivity and infrastructure. In operations, vehicles may have to move cross-country, even across the border during war. ZETs are totally dependent on battery power and the charging infrastructure support ecosystem, something which may not be possible in field locations. Current battery technology and commercially available configurations do not support range and reach of more than 250-300 kms at best, while the diesel ALS or Tata 2.5 Ton have ~1000-1200 kms ranges. These are the perceived challenges of the users and other stake holders in play.

BEV is one option. There are other alternate fuel technologies also available today, mostly at concept stage except CNG. Solar and wind power is unsuitable for mobility solutions and hence has not been discussed. CNG is a tried and tested technology and large number of cities and towns have the supply chain and Pan-India about 4,900 CNG refueling stations. Manufacturers exhibited concept LNG trucks during Auto Expo 2023.

However, LNG business logistics chain in retail refilling is practically absent in the country. Also, India has 44.7% import dependency of natural gas and importantly, natural gas reserves are finite like other fossil fuels. Hydrogen ICE engines and Hydrogen Fuel Cell EVs have come up as other alternate technology. Here again the availability in retail and supply chain being at infancy were identified as problems during the research. Significantly, availability of green hydrogen came up as a major issue. In the long run, hydrogen as a fuel, definitely has focal promise.

Advanced chemistry cell battery technology is still nascent. Government has undertaken very focused and key initiatives in framing policies and promoting industry by introducing PLI schemes for automotives, components and batteries, besides its FAME-II scheme. It is likely by 2024, India should become a indigenous manufacturer of batteries. Thereafter, market demand will drive the direction of technology. Simultaneously, many technologies are being worked up, Solid-state, semi-solid state, metal-air etc being some important ones. The research identified ACC batteries with energy power in range of 350+ KWh/kg and 1,500+ cycle life suitable for ZETs, but these would take some time to be developed.

Hybrids, therefore, seem to be the next best option, which is the major theory derivation from the exploratory study. A Diesel-Electric hybrid will operate on electric power for as long as the battery has potential, thereafter, seamlessly shift to diesel. Operations during peacetime and within station/ cantonment moves for training or administrative tasks would primarily be on electric. When long moves are to be undertaken or during operations/ mobilisation, when battery energy gets exhausted, the diesel engine would take over automatically. This proposition balances the environmental de-carbonization needs versus the concerns of the army. Having said so, it brings forth certain challenges of additional weight which can be addressed by power balancing and other means.

Hybridization of the IA transport fleet can be done by retrofitting its existing inventory of ALS and 2.5 ton Tata vehicles or designing / developing a new vehicle. Both have cost implications, though former has lesser. In any case conversion of BS-III to BS-VI engine should be the first step, without awaiting anything else. Commonality and upgradation to a common class load carrier, supplied by a single manufacturer is also discussed in detail. Incidentally, most developing countries are working towards hybrid technology. Many industry players like Oshkosh Defence have developed hybrid TLVs. IA is still powered on Gypsys, while some Tata Safari Storme have been purchased. It is an opportune time to shift to a hybrid. The research lists the numerous diesel vehicles developed by domestic OEMs, which have potential to be made hybrid. Similarly, IA has declared and initiated purchase action for EV buses. These are to be used for transportation of troops to de-bussing points in operations, which have charging challenges. Therefore, it is suggested that either we have a robust swappable battery supply chain in place or purchase Diesel-Electric hybrid buses.

Other recommendations look upon expansion of hybrids to civil trucks which will have mass acceptance due to elimination of need for enroute charging; just deport charging infrastructure would be enough. Also, these can be exported to friendly foreign countries and purchased by other PMF/ CAPF/ police etc forces. There are mobile re-charging and re-filling options also available in the market and these be reviewed as part of the EV/ZET/VLET ecosystem. Furthermore, all stations will eventually have EV charging infrastructure requirements. Hence, we need to address the issue in a holistic manner, as has been discussed in the study. Specialist vehicles offer themselves to hybridization due to immense power by the electric drivetrain, silent operations and better responsiveness.

A methodology for further study and project implementation through professional consultancy has been suggested, in partnership with other governmental departments, industry and experts.

The study goes on to extended mandate and suggest some out-of-the-box solutions to better utilisation of 3rd tier transport being planned for optimisation, through a ‘Dual-Use Civil-Military Transport Company’. This would reduce the dedicated manpower holding, reduce defence expenditure on pension bills and give total assurance of mobility during operations/ war. It also suggests hiring of ZET/VLET as CHT as also, production of some percentage of 4x4 civil trucks by industry annually to meet national defence requirements, costs being offset through PLI scheme.

The study has limited itself primarily to medium and heavy load carriers. Further simultaneous professional and outsourced stud(ies) by IA are imperative and these have been indicated at relevant places in the research recommendations.

INTRODUCTION

Chapter 1 : Introduction

> "India is well poised to embrace EV technology and that the future of electric vehicle is bright. The entire EV ecosystem in the country is taking right steps towards gaining larger acceptance"
>
> - PM Narendra Modi (August 2022) speaking at a Maruti Suzuki event

1.1 Background and Build-up to Intent

Prime Minister's office (PMO), Ministry of Heavy Industries, Ministry of New and Renewable Energy (MNRE), Ministry of Road Transport and Highway (MoRTH) and NITI Aayog, besides others, have been at the driving seat of transforming mobility in the country. To generate traction in adoption of Electric Vehicles (EVs), Faster Adoption & Manufacturing of Hybrid & EV (FAME-I) was introduced in Apr 2015 (extended till Mar 2019) with a goal to convert 30% of total vehicles to EVs by 2030. FAME-II was implemented from Apr 2019 (extended till 2024) with a ₹10,000 Cr budget and an objective of having at least one charging station in every 3x3 km grid & every 25 kms on both sides of highways. Tremendous efforts are being undertaken on various fronts including manufacturing EVs and batteries, assured minerals supply and technology.

Vehicle market in India is well established and varied. A large number of players have taken the plunge into 2-wheeler, passenger cars and buses segments EV-isation led by Tata Motors including Mahindra & Mahindra, Morris Garages, Hyundai and Maruti, Hero Electric, Revolt Motors, Okinawa Autotech, Bajaj, TVS, Ashok Leyland Electric Bus, JBM Solaris Ecolife, Electric Bus K9 and Skypak XL Bus. The EV truck segment was mostly nascent, pioneering with a lone player IPL Tech EV based out of Faridabad. Auto Expo 2023 saw a number of pioneer alternate energy vehicle options in the truck segment, including BEV, natural gas (CNG and LNG), Hydrogen ICE, FCEV, some hybrids etc.

Production Linked Incentive (PLI) schemes for automotives, components and batteries have been launched by the government for almost ₹1,00,000 cr. The support structure in terms of charging stations, maintenance setups and battery suppliers are also coming along. Governmental initiatives are substantial and new technologies, as also alternate fuel options, are being explored for implementation.

1.2 Statement of Problem

The Indian Army (IA) consumes approximately 4,65,000 KL of fossil fuel with a budget of ₹3,700 Cr. A gypsy vehicle emits about 4.6 MT and a truck 223 MT of carbon dioxide per year. The mainstay heavy carriage for IA is Ashok Leyland Stallion (ALS), still of (Bharat Stage) BS-III emission standards (Bharat stage emission standards BSES, 2022) (ACKO, 2022). Army formations are deployed in all parts of the country, including peace and far-flung field areas. Most vehicles will be employed during operations undertaking cross-country movement, un-metalled and on metalled roads, depending upon operational roles and terrain.

World over, militaries are yet to commence EV-isation of their fleets, despite its environment-friendly and stealth advantages, primarily due to range anxiety, power and speed required during operating in difficult terrain. Though some R&D and innovations in military EVs are being progressed by developed countries, cogent plan for large-scale EV adoption for militaries is not evident from content analysis, though a number of steps by few countries have been taken, not particularly in medium or heavy trucks, and examined in this research.

1.3 Concerns of IA

Main apprehensions of the IA is that adoption of EVs should not in any way compromise its operational requirements and effectiveness. Though army vehicles are located during peacetime in the hinterland, other than those deployed in operational areas, eventually when army is mobilised for conflict, they will also move to respective operational areas. These areas are deserts, mountains and jungles, have difficult terrain, extreme weather and climatic conditions and do not have adequate support infrastructure, even electricity at places. Even if vehicles are fully charged, EVs will eventually exhaust their energy and get stranded. Hence, range anxiety is dominant. The civil infrastructure with respect to other Alternate fuel vehicles (AFV) technologies viz natural gas, hydrogen etc is still nascent in the country.

1.4 IA's Focused EV Introduction Plan

During the Army Commander's conference in 2021, the IA decided on a ballpark figure of 10% fleet EV-isation. A 12 Oct 22 news report conveyed IA's decision to change fossil fuel vehicles to electric i.e. 25% of light vehicles, 38% buses and 48% bikes in selected Army units and formations, primarily in peace stations. The nuts and bolts of implementation are at preliminary stages, though process has commenced in earnest. What is still left out is tactical light vehicles, load carrier trucks and specialist vehicles.

This issue is further examined in the research.

Thus, scope exists to study the possibility and extent to which AFVs can be introduced in the IA. And if so, for which all class of vehicles; for which all formations/locations and what technology is best suited. AFV include electric, hydrogen ICE and FCEV, solar, bio-fuel, natural gas, varieties of hybrids etc. Maximum proliferation is in the EV market, which is growing exponentially, hence is being discussed now. Though Hydrogen as a fuel is cleanest and most advantageous, takes less time to re-fill, does not require batteries (made out of rare earth minerals), battery charging stations or battery replacement packs and has advantages of lesser weight. But it costs more as of now, it needs to be green (not grey or black) and it requires support structure for re-filling. Specifically, EV can be of three main types Pure EVs or Battery Electric Vehicles (BEV), Hybrid EV (HEV) or Plugin Hybrid EV (PHEV); similarly for other fuel types there are various combinations and these are disused in details in subsequent chapters. The study will explore the choice best suited for the IA.

1.5 Research Problem

Fossil Fuels are the majority sources of power, they are finite, pollute the environment, requires elaborate supply chain (specially in challenging areas where Army operates) and have high lifecycle costs from extraction till consumption. Research & development (R&D) for induction of all types of alternate fuels viz electric/battery based, hydrogen, solar, methane etc has being seen, specially over the last five to seven years. World at large through protocols/agreements and Government of India in specific is also aligned and pushing towards the ‘green-shift’ with its policies, initiatives and incentives (FAME-I, II, PLI schemes etc). Technology (of AFVs, especially EVs) exists and market has commercially available variants. Also technologically it has witnessing an upwards curve, and rising. Segments of 2W, cars and buses have seen maximum proliferation, while light, medium and heavy trucks negligible, even though R&D is being done in that sphere. EVs require elaborate charging infrastructure. India has capability to produce electric motors for long now. Batteries are the critical component of EVs due to limited availability of rare earth minerals. Countries are jostling to secure these at all costs. It is imperative to mention that there is simultaneous R&D and development in other forms of fuel sources viz hydrogen IC engines, CNG, LNG, FCEV and other hybrid variants etc also.

Militaries consume huge quantities of fossil fuels and pollute environment. Backbone load carrier of Indian defence forces is the ALS which meets only BS-III standards, while the rest of the country is on BS-VI. Government has taken out policy on ZETs (Zero Emission Trucks). Militaries operate in difficult areas making elaborate infrastructure creation challenging. Army is especially concerned with current EV technology available in markets, for specific class of transport and the aspect of range-anxiety in operational conditions. Thus, there is a **felt need and justification** for induction of alternate fuel vehicles in the IA, with special focus on ZETs trucks i.e. load carriers.

1.6 Research Strategy

The study employs a "**Mixed Research Strategy**" – qualitative and quantitative. Theories of the advantages, challenges and justification of alternate fuels, especially EVs, exist. However, in specific no research on introduction of EVs in the IA as a comprehensive cogent policy and plan-of-action has been done; for that matter elsewhere in the world, even though some broad policies have been given out and few purchases have been made including by IA, as also ongoing R&D on the technology is in pipeline(s).

1.7 Research Objectives

The aim of the research is to explore the feasibility, extent and scope of introduction of AFVs in the IA and give recommendations for its implementation, with special emphasis on zero/ very low emission Trucks.

1.8 Research Design

The research design is primarily "**Inductive**" based on study of IA specific issues, governmental policies, market maturity in terms of technology, EV proliferation in 2W, cars and other 4W, buses, all categories of trucks, R&D world-wide, challenges of infrastructure, operational requirements of the Army through study of various content and its analysis towards derivation of questions and development of theory. Where existing technology proliferation has taken place in civil and R&D in other militaries, it will be "**deductive**". The study is based on the literature review on the development of open internet, governmental efforts and material available on the subject and will rely on unstructured and semi-structured interviews of select group of officers concerned with policy operations, logistics and maintenance. Subject to resources and possibility, government policy makers and industry players have been interviewed. Therefore, primarily "**Exploratory**" approach has been adopted in the research. Identified gaps have been endeavoured to be filled in using more structured questionnaires designed to solicit objective answers and responses obtained analysed to arrive at important deductions.

1.9 Research Questions

(a) What technology of alternate fuel vehicles is best suited?

(Hydrogen fuel, solar, electric, bio-diesel, ethanol, compressed natural gas etc)

(b) What are the types of selected alternate fuel vehicles and which type would be best suited for induction?

(Pure EV, Hybrid EVs, Plug-in HEVs in the example of EVs; natural gas, FCEV, hydrogen ICE, diesel-electric and other forms of hybrids etc keeping market maturity, availability and other factors in mind, including other component technologies required)

(c) What is the extent to which induction of alternate fuel vehicles is feasible in the IA, in all classes of transport with special focus on ZETs?

(Keeping in mind the operational requirements of the forces and inherent limitations of such transport)

(d) Which all locations, formations or stations can the technology being proposed pragmatically be absorbed by IA and to what extent?

(e) What is the road map and way ahead to achieve the proposed objective, technologies, components, including support infrastructure required to be invested into, life cycle maintenance, fuel refilling/battery replacements and alignment with governmental civil infrastructure?

1.10 Chapterisation Scheme

Chapterisation of the thesis is as under:-

(a) **Chapter 1 : Introduction.** The chapter gives a brief insight of the rationale for the study on feasibility of induction of alternate fuel vehicles in IA, background of the subject, global and national environment with specific reference to militaries, including IA/ defence forces. It also broadly covers the current market maturity, technologies of vehicles, batteries and management software. It includes the Statement of the Problem, Research Objectives, Research Design, Rationale and Justification for the study and the Research Questions

(b) **Chapter 2 : Review of the literature**. The chapter elaborates on the literature and details of research methodology and data collection. Research strategy and methods are also enumerated herein. The scope and limitations of the research are also elucidated herein.

(c) **Chapter 3 : Analyses of Technologies of Medium and Heavy Duty Zero or Very Low Emission Trucks and their Feasibility for Induction in IA**. Discussion on each construct is undertaken herein in order to bring forth answers to the research question. The drivers for introduction of alternate fuel vehicles, technologies feasible, the locations where introduction is possible with number of vehicles, balancing the operational requirements with limitations of EVs, cost-benefit analysis, proposed plan and road map for implementation, associated support infrastructure required, change management during transition, maintenance and training are covered in this chapter. The chapter being large has been broken down into following parts:-

(i) Technologies Basics, Availability, Maturity and Analysis for Suitability of Medium and Heavy Zero-Emission Trucks.

(ii) Battery Electric Vehicles (BEV) or Pure EV.

(iii) Hybrid EVs/ Strong Hybrids/ Plugin Hybrid EVs.

(iv) Natural Gas (CNG, LNG, Bio-fuel)

(v) Fuel Cell EVs.

(vi) Hydrogen IC Engine Vehicles.

(vii) Diesel-Electric Hybrids.

(viii) Battery Technology, Advanced Chemistry Cells and Battery Management System.

(ix) Charging Infrastructure.

(x) Electric Motors and Transmission drivetrains.

(d) **Chapter 4 : Government Support, Policies and Guidelines**. Policies, guidelines and various budgetary incentives issued by the government to promote, facilitate and accelerate adoption of alternate fuel transportation systems are discussed in this chapter.

(e) **Chapter 5 : Operational Requirements of IA**. The operational logistical requirements of the army are enumerated herein so as to arrive at the feasible and most suitable plan for induction of AFVs in IA.

(f) **Chapter 6 : Survey, Results, Data Analysis and Findings**. The findings on all research questions and constructs as arrived at during the research are presented in a cogent manner, leading to the way ahead and actionable recommendations, including interviews and survey through questionnaire.

(g) **Chapter 7 : Conclusion and Recommendations**. The road map for induction of alternate fuel vehicles, in various types of transports, are enumerated in this chapter alongwith the support infrastructure required, maintenance, repair and disposal policies, as also feasibility in other class of vehicles.

REVIEW OF THE LITERATURE

Chapter 2 : Review of the Literature

2.1 Scope of Literature Review

The topic and subject of research is vast and exploratory, but less studied. However, literature exists for connected issues and these have been scrutinized. Literature review was done based on broad research parameters and questions framed. The focus areas for review have been as under:-

(a) Analyse from secondary data the need and justification for use of EVs/ Alternate Energy or Fuel Vehicles (AEV or AFV) in general and specifically by the IA.

(b) Review the available technologies of alternate fuels which are available in the market today, what is in pipeline and at which stage to explore the possibility of implementation. Do so also with specific reference to India (including industry and DRDO) and the IA.

(c) Explore what has been done in militaries, world over and at what scale. Also, find out what all kinds of R&D has been done or is being done/ in pipeline. Endeavour to determine what kind of technology and class of vehicles are being intended to be introduced by other armies and weigh-up its suitability for IA.

(d) Assesses the worldview of various stake-holders with regards to the subject, their enthusiasm, apprehensions, challenges and the possibilities/limitations they permit/impose.

(e) In the larger context, explore market availability of alternate fuels and their components, EVs, batteries, software, etc as also the rush for securing rare earth metals by various countries and efforts of the government.

(f) Study market trends of AFVs in two-wheelers (2W), three-wheelers (3W), light vehicles, SUVs, light, medium and heavy trucks / Zero Emission Trucks (ZETs) as also buses.

(g) Identify through literature review basic infrastructure requirements for AFVs.

(h) Study other connected issues with AFVs.

2.2 Content Analysis

The scope being very wide yet nascent, a very huge number of government policies and guidelines, books, online documents and media had to be studied to gain better knowledge of the subject specific. The following literature was studied in detail and content analysed, including gaps, as under:-

(a) NITI Aayog in conjunction with other ministries and RMI[1] published a

[1] Rocky Mountain Institute

report on "Transforming Trucking in India – Pathways to Zero-Emission Truck Deployment" in September 2022 (Niti Aayog, RMI, 2022). An elaborate

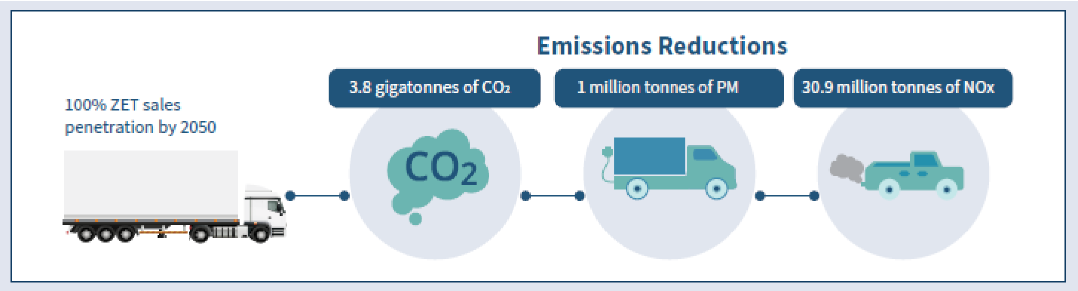

Figure 1 : Environmental Impact of 100% ZET Penetration in India by 2050

Source : NITI Aayog

e

nt it brings out the anticipated exponential growth of the trucking industry in the country, given the plans for a 5 trillion economy, in sync with the National Logistics Policy and Prime Minister's Gati Shakti Plan and the fact that, therefore, current pollution levels will also thus rise with the same factor. The potential for deployment and employment of ZETs, its strategies, policies, technologies, charging infrastructure and financial and business models are discussed. Solutions are recommended in establishing the ecosystem to support ZET induction, including seven national highway ZET corridors and other policy interventions. An excellent policy initiative, the paper primarily and comprehensively deals with EVs, based on the plan for having adequate number of battery charging stations enroute, though it does not address hybrid options, which may have been the logical transitional step moving from fossil fuel to Pure EVs. Another aspect that has not been addressed is possibility of swappable batteries. Both these aspects are, at face value, essential for the IA specifically and are thus explored further in the study.

(b) Study of e-books on other alternate fuel components viz drive-trains and power-trains, transmission systems, batteries, hybrids etc viz Heavy Duty EVs (Arora, Abkenar, Jayasinghe, & Tammi, 2021), Heavy Duty Truck Systems (Bennett, 2020), Electric Powertrains (Hayes & Goodarzi, 2018), Electric and Hybrid Vehicles (Husain, 2021) give a clear insight into the systems and technical and technological possibilities. Following chapters bring out the best options available to the AFV being proposed to the IA, basis some of these concepts, in particular trucks.

(c) NITI Aayog has partnered with WRI to take out three volumes of papers on Need for Advanced Chemistry Cells (ACC) Energy Storage in India (Singh, Ghate, Ningthoujam, Gupta, & Sharma, 2022). The paper is an extremely comprehensive study of various technologies in batteries today and in the future scenario, status of various works, suitability of batteries for various class and type of vehicles and governmental initiatives, funding and incentives for manufacturers to produce ACC, need to address both demand and supply sides, national efforts in securing its interests geo-politically and involve etc. The researcher has derived by detailed study of the paper, what it does not bring out clearly, and through interview of the author and others so as to find out suitability with respect to trucks and specifically the IA.

(d) On 20 Apr 2022, the government took out its draft policy on battery swapping (Niti Aayog, 2022). The policy aims to create a conducive ecosystem by promoting ‘battery swapping’ which requires less elaborate infrastructure or can be done in a distributed manner, takes less time to ‘swap’ viz-a-viz re-charging EVs. The final policy is yet to be issued. The researcher during interview with concerned authorities brought out the gap with respect to its 'intended' silence (as is mentioned in the policy itself) on similar policy for heavy vehicles including four wheelers (4W), trucks and buses. For the study, the requirement of swappable battery system and ecosystem is further studies and discussed in ensuing chapters.

(e) Study of documents on Electric Powertrain - Energy Systems, Power Electronics and Drives for Hybrid, Electric and Fuel Cell Vehicles (Hayes & Goodarzi, 2018), Electric and Hybrid Vehicles - Design Fundamentals (Husain, Electric and Hybrid Vehicles - Design Fundamanetals, 2021), Modeling and Optimal Design of All-Wheel-Drive Hybrid Light Trucks (Pan, Zhang, Peng, & Ravi, 2019) and Performance Evaluation of a Heavy-Duty Diesel Truck Retrofitted with Waste Heat Recovery and Hybrid Electric Systems (Villani, Lombardi, & Tribioli, 2020) give a fair idea on aspects related to hybrid AFVs.

(f) Vehicles with respect specifically to army was done by study of literature viz Army Driving Forward With Electric Vehicle Plans (Tadjdeh, 2019), Framework for energy storage selection to design the next generation of electrified military vehicles (Rizzo, Onori, & Catenaro, 2021), Range Extenders for Electric Vehicles (Morozov, Humphries, Zou, Rahman, & Angeles, 2018) and The Use of Renewable Energy to Power Military Vehicles (MSG Cho & Bell, 2021). Study of Oshkosh Unveils Silent But Deadly eJLTV Hybrid (Seabaugh, 2022) (Oshkosh Defense, 2023) and 'US Army picks 6 companies to tackle how to power electric combat vehicles in the field' (Judson, 2021) brings forth the trends for AFV in militaries as also for Tactical Light Vehicle (TLV) category in US Army were studied. Nothing was available for military trucks.

(g) NITI Aayog paper on charging infrastructure titled ‘Handbook of EV Charging Infrastructure Implementation’ (Kant, et al., 2022) was studied to arrive at the requirement of charging infrastructure. The NITI Aayog paper presented a gap as it does not address the specific requirements of trucks, probably these being non-existent in inter-city traffic as of now. Further study of ‘Charging solutions for electric truck and van fleets’ (ABB E-mobility Brochure, 2021) brought some clarity on the subject. The balance was clarified by study of other documents and interviews with experts.

(h) IA has commenced the process for introduction of EVs in 2W, light vehicles and buses categories as per articles titled ‘Army Commander's Conference : Apr 2022 - E-vehicles in the Indian Army’ (Kulkarni & Banerjee, 2022). The authorisation / holding of ALS, 2.5 Ton vehicles and Gypsy and structure of IA was derived from open source (35,000 Maruti Gypsies of Indian Army to retire, 2022), (Baggonkar, 2016), (Wikipedia, 2011), (Sanjai, 2016), (Wikipedia, 2022) and (Mishra, 2022). The latest trends in IA vehicles were studied from internet open source (Times Drive Desk, 2021) and (Bhardwaj, 2022).

(j) The legislature is concerned with the issue of fossil fuel pollution. The Parliamentary Committee headed by Dr K Keshava Rao has pointed out to the MHI and others to expedite proliferation of EVs and support infrastructure (Parliamentary Standing Committee Report, 2022).

(k) Numerous other documents, articles, website and media available on internet was analysed to give direction to the research and endeavour to bring forth meaningful recommendations. Relevant literature is referenced appropriately. However, all are not listed to avoid clutter.

2.3 Gaps

In summary, the prominent gaps in subject of study are as under:-

(a) The IAs proposal is silent on transition of a large portion of its vehicular inventory to alternate fuels. The possible functionalities and exploitation of AFVs being proposed to be introduced viz certain percentages of cars, bikes and buses, has not been enumerated in open domain.

(b) The technology to be introduced has not been spelt.

(c) Whether IA plans to pick up 'developed'/ tried-and-tested technology or it has plans to launch a collaborative effort, has not been detailed.

(d) Steps towards introduction plan of ZETs/ heavy EVs/ load carriers have not been enlisted.

(e) Proposals to merge, collaborate and sync with the governmental plans for ZETs and charging infrastructure has not been given out.

It is evident from content analysis that scope for induction of alternate fuel vehicles / EV-isation in IA exists. It needs to be decided as to what extent, where all, what class of vehicles and the type of technology which should be adopted. A phased implementation plan also needs to be chalked out alongwith other connected support aspects.

2.4 Limitation/Scope

The research studies the adoption of ‘clean and green’ technology by introduction of AFVs in the IA. The current study does not cover details of other defence services viz Air Force and Navy who have a different operational role, transport employment methodology and fuel-consumption sources. For that matter it does not pertain to other para-military forces also, though recommendations and inferences of this study may be applied to any force operating trucks in challenging terrain with constraints, post-research completion, thus making them shared beneficiaries. All types of transport and aerial platforms cannot be covered under the subject due to obvious limitations, which can be further studied as the markets for these platforms mature and domestic or international availability improves. Since technologies in all classes of vehicles are still at evolutionary phase of development and for load carriers/ ZET at nascent stage, thus, the study has designed limitations in its scope. The Army has given its intent on induction of EVs in passenger 2W, 4W and buses, thus, the research will cover all class of vehicles with special emphasis on load carriers/ ZETs, while bringing forth any recommendations applicable to other categories addressed or not (The Print, 2022). Specific confidential raw data was not be available and hence has been obtained from open source.

2.5 Research Methods Applied and Data Sources

The research is exploratory, as evident from above discussion. Data on vehicular holdings etc will be relied on from open source and analysed using available tools. Research questions are designed and directed to achieve the laid down objectives. All stake holders have been interviewed (mixed format) to arrive at an implementable plan. Questionnaire has been designed to get answers to research questions.

Research Methods. Both **qualitative** and **quantitative** research methods have been used.

Data Collection Plan. Primary and Secondary data sources have been collected as under:-

(a) Primary Data. Primary data was collected as under:-

(i) Current fuel consumption of the IA, fleet holding inventory-types, and budget spent was endeavoured to be collected from the department initially, to arrive at the justification. Keeping confidentiality in mind, only open source data was used.

(ii) Data on vehicle holding, especially for locations/stations where research points to possibility of introduction of alternate fuel vehicles, was also obtained from internet open source, since at this stage feasibility and technology proposed to be introduced was more important than numbers.

(iii) With the aim of understanding important departmental and operational concerns of the Army, questionnaire and interviews formed the basis of collection of primary data. The focus-group comprised of officers currently holding (or have had in the recent past held) appointments in policy framing, operations, logistics, transport and/or maintenance branches.

(iv) If feasible, views of policy makers in the government (MHI, MoRTH), R&D (DRDO), and think-tanks (NITI Aayog, WRI, RMI, ARAI[2]) and industry players (Ashok Leyland, Tata Motors, IPL Tech Ltd), especially for ZETs, vehicle technology and batteries, were also obtained to get a 360^{O} view of the issue at hand.

(v) Certain un-structured and semi-structuring interviews were also undertaken, designed to obtain answers to constructs.

(vi) **Sample Size was planned** at 95% confidence level (z-score 1.96), standard deviation of 0.5 and 10% margin of error (confidence level 0.10) i.e. **96**, though the **number of responses received** were **162** i.e. approximately increasing confidence level to 99% or reducing margin of error to 7.5% based on under mentioned formula:-

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[2] Automotive Research Association of India

$$\text{Sample Size} = \frac{(\text{z-score})^2 \times \text{StdDev} \times (1-\text{StdDev})}{(\text{Confidence interval})^2}$$

(b) Secondary Data. Secondary data was collected from literature review and content analysis of various research papers, books, articles in academic journals, policy documents, web blogs, web news and articles, Parliamentary Standing Committee Report, NITI Aayog papers etc. This facilitated better understanding of the government policy, alternate fuel and EV technologies available, EV-isation of types of vehicles, battery and battery management technology, support infrastructure, component technologies, progress on the subject by other militaries, etc.

(c) Google Forms, as readily available structured online tools, using indicators derived from content analysis, comprising of both open-ended and closed-ended questions; Power BI and MS Excel analytical tools were used. Pre-administration, pilot test of the survey tools was done by sharing it with my guide Prof. Suresh Misra, Dr Surabhi Pandey, experts and others for review.

ANALYSES OF TECHNOLOGIES OF MEDIUM AND HEAVY DUTY ZERO AND VERY LOW EMISSION TRUCKS AND THEIR FEASIBILITY FOR INDUCTION IN IA

Chapter 3 : Analyses of Technologies of Medium and Heavy Duty Zero or Very Low Emission Trucks and their Feasibility for Induction in IA

3.1 Technologies Basics, Availability, Maturity and Analysis for Suitability of Medium and Heavy Zero-Emission Trucks

3.1.1 Zero Emission Trucks

NITI Aayog has initiated a roadmap guideline paper on Zero Emission Trucking in India (Niti Aayog, RMI, 2022). India transports ~4.6 billion tons of freight annually. It generates a transport demand of 2.2 trillion ton-km at the cost of ₹9.5 lakh Cr. (Gaton, 2019) (Ghate, Lakhina, & Shiledar, 2021).

Transportation costs are a major driver (62%) of overall logistics costs in India, accounting for 14% of India's GDP. Road transport (i.e., trucks) carries the bulk of India's goods, 70% of today's domestic freight demand. No of trucks are 4 million in 2022. Heavy and Medium Duty Trucks (HDTs and MDTs, respectively) are responsible for most of the road transportation, accounting for 76% and 21% of the road freight demand.

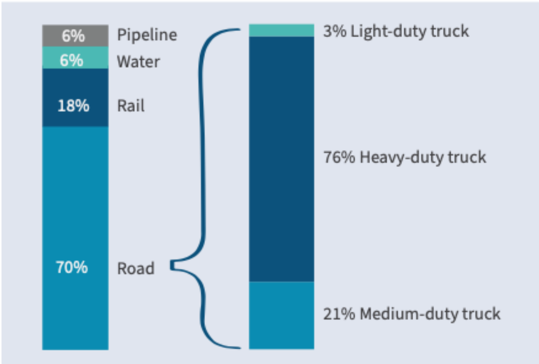

Figure 2 : Freight Movement in India in 2022 (% of tonne-kms)

Source : Niti Aayog

Road freight movement is expected to increase to 9.6 trillion ton-km by 2050. No of trucks are expected to quadruple to 17 million in 2050.

Heavy- and medium-duty trucks are responsible for most of that road transportation.

ZET adoption can dramatically lower associated fuel costs by upto 46% over the vehicle's lifetime, with broad implications for the Indian economy. ZETs would be a significant source of demand for domestically produced batteries (up to 4,000 gigawatt-hours [GWh] cumulative through 2050). With cost competitiveness, and technology maturity, nearly 9 in 10 trucks sold in 2050 can be ZETs (85% sales penetration).

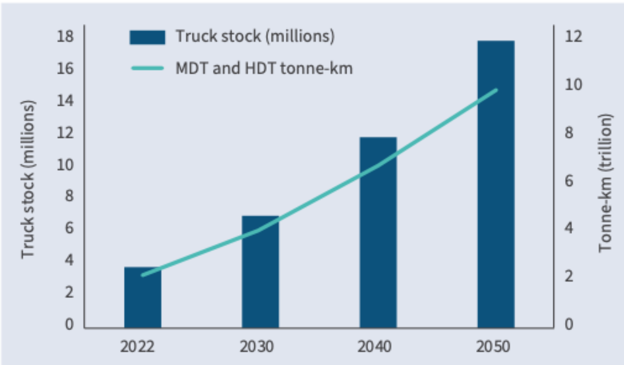

Figure 3 : Anticipated Growth of India's Truck Stock and Road Freight Market through 2030

Source : Niti Aayog

Today, road freight accounts for more than 25% of oil import expenditures—and is expected to grow over 4x by 2050. ZET adoption can eliminate a cumulative total of 838 billion liters of diesel consumption by 2050, which would reduce oil expenditures by ₹116 lakh Cr through 2050.

Trucks represent just 3% of the total vehicle fleet (including both passenger and freight) yet are responsible for 53% of PM emissions. Widespread ZET adoption could reduce cumulative trucking particular matter (PM) and nitrous oxide (NOx) pollution ~40% by 2050, substantially improving air quality in India.

The trucking sector is responsible for one-third of transport-related CO2 emissions in India. A determined transition to ZETs can lead to 2.8–3.8 giga tons of cumulative CO2 savings through 2050, which is equal to or greater than India's entire economy-wide annual green house gas (GHG) emissions today. It will reduce annual trucking carbon emissions 46% by 2050.

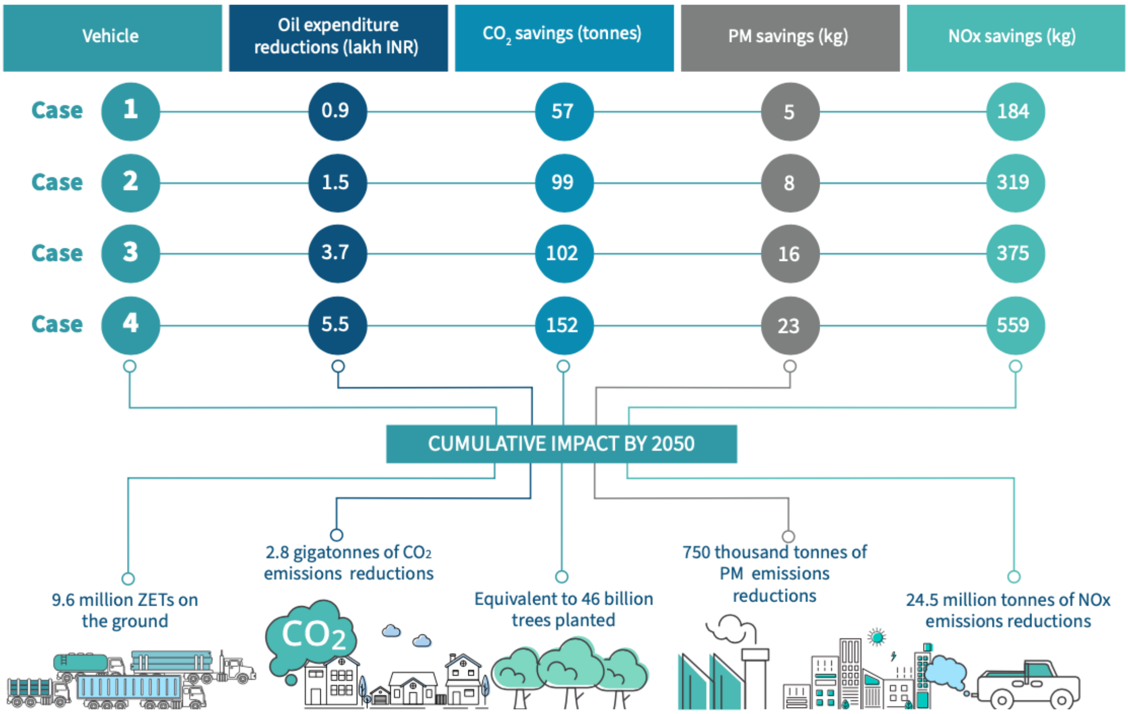

Figure 4 : Reduced Annual Trucking Carbon Emissions

Source : Niti Aayog

3.1.2 Alternate Fuel Trucks

> **India - High-level Segment Statement COP 27 at UNCC**
>
> Hon'ble PM announced India's aim of **achieving net zero emissions by 2070** at Glasgow. Within one year, India has submitted its Long-Term Low Emissions Growth Strategy indicating low carbon transition pathways in key economic sectors. Responding to the call for increased ambition in our 2030 climate targets, India updated its **Nationally Determined Contributions** in August 2022. We have embarked on far-reaching **new initiatives in renewable energy, e-mobility, ethanol blended fuels, and green hydrogen as an alternate energy source**. This is a testimony to our ethos of collective action for global good.

Most vehicles, especially in the trucking category, are based on fossil fuels internal combustion engines. Fuel, generally diesel, is sprayed into the engine cylinders at high pressure. It burns in combination with oxygen thus moving the cylinder pistons. This converts into a mechanical movement, which is transmitted through the powerdrive sub-system of the vehicles to the propeller shaft, axles and wheels. Thus, moving the vehicle.

Fossil fuels are finite resources and cause very high carbon emissions detrimental to the environment. United Nations has set Sustainable Developmental Goals for member countries, of which India is a signatory. In particular SDG-13 pertains to Climate action where EVs will help achieve renewable energy goals in the transport sector (SDG target 7.2) and help combat air pollution and related health impacts (SDG target 3.9) (How E-Vehicles Are Contributing Towards Sustainable Development, 2022). India has also pledged its part.

Simplistically put, alternate fuels can be defined as those which are cleaner and cause less pollution. There are several alternative fuel options available for trucks, including:

(a) **Battery Electric Trucks**. Powered by electricity, electric trucks have batteries or fuel cells that store energy, which is used to power an electric motor.

(b) **Hybrid Trucks**. These trucks use a combination of an electric motor and a traditional internal combustion engine, either of which could be the primary drive and the other the secondary one. The batteries are charged using regenerative braking or through the diesel engine generator.

(c) **Plug-in Hybrid Trucks**. A combination of an electric motor and traditional internal combustion engine wherein the electric motor is charged through a plug-in system akin to an EV or ZET. It could also use a combination of diesel engine generator charging for its batteries.

(d) **Natural Gas Trucks**. These trucks run on compressed natural gas (CNG) or liquefied natural gas (LNG) and they have fewer emissions than diesel trucks. Propane Trucks run on LPG, a clean-burning alternative fuel that is less expensive than gasoline or diesel.

(e) **Bio-Fuel Trucks**. These trucks run on bio-fuels such as biodiesel, bio-ethanol, and bio-methane, which are made from renewable resources such as plant materials.

(f) **Hydrogen Fuel Cell Trucks**.These trucks run on hydrogen and they have zero emissions, only producing water vapour.

(g) **Hydrogen ICE Trucks**. These trucks have H-Series multi-cylinder engines, with minor changes to the engine head unit and fuel injection system, making it compatible to run on green hydrogen. Hydrogen Fuel is typically stored in Type 4 carbon-fiber composite cylinders with high-pressure endurance.

Each alternative fuel option has its own set of advantages and disadvantages, such as cost, range, infrastructure, and emissions. It's important to evaluate the specific needs of a fleet or business and compare the costs and benefits of each option before making a decision. There are certain common advantages and disadvantages of AFVs, tabulated as under:-

Advantages AFVs

- Produce low or zero emissions, which can help to improve air quality and reduce the environmental impact of military operations.
- AFVs are generally much quieter than traditional gasoline or diesel trucks, which can be an advantage in stealth operations.
- They can help to reduce a country's dependence on fossil fuels, which can be a strategic advantage in times of war or conflict.
- Most AFV trucks have fewer moving parts than traditional gasoline or diesel trucks, which can result in lower maintenance costs.
- AFV offer higher energy efficiency than traditional gasoline or diesel trucks, which can result in longer range and lower fuel costs.

Disadvantages AFVs

- High initial cost. AFV trucks are currently more expensive than traditional diesel trucks, though overall total cost of operation over lifecycle maybe lesser.
- AFVs require recharging/ refilling infrastructure for charging batteries/ natural gas/ hydrogen etc.
- Some of the sources of energy may themselves not be from clean energy i.e. grey or black. E.g. hydrogen produced from coal, batteries etc
- Availability of critical rare-earth minerals etc may be a geopolitical issue for most countries.
- Single re-charge or re-fill may offer limited range, which may in turn affect the operational logistics efficiency of military.

3.1.3 Market Proliferation of AFVs and EVs in India

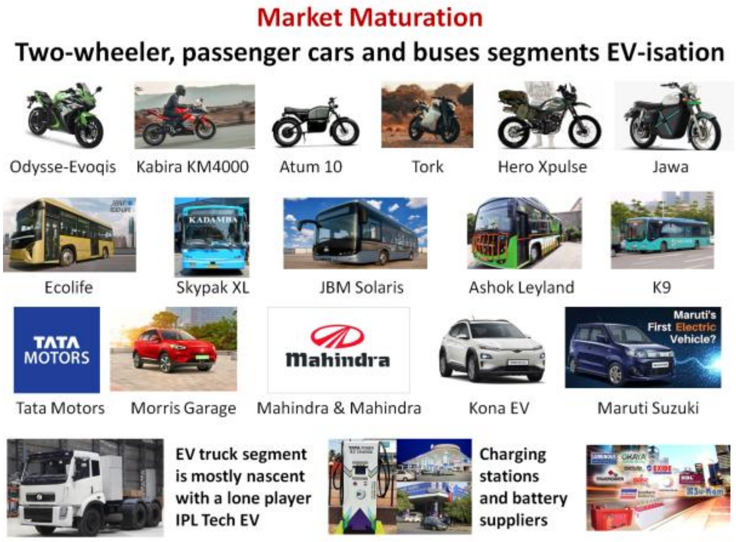

Figure 5 : Market Maturation India (2022)

All pictures where sources are not mentioned, are by researcher

e-Two-wheelers (e-2W). As of 2022, India's overall EV penetration, including e-2W, is 3%. Although the electrification of mobility in India is still at a nascent stage, there is massive headroom for growth. (Agarwal, 2023). Ownership cost savings of electric 2W ranging from 20-70% over petrol 2Ws. The sale volumes in India are expected to reach ~22 million by 2030. In fact, at 2,77,910 units, sales of e-2W in April-September 2022 are a 404% increase over H1 FY2022's 55,147 units. The growth is not just restricted to scooters; it has proliferated into motorcycles.

e-Four Wheeler (e-4W) Light Passenger Vehicles, including SUV. The growth story of e-4W passenger category has progressed from nascent to quick progression. The retail numbers reveal that cumulative retails in the first six months of FY2023 crossed 18,000 units. At 18,142 units, the segment registered a 268% year-on-year growth (H1 FY2022: 4,932 units). The month-on-month growth is at table below. In Q2 FY2023's (July-September 2022), sale of 10,015 units are a 23% increase on Q1's (April-June) 8,127 units. The market is led by Tata Motors, followed by MG Motors India. (Dalvi, 2022) Auto Expo 2023 revealed more number of players (like BYD) coming in with more technically & cost attractive variants in this 'low-hanging fruit' market slice.

ELECTRIC CAR SALES RECORD 268% YoY INCREASE IN FIRST-HALF OF FY2023							
ELECTRIC CARMAKERS	**April '22**	**May '22**	**June '22**	**July '22**	**Aug '22**	**Sep '22**	**Total**
Tata Motors	1,812	2,495	2,724	2,891	2,765	2,831	15,518
MG Motor India	245	247	235	268	316	280	1,591
Hyundai Motor India	23	27	51	61	73	74	309
BYD India	21	42	49	44	45	63	264
Mahindra & Mahindra	13	9	19	26	17	112	196
BMW India	17	9	5	5	25	27	88
Audi	8	8	14	8	14	10	62
Porsche	4	5	4	7	7	13	40
Mercedes-Benz	11	5	3	2	4	7	32
Jaguar Land Rover India	3	7			0	1	11
Others	4	1	7	17	1	1	31
Total	**2,161**	**2,855**	**3,111**	**3,329**	**3,267**	**3,419**	**18,142**

Figure 6 Electric Car Sales

Source : Autocar Professional

e-4W Tactical Vehicles. During Auto Expo 2023, Pravig, a Bangalore based startup, showcased an EV for the armed forces. It is powered by a dual-motor with all-wheel drive, permanent magnet synchronous motor (PMSM) producing 620 Nm torque and 408 HP, 0-100 in 4.9 secs and top speeds of 210 kmph. Powered by 90.9 KWh Li-Fe batteries with claimed range of 500 kms, charges 0-80% in 30 mins and has a battery life of 10 lakh kms. The segment has tremendous scope, but the scales will rise only with demand, as also battery technology maturity (giving more ranges in single full-charge).

Figure 7 : Pravig's Veer EV

Source : Autocar Professional

EV Buses. The e-bus market in India has grown 65% in 2022 and it is growing in a major way (Sustainable Bus, 2023). The electric bus sales were 1,939 units in 2022 compared to 1,171 units in 2021, weighing in at 0.2% of the total electric vehicles sold in India. The bus segment had significantly higher EV penetration than other vehicle segments in all three major electric vehicle sales states, with 15% penetration in UP, 12% in Karnataka, and 8% in Maharashtra. Major market players are PMI Electro Mobility (34%), Olectra Genentech (27%), Switch Mobility (15%) and JBM Auto (14%).

Figure 8 : Switch Mobility Bus showcased at Auto Expo 2023

e-4W Trucks Load Carriers (ZET).

IPL Tech Ltd's Rhino 5536 was the only one in the truck segment till 2022. The recent Auto Expo at Greater Noida witnessed large number of mainstream players who have come out with the EV variants. Companies showcased concept/ prototype variants with other fuels also viz CNG, LNG, Hydrogen ICE, Hydrogen FCEV etc. None exists in the diesel-hybrid hybrid category though. IC engine designs were difficult. Now, in the smaller EV truck segment (upto 1 / 2 ton category) large number of new OEMs are also emerging (Ashok Leyland, SML, Tata ACE, Omega Seiki Mobility, etc). Some of these tasks are being performed by larger e-3W segment innovations too, mostly restricted within city operations. More of truck technology and variants are discussed in ensuing sections.

Figure 9 : Trucks Market in India (2022)

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3.1.4 Global Trends : Heavy Duty ZETs in Defence

It is not widely reported that any country's defence forces have inducted electric (or other alternate fuel) trucks into their fleet on a large scale. However, there are instances of electric trucks being conceptualised, piloted or tested by some defence forces of developed countries to be used for specific purposes such as logistics, cargo transport and support operations.

For instance, the US military has been testing and evaluating electric trucks for potential use in logistics and transportation operations, as also in the light tactical passenger carrying category. The US Navy has also been testing electric trucks for use at naval bases. Similarly, the Canadian military has also been testing electric trucks for use in logistics operations. Additionally, some countries are working on developing military-grade electric trucks.

It's worth noting that the use of electric trucks in defence forces is a relatively new phenomenon, and it's likely that more countries will begin testing and incorporating electric trucks into their fleets in the future as the technology improves and becomes more widely available.

3.2 Pure EV/ BEV ZETs

A battery electric vehicle (BEV), pure electric vehicle, only-electric vehicle, fully electric vehicle or all-electric vehicle is a type of electric vehicle (EV) that exclusively uses chemical energy stored in rechargeable battery packs, with no secondary source of propulsion (a hydrogen fuel cell, internal combustion engine, etc.). BEVs use electric motors and motor controllers instead of internal combustion engines (ICEs) for propulsion. Also called Pure EVs.

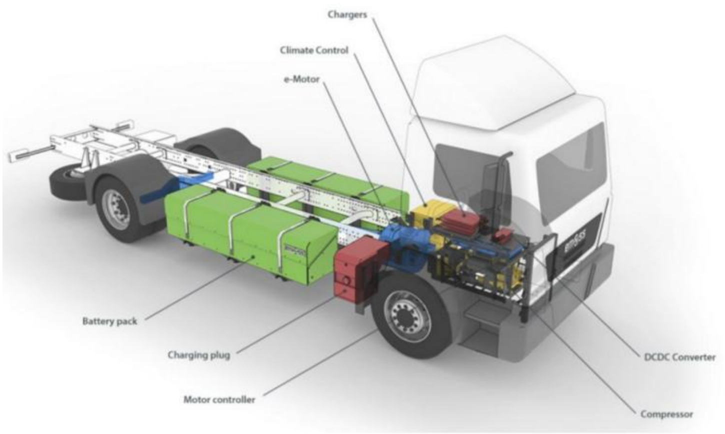


Figure 10 : Schematic Working Battery EV
Source : AMK-Kustannus

An electric truck is an electric vehicle powered by batteries designed to transport cargo, carry specialized payloads, or perform other utilitarian work. Electric trucks have serviced niche applications like milk floats, pushback tugs and forklifts for over a hundred years, typically using lead-acid batteries, but the rapid development of lighter and more energy-dense battery chemistries in the twenty-first century has broadened the range of applicability of electric propulsion to trucks in many more roles.

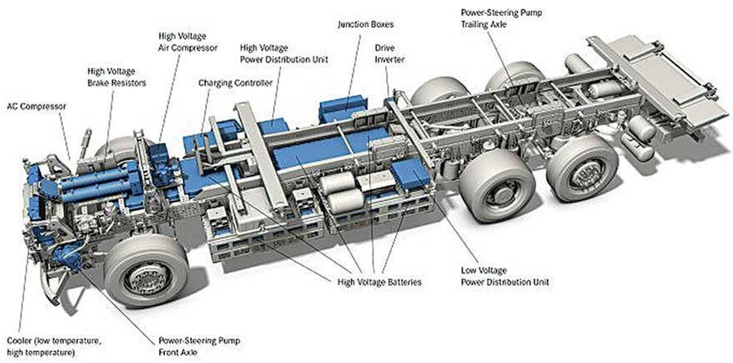


Figure 11 : Schematic Battery EV
Source : Mercedes Benz Actros

Figure 12 : Tesla Semi Truck
Source : Tesla

Electric trucks reduce noise and pollution, relative to internal-combustion trucks. Due to the high efficiency and low component-counts of electric power trains, no fuel burning while idle, and silent and efficient acceleration, the costs of owning and operating electric trucks are dramatically lower than their predecessors.

Long-distance freight has been the trucking segment least amenable to electrification, since the increased weight of batteries, relative to fuel, detracts from payload capacity, and the alternative, more frequent recharging, detracts from delivery time. By contrast, short-haul urban delivery has been electrified rapidly, since the clean and quiet nature of electric trucks fit well with urban planning and municipal regulation, and the capacities of reasonably-sized batteries are well-suited to daily stop-and-go traffic within a metropolitan area.

Figure 13 : Freightliner eCascadia Semi-Tractor
Source : Wikimedia

In the category of Semi-trailer and tractor trucks, the models produced are Tesla Semi, BYD 8TT, MAN eTGM, Freightliner eCascadia semi-tractor, Autocar Trucks E-ACTT.

Figure 14 : BYD 8TT
Source : BYD

3.2.1 BEV Operation : Power-on through Acceleration to Braking

When the driver partially turns the key, ions and electrons from the high-voltage batteries are made available to power the truck. Once the driver fully turns the key (as if "cranking" the truck), the high-voltage system sends energy to the powertrain. Upon being pressed, the accelerator sends a software signal to the inverter, a switch that rapidly opens and closes to convert a direct current (DC) signal into alternating current (AC). AC power energizes the electric motor and creates torque. Rotational energy is fed into the electric powertrain, which causes the wheels to turn and the vehicle to accelerate. In addition to standard braking, the truck can be stopped via brake recuperation, also known as regenerative braking in passenger EVs. This allows the batteries to recharge. Energy travels from the e-motors to the inverter and all the way back to the batteries.

Battery-powered trucks have less noise, smoother acceleration and more torque. On their own, batteries are just huge stores of power. However, when controlled by the right software, they're incredibly smart. Each battery is optimized via a **Battery Management/ Monitoring System** (BMS). The BMS is a controller that uses specialized software to keep tabs on what's happening inside each battery and help them operate efficiently. The BMS is used to coordinate all the internal components and systems.

The **Thermal Management System** (TMS) pays attention to charge and temperature within each battery cell, so it can ensure that all systems run safely and efficiently. For example, if one battery gets too warm, the BMS calls on the truck's TMS to quickly reduce the battery's temperature via liquid cooling. In cold environments, the BMS can use the same system to keep batteries warm and performing their best.

The most central software-related part is the **electric Common Powertrain Controller** (eCPC), also called the powertrain controller. When the driver depresses the accelerator about halfway – or 50%, the powertrain controller receives this request to accelerate and immediately checks with other components to determine if giving 50% torque to the e-motor is both safe and efficient for the system. If all requirements are met, the powertrain controller allows the inverter to pull energy from the battery and send it to the e-motors to meet the driver's demand for 50% torque. If the powertrain controller determines that giving 50% torque is not ideal (for example, if the truck is stationary or moving slowly), it will reduce torque to the ideal level – for example, 30%. The eCPS is engineered to work with a wide range of truck parts to intelligently maximize them – while also being as efficient as possible.

An electric truck has high and low voltage batteries. The **High-voltage batteries** give an electric truck its "go." They power many parts of the vehicle viz giving drive one to three e-motors (depending on configuration) as well as an electric air compressor, which provides air pressure for the truck's pneumatic brakes and suspension system. The **Low-voltage batteries**, usually located under the hood of an electric truck, power low-voltage components, such as in-dash controls and various integrated systems.

Brake Recuperation is Energy out – and Back in. For electric trucks, energy is a two-way street. Not only can the batteries and inverter power the e-motor, which ultimately drives the e-axle and wheels. The entire system can work in reverse. The driver can quickly initiate a process called brake recuperation. Brake recuperation allows the e-motor to convert mechanical motion back into electrical charge that can be stored in the batteries. Brake recuperation is automatic and smart in most ZETs. It’s the future.

Battery-powered trucks, engineered with simplicity and durability in mind, have fewer moving parts, which can help minimize maintenance in the long run. Example the e-motor and 2-speed transmission.

3.2.2 Status of ZET Market in India

IPL Tech Ltd Rhino 5536 ZET. In the Indian ZET manufacturing space IPL Tech Ltd has been the pioneer. They have built the Rhino 5536 ZET. The company was started in 2018 by three Engineers Subodh Yadav, Sid Das and Chetan Singhal. The truck caters for the electric heavy-duty commercial goods carriers, which have wide applications in mines, ports, infrastructure development, construction, and inter-warehouse freight transport. The company rolled out several industry-first initiatives, including the roll-out of the Driver app, with on-time delivery of construction materials, deployment of electric trucks, widespread adoption while reducing incidents of miscommunication and delays. The company has manufacturing capacity of 250 trucks a month and with its expansion plans it aims to achieve a target of 2750 per month in the near timelines.

Figure 15 : IPL Tech Ltd Rhino 5536 ZET

Source : Hindu Business

With a 265 kWh LFP battery it offers a 250+ kms range with a 160 kW charge (0 to 100 percent in 90 minutes), regenerative braking, power of 360 HP, 90 kmph top speed, Unparalleled torque 483 bhp, state of art BMS. 23 degree gradient climb, highly efficient electric motor with automatic transmission.

Auto Expo 2023 saw proliferation of a number of alternate fuel vehicles in the trucks category. BEVs were in the most advanced stages of production/ sales, specially in low to medium-duty categories.

Volvo-Eicher Pro 2049 EV. The Eicher Pro 2049 light ZET, by Volvo Eicher Commercial Vehicles (VECV), is targeting the 5-ton GVW class, a 'sweet spot' between the mini- or pick-up truck and ICV truck segments, suitable for intra-city and sub-urban applications. Equipped with a larger 64 kWh battery pack, the Eicher Pro 2049 EV claims a driving range of up to 174 kms in single charge as per manufacturer's test standards.

Figure 16 : Volvo-Eicher Pro 2049

Source : VECV

Ashok Leyland BOSS EV. BOSS EV has a GVW of 12 Tons and a payload capacity of 7.5 tons. Max power of 140 kW and max torque of 1065 Nm is produced by a Permanent Magnet Synchronous Motor and gives a max speed of 80 kmph. The battery pack of 284

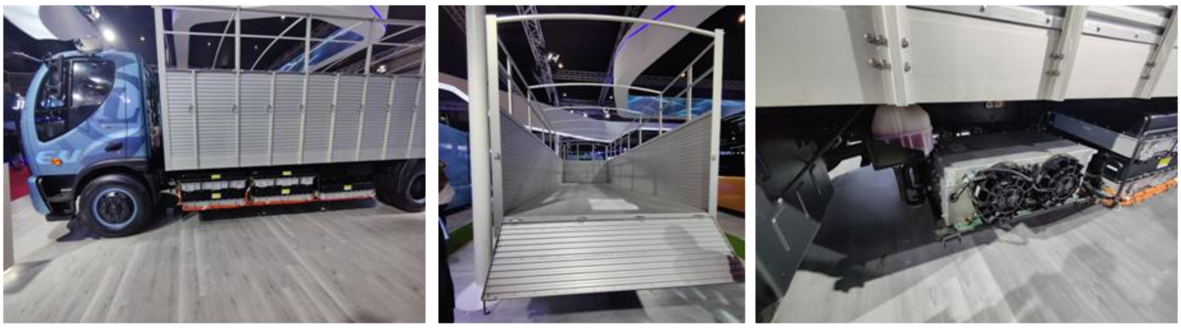


Figure 17 : Ashok Leyland BOSS EV

Source : Ashok Leyland

kwh is Li-Fe NMC configuration supports fast charging with a BMS and fully integrated cooling system, 8 kW chassis mounted chiller.

Tata Motors Ultra E.9. The Ultra E.9 carries a GVW of 9 Tons and a payload of 4 tons. It is designed for city transportation needs. It has a 3-phase PM type traction motor delivering power of 250 kW and 950 Nm torque. The 110-148 kWh Li-Fe battery pack takes 1.5-2 hours on DC charging equipped with CCS2 protocol connector, offering a range of 120-150 kms. It has an automatic direct drive type transmission with Banjo type e-axle. The EV has a deck length of 17 feet.

Figure 18 : Tata Ultra E.9
Source : Tata Motors

Tata Motors Prime E.28K. Prime E.28K is offered with a battery capacity of 453 kWh, which gives an operating range of 150-200 kms ideal for Tipper applications. Equipped with 245 kW traction motor providing max torque of 2950 Nm at 3000 rpm, 2-speed auto-shift e-GBox with PTO provision, it is configured with 18 m^3 body suitable for applications like shallow mining, mineral movement, bulk cargo movement and port applications.

Figure 19 : Tata Prime E.28K
Source : Tata Motors

3.2.3 Infrastructural Support Required

Medium- and Heavy-Duty Electric Vehicle Charging a megawatt-scale charging system enabling drivers to charge in less than 30 minutes, preferably at reasonable costs. The figure depicts the infrastructure required and its layout.

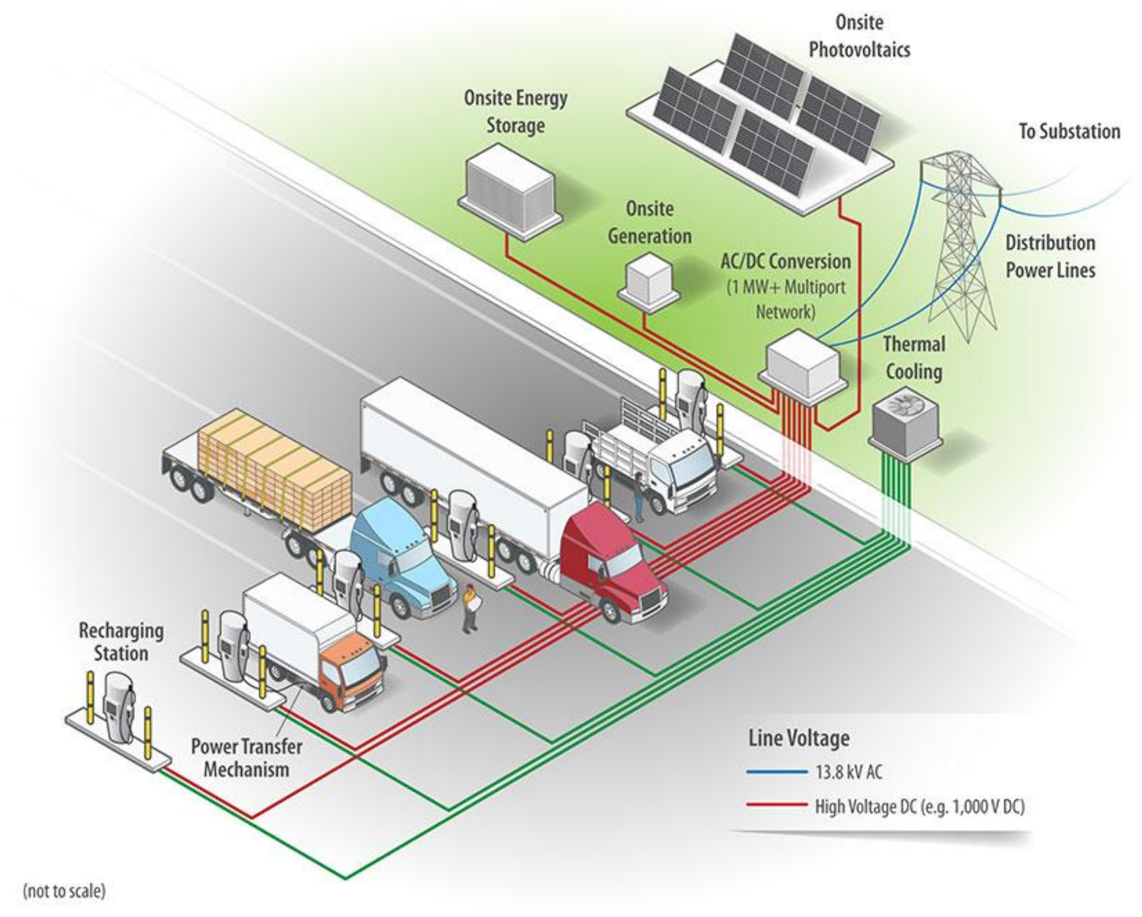


Figure 20 : Charging Infrastructure Required by ZETs

Source : NREL Transforming Energy

The **process of establishing a fleet electrification infrastructure** commences with determining the daily average and maximum meterage of vehicles and their numbers. Each vehicle has an EV Energy Consumption Rate. This may vary from 0.6 kWh per mile for a 2-wheeler or 4 Wheeler light vehicle, through 2 kWh per mile for a bus and going upto 2.8

to 3.5 kWh per mile for a heavy duty truck. The Charging Energy Requirement (KWh per charge) is calculated based on vehicle mileage travelled between charges and EV Energy Consumption Rate of that vehicle. Once this is calculated for each type of vehicle and totalled up, the Average Power Demand in kW can be calculated by dividing it by the Charging Window which is available in terms of hours. This will establish the Energy Demand per Day of the Fleet Charging Infrastructure established for the station. It is imperative that 25% margin of the total voltage required for the garage should be taken into account.

Station level charging infrastructure should be planned, preferable at one/ limited number of garages/ locations, to effect cost-savings. Separate **MES work** will have to be undertaken, and such charging infrastructure will need to be formalised and included under Defence Works Procedures (DWP). MES will have to be involved in conjunction with respective DISCOM to setup arrangements for payments based on consumption.

3.2.4 Electric Trucks in Defence

ZETs have an achievable range of 250 odd kms, lesser in mountains and difficult terrain. They have the biggest pluses on high power, torque and quick response, besides being silent and clean. So overall, electric trucks are a promising alternative to traditional fossil fuel-powered trucks, but they suffer from the disadvantages of range anxiety and requirement of charging infrastructure, especially enroute and in forward-most areas. Some of it can be offset by swappable battery options. Hence, may not be suitable for all types of military operations in the current (2023) timeframe. As battery technology improves, packs more kwh per kg and assured ranges of 1000+ kms, the acceptability will increase.

3.3 Hybrid EVs/ Strong Hybrids/ Plugin Hybrid EVs

A hybrid electric vehicle combines conventional internal combustion engine (ICE) system with an electric system (hybrid vehicle power-train). If both powertrains exist and are capable of operating independently while using an external source/source for charging, it is termed as a Plug-in HEV (also called Full Hybrid). A PHEV's battery pack is smaller than all-electric vehicles for the same vehicle weight (due to the necessity to still accommodate its combustion engine and hybrid drivetrain), but has the auxiliary option of switching back to using its gasoline/diesel engine like a conventional HEV if the battery runs low, alleviating range anxiety especially for places that lack sufficient charging infrastructure.

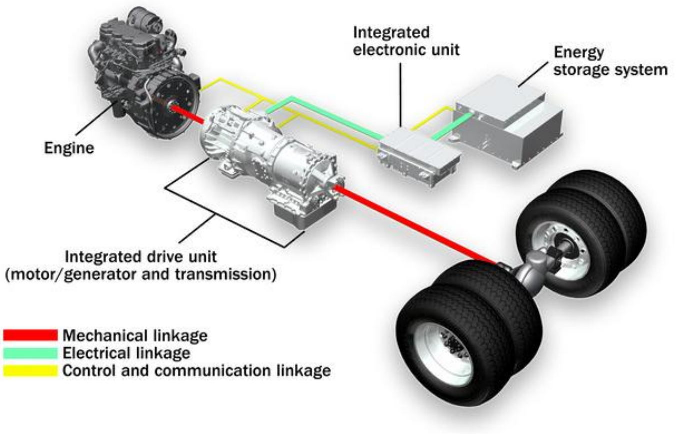


Figure 21 : Schematic How Hybrid EV Works

Source : Green Car Congress

HEVs make use of efficiency-improving technologies such as regenerative brakes which convert the vehicle's kinetic energy to electric energy, in turn which is stored in a battery or super-capacitor. Some varieties of HEV use an internal combustion engine to

Figure 22 : BAE Parallel Electric Hybrid Truck

Source : BAE Systems

turn an electrical generator, which either recharges the vehicle's batteries or directly powers its electric drive motors; this combination is known as a motor–generator.

Hybrid electric vehicles can be classified according to the way in which power is supplied to the drivetrain. n parallel hybrids, the ICE and the electric motor are both connected to the mechanical transmission and can simultaneously transmit power to drive the wheels, usually through a conventional transmission. In series hybrids, only the electric motor drives the drivetrain, and a smaller ICE (also called range extender) works as a generator to power the electric motor or to recharge the batteries. Power-split hybrids have the benefits of a combination of series and parallel characteristics.

3.3.1 Hybrid Transmissions

The purpose of a hybrid transmission is to option more than a single source of driveline torque and recapture driveline energy that would otherwise be lost. Electric hybrid transmissions are required to play a role in “recycling” driveline energy that can—under the right circumstances—improve fuel efficiency.

Hybrid Electric Drive

Hybrid electric drive has become common in many intra-city commercial vehicles especially transit buses. Electric hybrid drive can produce improved fuel economy in start-stop type applications and

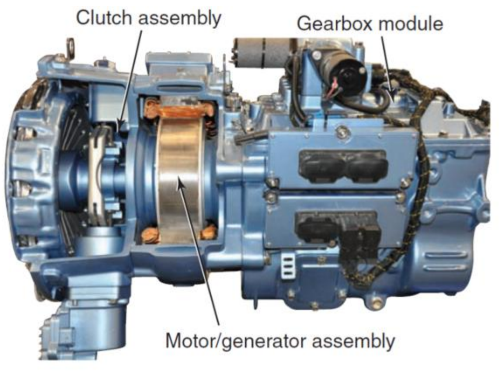


Figure 23 : Eaton Hybrid Transmission
Source : CENGAGE

reduce noise. The primary power source of the vehicle is typically a diesel or natural gas engine but there is a motor-generator unit within the hybrid transmission. When functioning as a generator, the motor-generator unit converts driveline mechanical energy into electrical energy to be stored in battery or capacitor banks. It then reverses its role to use the stored electrical energy to provide driveline torque. The figure shows an Eaton hybrid transmission.

Rectifiers and Inverters

The motor-generator in hybrid electrical systems generates alternating current (AC) and, in turn, is driven by AC. However, the electrical energy it produces has to be stored in battery and capacitor banks as direct current (DC); this requires a cycle of rectification (AC to DC) and inversion (DC to AC). The solid-state inverters seldom fail but these produce heat when operating, another source of potential danger, hence caution is required while working on hybrid electric systems. The figure shows a cutaway of an Eaton hybrid electric transmission highlighting the motor-generator.

Figure 24 : Eaton hybrid electric transmission motor-generator
Source : CENGAGE

Scania P-series Hybrid is a heavy-duty truck that features a parallel hybrid system that combines a diesel engine with an electric motor (Scania, 2022). It’s Hybrid and Plug-In Hybrid trucks takes the strengths of

Figure 25 : Scania P-series Hybrid
Source : Electrive

both the electric powertrain and the traditional combustion engine powertrain, to ensure the vehicle can run emission-free when needed, while still retaining the extended range possible when running on biofuels. There is fully automated switching between combustion engine and electric operations. It comes with 230 kW with separate loop oil cooling and a 6-speed dual motor clutchless gearbox. The battery is 90 kWh giving up to 60 km range. The GVW is 36 tons. The Scania P-series Hybrid is designed for regional and local distribution applications, and its hybrid system provides improved fuel efficiency and reduced emissions.

An electric power train is intended to achieve better fuel economy, better performance and in case of plug-in hybrids assurance of range. The most common type of HEV is hybrid electric car, although hybrid electric trucks, in pickups and tractors categories, also exist from companies such as GM, Mercedes Benz, Navistar, Isuzu, DAF trucks, MAN, Nisan, Renault.

However, the electric drive is only available for shorter distances. This makes them less suitable from environment protection point of view and for military operations, as most portion of average drive will be diesel/ gasoline. Though the technology itself has achieved success and significant maturity levels in diesel light passenger vehicle and SUV segments, including in India.

3.3.2 Infrastructural Support Required

The HEV do not require elaborate charging infrastructure as the batteries which power the motor are charged only from the diesel engine and regenerative braking. However, PHEV require as elaborate a charging infrastructure as for Pure EV ZETs, as discussed in preceding section.

3.3.3 Hybrid Trucks in Defence

Hybrid trucks are a promising alternative to traditional fossil fuel-powered trucks, but they may not be suitable for all types of operations and fleets. They offer a good balance of fuel efficiency and emission reduction in comparison to traditional trucks. It's important to evaluate the specific needs and requirements of a business or fleet before deciding to invest in hybrid trucks. Within Hybrid options, Plug-in Hybrids offer better advantages though have an additional weight trade-off.

Research reveals that militaries have preferred diesel-electric hybrids over HEV/PHEV low emission options in the trucks category. Hence, this is not the top recommended option for implementation.

3.4 Natural Gas : CNG (Compressed Natural Gas) and LNG (Liquefied Natural Gas

3.4.1 Compressed Natural Gas Trucks

Heavy-duty compressed natural gas (CNG) vehicles work much like gasoline-powered vehicles with internal combustion engines. Many heavy-duty natural gas vehicles use **spark-ignited** natural gas systems, but some systems use a **diesel-like compression injection**. In a spark-ignited system, the engine functions the same way as a gasoline engine. Natural gas is stored in multiple fuel tanks, or cylinders, typically behind the cab of the vehicle. The CNG fuel system transfers high-pressure gas from the fuel tank through the fuel lines, where a pressure regulator reduces the pressure to a level compatible with the engine fuel injection system. The ECM controls the fuel mixture, ignition timing, and emissions system; monitors the operation of the vehicle; safeguards the engine from abuse; and detects and troubleshoots problems. High pressure regulator reduces and regulates the pressure of the fuel exiting the tank, lowering it to an acceptable level required by the engine 's fuel injection system. Finally, the fuel is introduced into the intake manifold or combustion chamber, where it is mixed with air and then compressed and ignited by a spark plug. The exhaust system channels the exhaust gases from the engine out through

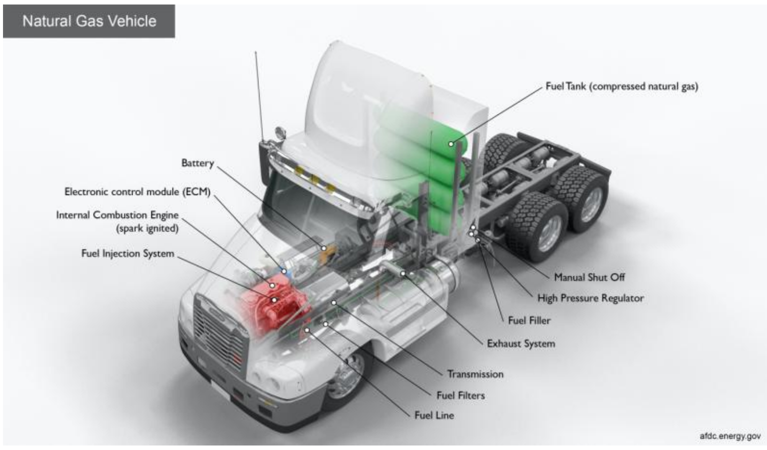


Figure 26 : CNG Vehicle Functioning

Source : AFDC energy

the tailpipe. A three-way catalyst is designed to reduce engine-out emissions within the exhaust system. In the Internal combustion engine (spark-ignited) configuration, fuel is injected into either the intake manifold or the combustion chamber, where it is combined with air, and the air/fuel mixture is ignited by the spark from a spark plug. (Alternate Fuels Data Center, 2020)

3.4.2 Liquefied Natural Gas Trucks

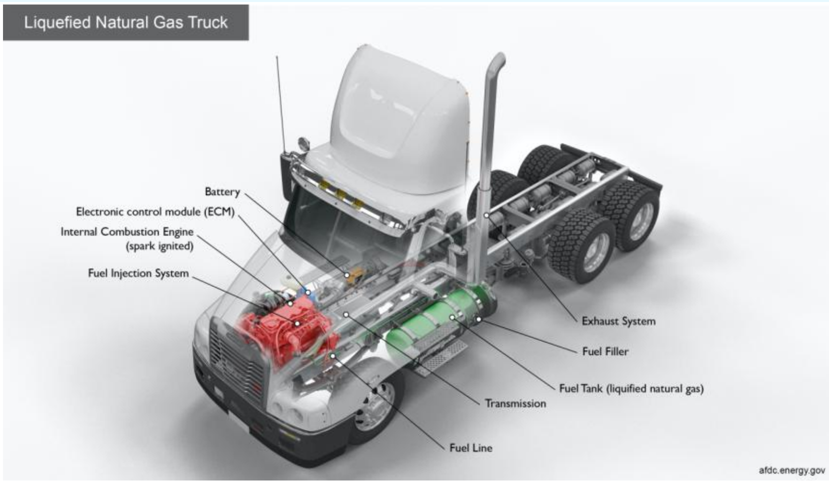


Figure 27 : LNG Vehicle Functioning
Source : AFDC energy

Heavy-duty liquefied natural gas (LNG) vehicles work much like gasoline-powered vehicles with a **spark-ignited internal combustion engine**. The natural gas is **super-cooled** and **cryogenically stored in liquid form**, usually in a tank on the side of the truck. LNG is typically a **more expensive option** than compressed natural gas (CNG) and is most often used in heavy-duty vehicles to meet **longer range** requirements. Because it is a liquid, the energy density of LNG is greater than CNG, so more fuel can be stored on board the vehicle. This makes LNG well suited for trucks traveling greater distances. The ECM controls the fuel mixture, ignition timing, and emissions system; monitors the operation of the vehicle; safeguards the engine from abuse; and detects and troubleshoots problems. The Fuel injection system introduces fuel into the engine's combustion chambers for ignition. A metal tube or flexible hose (or a combination of these) transfers fuel from the tank to the engine's fuel injection system.

(Alternate Fuels Data Center, 2020)

Natural Gas Trucks are low emission, reduce fossil fuel dependency, are cost effective and more efficient. However, they have a limited range compared to traditional diesel trucks, which can make them less suitable for long-distance hauls. The initial cost is higher and the powertrain is more complex, difficult to maintain and repair. Natural gas needs to be handled with care being highly inflammable to avoid accidents.

Infrastructural Support Required. The CNG and LNG trucks necessarily require the gas companies infrastructure where they are to operate. As in February 2023 there are more than 3000 CNG filling stations in the country, compared to LNG in just double digits and approx 70,000 for diesel/ petrol. (Wikipedia, 2022) So, infrastructure is yet to come up fully, though government efforts have been highlighted in the research paper.

No material could be found wherein natural gas trucks are specifically being used by any army or military. It has limited applicability for defence use, primarily due requirement of dedicated infrastructure and its sparseness, specially in remote areas where army will operate.

3.4.3 Natural Gas Production and Distribution

Natural gas is primarily made up of methane, with low concentrations of other hydrocarbons, water, carbon dioxide, nitrogen, oxygen, and some sulfur compounds. Natural gas is extracted from subsurface rock formations via drilling. Advances in hydraulic fracturing technologies have enabled access to large volumes of natural gas from shale. Chemically identical to conventional natural gas, renewable natural gas RNG) is the purified product used as a vehicle fuel, which is produced by purifying biogas produced from decaying organic materials. Biomethane, which is another term for this processed pipeline-quality fuel, refers to purified biogas and is interchangeable with traditional natural gas but is often used in non-vehicle applications. Like conventional natural gas, RNG can be compressed (CNG) or liquefied (LNG) for use in vehicles.

Although natural gas accounts for 6% of the country's energy consumption, India plans to boost the natural gas market share to 15% by 2030 as part of the country's plan to reduce air pollution and use cleaner-burning fuels. (EIA International, USA, 2022)

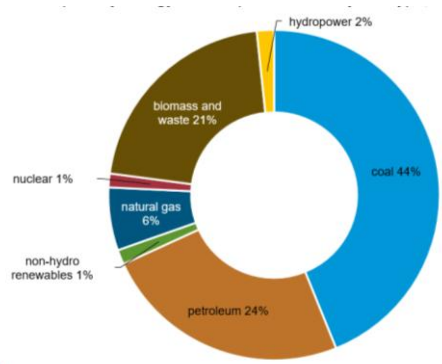


Figure 28 : Total Primary Energy Consumption by Fuel Type 2020

Source : EIA

India's government implemented upstream policy changes in 2016, which included giving companies more pricing freedom by allowing them to market natural gas at higher prices to all sectors. Companies can also explore and produce unconventional natural gas, such as coalbed methane and shale gas, from existing production contracts at conventional natural gas fields and can bid on all hydrocarbon blocks of interest without waiting for an official government bidding round. As a result of these changes, exploration and production companies have increased their investments for technically challenging natural gas fields (mainly unconventional and deepwater basins).

India's natural gas demand rose every year since 2015, except for a 1% decrease in 2020, to reach 2.3 Tcf (Trillion cubic feet) in 2021. India's natural gas demand grew in 2021, despite pandemic-related disruptions and the effects of increased costs of liquefied natural gas (LNG). Much of this growth can be attributed to the extensive expansion of natural gas distribution infrastructure. The government plans to invest $60 billion in its expansion and aims to connect 70% of the country's population to the natural gas grid.

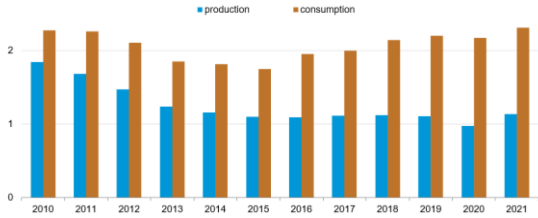


Figure 29 : India's Natural Gas Production and Consumption 2010-2021

Source : EIA

In 2021, India was the world's fourth-largest LNG importer, importing about 1.2 Tcf (7%) of global trade, a 10% decrease from 2020. India has six existing LNG import terminals at Dahej, Ratnagiri, Hazira, Ennore and Mundra with annual peak output of 1896 bcf (billion cubic feet) per year. With six more projects in pipeline the capacity will be hiked by another 1440 bcf.

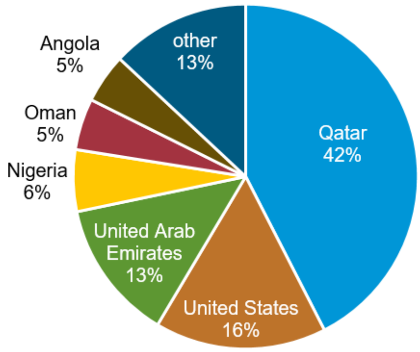


Figure 30 : India's LNG Imports 2021

Source : EIA

India's government considers the development of natural gas infrastructure, including long-distance pipelines, re-gasification terminals, and distribution stations for using more compressed natural gas in the transportation sector, a priority. The country's operational natural gas pipeline network was approximately 12,400 miles in 2021, and an additional 9,500 miles are under construction. The government's goal is to increase natural gas consumption to a 15% share of the country's total energy consumption by 2030. In India's 2021–2022 budget, the government formalized a plan to set up an independent natural gas transmission system operator. This step is integral to making natural gas more cost competitive.

3.4.4 CNG Distribution

The vast majority of the nation's compressed natural gas (CNG) supply is distributed via the established natural gas distribution system. The number of Compressed Natural Gas (CNG) stations in India have risen from around 380 in 2011 to 900 in 2014 to 4500 in 2022 and another 3500 are planned by 2024 to make the total numbers to about 8000 in 25 states/UT. (ET Enrgy World.com, 2022) (P.I.B. India, 2021)

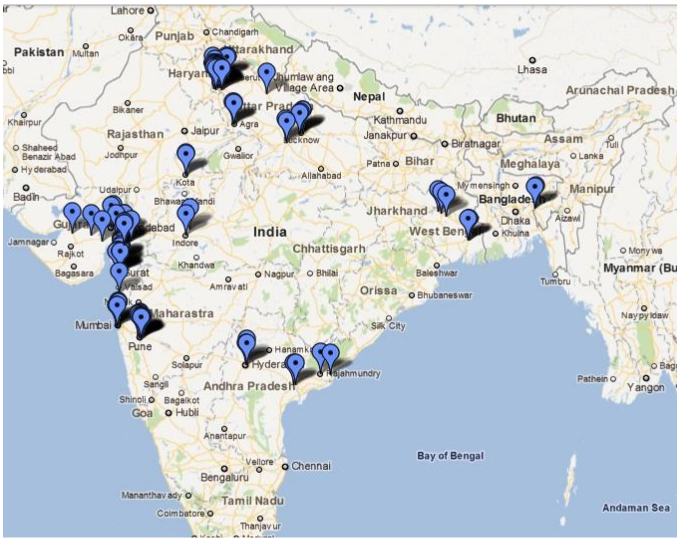


Figure 31 : CNG Distribution Network India

Source : The Automotive India

Unlike gasoline or diesel stations, compressed natural gas (CNG) stations are not "one size fits all." Building a CNG station for a retail application or a fleet requires calculating the right combination of pressure and storage needed for the types of vehicles being fueled. Making the right choices about the size of the compressor and the amount of storage at the station will impact the cost of fuel and range for vehicles. There are two types of CNG infrastructure: time-fill and fast-fill. The main structural differences between the two systems are the amount of storage capacity available and the size of the compressor. These factors determine the amount of fuel dispensed and the time it takes for CNG to be delivered. Most CNG stations include one of these two system types, but "combination fill" stations include both types.

Generally, fast-fill stations are best suited for retail situations where vehicles arrive randomly and need to fill up quickly. All public CNG stations have a fast-fill option. Fast-fill stations receive fuel from a local utility line at a low pressure and then use a compressor on site to compress the gas to a high pressure. Once compressed, the CNG moves to a series of storage vessels so the fuel is available for a quick fill-up. CNG can also be delivered via dispensers alongside gasoline or other fuel dispensers.

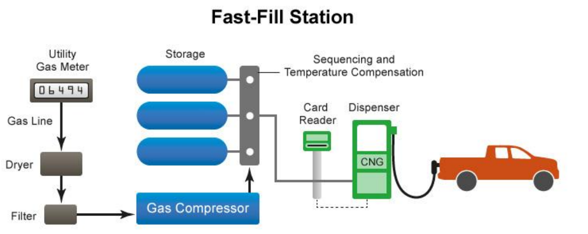


Figure 32 : Fast-Fill CNG Station

Source : Energy Education

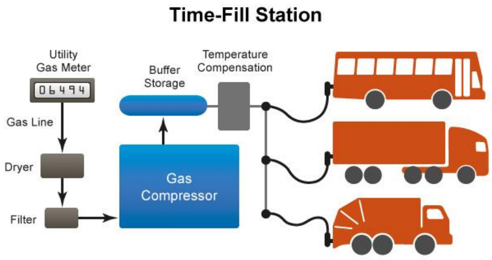


Figure 34 : Time-Fill CNG Station

Source : Energy Education

Time-fill stations are used primarily by fleets and work best for vehicles with large tanks that refuel at a central location every night. At a time-fill station, a fuel line from a utility delivers CNG at a low pressure to a compressor on site. Unlike fast-fill stations, vehicles at time-fill stations are generally filled directly from the compressor, not from fuel stored in high pressure vessels. The size of the compressor needed depends on the size of the fleet. Although there is a small buffer storage tank, its purpose is not to fill vehicles but to keep the compressor from cycling off and on unnecessarily—wasting electricity and causing undue wear and tear on the compressor. The storage tank is sometimes used to "top off" vehicle tanks during the day.

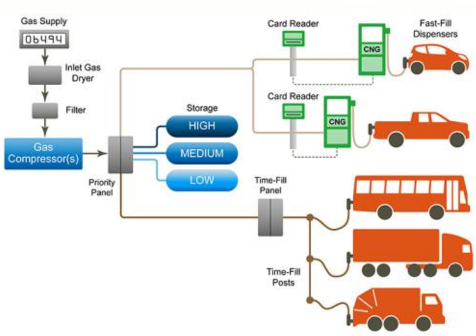


Figure 33 : Combination-Fill CNG Station

Source : Energy Education

Combination-fill stations include both the fast-fill and time-fill components in one system.

The vehicles connected to the time-fill posts are filled directly from the compressor, usually overnight. Vehicles at the fast-fill dispensers are filled from the storage vessels or from the compressor, depending upon need. This design gives a fleet flexibility.

3.4.5 LNG Distribution

LNG must be super-cooled and stored in its liquid form at -260°F before being converted back into a gas. LNG must be in its gaseous form before it enters the domestic pipeline distribution system and is ultimately delivered to the end user. LNG can be used in vehicles, although CNG vehicles are more common. A limited number of LNG fuelling stations are available. Many LNG users are fleets that have private fuelling infrastructure for their vehicles. Large-scale liquefaction facilities provide LNG fuel for transportation nationwide, and LNG must be delivered to stations via trucks. LNG stations are structurally similar to gasoline and diesel stations in that they have a storage tank, meters, and dispenser. LNG dispensers deliver fuel to vehicles at pressures of 30 to 120 psi. Because LNG is stored and dispensed as a super-cooled liquefied gas, protective clothing, face shield, and gloves are required when fuelling a vehicle, and personnel must also be trained on fuelling procedures. There are three options for LNG fuelling: mobile, containerized, and permanent large stations. In mobile fuelling, LNG is delivered by a tanker truck that has on-board metering and dispensing equipment. A starter station, or containerized station, includes a storage tank, dispensing equipment, metering, and required containment. A

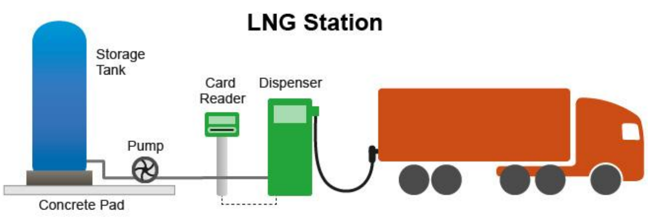


Figure 35 : LNG Station

Source : Energy Education

permanent station has greater storage capacity and is tailored to meet fleets' needs.

3.4.6 Vehicle Performance

Natural gas vehicles (NGVs) are similar to gasoline or diesel vehicles with regard to power, acceleration, and cruising speed. The driving range of NGVs is generally less than that of comparable gasoline and diesel vehicles because, with natural gas, less overall energy content can be stored in the same size tank. Extra natural gas storage tanks or the use of LNG can help increase range for larger vehicles.

In heavy-duty vehicles, dual-fuel, compression-ignited engines are slightly more fuel-efficient than spark-ignited dedicated natural gas engines. However, a dual-fuel engine increases the complexity of the fuel-storage system by requiring storage of both types of fuel and the integration of diesel after-treatment devices.

3.4.7 Market Maturity

Pure CNG vehicles have been in India for almost 15 years now, though LNG is a new phenomenon fin transportation technology. Natural gas trucks have seen tremendous maturity levels in the recent past, especially in India.

Ashok Leyland LNG A6 6x4 Tractor. The vehicle is powered by A6 LNG engine producing 240 kW power @2200 rpm and 1200 Nm torque

Figure 36 : AL LNG A6 6x4 Tractor

Source : Ashok Leyland

@1200-1800 rpm. 990 L LNG is stored in cryogenic tanks (behind cabin) at -162^{O}C, allowing large quantities of liquid gas, hence longer ranges. The LNG tractor is also equipped with 160 L (4x40 L) CNG tanks on right hand side. The vehicle automatically switches to CNG when LNG is exhausted. It has a 9-speed syncromesh gearbox. The GVW of vehicle is 55 tons and max speed 80 kmph.

Tata Motors Prima G.35K LNG. Tata Prima G.35K LNG is in the tipper range of trucks and is powered by fuel-efficient Cummins 6.7 L gas engine capable of generating 280 HP and 1100 Nm. It has high gradability of 47^{O} and is suitable for mining and construction sectors. It offers ~24 hours continuous operation with dual LNG fuel tanks of 300L to 600L capacities. The GVW is 35 tons and range of 150 to 300 kms.

Figure 37 : Prima G.35K LNG
Source : Tata Motors

Volvo FM420 LNG 4x2 Tractor. The Volvo FM420 LNG 4×2 tractor offers 1,000 km range with full tank of LNG, with similar performance, drivability, and even higher productivity than diesel-powered FM trucks. The company is already offering LNG-run FH and FM trucks in 420 and 460 hp power ratings with gross vehicle weights of up to 64 tons in Europe. The LNG trucks are undergoing trials in India pre-commercial launch. FM420 LNG tractor is powered by G13C420 natural gas, spark-ignited engine generating 420 hp at 1,400-1,800 rpm and peak torque of 2,100 Nm at 1,000-1,400 rpm. It is mated to a 12-speed I-Shift

Figure 38 : Volvo FM420 LNG 4x2
Source : VECV

AMT gearbox. Further, the LNG engines claim 20 percent less CO2 emissions than diesels. Using bio-LNG results in one-hundred percent less CO2 emissions. The truck is equipped with a 205 kg gas tank, which can support about 1,000 kms of driving range, according to Volvo Trucks.

Tata Motors Signa G.48T. Tata Signa G.48T is a CNG truck powered by Cummins 6.7 litre BS6 gas engine capable of generating 280 HP and 1100 Nm torque. The body is customisable on a modular platform architecture. It offers 500 to 1000 kms range. With CNG tank Cascade option of type1 and type4 cylinders. The type4 cylinder gives ~34 tons payload option. GVW is 47.5 tons. It has dual-filling nozzles for reducing refilling time. Vehicle is fitted with a 9-speed gearbox. It has gradability of 28^{O}. It is suitable for cement applications, bulker and fly-ash, market load operations and denser FMCG movement.

Figure 39 : Tata Signa G.48T

Source : Tata Motors

Tata Motors Prima Intra Bi-Fuel (CNG+Petrol). Tata Intra Bi-fuel is a pickup with CNG and Petrol fuel bi-fuels. It has a payload of 900-1000 kgs and GVW of 2.3 tons. The CNG tank has capacity of 80-110 litres and petrol tank 5-35 liters, giving a range of 300 to 800+ kms. Powered by a 1.2 litre NGNA bi-fuel CNG engine, it gives power and torque of 43kW @4000 rpm and 106 Nm @1800-2200 rpm with petrol and 39kW @4000 rpm and 95 Nm @1800-2200 rpm with CNG. It has a GBS 65-5 gearbox assembly. Ideally suited for small

Figure 40 : Tata Prima Intra Bi-Fuel

Source : Tata Motors

load, long inter-city operations like carriage of fruits and vegetables, LPG cylinders, food grains, FMCG and e-commerce.

Volvo-Eicher Pro 8055 CNG-LNG Hybrid. Volvo-Eicher has put together the 55-ton 8055 LNG-CNG hybrid vehicle bringer together best of both in terms of clean fuel options and longer ranges of 700-1100+ kms. It has a 8-liter engine with electronic port fuel injection that delivers optimal power and mileage. The engine is mated to a 9-speed manual gearbox with a crawler gear function. With stress on safety it is configured with a SS304 LNG tank and 3-way CNG filling valve. The 4×2 tractor is powered by a 6-cylinder VEGX8 natural gas spark-ignited engine aided by an ECU-controlled multi-port fuel injection system. Given LNG's scarce refueling network in India, the truck makers are trying to offset the range anxiety with the the flexibility and practicality of dual-fuel trucks that gain the advantage of CNG network in the country. Since both the fuels are largely the same, minor changes to fuel injection system and electronics is all that is needed to make the gas engines dual-fuel compliant.

Figure 41 : Volvo-Eicher 8055 LNG-CNG Hybrid

Source : Eicher

3.4.8 Bi-fuel Natural Gas Vehicles

A bi-fuel natural gas vehicle can use either gasoline or natural gas in the same internal combustion engine. Both fuels are stored on board and the driver can switch between the fuels. The vehicle is equipped with separate fuel tanks, fuel injection systems, and fuel lines for both fuels.

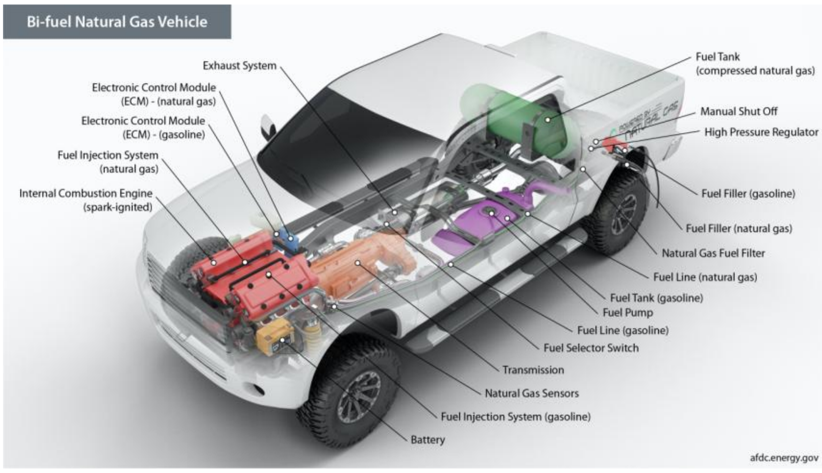


Figure 42 : Bi-fuel Natural Gas Vehicles

Source : AFDC.energy

The battery provides electricity to start the engine and power vehicle electronics/accessories. There are two Electronic control module (ECM) (Natural gas and Gasoline). The ECM (G) controls the gasoline mixture, ignition timing, and emissions system; monitors the operation of the vehicle; safeguards the engine from abuse; and detects and troubleshoots problems. In a bi-fuel natural gas configuration, the ECM (NG) communicates with the ECM (G) and controls the natural gas mixture, ignition timing, and emissions system; monitors the operation of the vehicle; safeguards the engine from abuse; and detects and troubleshoots problems.

There are two Fuel injection systems - Natural Gas and Gasoline. Similarly, two pipelines transferring separate fuels. A fuel pump that transfers fuel from the tank to the engine's fuel injection system via the fuel line. On bi-fuel vehicles, Fuel selector dashboard switch allows the driver to select between fuels. In Internal combustion engine (spark-ignited) configuration, fuel is injected into either the intake manifold or the combustion chamber, where it is combined with air, and the air/fuel mixture is ignited by the spark from a spark plug. The Natural gas sensors monitor the pressure of the fuel supply and relay that information to the electronic control module. The High pressure regulator reduces and regulates the pressure of the fuel exiting the tank, lowering it to an acceptable level required by the engine's fuel injection system. The Natural gas fuel filter traps contaminants and other by-products to prevent them from clogging critical fuel system components, such as fuel injectors. The manual shut off allows the vehicle operator or mechanic to manually shut off the fuel supply. Exhaust system: The exhaust system channels the exhaust gases from the engine out through the tailpipe. A three-way catalyst is designed to reduce engine-out emissions within the exhaust system.

3.4.9 Natural Gas Trucks in Defence Sector

Natural gas trucks are a promising alternative to traditional diesel trucks, but they may not be suitable for all types of operations and fleets. They offer a good balance of fuel efficiency and emission reduction in comparison to traditional diesel trucks. It's important to evaluate the specific needs and requirements of a business or fleet before deciding to invest in natural gas trucks.

3.5 Bio Fuel Vehicles

Figure 43 : Soybean Powered Bus
Source : ACS.org

Bio-fuel trucks are no different (upto a certain percentage of mixing of bio-fuel in diesel), except the fuel that they use. Bio-fuels are bio-ethanol and biodiesel, made from renewable sources of carbon that have been harvested recently (plants, trees, grass or agricultural waste). When burned, bio-fuels produce far less sulphur oxide, ozone and carbon monoxide, but still release carbon dioxide into the atmosphere. Bio-fuel can act as a substitute for fuels like petroleum, propane, coal and gas. Bioethanol is formed by breaking down the cells of living organisms into sugars, which are then fermented to produce ethanol; a type of alcohol. It can also be made by extracting starch from plants like maize and wheat, which in turn can be used to make sugar. Biodiesel is made by combining vegetable oil or animal fat with alcohol. Good sources include rapeseed, soybeans, coconut, algae, palm oil and jatropha plants. On their own, both bio-ethanol and biodiesel contain less energy per litre than pure petrol or diesel, although when mixed together they improve combustion performance and reduce emissions of harmful gases like carbon monoxide and sulphur oxide.

Bio-fuel Trucks have all the advantage of alternate fuel vehicles to include low emissions, use of renewable energy options, cost efficiency over its lifetime and use of agricultural waste creating less pollution, local jobs and reduced transportation. However the disadvantages are limited range making them less suitable for long-distance hauls, high initial costs, limited refueling infrastructure, more complex powertrain, limited availability of bio-fuels hence question of reliability and land use issues as some bio-fuels are made from crops grown specifically for fuel production, which can lead to land use issues, such as deforestation and displacement of food crops.

3.5.1 Bio-Fuel Vehicles in Defence

Bio-fuel trucks are an interim option during transition to achieving zero emission. It seems unlikely that bio-fuels will ever be a direct replacement for petrol and diesel. They offer a promising alternative to traditional gasoline or diesel trucks, but they may not be suitable for all types of operations and fleets. They offer a good balance of fuel efficiency and emission reduction in comparison to traditional gasoline or diesel trucks. It's important to evaluate the specific needs and requirements of a business or fleet before deciding to invest in bio-fuel trucks.

3.6 IC Engine Vehicles Using Bio-Fuels

A number of initiatives have been taken by the government towards promotion of better quality and less polluting fuel, including introduction of blending of ethanol, methane, jathropa, other bio-fuels etc. The basic engine technology of a truck does not change by change of fuel, atleast upto a certain percentage of blending. During interaction at Auto Expo 2023 with IOCL officials and other technology providers, it was learnt that beyond 10% blend the use of fuel requires better additives, can harm engines in long run and hence there is a need to modify engines accordingly; or atleast certain parts of it so as to sustain the engine life longer. This technology is no further discussed herein after.

3.7 Hydrogen FCEV

3.7.1 FCEV

Fuel Cell and Hydrogen (FCH) technologies hold great promise for energy and transport applications from the perspective of meeting energy, environmental and economic challenges. Emissions from conventional vehicles are causing significant air quality issues in many locations, particularly in urban areas. Many countries now have firm carbon emission reduction targets, and are seeking to improve energy security by reducing reliance on fossil fuels. Fuel cell electric vehicles have been identified as a promising technology to help achieve these strategic goals with minimal impact on the driver in terms of functionality or convenience (H2 Mobility EU, 2020). Hydrogen, when used in a fuel cell to provide electricity, is a zero tailpipe emissions alternative fuel produced from diverse energy sources. Currently, drivers of light-duty fuel cell electric vehicles (FCEVs) can fuel up at retail stations in less than 5 minutes and obtain a driving range of more than 300 miles. Research and commercial efforts are under way to expand the limited hydrogen fuelling infrastructure and increase the production of FCEVs. (Alternate Fuels Data Centre, 2020).

The interest in hydrogen as an alternative transportation fuel stems from its ability to power fuel cells in zero-emission vehicles, its potential for domestic production, and the fuel cell's fast filling time and high efficiency. In fact, a fuel cell coupled with an electric motor is two to three times more efficient than an internal combustion engine running on gasoline. Hydrogen can also serve as fuel for internal combustion engines. However, unlike FCEVs, these produce tailpipe emissions and are less efficient.

3.7.2 Fuel Cell Technology

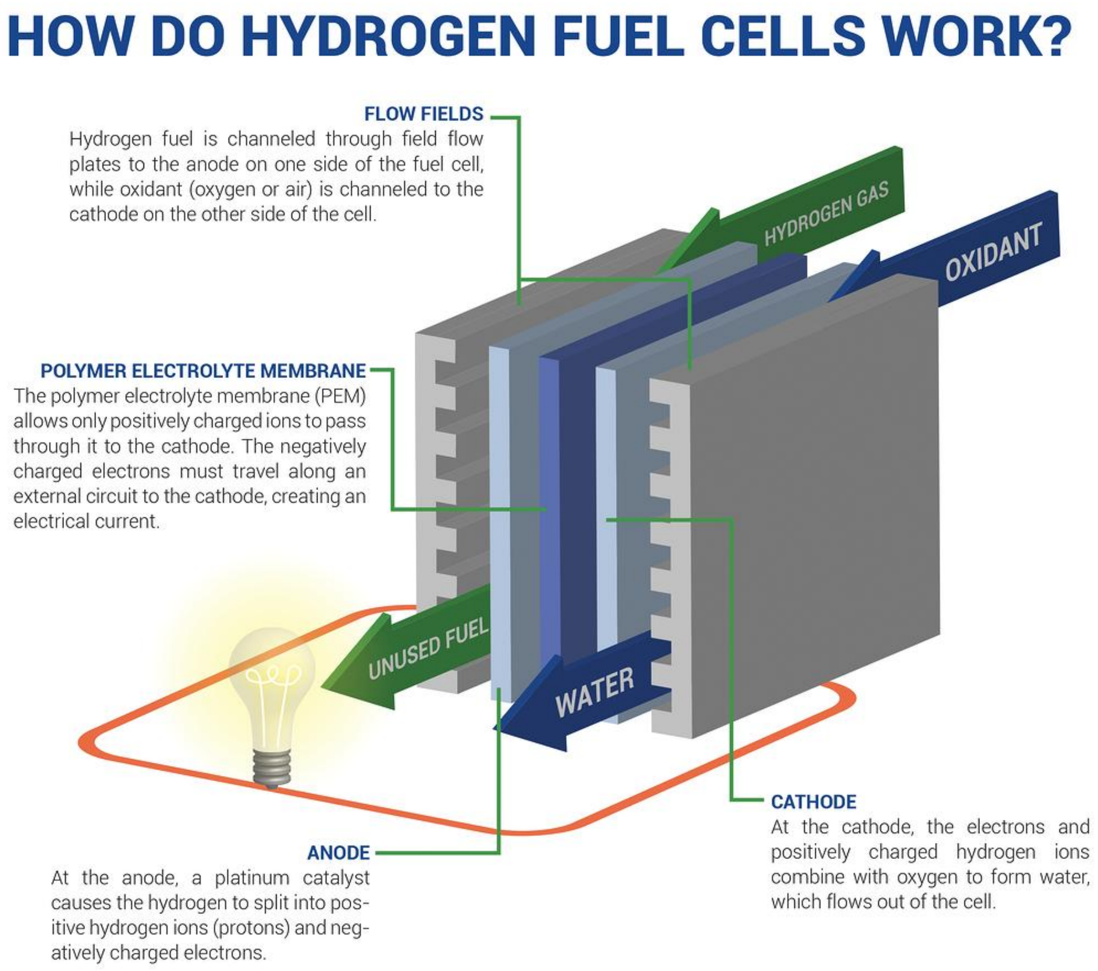


Figure 44 : How Hydrogen Fuel Cells Work

Source : Setra Systems

A fuel cell is an electrochemical energy converter in which hydrogen and oxygen react, in a controlled manner and without combustion, to water, thereby generating power and heat. The same process operates in reverse during electrolysis. A fuel cell is divided into two via a thin membrane – the Polymer Electrolyte Membrane (PEM). The membrane is coated on both sides with a catalyser and a gas-permeable electrode. (Lish, 2017)

Hydrogen and oxygen can migrate from one side to the other through the fine gas channels. The catalyser separates the hydrogen into an electron and a proton. The positively charged protons can pass through the PEM, the negative electrons, however, cannot. Current is thereby generated. If the electrodes are connected, direct current will flow. Pure water (H2O) is the by-product of this electrochemical reaction. Many fuel cells are lined up to form stacks when deployed in vehicles, in order to boost the electric current output.

Hydrogen can be produced from diverse, domestic resources, including fossil fuels, biomass, and water electrolysis with electricity. The environmental impact and energy efficiency of hydrogen depends on how it is produced. It is accordingly classified as black, grey or green. Most hydrogen is produced at or close to where it is used, typically in industries. Importantly, hydrogen's energy content by volume is low thus storing it is a challenge because it requires high pressures (700 bars), low temperatures, or chemical processes to be stored compactly. Overcoming this challenge is important for light-duty vehicles because they often have limited size and weight capacity for fuel storage. Typically, the storage capacity for hydrogen in vehicles should enable a driving range of more than 450+ kms (a days haul on tank full) to meet consumer needs. Refueling takes about 5 mins to tank full.

For widespread use of fuel cell electric vehicles, elaborate infrastructure for distribution of hydrogen through fuelling stations is required, which still needs to be developed. For instance Delhi has just two such stations as of January 2023. Hydrogen is distributed through pipelines, High pressure tube trailers or liquefied hydrogen tankers. Creating an infrastructure for hydrogen distribution and delivery to thousands of future individual fuelling stations will present numerous challenges.

3.7.3 Working of Fuel Cell Electric Vehicles

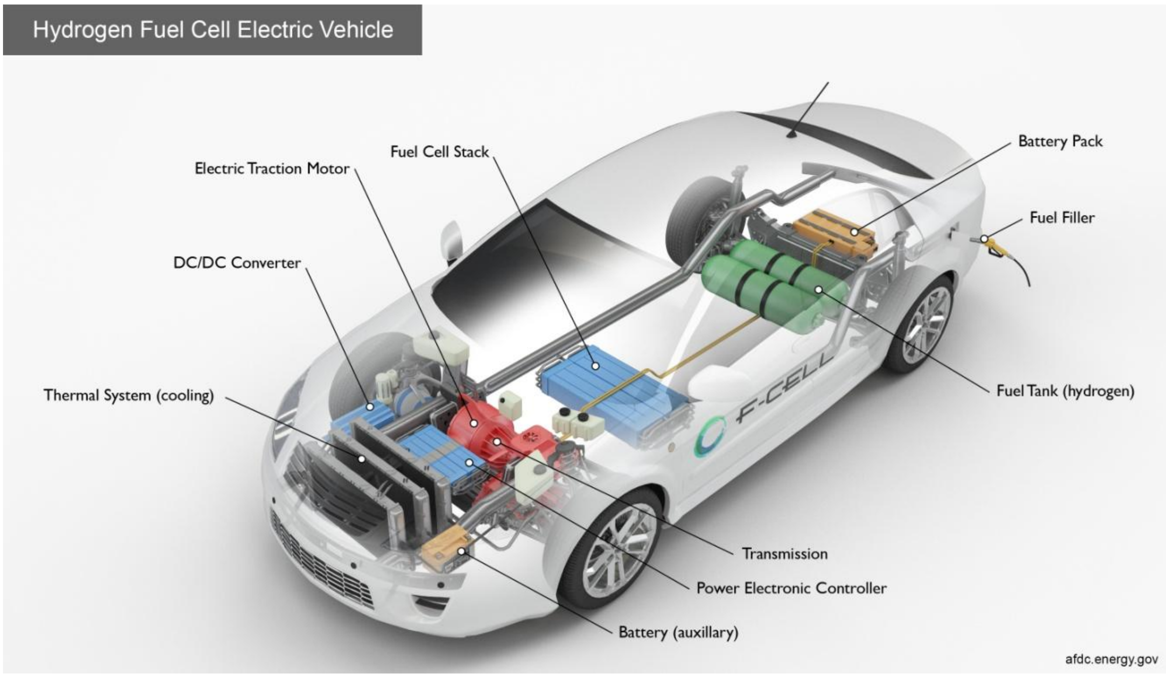


Figure 45 : How Hydrogen FCEV Work

Source : AFDC.energy

Fuel cell electric vehicles (FCEVs) use electricity to power an electric motor. In contrast to other EVs, FCEVs produce electricity using a fuel cell powered by hydrogen, rather than drawing electricity from only a battery. During the vehicle design process, the vehicle manufacturer defines the power of the vehicle by the size of the electric motor(s) that receives electric power from the appropriately sized fuel cell and battery combination. Although automakers could design an FCEV with plug-in capabilities to charge the battery, most FCEVs today use the battery for recapturing braking energy, providing extra power during short acceleration events, and to smooth out the power delivered from the fuel cell with the option to idle or turn off the fuel cell during low power needs. The amount of energy stored onboard is determined by the size of the hydrogen fuel tank. This is different from an all-electric vehicle, where the amount of power and energy available are both closely related to the battery's size.

3.7.4 Components of a Hydrogen Fuel Cell Electric Car

The Fuel tank (hydrogen) stores hydrogen gas onboard the vehicle until it's needed by the fuel cell. An assembly of individual membrane electrodes that use hydrogen and oxygen to produce electricity from the **Fuel cell stack** in the FCEV. The **Power electronics controller (FCEV)** unit manages the flow of electrical energy delivered by the fuel cell and the traction battery, controlling the speed of the electric traction motor and the torque it produces. The high-voltage battery in the **Battery pack** stores energy generated from regenerative braking and provides supplemental power to the electric traction motor. **Thermal Cooling (FCEV) system** maintains a proper operating temperature range of the fuel cell, electric motor, power electronics, and other components.

The **DC/DC converter** converts higher-voltage DC power from the traction battery pack to the lower-voltage DC power needed to run vehicle accessories and recharge the auxiliary battery. Using power from the fuel cell and the traction battery pack, the **Electric traction motor (FCEV)** drives the vehicle's wheels. Some vehicles use motor generators that perform both the drive and regeneration functions. The **Transmission (electric)** transfers mechanical power from the electric traction motor to drive the wheels.

3.7.5 Availability and Maturity Level of Technology in India

Figure 46 : Ashok Leyland FCEV

Source : Ashok Leyland

Ashok Leyland FCEV. The vehicle is a technology showcase powered with green hydrogen and offers zero tail-pipe emissions. The fuel cell (with rated output of 80 kW, 400-750 V) is where atmospheric oxygen reacts with hydrogen to produce electricity that powers the truck. This vehicle has a 650 V, 55kWh Li-NMC battery pack that provides additional thrust to ascend any terrain powered by a PMS motor with max power torque rating of 360 kW/ 3000 Nm. Hydrogen is stored in Type-4 four tank configuration with total capacity of 33.6 kgs (350 L) in the 28k GVW vehicle, giving speeds of 80 kmph.

Volvo-Eicher 3015 HCEV. Eicher Pro 3015 Hydrogen truck is VECV's technology demonstrator for zero-emission transportation, powered by battery packs sourcing energy from a hydrogen fuel cell system. The 16-19 ton GVW truck is equipped with a hydrogen fuel cell system and a high energy density lithium-ion battery pack. It can support up to 400 kms of range with full tank of hydrogen. The battery pack powers the liquid-cooled motor that drives the rear axle. The hydrogen fuel cell system, which processes hydrogen fuel to generate electrical energy by way of chemical reaction, is the ultimate power source for the battery pack, and essentially acts as a range-extender for the vehicle. The truck's hydrogen system operates at a pressure of 350 bar. The vehicle (displayed at Auto Expo 2023) is merely a technology demonstrator and far-away from commercial launch.

Figure 47 : Volvo-Eicher 3015 HCEV

Tata Motors Prima H.55S. The Tata Prima H.55S is a FCEV powered by a Cummins 6.7L hydrogen engine with 290 HP @ 2300 rpm and 1200 Nm torque at 1200-1600 rpm. The vehicle has a GVW of 55 tons and payload capacity of ~38 tons. It has three hydrogen fuel storage Type-3 tanks with 50 kgs capacity @350 bars. It is estimated to give range of 350-500 kms, with a 9-speed HD gearbox, and upto 23% grade-ability.

Figure 48 : Tata Motors Prima H.55S

Source : Tata Motors

Tata Motors Prima E.55S. The Tata Prima E.55S is a FCEV powered by a Cummins 6.7L hydrogen engine with 290 HP @ 2300 rpm and 1200 Nm torque at 1200-1600 rpm. It has a fuel stack with higher capacity of 220-240 kW; 22-34 kW battery pack and traction motor peak power/torque of 470 kW/ 2500 Nm. The vehicle has a GVW of 55 tons and payload capacity of ~38 tons. It has three hydrogen fuel storage Type-3 tanks with 50 kgs capacity @350 bars and refueling time of ~ 20 mins. It is estimated to give range of 350-500 kms, with a 9-speed HD gearbox, and upto 24.5% grade-ability.

Figure 49 : Tata Motors Prima E.55S

Source : Tata Motors

3.7.6 Hydrogen Refueling Stations (HRS)

Hydrogen gas (H2) is compressed at about 350-700 bars pressure via advanced mechanism, to be suitable to be used as a fuel, and is then distributed via a dispenser (similar to the ones used in fossil fuel stations). Industrial gas companies have developed hydrogen fuel dispensing systems that are safe and user-friendly and international standards to ensure compatibility between all refueling stations and vehicles.

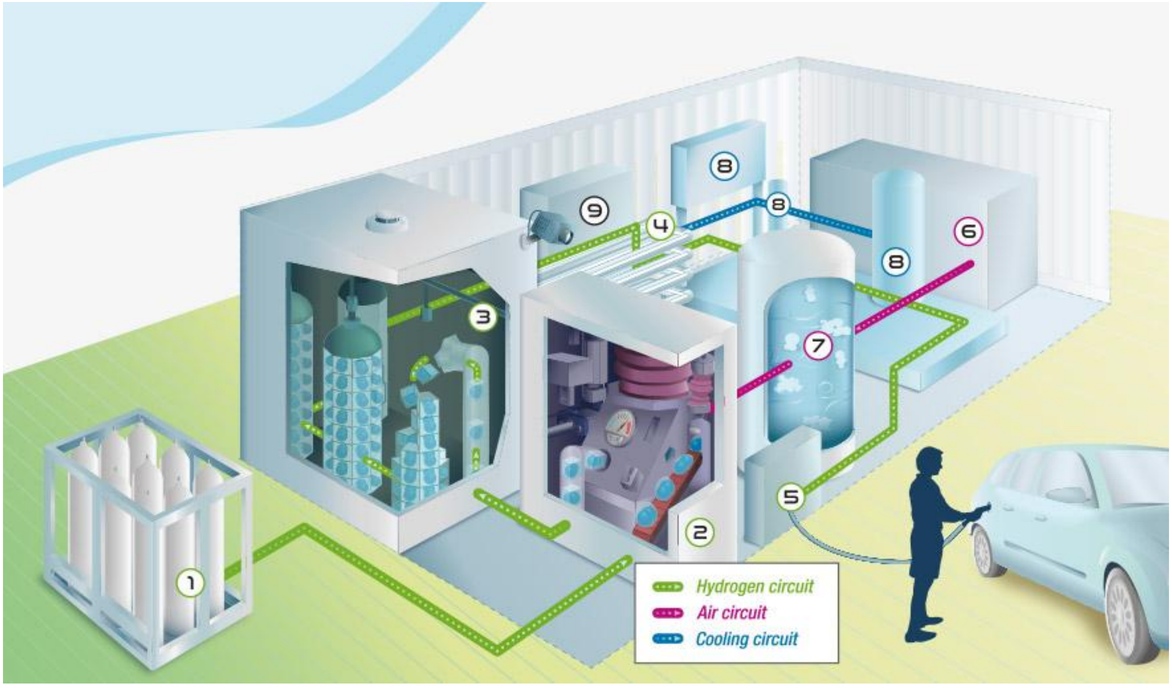


Figure 50 : Hydrogen Refuelling Station

Source : H2ME.eu

Hydrogen is often delivered to the fuelling location in pressurised tanks on lorries. However, at suitable sites hydrogen can be produced on-site by electrolysis, in the best case with the aid of renewable electricity obtained via direct coupling (wind/solar), or through grid-balancing services.

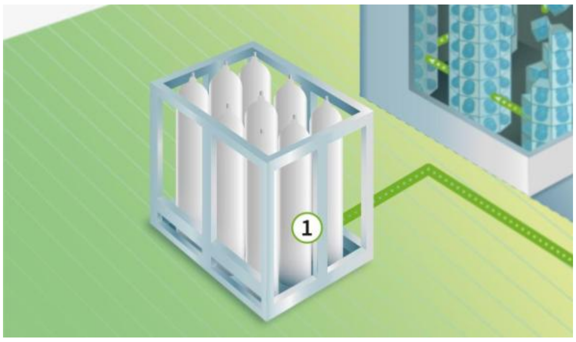


Figure 57 : 1. Source of hydrogen - Low pressure H2 is stored in bottles ("cylinder racks"), tanks or tube trailers

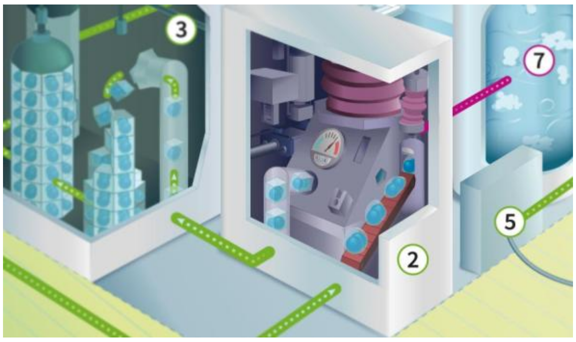


Figure 58 : 2. Boosters - H2 is compressed using boosters

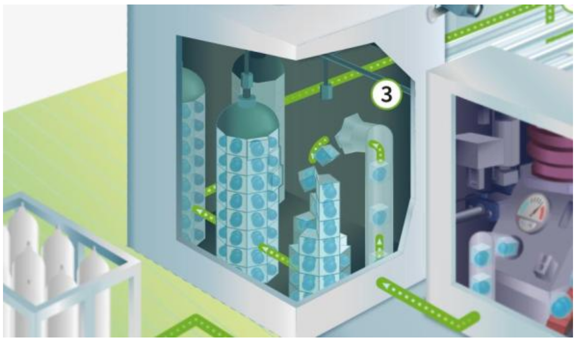


Figure 56 : 3. Buffers - Once the pressure has been increased (700 bars) H2 is stored in bottles known as buffers

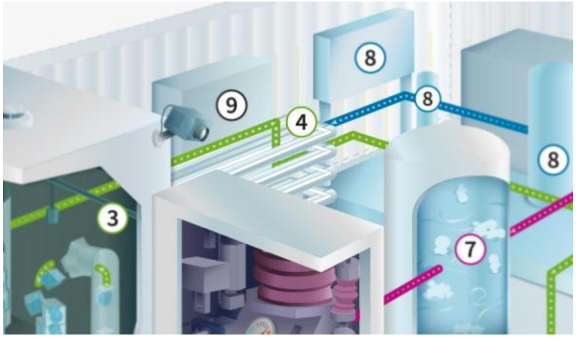


Figure 55 : 4. Exchanger - Before it is distributed, H2 is cooled using the exchanger and the refrigeration unit

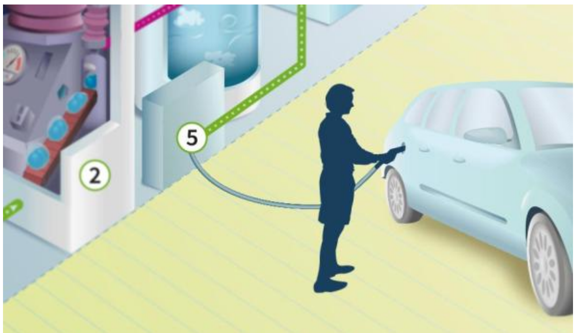


Figure 53 : 5. Dispenser - It enables distribution of H2 to the vehicle's tank, filling it in a few minutes

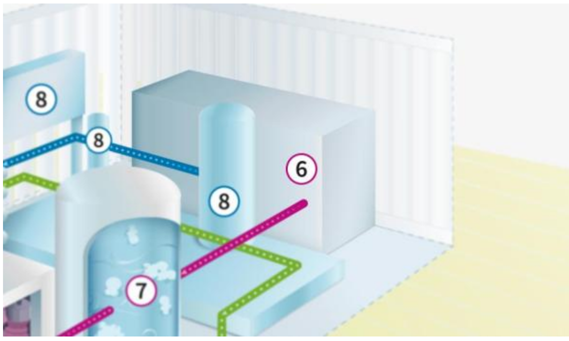


Figure 54 : 6. Air compressor - H2 is compressed using boosters

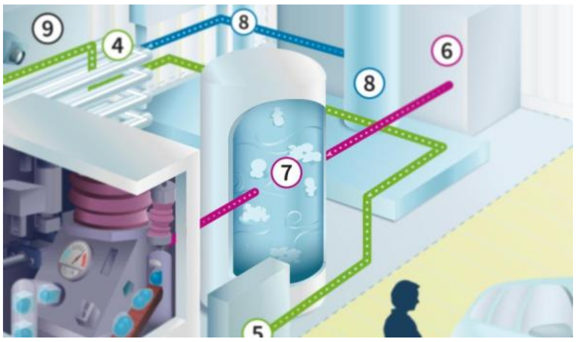


Figure 51 : 7. Buffer tank - It regulates and supplies the air needed to make the boosters function

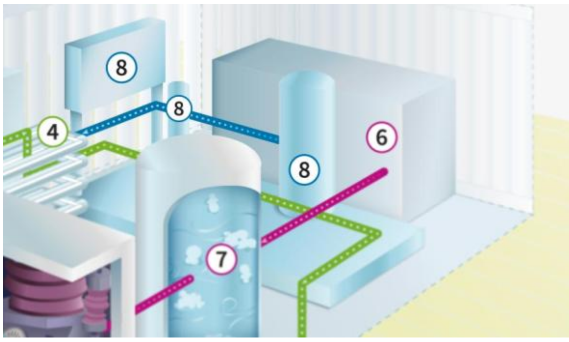
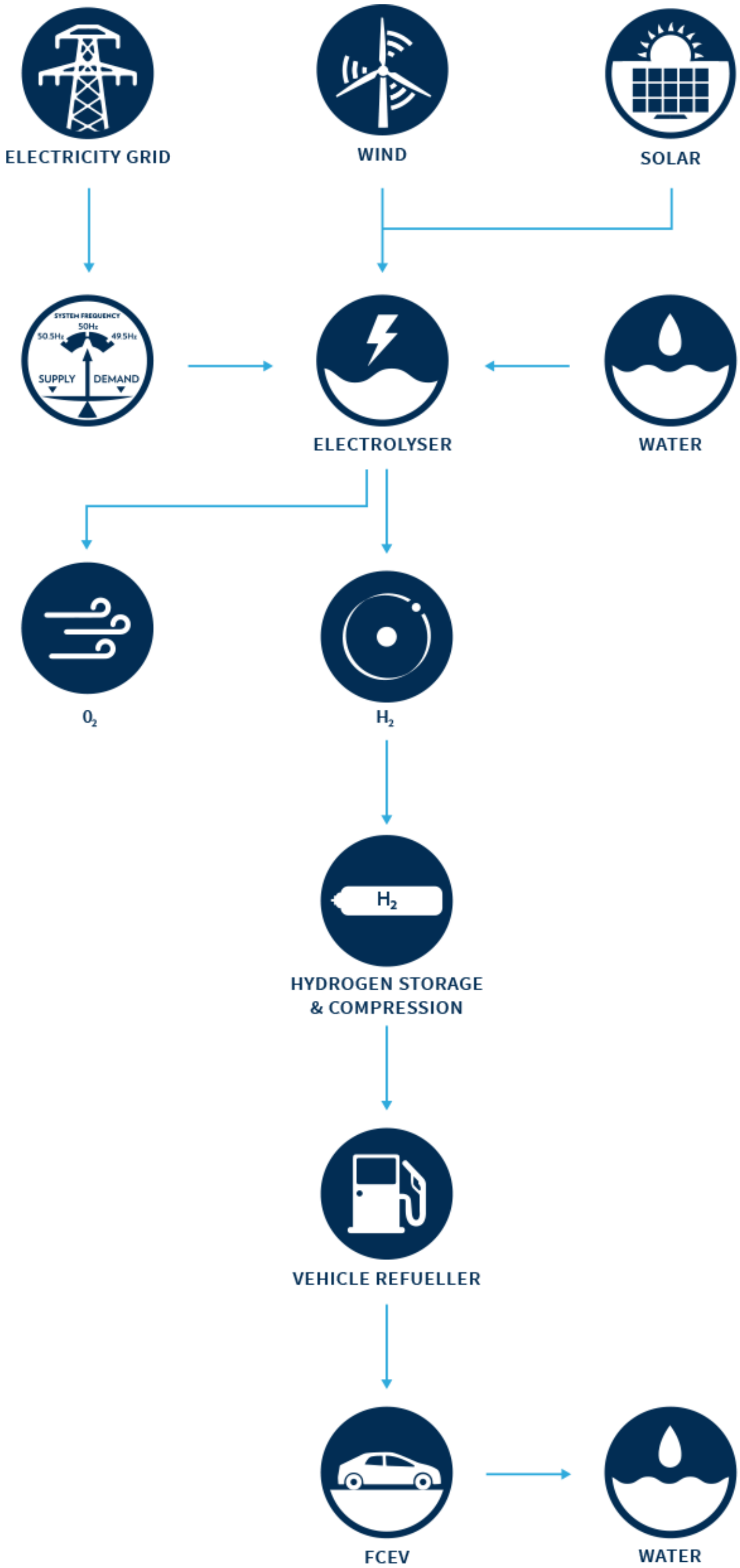


Figure 52 : 8. Refrigeration - Unit supplies cooling fluid to the exchanger, and is made up of a buffer tank that stores and regulates the flow of the liquid, the pumps and the electrical control cabinet

3.7.7 On-Site Production of Hydrogen



The diagram highlights how hydrogen can be made without any fossil fuels in the production and delivery of the fuel, as it is made on-site. Renewable Energy and excess electricity from the grid is used, along with water to generate hydrogen and oxygen gas via the electrolyser. The hydrogen gas is stored and then used to refuel fuel cell electric vehicles.

Figure 59 : On-site Hydrogen Production

Source : H2ME.eu

3.7.8 Hydrogen Fuel Cell Trucks in Defence

Hydrogen fuel cell trucks are a promising alternative to traditional gasoline or diesel trucks, but they may not be suitable for all types of operations and fleets. They offer a good balance of fuel efficiency and emission reduction in comparison to traditional gasoline or diesel trucks. Fuel cell trucks are highly efficient and have a longer range than battery-electric vehicles. Refueling time is fast. Vehicles can be refuelled in a matter of minutes, which is much faster than recharging a battery electric vehicle. However, initial costs are higher and they have a more complex powertrain. But the major disadvantage is the limited refueling infrastructure, specially in forward areas. Hydrogen production and distribution is still in the early stages of development and these challenges make reliability of hydrogen fuel an issue.

3.8 Hydrogen ICE

One of the very first Internal Combustion (IC) engines ran on a mixture of hydrogen and oxygen—and featured an electric spark ignition mechanism. Its inventor, a former Swiss artillery officer named François Isaac de Rivaz, used it to build a vehicle that could carry heavy loads over short distances.

3.8.1 Hydrogen Internal Combustion Engine

Hydrogen Internal Combustion Engine (ICE) vehicle or HICEV is a type of hydrogen vehicle using an IC engine. Both hydrogen ICEs and hydrogen FCs can power vehicles using hydrogen, a zero-carbon fuel. Internal combustion engines tend to be most efficient under high load—which is to say, when they work harder. FCEVs, in contrast, are most efficient at lower loads. So, for heavy trucks that tend to spend most of their time hauling the biggest load they can pull, internal combustion engines are usually the ideal and efficient choice. HICEVs are different from hydrogen fuel cell vehicles, which use electrochemical use of hydrogen (rather than combustion). They do not need battery packs. Hydrogen ICE is simply a modified version of the traditional gasoline-powered ICE. The absence of carbon means that no CO_2 is produced, which eliminates the main greenhouse gas emission of a conventional petroleum engine. (Nebergall, 2022)

Hydrogen engines often are able to operate with lower grade hydrogen (without need for purification); they have robustness for impurities. ICE technology is much mature than Fuel cell for instance.

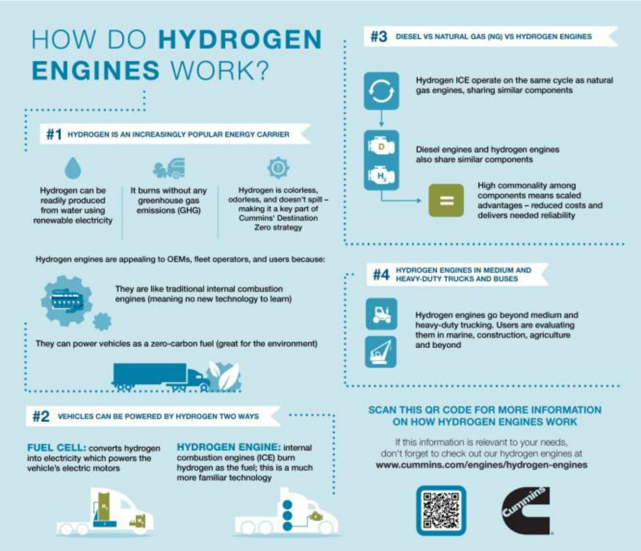


Figure 60 : Cummins – How Hydrogen IC Engine Vehicles Work

Source : H2ME.eu

As pure hydrogen does not contain carbon, there are **no carbon-based pollutants**, such as carbon monoxide (CO), CO_2, and hydrocarbons (HC), in the exhaust. Hydrogen combustion occurs in an atmosphere containing nitrogen and oxygen, however, it can produce **oxides of nitrogen** (NOx). Most hydrogen engines are spark ignited (SI) engine variants with similar engine hardware to natural gas and gasoline engines. Certain components of the engine like the fuel delivery system and spark plugs are changed to use hydrogen instead of petrol or diesel. The combustion process is like other high temperature combustion fuels, such as kerosene, gasoline, diesel or natural gas. As such hydrogen combustion engines are not considered zero emission. Hydrogen engines often require an exhaust treatment system to remove this excess NOx. Hydrogen is difficult to handle. Due to the very small molecular size of the hydrogen atom, hydrogen is able to leak through many apparently solid materials. Escaped hydrogen gas mixed with air is potentially explosive. Compared to conventionally-powered ICEs, hydrogen ICEs only offer between 20–25% efficiency, power output varies basis the energy density of the hydrogen/air mixture and hydrogen ICEs are also prone to knocking, which can negatively impact engine durability as well as fuel efficiency (can be overcome with an exhaust gas recirculation system). (Ahmad, 2021)

A commercially available gas mixture known as Hythane contains 20% hydrogen and

80% natural gas. At this ratio, no modifications are required to a natural gas engine, and studies have shown that emissions are reduced by more than 20%. (EERE Energy, 2001).

Experts advocate hydrogen combustion engines for commercial vehicles as they need to operate for a set number of hours and have fixed journey points. If a few hydrogen refueling stations (green hydrogen) are set up on dedicated freight routes, commercial vehicles can make the transition to H2-ICEs. In fact, heavy machinery specialist JCB is working on adopting hydrogen combustion engines. In India, Union Minister for Road Transport and Highways Nitin Gadkari has encouraged the use of hydrogen as an automotive fuel on multiple occasions. Recently, government-run GAIL India announced setting up a 10 MW green hydrogen facility, the country's largest such plant, over the next two years. In the private sector, Mukesh Ambani-led Reliance Industries is also working on a technology to bring down the cost of green hydrogen, besides other companies like Adani Green Energy. (Sarkar, 2021). However, till all these efforts materialise, H2-ICE vehicles will remain a little far from becoming a mainstream viable option for consumers.

3.8.2 Market Maturity

Ashok Leyland 4125HN H2 ICE 8x2 DTLA. Ashok Leyland 4125 HN features a H-Series 6-cylinder engine with minor changes to the engine head unit and fuel injection system, making it compatible to run on green hydrogen.

Figure 61 : Ashok Leyland 4125HN H2 ICE 8x2 DTLA

Source : Wagenclub

The Hydrogen ICE is an emerging and promising technology for short- and mid-term energy transition away from diesels. It claims to deliver power and torque equivalent to a conventional diesel or CNG. It gives 186 HP @ 2400 rpm of power at 900 Nm @ 1200-2000 rpm, by virtue a variable-geometry turbo-charger. It is built on AVTR modular platform, thereby making it customizable to suit multiple axle configurations and end-use applications. The hydrogen fuel is stored in 3 lightweight Type 4 carbon-fiber composite cylinders stacked in a separate compartment behind the cabin, with high-pressure endurance of up to 350 bar with 25.2kgs (@350L) capacity. The truck has a GVW of 40.5 tons giving max speeds of 80 kmph. Reliance has partnered with Ashok Leyland on this project for commercial trucks.

3.8.3 Infrastructural Support Required

This has been addressed adequately in the previous section.

Figure 62 : Musashi 9 Liquid hydrogen truck

Source : Musashi

Figure 63 : Cummins H2 ICE Concept Truck B6.7H at Auto Expo 2023

Source : Cummins

3.9 Diesel-Electric Hybrid Trucks

Diesel-electric hybrid trucks use a combination of a diesel engine and an electric motor to power the vehicle either of which provide the primary / secondary / hybrid source of propulsion. Electric motor provides additional torque to the drivetrain when needed. Diesel engine is used to extend range. The energy generated by the diesel engine can also be used to charge the batteries of the electric motor, which can then be used to power the vehicle, when the diesel engine is not operating at its most efficient level.

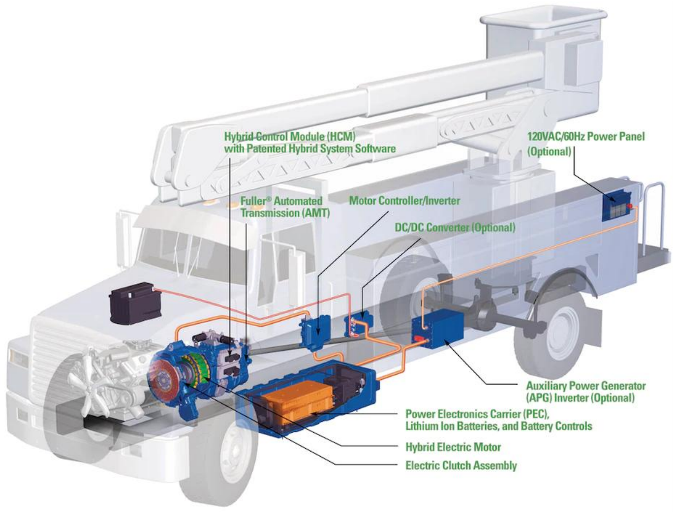


Figure 64 : Diesel-Electric Hybrid Trucks

Source : OEMofHighway.com

Diesel-electric hybrid trucks offer a number of benefits compared to traditional diesel trucks. This can improve fuel efficiency and reduce emissions, since the electric motor can be used to assist the diesel engine during acceleration and other high-demand scenarios. Additionally, the electric motor provides an immediate source of power compared to a traditional diesel engine, which gives overall improved vehicle performance and responsiveness.

However, diesel-electric hybrid trucks can be more complex and expensive to produce compared to traditional diesel trucks, due to additionally cost of batteries, motor and other components. But when assessed on the Total Cost of Ownership (TCO) of a diesel-electric hybrid truck over its lifetime it will likely be less costly and less polluting and maybe even have longer utility service life. As government continue to tighten emissions regulations and fossil fuel prices continue to rise, while battery costs reduce and technology improves, diesel-electric hybrid trucks will become increasingly popular as a way to reduce operating costs while still delivering the performance and power required by heavy-duty commercial vehicles.

3.9.1 Power train : Diesel-Electric Hybrid Trucks

The powertrain or drivetrain in diesel-electric trucks is a combination of a diesel engine, an electric motor, and a system of batteries and power electronics that work together to provide propulsion for the vehicle. The system can be divided into three main components: the engine, the electric motor, and the power electronics and energy storage system.

(a) The Diesel engine provides the primary source of power for the vehicle, and it operates like a traditional diesel engine in a conventional truck. Fuel is burned in the engine to generate mechanical energy, which is then transmitted to the drive wheels through a transmission system.

(b) The Electric motor acts as a supplementary power source, providing additional torque to the drivetrain when needed. It can also serve as a generator, capturing energy that would otherwise be lost during deceleration or braking and storing it in the batteries (regenerative braking).

(c) The power electronics and energy storage system includes the batteries, the power electronics that control the flow of energy between the batteries and the electric motor, and the charging system that recharges the batteries. It also controls the flow of energy between the diesel engine and the electric motor, ensuring that the vehicle has the power it needs when it needs it.

The diesel-electric powertrain provides a flexible and efficient way to power heavy-duty vehicles, offering improved fuel efficiency and reduced emissions compared to traditional diesel trucks.

Series Hybrid Diesel-Electric Truck

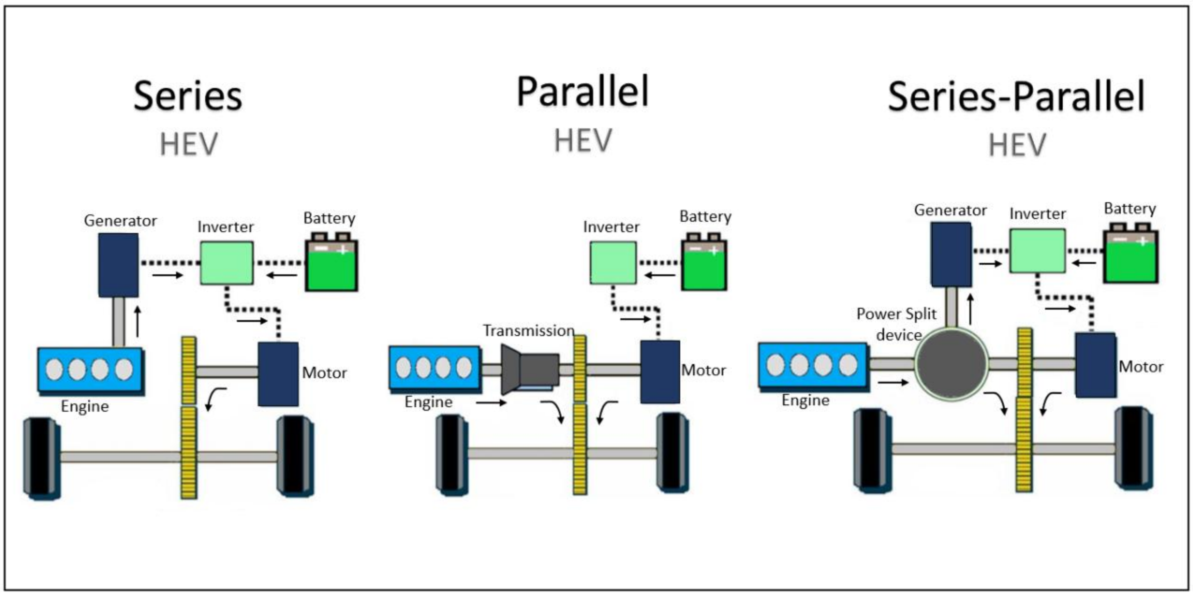


Figure 65 : Series, Parallel, Series-Parallel Architecture

Source : NHTSA.gov

The electric motor is the primary drive component in series configuration. The diesel engine is primarily used to generate electricity and recharge the batteries, while the electric motor provides the majority of the propulsion. This type of powertrain is referred to as a "Series Hybrid". The diesel engine is connected to a generator, which converts the mechanical energy produced by the engine into electricity. This electricity is then stored in batteries and used to power the electric motor, which drives the wheels of the vehicle. The diesel engine can be used to supplement the electric motor when additional power is required, such as during high-load conditions or when the battery is depleted. Batteries can also be charged by regenerative braking.

The advantage of this configuration is that the electric motor can provide near-silent, zero-emission operation for short distances, and the diesel engine can be used to extend the range of the vehicle and recharge the batteries. This allows for a reduction in fuel consumption and emissions compared to a traditional diesel truck, especially where short trips and stop-and-go driving are common.

The series hybrid configuration can be more complex and expensive compared to a traditional diesel-electric hybrid, since it requires a larger battery pack, a more sophisticated power electronics system, and a larger generator. Additionally, the cost of the batteries and other components can be a significant factor in the total cost of ownership of a series hybrid diesel-electric truck, total cost of ownership may be lesser though.

Parallel Hybrids Diesel-Electric Trucks

Parallel hybrid diesel-electric trucks are a type of hybrid vehicle that uses both a diesel engine and an electric motor to provide propulsion. In this configuration, both the diesel engine and the electric motor can drive the wheels of the vehicle independently or together, depending on the driving conditions and the needs of the driver.

In a parallel hybrid diesel-electric truck, the diesel engine and the electric motor are both connected to the transmission system or drivetrain, and the power electronics system controls the distribution of power between the two components. During normal driving, the diesel engine provides the primary source of propulsion, while the electric motor can assist the engine during acceleration and other high-demand scenarios, improving fuel efficiency and reducing emissions.

In addition to providing supplemental power during acceleration, the electric motor can also function as a generator, capturing energy that would otherwise be lost during deceleration or braking and storing it in the batteries for later use (regenerative braking).

The advantage of the parallel hybrid configuration is that it provides a balance between fuel efficiency and cost-effectiveness, since it uses both the diesel engine and the electric motor to power the vehicle. It also offers improved performance compared to traditional diesel trucks, since the electric motor can provide additional torque when needed and the batteries can store energy that would otherwise be lost.

Overall, parallel hybrid diesel-electric trucks are a cost-effective solution for heavy-duty commercial vehicles, offering improved fuel efficiency and reduced emissions compared to traditional diesel trucks. The specific design and performance of each parallel hybrid diesel-electric truck can be defined and manufactured depending on army’s requirements and needs.

Series-Parallel Diesel-Electric Hybrid Truck

Series-parallel diesel-electric hybrid truck powertrain combines elements of both series and parallel hybrid systems to provide a flexible and efficient solution for heavy-duty vehicles. The hybrid vehicle uses both a diesel engine and an electric motor to provide propulsion. In this configuration, the electric motor serves as the primary source of propulsion, while the diesel engine acts as a backup power source and generator.

In normal driving conditions, the electric motor provides the majority of the power required to drive the wheels of the vehicle, while the diesel engine acts as a generator, recharging the batteries and providing additional power when needed. During acceleration or other high-demand scenarios, the diesel engine can assist the electric motor, improving performance and providing additional power. During deceleration or braking, the electric motor can act as a generator, capturing energy that would otherwise be lost and storing it in the batteries for later use. The batteries can also be recharged by the diesel engine, providing a backup power source for the electric motor when needed.

Where electricity is available, the batteries can be charged using plug-in power, either from a wall outlet or a dedicated charging station. Plug-in charging is an effective way to recharge the batteries of a hybrid truck, as it provides a convenient and efficient way to recharge the vehicle overnight or during extended periods of downtime. By charging the batteries in this way, the diesel engine can be used less frequently, reducing fuel consumption and emissions and helping to extend the range of the vehicle. The specific charging capabilities will depend on the size of the battery pack and the requirements of the army. Larger battery packs provide extended electric-only range. The charging rate, charging time, and other details will depend on the specific design of the hybrid system and the charging infrastructure available.

The advantage of this configuration is that it allows for near-silent, zero-emission operation, while still providing the extended range and performance capabilities of a diesel engine, offers reduced fuel consumption and emissions compared to traditional diesel trucks. It may be more complex and expensive compared to a series diesel-electric hybrid, since it requires a larger battery pack, a more sophisticated power electronics system, and a larger generator. Additionally, the cost of the batteries and other components will add to the total cost of ownership of such a vehicle, hence, a detailed General Staff Qualitative Requirement (GSQR) on technical specifications should be given out.

3.9.2 Market Availability

Diesel-hybrid electric trucks are preferred for long distance hauls, specially since electric charging facilities are far and few enroute, while most depots may have it. It gives flexibility to the fleet operators. Here are few examples, while development of more and better models is a continuous process:-

Figure 66 : Volvo FE Hybrid

Source : Volvo-Eicher

Currently available in Europe, the **Volvo FE Hybrid** (Volvo, 2022). This truck is designed for city and regional distribution, and features a parallel hybrid system that combines a diesel engine with an electric motor. It carries 27 tons GVW and give a 200 kms range. The powertrain has 2 electric motors generating massive power of 225 kW/ 300 hp. With a 265 kWh battery it charges in 2h with DC and

11 h with AC charger.

The **US Freightliner M2 112 Hybrid** is a Class 8 vehicle that is used for heavy-duty applications such as delivery, distribution, and refuse collection (Freightliner, 2018). It features a diesel-electric hybrid system that delivers up to 30% fuel savings. With a GVW of 36k tons it falls under the class 7/8 of trucks. It generates 260-525 HP and torque of 1000-2500 Nm.

Figure 67 : Freightliner M2 112 Hybrid

Source : e-Frightliner

Figure 68 : Mitsubishi Fuso Canter Eco Hybrid

Source : Mitsubishi

Mitsubishi Fuso Canter Eco Hybrid is a 2012-13 model which is designed for urban delivery and features a series hybrid system that combines a diesel engine with an electric motor (Mitsubishi Fuso, 2013). It comes under the light truck category with ¾.5 ton payload capacity. The Mitsubishi Fuso Canter Eco Hybrid is available in Japan and Europe.

Hino 195h-DC Hybrid is a medium-duty truck that is used for delivery and other urban applications (Hino Trucks, 2022). It features a parallel hybrid system that combines a diesel engine with an electric motor, and delivers up to 30% fuel savings. The Hino 195h-DC Hybrid is available in the United States.

Figure 69 : Hino 195h-DC Hybrid

Source : Hino Motors, Japan

Figure 70 : Iveco Eurocargo Hybrid
Source : Iveco

Iveco Eurocargo Hybrid. The truck is designed for city and regional distribution and features a parallel hybrid system that combines a diesel engine with an electric motor (IVECO Eurocargo Hybrid). Varients are from 7.5 to 18 tons. It has a proprietary Hino J05E-TP 5L turbo diesel engine: 210 HP, 440lb.-ft. torque; 14,500 GVW, 6-speed automatic transmission; Hybrid system with Ni-MH battery and a 113 litre fuel tank. The Iveco Eurocargo Hybrid is currently available in Europe.

Kenworth T680 Hybrid is a Class 8 heavy-duty truck that features a parallel hybrid system that combines a diesel engine with an electric motor (Kenworth, 2021). They use lithium-ion batteries to achieve the zero-emissions range of 50 kms and to supplement power from the generator when climbing grades. It uses the Cummins Westport L9N Near Zero emission engine fueled by compressed natural gas driving a generator to extend the truck's battery range. The Kenworth T680 Hybrid is designed for long-haul applications, and its hybrid system provides improved fuel efficiency and reduced emissions.

Figure 71 : Kenworth T680 Hybrid
Source : Kenworth

Peterbilt Model 579 Hybrid. A Class 8 heavy-duty mild-hybrid (prototype) truck features a parallel hybrid system that combines a diesel engine with an electric motor (Peterbilt, 2022). It is designed for long-haul applications, and its hybrid system provides up to 30% fuel savings.

Figure 72 : Peterbilt Model 579 Hybrid
Source : Peterbilt

Couple of use cases of Diesel-Electric Hybrid trucks are discussed in more details in ensuing paragraphs.

Use Case 1 : Diesel Electric Logging Truck by **Edison Motors** (www.edisonmotors.ca)

Figure 73 : Diesel-Electric Hybrid Truck by Edison Motors

Source : Edison Motors, USA

It works as a fully electric truck or a fully diesel truck, as per requirement. The trucks batteries can be charged as a plug-in ZET through the grid, when available; when not, the diesel engine works as a Level-4 Fast Charger and converts mechanical energy to electrical energy which is used to re-charge the batteries. It is essentially a range extender, taking away the concerns of range and need to re-charge from a grid, always looking for charging infrastructure enroute.

As per Chace Barber, the Founder and CEO of Edison Motors, with 30 litres of diesel, in

30-40 mins, while on the move, used to re-charge batteries to almost full charge, the vehicle could run 200 kms, which would otherwise require 100-120 litres (i.e. 70% reduction in consumption of fuel). Logging trucks are used to get logs of felled trees from mountains in Alaska and North America. This is a truck which has no load when going up the slopes and uses the battery power. When coming down with full load, it also (additionally) uses ‘regenerative braking’ (AC motor) to put charge back into the batteries. And when needed the diesel engine re-charges batteries (akin to a diesel generator used in locomotive for years). The truck has a cooling system (coolant) for the battery banks. To counter the low temperatures, there is a diesel heater. (Barber, 2022) (Barber, Diesel-Electric Hybrid Trucks - Edison Motors, 2022) (Podcast, Ex-Logger Aims to Beat Elon Musk in Electric Trucks, 2023)

The transition from Pure diesel to BEV trucks (ZET) is constrained by battery technology, energy-density, cycle-life etc; and maybe a decade from reaching its full potential. The Diesel-Electric Hybrid is the logical bridge in that gap.

The main advantages in a Diesel-Electric truck are the power and the torque. The torque-curve on an electric motor is flat. In a normal diesel truck the torque rises, hits peak RPM and then falls again. In diesel-electric truck we get instant high torque and RPM right from zero. It has three electric drive motors, each with 250 Kwh Li-Ion batteries, which gives over a 1000 horsepower, and the torque is 110,00 foot-pounds smooth and linear. The cost is also lesser therefore.

The fuel savings are tremendous in heavy logging, 75%+ of fuel savings. The electric motor is used when there is peak load demand during starting, lugging that weight of 65 tons, at 1000 HP. Once the momentum is achieved, the batteries do not consume that much. Also, when braking, specially going down slope, the AC motor acts as a generator, regenerating to re-charge the batteries. The more difficult the terrain of operation, the better will be the fuel mileage due to regenerative braking. Pure diesel engines are most inefficient in mountains, due to excessive gear change, turbo-ineptitudes etc.

When the battery reaches about 50% levels, the diesel charging takes over, thus ensuring the life of the batteries increases two-folds. Also, since the diesel engine runs much lesser, its life is also extended x2. If applied to the ALS, its planned life of 11 years would be approximately doubled, hence massive savings over the TCO..

On weight penalty, a MW of batteries required in a Tesla BEV weigh a ton plus of extra weight. Logging trucks require 2.5 MW. Diesel-Electric Hybrid uses smaller batteries 250 Kwh since they are used for peak load demands and for a couple of hours of operation, then re-charged, they can afford to be smaller, hence lighter (quarter of size). Also, the diesel engine size has been reduced since the peak demand is met by the electric drivetrain, from a 15-litre Cummins engine to a 9-litre, hence lesser weight. This original diesel truck weight has reduced from 9000 kgs to 8800 kgs for the Diesel-Electric Hybrid. The government gives extra 1.5 tons weight carriage allowance to EVs, so that’s added payload. Though, now additional functionalities and weight (500-1000 kgs) have been added to it.

On reliability aspects, a mechanical system has numerous moving parts, hence higher maintenance needs. Electric motors are magnets spinning inside copper coils. Some electric motors are in operation for the last half century or more and still operating. Diesel-

Electric freight trains have been in operation for years and years. They are reliable, re-build them and very easily recyclable. If designed well, they will be reliable and easily serviceable.

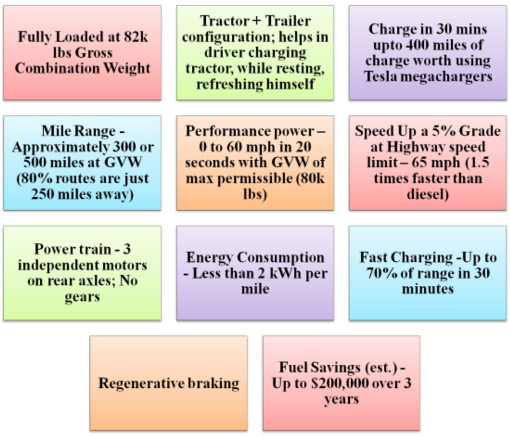
In essence, the Diesel-Electric Hybrid ZETs are more reliable, gives more power, lesser maintenance, better fuel mileage, less polluting and higher gross payload capability. Elaborate and costly enroute charging infrastructure is not required in forward areas (or state and district highways for that matter), thus public exchequer savings. They will last longer, have a longer life cycle, hence, lower total cost of ownership. It is the logical way forward, for the transition to full electric a decade on.

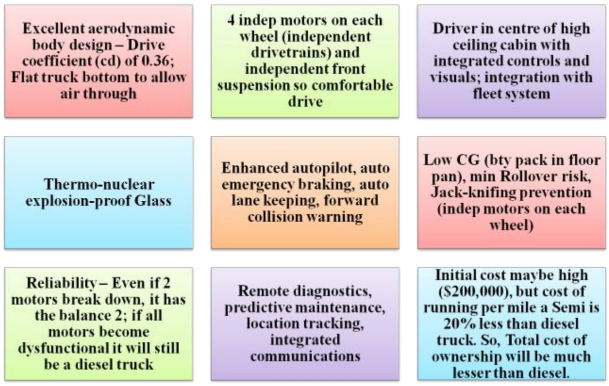
Maintenance and spare issues will have to be addressed, in the field areas and base. Commonality of parts is an important consideration. Supply chain assurance is also required.

Use Case 2 : Tesla Semi[3]

Figure 74 : Tesla Semi Truck

Source : Tesla Motors





The Tesla Class 8 truck is powered by four independently controlled AC electric motors positioned on each of the drive wheels. During over-the-road operation, the vehicle battery bank can be recharged using regenerative braking, which is said to be powerful enough to minimize the use of the service brake pedal. Independent motor control means that each

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[3] www.tesla.com/semi

motor can apply positive or negative torque to the drive wheels, minimizing trailer swing and jackknife incidents. If of two of its four drive motors were to fail, the truck could still operate with the remaining two. No transmission is required, and from the onset, the truck will be equipped with Level 3 semi-autonomous capability. Tesla telematics and self-diagnostic capability will be integrated into the control electronics. All this, combined with electric steering (autonomous control-ready), will ensure that the truck is easy to manage by a driver with much lower skill levels than those required to drive current Class 8 semi-trailers.

As regards the Tesla Driver Experience, anyone who has driven a hybrid electric vehicle will vouch for the superior off-the-line torque (acceleration) provided by AC electric motors compared with a conventional diesel-powered truck or bus drivetrain. This element of the driving experience is further improved in an all-electric truck. A bob-tailed Tesla truck is claimed to be capable of a 0-60 mph (0-96 km/h) launch, which betters that of some performance cars. When the same tractor is coupled to a fully loaded trailer, it can accelerate from 0-60 mph (0-96 km/h) inside of 20 seconds and hold a 65 mph (100 km/h) road speed while climbing a 5 percent grade. In addition, the driving experience is improved. The driver faces two touch screen displays mounted on either side of the steering wheel; these are used to display the vehicle navigation system and vehicle operational status. In addition, the truck is equipped with full telematics capability known as vehicle to infrastructure (V2I), infrastructure to vehicle (I2V), and vehicle to vehicle (V2V). V2V is a key technology required to enable truck platooning convoys, which are a major energy saver.

These are few examples of diesel-hybrid electric trucks from around the world, and there are many other models and manufacturers producing similar vehicles.

3.9.3 Suitability for Military Operations

Diesel-electric hybrid trucks can be most suitable for military operations in desert and mountainous terrain. The ability to use the electric motor for additional power can also provide better performance in challenging terrain, since the electric motor can provide extra torque when needed to help the vehicle climb steep inclines and navigate rough terrain.

(a) In mountainous terrain, the ability to control the distribution of power between the diesel engine and the electric motor can be beneficial, as it allows the vehicle to optimize performance and efficiency depending on the driving conditions. The regenerative braking capability of the electric motor can also help to reduce wear and tear on the brakes, which can be important in mountainous terrain where frequent braking is required.

(b) In desert environments, the ability of the diesel engine to provide extended range and high performance can be an advantage, especially for missions that require the vehicle to cover long distances or operate in remote areas. The diesel engine can also provide backup power for the electric motor, which can be important in conditions where the battery pack may be depleted.

The specific design of the hybrid system and the overall capabilities of the vehicle will play a significant role in determining its suitability for military operations in mountains and deserts. The diesel-electric hybrid trucks can be designed specifically for off-road use, with features such as high-clearance suspension, heavy-duty axles, and robust drivetrain components, fuel efficiency and also for on-road performance during normal peacetime.

Military Diesel-Electric Hybrid Trucks. AFVs are still at nascent stages of trials, prototyping and induction into armies. Very few examples of Diesel-Electric Hybrid technology used by world militaries can be cited, as hereunder. This will demonstrate that the technology is being tested for induction. The justification for the technology has already been elucidated above.

Oshkosh Defense Heavy Expanded Mobility Tactical Truck (HEMTT) A4 Electric Hybrid (Oshkosh Defense, 2021). This is a heavy-duty military truck that uses a series hybrid system to combine a diesel engine with an electric motor. The HEMTT A4 Electric Hybrid is designed for off-road and on-road applications and is currently undergoing testing by the US Army.

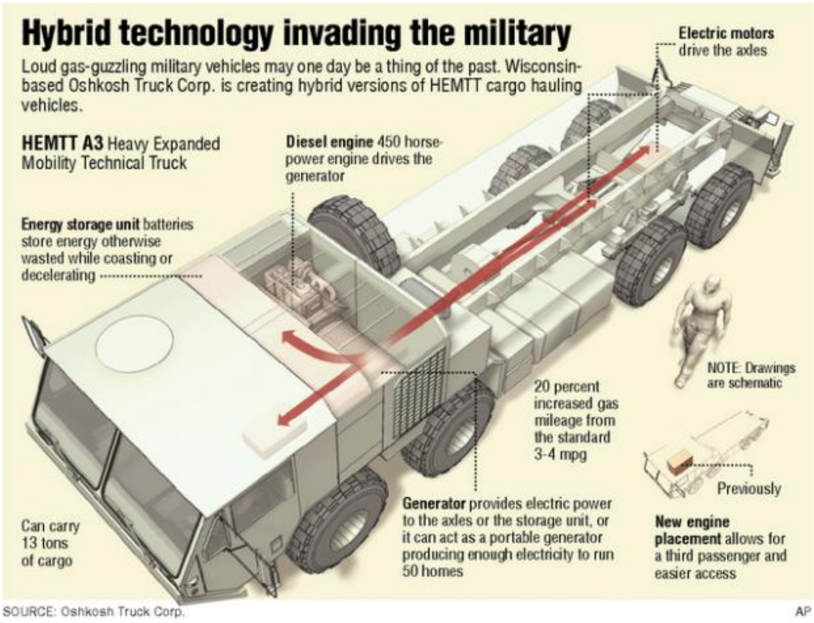


Figure 75 : Hybrid Military Trucks by Oshkosh

Source : Oshkosh

Tatra Phoenix Hybrid: Tatra Phoenix is a heavy-duty military truck that uses a diesel-electric hybrid system (Tatra Trucks, 2022). The system includes a 13-liter diesel engine and an electric motor, which work together to provide improved fuel efficiency and reduced emissions. The company is working on a hybrid truck with a TATRA engine and a generator or on a battery vehicle with an IC engine as a range extender, and in cooperation with the Czech Technical University, as also on a TATRA engine burning hydrogen.

iDEX 2023 held from 20-24 Feb 2023 at Dubai demonstrated **Edge Systems, Defender8-2T and MilRem Robotics autonomous modular 23 T Remote Combat APCs** being run on Hybrid diesel-electric drivetrain, with 12 ton payload, demonstrating the high acceptability of the technology by the military (Military TV, 2023).

In nutshell, environmental factors justify the need for use of alternate fuel vehicles by the militaries and hybrid diesel-electric technology exists. So, it's a practical and doable option. It meets the operational needs of the army. The design and technology should be efficiently and effectively married so as to get the right balance of diesel engine versus electric motor & battery weight, the longest range feasible and the max payload. It totally eliminates for enroute charging infrastructures and at slow charging facilities (during long halts and overnight) will in any case be available. Pure EV ZETs are yet far, primarily due to high energy density batteries and advanced chemistry cells being at development stage for the next decade or so. Thus, this option is being strongly recommended.

3.10 Diesel-Electric Hybrid Technology in Light Tactical Vehicles

Ideally, and as per the scope of research, discussion on Diesel-electric hybrid light tactical vehicles at best should have been restricted to a passing reference. However, given the progress of this technology - transitioning into bulk production and orders in other armies, colossal possibilities and opportunities for the IA, it has been undertaken as a separate mini chapter rather than a section in the previous chapter. The focus is on US and UK Armies where substantial progress has been made and is underway and time limitations forbade wide-scale study of other armies.

3.10.1 Non-Tactical Vehicles will Transform to BEVs or Pure EVs

To combat climate change, boost U.S. industry and achieve operational advantages, the US Defense Department has ambitious plans to transform its fleet of ground vehicles through the introduction of electric and hybrid-electric drive technologies. The Department of Defense has plans to transform to zero-emission about 170,000 non-tactical vehicles (cars and trucks used on bases), the ‘low hanging fruit’. Similar are the initiatives taken recently by the IA. But when done at commercial scale, infrastructure needs to be developed at those bases. (Harper, 2022)

3.10.2 Tactical Transport Not Yet Ready for Transforming to Hybrid..?

A US General’s view on converting tactical vehicles to hybrid – “The initial push will be for hybrid-electric drive, or HED, because full electrification for our complex weapon systems at the forward edge of the battlefield is a goal that we don’t believe that currently our technology will support," said Army Lt. Gen. Duane Gamble, deputy chief of staff, G-4. (Harper, 2022)

3.10.3 The Industry is Geared by for Hybrid for Tactical Light Vehicles

In an article titled '**100,000 Diesel-Killing Electric Vehicles For US Army, Eventually**', Clean Technica reports US companies, QinetiQ and AM General, have laid the foundations for the future of electric-powered land combat vehicles which will enable the delivery of next generation technologies while driving down carbon emissions in the defence sector, by applying a **hybrid electric drive system** to defence's most **iconic HUMVEE family of vehicles**. The hybrid approach will provide some tactical advantages over full electrification to US Army. It will enable the vehicles to tackle more hostile terrains, while increasing lethality by giving it the ability to conduct extended periods of silent watch and silent running. This includes minimising the vehicle's acoustic and thermal signatures. (Casey, 2021)

In an article titled "**The Hybrid Battlefield**", Pailton Engineering, UK reported that **Oshkosh Defense** unveiled the first ever silent drive **Hybrid-Electric Joint Light Tactical Vehicle** (JLTV). (Brereton, 2022). It analyses the role hybrid-electric vehicles will play on the battlefields of the future. The **eJLTV** claims to offer the same performance levels as its diesel counterpart but with a **20% improvement in fuel economy**. The vehicle's lithium-

Figure 76 : Oshkosh Defense e-JLTV Joint Tactical Light Vehicle

Source : Oshkosh

ion battery charges while in use and can be fully charged in 30 minutes, providing approximately 30 minutes driving time.

Hybrid technology offers the tactical advantage of silent drive, extended silent watch and increased exportable power for use in combat and reconnaissance scenarios. Both the military and original equipment manufacturers (OEMs) have been developing and testing hybrid variants of their vehicles in recent years (like the electrified version of Infantry Squad Vehicle by GM Defense). Mike Sprang, program manager for the JLTV Joint Program Office, told Breaking Defense last year that his office was already looking at incorporating some of the lithium-ion battery technologies mentioned in today's Oshkosh press conference. "We're saying use that architecture to not have to turn on your engine when you first need radios, when you first need HVAC [heating and cooling], and **when the battery is drained to a certain point the engine turns on, charges, then shuts off again**," Sprang said.

Figure 77 : GM Defense CEO Steve DuMont stands aside the All-Electric Military Concept Vehicle at its Concord, NC production facility

Source : GM Defense

Interestingly, the US Army previously experimented with **hybrid diesel-electric Humvees**, noting **in 2011** that future battery technologies could make the concept more feasible than it was at the time.

However, in **June 2021**, a **report** sponsored by the **deputy assistant secretary of the Army for research and technology cast doubt** on the **long-term viability of electric**

military vehicles (Pure EVs or BEVs), citing concerns about vehicle **weight** and the **need for charging infrastructure** as major obstacles. Larger vehicles like the Medium Tactical Vehicle Replacement (MTVR) would require even larger batteries, so electrification is only really an option for smaller, lighter vehicles. The challenge of recharging the vehicles is perhaps even greater. A fleet of electric vehicles would require a vast mobile charging system, which would hinder the Army's ability to be mobile. Given these challenges, it is difficult to imagine electrification being feasible for the military sector for a very long time.

Given the obstacles to adopting fully electric vehicles, hybrid technology has considerable appeal. As the battery can charge itself while the vehicle is in use, this solves the problem of needing charging infrastructure. Furthermore, although the hybrid vehicles will likely weigh more, these gains are not of the same magnitude as for fully electric vehicles. The eJLTV weighs an additional 453 kgs and although this is not insignificant, it is substantially less than the weight of a battery that would be required for a fully electric JLTV.

The tactical benefits of eliminating the noise and heat signatures associated with diesel engines include increased stealth. Added to this is the opportunity of using hybrid vehicles to export power to where it is most needed. The next generation of vehicles could potentially power an army field hospital or provide emergency power to relief teams in a disaster zone.

Most experts would be united in recognising that the challenges of introducing electric-hybrid technology to the military sector are greater than for commercial vehicles. Military vehicles must be purpose built and face greater challenges in comparison to commercial vehicles, from being shot at to enduring extreme temperatures and terrains. Everything from the steering parts to the windows need to be designed with this in mind. However, the unveiling of the eJLTV shows that **hybrid-electric vehicles are becoming a more feasible option going forward, especially for lighter vehicles**.

Brig. Gen. Glenn Dean, Program Executive Officer for U.S. Army Ground Combat Systems, told Defense News in 2022 that fully electric vehicles are still impractical for most military applications. "**I'm not sure we're going fully electric any time soon**". "Maybe for robotic platforms. That might be the first case, because it's about size and weight. If you took the amount of batteries with current technology that you would need to move an Abrams tank purely electrically, it's bigger than the tank, so we have a packaging and storage problem when it comes to pure electric." (Johnson, 2022) (Tingley, 2022). Dean added, however, that the **Army has looked at the types of hybrid electric systems** that Oshkosh has put forward with the **eJLTV may be more feasible**. "**We've looked at that every couple of years," Dean said. "The question is: Are we there yet? I suspect we may be at the point where hybrid electric is probably there."**

One of the **most significant barriers** when it comes to **deploying EVs is the need for charging stations or other electrical infrastructure** which would be **hard to come by in a combat zone or forward-deployed austere environment**. Oshkosh is attempting to **circumvent that barrier entirely by keeping the JLTV's existing diesel motor**, which is **capable of charging the vehicle's lithium-ion battery system while in diesel mode**. Oshkosh claims the vehicle's existing motor can charge the eJLTV's battery **in just 30 minutes**. While the company has no existing **plans to incorporate plug-in charging**

capacity, the company has such a capability which could easily be added in the future if requested. Oshkosh claims a full charge will offer 30 minutes of electric operation, depending on how the vehicle is driven, and users **can switch between diesel and "silent drive" modes on the fly**. The eJLTV can export up to 115 kilowatts of power, making it useful as a mobile power station that eliminates the need for towed generators or other means of providing power to forward locations.

3.10.4 Governmental Policy and Budgetary Support

Report of House of Representatives Committee on Armed Services Regarding Clean Fuel Transportation for Defense

US Army has taken concerted steps towards transition to alternate fuel vehicles. The July 2022 House Of Representatives Report on Armed Services (Section 314) directs a "Pilot Program for Transition of Certain Non-tactical Vehicle Fleets of Department of Defense to Electric Vehicles" (pp 117), to facilitate the transition to EVs while mitigating grid stress through microgrids and other infrastructure to cover the energy demand required to charge these vehicles. (House Of Representatives Report (117-397) Of The Committee On Armed Services House Of Representatives on H.R. 7900, 2022). The committee while commending the Department's commitment to investing in energy efficient technologies, including zero emissions non-tactical vehicles and related charging infrastructure directed the Secretary of Defense for Environment and Energy Resilience to brief the Committee on efforts to deploy wireless electric vehicle charging infrastructure at defense installations, to include information on how those efforts may be influenced by industry standards for wireless electric vehicle charging (pp 388). Section 221 requires the

Secretary of Defense to carry out a pilot program to award assistance to eligible entities to facilitate the research, development, and production of electric battery technologies that may be useful for defense-related purposes. The committee acknowledged the Army's tactical and combat vehicle electrification (TaCV–E) program and directed the Secretary of Army to provide a report on the advisability, feasibility, and estimated cost of conducting a tactical vehicle electrification pilot program through a Cooperative Research and Development Agreement (CRADA)-like structure with industry to experiment, demonstrate, and capture lessons learned from mature vehicle electrification technologies and associated integrated infrastructure.

3.10.5 `

In the survey, a large majority (~80%) agrees to **introduction of AFVs** in the **"Light Tactical High Mobility Vehicle segment"** in the Indian Army and a sizeable percentage (~50%) of people want them **with trailers**. Diesel-Electric Hybrids offer that opportunity and advantages, while overcoming the apprehensions of range, charging infrastructure and difficulties of operating in various terrains. Indian has about >40,000 light tactical vehicles on its inventory, including Gypsy's, Safari Storme and other variants. This could lead to significant control on carbon emissions.

3.11 Energy Storage Technology, Battery Management System, Advanced Chemistry Cells and Charging Infrastructure

3.11.1 Charging Solutions

As proliferation of ZETs in Indian markets penetrates deeper in near future, the energy storage within the trucks and charging infrastructure in depots as and more importantly enroute gains priority; enroute less for Very Low Emitting Trucks (VLET). The simultaneous development of the entire ecosystem around these truck operations is critical. The charging strategies adopted by truckers will be different for varied operations.

(a) Operations within cities or satellite stations will primarily needs depot-based charging infrastructure. ZETs will be perfectly feasible in this scenario. The current battery power parameters will offer enough energy and reach to these trucks for operations within a given geographical area.

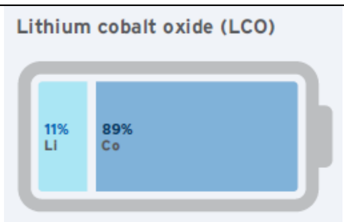
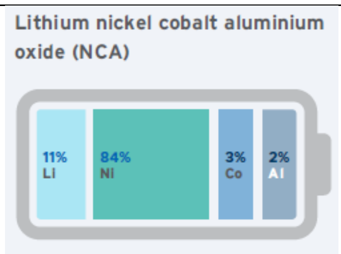
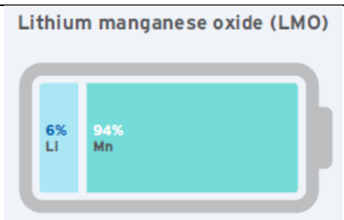
(b) Inter-city or Pan-India operations will require enroute charging, or have diesel-electric hybrid trucks/ VLETs.

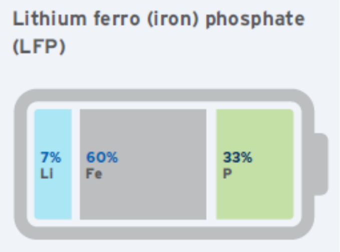
(c) Reach could be extended in both cases by use of swappable battery systems, and importantly keeping the packs within 25 kgs for easy of handling and change. Mobile charging stations (vehicles) would offer an alternate solution to the problem, when placed along major roads/ routes.

The focus of this section will be on the electric power and charging ecosystem for trucks primarily.

3.11.2 Battery Technologies

Lithium-Iron (LiB) have emerged as the dominant market force driving EVs. They have high density and lowering costs. Multiple types of cell designs and configurations exist. They have power densities of 300 W/kg, specific energy in range of 120-275 Wh/kg and cycle life of 1500-6000 cycles. The battery technologies available in markets today are as under:-

Cell Schematic	**Pros**	**Cons**	**Applications & Developments**
	• High energy density and moderate load capabilities • Acceptable cycle life	• High proportion of cobalt • Poor heat resistance and safety	• Popular for consumer electronics • DuPont has used LCO cathodes to demonstrate 26% higher energy density
	• High energy and power density • Good cycle life	• Poor thermal energy management and safety issues • High cost per kWh	• Popular in **EV** powertrains, including Tesla
	• Excellent power discharge and maximum load • Fast-charging	• Low energy density • Low cycle life	• Used in **EV** designs with a hybrid battery pack, in combination with NMC batteries - LMO's high power

Cell Schematic	Pros	Cons	Applications & Developments
	capability • Good thermal stability and safety • Relatively low cost		discharge allows better acceleration performance • Because of comparative low cell durability, uptake has been limited
	• Low cost • Thermally stable • Excellent cycle life, fast-charging capability • Uses easy-to-source minerals • Flat voltage discharge curve	• Lower energy density than NMC batteries	• Increasingly being considered as a replacement for NMC in **low/ mid-range EVs** (including electric buses) with improvements in pack-level energy density • Reliance New Energy Ltd. (ACC PLI awardee) plans to acquire Lithium Werks BV, experts in LFP cell and module manufacturing. • Tesla has announced transition from NCA batteries to LFP for standard range EV models. • Contemporary Amperex Technology Co., Ltd. (CATL) and Build Your Dreams Co., Ltd. (BYD) announced the cell-to-pack (CTP) design for LFP batteries in 2020, which allow energy density up to 140

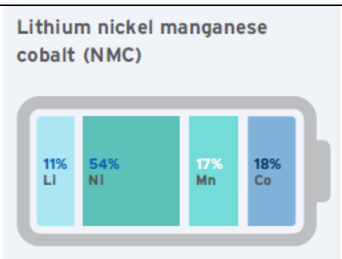
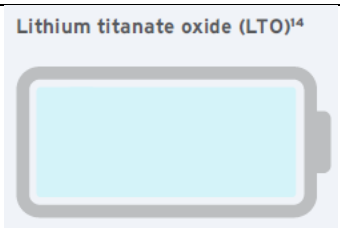
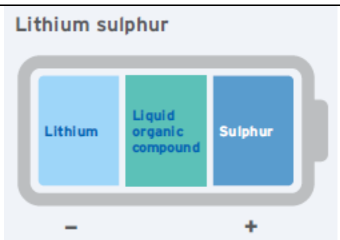
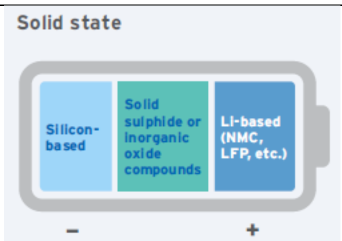
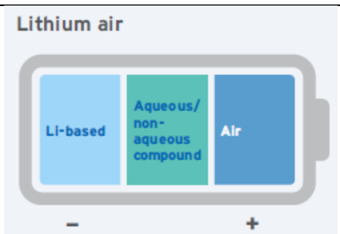
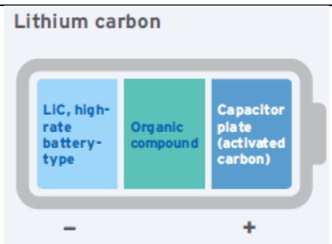
Cell Schematic	Pros	Cons	Applications & Developments
			Wh/kg.
	• High energy density	• Reliance on cobalt • Poor thermal performance and safety	• Current chemistry of choice for **EVs** • Increasingly being optimized to achieve lower cobalt proportions, (supply chain concerns and lowering costs) • Industry moving to high energy density NMC 811 (decline in price premium) • GODI India (Telangana) domestically manufacturing NMC wef January 2022; obtained BIS certification in July 2022
	• Extremely long cycle life (~7,000 cycles) • Excellent thermal management and safety • Fast charge/ discharge capabilities	• Low energy density • Higher costs	• Suitable for stationary storage projects

Table 1 : Comparison of Commercial Lithium Iron Battery Variants

As adoption of LiBs goes mainstream, established battery manufacturers are developing advanced LiBs with improved performance and lower costs. These **advanced LiBs** have identified new manufacturing processes, cell design factors, and battery components to enhance the performance and efficiency of legacy LiBs. Advanced LiBs will play a key role in accelerating EV growth in all categories. Leading advanced battery technologies are covered hereunder:-

Advanced Chemistry Cell Schematic	**Pros**	**Cons**	**Applications & Developments**
	• Higher specific energy and power discharge compared with conventional LiBs • High tolerance for extreme temperatures • Uses low-cost and easily disposable input material	• Low cycle life and longevity	• **Truck and bus** electrification • Industry expects LiS technology evolution for specialist, high performance applications. • Research groups at University of Michigan have reported advancements at lab scale in membrane/ interlayer materials that allow higher cycle life
	• High thermal and impact safety because liquid electrolyte is replaced by a solid • Reduced dendrite growth issues extend service lifetime • High specific energy and low	• Cycle life highly dependent on specific anode–cathode mix (currently <1,000 cycles) • Not commercially viable currently; expected to reach mass market in 3–5 years	• **Long-range EVs** • Samsung announced construction of solid-state pilot line in South Korea; Nissan plans to mass-produce proprietary solid-state batteries by 2028 at $75/kWh pack targets. • Solid Power is already producing 20 Ah solid-state batteries in low-

Advanced Chemistry Cell Schematic	Pros	Cons	Applications & Developments
	cost		volume batches. • Volkswagen may be planning for EVs with solid-state batteries as soon as 2025, using QuantumScape's technology (Solid-state Li metal battery - node-less cell design, high energy density, low material cost)
	• Very high theoretical energy density • Uses abundant, low-cost materials for electrodes, offering lower bill of materials	• Technology still in R&D stage, currently limited by low efficiency and poor cycle life	• Residential storage, **EVs** • Technology is still in R&D phase (advanced materials research)
	• Combines benefits of traditional LiBs with capacitors - good energy/power density and fast recharging • Promises low carbon footprint • Low cost, relatively abundant materials	• Technology in very early stage, with limited number of makers	• **EVs (especially 2-/3-wheelers)** where fast charging can add value • Allotrope Energy announced this technology for long-range and fast-charging use in last-mile delivery segment (electric 2-wheelers) in partnership with Mahle Powertrain.

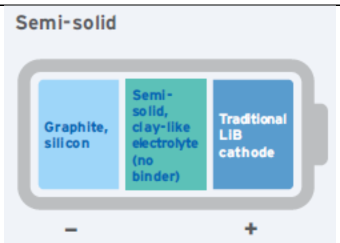
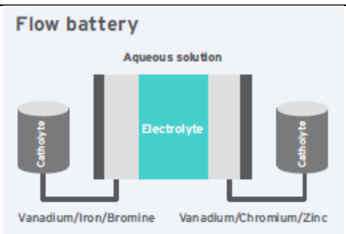
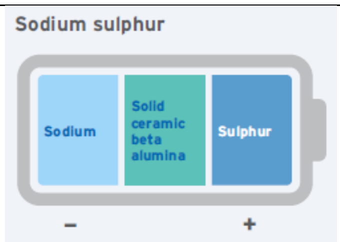
Advanced Chemistry Cell Schematic	Pros	Cons	Applications & Developments
	• Not susceptible to thermal runaway; does not need external cooling system		
	• Design eliminates the need for binder material, making the cell cheaper and lightweight • Storage capacity not limited by battery size (as in flow batteries) • Promises safer performance than incumbent battery technologies	• Technology not expected to be commercialized before 2025 • Currently faces issues with electrode separators, R&D in solid electrolyte material with sufficient electrical conductivity	• Can be tailored for specific applications (e.g., stationary storage, **EVs**) • 24M announced the advanced semi-solid manufacturing process in 2015 and has since struck strategic partnerships with Kyocera (residential storage solutions) and Volkswagen, as well as Lucas TVS to set up production capacity in India

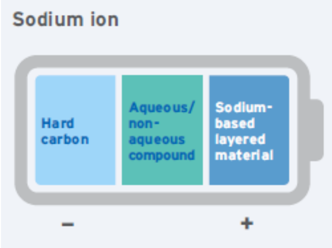
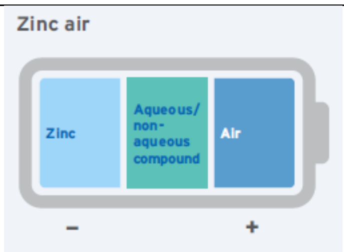
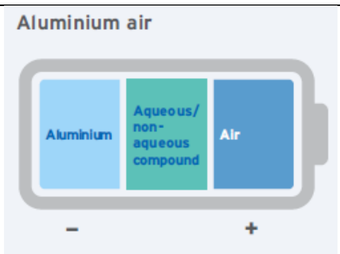
Table 2 : Comparison of Advanced Lithium Iron Battery Variants

LiB chemistries rely heavily on scarce minerals such as lithium, cobalt, nickel, and graphite. India has negligible natural reserves of these materials and has minimal control over the supply chain. Heavy reliance on importations, of either minerals or cells, creates an energy security risk that could hinder successful economic development of both EVs and renewable energy. Alternative and advanced cell chemistries will be vital for India's growing storage needs. These include technologies that maximise the use of resources abundant in India, such as sodium ion, aluminum air, liquid metals, and zinc hybrid.

Recent discovery of **5.9 tons of lithium reserves** by Geological Survey of India in Riasi, Jammu will give self-sufficiency to the country and foster growth of EVs and ZETs particularly (Business Standard, 2023). Granting of mining rights, export control and setting up of refining and manufacturing industry ecosystem domestically will play an important role for optimal and efficient use.

Other **emerging battery technologies** are covered hereunder:-

Cell Schematic	**Pros**	**Cons**	**Applications & Developments**
	• Offers very long cycle life because anolyte and catholyte are stored in external tanks • High power and voltage delivery performance	• Low specific energy • Requires special housing for thermal safety • High system costs currently	• Long-duration storage; typically used for stationary applications
	• Very high cycle life • Good specific energy • Low input material costs; cost competitive with traditional LiBs • Uses environmentally benign materials	• High temperatures required for operation raise safety concerns and require special housing • Currently high system costs	• Long-duration storage; grid support applications

Cell Schematic	Pros	Cons	Applications & Developments
	• Low material cost for sodium, more abundant and sustainably sourced • Allows easy and safe transport without loss of performance • Low tendency for dendrite growth on charging	• Currently in initial commercialization phase, has not achieved scale • Relatively lower energy density and cycle life performance	• Grid-scale storage
	• High theoretical energy density • Higher safety performance compared with incumbent LiBs • Low-cost materials for the electrodes allow lower overall manufacturing cost	• Technology has not reached mass market penetration; currently expensive to manufacture rechargeable zinc-air batteries • India has limited zinc reserves	• Small consumer electronics • Potential use in long-duration storage
	• High theoretical energy density, lightweight • Easily recyclable cell raw material	• Technology still in early R&D stage • Typically non-rechargeable, so battery replacement	• **Long-range EVs** and unmanned air vehicles (UAVs) • Technology still in R&D phase (advanced materials research)

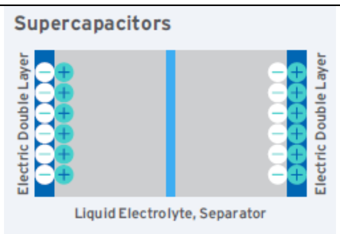
Cell Schematic	Pros	Cons	Applications & Developments
	• Not susceptible to thermal runaway • India has abundant aluminium reserves	stations need to be built out if the technology achieves commercialization	
	• Very high cycle life • Good specific energy • Low input material costs; cost competitive with traditional LiBs • Uses environmentally benign Materials	• High temperatures required for operation raise safety concerns and require special housing • Currently high system costs	• Fast-response grid support applications • Medical devices and consumer electronics

Table 3 : Other Emerging Battery Technologies

3.11.3 Batteries for Medium/ Heavy Duty Vehicles

The Advanced Chemistry Cell (ACC) Volume II study by Niti and RMI (Singh, Ghate, Ningthoujam, Gupta, & Sharma, 2022) indicate consider various parameters to determine the best-fit batteries for various applications/ types of transport. For EV applications Energy Density and Power Density are considered high priority considerations for batteries (others being cost, recyclability, safety, and performance in hot and cold conditions). Heavy/ commercial i.e. ZETs require high energy densities (Wh/kg) as also high Power density (W/kg). High-average life cycles and high charge rate are also preferred.

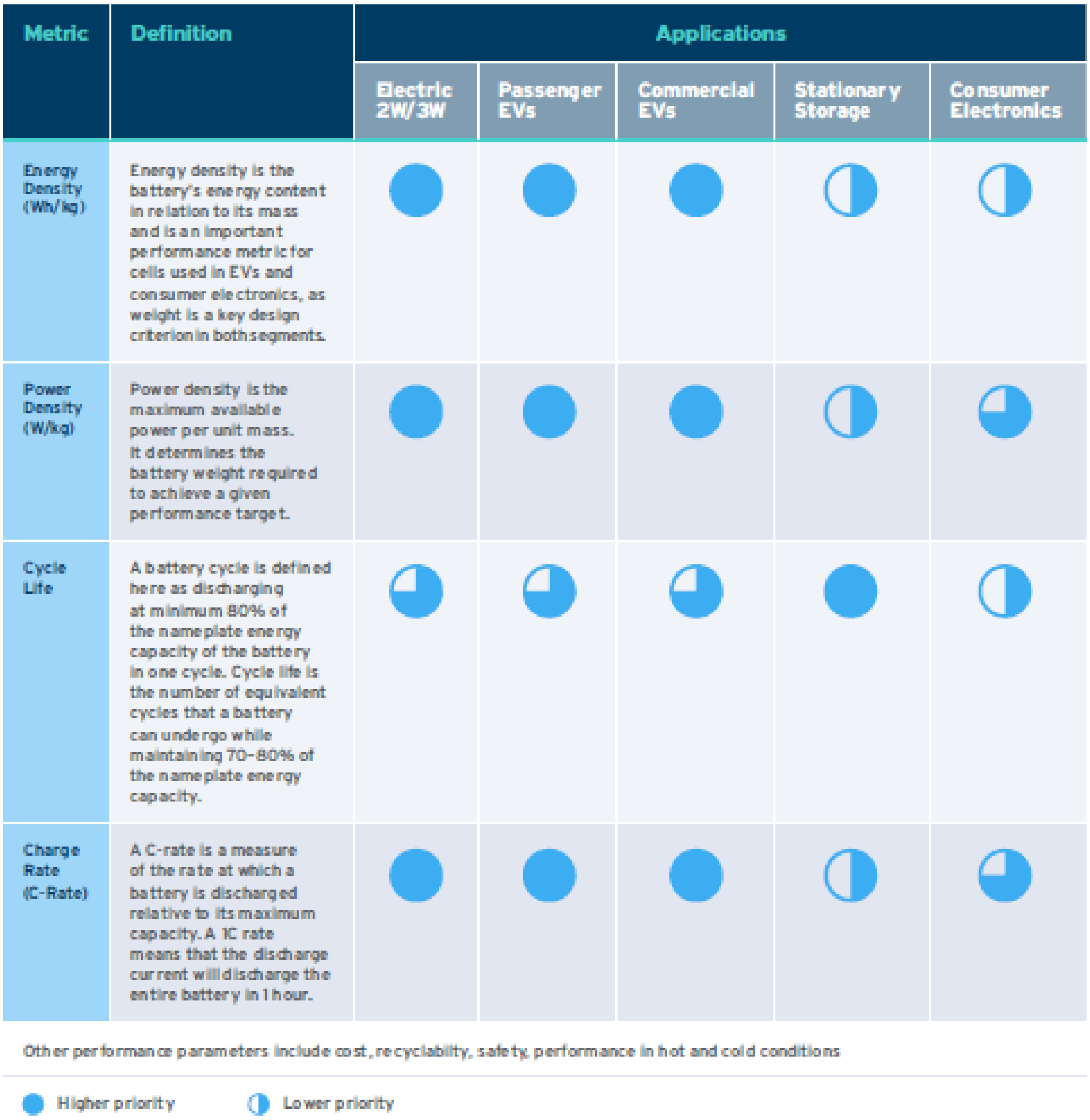


Figure 78 : Battery Performance Matrix and Best-Fit Applications
Source : NITI, RMI

Director e-mobility NITI Aayog, during interview, was asked as to which technology was best-fit for heavy duty ZETs/ hybrids and how ACC technology is likely to shape-up and mature by say ~2030. Similar question was posed to technical expert on energy storage at WRI. It emerged from discussions that based on current performance parameters, the battery technology landscapes looks as under:-

Technology Landscape in 2022						
		Energy Density (Wh/kg)				
		≥ 50	≥ 125	≥ 200	≥ 275	≥ 350
Cycle Life	≥ 1,000	Lead Acid	LMO	LCO	NCA, NMC 622, 811	
	≥ 2,000		LFP, Sodium-Ion	NMC 111, 532		
	≥ 4,000		LTO			
	≥ 10,000	Advanced Redox				

Figure 79 Current Battery Technology Landscape

Source : NITI, RMI

Given various policy vitalizations, the expected technology landscape with respect to battery performance would like as under, with ever increasing energy densities and life cycles as technology accelerates faster than expected (thus shifting the values therein):-

Expected Technology Landscape in 2030						
		Energy Density (Wh/kg)				
		≥ 50	≥ 125	≥ 200	≥ 275	≥ 350
Cycle Life	≥ 1,000	Lead Acid	LMO	LCO	NMC, NCA	Solid State, Al-Air, Li-Air
	≥ 2,000			LFP, Sodium-Ion		Lithium-Sulphur
	≥ 4,000				Sodium-Sulphur	
	≥ 10,000	Advanced Redox	Lithium-Carbon, LTO		Semi-Solid	Zn-Air

Figure 80 : Battery Technology Landscape in 2030

Source : NITI, RMI

On the question of which is the best suited technology for medium and heavy-duty in immediate future, the experts see promise in LFP technology, in their advanced-avatars, in nesr future. In the 2028-2030 scenario solid-state, semi solid-state, Zinc-Air etc will emerge. Life-cycles in the range of >~1500-2000 (which imply a ~10-11 years battery life with once daily charge-discharge cycle). The desired energy density for ZETs/ hybrids would be in the range of 300-350+ Wh/kg, which would give enough juice to batteries to be volumetrically efficient and achieve longer ranges. As far as the next decade was concerned soli and semi-solid state batteries was the future when more power density would be achieved.

Expected Applications						
Specific Energy (Wh/kg)		**>=50**	**>=125**	**>=200**	**>=275**	**>=350**
Cycle Life	**>=1,000**	Backup Power	2W/3W EVs Consumer Electronics	Consumer electronics		
	>=2,000	Rooftop Photovoltaic (PV) Microgrids Frequency Regulation Renewable Integration		4W EVs High-Performance 2W/3W EVs Buses Consumer Electronics		
	>=4,000		Medical Devices	High-Performance EVs Electric Planes Drones		
	>=10,000					

Table 4 : Battery Performance v/s Expected Applications for EVs/ZETs

Specifically with focus on mobility, in the 2030 landscape the promising technologies are:-

- Aluminium-Air and Lithium-Air would likely give energy densities of >=350 Wh/kg and >=1,000 cycle life;
- Lithium-Sulphur energy densities of >=350 Wh/kg and >=2,000 cycle life;
- Sodium-Sulphur would give energy densities of >=275 Wh/kg and >=4,000 cycle life
- Solid-state batteries energy densities of >=350 Wh/kg and >=1,000 cycle life;

The requirement framework of the IAs choice of VLET/ZET, thus, should be in sync with above, keeping market developments of ACC (under PLI scheme) in mind.

3.11.4 Battery Management Systems

Figure 81 : Battery Management System

Source : Siemens

A BMS monitors the overall health and temperatures across the pack, and open and closes various valves to maintain the temperature of the overall battery within a narrow temperature range to ensure optimal battery performance. Safety-wise, this is the most critical component. Battery management information system (BMIS) software and hardware can feature the following:

- Automated battery load testing: ECU-driven. This can usually be enabled only for lead-acid, wet cell batteries. Li-On batteries are more volatile and usually have voltage-sensitive chips located within them.
- Seven-wire trailer cord tester (verifies performance in each circuit).
- Intelligent battery disconnect: monitors system voltage and both charging and cranking circuit performance.
- Data mining: data display and analysis.
- Data logging: records data such as how much battery discharges over a weekend, how chassis electrical loads are used, time and date stamping electrical events. May make use of telematics or a cell phone modem to communicate with data hub.
- Automatic software updates: may occur through telematics or by means of the chassis data bus when connected.

Batteries today have **integrated thermal management system** to ensure against thermal runaway and fire-risk.

3.11.5 Charging Methodology and Chargers

The government's think tank NITI Aayog, in conjunction with others, has taken out the EV Charging Infrastructure guidelines (Kant, et al., 2022). Of noteworthy interest are two literature – firstly, Netherland based company has also studied charging infrastructure requirements for EVs (ABB E-mobility Brochure, 2021) and second, a guidebook on fleet electrification and infrastructure for medium and heavy vehicles (Pacific Gas & Energy, 2019). These professional companies qualify in fleet electrification ecosystems. The typical charger portfolio is as under:-

Figure 82 : Charger Portfolio

Source : ABB

Both overnight slow AC charging and fast DC charging options can be explored for installation. DC Fast chargers will charge faster, a large number of trucks, in shorter timeframes and stand the IA in good stead; though will be costlier. The charging architecture could also include sequential charging (one power cabinet connected to three depot charge boxes), parallel charging (single charger with two outlets) and both systems enhanced by an intelligent charging management system (which has other advantages for power and resource saving, etc also).

There are also other options, besides fixed charging sockets (wall/ stand mounted boxes). A control box with cable management system (motorised or simple retraction) provides flexibility and is suited for garages with less space around vehicle. Within depot boxes, single or dual CCS outlets installations are feasible.

Figure 83 : Drop Cable System of Charging

Source : ABB

Figure 84 : Battery Swapping Infrastructure for Heavy Trucks

Source : Geely, Stuff.co.nz, Car News China, Etrucks, CMAC & MDPI

3.11.6 Charging Infrastructure at Military Stations, Cantonments, Parking Bases and Enroute in Field Areas

The government is planning provision of charging infrastructure on seven major national highways. Long distance travel by army AFVs/EVs, within and/or outside command jurisdictions, can be hooked onto it with book debit accounting.

The IA will need to adopt a **systematic professional approach** towards establishing '**Fleet Charging Stations**' **infrastructure** within cantonments and military stations,

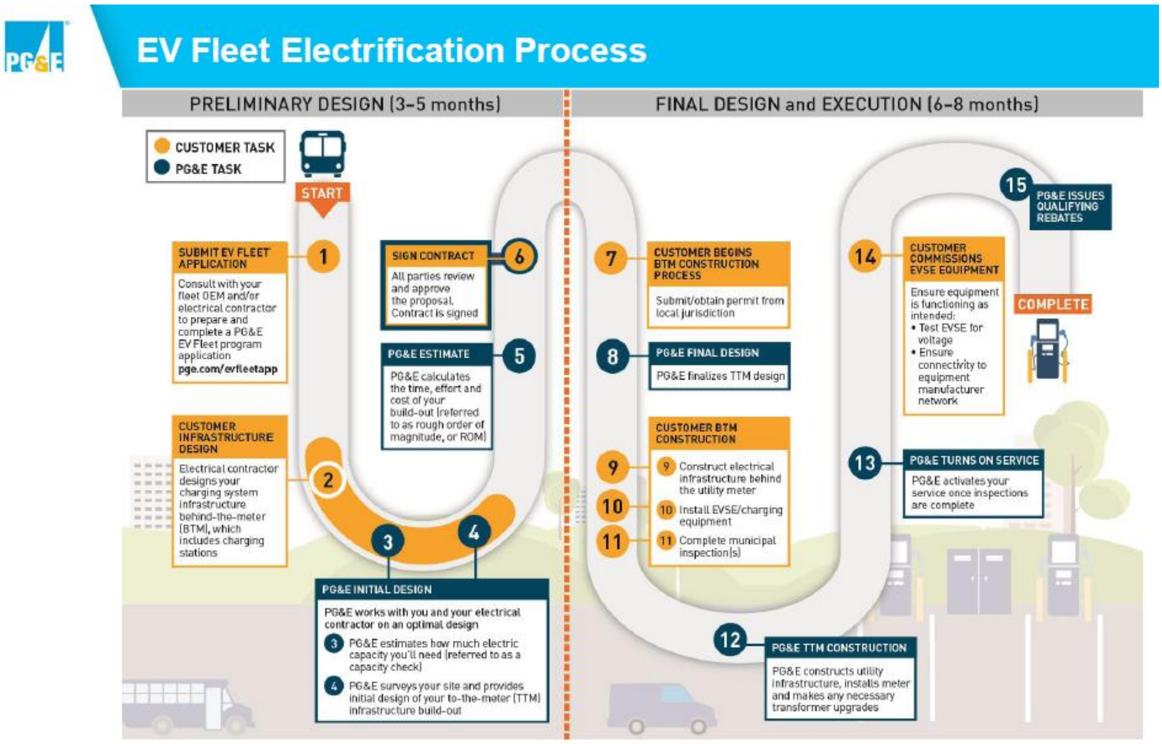


Figure 85 : PG&E Fleet Charging Infrastruture Establishment Process Flow Chart

Source : PG&E

through a **Consultancy Firm**. This should be done in conjunction with the '**EV Support Infrastructure (charger) Provider**' companies many of which operate now in India viz Tata Power, Reliance Energy, Charge Zone, Ather, Ola Energy, etc. PG&E proposes a 8 months period from start-to-end establishment of Fleet charging infrastructure (Pacific Gas & Energy, 2019).

Various relevant questions with respect to e-mobility charging will need to be answered viz location of EV charging integrated garages/location within a station; integration with civil/ secure access to others where feasible/ desired; integrating MES/ combat engineers with civil electricity supply/ distribution companies including billing and accounting (Ministry of Power has empowered such facilitation through its policy of January 2022);

detailed study, DPR followed by outsourcing contract; duration of contract; option of leasing operations etc. This is specially important as IA has already embarked upon procurement of EVs for the initial phase in select stations (The Print, 2022).

The process of establishing a fleet electrification infrastructure commences with determining the daily average and maximum meterage of vehicles and their numbers. Each vehicle has an EV Energy Consumption Rate. This may vary from 0.6 kWh per mile for a 2-wheeler or 4 Wheeler light vehicle, through 2 kWh per mile for a bus and going upto 2.8 to 3.5 kWh per mile for a heavy duty truck. The Charging Energy Requirement (kWh per charge) is calculated based on vehicle mileage travelled between charges and EV Energy Consumption Rate of that vehicle. Once this is calculated for each type of vehicle and totalled up, the Average Power Demand in kW can be calculated by dividing it by the Charging Window which is available in terms of hours. This will establish the Energy Demand per Day of the Fleet Charging Infrastructure established for the station. It is imperative that 25% margin of the total voltage required for the garage should be taken into account.

The planning of the layout of the facility will have to be undertaken in terms of adequate space for movement of transport, location of chargers, distances from the meter, need for underground wiring, location of solar array banks, location of battery storage facilities, availability of flexible and extended wire charging facilities being provided by the charging company, location and size of hydrogen production and refueling infrastructure, location of CNG and LNG tanks, security and safety for various types of fuels, fire-fighting etc should also be considered. The EV charging interface may be a plug-in facility, an overhead or pantograph facility and in due course of time may also be a wireless charging facility. Generally for heavy vehicles, plug-in facility would be the norm. The chargers should be made available by the provider with multiple connector options (based on vehicle specifications) in AC and DC configurations. These could be wall mounted, integrated or modular systems. Generally auto cut off system, after 100% charge, is the norm. With a single charger, multiple number of vehicles can be connected and software control options of sequential or parallel charging can be implemented.

It is also important to develop and install a Fleet Management System to ensure optimised charging and control of such EVs. This can be undertaken as a central project by the IA or MOD (keeping eventual inter-service logistics integration in mind over the near future) and shared across the board with all players.

3.11.7 Mobile Re-chargers and Re-fuellers

Figure 86 : Repos Energy at Auto Expo 2023

Source : Automotive India

Ideally battery configuration for EV should be enough to provide requisite reach and range in one full-charge. Given energy storage maturity levels today, it is not feasible. Dedicated enroute charging facilities are cost-prohibitive and may not be possible Pan-India, or at least where IA operates. Hence, '**Mobile Charging Facilities**' need to be explored. Recently concluded Auto Expo 2023 showcased companies exhibiting such technologies wherein (clean energy) mobile re-fuelling and re-charging options were displayed, including battery swap modules, fossil fuel, hydrogen, natural gas etc.

Trial of **mobile charging infrastructure** can also be undertaken at specific identified locations (specially in field), incorporating requisite types of alternate fuels. In most cases vehicles will not be playing more than the maximum range available to them after initial full charge, to their capacities. Existing refuellers may be considered for modification and replacement in the long run, basis study of operational requirements for Hybrid VLETs.

3.12 Electric Motors and Transmission Drivetrains

The **Electric Motor** is the driving power of the system, the heart so to say. Hence, its design, configuration and selection needs to be the best, which suits Army's operational needs keeping various other considerations in mind. Tremendous technological improvements have been done to powertrains by companies worldwide. There are various types of Electric Motors[4] viz Brushed DC Motor, Brushless DC Motor, Permanent Magnet Synchronous Motor (most commonly used), Induction Motors, Switched Reluctance Motors, Synchronous Reluctance Motor and Axial Flux Ironless Permanent Magnet Motor.

Axial Flux Ironless Permanent Magnet Motor[5] is the most advanced used in heavy duty EVs. It has It has an external rotor with no slots. The use of iron is avoided here, hence no corrosion or rusting. The stator core is also lapsed-in to reduce the weight of the machine. The air gap is radio field type providing better power density. A notable advantage of this is that the motors can be mounted on the lateral sides of the vehicle, placing the stator windings on the axle. The slot-less design improves efficiency by reducing copper losses and more space is available.

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[4] https://www.youtube.com/watch?v=6H5vtu5_SF4
[5] https://www.emworks.com/ckfinder/userfiles/files/Axial%20Flux%20Motor.pdf

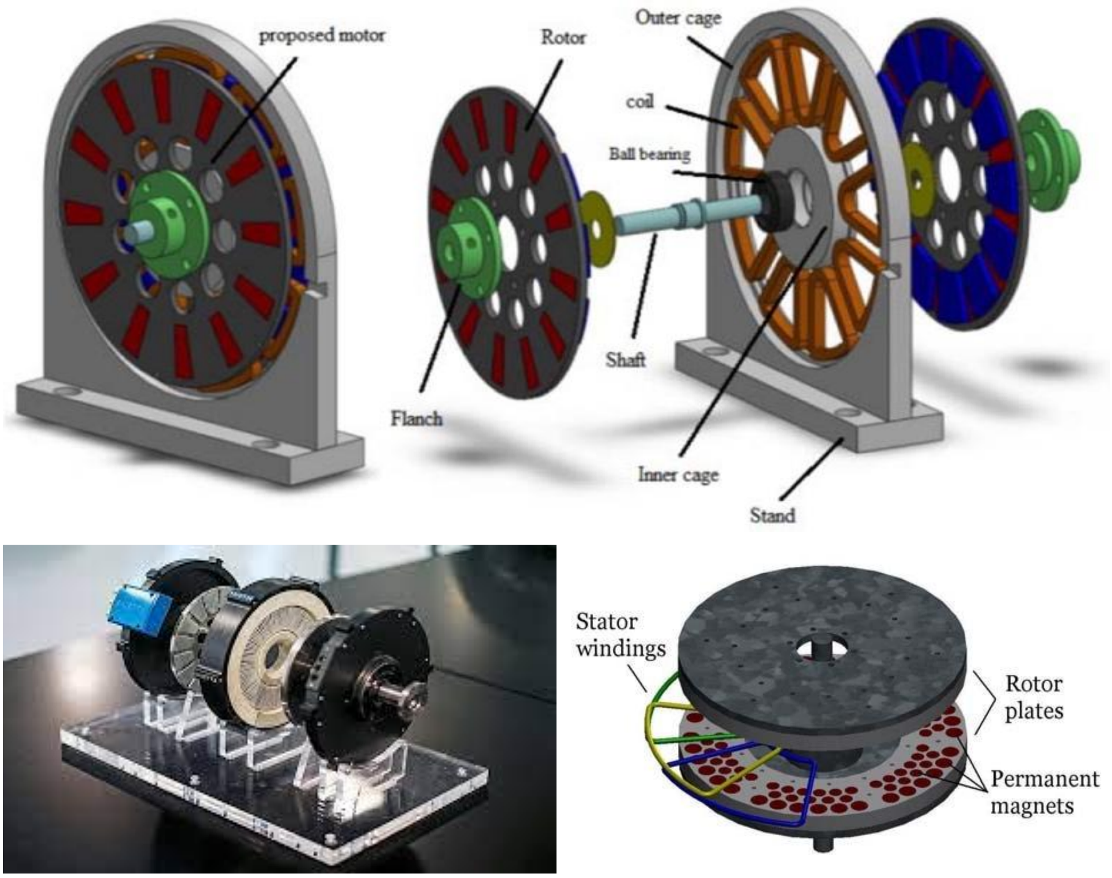


Figure 87 : Axial Flux Ironless Permanent Magnet Motor

Source : EM Works

Placement of an **electric motor in suitable configuration** an EV plays a very important role in the power delivery and purpose of the vehicle. EVs can come in different configurations viz single motor, dual motor, triple motor (a single motor drives either the front or rear and balance two on the other drive), or a four motor configuration in which each of the motors is dedicated two each of the wheels. Single and twin motors are most common in light passenger cars and SUVs. Heavier load carriers however require

Figure 88 : 3-Motor Powertrain

Source : Electrek

a 3 or 4 motor combination.

Figure 89 : Distributed Multi-Motor Powertrain

Source : Audi

The **distributed multi-motor driven Powertrain (3 or 4 motors)** make the vehicle all wheel drive (e.g. Audi e-Tron S, Tesla S and X variants). The two (generally rear) motors drives in normal course bringing in torque directly to respective wheels through a single speed transmission (electric torque vectoring) (which eliminates the need for a differential). This enhances efficiency, improves handling, grip and stability. The other motor(s) come into play when the driver need more performance, specially important in mountaneous terrain with higher gradients and in deserts where otherwise traction is lesser and ground undulating.

Figure 90 : 4-motor drive Powertrain

Source : Electrek

In **four motor configuration** motors are either mounted on respective axles or maybe hub-motors (in-wheel electric motors). Four motors means proper torque vectoring, ensuring differential speeds for all wheels and hence tighter sharper turns, essential in mountains. It is also faster and more responsive as it adjusts torque electronically.[6]

The **VLET/ ZET vehicle design chosen for the Indian Army** (or existing fleet retrofitted) should ensure that the **best automotive mechanical drivetrain technology is incorporated** which will give better and assured performance under difficult terrain and weather conditions obtained in mountains, deserts etc.

[6] https://www.msn.com/en-in/autos/news/nissan-reveals-new-all-wheel-drive-system-for-electric-vehicles/ar-AA14JvBL?ocid=msedgntp&cvid=6a9d0f17bc9141eca55e91fa99cd57e3

सत्यमेव जयते

NITI Aayog

भारी उद्योग मंत्रालय
MINISTRY OF
HEAVY INDUSTRIES

सड़क परिवहन
एवं राजमार्ग मंत्रालय
MINISTRY OF
ROAD TRANSPORT
AND HIGHWAYS

सड़क परिवहन
एवं राजमार्ग मंत्रालय
MINISTRY OF
ROAD TRANSPORT
AND HIGHWAYS

GOVERNMENTAL SUPPORT, POLICIES AND GUIDELINES

Chapter 4 : Government Support, Policies and Guidelines

4.1 FAME-II subsidy

13,92,265 EVs were running on the roads of India as in August 2022. FAME India Scheme Phase-II provided buyers of EVs, meeting FAME criteria, an upfront reduction in the purchase price of electric vehicles. Under Phase-II of FAME India Scheme, 7,45,713 EVs had been supported till 07 Dec 2022 by way of demand incentive amounting to about ₹ 3,200 Cr.

Under Phase-II of FAME (Faster Adoption and Manufacturing of Electric Vehicles) -India Scheme, ₹ 1000 Cr was allocated for development of charging infrastructure. The Ministry of Heavy Industries had sanctioned 520 charging stations infrastructure under Phase-I of the scheme. It also sanctioned 2,877 Electric Vehicle Charging Stations (EVCS) in 68 cities across 25 States/UTs and 1576 charging stations across 9 Expressways and 16 Highways under Phase II of FAME India Scheme. Under FAME India Scheme I & II, a total of 532 charging stations had been installed till mid July 2022. Additionally, Oil Marketing Companies as of July 2022 has established 3,448 electric vehicle charging stations at their retail outlets.

The **IA should avail of this subsidy for all its planned procurements**.

4.2 PLI for Automobile and Auto Component Manufacturers

The objective of the Production Linked Incentive (PLI) Scheme for Automobile and Auto components is providing financial incentives to boost domestic manufacturing of Advanced Automotive Technology products and attract investments in the automotive manufacturing value chain. Its prime objectives include overcoming cost disabilities, creating economies of scale and building a robust supply chain in areas of Advanced Automotive Technology products. It will also generate employment. This scheme will facilitate the Automobile Industry to move up the value chain into higher value added products. Sales targets have been given based on which incentives will be released.

Revenue eligibility criteria and minimum domestic investment conditions (over five years) for automotive and non-automotive companies were laid out. The Production Linked Incentive (PLI) Scheme for Automobile and Auto Component (September 2012) has been successful in attracting the proposed investment of ₹ 74,850 Cr against the target estimate of investment ₹ 42,500 Cr, over a period of five years. 75 applicants were approved under the "Component Champion Incentive Scheme" and 20 applicants were approved under "Champion OEM Incentive Scheme".

The Champion OEM Incentive scheme is a 'sales value linked' scheme, applicable on Battery Electric Vehicles and Hydrogen Fuel Cell Vehicles of all segments – 2 wheelers, 3 wheelers, passenger vehicles, commercial vehicles, Tractors, Automobile meant for Military use and any other Advanced Automotive Technology vehicle as prescribed by MHI depending upon technical developments. A proposed investment of ₹ 29,834 Cr is expected from approved applicants under Component Champion Incentive Scheme. To encourage industry to make fresh investments in indigenous supply chain of Advanced Automotive Technology (AAT) products of PLI Scheme for Automotive Sector, incentives upto 18% have been given.

PLI scheme for Automobile and auto components and PLI for ACC along with FAME Scheme will enable the country to leapfrog to environmentally cleaner, sustainable, advanced and more efficient Electric Vehicles (EV) based system.

4.3 Advanced Chemistry Cell PLI

Presently, most of the batteries were being imported from other countries, a large chunk being from China. The centre approved a PLI scheme for Advanced Chemistry Cells (ACC) for achieving 50 GWh of battery capacity for enhancing India's manufacturing capabilities with a budgetary outlay of ₹ 18,100 Cr. Under the initiative, the emphasis of the Government is to achieve greater domestic value addition, while at the same time to ensure that the levelized cost of battery manufacturing in India is globally competitive. The program is designed in such a manner that it is technology agnostic.

In Mar 2022 four successful bidders were chosen for incentives under the PLI scheme for ACC Battery Storage. Encouragingly, 130 GWh capacity was bid for (instead of anticipated 50 GWh). The manufacturing facilities are to be set up within a period of two years. Incentives are to be disbursed based on sale of batteries manufactured in India with emphasis on greater domestic value addition. It involves direct investment of around ₹ 45,000 Cr in ACC battery storage manufacturing projects. Net savings of ₹ 2 to 2.5 Lakh Cr is anticipated, on account of oil import bill reduction during the period, by adoption of this programme. Incentive structure will encourage industry to promote fresh investments in indigenous supply chain/ deep localization for battery manufacturing in the country.

PLI schemes for Automobile and auto components, ACC alongwith FAME Scheme will enable India to leapfrog to environmentally cleaner, sustainable, advanced and more efficient Electric Vehicles (EV) based system.

4.4 NITI Aayog Report on ZETs – Transforming Trucking in India

NITI Aayog issued a report on **Transforming Trucking in India – Pathway to Zero Emission Trucks Deployment** aimed to act as a foundation and prompt collaboration to make a ZET future a near-term reality in India. By pioneering early ZET adoption,

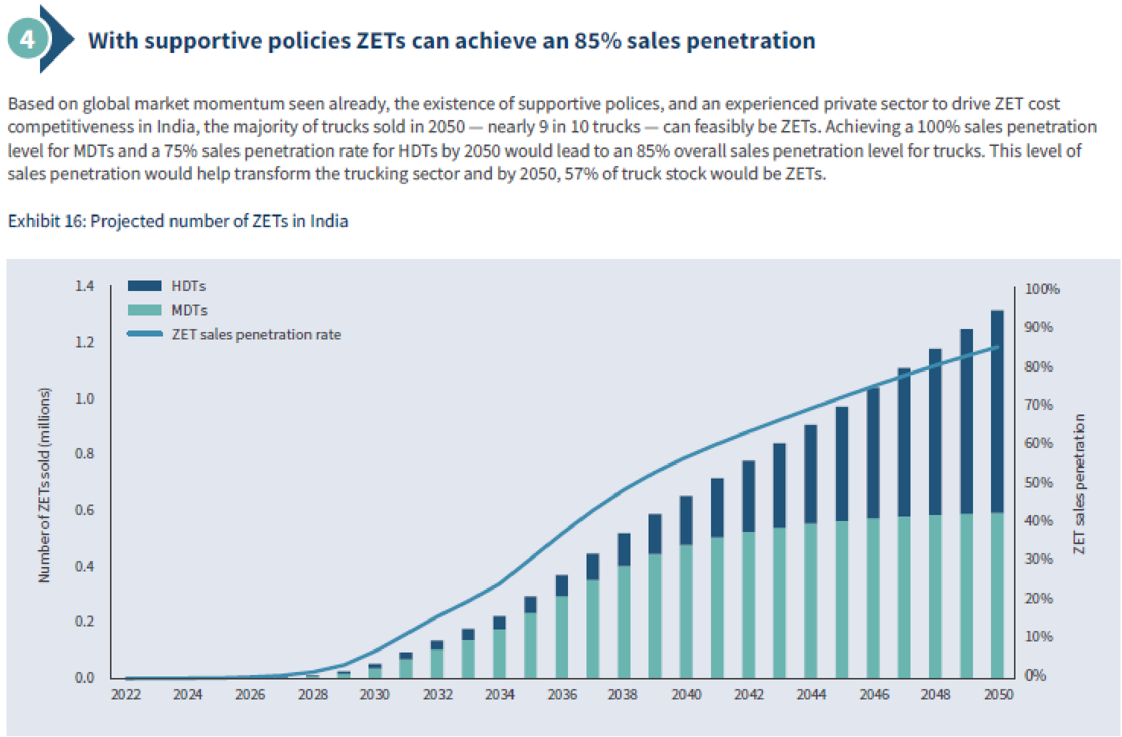


Figure 91 : ZET Growth and Sales Penetration in India

Source : NITI

ecosystem actors can unlock substantial economic, energy security, and emissions benefits for India, and together claim our position as a global leader in this urgent shift. The first of its kind paper was published in 2022 (Niti Aayog, RMI, 2022).

It brings out that the country is experiencing historical growth — urbanisation, population increase, the rise of e-commerce, and increasing income levels have heightened the demand for goods and services. Consequently, the road freight sector is expected to grow fourfold by 2050 to meet this rising demand. By continuing to run on fossil fuel these burgeoning fleets will only further pollute air, exacerbate public health hazards, increase energy costs, and drive-up emissions at a time when many countries are working valiantly to bring them down. As a signatory to and its commitments to COP27, India is well-positioned to become a crucial player in the inevitable transition to zero-emission freight vehicles. There are heavy costs involved on crude oil imports for diesel production.

ZETs are the clear-cut solution to all of these problems and more. By reducing both air pollution and costs while enhancing industrial and logistical competitiveness, ZET adoption can directly support the citizens and the Indian economy in addition to helping meet climate targets. This requires synchronised effort amongst private and public actors to increase the manufacturing supply and deliver the needed charging infrastructure to support a robust ZET ecosystem.

Policymakers can draw on previous national and state incentives that helped spur demand for passenger electric vehicle adoption. By coordinating similar efforts, they can help industry players transfer risk, reduce costs, and seed the nascent ZET market — ultimately harmonising ZET demand and supply to drive market scale.

Comments of Researcher. The pioneer policy is a step in the right direction. The paper **does not address hybrid trucks**, in the transitional phase while battery technology matures. The foreseeable disadvantage is heavy investment in charging infrastructure across the country, specially enroute, which in the case of diesel-electric hybrids can be restricted to the depots located at hubs only while highways may have swappable battery suppliers (should be addressed by NITI in the draft Battery Swapping Policy for ZETs/Hybrid VLETs) (Niti Aayog, 2022). Within ICE, better quality fuel (ethanol blend, higher BS standards etc) be used to reduce pollution levels.

4.5 Infrastructure for EV Charging

NITI Aayog has prepared and circulated a report titled "**EV Charging Infrastructure Implementation**" in Dec 2021 (Kant, et al., 2022) which offers a systematic approach that guides implementing authorities and stakeholders on planning, authorization, and execution of EV charging infrastructure. It presents an overview of the technological and regulatory frameworks and governance structures needed to facilitate EV charging, along with a step-by-step approach to build out the implementation roadmap. While the handbook focuses on the present needs of charging infrastructure development, it also touches upon considerations for future planning. The primary audience includes public and private sector stakeholders that are responsible for charging infrastructure implementation, such as electricity distribution companies, municipal corporations, urban development authorities, and charge point solutions providers and operators. The secondary audience is the regulatory authorities in state and central government agencies responsible for creating an enabling governance framework to support implementation.

Ministry of Power has issued "Charging Infrastructure for Electric Vehicles – the revised consolidated Guidelines and Standards" on 14.01.2022 to accelerate the E-Mobility transition in the country. Under the FAME-II Scheme of the Ministry of Heavy Industries, 2877 public EV charging stations were sanctioned in 68 cities. Action plans have been prepared by Bureau of Energy Efficiency (BEE) for 8 cities (with 4 million plus population i.e. Mumbai, Delhi, Bangalore, Ahmadabad, Chennai, Kolkata, Surat, and Pune). Scenario-wise targets have been prepared for Business as Usual (BAU), Moderate and Aggressive Scenarios for installation of chargers in these cities.

Ministry of Heavy Industries (MHI) had invited proposals from any Govt. Organization/Public Sector Undertaking (PSU) (State/Central)/Government DISCOM/ Oil Public Sector Undertaking and similar other Public/Private entities **to build and operate Public EV charging infrastructure on Expressways and National Highways** under FAME-II for Highways & Expressways, wherein PSU Energy Efficiency Services Limited (EESL), in consortium with Convergence Energy Services Ltd. (a subsidiary of EESL), has been awarded the work for **setting up of EV charging stations along 16 NH/Expressways**. In order to facilitate EESL in the above prospect, NHAI has signed an MOU with EESL. As per this MoU, NHAI shall provide space/land near toll plazas and its buildings for installation of Electric Vehicle Charging Stations, based on revenue sharing model, subject to an agreeable amount to NHAI and EESL. As part of the Wayside Amenities (WSAs), National Highways Authority of India (NHAI) has also awarded 39 such facilities for development. This will **assist in cross-state movement of military vehicles across the country**.

Power Ministry has also issued amendment in Charging Infrastructure for Electric Vehicles (EV), the revised consolidated Guidelines & Standards in Nov 2022 (Ministry of Power, 2022). This order is specially **important to IA as it will facilitate establishing EV charging infrastructure** in cantonments and military stations, through MES/ combat engineers.

The handbook **does not address charging requirements for heavy ZETs**.

4.6 Battery Swapping Policy

Government is in the process of obtaining comments on it's draft battery swapping policy (Niti Aayog, 2022). The policy (in its draft) addresses batteries for the 2W, 3W and light 4W vehicles only. **Higher capacity batteries, such as those required for medium and heavy trucks have not been addressed** therein. This can be a game-changer in terms of providing higher flexibility to heavy vehicle fleet operators, which will in turn ensure faster adoption of low emission mobility. It can also save resources by by-passing requirement to have enroute charging. Though it be done preferably in conjunction with civil (dual) adoption of this proposal, in any case **IA retains it independent option of using this methodology of battery swapping for heavy load carriers for its own fleet**.

4.7 Battery Re-cycling

Ministry of Environment, Forest and Climate Change, Government of India published the Battery Waste Management Rules, 2022 on 24th August, 2022 (Ministry of Environment, Forest and Climate Change, 2022) to ensure environmentally sound management of waste batteries. The rules cover all types of batteries, viz. Electric Vehicle batteries, portable batteries, automotive batteries and industrial batteries.

The rules function based on the concept of Extended Producer Responsibility (EPR) where the producers (including importers) of batteries are responsible for collection and recycling/refurbishment of waste batteries and use of recovered materials from wastes into new batteries. EPR mandates that all waste batteries to be collected and sent for recycling/refurbishment, and it prohibits disposal in landfills and incineration. To meet the EPR obligations, producers may engage themselves or authorise any other entity for collection, recycling or refurbishment of waste batteries.

The rules will enable setting up a mechanism and centralized online portal for exchange of EPR certificates between producers and recyclers/refurbishers to fulfill the obligations of producers. The rules promote setting up of new industries and entrepreneurship in collection and recycling/refurbishment of waste batteries. Mandating the minimum percentage of recovery of materials from waste batteries under the rules will bring new technologies and investment in recycling and refurbishment industry and create new business opportunities. Prescribing the use of certain amount of recycled materials in making of new batteries will reduce the dependency on new raw materials and save natural resources. Online registration & reporting, auditing, and committee for monitoring the implementation of rules and to take measures required for removal of difficulties are salient features of rules for ensuring effective implementation and compliance.

On the principle of Polluter Pays Principle, environmental compensation will be imposed for non-fulfillment of Extended Producer Responsibility targets, responsibilities and obligations set out in the rules. The funds collected under environmental compensation shall be utilized in collection and refurbishing or recycling of uncollected and non-recycled waste batteries.

The **IA is a sizeable consumer of batteries**, even with its current vehicular fleet (besides other usage). It can and **should engage itself in battery re-cycling in an institutionalized manner by becoming part of the battery recycling ecosystem**.

4.8 Green Hydrogen

India has joined the global race to develop a green hydrogen economy to bolster its energy security. After the release of India's maiden green hydrogen policy (Ministry of Power, 2022) , private and state-owned companies have made number of announcements about setting up projects producing green hydrogen.

The policy offers many incentives for setting up a green hydrogen facility. These incentives include single-window clearance for faster project approvals, allotment of land in renewable energy parks, priority access to inter-state transmission network, open access procurement within 15 days, waiver of inter-state transmission charges, and a 30-day energy banking policy. Through these measures, the government is promoting renewable energy transmission and setting up green hydrogen near the consumption sources.

Auto Expo 2023 saw a slew of hydrogen (and its ICE and FCEV variants) vehicles in various categories, including medium and heavy trucks, showcased.

However, the current policy **incentives** mainly **focus on the supply side**. **Developers and investors** need a visible off-take pipeline for their product. The government could provide this by **introducing a green hydrogen consumption obligation** (GHCO) **mechanism** for fertiliser production and petroleum refining, similar to the Renewable Purchase

Obligations (RPO). Strong off-take agreements will make the projects bankable. The government should formulate the second phase of the policy, including the above suggestions.

4.9 Highlights of Budget FY24 Supporting EVs and its Ecosystem

Earlier Actions by Government included:-

- Ministry of Road Transport & Highways (MoRTH) announced that battery-operated vehicles will be given green license plates and be exempted from permit requirements.
- MoRTH issued a notification advising states to waive road tax on EVs, which in turn will help reduce the initial cost of EVs.
- GST on electric vehicles was reduced from 12% to 5%; GST on chargers/ charging stations for electric vehicles reduced from 18% to 5%.

The **Budget FY 2023-24** includes the following steps towards promoting low emission e-mobility:-

- Government vehicles > 15 years scrapping policy has been issued – adequate funds have been allotted. This will also drive demand side.
- For EVs in Semi knock down (SKD) kits – duty has been increased from 30 to 35% and for complete knock down (CKD) kits duty increased from 60 to 70% - in an effort to encourage indigenous manufacturing.
- Custom duty has been exempted for capital goods and machinery required for manufacture of Li-Iron cells for batteries of EV/ storage. Also, extension of the scheme by a year.

- Custom duty exemption to bio-gas in CNG.
- Di-natural ethyl alcohol – exempt from basic custom duty to support ethanol blending.
- Battery storage systems of 4000 MWh capacity supported with viable gap funding.
- Green credit program.
- FAME-II got 800 cr in FY 22 and 2898 cr in FY 23. ₹ 5172 cr allocated in FY 24.
- PLI scheme for ACC allocated ₹ 604 cr in FY 24.

5.9 million tons of Lithium reserves have been discovered in Jammu by Geological Survey of India (GSI) in January 2023. Auction of the reserves is planned by mid-2023. (Business Standard, 2023)

OPERATING ENVIRONMENT OF THE INDIAN ARMY, CHALLENGES, OPPORTUNITIES, PECULIARITIES AND OPERATIONAL LOGISTICAL CONSIDERATIONS WRT SWITCHING TO ALTERNATE FUEL TRANSPORT

Chapter 5 : Operating Environment Of The Indian Army, Challenges, Opportunities, Peculiarities And Operational Logistical Considerations wrt Switching To Alternate Fuel Transport

5.1 Operational Logistics Peculiarities

EV proliferation across the country has taken-off in a big way in the 2-3 years. Generally everywhere for 2- and 3-Wheelers EVs are being sold and operated and support and maintenance facilities have come up. Cities largely are addressing EV support infrastructure for 4 Wheelers also. Other cities and towns are already being targeted by car manufacturers and EV support infrastructure companies. Government is planning establishing charging infrastructure on 7 major national highways (Niti Aayog, RMI, 2022).

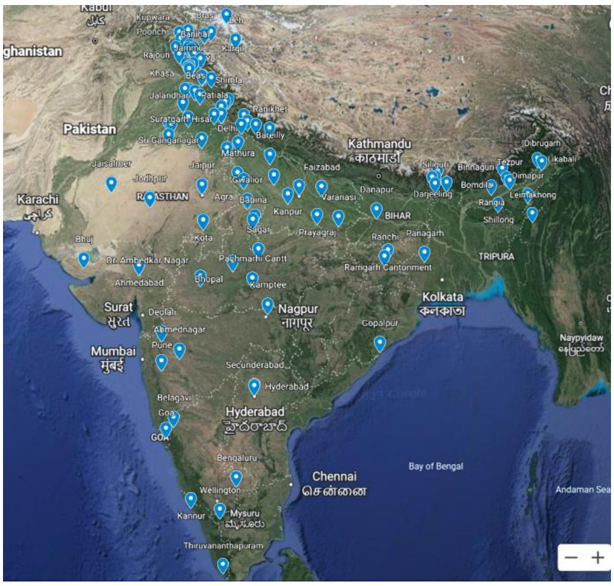


Figure 92 : Map of India

Source : Google Maps

There are large number of locations within the country where army has its presence in terms of troops and vehicles. About 60-75 cities/ towns / clusters comprise of such areas. Peace stations are generally located in the hinterland or non-border areas within cantonments or military stations. These may be in single large geographical areas or in multiple pockets. It could be well within towns or cities, or close to it, on its outskirts.

Numerous units, establishments and headquarters are located herein. Peace and static units comprise of headquarters of stations, Sub areas and Areas Headquarters. Static units could comprise of various types of hospitals, dental units, transport and supply units, base and static workshops, military post offices etc. Training establishments and centres, also called schools, colleges and training centres, are located in peace stations for imparting instructions and training to soldiers at various levels of service, starting from their recruiting till retirement. Besides these, there are recruiting centres and zones.

Field units, on tenure turnover basis, are also located in peace stations, before they again move out for their field tenure on borders. Field formations such as Brigades, Divisions, Corps and Command HQs are also located in these areas. These include Infantry battalions, Armoured and Artillery regiments, Air defence units, Engineer and Signal regiments, Supply and Transport units, EME units, Medical and veterinary units, military police units, and other specialist and units.

Besides pure army units, there are other defence establishments comprising of army personnel which include DRDO, NCC etc, however paid out of respective ministry budgets.

In addition, IAF and Naval units are also co-located at most stations. Incidentally, IAF is entirely dependent on army for its rations and Navy in few stations; an issue being addressed in joint logistics integration and theatreisation, to optimise resources. Similarly, integration of general purpose and duty transport will also likely be addressed.

Movement of vehicles within stations, garrisons and cantonments is generally for training purposes, movement of troops in convoys or independently, conduct of support, logistical and administrative duties which include collection of stores, essentials, rations etc, movement to/from hospitals etc. School bus duties are also performed by defence duty transport. The number of vehicles plying daily (density and frequency) and average daily mileage covered will depend on various factors such as number of units in a station, layout of units within the garrison/ station, type of operational preparedness tasks and training requirements of each formation and unit, location of training facilities and firing areas, location of administrative units, etc.

Transport is dedicated for each unit, formation and HQ on its establishment to ensure that it performs its designated operational task in an efficient, effective and time-bound manner. Formations have dedicated transport at the 2^{nd} and 3^{rd} tier. Transport available with units and formations is either used independently by the units and/or as a central pool for performance of various tasks during progressive phases of operations, in different timelines. When mobilization and operations are launched they play a vital role in providing logistical support to the formations for movement of weapons, men, ammunition, engineer stores, medical supplies, rations and other material in various phases of operations. A very large majority of this transport is 4x4 type of transport since they have to operate in difficult (hilly/deserts) terrain, under developed areas etc. Availability of fuel is also an issue and has to be ensured by its logistics units since it cannot depend on the negligible and unreliable civil infrastructure in forward areas. Thus, fuel is supplied in bulk petroleum lorries (BPL) which arrived from various oil depots (IOC/BPC/HPC) in frontier towns/cities. The fuel is then stored in underground tanks or barrels and vehicles are refuelled from there.

In gist, a very large majority of transport will be used in operations. Starting from World Wars when Opel, GM Motors and Scania would produce thousands of trucks till the recent Russia-Ukraine war when large vehicular convoys carrying ammunition, engineer, defence stores and essentials could be seen in support of fighting troops, trucks play an central logistical role. A typical truck can ply, without any need for refueling, approx 1000 kilometres with 300 litres (distributed in two 150 L tanks) @3-4 kmpl. It is a pertinent observation that a large majority of transport i.e. load carriers will be road bound, even during operations, delivering material of various types and moving troops to/from bases in the hinterland from/to road heads in the forward areas, beyond which even existing 4x4 transport has limitations (except specialist vehicles which are called HMVs or high mobility vehicles). It is in order to overcome such limitations that assault track ways (ATWs) or artificial tracks/roads are laid out.

There are various peculiarities of forward field areas where typically operations will be conducted, in terms of usage of transport, specifically load carriers. In mountainous areas and jungles, i.e. the areas of J&K and in the North eastern states, the main towns/cities connect the forward base by various configuration of roads (National and state highways NH/SH). Beyond these, movement is within valleys or existing roads. In most cases inter-valley lateral movement is practically non-existent due to non-availability of inter-connections. The roads infrastructure is under-developed, prone to slides, restricted due to weather, rains, snow etc. There are numerous landslides, especially in rains. The roads offer lesser traction and require more vehicular power. But, being linear and fixed, generally movement within a valley is structured, and takes place in the form of convoys moving from the mouth to the end of the valley, which return after completing task. In peace time movement is restricted to day light hours and undertaken in night for operational or training purposes. Transit facilities provide for overnight stays and refueling arrangements. Parking areas are very restricted in mountains. The travel within valleys may vary from 100 to max 300 kilometres typically. These areas are ideal for electrification, though they have challenges of adequate electricity availability, space for establishment of an EV Fleet Charging Infrastructure setup etc. Availability of electricity, once the vehicle has entered the valley, is generally restrictive, though development is taking place. Establishment of charging facilities beyond and in the valleys may have to be in the form of - whatever electricity is made available, fossil fuel generators, replacement battery packs, hydel power, solar arrays or wind mills, either existing or can be installed if feasible. The electricity produced can then be stored in energy storages and/or swappable battery packs, use of which is swift (subject to compatible modular battery design). Replacement of battery packs would be almost as swift as or faster than refueling fossil fuel vehicles. However, charging may take longer time from 0 to 100% in <90-120 minutes through DC fast chargers or typically 8 hours overnight with slow charging facility, which will generally be the case during peacetime. Reliance on civil transport by hiring is limited, due to less population in those areas. Though, once contracted for specified periods, transport is made available from hinterland. These areas also disrupt and make difficult the maintenance and spares re-supply supply chain. Fuel for ALS has to be carted to forward areas and is catered for in underground tankages and barrels, which is a logistical nightmare during operations as the requirement increases manifolds. Mountains offer for excellent re-charging of batteries on the go using the regenerative braking technology.

In deserts the distances between locations are slightly longer. However, adequate road infrastructure exists including laterals. Cross country movement, by 4x4 defence duty transport (ALS), is feasible but extremely limited (For improved cross country mobility HMV vehicles are available. HMV vehicles are beyond the scope as these are classified as specialist vehicles). Similar issues with respect to poor availability of electricity exist in deserts. Many locations, which will be occupied during operations, are not existing army bases and hence adhoc infrastructure and charging facilities will have to be established in case electrification of the fleet is planned. This can be achieved by establishing EV Fleet Charging infrastructure in existing bases abinitio, and exploring the options of recharging mobile facilities based on 4x4 transport, as displayed by companies during Auto Expo 2023 which can easily and quickly recharge the fleet. Use of Swappable batteries can also be explored and these can be replaced at designated locations.

Units are located at peace stations in rotation. The transport is generally used for training and administrative duties. Movement of vehicles in hinterland is generally restricted within cantonments and military stations. For load carriage, movement of defence stores etc, vehicles may be required to move inter-city, generally on highways. However, for operational training they are required to move to their operational areas, train, test, validate various tasks and practice for contingencies. This requires large scale and long distance moves. Once in the training areas, the situation is similar of operational areas, as above, and same they are faced with similar challenges if the fleet is of BEV category.

It becomes evident from the above that pure EV-isation or conversion to BEV, the existing Army heavy duty transport, can have adverse ramifications during operations due to peculiarities of the technology, limited battery capacities and ranges of vehicles, poor infrastructure availability in forward areas, non-maturation of the technologies and industry, non-proliferation widespread. Use of purely alternative fuel source vehicles i.e. alternate fuel vehicles is a big step and transformational change to the existing logistics concept of the army. The main issues are recharging/ refueling of alternate fuels and the range anxiety and confidence of being dependent on them during operations in such difficult terrain and far-flung locations. Battery technology has not yet matured to give ~1000 kms range on one charge for heavy load carriers.

Thus, until the technology matures sufficiently and support infrastructure across the country develops, advance chemistry cell batteries with larger storage and density come into production and the industry matures, **development of fossil and non-fossil/alternate fuel based hybrid solution in medium and heavy trucks** for the IA, seems to be a practical and doable option. This would offset the disadvantages of both. A mix of these as hybrid will help achieve larger ranges. But the biggest disadvantage will now be in terms of increase in gross weight of the vehicle due to installation of electric motor, inverter, battery /alternate fuel storages and hence decrease in effective payload carrying capability, especially during operations. In order to offset this disadvantage, a **detachable and modular system**, to the extent feasible, can be developed in conjunction with the OEM/ manufacturers/ industry which will surmount the weight penalty. The current industry maturity is still at concept vehicle and pilot-project development phase and this offers the right time to collaborate across manufacturers, through the entire spectrum of technology, either on cost and no-cost basis, as best achievable.

Additionally, whatever **solutions in medium and heavy duty trucks are available today** (and in the near-future) need to be **procured and tried as pilot projects simultaneous** with development of fossil-non fossil fuel hybrid. Med and Heavy load carriers are readily available to be picked up off-the-shelf (Ashok Leyland, Volvo-Eicher, Tata Motors, IPL Tech Ltd etc), with suitable clauses for operation and maintenance.

Interestingly, in some cases companies are even offering **comprehensive operations support contract** (e.g. IPL Tech Ltd for cement company contracts), if numbers justify economics of a project i.e. they provide the driver, charging facility and maintenance of vehicles, hence making feasible conclusion of (something akin to) outsourcing contracts (instead of buying), which can also be explored. In EVs, inventory management will likely be at a much reduced scale owing to an alternate simpler power-train and zero-emission eliminating the entire exhaust system.

A larger question remains as to **which hybrid to adopt**, as the non-fossil fuel component – battery incl ACC battery, Hydrogen Fuel cell, Hydrogen ICE, CNG, LNG or their combinations, all of which have been demonstrated (some as functional concept vehicles) by numerous manufacturers during Auto Expo 2023. The answer to this can only be found out through physical trials of all technologies. This aspect has been touched upon earlier and is further discussed in the document.

Since IA has already undertaken a pilot project to convert some of its transport fleet in peace stations into EVs, including buses, 2-wheelers, light vehicles, it may be a good idea to establish an **ecosystem** at the bases where pilot project is being undertaken. The ecosystem should therefore also include light, medium and heavy load carriers of all types of technologies being explored and demonstrated by the industry to include electric vehicles, hydrogen ICE vehicles, hydrogen fuel cell electric vehicles, CNN, LPG and a hybrid mix of these fuels also and incorporate them within the ecosystem being proposed i.e. an **EV (or alternate fuel) Fleet Charging Infrastructure Setup**.

A comprehensive approach to establishing an EV (or alternate fuel) Fleet Charging Infrastructure Setup is a must, since multiple agencies are involved. Since a large number of stakeholders are involved in setting up and operation of EV fleet Charging Infrastructure Setup, it is advisable to hire a **professional agency/ experienced consultant to prepare a Detailed Project Report (DPR) and undertake Pilot Project(s) initially**. These pilot projects could be undertaken simultaneously for limited number of stations. And can be expanded based on the feedback and improvements executed. Few locations can be selected and chosen initially, since cost of investment will be high, though beneficial.

5.2 IA's Vehicular Inventory

The **Two-wheeler (2W) category** comprises of primarily Royal Enfield and Hero Honda motorcycles primarily. These are used for despatch rider duties. They also have limited off-road capabilities. Market offers lots of EV options in this category, though near nil in hybrids, which is easy to build on, if so decided. Ideally, Army would one a single-fuel for all it's categories of vehicles. Due to technical difficulties having a diesel engine for a 2W of it's hybrid variant may be impractical. Hence, either an EV or Petrol-Electric hybrid option may be most suitable. If a Pure EV or Petrol-Electric Hybrid is chosen for 2W, it maybe desirable to have sufficient battery power and 'swappable' options therein.

Three-wheelers (3W) holding is negligible in IA, except those purchased out of regimental or private funds by establishments or institutes. Mostly those being purchased are of the EV category. These are also available on Govt e-Marketplace (GeM) platform.

4W Passenger Vehicles/ 4W SUVs/ Tactical Combat Vehicles/ Light APCs. Approx 35,000 Maruti Gypsy 4x4 GS has been the mainstay for IA for long. There are plans underway to induct new replacement vehicles in this category. Peace stations, some field areas and static units and HQs have Ambassadors, Maruti Dzire and Ciaz on their inventories. Additionally about 4,000 Tata Safaris Storme vehicles have been purchased, mostly deployed in field areas. Some smaller specific units also have other categories of vehicles to include Mahindra Scorpio etc. Numerous options are available in the market in this category. As discussed earlier **US, UK and other armies are exploring options of hybrid diesel-electric vehicles** for transforming their fleet.

In **India**, as of now very few Tactical Combat Vehicles or SUVs are on the inventory/ under order. But, the industry has been working on vehicles of subject (in fossil fuel), like the Quick Response Fighting Vehicle (QRFV) developed by TASL (Tata Advance Systems Limited) and DRDO. Kalyani M4 is a high mobility armoured carrier by Bharat Forge. Mahindra Armored Light Specialist Vehicle (ALSV) has a payload of 1 ton. **Mahindra Marksman** is a light armoured personnel carrier can seat 6 personnel. Renault Sherpa Light family of tactical vehicles has been made for NSG and CISF. Tata Merlin is a light armoured multi-role vehicle (LAMV). Maj Gen JS Mathru on his podcast on LinkedIn recommends having **hybrid armoured vehicles**. (Matharu, 2023).

Mine Protection Vehicles. Industry has been keeping pace with requirements of the defence forces and PMF. The vehicles under MPV category are Tata Kestrel, Mahindra Mine-Protected Vehicle-I (MPV-I), Mahindra Meva Straton Plus and Tata Wheeled Armoured Protection (WhAP). Most of the Tactical vehicles and Armoured Protection Vehicles are also mine protected.

All the above are diesel fuel run vehicles. It is not difficult for **industry** to use existing engine technology and add electric powertrain with battery, BMS and associated sub-assemblies to **come out with a hybrid model**, preferably in conjunction with IA, as this would have tremendous scope for export too.

Army Buses. Primarily short (30 seater) and long chassis (52 seater) of Tata and Ashok Leyland are held on inventory and used for transportation of troops. EV Buses are available in the market in almost all configurations with reaches upto 300+ kms. There is a large deficiency of buses presently. It offers a great opportunity to get EVs inducted into the Army.

In fact the IA has decided to convert it’s (actually make up existing deficiency) fleet of buses to EV (Kulkarni & Banerjee, Army Commander's Conference : Apr 2022 - E-vehicles in the Indian Army, 2022). However, the biggest problem is that while staff cars (Ambassador, Maruti Dzire and Ciaz etc) will not be used in operations being non-tactical category, buses will be used for transportation of troops to de-bussing points in very difficult areas and terrains. Hence, **army buses should be Diesel-Electric Hybrids** instead of pure EVs. Course-correction can be undertaken now itself, before the procurement process starts.

4W Light Load Carriers. The Tata 2.5Ton vehicle is part of the inventory under this category. There are approx 25,000 vehicles in service, as per open source data available. The market offers numerous options in BEVs under this category, which have higher payload capacities in the range of 6 Tons. But, there are **concerns and issues with BEVs** wrt ranges, electricity availability, infrastructural requirements etc in operational areas. This category has been discussed in detail separately.

4W Medium and Heavy ZETs. Primarily, ALS has been the workhorse of the IA for a long time now. We have the Mark-IV in service. Unfortunately, it meets only the BS-III standard. There are approx 75,000 vehicles in service. The market has similar payload capacity vehicles, infact upto even 45 Tons in the BEV category. However, **operational logistics concerns** above are also applicable to these vehicles. This category has also been discussed separately.

5.3 Steps Towards EV-isation of Vehicles of Indian Army

During the Army Commander's conference in 2021, the IA decided on a ballpark figure of 10% fleet EV-isation. A 12 Oct 22 news report conveyed IA's decision to change fossil fuel vehicles to electric i.e. 25% of light vehicles, 38% buses and 48% bikes in selected Army units and formations, primarily in peace stations. The process of procurement has commenced. Concerns for motorcycles and buses have been outlined above as these will be required to operate in difficult terrain and areas during war, hence need to be hybrid.

SURVEY, RESULTS, DATA ANALYSIS AND FINDINGS

Chapter 6 : Survey, Results, Data Analysis and Findings

6.1 Expert Views

6.1.1 Indian Army

Senior functionaries[7] were benevolent to grant audience and their time for interaction. User perspective was obtained from them. As has been brought out in Chapter 1, the broad actions undertaken until now were enumerated during interaction. The army has decided to go towards EV-isation. in 2021, the IA decided on a ballpark figure of 10% fleet EV-isation. Initial steps were taken in 2021 during the Army Commander's conference. In the Army Commander's conference held in April 2022, it was decided to change fossil fuel vehicles in to electric i.e. 25% of light vehicles, 38% buses and 48% bikes, in selected Army units and formations, primarily in peace stations. The procurement actions have since commenced.

The vehicles which are primarily being procured are EV. While for motorcycles and staff cars (Ambassadors, Swift, Ciaz etc), there is still a feasibility that it may work during war (since these are non-tactical vehicles and will not see deployment in difficult terrain), however for buses and other light (tactical) vehicles the IA should consider hybrid options, which will give more reliability and operational flexibility in view of advantages highlighted in previous chapter. Also, the options of 'upgradation of existing ALS' to include a BS-VI engine and hybrid drivetrain should also be looked at, being faster and

[7] Additional Director General Supplies & Transport (Fuel & Transport) and Director Transport

cheaper. More has been discussed in recommendations. For fresh procurement/ development, a faster route needs to be adopted.

6.1.2 NITI Aayog

NITI[8] Aayog has been an outstanding resource of technology, policy and material in conduct of the study and research, as also during personal interaction. Senior Advisor (Infrastructure Connectivity – Transport and Electric Mobility)[9] and Director e-Mobility[10] were interviewed. In particular the policy papers on ZETs (Niti Aayog, RMI, 2022), Advance chemistry cells (ACC) (Singh, Ghate, Ningthoujam, Gupta, & Sharma, 2022), draft Battery swapping (Niti Aayog, 2022) and EV charging infrastructure (Kant, et al., 2022) were discussed in detail. Government policies promoting the transformation into alternate fuel transport were highlighted by functionaries. The papers produced by the institute are transformational; it is strongly recommended that IA partner with NITI Aayog and other research organisations (WRI, RMI, E&Y etc) to conduct study on the subject.

Senior Advisor suggested to make a mobility plan for a given station, after carrying out detailed study under aegis of NITI incorporating all stakeholders.

LFP would be most suitable. Parameters of energy density would be 300-350 KWh/kg for heavy trucks with 1,500 cycle life. Fast charging options i.e. mega-watt hour charging (upto 4-6 C) must be explored for operational perspective (like Tesla Semi 900 KWh batteries gets charged in 30 mins). Range enhancers in terms of swappable batteries need

[8] National Institute for Transforming India
[9] Sudhendu J Sinha
[10] Shri Randheer Singh

to be delved into as well. Pre-charged battery modules could also be carried in convoy vehicles, like in case of FOL and/or mobile charging trucks could be placed along convoy routes; such options exist in the market today. The BMS sub-system should be excellently designed, being a critical component in battery safety and performance.

During discussions, the possibility of diesel-electric hybrid vehicles was discussed. It emerged that the technological feasibility exists. It was strongly suggested that proper study and pilot projects should be undertaken to test the concept before being rolled-out full-scale. NITI was prepared to partner with IA on the project. Further leads were also provided. All in all a fruitful interaction and worthwhile progress resultantly ensued.

It was observed that the ZET policy paper precludes hybrid variants (being nascent) and elaborate charging infrastructure is being planned on seven national highways Pan-India. The (draft) battery swapping policy does not cover heavy batteries for trucks. The ACC PLI was in pipeline and 2024 would see manufacturing by major players in India, assisted by PLI on automotives & components.

6.1.3 WRI

Based on lead given by Director e-mobility Niti Aayog, the technical head on the subject at WRI (World Resources Institute)[11] was contacted and interviewed telephonically. A subject master, he explained issues related to batteries with alacrity and patience, especially with respect to energy storage for heavy-duty vehicles. The section in Chapter 4

[11] Shri Praveen

is the result of these interactions and study of the 3 volume papers on Advance Chemistry Cells. In gist, it emerged that while over the next year and half, while companies granted PLI for ACC.

It transpired that in batteries, LFP was most suitable for trucks. In the long term solid state, semi-solid state, Lithium-Sulphur, Al-Air, Zinc-Air etc will also be available as R&D progresses. These will offer energy densities in ranges of 350 KWh/kg and 1,500 cycle life sufficient to give battery life of 10+ years easily. Range extender options should also be explored.

6.1.4 RMI

Principal RMI[12] was interviewed who gave wholesome suggestions on how to go about the project.

He reasoned that de-carbonising the military transport fleet is not an easy task and it requires a long term perspective and large investments, therefore needs to be studied well.

Timeframe of implementation is also important. If it is in the near future of next 5 years hybrid transformation being proposed will work. But, if we are looking at 20 years we can actually invest in infrastructure solutions for other emerging fuels like hydrogen, by when the ecosystem for it will fully come up. It should not turn out to be a sub-optimal lock-in.

---

[12] Jagabanta Ningthoujam is a Principal with RMI India. He works on electricity, hydrogen and battery related work streams.

Of course hybrid has a different value proposition, understandably, but it depends on the time horizon. Continued dependence on diesel has geo-political considerations also during war. Hybrid is a soft transition and may not always be the practical transition now.

There is a need to model either on software or have number of pilot projects with specified number of vehicles in all terrains. You need to undertake more professional studies. Research institutions and organisations have a worldwide view, including in developed countries and for their armies as well of technologies. The technical part will also have to be addressed.

6.1.5 Ashok Leyland

Vice President Corporate Affairs[13] and the R&D team at Ashok Leyland were contacted.

From: Bharat Huria bharat_huria@hotmail.com
Sent: 03 February 2023 18:44
To: YASH.PAL (CORPORATE AFFAIRS) YASH.PAL@ashokleyland.com
Subject: Study on Introduction of Medium and Heavy duty ZETs in Army

1. xxxx.

2. As discussed, taking it forward, given the operational logistics anxiety with respect to limited range and charging infrastructure challenges in remote forward locations of BEVs, may I have your comments on introduction of Hybrid (ICE-cum-Plugin EV) ZETs in Indian Army, with swappable (and removable) batteries and a compact drivetrain giving automatic power to all wheels.

3. The problem in Hybrid will be added weight. To solve this read on for the design being proposed......The idea is that most of the time the vehicles will be used on Electric-mode, until operational requirement arises, so when being used for operations we'll reduce the load by making removable modular battery and maybe even the motor, however whatever we propose has to be fail-proof. Once operations happen (which is likely to be for a much lesser time in the lifetime of the vehicle), the battery and motor can be removed. If the existing ALS can be made into a Hybrid Plug-in ZET, as per the design proposed above, it will allay all fears and anxieties and will find high acceptability therefore.

4. Towards this, may I get your views and confirmation or a broad ok as far as the design is concerned or something better may be proposed by the R&D/ design team. It’s important to know the "how it would happen"; so it would be most helpful and reassuring for the study, if its a rough sketch/ schematic can be enclosed.

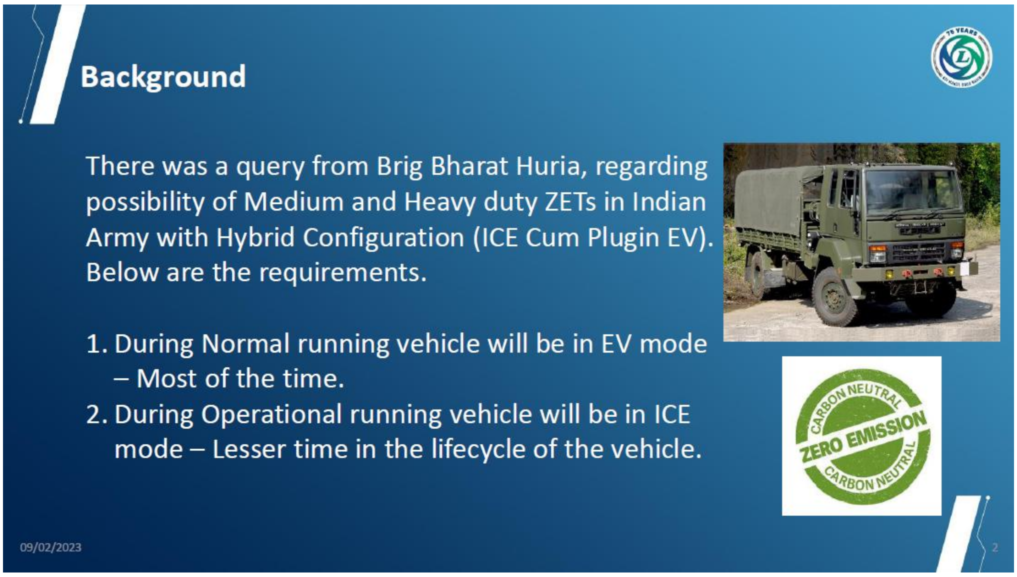
Thanks and warm regards,
Brig Bharat Huria

[13] Shri Yash Pal Sachar

Ashok Leyland makes the 'Stallion' (ALS) which is the mainstay of load carriers for the IA (amongst other services) for the last more than two decades. The need for an idea of a diesel-electric hybrid was initiated.

The team responded positively and shared the broad outline and schematics of the proposed hybrid ALS as has been discussed earlier under the 'Diesel-Electric Hybrid Truck' section and later in the 'survey data analysis' and 'recommendations' chapter. Screen shots of the proposal are hereunder:-

The Diesel-cum-electric hybrid IC engine concept was studied by R&D team of company.



It summarised the major components which are required to operate in hybrid mode, additional requirements primarily being in the plug-in electric drivetrain portion.

Major Aggregates Summary

ICE Cum Plugin EV

ICE	Plugin EV	Remarks
Engine	Traction Motor	
Fuel System	HV Battery pack	
Engine Accessories - Air Intake System, Cooling System, Exhaust System	EV Components - Battery Chiller, Motor Cooling, PDU, BMS, Motor Controller, Aux Inverters, DC-DC Converters	
Frames & Accessories		Common
Front & Rear Axles		Common
Suspension, Tyres & Wheels		Common
AGB & Propeller Shaft (Modified)		Common
Cabin & Loadbody		Common
Vehicle Electrical, Lighting & Accessories		Common

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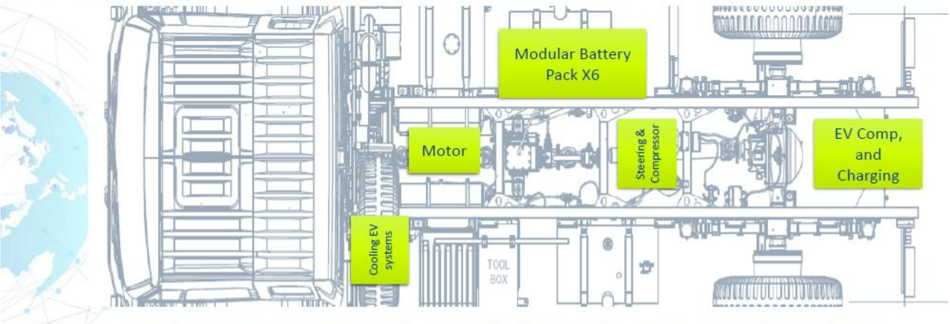
The R&D team has come up with a schematic layout of all the components in order to provide dual-drivetrains in the hybrid ALS model. This includes the traction motors, battery pack and EV components. So, it is seemingly a technically viable option, hence, the answer to the most important research question of feasibility of the likely arrived at technology is in affirmative.

Concept Study of Plugin EV in Stallion 4X4 MIV ICE Truck

Hybrid (Plugin EV in ICE Truck)



- Traction Motor – Clutch to be provided to cut off Engine and Gearbox from drive train during EV Mode
- Battery Pack (200kg * 6) to be packed; EV Components to be placed in rear for easy removal during operations
- Chiller and Motor Cooler to be placed on RH side; Steering, Compressor and HVAC motors to be placed in middle
- AGB to be moved back and Propeller shaft to be modified

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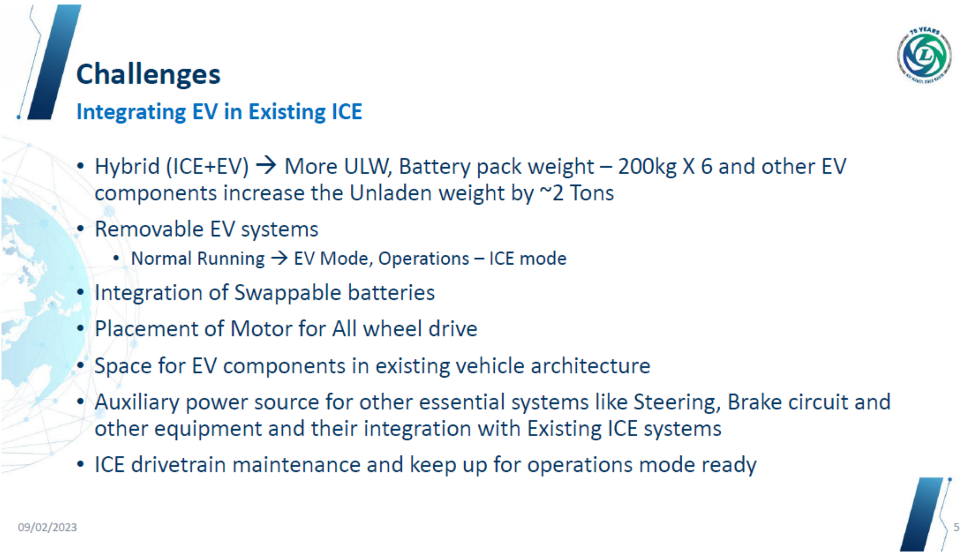
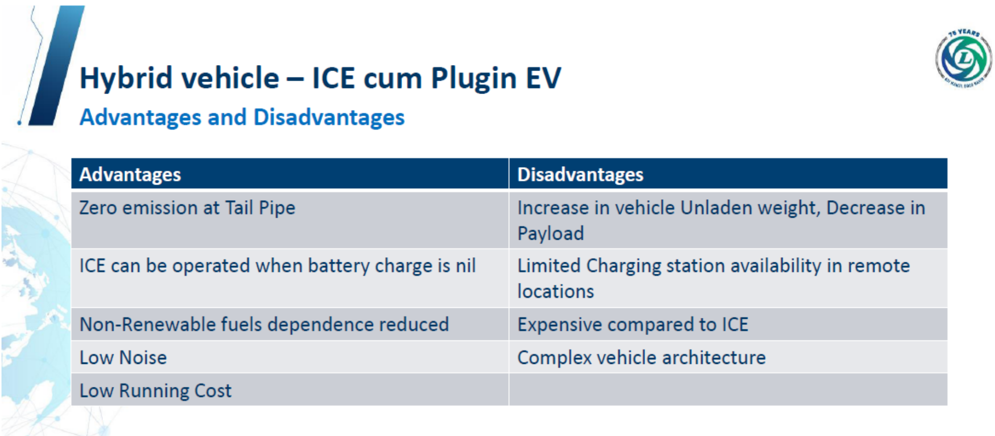
However, the Ashok Leyland team has listed the challenges that will need to be resolved.



The cost of the project will be given with exact requirements and number of vehicles.



Advantages	Disadvantages
Zero emission at Tail Pipe	Increase in vehicle Unladen weight, Decrease in Payload
ICE can be operated when battery charge is nil	Limited Charging station availability in remote locations
Non-Renewable fuels dependence reduced	Expensive compared to ICE
Low Noise	Complex vehicle architecture
Low Running Cost	

The proposal submitted on 09 Feb 2023 highlights the advantages and disadvantages of the concept.

6.1.6 IPL Tech Ltd

CEO[14], IPL Tech Private Limited was interviewed in October 2022. The company has been a pioneer in manufacture of ZETs in the category of 45 tons (primarily tipper trucks) for use in cement etc industry, within a eco-system permitting alleviation of range anxiety

[14] Shri Subodh Yadav

as the trucks are back at base at the end of day's operations. The company is progressing very soon towards enhancing its annual production to 2,750 trucks, which will make them a major player in the ZET industry. The IPL Rhino 5536 ZET still remains the biggest one in market though and the company is making good progress towards indigenisation. Though, as seen in Auto Expo 2023, now other mainstream players (Tata Motors, Ashok Leyland, Volvo-Eicher etc) have also jumped into the fray.

The possibility of a hybrid electric truck was discussed and it emerged as being technically feasible, albeit loss of some payload was inevitable, which could be counter-balanced by other methods after detailed study. They also offered to partner with VFJ, if given the opportunity to produce a hybrid, combining best of both technologies.

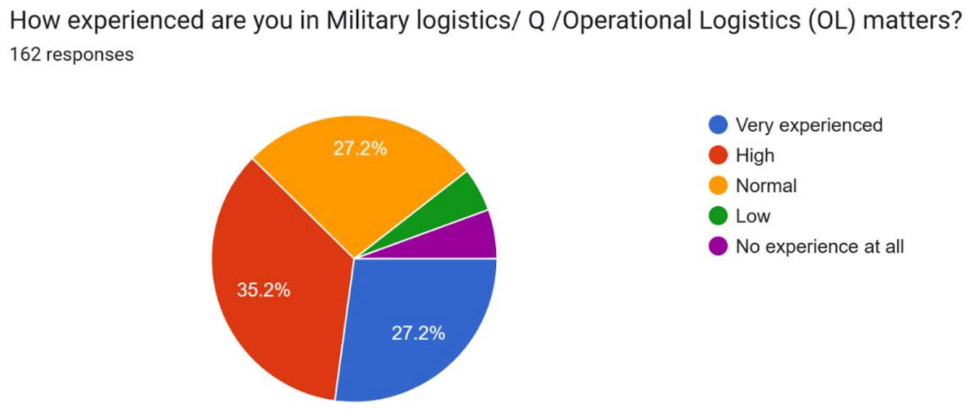
6.1.7 Auto Expo 2023

Personal visit of the researcher to Auto Expo 2023 at Greater Noida on 13 January 2023 was most constructive. Personal interaction with personnel at stall of alternate fuels like 'ethanol', 'bio-fuels' etc; e-2W stalls including other fuels; e-4W passenger cars including light tactical vehicles by Pravaig and Toyota Hilux; light, medium and heavy trucks and buses segments was an eye opener. The industry is conceptualising ZETs and all options (Natural gas, hydrogen ICE, FCEV etc) at a very fast pace. Joint ventures are also taking place, all supported and catalysed by Automotive and components PLI by the government. Thus, adequate opportunity exists for IA to venture into the field and seek options from the industry.

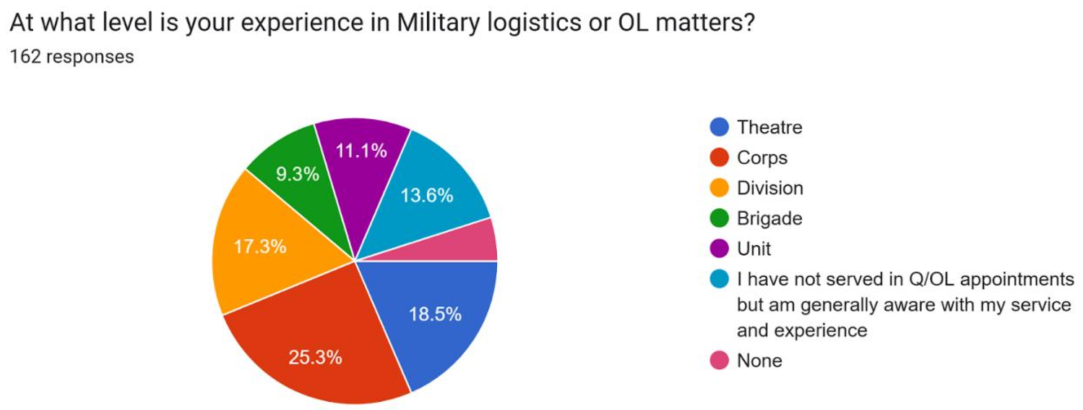
6.2 Survey through Questionnaire : Important findings and analysis

A survey of about 160+ participants was solicited online through Google forms (refer **Appendix 'A'**). The questionnaire was so designed to satiate answers to the research questions chalked out during the beginning of the study. In the survey there are total 30 questions. Initial 11 were informational or confirmatory. They will only be used to know what technical qualified people think or how well they were aware and then how they answered other questions can be explained by analysis. Next 7 questions were directly about the technology being recommended. 2 are about which locations and type of units should the induction of AFVs be done in. Next 2 are about how we should proceed further with procurement of heavy-duty trucks. Balance 7 are about associated technologies, other types of vehicles etc and 1 asking comments/suggestions. Google analytics and Power BI were used to analyse the responses.

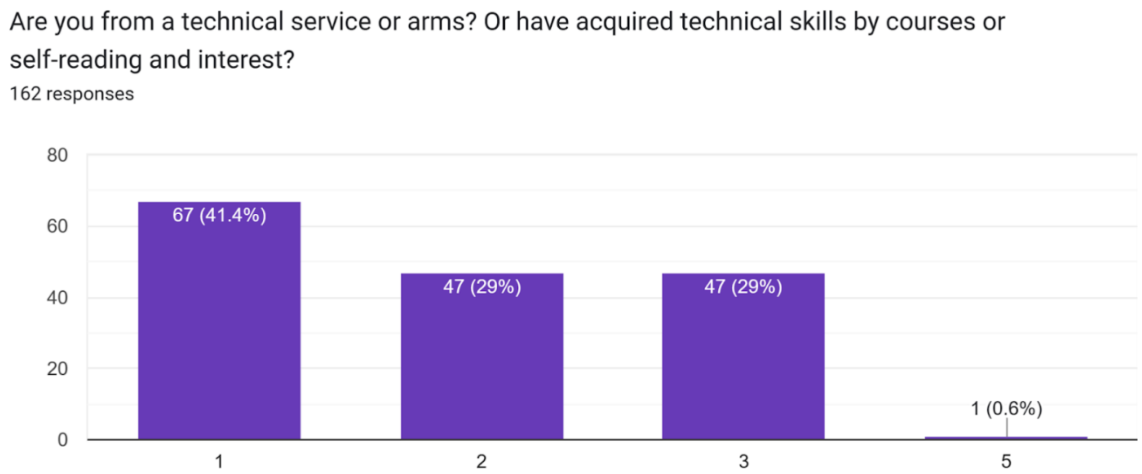
Q2. (Q1 was Name). About 90% people who undertook survey were normal to very experienced in military operational logistics matters.



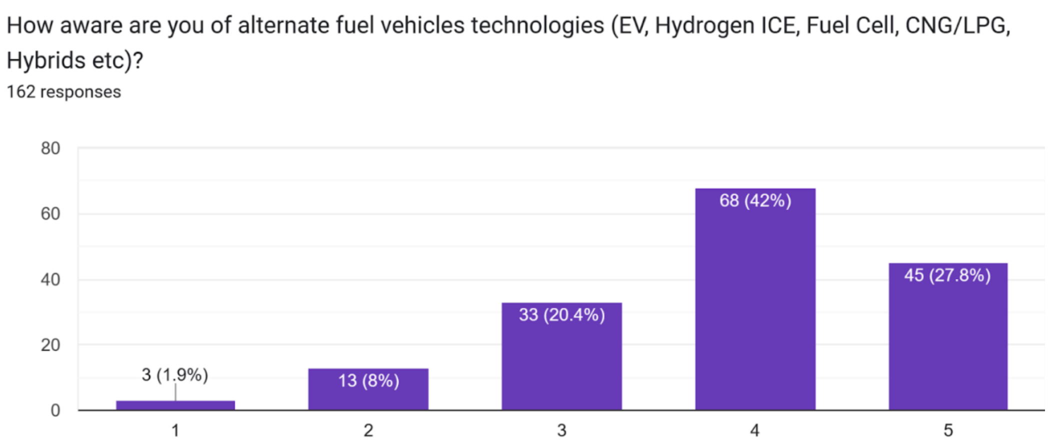
Q3. About 70.4% people had experience as operational logistics staff at theatre, corps, division or brigade levels.



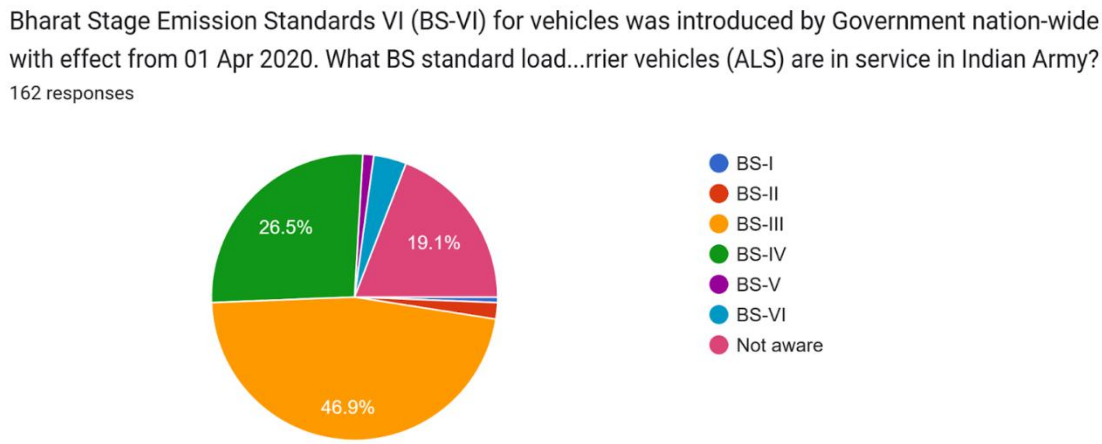
Q4. About 70% are from a **technical** service or have **acquired adequate technical skills** by courses or self-reading and interest (1 and 2).

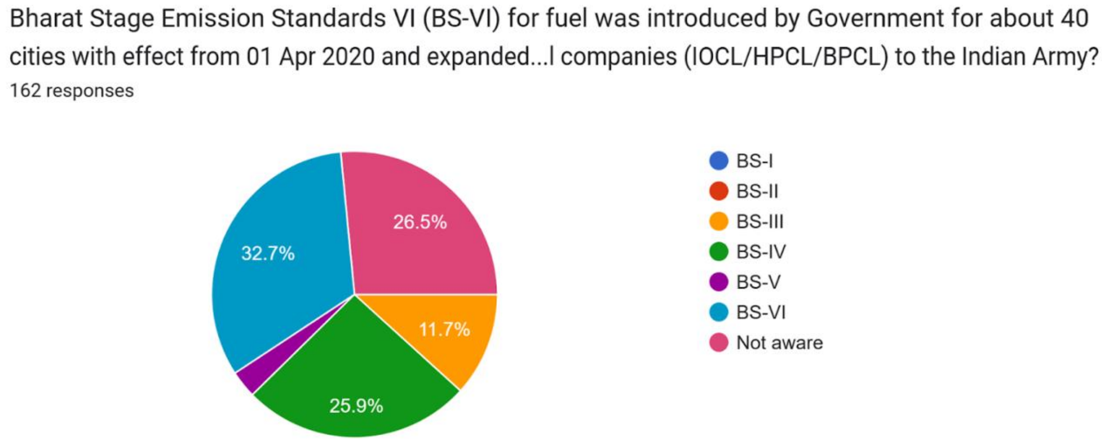


Q5. 90.2% people have some form of awareness about alternate fuel vehicles and technologies (3 to5).



Q6,7. Although most people (90%) are aware of Operational logistics matters; Majority (70%) are also technically well qualified, however, **only <50% knew** that the mainstay load carrier of IA i.e. **ALS**, which has been in service for >20 years now, **is BS-III** i.e. Bharat Stage **Emission Standards** III. Similarly and surprisingly, **only about 33% were aware** that fuel being supplied is **BS-VI fuel.**



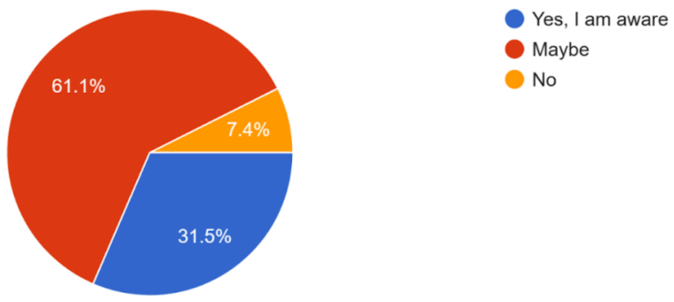


Poor awareness levels maybe one major factor which has not yet pushed adoption of cleaner fuels and alternate fuel technology vehicles.

Q9. The above is accentuated by the **large consumption** of **fossil fuel** annually by IA (>4.5 Lakh KL costing ~3.7k Cr). Surprisingly, **just 61% of a sizeable population** of **logistics experienced and qualified personnel were well aware** of the fact.

The consumption of FOL main grades annually by Indian Army is approx four and a half lakh plus kilolitres costing about 3700 crores

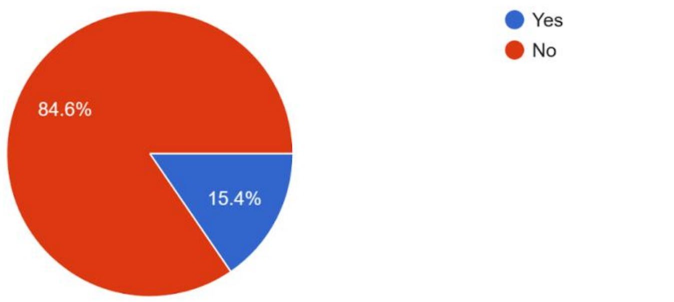
162 responses



Q8. Having said that, **85%** people agree that advantages of BS-VI fuels **cannot** be fully exploited when used in a vehicle of lower BS Emission Standard. Hence, atleast **upgradation of ALS to BS-VI engine** is imminent and should be on the agenda. Technical apprehensions, if any, can be brought forth and will be addressed by the industry. In fact with ethanol blending fuel quality will further improve and carbon emissions decrease.

Can we truly derive the full advantages of BS-VI fuel, while we use vehicles with lower BS Emission Standards?

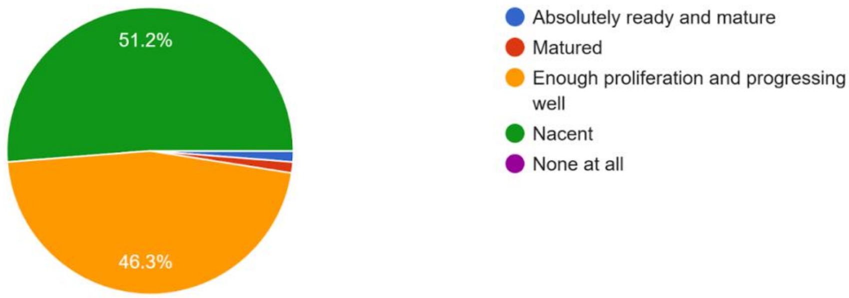
162 responses



Q10, 11. Majority feel that EV/AFV industry is either **'nascent' or 'progressing well'.** Also, majority feel that the alternate fuel industry for trucking is **'nascent' to 'none at all'**.

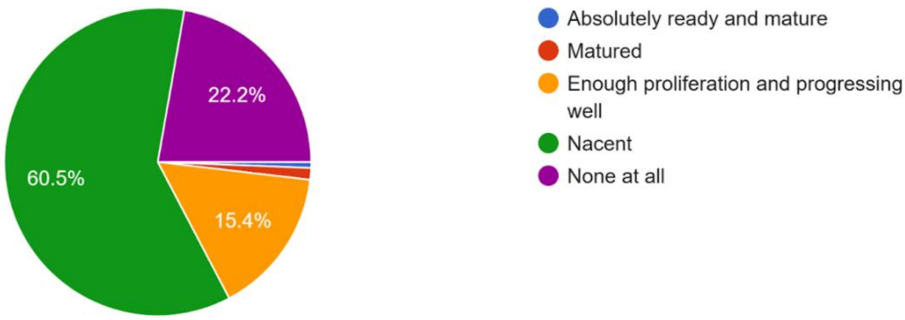
In your view what is the maturity level of EV industry in India, in general? Rate it as below

162 responses

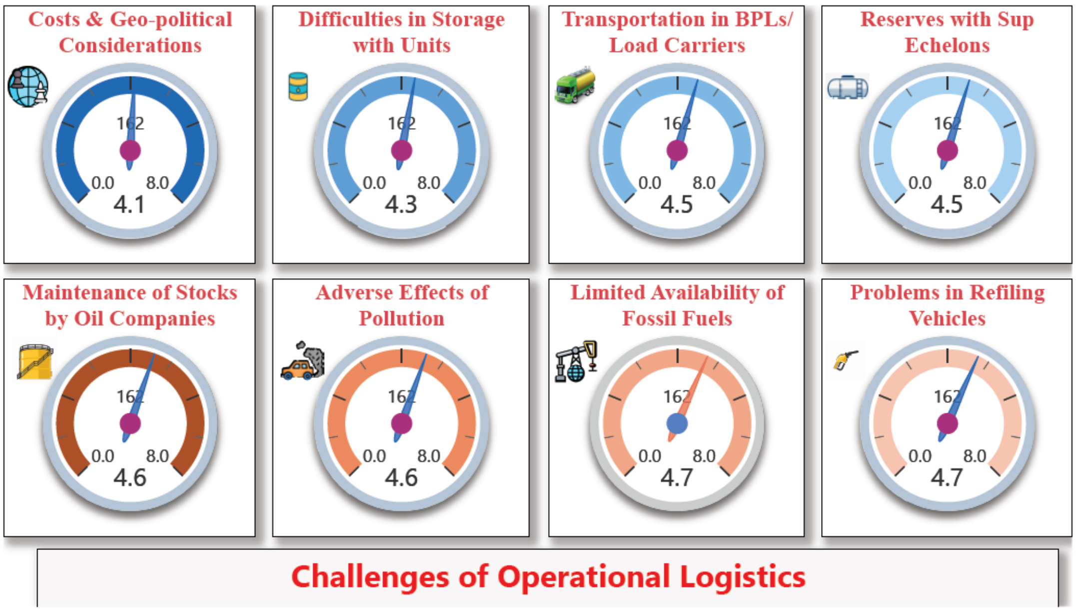


In your view what is the maturity level of EV industry in India, specifically for trucks? Rate it as below

162 responses



Q12. Participants were asked to rate difficulties associated with operational logistics of fossil fuel in deserts, mountains, jungles etc for Army operations. (1 - Most severe problem; 8 - Least of the problems)



The parameters of operational logistics difficulties were then sifted to get top three scores allotted to them in the survey questionnaire. When these were averaged 1) '**Geo-political turmoil and effect on crude oil costs**', 2) '**Storage difficulties in units in barrels and jerricans**', 3) '**Transportation of fuel in bulk petroleum lorries and trucks**' and 4) '**Difficulties associated with storage of fuel reserves with supply units**' emerge as the priority challenges, in view of the participants.

OL Difficulty Level (1-Highest)	Avlbty of Fossil fuel		Costs and Geo politics		Maint of Stks by Oil Coys		Maint of Stks with Sup Echs		Storages with units		Effects of Pollution		Probs in tptn BPLs and LCs		Problems in refilling vehicles	
	Weightage	Nos	Weightage	Nos	Weightage	Nos	Weightage	Nos	Weightage	Nos	Weightage	Nos	Weightage	Nos	Weightage	Nos
1	34	34	25	25	11	11	6	6	15	15	33	33	10	10	28	28
2	30	15	74	37	32	16	20	10	30	15	22	11	68	34	48	24
3	45	15	54	18	84	28	81	27	57	19	54	18	78	26	33	11
4	44	11	44	11	100	25	160	40	144	36	56	14	44	11	56	14
5	40	8	60	12	105	21	200	40	195	39	75	15	80	16	55	11
6	126	21	120	20	198	33	96	16	90	15	156	26	114	19	72	12
7	126	18	175	25	98	14	112	16	119	17	98	14	252	36	154	22
8	320	40	112	14	112	14	56	7	48	6	248	31	80	10	320	40
Total		162		162		162		162		162		162		162		162
Weighted Total	765		664		740		731		698		742		726		766	
Average (Min)	95.6		83.0		92.5		91.4		87.3		92.8		90.8		95.8	
Avg Top (Min) 3 Scorers	31.7		29.0		28.7		35.7		31.3		30.0		32.0		30.7	

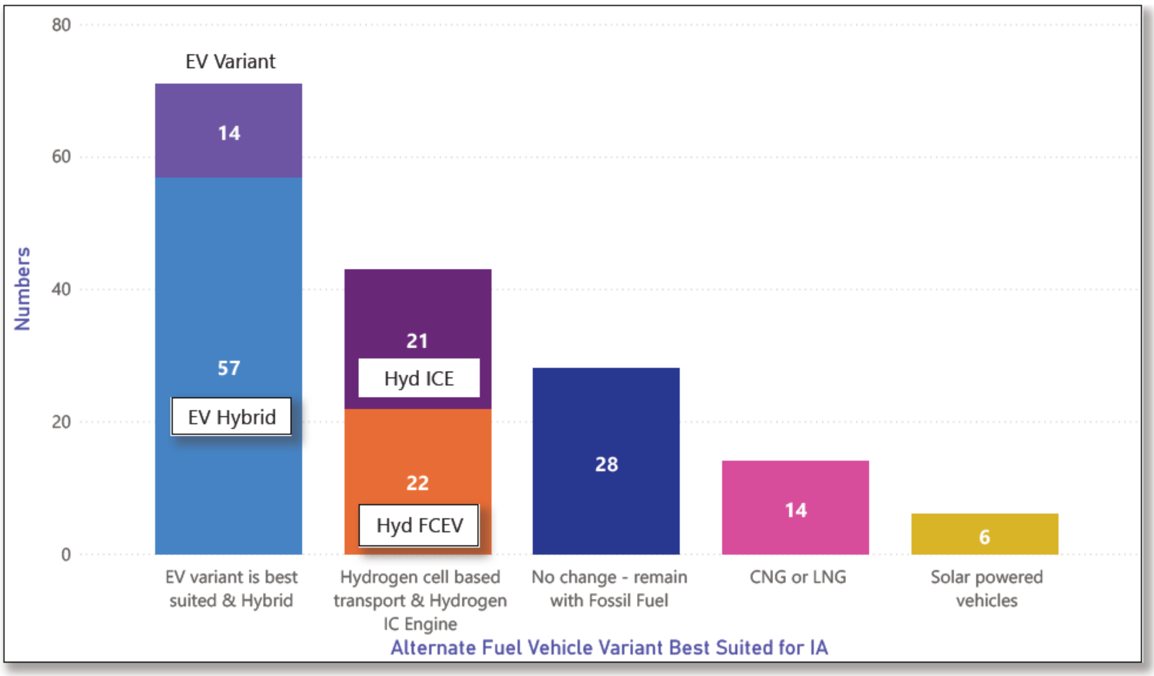
Table 5 : Operational Logistics Difficulties Parameter

The parameters of operational logistics difficulties were then sifted to get top three scores allotted to them in the survey questionnaire. When these were averaged 1) '**Difficulties associated with storage of fuel reserves with supply units**', 2) '**Transportation of fuel in bulk petroleum lorries and trucks**', 3) '**Availability of Fossil fuel**' and 4) '**Storage difficulties in units in barrels and jerricans**' emerged as the priority challenges, in view of the participants. Problems in refilling (Jerricans, automated pumping solutions, directly from Kerbside pumps), Effects of Pollution, Costs and affect of geo-political turmoil considerations and maintenance of stocks by oil companies were next in order of priority.

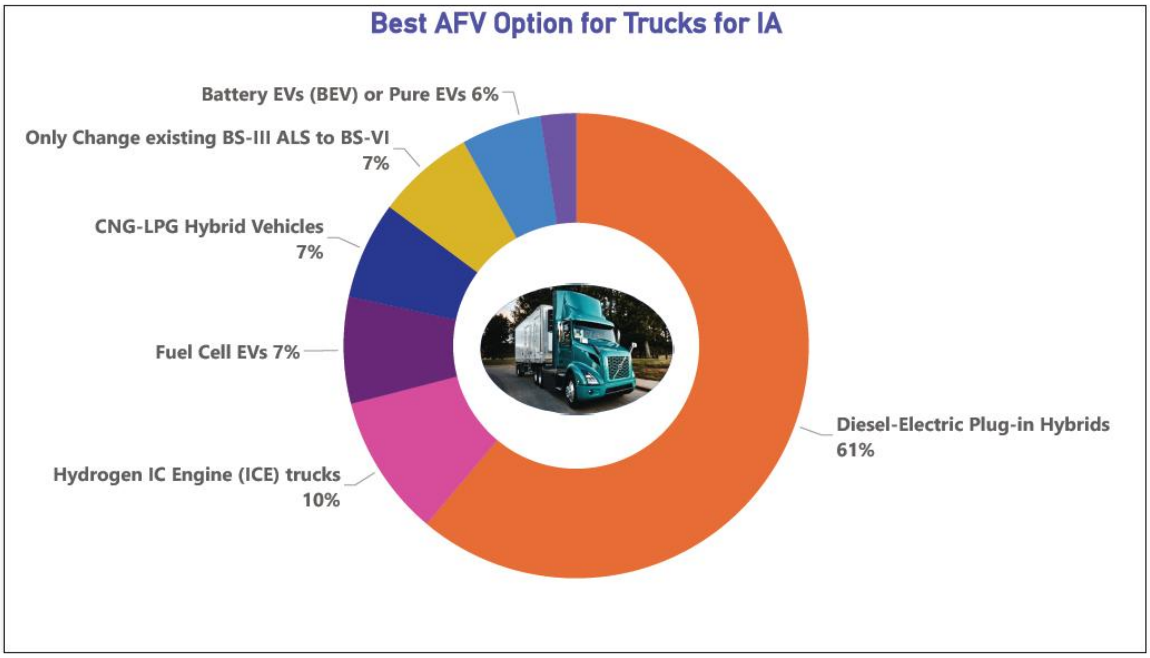
The union of above two methods give list the common perceived operational logistical challenges as, 1) '**Storage difficulties in units in barrels and jerricans**', 2)

'**Transportation of fuel in bulk petroleum lorries and trucks**' and 3) '**Difficulties associated with storage of fuel reserves with supply units**'. Adoption of alternate fuel vehicles will largely reduce the operational logistical burden, both during peace and war for the IA. Even if hybrid AFVs are adopted, the quantum of fuel consumption will drastically reduce, specially during peacetime.

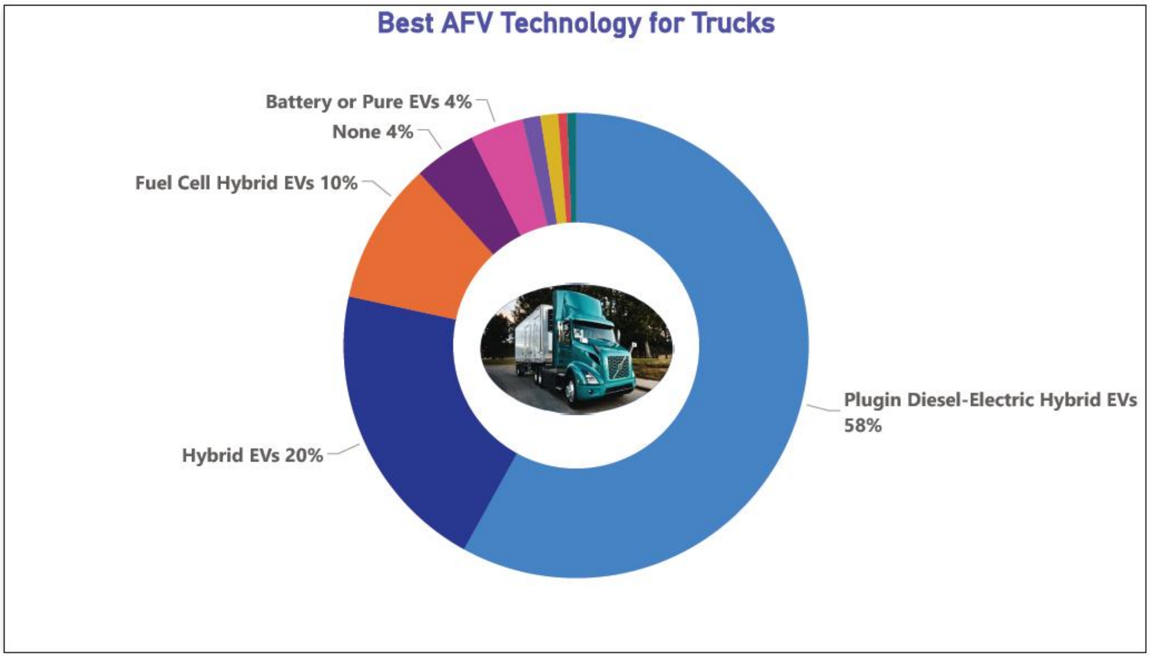
Q13. The next three questions focussed on the alternate fuel vehicle technology to the introduced. They were asked which **alternate fuel based / variant option of transport** is best suited for IA. Barring 17% who has opted for remaining with fossil fuel transport, balance 83% opted for some form of AFV. The majority 43% opted for EV or its hybrid variants, 14% for Hydrogen FCEV, 13% for Hydrogen IC engine technology, 9% went for CNG/ LNG option and 4% for solar.



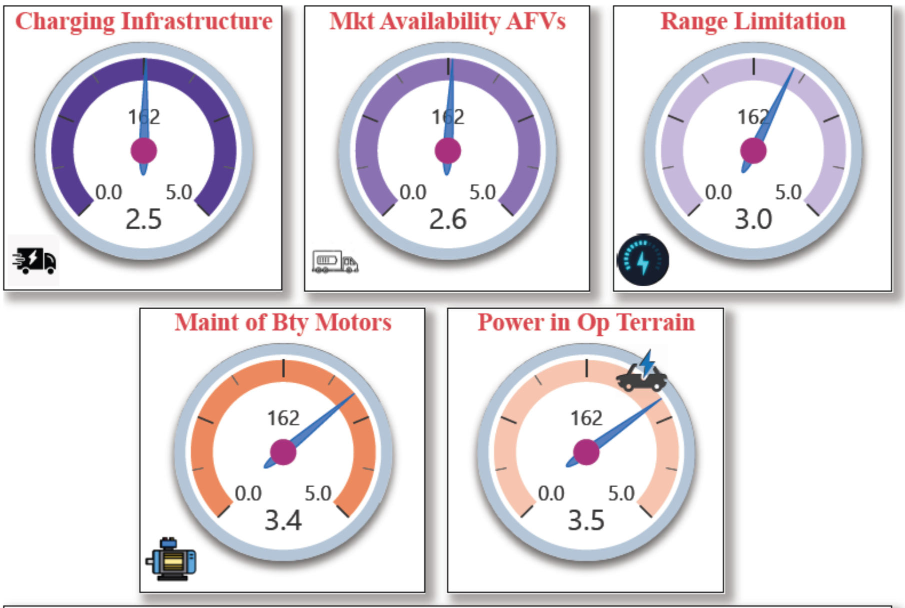
Q14. After highlighting the concerns regarding operational readiness with AFVs, charging infrastructure etc for each category, the participants were asked to choose the best option in **AFV trucks** for induction in the IA. An overwhelming majority (99 of 162) felt that Diesel-Electric Plug-in Hybrid would be best suited. Only 6% went in for Pure EV / BEV variant.



Q15. The option of **best AFV truck technology** was again solicited as re-confirmation in this question. 78% majority picked Plug-in Diesel-Electric Hybrid/ Hybrid EVs, re-affirming the advantages that this variant offers with respect to 'no range anxiety', 'no requirement of charging infrastructure enroute' and 'charging of batteries on the fly', plus of course other advantages of AFVs. Charging infrastructure at bases/ depots/ garages will be required though. The only disadvantage was that when the Diesel-Electric Hybrid truck runs on 'diesel', it is not a typical ZET and the truck falls under the Very low emission truck (VLET) category. However, that is necessary to give operational logistical freedom and flexibility to the army. In any case, during peacetime, the vehicle will ply maximum on electric-mode and that brings in huge environmental advantage.



Q16. Participants were then asked to grade the parameters affecting Operational Readiness in order of priority (1 being Most Limiting). 'Status of Charging infrastructure', 'Non-availability of truck technology in the market today and need for R&D' and 'Range anxiety' came as the top aspects in the minds of the participants with respect to AFVs. Applying the similar method as the previous square-matrix question, 'Maintenance of batteries and motors' also came up as an important concern.



Effect of Factors on Operational Readiness

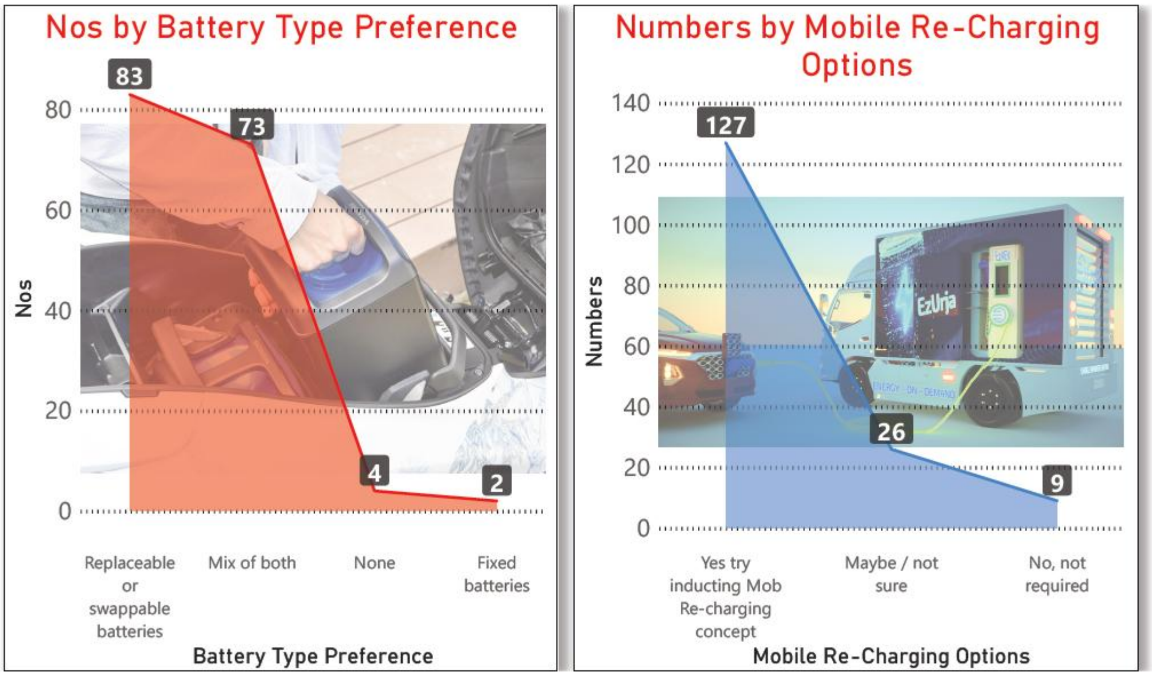
Op Readiness (1-Most Limiting)	Mkt Veh Avlbty Need for R&D		Charging infrastructure		Maintenance batteries motors		Range limitations		Veh Power in op terrain	
	Weightage	Nos	Weightage	Nos	Weightage	Nos	Weightage	Nos	Weightage	Nos
1	69	**69**	27	27	7	7	28	28	31	31
2	38	19	136	**68**	42	21	72	**36**	36	18
3	75	25	84	28	192	**64**	81	27	54	18
4	52	13	132	33	140	35	212	**53**	112	28
5	180	**36**	30	6	175	35	90	18	335	**67**
Total		162		162		162		162		162
Weighted Total	414		409		556		483		568	
Average (Min)	82.8		81.8		111.2		96.6		113.6	
Avg Top (Min) 3 Scorers	**43.3**		**43.0**		**44.7**		39.0		42.0	

Table 6 : Factor Affecting Operational Readiness

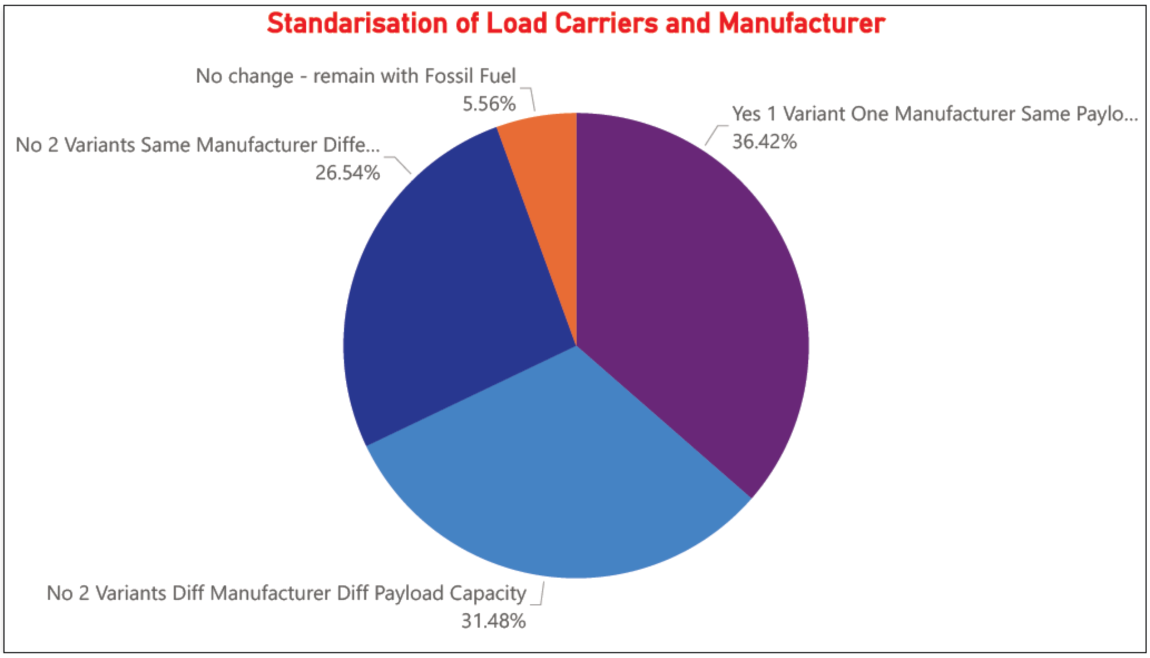
Hence, the answers to above three questions are vindicated and justified. The participants have pointed out to induction of 'Plug-in Diesel-Electric Hybrid Trucks' for induction as they allay the ibid concerns i..e range no longer is a problem as the truck can move on diesel or electric as feasible and charging infrastructure is required only at bases/ depots/ garages, not enroute. As regards technology, it already exits. It is a matter of getting it; when demand is generated, supply will follow. And there is cent percent applicability of this truck technology to civil trucks moving on thousands of kilometres of highways. There will be no requirement of elaborate infrastructure to be built enroute, only charging centres / hubs can be created at outskirts of major cities with all associated facilities. Once, battery technologies mature and ranges of 1,000+ kms are achievable over the next 8-10 years, Pure EV/ ZETs can be adopted. In the transitory phase Plug-in Diesel-Electric Hybrid Trucks will well serve the purpose.

Q17, 25. Participants were then asked to give their opinion for best option for AFV batteries, in case IA chooses to induct them. "**Replaceable or swappable batteries**" and

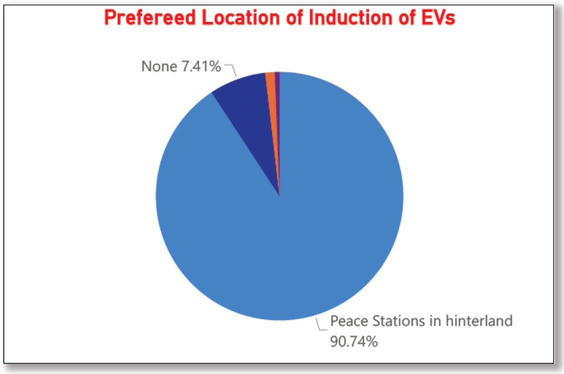
"**Mix of Both**" were equally predicted among the High Awareness people group. **96% people opted for 'Swappable' batteries or 'mix of fixed and swappable'**. In a subsequent question on preference for inducting 'mobile refuellers', which would primarily be AFVs i.e. vehicles having battery stacks with provisions to charge them through internal and/or external sources (such vehicles exists as demonstrated during Auto Expo 2023) which would be placed enroute on major routes or can accompany the convoys. This would also permit drivers to park elsewhere, while batteries are charged at another location within the garage, permitting high flexibility with regards to charging infrastructure.

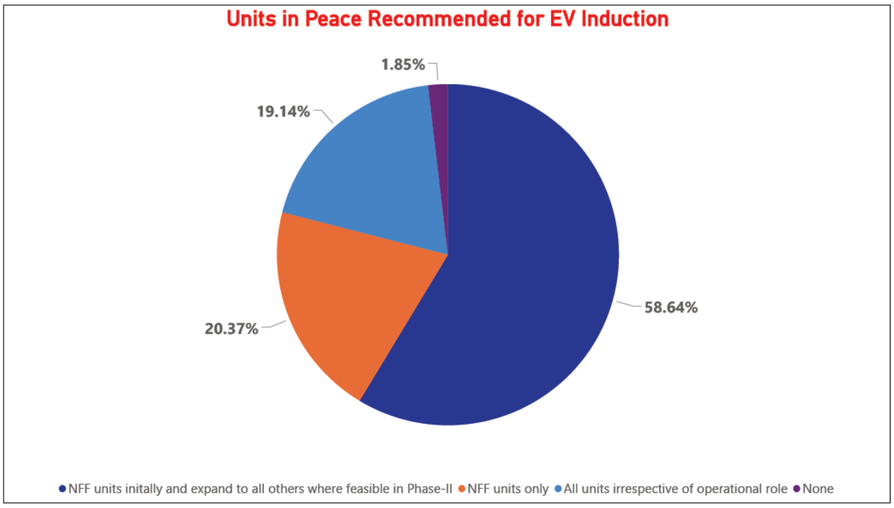


Q18. IA presently has two main categories in load carrier trucks i.e. 2.5 ton vehicle by Tata Motors and the Ashol Leyland Stallion in the 5/7.5 ton category (different sizes, payload, capacity etc). The question was to obtain a sense of standardization and getting it from one manufacturer, primarily to ensure commonality and ease in supply chain and maintenance. The response was nearly split three ways. 36% felt that a common vehicle from one manufacturer be inducted. 31% felt two categories, both from different manufacturers. And 27% felt two variants, but same manufacturer. However, **inducting a vehicle from a singular manufacturer** was opted by **63%**. The aspect of requirement of **two categories** in 2.5 ton and 5/7.5 ton could be **further studied**, including genesis of these categories, which was probably dictated by the class, category and technology then available, as the IA has not changed its 'B' vehicles for last more than two decades or so.

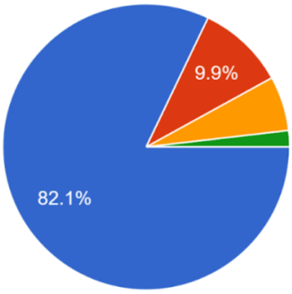


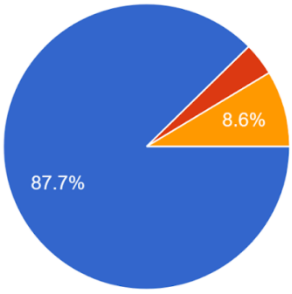
Q19, 20. On the question of terrain where EVs be immediately introduced and the type of units in peace stations where EVs can be introduced, the response was most expected. 91% opted for peace stations in hinterland, the safest best and having immediate effect. With regards to units, majority (59%) opted for 'initial induction in NFF units and subsequently to be extended to other units where feasible in Phase-II'. These are also incidentally the routes taken by the IA in its initial phase towards EV-ization.



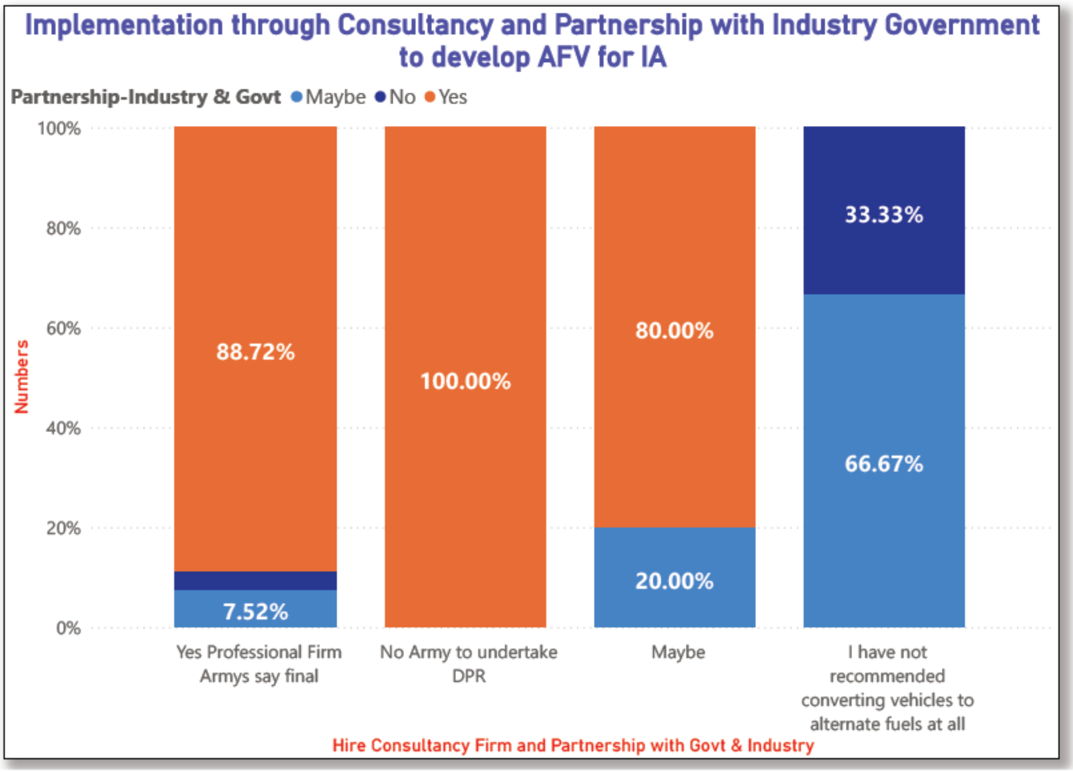


Q21, 22. The next two questions were aimed to get a sense of implementation of the proposal. Even though the focus of this study was on trucks, the other categories were also explored during the process and to bring knowledge gained to good use survey was accordingly extended. Generally, most procurements are done in the traditional manner by following the DPP (Defence Procurement Procedures) /DPM (Defence Procurement Manual) guidelines. Army Design Bureau (ADB) has been taking slightly modified procedures and routes with availability of funds and schemes viz Innovations for Defence Excellence (iDEX), Defence innovation organisation, 'Start-up India', 'Atma Nirbhar Bharat' et al. The first question was on going in for implementation of the project through a **professional, experienced and qualified Consultant**. **82% agreed that a professional and experienced firm should be selected. The process will incorporate Army's inputs and Army will have final say in approval**.



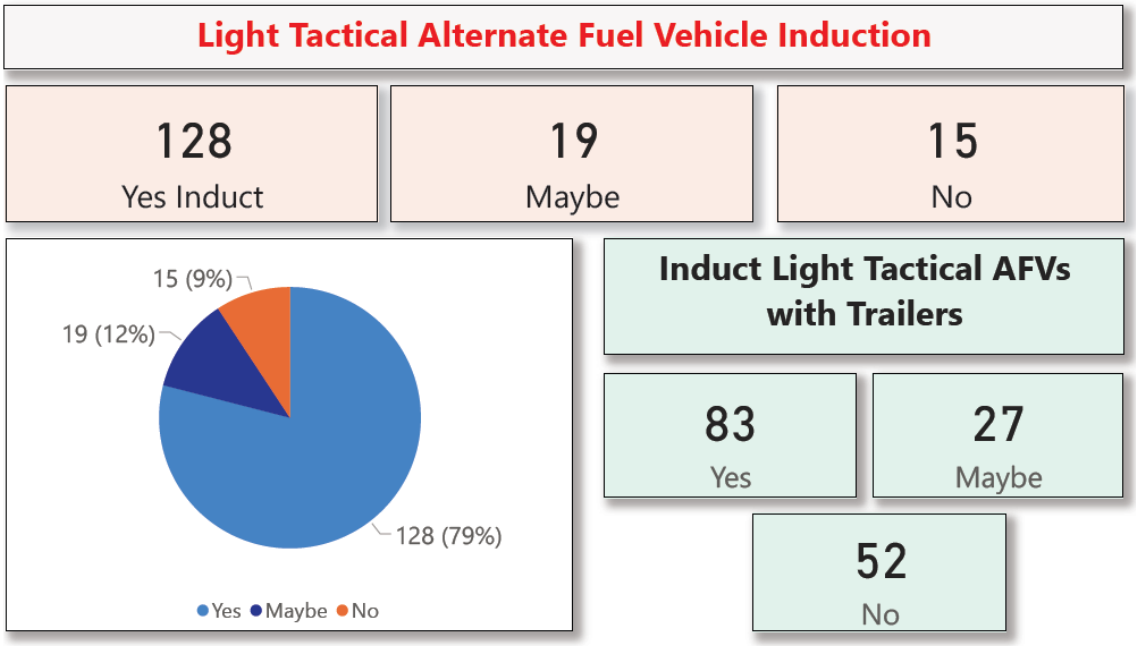


The other question was on the need to go into **partnership with industry and other government agencies** to develop an alternate fuel vehicle(s) for the Army. Here again, **88% opted for it**. The union of both is depicted hereunder.

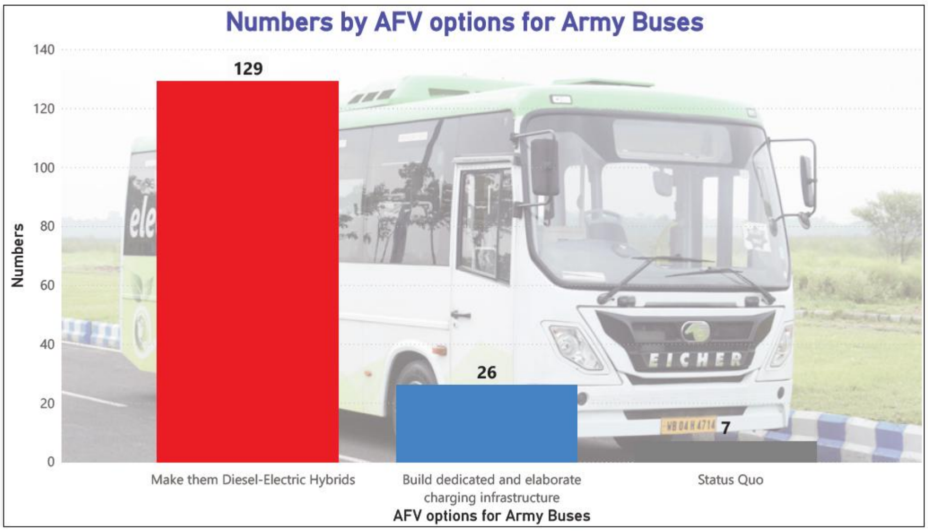


Q23, 24. The participants were informed that Armies of other countries are developing Hybrid EVs variants in the **Light Tactical High Mobility Vehicle segment** (eHMMWV) Electric High Mobility Multipurpose Wheeled Vehicle, eJLTV Joint Light Tactical Vehicle etc) for induction. They were asked to give their option if IA should also involve manufacturers to commence building prototypes in this category.

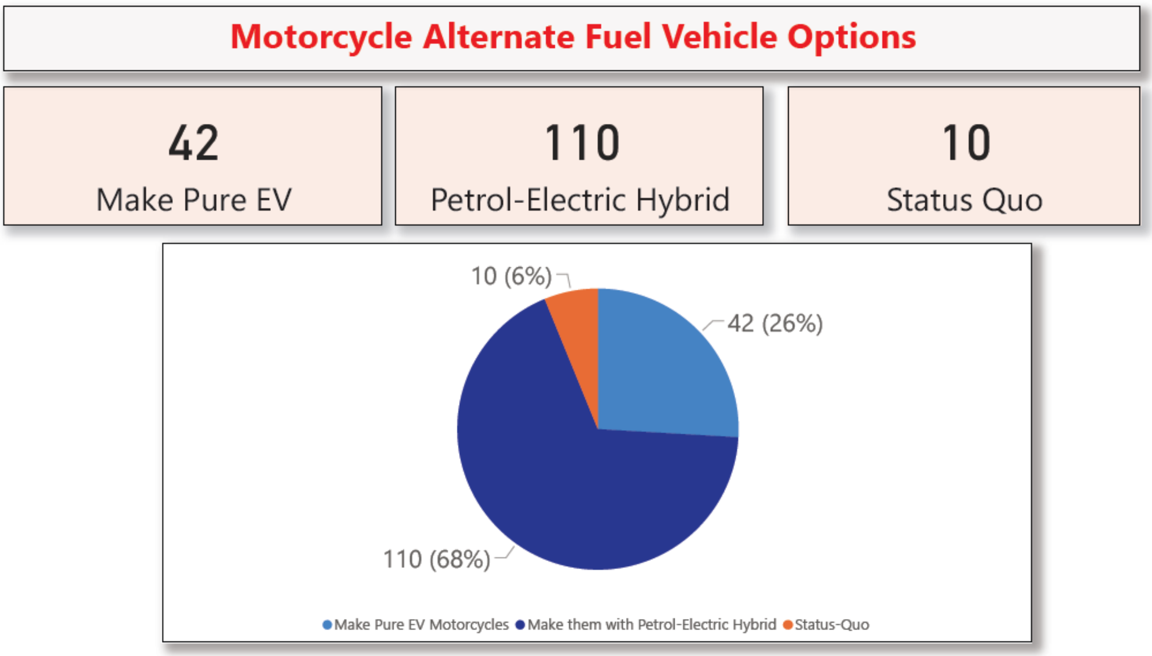
About 80% opted for it. And on the next question of getting these **with trailers**, **51% were sure** of it in the affirmative and **32% answered 'maybe'**. Trailers increase the load carrying capacity of smaller body of troops, give flexibility of attachment/ detachment, however, may reduce speed and cost more. So, the aspect of whether or not trailers are required with Light Tactical Vehicles; if so how many etc may be further studied.



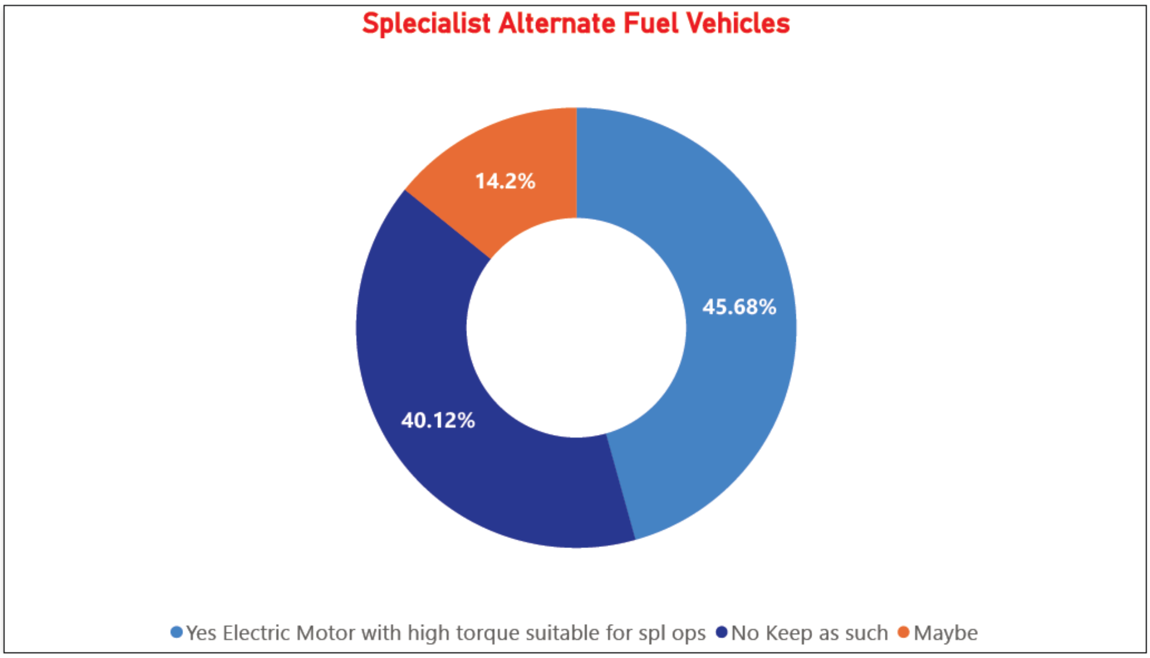
Q26. With regards to Army Buses which are used for carriage of troops to de-bussing points during operations, the question was that Pure EVs will face severe challenges in the field. IA has already initiated procurement of some quantities of deficient buses (38%) (The Print, 2022). However, these will pose serious operational difficulties in war time. **80%** of participants opted for '**Make Buses Diesel-Electric Hybrids** so that they operate on EV where feasible, else switch to diesel' during operations. The charging infrastructure built for trucks and load carriers, at bases/ depots/ garages at station-level, is common and will be used by buses also.



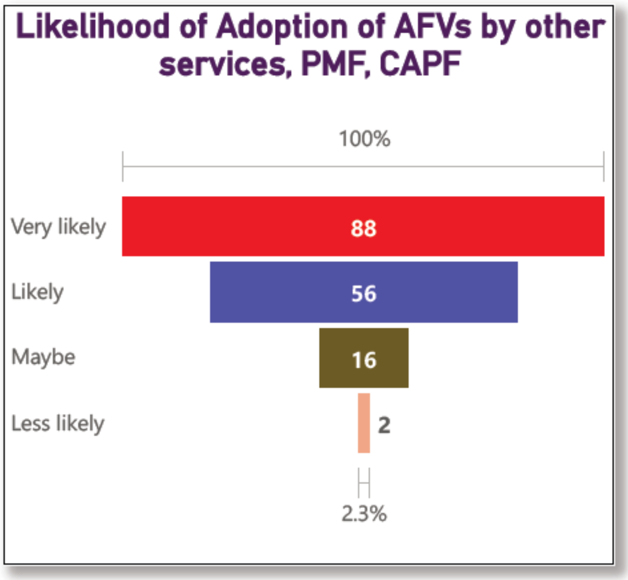
Q27. As regards AFV motorcycles, these are primarily used for Dispatch Riders (DR) duties and if we make them Pure EVs, the question is how will they operate in field areas during war, with no/limited charging infrastructure. 110 participants i.e. **68% recommended** making **Petrol-Electric Hybrid Motorcycles**. Incidentally IA has optioned for procurement of 48% Pure EV motorcycles in select army units (The Print, 2022). This needs a re-look.



Q28. The participants were then asked their views on other heavy and **specialist vehicles** like Ambulances, Mine Protection Vehicles (MPV), Armoured personnel carriers (APC), High Mobility vehicles (HMV) etc which also offer an opportunity for transition to alternate fuels. The views were split as indicated hereunder in the figure. However, this aspect can be further studied by IA, as electric motors provide very high torque, quick response and are silent.



Q29. The penultimate question was to obtain views with regards to further proliferation of such projects i.e. if IA adopts AFVs, will others services, PMF, CAPF etc follow suit. Majoprity were in the affirmative - 54% felt positive at 'very likely' and 35% felt it is 'likely'.



Q30. The last question was given for any further comments or suggestions. A word cloud created out of it is depicted hereunder. **EV, alternate, fuel, vehicles, time, charging** emerge as some of the most commented/ suggested.

6.3 Insights

The summary of participants, their awareness levels and qualifications are given in detail hereunder:-

- "**Maturity level**" of EV vehicles in India is "**progressing well**", so it is a good time to introduce EV in Army.
- An "**EV Variant**" of truck for IA is best suited.
- Considering Operation Readiness constraints, a "**Diesel-Electric Plug in Hybrid**" vehicle variant has a good prediction for being introduced in IA in future.
- "**Replaceable or Swappable Batteries**" are predicted as the best option in the truck being proposed.
- "**Peace Stations in Hinterland**" are preferred for **immediate induction of EVs** and it is better to start with "**NFF units initially and expand to all others where feasible in Phase-II**".

- "**Partnership with Industry and other Government Agencies**" is a must and "**Hiring a Consultant for implementation of the transition to alternate fuel vehicles**" is also an imperative. (>90%)
- "**Light Tactical High Mobility**" vehicles are needed for Indian Army and yes, we need them "**with Trailers**"
- We should try for "**Mobile Recharging options** for alternate fuel vehicles of IA" (>90%)
- Make "**Buses**" also "**Diesel-Electric Hybrids**" so that they operate on EV where feasible, else switch to diesel when operation logistics constraint them
- Make "**Motorcycles**" as "**Petrol-Electric Hybrid**" (>70%)
- It is "**Very likely**" that if Indian Army adopts an alternate fuel vehicle, it "**will be replicated by other services, PMF, CAPF, etc**"

RECOMMENDATIONS

Chapter 7 : Recommendations

Pragmatic recommendations have been made in ensuing sub-sections, while endeavouring to answer all research questions framed in Chapter 1 of the study after literature review and content analysis.

7.1 Transition to ZETs Medium and Heavy Trucks for the IA, Technology Permitting Adequate Ranges in Single Full-Charge

It has become evident from the discussions in previous chapters that a Pure EV or ZET would be most advantageous environmentally, while meeting the operational requirements of the IA. However, this can only be feasible if and when ZETs offer very long ranges in single full-charge, to the scale of 1000+ kms, which would give adequate assurances to the military for operations in Indian conditions. This is a far possibility in the timeframe of 8-10 years, by when hopefully battery technology advance significantly and become commercially viable.

A ZET or any truck running on an alternate fuel source (such as hydrogen ICE, FCEV, CNG, LPG etc) may not offer an optimal, effective, and efficient solution for the IA, as of today, given maturity level of technologies, battery cell advancements and EV support infrastructure limitations, especially in operational areas, which remains the major concern of the army. But when that happens, IA can transition to ZETs. It is also pertinent to note that a diesel-electric interim solution, as is being next recommended, has an EV component and hence commonalities of infrastructure will ensure benefit in long run.

It emerges from interactions with industry experts that the transition to Pure Electric Vehicles / BEVs is entirely dependent on maturation of the battery technology. It is for this reason that the government has invested ₹ 18,100 Cr, as PLI, in Advance Chemistry Cells. For the near future, LFP batteries seem to be the mainstay, with improved efficiency. The government has taken steps towards ensuring an uninterrupted supply chain of minerals (being imported) like lithium, cobalt etc. 5.9 billion tons of lithium reserves have also been discovered in the country recently, which give a supply chain advantage for the future and will catalyse the transition. The full transition to BEV is estimated to happen likely in the timeframe range of 2030 or there about.

7.2 Improve Existing ALS and Tata 2.5 Ton Vehicles and Upgradation to Diesel-Electric Hybrids

The ALS vehicles have been on the inventory of IA for the last about 25 years when 'Shakti MAN' (3 Ton) was phased out. 2.5 ton vehicles came in about two decades back as replacement of 1 Ton Nissan vehicles. BS emission standards were introduced in India in 2000 and BS-IV norms with effect from Oct 2010. While the country shifted from BS-III to BS-IV and subsequently in 2016 to BS-VI, the IA got a waiver to stay with BS-III primarily due to increase in circuitry and PCB controlled sub-systems and sensors which could be adversely affected due to enemy ECM. Incidentally, most of modern munitions, equipment and machinery all rely heavily on electronics. In BS-VI vehicles, the advanced electronics, in combination with other additional parts like catalytic convertors etc, played an important role in ensuring complete combustion of fuel-air mixture, reducing particulate matter in exhaust by thermal control and re-cycling/ re-use and thus controlling pollution. The country is mulling over graduating to BS-VI Phase-2 standards i.e. Euro VI norms now, while our transport fleet stays at BS-III (Auto Story, 2023). The other advantages and improvements in efficiency, which were incorporated in BS-VI engines by Tata Motors and Ashok Leyland, were also passed up by IA fleet consequently. Hence, improvements in existing models, even without contemplating hybridization, are necessitated in any case, with suitable ruggedization of electronic circuitry and incorporating other safety features.

As has emerged from previous discussions in the study, if the IA decides to de-carbonize its transport fleet, the next logical step after upgradation, should be adding the electric drivetrain to both the class of load carriers. Production of these vehicles takes place at VFJ, Jabalpur. Ashok Leyland during interview and subsequent interactions shared the schematics and possibility of adding the electric drivetrain to the Stallion terming it Hybrid (ICE and Plugin EV) Concept ALS.

- The suggested improvements are in the engine, upgrading it to BS-VI Phase 2. A compact automatic and intelligent drive to axles and all wheels would add tremendous value to the vehicle, making it highly responsive and less accident-prone. The exiting electrical and lighting system can be made more efficient by addition LED components and better quality reflective material and glass. Changes will also have to be done to the assembly gearbox and propeller shaft as the electric drivetrain has to be incorporated. The performance parameters, including power and range, will have to be laid out by the IA, based on detailed study of its operational requirements under various conditions, extreme weathers and terrain.
- The additional items will include the traction motor and motor controller, battery packs (swappable/mixed), intelligent BMS and thermal control system, auxiliary

inverter, power distribution unit, battery and motor cooling system, DC-DC converter and appropriate charging sockets.

- Only if gross weight increase and volume inefficiency result, after above modifications, and they impose serious net payload penalties (given the difficult terrain in which the vehicles will operate), the need and possibility of reducing engine power may also be explored. Current fuel tank capacity of 300 litres gives about 1200 kms range; this may be re-assessed.

This option of modification to existing fleet can be done ex-VFJ, will be comparatively cost-effective and can be phased-out i.e. rolled out based on annual replacement rate. There will be need for establishing shared charging infrastructure at all depots/ bases – these are discussed in greater details in subsequent recommendations. Enroute charging will not be required due to hybrid configuration and option of shifting to diesel power when needed. Fuel supply chain is also discussed later. The next recommendation is for development and induction of a new class of hybrid vehicles.

7.3 Diesel-Electric Hybrid Medium and Heavy Trucks for the IA

In the interim transition, before moving on to BEVs which will happen once the technology of batteries matures or batteries offer such large ranges that the need for external power source is made majorly redundant and charging infrastructure is built, **hybrids** will fill the gap. Reliance on traditional fossil fuel, mainly diesel and petrol, will remain the mainstay during operations for the defence forces, in all likeliness for the next few years till say ~2028-2030. It has become evident during review of technologies in Chapter 3, interviews with experts and survey that a fossil fuel-electric drive hybrid combination gives the required balance between addressing environmental concerns and meeting the operational logistics concerns of the IA, especially with respect to range and enroute charging or challenges of charging during thick of operations in far-flung difficult areas and terrain. Hence, a **Diesel-Electric Plugin Hybrid AFV**, which may not be a ZET in true meaning but the next best VLET nonetheless, may help in overcoming the apprehension of army, primarily zero-compromise on operational preparedness, the biggest concern of the forces. The payload penalty, due to carriage of both drivetrains, will have to be offset by better and efficient **engine design**. Unquestionably, the new diesel engine should meet **BS-VI specifications**.

It also emerges from analysis and discussions of various transmission configurations that a Series-Parallel Diesel-Electric Hybrid trucks will be better suited. The primary source will remain electricity for as long as the battery packs power the load carrier, after which either they are charged using plug-in electrical power or (enroute) where such facility does not exist, the diesel generator re-charges the battery a comparatively cleaner and fuel-economic option. In the worst case scenario when none of above is possible (unlikely) the truck operates purely on diesel engine power. This also offers an opportunity to improve other aspects of the existing 2.5 Ton and ALS fleet viz upgrading the engine from BS-III to BS-VI Phase 2[15] (Auto Story, 2023), increase in payload or load carrying capacity, have commonality and just once category of load carrier (including its variants) instead of two i.e. 2.5 Ton and ALS, improvements in drive cabin and comfort for better acceptability in civil and by other forces/ militaries also, study the need to have a fixed body or a tractor-trailer combination, re-introduction of attached trailers if fixed option is chosen, modular

[15] Real Driving Emissions (RDE) or Euro VI norms; Newspaper reports indicate adoption of BS-VI Phase 2 norms wef 01 Apr 2023. These norms mean that vehicles should meet emission standards not only under controlled or lab conditions, but also during on-road testing.

and detachable design for the power train, swappable batteries, and other associated aspects.

The negatives are firstly, initial high costs. This has to be seen in light with the total cost of operation (TCO) of the vehicle during its lifetime and the fact that the vehicle may have a longer life than a conventional IA diesel vehicle i.e. much longer than 11 years. Also, the maintenance issues may be reduced substantially. IA will have to plan to adequately and optimally run the vehicles during peacetime, options for which are discussed subsequently in recommendations in ensuing paragraphs. The design of the said vehicle can be funded, developed, patented, co-owned by the IA (and thus the government) if funded out of MoD budget. The advantage it will provide is that option of exports to other militaries and nations can be explored, as also control over it. Technology transfer and development with other manufacturers can also be undertaken as it will be extremely successful in civil operation on long routes, while also eliminating need for charging infrastructure totally. And this is equally applicable to other forms of alternate vehicles also including natural gas, hydrogen, fuel cell etc, hence likely to have higher acceptability. It will improve likelihood of proliferation in the country to most national, state and district highways, also including areas which are poorly connected and have less developed power and road infrastructure. Higher volumes will also bring down costs due to economy of scales. This will bring in additional funding, as also foreign currency to the government, assist in lower carbon emission and further proliferation.

Secondly, there is the need for having both re-fuelling and re-charging infrastructure. Diesel gives redundancy and longer range to the vehicle during operations. It also caters for additional civil vehicles hired or impressed during war. A continued fuel supply chain will also ensure FOL for CHTs hired or impressed during operations. Thus, the existing fossil fuel supply chain and support infrastructure will have to be maintained, albeit the scale and quantum will reduce substantially including the holding of assured stocks, barrels and extensive and elaborate adhoc organisational setups during war. All these aspects need to be listed, deliberated operationally and logistically, tried and tested to ensure their efficacy. Also, being hybrid there will be a requirement to charge the vehicle batteries, preferably through electricity. This is easily achievable at charging bases (and where easily feasible enroute or at transit parking facilities) where infrastructure will have to be established. The detailed requirements for the same are outlined in subsequent paragraphs.

Another drawback that would consequently accrue would be in terms of weight gain due to additional weight of batteries, dual powertrains and thus decrease in net load carriage. This can be offset by designing appropriate engine and motor power.

A new abinitio design will undoubtedly be better than a modified one. However, this can be analysed based on study of both, including costs and performance parameters, before being implemented.

Export to friendly foreign armies employing their transport fleet in similar difficult terrain and geography and being used for long hauls can also be explored.

7.4 Need for Commonality : Medium and Heavy Load Carriers

As mentioned previously 2.5 Ton vehicles were a replacement of ‘1 Ton Nissan’ and 5/7.5

Ton ALS for the 3 ton ‘Shakti MAN’ vehicle. Both served different purposes. Difficult areas and tight mountainous terrain dictated need for a more compact 2.5 Ton vehicle, which was also more economical. However, having two different technology-bases from two-different manufactures has inherent disadvantages in maintenance and supply chain, which in turn have financial implication, maintenance of reserves and inventory, training, supply chain logistics etc.

The IA has not changed its ‘B’ vehicles for last more than two decades or so. A **majority (63%)** of survey participants, well qualified in operational logistics, voted for **inducting a vehicle from a singular manufacturer**. The aspect of requirement of two categories in 2.5 ton and 5/7.5 ton could be further studied, including genesis of these categories, which was probably dictated by the class, category, phased-purchases (thus different companies emerging L-1 during tendering process) and technology then available. Adding a 1 ton **trailer** to 4x4 light tactical vehicle category could also be studied in conjunction, which will be extremely beneficial in carriage of ammunition pallets (approx 650 kgs) to gun areas, fuel refueling, other essential stores etc.

7.5 Financial Implications and Budgeting

The financial impact of any of the above proposal will be high. The larger debate of ‘justification and need to de-carbonize the military’ needs to be first answered, therefore. If yes, then it is a no-brainer and actions will have to be initiated. These may be phased-out to budget them over the next say few years. The military should seek additional governmental support and avail of all incentives being offered under various schemes.

7.6 Recommendations for Other Category of Vehicles

The best location for induction of BEVs i.e. motorcycles and staff cars would be peace stations in hinterland, which a majority of the surveyed samples also feel. However, despite what has emerged in the questionnaire results for ZETs/ VLETs/ Buses/ TLVs/ Specialist vehicles, it is the concerted and well though-out opinion of the researcher that the retrofitted or new fleet of hybrid transport, as has been proposed, would be best tried and tested under various field conditions. Hence, batches of each category should be procured and evaluated in mountains and deserts, Pan-India, under extreme conditions.

7.7 Recommendations for Other Category of Vehicles

The study primarily focussed on trucks/ load carriers/ ZETs. However, during the course of research, various findings point towards the technical feasibility and operational possibility of, alternate fuel technology for other category of vehicles also. The recommendations are summarised hereunder:-

7.7.1 Motorcycles for Despatch Riders

Motorcycles are used mainly by despatch riders in the Army, based on spark ignition (SI) engines and run on petrol. The market offers large No of e-2W products in the EV motorcycle class, with substantial ranges. Even hybrid (Petrol-electric) models are available/ feasible. These can be shortlisted off-the-shelf, which is the fastest option. Alternatively, manufacturers can be approached to make hybrid models (petrol-electric) motorcycles which can be trial evaluated and pilot tested. Petrol will present distinct disadvantages in terms of dual-fuel supply chain. In either case, swappable batteries are recommended.

7.7.2 Light Passenger Vehicles

Staff cars in peace stations fall under the non-operational category. These can easily be converted to BEVs, as they may not be required to move to difficult areas during operations. Even if they move to forward bases, the charging infrastructure can be used/ slow charging option will mostly be available.

As far as **4x4 GS transport** (**tactical light vehicle**) category is concerned, it is strongly recommend that **Diesel-Electric Plugin Hybrid** (same technology being proposed for heavy load carriers), be adopted. The use case of eJLTV of the US Army refers, amongst others (Seabaugh, 2022). Such hybrid TLV will be silent when operating in electric mode. It will also be able to output electric power for operation of signals, communication and other tasks.

> The eJLTV of US Army, developed by Oshkosh, is charged by running the diesel engine as a generator for the battery pack. 30 KWh LiB battery has a life of 10 years. It generates 400 HP, 20% fuel economy, 0-90 kmph in 10 sec and top speeds of 1100 kmph. A Plug-in hybrid option can be added. Existing JLTVs can also be converted into hybrids. 66,000 are likely to be purchased at price of $30 billion.

Maruti Gypsy and Safari Storme are both 4/5 seater light vehicles currently held with IA, with hardly any small arms protection. The new TLV is recommended to be designed to have small arms protection, to enable it to operate freely in operational areas. The TLV can be made in number of other configurations i.e. reconnaissance and surveillance, command & control, ambulance, machine gun mounted/ heavy gun carrier, close combat weapons support, 2-seater with flatbeds (utility) etc. Vehicles may also be provided for trailers (in certain percentage), to assist troops to carry loads when inducting and for subsequent use. The major problem for carriage of artillery ammunition to gun areas can also be resolved by providing for an open body trailers for carriage of palletised ammunition to gun areas which are generally located in severely underdeveloped terrain, to move to/from ammunition depots/ dumps. The trailers may incorporate heavy load lift capability (for palletised ammunition) using inherent power of electric motor. Development of such capability will aid in assured ammunition supply without solely relying on load carriers and Field Ammunition Trucks.

7.7.3 Tactical Armoured Personnel Carriers and Specialist Vehicles

The views in the sample survey were split with only 46% opting for hybrid option. However, this aspect can be **further studied** by IA, as electric motors provide very high torque, quick response and are silent. This aspect should be trial tested.

Armoured Personnel Carriers (APC) and various tactical and specialist vehicles are being developed by the industry as elucidated earlier in the study. These offer themselves to be converted to Diesel-Electric Hybrid variants. The silence of electric engines offers added tactical advantage. The power from the vehicle can be used for other operational purposes, alleviating need for dedicated separate generators.

Electric (hybrid) trucks offer great amounts of power. **Field Ammunition Trucks** (FAT) used by artillery to tow guns and carry ammunition, offer themselves to such configurations.

Other specialist vehicles such as **4x4, 6x6 and 8x8 variants of High Mobility Vehicles** (HMV) (including tank transporters) may also be considered for Diesel-Electric Hybrids. Tremendous electric power is likely to perform excellently in deserts, when coupled with suitable transmission. To save costs, **retrofitting option** may also be explored.

7.7.4 Buses

Buses are primarily used for troop carriage upto road head in operational area. BEV buses being planned to be procured by IA therefore need review in light of above. Though both short and long chassis buses are ideally suited for conversion to BEVs, as the market has numerous offerings today with 250-300 kms reach, however, the may not meet the operational logistics requirements, as yet. The problem of **poor charging infrastructure** in field areas also needs to be kept in mind. Even in peacetime buses are used for carrying troops in Northern and North Eastern commands in long route convoys. This can be addressed either by developing a **Diesel-Electric Hybrid** (as for load carriers), or existing vehicles can be **retrofitted to hybrid** configuration. Procurement of these from a single/ common bus OEM may also be reviewed, in light of inherent advantages, as discussed previously.

7.8 Establishing Charging Infrastructure at Cantonments, Military Stations, Parking Bases and Enroute including in Field Areas

In the hinterland the government is already planning provision of charging infrastructure on seven major national highways. The vehicles moving on these routes, within or outside command AOR, can be dependent on the same, as and when they come up. Book-debit based modalities for payments will have to be worked out in conjunction with charging support providers, akin to IOC Fuel Card.

Fleet Electrification system will have to be established at all stations. The **planning of the layout** of the facility will have to be undertaken in terms of adequate space for movement of transport, location of chargers, distances from the meter, need for underground wiring, location of solar array banks, location of battery storage facilities, availability of flexible and extended wire charging facilities being provided by the charging company, security and safety, fire-fighting etc should also be considered. The **EV charging interface** may be a plug-in facility, an overhead or pantograph facility and in due course of time may also be a wireless charging facility. Generally for heavy vehicles, plug-in facility would be the norm. The chargers should be made available by the provider with **multiple connector options** (based on vehicle specifications) in AC and DC configurations. These could be **wall mounted, integrated or modular systems**. Generally **auto cut off** system, after 100% charge, is the norm. With a **single charger, multiple vehicles** can be connected and **software control** options of **sequential or parallel charging** can be implemented. It is also important to develop and install a **Fleet Management System** to ensure optimised charging and control of such EVs.

The Charging Infrastructure (or The Ecosystem) will comprise of (preferably) a central location within a garrison/cantonment/military station where all EVs can be parked at night for depot charging. Trial of **mobile charging infrastructure** can also be undertaken at these locations, incorporating all types of alternate fuels. In most cases vehicles will not be playing more than the maximum range available to them after initial full charge, to their capacities. These central locations or **Fleet Charging Stations** will be provided with To-The-Metre (TTM) infrastructure from the electricity provider through the MES establishment of the station. Ministry of Power has now empowered such facilitation through its policy of January 2022. Beyond-The-Meter (BTM) infrastructure can be laid either through an MES work or in conjunction with the EV Support Infrastructure (charger) provider viz Tata Power, Reliance Energy, Charge Zone, Ather, Ola Energy, etc.

This can be undertaken as a central project by the IA or MoD (keeping eventual inter-service logistics integration in mind over the near future) and shared across the board with all players. **DWP needs to ne suitably amended to include EV charging infrastructure** in the list of authorised works.

The project will be cost-intensive and thus **measures to economise** need to be taken, some of which are:-

(a) Optimisation can be done by charging through the concept of dual shifts, using the same vehicle in 2-shifts with two different drivers, software control charging etc. In order to truly achieved reduction of carbon footprint it is also advisable to plan for solar, wind, hydel and other alternate forms of charging depending on feasibility in the area.

(b) Better economics can be achieved by availing public and private discounts. Substantial amount of subsidies are available through various central and state government schemes, subsidies, incentives and grants; discounts by power companies, EV support infrastructure providers, manufacturers etc, which should also be availed.

(c) Long term operation/maintenance contracts or contracts concluded pan-India will lead to lesser cost and economy due to the scales and higher value.

(d) Sharing infrastructure with sister services of Ministry of Defence (MoD), civil government, state transport organisations, other ministries, paramilitary forces and government organisations can reduce the burden on the Army. Metered system can be installed and book adjustment can be done through post debit system.

(e) A record of fossil-fuel savings (by keeping a check on less drawl from oil companies, as also software monitoring) will also indicate the actual economics achieved by the Army in its endeavour for migration to cleaner fuel options.

Issue of a broad **policy on the subject** by the **QMG branch** at Army HQs will kick start the EV-isation of the IA transport fleet.

7.9 Re-Fuelling and Re-Charging During Operations

Traditionally, for fossil fuel based vehicles, during operations, the Army build up on its existing fuel supply chain, which includes its drawl from oil company, stocking/ placing at requisite bases and locations in specified quantities and re-filling based on consumption or estimates.

If hybrid fleet of transport is inducted in the IA, **broadly the same system** will have to continue, albeit at a lesser scale in peacetime, and comparatively higher **during operations**, when all vehicles will be fully exploited to potential. Also, when civil transport is impressed or hired, there will a requirement of providing fuel to them.

As of now the Army uses both petrol and diesel. Petrol primarily for the motorcycles, light vehicle fleet of Gypsy’s and cars. The Safari Storme and Scorpio use diesel. Also, the new category of tactical and specialist vehicles including mine protection vehicles, are diesel fuel based.

For **battery re-charging**, the cantonments, military stations, bases, parking areas (and only selected identified areas enroute on major long/ fixed lines of communication) will require **Charging Support Infrastructure** to be established. The components of such a setup has been explained earlier.

Industry also offers / can be asked to produce for Army, **mobile vehicle-based setup with fast-chargers, swappable battery** etc. It may even carry a generator or mobile solar panels to charge the batteries, and hook up to an electricity grid where feasible.

Akin to carrying fossil fuel in barrels and jerricans, **swappable batteries can be carried on wheels** in a hybrid load carrier, as part of the convoy, or these vehicles can be placed at suitable locations.

7.10 Methodology of Implementation of Project

Army needs to commence the process with a detailed study through a **consultancy firm**, experienced on the subject. >80% of the survey participants have opined on these lines. The consultant should also draft the procurement, maintenance and rate contracts for entire inventory simultaneously. Computer-based modelling and simulation must be used to bring out all aspects of vehicle operation, charging and maintenance etc in DPR.

After approval of competent authority, simultaneously, an **organisational structure** needs to come up, as explained subsequently, for control of the entire process and monitoring at each stage.

Partnership with experts and other industry players is key to success. The process should involve detailed consultations with the industry and experts. **Detailed Project Report** to be finalised and sent to the government for acceptance in-principle and launch of pilot project alongwith requisite funding.

Inviting industry to participate and present various options of technology(ies), as suggested by the consultant or better.

Finalise proposal(s) and get **government approval** for Trial Evaluation for approved vehicle(s) at select places. Earmark **trial evaluation teams**. **External experts** (ARAI, IITs etc) may be incorporated, if required, for objectivity.

Industry will be required to incorporate changes, on shortlisted models. Undertake final trial evaluations thereafter. Then we need to forward proposal for acceptance by the government and **year-on-year budgetary allocation for next 10 years** (or as decided).

10-11 years is also the approx life of a load carrier in the IA.

Existing production facility at VFJ, Jabalpur should be explored.

The **technology is common use** and hence will have **high acceptability in civil also**. Given the high costs associated with establishment of enroute charging infrastructure, the diesel-electric hybrid model is a very practical technology configuration which can be used by the transport industry and fleet operators, until BEVs start to yield very large ranges suitable for long-hauls.

7.11 Organisation Structure

A **Joint Development Plan** needs to be prepared. A **suitable agency** is recommended to be employed, either directly or through a professional **consultant**. This is imperative to ensure the right product is delivered, within the timelines laid down, as per the specifications and parameters envisaged, with adequate scope for enhancements based on trials. It is pertinent to mention that NITI Aayog has outsourced and co-authored large number of policy papers and research on EVs, EV support infrastructure, ZETs etc, hence their expertise maybe solicited to take the project forward. **Multiple agencies and sub-stake holders** need to be clustered under a suitable department/ branch of the Army. The sub-stake holders[16] may include:-

(a) NITI Aayog (national level policy making agency),

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[16] Disclaimer : Names of companies herein are only indicative and available to the researcher through literature review, content analysis, interviews, interactions and visits to Auto Expo; these are NOT exhaustive by any means.

(b) IIT(s) (as many of them are already involved in R&D on the subject matter),

(c) Industry partners (Ashok Leyland, Tata Motors, Volvo-Eicher, SML are already existing players in defence industry and IPL Tech Ltd is technologically strong and mature). Additionally, Software development agencies, including battery management systems, Motor (Cummins, Crompton greaves, Kirloskar) and Battery manufacturers (specially those working on Advanced Chemistry Cell technology viz Reliance New Energy Solar Limited, Ola Electric Mobility Private Limited and Rajesh Exports Limited) may also be on-boarded, either directly, or through NITI Aayog/ Ministry of Heavy Industry or through manufacturers.

(d) Functional and decision-making representatives of Ministry of Power, Ministry of Heavy Industry, Ministry of Highways and Road Transport, Ministry of Renewable Energy and Ministry of Science & Technology may also be offered to be onboarded.

(e) ARAI (for abinitio adherence to specifications and thus faster approvals),

(f) EV Support Infrastructure providers, including those companies working on mobile re-charging solutions may also be incorporated.

Within the Army, a suitable **Organisation Structure** with lead department/ branch/ adhoc organisation needs to be created. **Army Design Bureau** (ADB) or such organization may be earmarked. They will need to be empowered with task-completion based tenures, adequate funding, move sanction authority, autonomy in decision making

Officers with sound engineering, technical and/or mechanical background need to be chosen. Initial **selection** is recommended through known expertise in database and final screening through an interview process to ascertain skill and motivation levels. Also, it is essential that a probation period be implemented, permitting calling forward reserve(s), in case of lesser than expected performance levels by team leader. Where required, suitable training grants be earmarked to empower the concerned officers. As the project progresses and pilot project are set to be launched, select officers (to operate alongwith representatives of other agencies) be posted to ensure judicious feedback during trials, to effect improvements.

Initially the **charter** of the team will be to guide the consultant to prepare the DPR. Preparation of DPR will ensure that the project is personality independent. It also needs to cater for modularity and upgradability in technology, as best feasible. They will serve as single point contact for the Army and facilitate system understanding. The DPR should also determine the cost of transfer of technology of final product to sister services/ PMF etc, to ensure CAPEX sharing of funding. Once the consultant produces the project report and it is accepted by the competent authority, the team will need to ensure implementation to each aspect, through various agencies. A feedback system to the concerned lead branch/ department will be given.

Technology is ever evolving and hence the product i.e. the **Hybrid VLET**, should be able to absorb better and superior technology, with negligible changes, upto final implementation stage. Such **modularity and upgradability** in technology being developed will need to be ensured.

Simultaneously **training of drivers from ASC** and other arms and services, as also **maintenance staff of EME** will needs to be formalised, to include defining new maintenance tasks for the hybrid VLET, amendment to training curriculum and precise.

7.12 Adoption Of Alternate Fuel Vehicular Technology : Applicability to Other Forces/ Organisations

Once the IA decides to adopt the Diesel-Electric Hybrid vehicular technology for its load carriers, the same can be replicated for Rashtriya Rifles (RR), Assam Rifles (AR), Border Security Force (BSF), Central Reserve Police Force (CRPF), Indo Tibetan Border Force (ITBP), Central Industrial Security Force (CISF) and other paramilitary forces. It cab be equally applicable for State and central police forces operating in difficult and remote terrain.

Other Central and State governments organisations and establishments including Public Sector Undertakings, DRDO etc can adopt BEV technology, where possible, including for buses.

7.13 Jointness and Integration of Services

It is a matter of time, in the medium to long term, when eventually all the services will be integrated, especially establishment of the Integrated (Tri-services) Logistics Command which would include the vehicular inventory (Kakkar, 2020). Government has already approved setting up of select Joint Logistics Nodes (JLN) at Mumbai, Guwahati and Port Blair (Pandit, 2020).

Thus, preparation of an efficient and common vehicle design platform for all service load carriers and specialist variants, as also other categories of 2W, tactical light vehicles, buses etc can be undertaken as a common project by the Department of Military Affairs (DMA), under the aegis of the Chief of Defence Staff (CDS).

Higher volumes will also bring down costs due to economy of scales.

7.14 Pathway for Indigenisation of the Proposal : 'Atmanirbhar Bharat'

Truck manufacturing is at very high levels of indigenisation already. Electric motor market is also matured sufficiently. Battery and BMS needs to be indigenised. Government has already given the requisite impetus to PLI in ACC, hence, 'atmanirbharta' or self-sufficiency can be well achieved to a large extent in the project. If extraction and refining of lithium found in Reasi (post auction) is undertaken within the country, as is being planned, it will further promote domestic manufacturing.

7.15 Optimisation Plans of IA : Alternate Model of Ownership

Seemingly beyond the mandate/ scope of the study, but certain relevant issues which emerged as derivative of the research, with respect to authorised defence duty transport at field level and civil hired transport, are being made hereunder.

7.15.1 What are the operational logistical requirements for establishment transport at 2nd and 3rd tier? How is shortfall met and issues? Why is IA looking at TA-isation and optimisation, and how?

IA has dedicated load carriers category of transport on its authorized establishment, besides others. These trucks fall under medium (Tata 2.5 Ton) and heavy (ALS 5/7.5 Ton) categories, all being 4x4 to permit some off-road movement in difficult terrain, an operational necessity. When in peace time these vehicles are run for training, administrative duties, transportation of military stores to forward bases and areas etc, movement generally being restrictive in terms of mileage covered, though time on road maybe substantial. Supplies to bases, being generally longer distances, are generally done by rail or outsourced civil transport or through contracts for delivery to first army destinations.

The above factors permit the transport to be preserved. The life of vehicles is fixed and they are condemned from service after meeting time and mileage twin criteria, though on ground condition has provision for waiver of either/ both. The unconstructive downside is that transport remains underutilized, which implies that the other support and supervisory elements are functioning sub-optimally too.

This has led to the IA finding alternate solutions to effect savings such as reduction in authorization specially of third tier of transport, TA-isation of some transport units, outsourcing of civil hired transport etc. During war besides these, other options of impressment also exist for faster mobilization and subsequent use (Kaushal, 2016)

(Kanwal, 2019) (Panag, 2019). The procedure is covered through the legal legislative provisions contained in Chapter II of 'Defence of India Act 1971' contains 'Emergency Powers' (DGCDHG, 1971).

7.15.2 Anticipated problems with the proposal - Non-availability of 4x4 civil trucks?

The problem (when operations take place) remains that firstly, the hired/ impressed transport is not owned and will have concerns to be made effective within the required timeframe and the mechanical condition of vehicles. Connected point is of creating adhoc structures for it and the fluid procedures. Secondly and more importantly, it is not 4x4 drive and hence will (or most likely maybe) rendered useless as soon as it is made to ply in difficult terrain, thus affecting operations. Thirdly, simply TA-isation of such transport units requires time for it to be embodied and made effective, besides expenditure on 4x4 vehicle holding, maintenance, personnel and the issue of its underutilization which remains. Incidentally, Assam Rifles and other PMF/central police forces also follow similar procedures.

To overcome this problem, it is firstly important to understand that 4x4 trucks are mostly not required in the civil transport industry and hence not manufactured. 4x4 vehicles are also costlier due to added drivetrain and components. Hiring of 4x2 transport during operations is a difficult task and the efficiency of transport to operate with and alongside IA is suspect. We therefore need a robust system.

7.15.3 Are there alternate solutions?

Improvement and ‘Hybridisation’ of load carriers offers an opportunity. The solution should be operationally robust, efficient and cost effective. The question is ‘How can we maintain a fleet and yet be economical, since the IA itself does not ply this transport optimally during peacetime?’. The answer lies in creating a military-civil joint operational organisation which will hold an inventory of fleet of Diesel-electric hybrid VLETs within military stations. The supervision of such structure will remain with the IA (ASC – its transport managers). It will outsource rest of the organizational structure to conduct its day-to-day operations, including maximum drivers, balance being uniformed with the nucleus. The unit will work akin to a civil logistics company. Vehicles will be offered for load haulage, inter-city moves and local hiring, on payment basis (at competitive rates in line with market trends). The profits accrued, post deductions for establishment of charging stations, improvement and maintenance, will be audited and deposited in government treasury at the end of financial year to be utilized by IA against capital/ revenue expenditure, as it decides.

It is proposed that (20) such units be transformed under the ‘**Dual-Use Civil-Military Transport Company**’ format, where average vehicle holding is approx 200 load carriers per unit. IA will have ownership rights. The board and directors will consist of IA officers only, as decided by the organisation post-due deliberations.

Vehicles will be registered and operated as civil vehicles. The gross revenue can be calculated based on number of vehicles, days of operation, rate per km including competitive marginal profit for the specified payload (Chaudhary, 2022). IA will accrue savings in terms of free land use and other infrastructure provided, thus adding to profits and income. Fleet will have to be the same inventory specifications as decided for the rest of IA so that operations in respective terrain and geographical areas are facilitated when employed there. The life of vehicles will purely be determined on their actual mechanical conditions, and being EV hybrids they will not be subject to time-dictated condemnation or scrapping. When required, the vehicles will be replaced with newer models. It will be advisable to have a common inventory of trucks in heavy-duty category.

Pool of drivers will be available with vehicles through its outsourced contract. Other issues with respect to employees and adherence to laws will be ensured by the selected vendor. Long-term manpower outsourcing contracts can be done, as per decision of the Company. No pensions etc need be paid.

IA will have assurance of use, when administratively and/or operationally required, by simply not offering it for hiring or recalling them. Online platform will be developed or hired for use encompassing all functionalities, with adequate security built-in and regularly audited. As operational situation demands, the area of hiring of vehicles can be restricted to have faster return-to-base or turnaround time. ‘First-right-to-use’ provision can be granted for this special purpose company for hiring by IA itself (instead of CHT outsourcing) if more economical. Also company may enter into lease agreement(s) with other governmental/ PSU organisations and/or civil firms.

Vehicles will be tracked and monitored through NavIC navigation systems (The Indian Regional Navigation Satellite System (IRNSS)). Communication systems will be provided on-board.

Vehicles can be repaired in-house or through a service agreement contract with the OEM.

Spares, replacements, oils, lubs and greases can be procured through the OEM service and maintenance outlets, at mutually negotiated discounted prices on MRP. If required some spares can be maintained by the company. Fuel will be drawn on book-debit system or from civil pumps as beneficial.

Accounts will be audited periodically through a selected Chartered Accountant firm, besides being offered to the DAD (Defence Accounts Department) and others mandated for scrutiny and review for checks and improvements.

It will be prudent and advisable to obtain government sanction for the project to lend official authority to it, being a step in the right direction, in line with the governments thinking.

7.15.4 How many such Companies?

Ideally, in the initial phase a field formation at Corps could have one each. These formations are generally located in bases from where most of the logistics in terms of weapons, arms, ammunition, spares, clothing and general stores & supplies, fuel, rations, etc emanate once forces need to be stocked up for operations (Wikipedia, 2022). Once the vehicle design is successful the same can be executed for other formations and units down the hierarchy, as appropriate.

7.15.5 Role During War

On mobilization and during war, the company organization will provide a base for further hiring being in the operations field and can be expanded upon for additional hiring of load carriers from the civil, also exercise control over additional transport under the TA-isation format wherein additional manpower is embodied during war and practiced annually during no-war-no-peace times.

7.16 Civil Hired Transport – Hiring of EV, AFVs and Hybrids

Additionally and meanwhile, a near-term action-plan can be adopted by the IA to hire/ outsource a part of its contracted fleet of all categories of vehicles, as EVs/ hybrids, including other alternate fuels such as Bio-fuel, CNG, LNG, hydrogen ICE, FCEV etc where available and feasible. This will not have any financial burden on the IA. The change may be undertaken, where possible immediately. At other locations a one-year (or so) preparatory period can be granted by suitable advertisement, including on Government e-Marketplace (GeM) platform. To make it financially feasible for vendors, the government can allow for CHTs to be hired under longer durations than the maximum two years feasible currently under Defence Procurement Manual (DPM).

7.17 PM Gati Shakti Project - Achieving National Aims

If successful, this model can be extended to transport held by other services, forces, organisations including central police forces, also other class of vehicles, as feasible after deliberations. The proposed model is in sync with PM's Gati Shakti project and National Logistics Policy. India has submitted its Long-Term Low Emission Development Strategy to UNFCCC during the 27th COP at Egypt (PIB GoI, 2022). It will provide operational logistics assurance while ensuring an economic solution, bringing down logistics cost substantially and generating capital for modernization of IA, thus achieving higher directional aims.

7.18 Generating Option for 4x4 CHT Configuration Needed During Impressment by IA

As mentioned earlier, IA impresses civil transport in conjunction with district administration and police reps, to meet additional needs for cargo haulage during mobilization. Almost all these vehicles travel with army convoys to forward areas and ply alongside defence duty transport i.e. ALS and 2.5 ton vehicles which are 4x4 and can more cross-country. However, all trucks available in civil are of 4x2 configuration, except some tipper class of specialized transport used in cement/ mining industries. Other than that, all CHTs hired or impressed are by design 4x2, as the industry does not need 4x4 and having such configuration means cost-addition.

This problem is further accentuated due to army's decision to optimise its 3rd tier transport. Hence, a gap exists and will continue to subsist till a solution is found. Even if 10-15% of all trucks produced annually by OEMs were made 4x4, they would meet the requirements of IA during operations. However, this would mean extra cost to company or fleet-owner. Hence, it is recommended that IA moot a proposal to government to **grant PLI** in next **budget** to offset the **additional cost of manufacturing** 10% (or as decided) trucks with **4x4 configuration annually**. The OEMs will be paid the incentive yearly. Consequently, requisite number of **4x4 vehicles will be available to meet army's requirement during operations/ mobilisation**. The proposal can be **studied further** by IA.

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Appendices

A. Survey Questionnaire

Introduction of Alternate Fuel Vehicles in the Indian Army, with special reference to Zero Emission Trucks (ZET)

Friends, I am doing a dissertation on the above mentioned topic in Indian Institute of Public Administration as part of the training. Your responses to my questions are on voluntary basis. Information and views are being collected for academic purposes. Data will purely be used for research.

Fossil Fuels are the majority sources of power, they are finite, pollute the environment, requires elaborate supply chain (specially in challenging areas where Army operates) and have high lifecycle costs from extraction till consumption.

- R&D for induction of all types of alternate fuels viz electric/battery based, hydrogen, solar, methane etc has being seen, specially over the last five to seven years. Infact the **Auto Expo 2023 showcased** many such running prototypes of **trucks in medium and heavy categories** based on Battery EVs, Hygrogen IC Engines, Fuel Cell EVs, Natural gas options and hybrids of these varieties.

- **Government of India** through its protocols / agreements, policies, initiatives and incentives (Guidelines, Rules, Orders, Reports, PLIs, FAME-I, II etc) is also aligned towards pushing for the 'green-shift'.

- **Technology** (of EVs) **exists**, and market has **commercially available variants**. Also, technologically it has witnessed an upwards curve, and rising. Segments of Two-wheelers, Cars and Buses have seen maximum proliferation, while light, medium and heavy trucks negligible, even though R&D is being done in that sphere with increased pace. EVs and other alternate fuels (Hydrogen, CNG, LNG) require elaborate **Charging Infrastructure**.

- India has capability to produce **Electric Motors** for long now; Govt has taken out PLI for automotives and component industry.

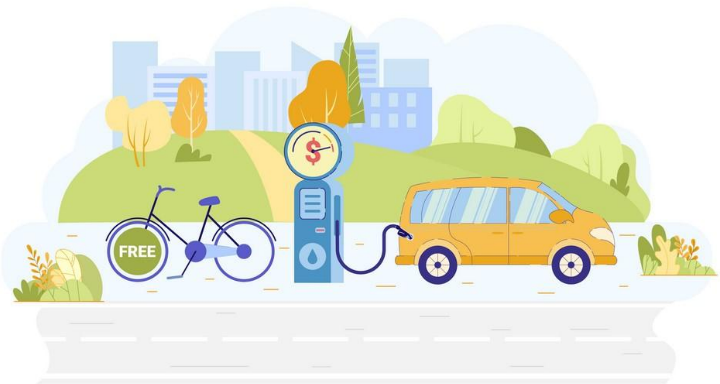
- **Batteries** are the critical component of EVs and hybrids due to limited availability of rare earth minerals. Countries are jostling to secure these at all costs.

Militaries consume huge quantities of fossil fuels and pollute environment. Backbone load carrier of Indian defence forces is the Ashok Leyland Stallion (**ALS**) which meets only **BS-III standards**, while the rest of the country is on BS-VI.

Militaries operate in difficult areas making elaborate infrastructure creation challenging. Army is especially concerned with ***current state of technologies*** (not having fully matured) as of now available in markets specially for trucks, lack of electricity support for ***charging infrastructure*** and the aspect of ***range-anxiety*** in operational conditions and terrain.

There is a **felt need and justification** for introduction of alternate fuel vehicles in the Indian Army. The important question is **which technology is best suited which meets the Army's operational requirements**. I request you to spare a few minutes to answer these questions

Alternate Fuel Vehicles



Q1. Name

Q2. How experienced are you in Q/OL matters *

- ( ) Very experienced
- ( ) Experienced
- ( ) Normal
- ( ) Low
- ( ) No experience at all
- ( ) NONE

Q3. At what level is your experience in military logiostcs *

- ( ) Theatre
- ( ) Corps
- ( ) Division
- ( ) Brigade
- ( ) Unit
- ( ) NONE

Q4. Are you from a technical arm/ service? Or have acquired technical skill by self learning, reading and interest?

	1	2	3	4	5	
Unaware	( )	( )	( )	( )	( )	Well aware

Q5. How aware are you of alternate fuel vehicles (Electric Vehicles EV, Hydrogen fuel vehicles, Solar powered etc) *

Unaware (1) to Well aware (5)

1 2 3 4 5

Unaware	( )	( )	( )	( )	( )	Well aware

Q6. Bharat Stage Emission Standards VI (BS-VI) for vehicles was introduced by Government nation-wide with effect from 01 Apr 2020. What BS standard load carrier vehicles (ALS) are in service in Indian Army? *

Unaware (1) to Well aware (5)

- ( ) BS-I
- ( ) BS-II
- ( ) BS-III
- ( ) BS-IV
- ( ) BS-V
- ( ) BS-VI

Q7. Bharat Stage Emission Standards VI (BS-VI) for fuel was introduced by Government for about 40 cities with effect from 01 Apr 2020 and expanded nation-wide. What BS standard fuel do you think is being supplied by oil companies (IOCL/HPCL/BPCL) to the Indian Army? *

- ( ) BS-I
- ( ) BS-II
- ( ) BS-III
- ( ) BS-IV
- ( ) BS-V
- ( ) BS-VI

Q8. Can we truly derive the full advantages of BS-VI fuel, while we use vehicles with lower BS Emission Standards? *

- ( ) Yes
- ( ) No

Q9. The average consumption of FOL main grades annually by Indian Army is 4 ½ lakh KL costing 3700 Cr *

- ( ) Yes, I am aware
- ( ) Maybe
- ( ) No

Q10. What is the maturity level of EV Industry in India in general? Rate it.

- ( ) 1. Absolutely ready and mature
- ( ) 2. Matured
- ( ) 3. Progressing well
- ( ) 4. Nascent
- ( ) 5. None at all

Q11. What is the maturity level of EV Truck Industry in India? Rate it.

- ( ) 1. Absolutely ready and mature
- ( ) 2. Matured
- ( ) 3. Progressing well
- ( ) 4. Nascent

- ( ) 5. None at all

Q12. What are the difficulties associated with logistics of fossil fuel? Please rate these in order of difficulty *

1 - Most problematic.
8 - Least of the problems

	1	2	3	4	5	6	7	8
Availability of fossil fuels	( )	( )	( )	( )	( )	( )	( )	( )
Costs/ Budgets/ Affect of International geo-politics	( )	( )	( )	( )	( )	( )	( )	( )
Maintenance of MSL and CGR with oil companies	( )	( )	( )	( )	( )	( )	( )	( )
Maintenance of GS reserves with supply echlons	( )	( )	( )	( )	( )	( )	( )	( )
Storage of GS reserves with units	( )	( )	( )	( )	( )	( )	( )	( )
Effects of Pollution due to use of fossil fuels	( )	( )	( )	( )	( )	( )	( )	( )
Problems in transportation (BPLs/Load carriers)	( )	( )	( )	( )	( )	( )	( )	( )
Problems in refilling (Jerricans, automated pumping solutions, directly from Kerbside pumps)	( )	( )	( )	( )	( )	( )	( )	( )

Q13. What alternate fuel based / variant option is best suited for Indian Army, in view of issues highlighted herein *

- ( ) EV variant is best suited
- ( ) Solar powered vehicles
- ( ) Hydrogen cell based transport
- ( ) CNG or LNG
- ( ) Hydrogen IC Engine
- ( ) No change - remain with Fossil Fuel

- ( ) Others _____________

Q14. Operation readiness is a major concern, expressed by most, for induction of alternate fuel (EV) vehicles in the Indian Army. The concern is primarily in the aspects of requirement of charging infrastructure, besides other.

Battery Electric Vehicles (BEV) requires charging infrastructure. Plugin HEV (PHEV) requires both fossil fuel and charging infrastructure. Fuel Cell EV is hydrogen baaed and requires hydrogen fuel stations; plus the issue of green hydrogen. For natural gas (CNG & LNG) elaborate setup is required.

However, Diesel-Electric Hybrid Plug-in trucks may be able to operate with charging infrastructure at depots. Enroute to achieve desired range, they'll operate on diesel or use diesel to re-charge the batteries. These may not be purely zero-emission but will meet operational requirements. They may have some effect on load carriage, as both fuel tank and batteries have to be carried, but that can be off-set by better & efficient design.

Which do you think is the best option in trucks for induction in the Indian Army? *

- ( ) Battery EVs (BEV) or Pure EVs
- ( ) Diesel-Electric Plug-in Hybrids
- ( ) CNG-LPG Hybrid Vehicles
- ( ) Fuel Cell EVs
- ( ) Hydrogen IC Engine (ICE) trucks
- ( ) No change to existing BS-III ALS
- ( ) Only Change existing BS-III ALS to BS-VI

Q15. Operation readiness is a major concern, expressed by most, for induction of alternate fuel (EV) vehicles in the Indian Army. Range and lack of infrastructure/ electricity where Army will operate are other major areas of concern.

Battery Electric Vehicles (BEV) gives limited ranges (120-250 kms) practically today.

Plugin HEV (PHEV) will give still better ranges since they use batteries as well as fossil fuels (range of 200+350 kms).

Fuel Cell EV is hydrogen based and FCEV also require dual fuel inputs i.e. fossil and hydrogen (ranges of 300+350 kms).

Hybrid EVs may have some effect on load carriage, as both fuel tank and batteries have to be carried (range of 100+350 kms). Biggest advantage is - Diesel Electric Hybrid EV that they do not require any elaborate charging infrastructure enroute. They can charge at their convenience.

Which do you think is the best option for trucks for introduction in the Indian Army? *

- ( ) Fuel Cell Hybrid EVs
- ( ) Hybrid EVs
- ( ) Plugin Diesel-Electric Hybrid EVs
- ( ) Battery EVs or Pure EVs
- ( ) None
- ( ) Others _________

Q16. Operational Readiness is affected by parameters as under. Please rate them in order of importance/ relevance *

1-Most limiting
5-Least limiting

	1	2	3	4	5
Availability of vehicles in Indian Market; Need for R&D and prototyping specifically for Indian Army	[ ]	[ ]	[ ]	[ ]	[ ]
Status of charging infrastructure	[ ]	[ ]	[ ]	[ ]	[ ]
Maintenance of vehicles batteries/ Maintenace of electric motors etc	[ ]	[ ]	[ ]	[ ]	[ ]
Range limitations	[ ]	[ ]	[ ]	[ ]	[ ]
Power, specially in deserts & mountainous terrain	[ ]	[ ]	[ ]	[ ]	[ ]

Q17. In case we choose to induct some form of alternate fuel vehicles in Army, which is best option for batteries *

- ( ) Fixed batteries
- ( ) Replaceable batteries
- ( ) Mix of both

Q18. ALS has heavy lift capability and Tata 2.5T is in the medium range. Both are from different manufacturers. The designs are also different. This has manitenance issues.
Do you think while we build either Diesel-Electric Hybrids or EVs or any other alternate fuel vehicles for Army, there is need, scope and opportunity for Standarisation to one type of vehicle (with different sizes, payload, capacity etc), from a manufacturer, with common parts to ensure commonality and ease in supply chain and maintenance? *

- ( ) Yes. Time is opportune. Just have one common variant with same payload, size and capacity in the new alternate vehicles being planned
- ( ) No 2 variants - different manufacturers. Have different variants with different payloads, sizes and capacities in the new alternate vehicles being planned
- ( ) No 2 variants - same manufacturers. Have different variants with different payloads, sizes and capacities in the new alternate vehicles being planned
- ( ) No change - remain with Fossil Fuel

Q19. Which terrain or location is ready for immediate induction of EVs in the Army *

- ( ) Peace Stations in hinterland
- ( ) Mountains
- ( ) Deserts
- ( ) None

Q20. Can all units in peace stations be included in the EV induction plan. What do you suggest? *

- ( ) NFF units only
- ( ) All units irrespective of operational role
- ( ) NFF units initially and expand to all others where feasible in Phase-II
- ( ) None

Q21. Do you think we need to go into partnership with industry and other government agencies to develop an alternate fuel vehicle(s) for the Army? *

- ( ) Yes
- ( ) No
- ( ) Maybe

Q22. A Consultancy Firm for implementation of such a project, as being proposed, brings on the table expertise, experience accountability and best global practices. But, it costs more. What are your views on hiring a consultant for implementation of the transition to alternate fuel vehicles for Army? *

- ( ) Yes. I agree. A professional and experienced firm should be selected. The process will incorporate Army's inputs and Army will have final say in approval
- ( ) No. Army by itself has the expertise to undertake the DPR (Detailed Project Report)
- ( ) Maybe
- ( ) I have not recommended converting vehicles to alternate fuels at all

Q23. Armies of other countries are developing Hybrid EVs variants in the Light Tactical High Mobility Vehicle segment (eHUMVEE High Mobility Multipurpose Wheeled Vehicle, eJLTV Joint Light Tactical Vehicle etc) for induction. Do you think that such option exists for Indian Army and we can start working on it by involving manufacturers and building prototypes? *

- ( ) Yes
- ( ) No
- ( ) Maybe

Q24. Willy Jeeps earlier came with trailers. This would assist in carriage of ammunition and stores to troops where roads were underdeveloped and of smaller classification. Do you think we need Light Tactical Vehicles with trailers? *

- ( ) Yes
- ( ) No
- ( ) Maybe

Q25. The market offers Mobile Re-Charging Options for alternate fuels. These can be placed enroute or as part of convoys. Vehicles have swappable batteries, Fast-Charging systems based on generators, etc. These will address Armys operational concerns for transition to alternate fuel vehicles. What are your views on it? *

- ( ) Yes, we should work on trying and inducting these
- ( ) No, not required
- ( ) Maybe / not sure

Q26. Buses are used for troop carriage. If we make Army Buses Pure EVs, how will they operate in operational areas? What are the options you suggest? *

- ( ) Build dedicated and elaborate charging infrastructure
- ( ) Make them Diesel-Electric Hybrids so that they operate on EV where feasible, else switch to diesel
- ( ) Do not convert them to any alternate fuel variant...status quo

Q27. Motorcycles are used by Dispatch Riders (DR) in Army. If we make them Pure EVs, how will they operate in operational areas? What are the options you suggest? *

- ( ) Motorcycles should be Pure EVs
- ( ) Make them with Petrol-Electric Hybrid
- ( ) Keep them as such, i.e. on petrol; Status quo

Q28. Other specialist vehicles like Ambulances, Mine Protection Vehicles (MPV), APC (Armoured personnel carriers), HMV (Heavy Mobility vehicles) etc also offer an opportunity for transition to alternate fuels. What are your views? *

- ( ) Yes. In fact the electric motor has high and steady torque and more power, suitable for special operations
- ( ) No. They serve different purposes. May not be cost effective. Keep them as such
- ( ) Maybe

Q29. If Army adopts alternate fuel vehicles for its fleet, do you think it can be replicated / adopted by other defence (IAF, Navy) (we are already moving towards integration and jointness), PMF, Central & State police etc who operate in similar difficult terrain / areas? What are your views? *

- ( ) Very likely
- ( ) Likely
- ( ) Maybe
- ( ) Less likely
- ( ) Not possible

Q30. Any other comments or suggestions? *

B. Focussed Interviews

Interviews were conducted with officials from the government to include NITI Aayog, industry players and manufacturers to get a sense of their views and feasibility of broad recommendations being made by the study