LANDSCAPE OF FUTURE FUELS IN INDIA:

OPPORTUNITIES, CHALLENGES AND WAY AHEAD

FEBRUARY 2023

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FOUNDATION

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FOREWORD

Erik Solheim
6th Executive Director of UN Environment
Former Norwegian Minister of Environment and International Development
President Green Belt and Road Institute

A few years ago when I was Minister in the Norwegian Government we decided to make a big bet on electric mobility. It turned out to be successful beyond all expectations. Last year 80% of all cars sold in Norway were fully electric. By 2025 we will reach 100% for personal vehicles.

This massive change away from our old fossil habits happened because the government decided to give an introductory offer to all buyers of electric cars. Taxes were changed to make electric vehicles cheaper in competition with gasoline powered ones. Owners of electric cars were allowed to run in bus lanes to get to work faster and they got preferred rates at ferries and parking lots. To put it simply: Government policies shifted our habits. Now the market will take over and finish the job.

Fortunately Norway is not alone. 25% of the new cars in the much bigger Chinese market will also be electric in 2025. In India, many state governments have launched policies for the green transformation. Big cities all over India are embarking on massive purchases of electric buses. Private companies like Ola, Mahindra, Tata and others are ramping up production of electric two, three and four wheelers as well as buses.

Electric mobility will certainly dominate the future of mobility. But we may need other clean alternatives also. Some vehicles may be too heavy and move too far for electric batteries to compete with green hydrogen. Biofuels may be better suited in some markets. This most valuable report highlights the different technologies which are already available. The future will most certainly bring improvements, but there is no need to wait. Alternatives to fossil fuel dependent transport are there in abundance as shown here.

The need to combat climate change is now. No country, sector or person can afford to be left out as the world moves towards a net zero emission paradigm. Transport sector is no exception. The path to achieve a net zero emission is not an option, but a must for the planet.

Innovation has meant that there are solutions like green hydrogen that can address challenges for mobility in tandem with electric mobility. Also, alternative approaches like bio-CNG, ethanol and biodiesel made from waste streams, can bring significant co-benefits, especially biofuels allaying food security concerns. Other solutions like methanol are fast emerging as alternate clean fuel.

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Such solutions become an opportunity for the oil and gas sector to reinvent itself and become energy providers with a basket of options on offer, enabling them to adjust to this ongoing energy transition.

India is leading the world today when it comes to demonstrable action to combat climate change. Prime Minister Modi is launching new green initiatives by the day. Many chief ministers of important states are following his leadership. Tamil Nadu for instance started 2023 by launching the Tamil Nadu Climate Mission and a $125 million fund to drive green investment in this progressive state.

The scale of Electric Mobility adoption is fast taking off in India. However, what remains less discussed is the conscious attempts at increasing the adoption of alternative fuels in the transport sector. There have been some successes, and some other options are still at a stage of nascency in India. However, the frameworks on policy are clearly strong enough to lay the foundation stones for propelling India's future fuels story. This is where this White Paper by OMI Foundation stands out, as it takes up the difficult task of rounding up the scenario and presenting a comprehensive picture.

The Indian story also serves as an example for many countries in the Global South, who are looking at what India is doing and want to learn from it. This paper is timely in this regard. It will help the readers learn about the actions being pursued and the learnings generated so far from India's experience on future fuels. This in turn can also inform their own policy making systems about the steps to be taken up.

I congratulate OMI Foundation on this paper and wish them all the best for future endeavours. Such endeavours do much to enrich policy discussions and bring the needed realism while keeping sight of the larger objective of achieving a desired Sustainable Planet.

FOREWORD

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

Harish Abichandani
First Trustee, OMI Foundation

As the world seeks to achieve a net zero paradigm, the burgeoning mobility sector has to rise to the occasion. The first step is to restrict an increase in greenhouse gas emissions and then to reduce emissions to zero. For India, rightly so, GHG emission reduction is not the sole target, as the country also faces an acute problem of air pollution plaguing its cities. This necessitates tackling the challenge of reducing tailpipe emissions on a war footing.

Technological advancements have presented multiple clean energy options in the mobility space, but it has to be viewed from the prism of addressing certain critical goals, including the need to provide an alternate cleaner fuel for vehicles which are already on the road. The transition also needs to percolate across all segments of transportation, necessitating an approach for certain segments like aviation, shipping and long-distance trucking, which have specific energy requirements given the nature of operations. The supply of alternate clean fuels also needs to be steady and dependable and not exposed to geopolitical challenges. Future fuels can definitely play a role here, and help reduce this import bill and safeguard India against unexpected events around the world.

India has been taking a lead in building a global biofuels alliance, one which compliments the efforts to increase the penetration of electric mobility in India. The intention therefore is to document and present the current level of adoption and development in future fuels, including biofuels and even cleaner sources like Hydrogen, and the role each can play as energy transition takes place within the mobility sector.

OMI Foundation's white paper on the landscape of future fuels in India presents an objective and comprehensive view, bringing together diverse alternatives with past experience and future projections. The paper has sought to see the current adoption status of the different options considered, creating a realistic perspective on the way forward around future fuels. The paper has done a noteworthy effort that will certainly help to inform the interested stakeholders of various domains.

Given the objectives of energy security that India seeks, it is important that such discussions take place enriching the narrative, and providing policy makers options from which they can choose.

CONTENTS

ABSTRACT

The transport sector is a rising significant contributor to India's greenhouse gas emissions, and is primarily caused by the consumption of fossil fuels to energise the sector's activities. The ongoing energy transition also affects transport; however, it is incorrect to assume that the entire sector can be electrified in the near future for a variety of techno-economic factors. In fact, estimates show that the contribution of liquid fuels in energising India's transport sector will still remain higher than fifty percent. Clearly this implies the need to find solutions to address the situation if a net zero scenario is to be achieved.

Given this context, a basket of fuel options has emerged in India - Ethanol, biodiesel, bio-CNG, methanol and green hydrogen - that can help address the challenge. As alternatives to conventional energy sources, they can play a huge role in taking us to the net zero goal. However, their role as mainstream alternative fuels towards the 2070 net-zero emissions target remains understated. This white paper analyses the landscape of "future fuels" in India through a multi factor analysis. It highlights their supply chain processes, the financial viability, sustainability and the policy framework under which it operates. The objective is to push future fuels into the mainstream narrative for low carbon mobility, which is required to drive net-zero targets.

INTRODUCTION

Transportation sector is a significant contributor to global fossil fuel demand, which further leads to emissions. In fact, road transport contributed 49.2% of entire global oil consumption in the year 2019. This share goes up to 60% when rail, aviation and the shipping industry are added (figure 1) (IEA, 2021). There has been a decline in the usage of oil for transport in 2021, with demand falling by more than 6 million barrels per day below 2019 levels, and leading to lower emissions by 600 Mt. CO_2 emissions related to international aviation in 2021 stood at only 60% (370 Mt) of their pre-pandemic levels (IEA, 2022). This was essentially due to the multiple lockdowns and travel restrictions across different countries, which directly affected the demand.In fact, OPEC has estimated that between 2021 and 2045, global oil demand is expected to increase by close to 13 mb/d, rising from 96.9 mb/d in 2021 to 109.8 mb/d in 2045 aviation, road transportation and petrochemical sectors being the main contributors to future incremental oil demand (OPEC, 2022). Another case to note here is the IEA's net zero scenario forecast, which also visualises oil consumption at 20 million barrels/day in the year 2050 (IEA, 2021). This, even if significantly down from around 90 million barrels/day as of 2020, shows a sense of expectation that oil cannot be phased out entirely.

Transport sector's various components lead the consumption of oil globally.

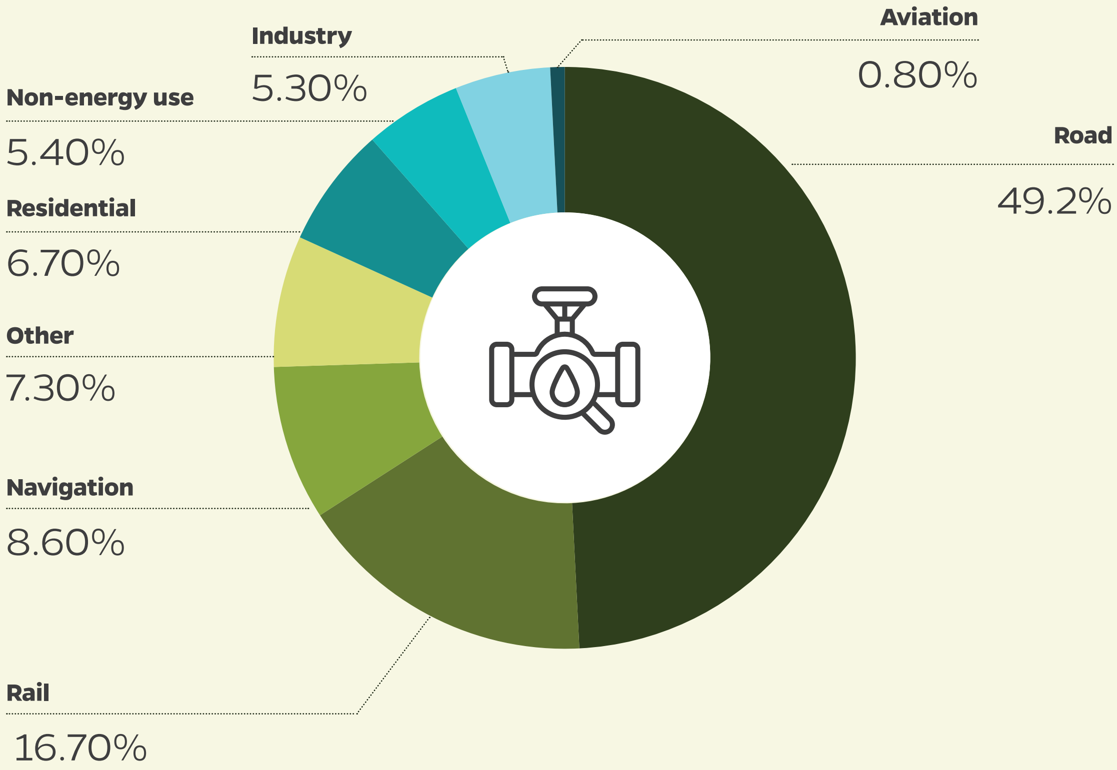

Figure 1: Oil consumption across sectors globally by end source.

Source: International Energy Agency (IEA), 2021.

Countries across the globe have been seeking to reduce the transport sector's carbon footprint by reducing emissions. The same holds true in India as well with an additional layer. In India's case, the focus is on reducing current emission levels while also avoiding potential future emissions from a growing transport sector. This is due to the faster pace of growth in emissions from the sector when compared to other sectors. (Kamboj, Malyan, Kaur, Jain, & Chaturvedi, 2022). Even as the transport sector accounts for less than a fifth of India's final energy use and almost 11% of India's energy sector related carbon dioxide emissions, the pace is expected to quicken alongside India's economic growth (Kamboj, Malyan, Kaur, Jain, & Chaturvedi, 2022).

Another factor in India's larger story is the role of transport in air pollution. The de-fossilisation of the transport sector is crucial to reduce climate effects, with emissions of soot particles and NOx being harmful to the environment and human health (Richter, et al., 2021). India's National Clean Air Plan (NCAP) identifies vehicles as a major contributor to the air pollution crisis in India (MoEF&CC, 2019). Given India has the highest estimated number of deaths attributable to exposure to air pollutants at 1.6 million for the year 2019 (Gupta, 2022), the necessity for cleaner alternatives to power transport is seen as a crucial part of the larger strategy.

A major factor that often gets ignored in all these discussions is the crucial aspect of energy security and India's dependence on imports to keep the transport sector moving. With a growing economy, there has been a rising demand for the diverse applications of crude oil and its refined derivatives even beyond the transport sector. Even when the lockdowns occurred in India, the demand for petroleum products dipped just marginally (Figure 2) (PPAC, 2022). While India is a net exporter of petroleum products, the dependency of the industry creates a persistent sense of vulnerability. This is also true for natural gas, which has a wide range of applications beyond transport. Thanks to government policy of prioritisation and price rationalisation, the Indian market see greater utilisation in cooking, transport and fertiliser industry. In contrast, the natural gas-based power sector plants in India continue to struggle with high prices.

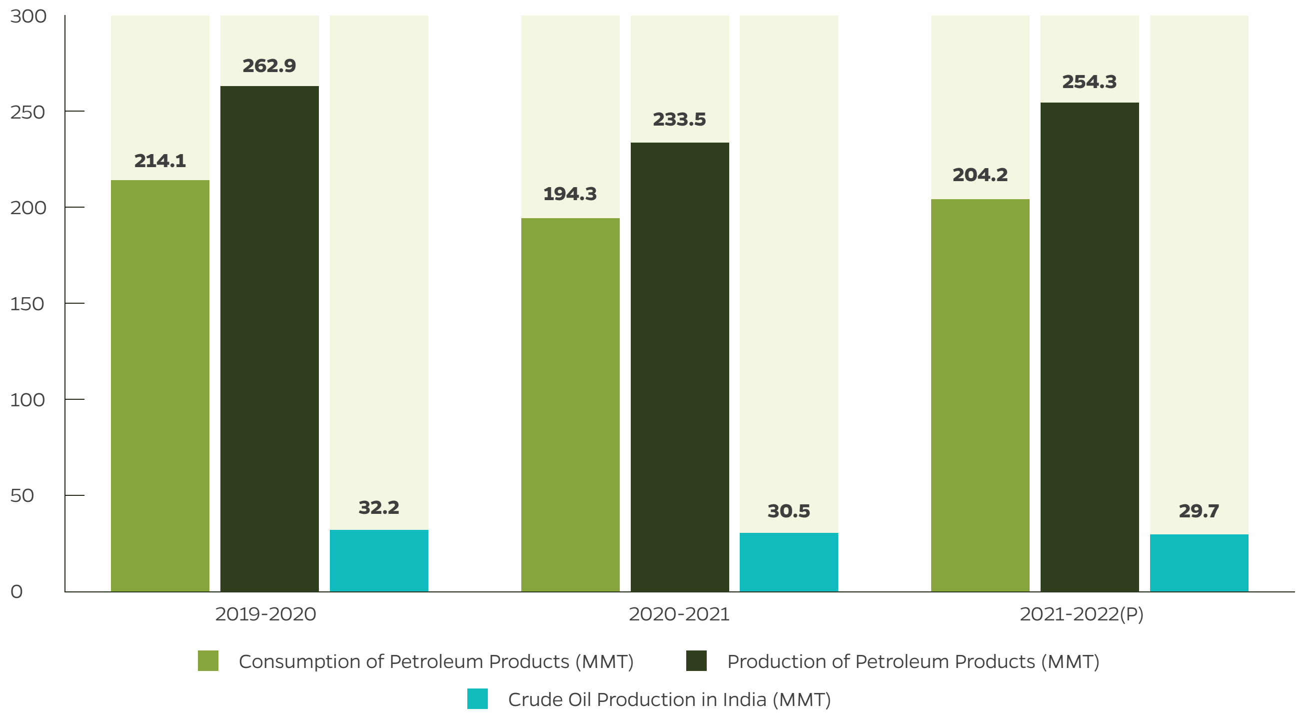

Figure 2: Consumption and Production of Petroleum Products Masks India's Low Level of Crude Production.
Source: PPAC, 2022

Global and national level discussions on these interlinked subjects has thus pushed the case for transitioning away from fossil fuels and reducing their consumption to the greatest extent possible. As part of the energy transition discourse, there are two tracks in particular that we see emerging:

I. Adoption of electric mobility
II. Adoption of future fuels.

In current times, there is a lot of discussion about the electrification of the transport sector. Technology and rising affordability is making EVs more viable and attractive. It is expected that electrification will play an important role in the transformation of the mobility industry and present major opportunities in all vehicle segments, also having effects far beyond (McKinsey & Company, 2021). A theoretical scenario of an all-electric future in the road transport sector is well within reach, with options available across different form factors.

However, the excitement around electric mobility ends up ignoring certain realities. Even under the most aggressive scenario for EV sales growth, it would account for at best 50% of the total fleet by 2050. Vehicle turnover is relatively slow, and keeping that in mind, one realises that even if 100% of vehicles sold were electric starting today, it would still take 20 to 25 years to replace the entire vehicle fleet with electric vehicles. Therefore, a significant share of vehicle miles travelled will rely on fuels at least in the near- to medium-term (Debnath, Khanna, Rajagopal, & Zilberman, 2019; Debnath, Khanna, Rajagopal, & Zilberman, 2019). For India too, it has been estimated that the uptake of electric vehicles will essentially be restricted to the two and three wheeler space (figure 3) and that even with aggressive rollouts, the share of oil in the total transport energy consumed will still be at 66 per cent in 2050 (Kamboj et al, 2022).

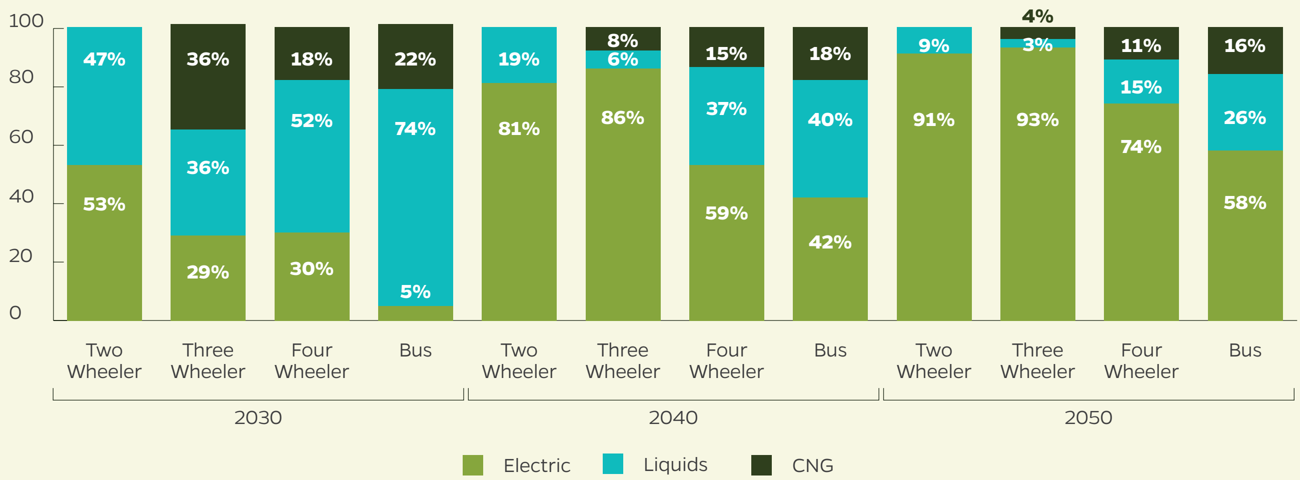

Figure 3: Electric vehicles will significantly gain share among new vehicles, especially in the two and three-wheeler segments.

Source: Kamboj et al, 2022

Even if electrification by 2050 is argued to be feasible, what is certain is that some of the alternatives like green hydrogen and advanced grade biofuels will have a role to play in niche transport sectors like shipping, aviation or long-distance trucking zones (Energy Transitions Commission, 2021). This is particularly true for developing countries where investment in infrastructure may be constrained by a variety of factors including political and economic interests. Given that many countries like India have significant public sector presence in the oil and gas sector coupled with sizable existing investments in oil and gas infrastructure, questions would definitely arise on keeping these investments and infrastructure relevant.

Also, the increased use of electricity for road transport could involve additional challenges and undesirable side effects, such as increasing pressure on electricity grids, requiring significant additional investment, and increasing the vulnerability of the transport system to power disruptions (IEA, 2021). In fact, decarbonisation of the transport sector will come to rely on both shifts towards electric mobility (electric vehicles and fuel cell electric vehicles) and shifts towards higher fuel blending ratios and direct use of low-carbon fuels such as biofuels and hydrogen-based fuels (IEA, 2021).

More than Just Decarbonisation

A shift from fossil fuels for transportation towards a future fuels economy also brings about a major socio-economic transformation. As in other economic and technological shifts, transitioning to a low carbon economy will result in additional jobs being created, jobs being substituted, jobs being eliminated and existing jobs being transformed (Ram, Osorio-Aravena, Aghahosseini, Bogdanov, & Breyer, 2022). This also raises the need for creating a bridge towards the specialised future jobs arising with the transition, ensuring that the transition is just and fair.

The role of future fuels is also significant, given the manner in which the oil and gas sector has generally responded to decreasing their carbon footprint over the years. Many oil companies have been investing in biofuels for decades, especially through research efforts and venture capital spending. In recent times, they have also placed their bets on green hydrogen and have committed to investments towards the same. Much of this in current times is being driven by the need to remain relevant in a post energy transition scenario and also to address concerns of environmentally conscious large shareholding groups. In their scenario forecasts, many oil and gas majors have placed a bet on the continued demand for combustible fuels, particularly for modes of transport that so far cannot make extensive use of electricity for a variety of technological and cost limitations that are yet to be overcome for now (i.e., heavy trucks and aeroplanes). Even as many governments are planning to phase out internal combustion engine vehicles, there is talk of investments in liquid biofuels among others. This discussion is strategic even in a context of low oil prices, as it is made in light of the awareness that there would be a need to have transition fuels for filling the gap till the entire vehicle fleet on the road gets replaced (Asmelash & Gorini, 2021). This is also driven by the fact that the differences in the roles between the various energy sources - renewable power, bioenergy, next-generation mobility, energy services, and hydrogen - is shrinking rather rapidly, with these factors fast emerging as compliments to each other. The oil and gas companies are trying to reinvent themselves as integrated energy players in the space, seeking to retain their profitable core while also capturing some of the large global opportunities now emerging in low-carbon markets in the process. The hope of these players is that they will emerge as the natural owners of some or more of these investment classes based on their capabilities, technologies, relationships, and other incumbent advantages (McKinsey and Company, 2021).

Evidence to this is somewhat visible in India. Today, we see efforts at diversification by the Indian oil and gas companies, pushed by regulatory nudges, primarily the National Biofuels Policy, in the following ways:

01

Procurement and sale bio-CNG under the SATAT scheme

02

10% ethanol blending with petrol, now revised upwards to 20%

03

5% biodiesel blending target, with procurement tenders to procure used cooking oil derived biodiesel

04

Announcements for production and distribution of green hydrogen and electric charging stations

In addition to this, the Ministry of New and Renewable Energy, Government of India has announced the following programmes under the National Bioenergy Programme (PIB, 2022) which seek to encourage the use of a variety of wastes and agricultural residues for generation of power and cogeneration projects:

- Waste to Energy Programme (Programme on Energy from Urban, Industrial and Agricultural Wastes /Residues) to support setting up of large Biogas, BioCNG and Power plants (excluding MSW to Power projects).

- Biomass Programme (Scheme to Support Manufacturing of Briquettes & Pellets and Promotion of Biomass (non-bagasse) based cogeneration in Industries) to support setting up of pellets and briquettes for use in power generation and non-bagasse based power generation projects.

- Biogas Programme to support setting up of family and medium size Biogas in rural areas.

The future fuels space also offers an interesting window of opportunity in paving a road for building a sustainable economy. For instance, it is well known that there is still an enormous development potential for bio-energy and the bio-economy in developing and less developed countries. The economies of these mostly tropical countries are still strongly based on agriculture and forestry. Manure produced by cattle and pig farms can be converted into biogas that can be used for cooking, heating and/or power generation. Similarly, wastes from food processing can be harnessed for use as fuel as well (UNIDO, 2021). Harnessing these can help address several of the Sustainable Development Goals (SDGs) (figure 4).

Figure 4: Bioenergy benefits align with Sustainable Development Goals (SGDs).

Source: UNIDO, 2021

EMERGING ROAD TRANSPORT FUELS OF THE FUTURE

The progress of the future fuels landscape has moved sharply in recent years. Technological advancements to address environmental concerns accompanying the impending energy transition have led to the emergence of a significant new generation of alternatives to petrol and diesel and other specialty fuels across the transport sector (Ghadikolaei, et al., 2021). Consequently, we are in the era where advanced generations of future fuels are fast emerging. This has also helped open a wide array of options in terms of feedstock utilisation so that challenges like food security concerns can be addressed in due course of time (Table 1). Eventually though, we see five major options emerging in the process – bio-CNG, second-generation (2G) ethanol, biodiesel, methanol and green hydrogen. These fuels themselves can form intermediates across other supply chains, thus enhancing their value and consequently longevity. Thus, there is a need to evaluate fuels on their own merits (refer to annexure for more details around automotive properties).

Table 1: Classification of Future Fuels based on Feedstock

Fuel Type	Types of Feedstock	Feedstock Collection	Feedstock Availability
Bioethanol	**First Generation Feedstock:** Sugarcane Juice, Sugar B-Molasses, Sugar C-Molasses, Sugar beet, Cassava, Sorghum, Corn, Sweet Potato, Grains, Petrochemical route. **Second Generation Feedstock:** Lignocellulose, cellulose, forestry residues, agro-waste, wood residues, other organic wastes rich in sucrose content can be used to produce ethanol. Such feedstocks are typically rich in cellulose, hemicellulose and lignin. Energy crops are also counted as a second generation feedstock as they don't compete with food, and are typically cultivated on wastelands. Energy cane is one such example due to its high fibre content.	India relies on sugarcane as the primary feedstock for its ethanol plants. Sugarcane farming is increasingly tilting towards catering to ethanol production, thanks to aggressive fuel blending mandates from the government. Supply chain mechanism is relatively more organised and centralised with participation from large refineries, with them enter into contracts with Oil Marketing Companies (OMCs) to support national level fuel blending programmes and demand from the medical, liquor and cosmetic industry.	India produced 500 million metric tonnes of sugarcane for the year 2021-22. Major sugarcane producing states are UP, Maharashtra, Karnataka, Tamil Nadu, Bihar, Gujarat, Haryana, Andhra Pradesh, Punjab, Uttarakhand. Currently, around 6 million metric tonnes of sugar is utilised to produce ethanol. This is sourced from the surplus sugar production that takes place in India. India produced an estimated 23.1 million tonnes of corn in the Kharif Marketing Season (KMS) 2022-23. Major corn producing states in India are Andhra Pradesh, Karnataka, Rajasthan, Maharashtra, Bihar, Uttar Pradesh, Madhya Pradesh, Himachal Pradesh and Arunachal Pradesh in the north-east.

	Third Generation Feedstock: Ethanol can also be produced from algae, but it is currently not considered economically viable.	Feedstock is supplied by the farmers to the ethanol refineries in trucks and tractors against a minimum procurement price.	Another grain in consideration is rice. 130 Million metric tonnes of rice was produced in the year 2021-22 in India. Currently, the government intends to utilise around 17 million tonnes of surplus foodgrains, particularly surplus rice and corn apart from sugarcane molasses, for manufacturing ethanol to achieve the target of 20 per cent blending with petrol by 2025. This is necessary because the amount of sugar that can be diverted remains limited.

Fuel Type	Types of Feedstock	Feedstock Collection	Feedstock Availability
Bio-CNG	**Municipal Solid Waste (MSW) and Sewage**: The organic fraction of Municipal Solid Waste (representing roughly 40-50% of the total mixed waste) is a suitable feedstock. Organic waste is biodegradable, therefore can be broken down into simpler gaseous and solid compounds. Other than MSW, the feedstock could also include sewage water sludge and industrial organic waste. **Agro-waste:** Non-woody agricultural waste (like paddy straw, wheat straw, bagasse, etc), animal waste (cow dung, faecal waste) and more such feedstock options. Cow dung, in particular, is considered a good feedstock making a rich culture for digesters in biogas/bio-CNG plants.	**MSW:** Urban Local Bodies (ULBs) collect MSW from households, hotels and industries. In a favourable case, waste goes through primary segregation, where recyclable inorganic fraction is separated by ragpickers (who mostly belong to the informal economy). The remaining portion, consisting of non-recyclable inorganic and decomposable organic fraction, gets transported into a storage cum segregation facility where the inorganic fraction is removed and sent to landfills for dumping. The remaining part is almost fully organic in nature and is ready to be sent to the digestor of a bio-methanation plant. **Agro-waste:** Usually stored by farmers in fallow lands. Cellulose-rich agro-waste is typically harder to digest, and therefore has a lower gas yield.	Organic solid waste is found across all human settlements - rural and urban. In cities, MSW is the dominant form of waste, growing rapidly. According to World Bank estimates, 277.1 MMT of MSW is generated in India annually. Estimates suggest that over 1.5 million tonnes per annum (MTPA) of automotive-grade Bio-CNG can be generated by treating MSW alone in India . India produces upto 350 MMT of agricultural waste per year. This translates in to 0.12 MTPA of automotive grade bio-CNG, depending on the type of stubble. India generates upto 1.7 MMT of faecal waste per annum, 78% of which is left untreated.

		In India, the waste is transported to the bio-methanation plant either by the farmer or the plant agency, as per the decided contract, against a minimum price in tractors or trailers. **Sewage water waste sludge:** Supplied by the ULBs through a wide distribution of piping networks to Sewage Treatment Plants (STPs). A co-located biogas plant is a resourceful way to dispose of the sludge.	

Fuel Type	Types of Feedstock	Feedstock Collection	Feedstock Availability
Biodiesel	Palm, Jatropha, Rapeseed, Soybean, Sunflower, Cottonseed, Safflower, Peanut Oil, Used Cooking Oil. Biodiesel can also be prepared from hydrotreated Vegetable Oil, Animal Fat, Pongamia, coal to oil. Algae is another source now being seriously considered.	Plant/refinery operated collection system - used cooking oil from hotel industry, energy crops collected from farmers under National Biodiesel Mission.	Jatropha plantations are spread across the states of Telangana, Rajasthan, Chhattisgarh and Andhra Pradesh primarily. As of 2018, It is reported that Jatropha occupied around 0.5 million hectares of low-quality wastelands across the country, of which 65-70 per cent were new plantations of less than three years. Used cooking oil (UCO) is being promoted under RUCO programme of the Food Safety and Standards by Authority of India (FSSAI). India produces 2,700 crore liters of UCO as per Ministry of Petroleum and Natural Gas. Palm stearin oil is currently being imported from Indonesia, primarily. It is estimated that India's annual demand for palm oil, mostly led by cooking medium requirements, is 9 million tonnes each year. Over 62% of edible oil import in India constitutes palm oil.

Fuel Type	Types of Feedstock	Feedstock Collection	Feedstock Availability
Methanol	Oil, Natural Gas, Agricultural Waste, Forestry Residues, Municipal Solid Waste, Hydrogen, Carbon Dioxide. Natural Gas, Indian High Ash Coal, Biomass, MSW, Stranded and Flared Gases.	Wood was one of the earlier feedstocks for the production of methanol. The destructive distillation of wood was the method adopted in the process. However, this biomass type was abandoned long back in favour of fossil fuel based production. The shift away was also prompted by the large requirements of wood, leading to large scale deforestation. Thanks to the shift to fossil fuel based technologies, coal and natural gas are the preferred mainstream sources, which are processed to first produce syngas and then methanol subsequently. However, given the associated environment and carbon footprints, alternatives are being sought. Bio-methanol is methanol produced from biomass or solid waste. The production method is significantly different from that of conventional methanol. Also, renewable energy can be used to produce methanol from these sources. As the demand for green methanol rises, this combination of biomass/MSW and renewable energy can potentially lead to a shift in the methanol production method away from the present industry practice. e-methanol is another alternative where carbon dioxide is used to generate methanol with the help of electricity generated from renewable resources like wind and solar.	India is a net importer of natural gas, importing 30,776 MMSCM of liquified natural gas (LNG) in 2021-22. As per September data, natural gas was used primarily by fertiliser (32%) followed by City Gas Distribution (cooking, transport etc.) (21%) and other uses liked creating petrochemicals (22%). Thus, its utilisation for methanol production remains unlikely. Abundant coal reserves in India (estimated at 319.02 billion tonnes) has driven interest towards adoption of methanol for a variety of industrial and mobility purposes. However, the exact estimates of coal availability are contested. Biomass stocks, especially crop stubble, is an easy source for bio-methanol production. However, seasonal availability and logistical issues need to be sorted out to enable its utilisation. As noted for bio-CNG, India produces upto 350 MMT of agricultural waste per year. Municipal solid waste is another option. However, the technology around it is still considered expensive. 277.1 MT of municipal solid waste is generated each year in India. Carbon dioxide can be sourced from various sources e.g. flue gas from power plants, cement kilns etc.

Fuel Type	Types of Feedstock	Feedstock Collection	Feedstock Availability
Green Hydrogen	Water and Electricity	Water sourcing as feedstock would be necessary via pipe-lines since most plants related to green hydrogen are intended to be setup near green energy generation plants	India is officially listed as a water stressed nation. Of course, the quantum of water needed still remains debatable, ranging between 22-32 kg of water for every kilogram of hydrogen. Even desalination-based strategy is not preferred due to the high cost implications it carries.

Source: Authors' compilation of analysis from multiple sources

PRESENT POLICY LANDSCAPE OF FUTURE FUELS IN INDIA

The future fuels policy landscape is characterised by an overarching policy framework at a national level. Steps taken towards promoting future fuels have a history to them. In the past two decades, we have seen a concerted push to promote biofuels in India for fuel substitution via blending. In recent times however, there has been a slight calibration in the approach. When one scans the present day biofuels policies of states like Bihar, Assam, Karnataka and Chhattisgarh among others, it is seen that there are three drivers for promoting biofuels -

01

The productive use of surplus agricultural produce and agricultural waste.

02

Adding value to the crop surplus to boost farmer income.

03

Creating jobs and encouraging greater investments in the state.

This is one major reason why states have been pursuing this in a comprehensive manner for both ethanol and biodiesel, with some even setting up boards of their own. Then there are states like Uttar Pradesh that cover bio-CNG, ethanol and biodiesel through their Bio Energy Policy. The one exception in this regard is Himachal Pradesh, as it promotes biofuels adoption instead of production, a result of combating rising air pollution in the state through its Clean Fuels Policy (figure 5).

Biofuels in India - Policy Status

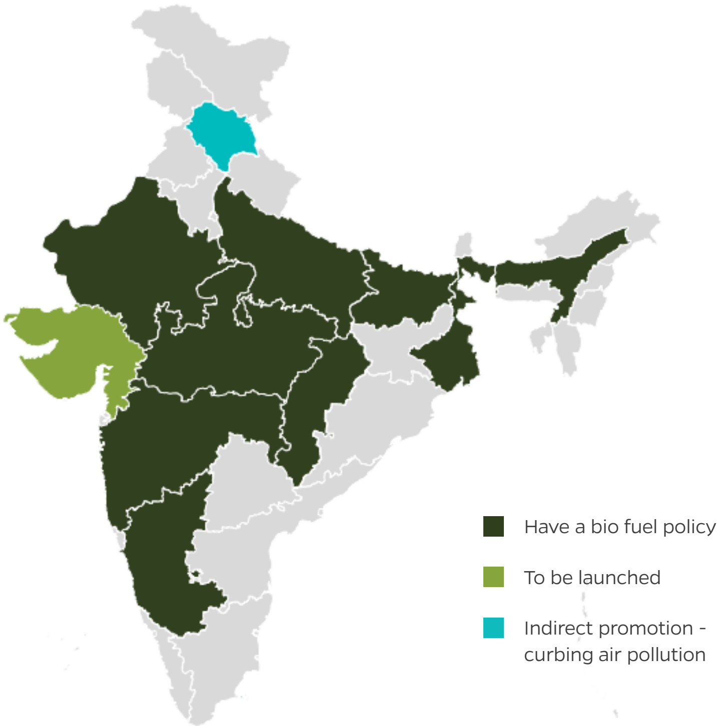

Figure 5: States are expressing interest around future fuels by formulating Biofuels Policy.
Source: Author's analysis of state policies on biofuels as on January 11, 2023.

The biodiesel story has been rather interesting over the past decade and a half. In the initial days, the National Biofuels Policy pushed for the adoption of biodiesel produced from non-food specialty crops like jatropha which failed for a variety of reasons, including poor jatropha seed yield, limited availability of wasteland and high plantation and maintenance costs. Consequently, because of limited availability of biodiesel and the volatile nature of its prices, the speed of blending had suffered a setback (Lahiry, 2018). Since then, in an attempt to revive the biodiesel program, the larger emerging trend of substitutes like used cooking oil (UCO) got mainstreamed, with the government launching a UCO biodiesel procurement program (PIB, 2021). Also, acceptability of bio-diesel by automotive sector is limited due to some of its adverse properties such as cold flow properties, oxidation stability and corrosiveness with automotive fuel system materials (Sorate and Bhale, 2015).

Ethanol in contrast has witnessed a significant growth story, with a revival of the blending mandate alongside a serious push. The E-10 petrol blending mandate was achieved ahead of the scheduled timeline, and the government is now pushing for an E-20 target by 2025. E-10 saw the sugar industry rise up and repurpose itself to produce ethanol from molasses and some degree of food crops used for Industrially Manufactured Foreign Liquor (IMFL) getting distilled. However, going ahead, it is obvious to many that a change of feedstock would be necessary to avoid the food security versus energy requirement debate. This debate has become a point of focus in India with recent developments. In fact, at the time of the broken rice export ban being announced, the sharp rise in demand by distilleries was identified as a reason for bringing in the ban by some quarters (Sajwan & Shagun, 2022). A variety of options are available that can be the alternatives, and their adoption can spur the next wave of production.

Bio-CNG has definitely generated considerable interest thanks to its co-benefit of solid waste management. The SATAT scheme has helped to create a market for the procurement of biogas for transport purposes. Of course, there is a question if it is suitable to push for bio-CNG in transport and not restrict its use to industrial and commercial thermal purposes. That discussion has been prompted by a series of concerns including lack of centralised biomass availability, changing and short-lasting regulatory frameworks, monopolistic and protective tendencies in the energy and waste business absence of clear rules for gas-grid, and lack of highly efficient heavy-duty gas vehicles (IRENA, 2018). However, with many of these barriers being addressed in India, bio-CNG has great potential for its adoption and the ease of transition away from liquid fossil fuels driven vehicles, particularly in the transport space as a bridge towards more advanced modes of energising transport like electric vehicles or hydrogen powered vehicles.

Methanol is being used in vehicles around the world, particularly in China, which is the world's largest user of methanol for automotive fuel (Methanol Institute, 2021) (see Case Study below). This has been driven by coal to methanol (CTM) technology, significant interest has been generated in India for pursuing the same. However, given the CTM process emissions, there has been an attempt to look at alternative feedstocks and associated processes. Biomass based methanol has shown considerable promise, where municipal solid waste and/biomass stock like crop stubble can be harnessed to make methanol. The latest research in this space explores the use of e-methanol, where carbon dioxide is used as feedstock. Methanol is also being seen increasingly as a carrier for hydrogen, with advocates suggesting the use of methanol beyond transportation.

CASE STUDY: CHINA'S ADOPTION OF METHANOL IN TRANSPORT

Demand for methanol in China has been growing steadily since the nineteen eighties, as it sought to maximise its coal resources and reduce oil imports. China's adoption of methanol has been essentially driven by its central government's policy to ensure energy security and tackle high energy prices of crude oil and the volatility around these prices (Methanol Institute, 2021).

In 2009, the Chinese central government announced a national standard for 85% methanol-blended gasoline (M85), following which some provincial governments announced standards for M15, M30 and M50 methanol gasoline (ICIS C1 Energy, 2010). In 2014 a two-year pilot program on methanol-fueled vehicle deployment in four pilot provinces and one city with an additional 1800 methanol-fueled vehicles, eventually leading to mainstreaming (Yao et al, 2018).

Increased demand has been fueled by methanol gasoline blending and dimethyl ether (DME) – the two combined account for 33% of the Chinese methanol demand.

7 million

Tons of methanol as transportation fuels last year.

5%

of China's fuel consumption in the transport space.

Green hydrogen is still a frontier in some respects, given its rather modest production figures. By 2030, India estimates to produce 5MT of green hydrogen. Comparatively, India's current grey hydrogen production is 6MT per annum. While the feedstock is essentially water and the cost of production is theoretically low thanks to cheap renewable energy, the production of electrolysers has to rise considerably. This has to be accompanied by a necessary fall in the cost of electrolysers themselves. Globally planned announcements have taken place on targets and promised investments. However, transport and storage issues still need to be addressed suitably to ensure a larger uptake across mobility. Water consumption is also another area where concerns remain. Some pilots have started in India and announcements related to setting up of large-scale production units have also been made (Pathania, 2022). Some states have also made policy announcements around green hydrogen, pre-empting significant investment opportunities in this space (figure 5). However, actual ground level action will take time to show results. The long-distance trucking segment is emerging as a contender for deployment of hydrogen. Niche areas like shipping and aviation are other contenders.

Government of India approved the National Green Hydrogen Mission on January 4, 2023. The Mission with an initial outlay of INR 19,744 crore, aims to achieve the following outcomes (PIB, 2023).

- Development of green hydrogen production capacity of at least **5 (million metric tonnes)** MMT per annum with an associated renewable energy capacity addition of about 125 GW in the country
- Over **INR 8 lakh crore** in total investments, and the creation of over **6 lakh** jobs
- Cumulative reduction in fossil fuel imports over **INR 1 lakh crore**; and
- Abatement of nearly **50 MMT** of annual greenhouse gas emissions.

The Mission, as per the official statement, is meant to facilitate demand creation, production, utilisation and export of Green Hydrogen. Financial incentive mechanisms are to be launched that target domestic manufacturing of electrolysers and enable production of Green Hydrogen. Additionally, the programme aims to identify and develop Green Hydrogen Hubs, where large scale production and/or utilisation of Hydrogen can be undertaken (PIB, 2023).

Green Hydrogen- Policy Status

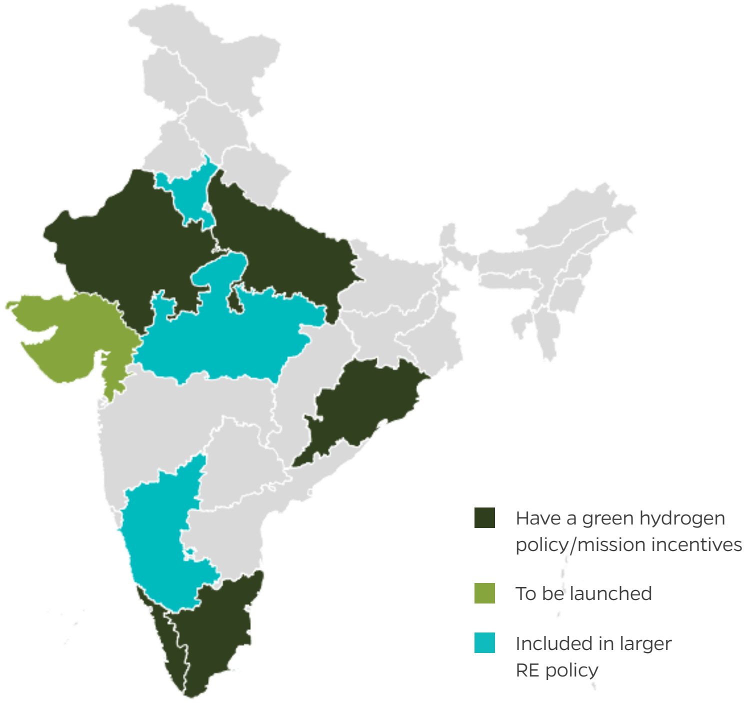

Figure 6: States with a Green Hydrogen Policy and those with plans for a Green Hydrogen Policy.

Source: Author's analysis of state policies as on January 11, 2023.

The Indian automotive market is also responding to policy signals emerging with future fuels. While 2o percent ethanol blend and 5 per cent biodiesel blend mandates do not merit much vehicle type change, there are options being considered by companies to look at vehicles that can work with higher ratios like E80 (ethanol at 80% ratio) or B100 (100% biodiesel). Companies like Toyota are working to explore other forms like flex fuel technologies as well, as they started a pilot with a flex fuel hybrid vehicle (petrol, ethanol and electric powertrain) developed for the Brazilian market (ANI, 2022). On similar lines, Volvo CE has introduced a range of construction equipment that can run on 100 percent biodiesel (Financial Express, 2022). Flex fuels can also be utilised for methanol, though there has not been any announcement around it specifically.

For hydrogen, a blending ratio of up to 20% with CNG does not necessitate any difference from current vehicle technology. Hydrogen-CNG (H-CNG) with a ratio mix of 18 percent hydrogen was approved as an automotive fuel in 2020 (Nandi, 2020). There is currently one vehicle on sale: - Dzire Tour H2 CNG - sold by Maruti Suzuki that can operate on this mix (Parikh 2020). There are no fuel cell vehicles currently available in India, though there have been announcements by Toyota (Khatri, 2022) and TVS (Autocar India, 2022) in the passenger car and two wheeler segments have come this year.

In all of this, Bio-CNG stands out without much trouble, as it does not require any changes in regular CNG vehicles, and can be used as is. This makes it rather attractive, given how the penetration of natural gas-powered vehicles has started to increase in India. In 2021, there was almost a four-fold increase in the registration of vehicles powered by CNG, driven by people opting for cheaper alternatives to petrol/diesel vehicles (Balachandar, 2022). This is particularly true of the long-distance trucking industry, with companies like Tata Motors launching new models in this space (Economic Times, 2022).

ASSESSING THE MARKET STATUS OF VARIOUS FUELS

There are different kinds of fuel alternatives today for the transport sector, though it must be pointed out that not all options would qualify necessarily as a clean fuel. For instance, coal to oil (CTO) developed through the Fischer Tropsch or other methods would still be a fossil fuel driven process (Martins & Brito, 2020). Similarly, a non-carbon fuel like methanol could also be manufactured using natural gas. However, recent technological advances of making methanol from carbon dioxide or biomass and municipal solid waste have changed the paradigm. Therefore, renewable methanol (IRENA and Methanol Institute, 2021) can be a serious contender.

Indian discourse in this matter points to a mixed approach on the subject of alternative fuels. For instance, the push for methanol is essentially seen from the paradigm of utilisation of India's coal reserves. This would disqualify methanol in the larger discussion from a Decarbonisation paradigm. Given the technology advancements, the potential for a change in the way mobility gets powered with future fuels to a large extent is a distinct possibility.

Next, when one looks at the various policies, we see three distinct set of policies that surface:

01

National Policy on Biofuels mentioning a variety of biofuels – bioethanol, biodiesel and bio-CNG.

02

National Green Hydrogen Mission giving an outline of ambitions of India to become a green hydrogen hub.

03

State policies on the two sets of options.

Apart from these policies, there are a variety of other factors that have a direct impact on the production and market outlook for the future fuels.

The paper takes a two-step approach of assessing the landscape of alternative fuels: literature review and control matrix and radar chart visualisation.

Within the literature review process, thirty factors surrounding the five alternative fuels were identified for the purpose of data collection. Information collected helped understand the evolution of the market and the current status for the five future fuels, ranging from feedstock availability and technology readiness to policy support and interest from the automotive industry. This helps to identify the factors to which there is a degree of sensitivity. Sensitivity here refers to the fact that any change in these factors leads to a change in the overall market scenario for any particular fuel. For instance, shortage of sufficient waste for producing bio-CNG due to procurement issues can gravely impact its production. These factors were then categorised into three buckets to facilitate an understanding of their impacts – Feedstock and environment parameters, Economic parameters, and Policy and ecosystem parameters (figure 7). However, it has to be pointed out that there is a certain degree of overlaps in the impact created by the factors.

Feedstock and Environment Parameters

- Nature of Feedstock
- Feedstock Collection
- Feedstock availiblity in India
- Energy/Fuel Derivation Potential in India
- Current Production Figures
- Feedstock Procurement: Impact on land use
- Feedstock to Fuel: Other raw materials required
- Conversion to Fuel: Process Efficience
- GHG Reduction Potential

Economic Parameters

- Storage Facility
- Transportation provisions needed
- Approx. CAPEX in setting up a plant
- Approx. annual OPEX
- Breakeven point (years)
- Clearances required
- Scalability
- Sale outlets and distribution channels
- Pricing mechanism

Policy and Ecosystem Parameters

- Current market penetration
- Economic Viability and Business Interest
- Technology Readiness Level (TRL)
- Properties as an automotive fuel
- Stakeholders involved in feedstock procurement, production and sale of the fuel.
- National Policy Support Programmes
- Financial Support
- Sustainability check: how does it compete with other applications?
- Interest from the automotive Industry

Figure 7: Factors influencing the landscape of future fuels.
Source: Author's analysis.

Following the literature review, a control matrix was developed based on the thirty factors to assess the progress around the five fuels in India and the current status of the various fuels in India. The factors have been first scored between a range of 0-0.1 to highlight the level of progress and the complexity of challenges around the subject, with references to the levels of achievement across the thirty parameters and the issues involved (refer annexure 2). The scores eventually feed into a radar chart (figure 8). Radar chart method was chosen because it is useful to visualise comparisons of multivariate quality data (Nowicki & Merenstein, 2016).

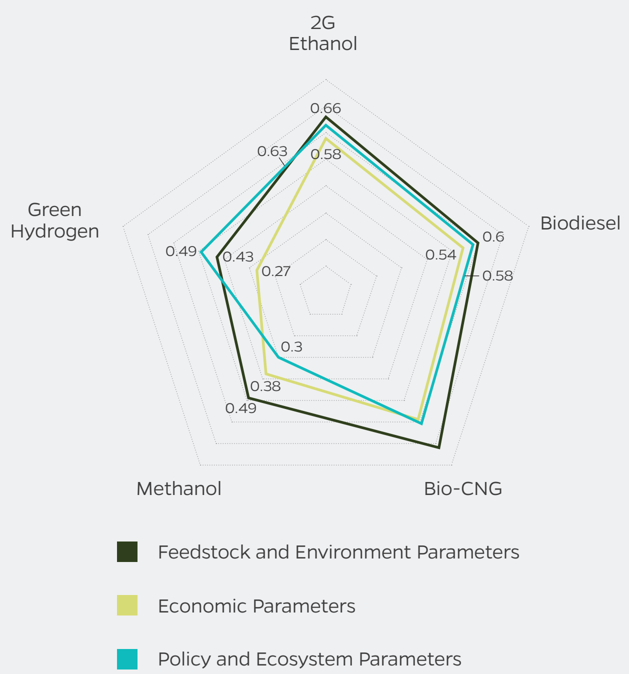

Figure 8: Present landscape of future fuel options available in India.
Source: Author's analysis.

The analysis shows that the future fuels landscape presently is skewed towards two options – bio-CNG and second generation ethanol, while green hydrogen and methanol are laggards in the present scenario. Policy ecosystem for Green Hydrogen is now at par with bio-CNG and second generation ethanol, given the recent announcement of targeted outcomes such as the creation of six lakh jobs and capital outlay of INR 19,744 crore. Such policy interventions are expected to enthuse industry, leading to substantial investments and development in the near future. Biodiesel, due to a combination of factors, fares somewhere between these two categories. However, there are uncertainties around the larger diesel ecosystem itself that threaten to further restrict its applicability. For instance, following deregulation of diesel prices in India, we have seen a considerable reduction in the uptake of new diesel vehicles in the car segment. In fact, diesel vehicles' share among Indian passenger vehicles fell drastically from 58 percent in 2012-13 to 17 per cent by March 2021 (Rampal, 2021), raising questions on the viability of biodiesel in the medium term despite procurement tenders being released by the government.

CURRENT STATUS IN INDIA - MARKET PENETRATION AND UTILITY

The current status of adoption of future fuels in India has different drivers, ranging from pollution and waste management concerns to decarbonisation and energy security. What is evident is that the market penetration levels have reached a critical level of penetration, and the same is poised to climb up further. For instance, when it comes to first generation ethanol and bio-CNG, there has been considerable pickup in the automotive space, thanks to blending mandates. Biodiesel of course did not work out, while green hydrogen is still to replace grey hydrogen at a scale of note. Methanol production in India remains on the lower side, as its usage is essentially for niche applications so far in India, and though some pilots have started in the space, it is yet to pick up.

As one examines the consumption of the future fuels, technology readiness levels and automotive properties of the various fuels stand out starkly (refer annexure 1). The lack of suitable options in the automotive space also highlight the limits to further consumption of some of the future fuels as well. For instance, while we have CNG-based flex fuel engines, the Indian market does not have ethanol-based flex fuel automotive offerings on a commercial scale yet. This has in turn led to more interest being seen in partial blending of petrol and diesel with ethanol and biodiesel.

Then other issues also slow down adoption. Under the SATAT scheme, while 5,000 plants were to come up, barely a scratch of the 3,000 odd plants granted licences have become operational. Here, the policy ecosystem is even more complex due to the involvement of urban local bodies, which cannot jointly bid for such projects. Such options and integration with other objectives must be encouraged. For instance, renewable methanol can also be produced from municipal solid waste; however, lack of a market for methanol in India beyond niche applications would raise questions on the financial sustainability of such a project (see annexure 1).

Scaling up of future fuel production projects in India can also help achieve other objectives. For instance, the Lehragaga bio-CNG plant in Sangrur of Punjab is designed to consume 100,000 tonnes of paddy straw (PIB, 2022). This paddy straw as per reports shall be procured from 6-8 satellite locations within a 10 km radius of the plant. The plant provides a much-needed alternative to stubble burning for 40,000 – 45,000 acres of farm land. Stubble burning is a major nuisance leading to air pollution in North-west India, often taking it to crisis levels, and such measures can be of extreme benefit. Second generation ethanol and renewable methanol also offer such opportunities. However, the threat of stubble procurement problems can derail such a process. Such a problem was seen with biomass-based power plants in the past, due to which the potential of the space could not be fully utilised despite great promise.

However, the sustainability of future fuels on a life cycle basis is highly susceptible to a variety of factors, as discussed earlier. First generation ethanol endangers food security as it relies on food-based biomass as feedstock, which competes with food, land and water resources. We have already seen such questions arising when the export of broken rice was banned by the Indian government some time back (Sajwan & Shagun, 2022. Long term land use change also becomes a challenge, as was seen in the case of Jatropha. Energy crops like energy cane can offer alternatives to create second generation fuels, since low sucrose content and high fibre content makes it a good feedstock for fuel, with high yield. Yet, better alternatives that do not compete with food security will always be desired. Similarly, the negative outcomes realised with corn for ethanol and jatropha for biodiesel lowered the appetite for biofuels for a while. While waste cooking oil as feedstock is rather useful from a variety of viewpoints, it must be said that the production method choice may determine energy competition.

One big challenge to the green hydrogen ecosystem – water consumption – is yet to receive adequate attention in India. On the spot renewable energy consumption for production of hydrogen is in theory an ideal. However, 54% of India faces a high to extremely high degree of water stress. Even if the current hydrogen production of 6MT were to turn entirely green, there would be a need for 132 -192 million tonnes or 134 - 195 million cu.m. of water, more than 10% of Delhi's annual water demand (Pathania, 2022).

SUMMARY AND CONCLUSION

Future fuels certainly deserve greater attention, given how it is increasingly evident that an all-electric transport sector is certainly not within reach for India by 2050. Technical and economic factors are a big determinant in the realisation that even by 2050 the world cannot go fully electric, and transport would definitely have to find solutions around its present state of operations to achieve the net zero goal. In India's case, it is also clear that segments like the four wheeler segment will definitely be using some kind of future fuel as a preferred mode.

Much of these lessons, be it in terms of production capabilities or market adoption, have been generated that show how certain fuels are better placed than the others. That is not to say that only certain fuels should be pursued; instead, this is an indicator of identifying the gaps that when filled can propel their adoption. The importance of certain segments of future fuels in energy security is certainly recognised, and it gets further credence from the fact that the Government of India has announced its intention to pitch for a global biofuels alliance at the G-20 ministerial in December 2022 (Narayan, 2022). This is critical, given how all G20 nations have committed to adoption of biofuels as part of their ambitions for mitigating climate change (Nascimento et al, 2022). However, Sustainability standards for biomass use exist in only seven of the twenty countries despite the relative widespread use of biofuels, especially in the transport sector (Nascimento et al, 2022). Clearly, much more needs to be done to ensure at the minimum, such as setting global standards on defining such a benchmark.

Similarly, the role of the developed world in raising resources to support a green hydrogen economy's emergence in the developing world is critical, involving technology transfer and finance. Richer countries have committed to significant investments for building the green hydrogen ecosystems (Pathania, 2022). With the National Green Hydrogen Mission, India too has now proposed a framework to promote production of electrolyser manufacturing capabilities and spur innovation with seed financing to develop its own capacity. India's efforts can definitely set a template for several nations in the Global South, keen to introduce robust institutional frameworks for a green hydrogen ecosystem. A platform, similar to the International Solar Alliance (ISA), will also create a forum for nations to learn from each other and provide assistance where required to hasten the transition, while ensuring efficient allocation of resources needed to nurture future fuels ecosystem. Green hydrogen is certainly important, given how many countries have featured it prominently in their net zero ambition plans at the international diplomatic fora. Given this factor, any form of inequity on this will be deemed as a violation of the common but differentiated responsibility (CBDR) principle of environmental law at many levels.

All said and done, there are challenges for future fuels. Resource selection and utilisation are critical to ensure that the concerns around the issues like food and water security for ethanol and green hydrogen are suitably addressed in India. Segregation of waste will be critical for bio-CNG's success in urban India, while supply chain disruptions can threaten such efforts in rural India. Technology options available in India are limited in the case of certain fuels even though they are rather mainstream in various parts of the world. Addressing them will be key to ensuring that the future fuels landscape in India is robust and living up to its promise.

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ANNEXURE 1:
PRODUCTION, VIABILITY AND AUTOMOTIVE PROPERTIES OF FUTURE FUELS

BIOETHANOL

Current production figures:
- Ethanol production in India stood at 3.257 billion litres last year and 2.981 billion litres in 2020. Ethanol imports into India stood at 648 million litres in 2021 and 669 million litres in 2020.

Current market penetration:
- First generation (1G) ethanol: High, as it has been in high demand for other industries as well
- Second generation (2G) ethanol: very low
- Third generation (3G) ethanol: nascent

Economic viability and business interest:
- Profitable.
- Shifting to farming for ethanol production is actively being promoted by the government to facilitate import independence and boost farmers revenue. Although setting up of the plant is expensive, the rising demand, especially from the E20 programme, means an assured market for investors.

Technology readiness level:
- High; mature technology for first generation distilleries
- Low for 2G distilleries; still an emerging technology and expensive to operate
- Nascent for 3G ethanol; although technology is proven, it has not been demonstrated to be viable on a large scale

Properties as an automotive fuel:
- Excellent additive to petrol, results in better oxidation, and hence cleaner burning and reduced engine knocking.
- Reduces tailpipe emissions. High blending percentage of ethanol in petrol means lower cost to consumers.

Transport provisions needed:
- Tractors and trailers (running on mostly diesel) carrying feed stock from farms to refineries are needed for feedstock.
- For processed fuel, trucks moving from ethanol refineries
- to crude refineries for blending, from crude refineries to fuel dispensing retail units.
- Almost all transportation provisions currently rely on fossil fuels, contributing to GHG emissions in the supply chain of bioethanol. Decarbonising it would be crucial to truly classify bioethanol as a clean fuel.

Storage facility:
- Designated storage spaces in farmlands, refineries, transportation hubs and refineries.

Capex:
- Setting up a 1G ethanol plant costs around INR 100-200 crores.
- INR 800 - 1,000 crores are approximately required to set up a 2G bioethanol refinery.
- For 3G ethanol, the capital cost has been pegged between \$23 - \$46 per GGE/year or INR 26,288 - 52,576 / litre per year (GGE refers to gasoline gallon equivalent).

BIO-CNG

Current production figures:

- Exact figures for the current biogas production are not known, as it includes plants across all scales - domestic level, community level and commercial scale commissioned under SATAT scheme.
- A 2018 study estimates the production of biogas to be over 2 billion cubic metre per year (~2.5 MMT per year) in India.

Current market penetration:

- Low. As of 2022, bio-CNG is being used in small pockets in a captive demand environment or being blended in small percentages with conventional CNG.
- Cities like Indore, Nagpur, Bhopal and Pune have been notable users, running some of their city bus fleets and garbage trucks on the fuel.

Economic viability and business interest:

- Bio-CNG plants start becoming profitable after 3-5 years as per most estimates. Given the high demand of CNG and rising petrol and diesel prices, a growing market exists.
- Businesses that have shown interest and are playing an active role are mostly localised at city level. For example, NXG Pune project, Carbon Masters (Bengaluru), Bioen, Praj industries, Spectrum Renewable Energy Limited (SREL), Green Elephant, Primove Engineering, Mahindra World City and some ULBs are showing interest.

Technology readiness level:

- High: Mature Technology, active since decades

Properties as an automotive fuel:

- Cleaner than conventional fuels in terms of CO_2, NOx, CO, Hydrocarbons and suspended particles.
- Acts as a drop-in fuel for CNG based powertrain with no component modification required in engine design and materials.

Transport provisions needed:

- Trucking network and gas pipeline infrastructure.

Storage facility:

- Site of production: Storage domes linked to the digestors, later stored in centralised facilities.
- During transportation: Highly pressurised cylinder cascades loaded in heavy duty trucks
- Site of consumption: underground storage tanks at retail outlets.

Capex:

- Producing 0.4 TPD of bio-CNG requires up to INR 1.65 crores of capex, while a 5 TPD plant requires Rs.16 crores.

BIODIESEL

Current production figures:
- 10.41 crore litres of bio- diesel was blended in 2019-20 prior to COVID lockdowns by the OMCs. This may be taken as the conservative estimate of the biodiesel production in India.

Current market penetration:
- The current penetration has declined since 2019 for a variety of reasons. Diesel consumption has been falling India and it is estimated that it will not even touch the pre-pandemic levels in FY 23 due to electrification and clean fuel adoption unlike ethanol.

Economic viability and business interest:
- Viability and business interest on biodiesel is directly linked to the diesel market, which has been struggling even after the lockdown has gone.
- While the B20 program announcement does create a market, the laggard performance of the overall diesel market can be a hurdle. Even if there are specific sectoral uses like aviation and railways taken into consideration, there is competition.
- Concerns around air pollution and its link to diesel run vehicles has also caused many automakers to focus more on petrol models. Lifetime criteria also imply that the vehicles have to be mandatorily scrapped earlier in the case of diesel powered vehicles than petrol powered vehicles. This in turn further restricts the market for biodiesel.

Technology readiness level:
- High: transesterification process.
- Alternative methods: On the use of other alternatives like algae based or pyrolysis, while technology is ready, yield and cost issues prevent from mainstreaming of technology.

Properties as an automotive fuel:
- Acceptability of bio-diesel by the automotive sector is limited due to some of its adverse properties such as cold flow properties, oxidation stability and corrosiveness with automotive fuel system materials.
- Also, when it comes to blending, the ideal mix ratio has been determined at 20%. Beyond that, there are issues seen in terms of emissions due to improper combustion.

Transport provisions needed:
- Ensure that trucks and railcars are constructed of aluminium, carbon steel, or stainless steel.
- Ensure proper inspection or washout (washout certificate) before loading.
- Check for previous load carried and residual. Generally only diesel fuel or biodiesel is acceptable as a residual. If the vessel has not gone through a washout, some residuals (including food products, raw plant oils, gasoline, or lubricants) may not be acceptable.
- Ensure that there is no residual water in the tank.
- Check that hoses and seals are clean and made from materials that are compatible with B100.
- Determine the need for insulation or a method to heat truck or rail car contents if shipping during cold weather.
- Regardless of how the biodiesel arrives, procedures that prevent the temperature of B100 from dropping below its cloud point must be used to store and handle it.

Storage facility:
- Most tanks designed to store diesel fuel will store B100 with no problem. Acceptable storage tank materials include aluminium, steel, fluorinated polyethylene, fluorinated polypropylene, Teflon®, and most fibreglass.
- Brass, bronze, copper, lead, tin, and zinc may accelerate the oxidation of diesel and biodiesel fuels and create fuel insolubles (sediments) or gels and salts when reacted with some fuel components.
- Lead solders and zinc linings should be avoided, as should copper pipes, brass regulators, and copper fittings. The fuel or fittings tend to change colour, and insolubles may plug fuel filters. Affected equipment should be replaced with stainless steel, carbon steel, or aluminium.

Capex:
- $5.94/litre or around INR 490/litre.

METHANOL

Current production figures:
- India's production capacity is 4.74 lakh MT. However, capacity utilisation is only 49%.
- Recently, a coal to methane pilot has been launched using 0.25 tonnes per day of methanol from 1.2 tonnes per day of high ash Indian coal.

Current market penetration:
- Limited penetration. Attempts to increase its utilisation in the economy for energy purposes has seen limited success at best.

Economic viability and business interest:
- There is a significant economic case for increasing production within India and also deploying it across the energy sector's spectrum of uses. From blending to conversion, there are several kinds of uses.
- This also creates opportunities that complement other industries like hydrogen.

Technology readiness level:
- Gas and coal based - high.
- Biomass based - medium
- CO2 based - low.

Properties as an automotive fuel:
- Although slightly lower in energy content than petrol and diesel, methanol can replace both these fuels in the transport sector (road, rail and marine), energy sector (comprising DG sets, boilers, process heating modules, tractors and commercial vehicles) and retail cooking (replacing LPG [partially], kerosene and wood charcoal).
- Blending of 15% methanol in gasoline can result in at least 15% reduction in the import of gasoline/crude oil. In addition, this would bring down GHG emissions by 20% in terms of particulate matter, NOx, and SOx, thereby improving the urban air quality.

Transport provisions needed:
- All shipping containers (tank cars, tank trucks, barges, drums and barrels) should be of carbon steel and in a clean and dry condition prior to loading.
- Air pressure should never be used to load or unload methanol. Pumping is preferred but inert gas should be used when pressure loading or unloading.

Storage facility:
- Methanol should be stored in clean containers made from either mild steel, stainless steel, high density polyethylene or vulcanised natural rubber. Unsuitable container materials include zinc, aluminium, magnesium, magnesium alloys, lead, tin, titanium, plasticised PVC, polystyrene or polymethyl-methacrylate. Storage tanks should be constructed with an internal floating roof and an inert gas pad to minimise vapour emissions.
- Methanol should be stored in well-ventilated areas away from direct sunlight and moisture. It should not be stored with oxidising materials such as perchlorates, chromium trioxide, bromine, sodium hypochlorite, chlorine or hydrogen peroxide, owing to fire and explosive dangers.
- Because of the flammability of methanol, storage tanks should be enclosed by a dike and protected by a foam-type (either carbon dioxide or dry chemical) fire- extinguishing system.

Capex:
- Capital costs for large-scale methanol plants vary from $200/tpy of capacity to $700/tpy of capacity (INR 16,328 - 57,146 /tpy), although the average is approximately $530/tpy (INR 43,268) of capacity.
- 1,560-2200 USD/t (INR 1,27,354 - 1,80,000) for biomass based methanol plant; 2,000- 2,780 USD/t (INR 1,63,000 - 2,26,960) for MSW based ethanol plant.
- The current production cost of e-methanol is estimated to be in the range of $800-$1,600/ mt (INR 65,310 - 1,30,620) assuming CO2 is sourced from BECCS (bioenergy with carbon capture and storage) at a cost of $10-$50/mt (INR 810 - 4,060). If CO2 is obtained by DAC (direct air capture), where costs are currently $300-$600/ mt (INR 24,491 - 48,982), then e-methanol production costs would be in the range $1,200- $2,400/mt (INR 97,965 - 1,95,930).
- In India, the per litre cost of methanol production in India is INR 25-27 or even more depending on the volatility in the price of imported natural gas.

GREEN HYDROGEN

Current production figures:
- Green hydrogen production in India is insignificant in production terms for now.

Current market penetration:
- Negligible.

Economic viability and business interest:
- Green hydrogen has definite interests, with major oil and gas companies of India announcing plans to engage in its production. They have even announced that they will ensure that the price of hydrogen comes down significantly.

Technology readiness level:
- Medium to high, depending on the choice of electrolysers.

Properties as an automotive fuel:
- Hydrogen storages have energy storage densities that are less than those for gasoline storages on both mass and volume bases. This is especially an issue in automotive applications of hydrogen as a fuel.
- Also, from an automotive perspective, the overarching technical challenge is the ability to store the necessary amount of hydrogen required for a conventional driving range (greater than 300 miles), within the constraints of weight, volume, durability, efficiency, and total cost.

Transport provisions needed:
- Current pipelines for natural gas and LNG transport containers can be repurposed for blended hydrogen. Similarly, carrier liquids can be deployed to achieve the same.

Storage facility:
- Storing hydrogen can be a challenge because of volumetric requirements. Its embrittlement and corrosive properties also restrict the kind of materials needed for this purpose. The options needed are currently on the expensive side, but their cost may come down.
- Repurposing the existing infrastructure for the storage of transport is possible when it comes to certain blend percentages (ideally under 20%).

Capex:
- The average costs for a 1 MW unit could vary significantly: from around 550 USD/kWh (INR 44,900) (for alkaline technologies) to more than 6,500 USD/kWh (INR 530,644) (for solid oxide ones).

ANNEXURE 2:

Parameter	2G Ethanol	Biodiesel	Bio-CNG	Methanol	Green Hydrogen	Scoring Implication
Feedstock and Environment Parameters						
Nature of Feedstock	0.06	0.06	0.08	0.04	0.03	(lower score means more nuanced feedstock requirements in current form. For instance, biodiesel programme in India needs used cooking oil, while 2G ethanol looks at biomass stock. Unlike these wastes, green hydrogen needs fresh water.)
Feedstock Collection	0.06	0.06	0.05	0.03	0.03	(higher score means easier availability of feedstock)
Feedstock Availibility in India	0.09	0.07	0.09	0.08	0.05	Higher score refers to greater feedstock availability)
Energy/Fuel Derivation Potential in India	0.08	0.08	0.08	0.08	0.07	Higher score means greater potential)
Current production Figures	0.06	0.03	0.05	0.01	0	(higher score means greater production)
Feedstock Procurement: Impact on land use	0.03	0.03	0.07	0.04	0.04	(lower score means greater impact on land use)
Feedstock to Fuel: Technology	0.07	0.07	0.07	0.05	0.04	(lower score means more complex technology)
Conversion to fuel: Other raw materials required	0.08	0.08	0.08	0.04	0.04	(lower score means greater dependency on other raw materials)
Conversion to fuel: Process Efficiency	0.07	0.06	0.08	0.08	0.06	(higher score means better process efficiency)
GHG Reduction Potential (GHG emitted during the process vs GHG prevented by end use)	0.06	0.06	0.07	0.04	0.07	(higher score means greater mitigation potential in current form)
Total	**0.66**	**0.6**	**0.72**	**0.49**	**0.43**	

Parameter	2G Ethanol	Biodiesel	Bio-CNG	Methanol	Green Hydrogen	Scoring Implication
Economic Parameters						
Storage facility	0.08	0.08	0.08	0.04	0.01	(lower score means difficulty in storage)
Transportation provisions needed	0.04	0.04	0.04	0.04	0.02	Lower score means easier to transport
Approx. CAPEX in setting up a plant	0.07	0.06	0.08	0.04	0.02	(higher score means lower capex)
Approx. annual OPEX	0.06	0.05	0.05	0.03	0.01	(higher score means lower capex)
Breakeven point (years)	0.07	0.06	0.06	0.03	0.03	(lower score means longer breakeven point)
Clearances required	0.05	0.05	0.05	0.06	0.04	(lower score means more clearances)
Scalability	0.08	0.07	0.08	0.06	0.06	(higher score means higher scalability)
Sale outlets and distribution channels	0.05	0.05	0.05	0.01	0.01	(direct sales do not take place; instead, blending of fuels takes place)
Applications of the fuel	0.03	0.03	0.05	0.06	0.06	(higher score refers to higher applicability)
Pricing Mechanism	0.05	0.05	0.05	0.01	0.01	(higher score refers to existence of mechanism and suitability of price regime)
Total	**0.58**	**0.54**	**0.59**	**0.38**	**0.27**	

Parameter	2G Ethanol	Biodiesel	Bio-CNG	Methanol	Green Hydrogen	Scoring Implication
Policy and Ecosystem Parameters						
Current market penetration	0.06	0.04	0.06	0.01	0.01	(higher score means greater penetration in transport sector)
Economic Viability and Business Interest	0.07	0.07	0.06	0.04	0.04	(higher score means good level od economic viability and business interest extant)
Technology Readiness Level (TRL)	0.08	0.08	0.08	0.07	0.04	(higher score refers to better TRL)
Properties as an automotive fuel	0.07	0.06	0.08	0.06	0.05	(higher score refers to ease of use in ICE engines)
Stakeholders involved in feedstock procurement, production and sale of the fuel	0.06	0.06	0.05	0.02	0.01	(higher score refers to value chain depth and number of players involved)
National Policy Support Programmes	0.1	0.1	0.1	0.05	0.1	(higher score refers to greater clarity in policy at central levels)
State level Policy Support Programmes	0.05	0.05	0.03	0	0.05	(higher score refers to significant states putting out policies to support alternative fuels)
Financial Support	0.03	0.03	0.03	0.01	0.07	(lower score refers to lower financial support)
Sustainability check: how does it compete with other applications?	0.05	0.05	0.06	0.02	0.06	(higher score refers to greater sustainability)
Interest from the automotive Industry	0.06	0.04	0.06	0.02	0.06	(higher score refers to greater interest from automotive industry)
Total	**0.63**	**0.58**	**0.61**	**0.3**	**0.4**	

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