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ASIAN CLEAN FUELS ASSOCIATION

ENHANCING INDIA'S BIOFUELS PROGRAMME

Examining the Role of Oxyfuels in India's Clean Fuel Transition

Knowledge Partner

THE ENERGY AND RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future

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MESSAGE FROM THE **DIRECTOR-GENERAL, TERI**


Vibha Dhawan, PhD

As the Director-General of The Energy and Resources Institute (TERI), I am delighted to present this report which is the result of joint efforts by TERI and the Asian Clean Fuels Association (ACFA). The publication focuses on the significance of India's multi-fuel opportunity and the transformative role of fuel ethers in driving a sustainable energy future.

To steer India towards a greener and sustainable path, the Government of India, has undertaken several landmark policy measures. Notable initiatives include the removal of subsidies for petrol and diesel, incentivizing electric vehicles in 2019, providing fuel gas for cooking to millions of households, and scaling-up emerging technologies like battery storage, low-carbon steel, cement, and fertilizers. Furthermore, the government's emphasis on creating 'Fuels of the Future,' including the expansion of alternate fuels such as green hydrogen, marks a decisive shift towards cleaner energy sources.

Amidst these endeavours, India's status as the third-largest user of transport automobiles worldwide has highlighted the urgent need to strategically reduce our dependence on imported fossil fuels. The promotion of India's 'ethanol economy' through the Ethanol Blended Petrol (EBP) Programme has been a significant step in effective realization of this goal. The Programme, over the years, has made a noteworthy contribution in steady increase in ethanol blending, is a testament to India's commitment to create a more sustainable and self-reliant fuel ecosystem.

Fuel ethers can catalyze positive economic and social impacts. By mitigating air pollution, we can alleviate its adverse effects on public health, productivity, and overall well-being, fostering a healthier and more resilient society. The affordability and accessibility of cleaner fuels through fuel ethers can positively impact the lives of millions of Indians, promoting equitable energy access. The tailwinds for energy security and economic gains can help project India's status as a major global economy.

As we strive together to promote sustainability, this report presents an extensive analysis of ETBE, MTBE, and other fuel ethers, examining their availability, environmental impact, economic feasibility, and technical viability. This study serves as a fundamental basis for investigating a 'complementary fuel approach for India' by combining ethanol and ETBE.

My sincere appreciation goes out to the diligent researchers, knowledgeable experts, and dedicated contributors whose invaluable perspectives have made significant contributions towards the development of this report. United as a team, let us welcome the diverse possibilities of multi-fuel utilization, guiding India towards a future of sustainability and prosperity in the energy sector.

MESSAGE FROM THE **EXECUTIVE DIRECTOR, ACFA**

Mr Clarence Woo

As the Executive Director of the Asian Clean Fuels Association (ACFA), I take great pride in presenting this collaborative report by ACFA and TERI, centred on India's multi-fuel opportunity and the pivotal role of fuel ethers in shaping a sustainable tomorrow.

Amidst the global battle against climate change, India has taken momentous strides by committing to ambitious targets of achieving net-zero emissions by 2070 and meeting 50% of its electricity demands from renewable sources by 2030. Yet, the pressing challenge remains, India's considerable reliance on fossil fuels for transportation energy, accounting for a staggering 70% of our energy consumption.

To effectively address this challenge, a unified approach is essential, with policy measures aligned to the government's vision of enhancing India's carbon neutrality. The government's emphasis on 'fuels of the future,' sets the stage for innovation and transformative change in our energy landscape.

As a complementary solution, India can explore integration of fuel ethers into its proposed fuel blend. Fuel ethers like ethyl tert-butyl ether (ETBE), methyl tert-butyl ether (MTBE), tert-amyl methyl ether (TAME), and tert-amyl ethyl ether (TAEE) offer numerous benefits, enabling cleaner burning of petrol in engines and acting as octane boosters, replacing undesirable compounds that may have critical technical or toxicological properties. Ethers have been widely adopted in other countries, and their advantages have been demonstrated through demonstrative case studies.

The multifaceted advantages of incorporating fuel ethers into India's fuel mix cannot be overstated. Fuel ethers contribute to lower harmful emissions, reduced particulate matter, and improved fuel combustion, significantly improving air quality. Moreover, they help reduce Scopes 2 and 3 emissions, offering a viable and cost-effective option to curb total greenhouse gas (GHG) emissions. Their direct production at refineries substantially reduces emissions related to distribution logistics and handling, thereby enhancing energy security. Implementing fuel ethers as part of the fuel blend offers potential cost-benefits, improved fuel efficiency, and a more sustainable energy ecosystem.

As we collectively endeavour to foster sustainability, this report provides a comprehensive assessment of ETBE, MTBE, and other fuel ethers, evaluating supply and demand, environmental implications, economic viability, and technical perspectives. It serves as a foundation for exploring a 'complementary fuel strategy for India' through the co-blending of ethanol and ETBE. This strategy offers the potential for upgraded fuel quality, alignment with gasoline trade flows, and the realization of India's aspirations for higher research octane numbers (RON) and improved transportation efficiency.

Through this report, we endeavour to provide valuable insights and a comprehensive assessment of India's biofuels programme, focusing on the co-blending of ethanol and ETBE, thereby charting a course to optimize fuel quality, trade flows, and transportation efficiency.

This report would not have come in its present form without the untiring efforts of TERI's researchers, experts, and contributors. Together, let us seize India's multi-fuel opportunity and propel the nation towards a greener and more prosperous future that serves as a beacon of environmental stewardship for the world.

While the ethanol blending programme has numerous benefits, such as conserving foreign exchange reserves, promoting domestic agriculture, and addressing environmental concerns, we must thoroughly evaluate its expansion. Challenges, such as potential implications on food security due to increased feedstock production and the technical impact of ethanol-blended fuels on the environment, warrant thoughtful consideration. Additionally, the infrastructural challenges related to ethanol storage and transportation further emphasize the need to explore complementary strategies.

CONTENTS

ACKNOWLEDGEMENTS

This report is the outcome of the study 'Examining the Feasibility of Adopting Advanced Biofuels like MTBE and ETBE in India: Challenges and Opportunities' conducted by The Energy and Resource Institute (TERI). This important study was carried out with the financial support from Asian Clean Fuels Association (ACFA). TERI is deeply grateful to Dr Clarence Woo, Executive Director, ACFA for putting his trust in TERI team. The project could not have been accomplished in the absence of his constant support.

TERI would like to thank all the individuals, experts, and organizations who had provided guidance and feedback during the course of the study. The Institute is deeply grateful to all the valuable insights it gained through participation of various stakeholders during two e-consultation workshops arranged by ACFA and FTI. The stakeholders, included but not limited to Ministry of Petroleum and Natural Gas (MoP&NG), Ministry of New and Renewable Energy (MNRE), NITI Aayog, Oil refineries like Indian Oil Corporation Limited (IOCL), Hindustan Petroleum Corporation Limited (HPCL), Bharat Petroleum Corporation Limited (BPCL), Nayara Energy Limited, SIAM, Adani Total Gas, LyondellBasell Industries, Saudi Basic Industries Corporation(SABIC), Evonik Industries AG, Saipem, ECOFUEL.

The technical consultations with Dr Walter R. Mirabella, Chairman, Global Fuel-Ethers Industry Technical Team, Mr Hendrik Fischer Evonik, Dr Mohammad Bismillah Ansari of SABIC proved invaluable as they provided authenticity to the work. The project team would like to acknowledge the contributions from Mr Shri Prakash, Project Internal Adviser and Distinguished Fellow at TERI for his support and expert insights in the internal meetings throughout the study.

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Ms Lilis Susanto and Ms Nurfarahis Linda from ACFA do require special mention for providing us with the administrative support. Efforts of our colleague, Mr Swapan Das, are truly appreciated. We would like to extend our gratitude to TERI Press for carrying out editing and designing of the report.

TERI team believes that the outcome and recommendations from this detailed study will encourage and benefit policymakers in India to make informed decisions in modifying the biofuel policy.

EXECUTIVE SUMMARY

Executive Summary

In the global fight against climate change, India has taken an aggressive step by committing to reach its net-zero targets by 2070 and meeting 50% of its electricity requirements from renewable energy sources by 2030. Being the third-largest user of transport automobiles in the world, India's dependence on fossil fuels for transport energy is relatively high (70%).[1] To counter this dependence and achieve net-zero goals, collaborative policy measures that are in sync with the steps taken by the government to improve India's carbon neutrality are needed. Aligned with this, Prime Minister Modi has also emphasized 'fuels of the future',[2] including the expansion of alternate fuels such as green hydrogen.

Biofuels have emerged as a viable way to reduce the country's dependence on imported fossil fuels, through the expansion of the Ethanol Economy, and promotion of Ethanol Blended Petrol Programme (E20) preponed from 2030 to 2025. However, this approach presents some latent challenges, including issues related to food security, environmental impact, infrastructural challenges, and scalability. The Government of India has also announced that from April 2020 onwards, all vehicles sold in India must comply with Bharat Stage VI Emission Standards, notably for making improvements in three principal areas—emission control, fuel efficiency, and engine design.

With the success of the Ethanol Blending Programme, the Government of India can expand its portfolio of other new alternative fuel blends such as green hydrogen and fuel ethers. Fuel ethers such as ethyl tert-butyl ether **(ETBE), also colloquially referred to as 'easily to blend with ethanol'**, and methyl tert-butyl ether (MTBE), are efficient fuel components which enable cleaner burning of petrol in engines. The most significant advantages of ethers include the following:

» **Energy security and balance of trade**

Fuel ethers are directly produced at refineries and are widely available for import or local production in India. The Indian MTBE market is expected to grow at a compound annual growth rate (CAGR) of 5.9% by 2030,[3] with 75% used in gasoline-blending applications. There are many significant players already producing ethers in the Indian market including leading Oil Marketing Companies (OMCs) such as Indian Oil Corporation Limited, Haldia Petrochemicals, Hindustan Petroleum Corporation Limited, Bharat Petroleum Corporation Limited, and Reliance Energy. With the raw materials for ethers already available in India, the ability to meet the growing demand of fuel ethers, can be met domestically itself. Fuel ethers can also significantly contribute to the energy security and climate change agenda of the country by its direct impact on the reduction of Scopes 2 and 3 emissions (no secondary distribution infrastructure). They also have a higher energy content, resulting in improved combustion, higher fuel efficiency (less energy needed per travelled mileage) and reduced greenhouse gas (GHG) emissions. ETBE-blended gasoline can reduce GHG emissions up to 30% more than E10 compared to ethanol-free (or non-oxygenated) gasoline.[4,5]

» **Financial viability and social impact**

India incurred loss of USD 45 billion in 2019 as the country faced a total of 1.7 million deaths due to air pollution (18% of all fatalities).[6] Each year, air pollution costs Indian businesses nearly USD 95 billion. This translates to 3% of the gross domestic product (GDP). Improving air quality thus has significant social and economic benefits and fuel ethers can play a decisive role in this transition. In addition, fuel ethers will reduce the car maintenance costs and the costs per travelled mileage, thus effectively the cost to the consumer will reduce. Using ethers in the gasoline blend opens up the opportunity for refiners to blend low-value blending stock like C4 and C5 streams in the finished petrol. Owing to the volumetric gain when adding ethers, refiners will enjoy larger volume to sell. No additives are necessary while blending ethers, this represents savings to refiners.

» **Cleaner air—reducing the impact of air pollution**

Addition of fuel ethers to fuel blends results in the release of less harmful evaporative and combustion emissions — lower total volatile organic compounds (VOCs), total toxics, oxides of nitrogen (NO_x), total hydrocarbons (THC), and less ozone formation. In addition, they also improve the RON of gasoline (in line with BS VI requirements) when blended, resulting in cleaner combustion and less evaporative emissions. With up to 15% less aromatics blended into the gasoline, fuel ethers emit comparatively less particulate matter ($PM_{2.5}$), thus contribute towards air pollution mitigation.

» **Reliable fuel quality at the pump**

With the BS framework, the fuel quality upgradation programme in India has mandated various characteristics to which regular and premium fuels need to adhere to. The octane number was further increased to 91 and 95 for regular and premium, respectively, under BS III and beyond.[7] The octane number of petrol indicates the quality of fuel. The higher the octane number, better the quality. Fuel ethers help refiners achieve optimization, improvement in refinery's flexibility and energy efficiency by relaxing severity of the refinery's operating units, include less valuable refining streams (C4+) in the gasoline pool, while adhering to the RVOP value of BS VI gasoline specification and improving overall production costs and sustainability factors. This also reduces quality issues (no impact of comingling leading to off-spec fuel) and allows consistent fuel quality along the distribution (direct from refinery) to the pump sites.

Globally, MTBE is used in regions that together account for around half of the global gasoline demands. Key MTBE markets include China, other Asian countries, Middle East, and South America. Projections suggest highest growth in gasoline demand would be reached by 2030. Global demand for fuel ethers is led by China (37%), followed by the Middle East (16%), other Asia (14%), Europe and Latin America (13%), and Former Soviet Union FSU (6%). The most advanced G20 and Organization for Economic Co-operation and Development (OECD) countries need a transition plan—an energy transition pathway involving liquid fuels as part of the energy mix solution. The rest of the developing world is projected to continue to utilize liquid fuels even longer, with demand peaking up only by 2045. This means that a larger global problem will still need to be resolved for air pollution, GHG, fuel efficiency, and energy economics for both consumers and environment.

Given these considerations, the study is an assessment of ETBE, MTBE group of oxygenates/ethers from supply and demand, environmental, economic, and technical perspective. It serves as a baseline for further assessment towards Enhancing India's Biofuels Programme—co-blending of ethanol and ETBE—the benefits of which will lead to an upgrade in fuel quality facilitating alignment to gasoline trade flows (no niche markets); meeting of India's higher RON aspirations, increasing efficiency in transportation.

REPORT **AT A GLANCE**

REPORT AT A GLANCE

- In 2021 road transport in India accounted for 14% of the total energy consumption against 20% of the global average.
- In 2021 at ~280 Mt CO2, India's road transport accounted directly 12% of the total energy related and > a quarter energy demand related CO2 emission
- Transport sector in India is the third-largest energy-related GHG emitter.
- Higher ethanol and methanol blends will have a potential impact on the environment and food security concerns.
- Stringent specs for lesser emission and higher engine efficiency (95 RON under BS VI) have become inevitable, which conventional gasoline components like reformate and isomerate may not help in achieving.
- Ether alcohol co-blend options offer a viable solution for achieving GHG reduction target, social and economic impact.
- By considering MTBE/ETBE into the oxygenates mix, India can meet its higher RON aspirations, contribute to fuel economy, and improve air quality.
- Ether alcohol co-blending will deliver synergistic advantage including ease of use C4/C5 valorization making it cost effective
- Ether alcohol co-blending will fix certain drawbacks of only ethanol blending like commingling, water tolerance, material compatibility and Scope 1+2 emission
- Ethanol is best served infused with ETBE. India can consider producing ETBE from its own 2G ethanol production.
- Advanced R&D for Renewable ETBE and Bio MTBE for using bioethanol, biomethanol and domestic low-cost waste feedstocks to secure supply chain sustainability.

KEY BENEFITS OF FUEL ETHERS

Benefits for Policy Makers

ENERGY SECURITY AND BALANCE OF TRADE

- Fuel ethers are already directly produced at the refinery (no additional Scopes 2 and 3 emissions in its distribution and production value chain) and are widely available for import or local production in India.
- ETBE-blended gasoline can reduce GHG emissions up to 30% more than E10 compared to ethanol-free or non-oxygenated gasoline.
- Raw materials for production available in India, domestic ability to meet the growing demand of fuel ethers is self sufficient.

FINANCIAL VIABILITY AND SOCIAL IMPACT

- Significant health benefits to cleaner air have a direct impact on the GDP of India
- Less costs to refiners due to higher energy efficiency in operating refinery units, no need of additional anti-foaming agents and CAPEX expenditures, valorization of low value, high RVP refinery streams such as C4/C5.
- Less costs to consumers due to less corrosion and therefore maitenance of the cars, fuel efficiency - less costs per mileage

Benefits for Refiners

CLEANER AIR: REDUCING THE IMPACT OF AIR POLLUTION

- Lower harmful evaporative and combustion emissions - lower total VOC, total toxics, oxides of nitrogen (NOx), total hydrocarbons (THC), and avoid ozone formation.
- Improves the RON of gasoline (in line with BS VI requirements), when blended
- Cleaner combustion and less evaporative emissions (upto 15% less reformate/aromatics blended into the gasoline) – less particulate matter (PM2.5), compared to ethanol, which has a cooling effect on combustion and therefore leads to more PM2.5 generation.

RELIABLE FUEL QUALITY AT THE PUMP

- Blended fuels offer consistent and reliable fuel quality, with direct blending at the refinery itself
- No impact of comingling effect of different ethanol blends, leading to off-spec fuel
- Consistency in fuel quality during distribution (direct from refinery) to the pump sites

INDIA'S CLEAN FUEL **ROAD MAP SO FAR**

Energy transition is composed of three sub-transitions—power sector transition, mobility transition, and industrial decarbonization. In India's case, these three collectively account for about 70% of the total emissions (40% from the power sector, 10% from road transport, and 20% from industry). All three are unfolding in parallel, but at different phases of evolution, with the most mature being the power sector transmission. In India, the mobility transition has been prioritized as a 'significant push to EV', but it needs to go beyond that. A global by-product of modernized urban existence includes a substantial impact on air quality across countries. This is caused not just by the rapid industrialization processes (power plants, construction, industrial smoke) but also by tailpipe exhaust emissions in growing cities and towns. This has also resulted in a range of health issues, in some cases, directly correlated to the types of emissions in the air.[8] The World Health Organization (WHO) has consistently red-lined the danger to human health from air pollutants.

Historically, India had to take considerable steps in promoting and mandating clean fuels. Indian fuel upgradation programme that began in 1991 with notification of vehicular emission norms for new vehicles was revised in 1996. India has followed a regulatory pathway for fuel quality and vehicle emissions standards termed as Bharat Stage (BS). The BS Standards regulate tailpipe emissions of air pollutants including particulate matter ($PM_{2.5}$), SO_x, and NO_x, carbon monoxide, hydrocarbons, and methane. They have been developed for all vehicle categories and apply to vehicles manufactured since April 2020. BS 2000 (Euro 1 equivalent, BS I) vehicle emission norms were introduced for new vehicles from April 2000. BS II (Euro 2 equivalent) emission norms for new cars were introduced in Delhi from the year 2000 and were subsequently extended to the other three metro cities in 2001. The emission norms for CNG and LPG vehicles were notified in the year 2000 and 2001,[7] respectively.

India's current gasoline standards took effect on 1 April 2010. These standards required marked improvements from pre-2010 levels. Under BS II, the octane number had increased to 88 and 93 for regular and premium fuels, respectively. It was further increased to 91 and 95 for regular and premium fuels, respectively, under BS III and beyond. BS IV Standards were implemented in 2017 while in April 2020, India leapfrogged from BS IV to the implementation of BS VI, with current standards like Euro 6 norms. The shift of Indian gasoline specification over last 20 years is shown in **Table 1**. Transitioning from BS IV to BS VI standards led to a significant drop of diesel-powered passenger cars from 30% in 2019 to 18% in 2020. Concurrently, there has also been a significant shift from diesel to gasoline engine vehicles in the category of light commercial vehicle (LCV) fleet.[9,10,11]

Upgrading global average gasoline octane is of manifold benefit in improving the fuel economy, energy efficiency, global fuel standards, enhancing GHG benefits and reducing air pollution. Around 75% of the world's petrol is run on 91/92 RON (on average or lower).[12] An immediate and cost-effective solution can be employed with an upgrade of global octane requirement to a minimum of 98 RON (or at least 95 RON) from the current global average of 91/92 RON). Many developed countries are pushing towards higher RON (for example, 102 in Europe). The upgrade of octane from 90 RON to 95 RON alone brings an immediate fuel economy improvement by 2% to 10%. The value of improving fuel is immense, as it helps

TABLE 1: Advancements in India's gasoline specifications

Characteristics	Unit	BS II	BS III	BS IV	BS VI
Implementation date		**2001 (select cities) 2005 (nationwide)**	**2005 (select cities) 2010 (nationwide)**	**2010 (select cities) 2017 (nationwide)**	**2018 (NCT) 2020 (nationwide)**
Density 15°C	kg/m³	710–770	720–775	720–775	720–775
Research octane number (RON)	Min.	88/93⁺	91/95⁺	91/95⁺	91/95⁺
Anti-knock Index (AKI) or	min	84			
motor octane number (MON)			81/85⁺	81/85⁺	81/85⁺
Sulphur, max	ppm	500	150	50	10
Lead, max	g/L	0.013	0.005	0.005	0.005
Benzene, max	% volume	3 (metro) 5 (nationwide)	1	1	1
Aromatics, max	% volume	-	42	35	35
Olefin, max	% volume	-	21/18⁺	21/18⁺	21/18⁺
Oxygen content, max	% mass	-	2.7	2.7	3.7/4.5⁺
Reid vapour pressure (RVP) @ 37.8 @C, max	kPa	35-36	60/67	60/67	67

⁺ Fuel quality specification for premium gasoline

automakers meet CAFE and global fuel standards. Nevertheless, there are striking differences in market share of high-grade gasoline and octane in countries such as EU against Asia, the Middle East, and Africa. There are several regular grade gasoline types in service stations except EU RON 95 blend gasoline. The consumer trends in US, Canada too indicate a shift to high RON. Worldwide Fuel Charter has recommended RON 98 and RON 102.[13] As long-term targets for 2030

Around 75% of the world's petrol is run on 91/92 RON (on average or lower). An immediate and cost-effective solution can be employed with an upgrade of global octane requirement to a minimum of 98 RON (or at least 95 RON) from the current global average of 91/92 RON and beyond are made, the focus globally has shifted to emission reduction and renewable/alternative energy developments. The flip side is that the higher-octane gasoline comes at a price for the producer and the present challenge is to recover this in the end-use market. Octane enhancers such as fuel ethanol and MTBE/fuel ethers are the most cost-effective way of upgrading the octane in fuels.

The current gasoline octane mix shows the need of India as high-octane proponent to focus on enhancing the fuel compression ratio presented in **Table 2**. As a successful strategy, several countries in the world are using ETBE, MTBE as an enabler for higher RON fuels towards achieving their air quality, decarbonization and sustainability goals. India with its expansive biofuels policy, can also consider ether-blended fuels as a tool to further strengthen its transition to clean fuels.

TABLE 2: Gasoline octane mix and future scenarios[14]

Country	2020 octane mix-market share	2025 and beyond octane mix market share	Comments
China	89 / 92 / 95 / 98 15%/ 40%/ 40%/ 5%	92 / 95 / 98 40%/ 50%/ 10%	While China has the highest gasoline quality standards, current octane ratings are well below EU standards, leaves plenty of space for improvements
India	91 / 95 / 98 96% / 3% / <1%	91 / 95 / 98 90% / 10% / <1%	India transitioned from Bharat IV (Euro 4) to Bharat IV (BS VI equivalent to Euro 6) fuel standards, 95 RON market share expected to grow to >10% on consumer preference
Taiwan	92 / 95 & 98 20% / 80%	92 /95 & 98 10% / 90%	Mature market, running on Euro 5/6 equivalent standards, (% and higher RON grades represent 80%. could move towards 95 min
Indonesia	88,90,92/95/98 >80% />17%/2%	92 / 95 / 98 80 / 15 / 5	Upgrading fuel standards to Euro 4 and phasing out 88 and 90 RON gasoline, leading to a substantial increase in octane demand
Malaysia	95 / 97 / 98 85% / 14% / 1%	95 / 97 / 98 90% / 9% / 1%	Upgrading fuel standards to Euro 5M (Euro 5 equivalent) by 2024
Japan	90 / 99 92% / 8%	95 / 98 85% / 15%	Declining demand, Euro 6 equivalent standards but 'low-octane' market (consumer cost awareness), requires fuel standard review, considered unlikely

» Top three gasoline-consuming countries already at best possible levels in fuel quality standard
» China and India the high-octane proponents can focus on enhancing the compression ratio of fuels
» IOC introduced India's first 100-octane gasoline; ACFA sees enormous potential for octane growth
» EU consolidated use of ETBE and using 5% ethanol (average) after 20 years' experience[15]
» EU: ETBE blending 5.5% (France), 4.9% (Slovakia), 12.7% (Spain)[15]
» EN228: ETBE and ethanol blending % in E5 (avg.) is ethanol 4.08%, ETBE 3.53%, ethanol equivalent 5.7 %[15]

UNDERSTANDING OXYFUELS(ETHERS) AND **THEIR ENABLING ROLE IN ENHANCING CLEAN FUELS AMBITION OF INDIA**

Fuel ethers, including MTBE, bio-MTBE, bio-ETBE, TAME, bio-TAME and TAEE, are the key components in the production of high-octane fuels. They are the clean and efficient replacement for compounds, for instance, toxic lead that poses a proven risk to health and the environment. Whether manufactured from traditional hydrocarbons or renewable biomass, fuel ethers are more energy denser than alcohols. Therefore, they increase petrol's performance, while reducing the emissions of air pollutants and CO_2 across their life cycle and have several benefits for consumers, vehicle producers, and refiners.[16]

CONSUMER

- **Improved fuel efficiency:** Allowing cars to run longer distances with the same amount of fuel.
- **Prevention of engine damage:** More efficient combustion of petrol, no corrosion.
- **Improved air quality**
- **Reduced emissions of exhaust pollutants** such as VOCs, NO_x ,and particulates (PM).
- **Less car maintenance and better fuel efficiency** leads to less overall costs to consumer per travelled mileage.

VEHICLE PRODUCER

- **Compatible with existing as well as alternative, power train technologies** (like hybrid cars), improving their environmental performance.
- **Help reduce fuel consumption** by improving the volumetric and thermal efficiency, complementing engine technologies such as direct injection, turbocharging or higher engine compression ratios.
- **Help reach CO_2 emission reduction goals** and renewable energy source targets throughout their life cycle.
- In the Worldwide Fuel Charter, **vehicle producers have indicated preference for using fuel ethers over other fuel components** such as ethanol (alcohol).
- Support vehicle producer to achieve their **sustainability targets.**

REFINER

- Reduces the **need for more energy -intensive fuel components,** reducing overall CO_2 emissions and improving the sustainability performance.
- Provides refiners with **more blending options for volatile liquid fuels,** especially for petrol engine fuels, due to low reid vapour pressure (RVP)
- **Compatible with the existing refinery infrastructure, fuel supply, and distribution system** without additional investment.
- Reduced cost of production of fuel **due to blending of low value high volatile streams (C4+).**
- Provides the **possibility of blending light olefins** in petrol.
- Increases **refining petrol production. Access to a high-octane-blending component** is particularly valuable during refinery outages and distribution system disturbances when additional supplies are needed most.

Globally large number of countries are using MTBE mix as octane booster in gasoline as a part of national strategy towards achieving GHG reduction target. Only in Australia/New Zealand and parts of the United States, MTBE use is limited, although at the national level in the US, there is NO federal ban on the use of MTBE. Among the ethers, MTBE supply vs demand trend in past 35 years is presented in **Figures 1 and 2**. There has been a significant increase in demand for MTBE in the eastern hemisphere over the last 20 years.

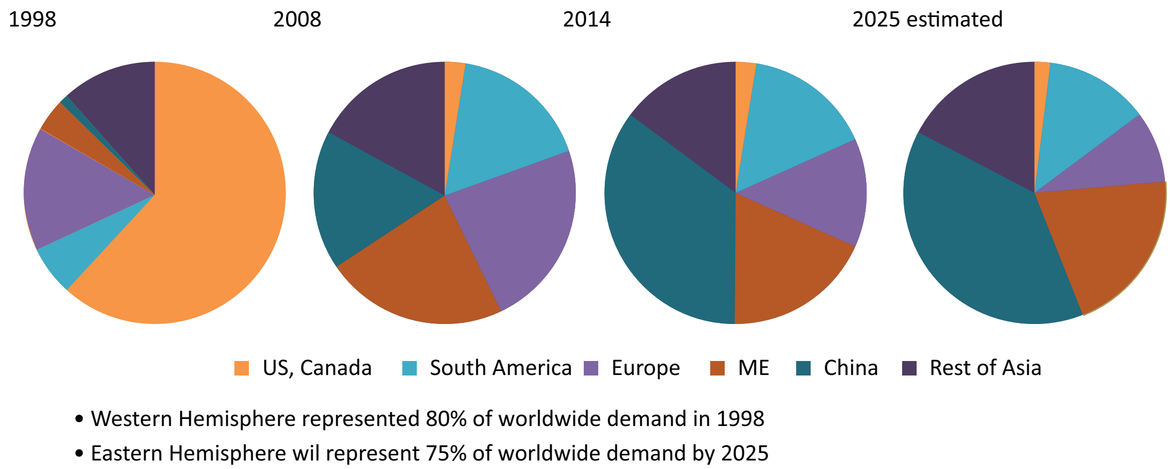

FIGURE 1: Worldwide demand change 1990-2025[17]

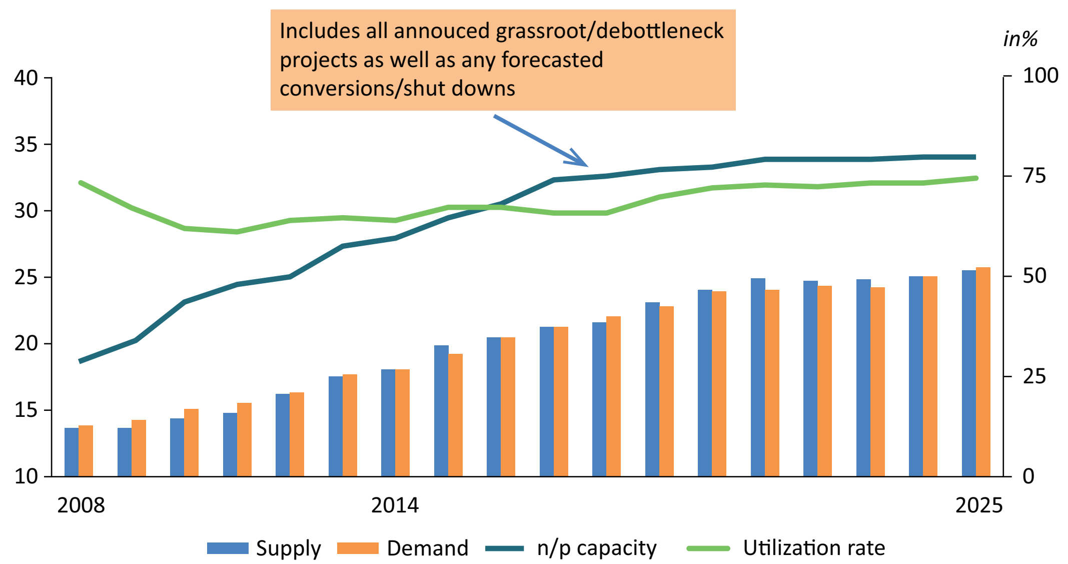

FIGURE 2: Supply and demand capacity 1998–2025[16,18]

MTBE market has witnessed a strong continuous growth since 2002, helping regulators improve air quality and reduce pollution, while meeting new environmental standards and abating climate change. MTBE has been in use in Europe for more than 40 years as a safe and clean octane enhancer. Europe, South Korea, Taiwan, and Malaysia enhanced their fuel quality to RON 95 and above, by allowing up to 15% MTBE or 22% of ETBE in the final gasoline blend. Presently, EU fuel quality directive 2009/30/EC allows max 3.7 mass% O-ether 22 vol.% + C5 fuel ethers whereas, US gasoline blend fuel cap allows max 2.7 mass % oxygen limiting to a maximum ETBE blend up to ~17 vol%. The MTBE production in the US is largely for export markets in Mexico, Venezuela, Asia, and Europe. Regarding capacity addition, MTBE expansion is expected to be focused on Asia and United States.

Global ETBE market is expected to grow at 4% annually with Japan and EU countries being main contributors to this growth. Japan on its own uses around 1.6 million mt/year to meet its biofuels

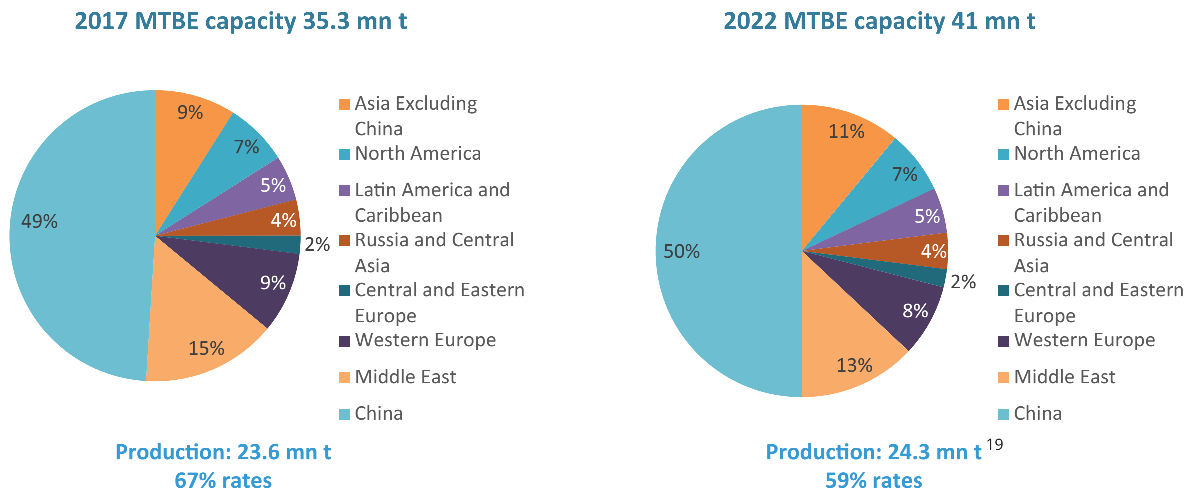

FIGURE 3: MTBE present global capacity by region

mandate, drawing upon the higher value of ETBE over direct ethanol blending due to many reasons on overall cost effectiveness, better gasoline blending characteristics and engine performance, as well as improved GHG reduction and air pollutants. Japan evaluated E3, E5, and E10 against 8% ETBE since 2007 and E3 was available till 2017. In 2018, Japan's GHG reduction target revised to 50–55%, and is expected to be revised again to 70% by 2027, with ETBE spearheading. By replacing around 500,000 kl of crude oil equivalent every year, Japan has been able to significantly reduce its GHG emissions since 2010.

In case of the ETBE production (Figure 4) Europe holds over 60% of the global ETBE capacity and about one quarter is in North America.[20]

MTBE and ETBE from Renewables

One of the major advantages is that these ethers can be produced both from hydrocarbons and renewable biomass and thus can utilize all forms of ethanol, methanol, and butanes.

When the alcohol obtained from biomass is used in the production of MTBE, ETBE or TAME, it is considered as a 'Bioether'. Bio MTBE is increasingly being considered, to be produced from bio/e-methanol. In order to support GHG mitigation in transport, production capacity of sustainable renewable methanol must increase from the current level of less than 1 million tonnes per year to cover a part of the transport sector. Today methanol is at the global production capacity of about 125 million tonnes. Production costs and GHG reduction potentials of renewable methanol produced on an industrial scale can be competitive to established renewable fuels, using suitable resources like 2G feedstocks or waste woody biomass. Supporting elements on strategic, regulatory, technical, and communicative level are of overarching importance like for any alternative fuel in transport.[22]

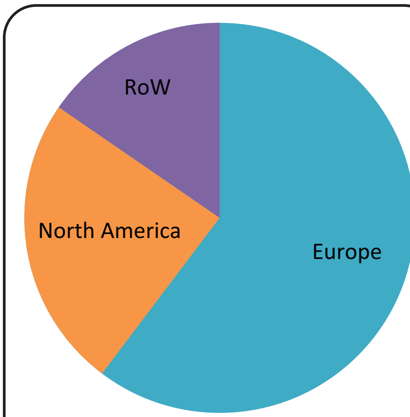

FIGURE 4: Global ETBE demand per region [20]

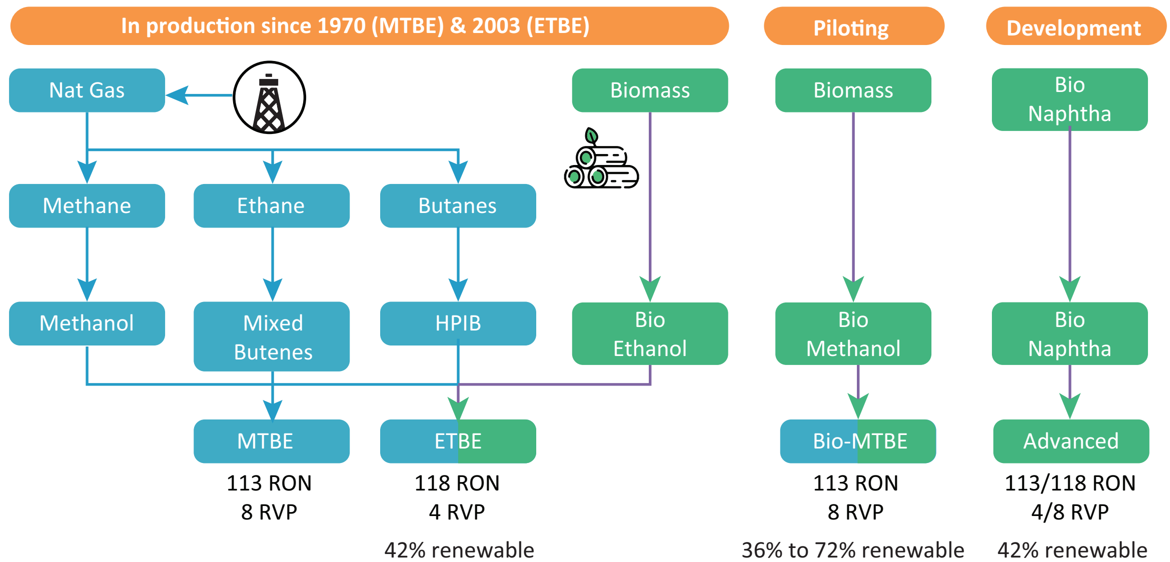

FIGURE 5: Production of oxyfuels from hydrocarbons or renewable biomass[21]

ETBE on the other hand, can be derived from two pathways, namely, ethanol and i-butene or (fully renewable production) and ethanol and tertbutyl alcohol (TBA). Historically, partially renewable ETBE has been obtained by combining a molecule of renewable ethanol with a molecule of fossil isobutene using a simple and proven process. It is used as an additive in vehicle fuel, up to a maximum of 22%. The global market for the product is currently valued at more than €2 billion, or more than 3 million tonnes annually. Bioethanol is obtained from renewable sources in first- and second-generation biorefineries.

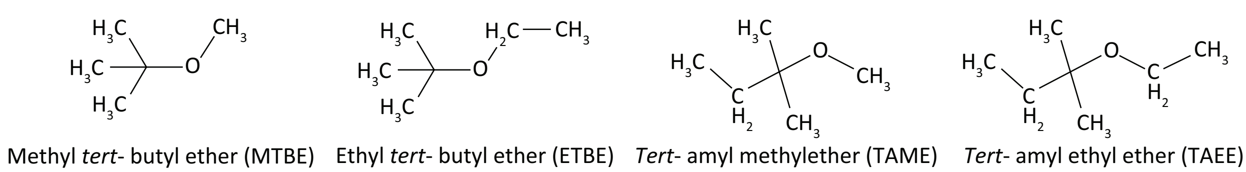

FIGURE 6: Structures of fuel ethers[23]

This purely renewable ETBE holds the potential for incorporating 2.7 times more renewable energy in gasoline than with traditional biofuels. It will also help to cut greenhouse gas (GHG) emissions even further. Europe has also classified ETBE produced with bioethanol as a biofuel, meeting all the renewable targets as ethanol does.

ENERGY SECURITY AND BALANCE OF TRADE

Evolving Transport Energy Demand in India is Significantly Impacting the Need for Enhanced Fuel Blends

Between 2000 and 2019, transport energy demand in India grew 3.5 times, and GHG emissions from passenger road transport alone quadrupled.[24] With rising disposable income, India has experienced a

TABLE 3: Technical, environmental, and cost-benefits of fuel ethers

Technical attributes ether compared to ethanol	Technical impact	Environmental gain	Cost-benefit
Low RVP and miscibility with HC, No waiver needed	Decrease in the reid vapour pressure (RVP) of finished gasoline, less VOC, THC, less evaporative emissions, less $PM_{2,5}$, less NO_x	Improved air quality Reduced air pollution	**To refiners**: Higher % mix of low cost C4 & C5 into the gasoline pool possible
Lower water affinity No azeotrope like alcohols	Does not mix with water No phase separation No corrosivity Superior distillation properties than alcohol	Less water pollution	**To consumer**: Longer run of the car, less maintenance costs Less Corrosion – longer life of the car
High-heating value 35 MJ/kg	Improved fuel efficiency v/s ethanol blended gasoline	Less pollution due to higher energy efficiency	**To consumer**: Less fuel per mileage travelled
Reliable fuel quality	Blending at the refinery site	Reliable gasoline quality at the pump No mixing outside the refinery No need of secondary logistic	**To refiners**: No need of investment in secondary logistic infrastructure Improved sustainability performance To policy makers: better control of quality and tax income

five-fold growth in per capita vehicle ownership, registering a total road vehicle stock of over 250 million in 2019 comprising two-wheelers (2W), three-wheelers (3W), and four-wheelers (4W).[24]

Vehicle ownership in India is geographically diverse, depending on the population of the cities, and it varies from metro cities to towns and villages. In 2019, India registered 225 vehicles for every thousand people on average, with Maharashtra holding the highest number of registered vehicles at 35 million.[25]

In contrast, other G20 countries like the USA, Japan, and Europe have car ownership rates substantially higher than 500 cars per 1000 population.[26] With the expected growth in per capita GDP, India is expected to go down the same path unless there is early deployment of effective mitigation measures. With a population of more than 1.3 billion, accounting for 17.8% of the global population in 2019, a lack of broad policy interventions encompassing the 'avoid-shift-improve' framework is likely to heighten GHG emissions from the Indian transport sector significantly. Thus, any successful effort to limit the global temperature increase to below 1.5°C necessitates consideration of India's fast-growing appetite for mobility and private vehicle ownership.[27]

A first of its kind study has been conducted by NREL, USA to understand the impact of ethanol-blended fuel at various blending levels (10%, 15%, and 20% vol.) on 'in-use' vehicles built to differing emissions and manufacturing standards around the world.[26] This study focuses on automobiles used in India along with six other countries such as China, Japan, Mexico, South Korea, Canada, and Indonesia (in order of vehicle fleet size). Historical experiences in the United States and Brazil are used as references for the analysis.

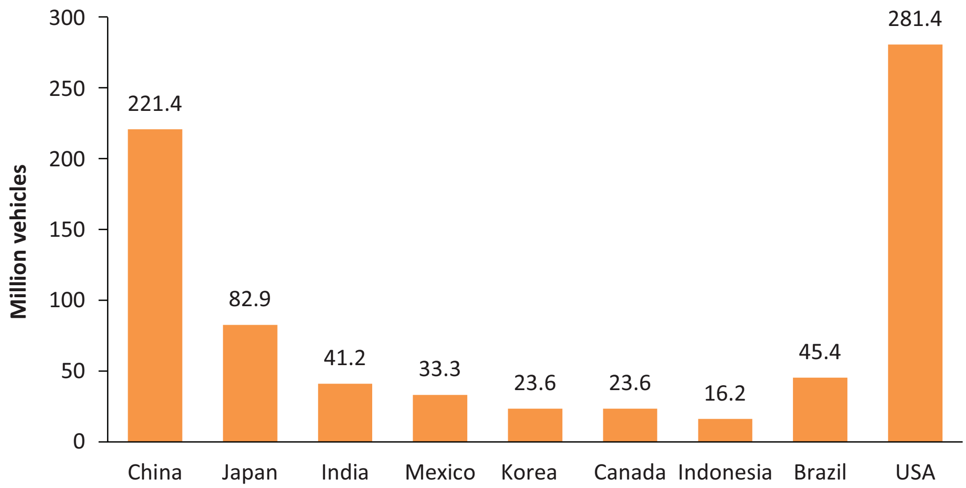

FIGURE 7: LDVs in operation in seven study countries, in addition to Brazil and the United States[26]

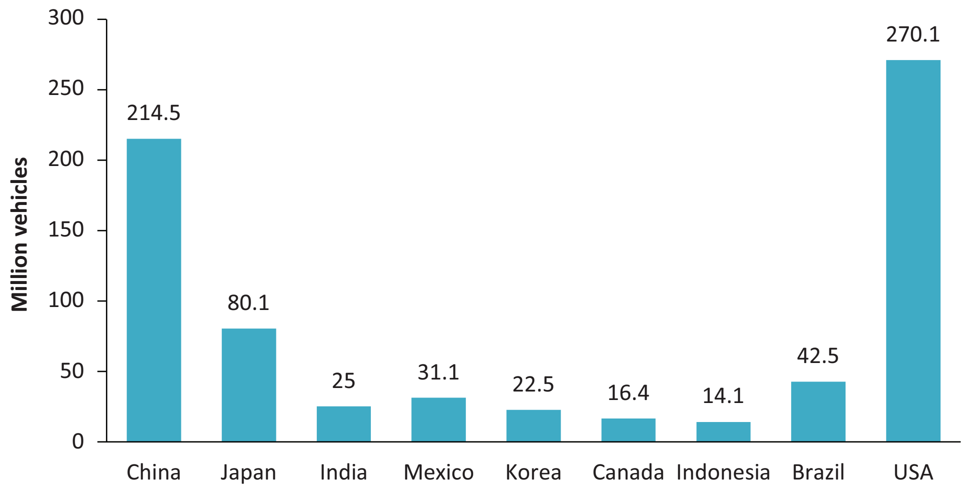

FIGURE 8: Gasoline using LDVs in operation in seven study countries in addition to Brazil and the United States[26]

Special assessment of fleets like motorcycles and scooters are made owing to their dominance in India and Indonesia which use gasoline as major fuel. Figures 7 and 8 show 40 million light-duty vehicles (LDVs) could be non-gasoline fleet among 400 million LDVs potential gasoline fleet while China owns half of the total market share. LDVs breakdown by fuel type in operation in seven countries, in addition to Brazil and the United States.[26,28] The Pre-2005 LDVs make up 11% of the gasoline LDV fleet and assessed to be compatible with E10.

While NREL's analysis indicates that all LDVs in the seven selected study countries are highly likely compatible with E10, a similar analysis for motorcycles in India indicates full compatibility with E10 and that many motorcycles are also compatible with E15. It is inferred that for E20, studies are not as extensive but are still highly significant. **A long-term durability study conducted on mileage accumulation dynamometers presents convincing evidence that Tier 2** technology-level vehicles have materials of construction and engine control authority for compatibility with E20, although this conclusion is not as strong as those drawn for E10 and E15, which are also partly based on real-world experience.[26] Similar concerns are expressed in other reports.[9] It is apprehended that despite a range of available incentives, the task of achieving 20% blending target seems uphill given the uncertainties linked to vehicle compatibility with fuel blends above E10 along with additional issues of feedstock availability, implications of food security, trade balances and environmental sustainability.[28,29]

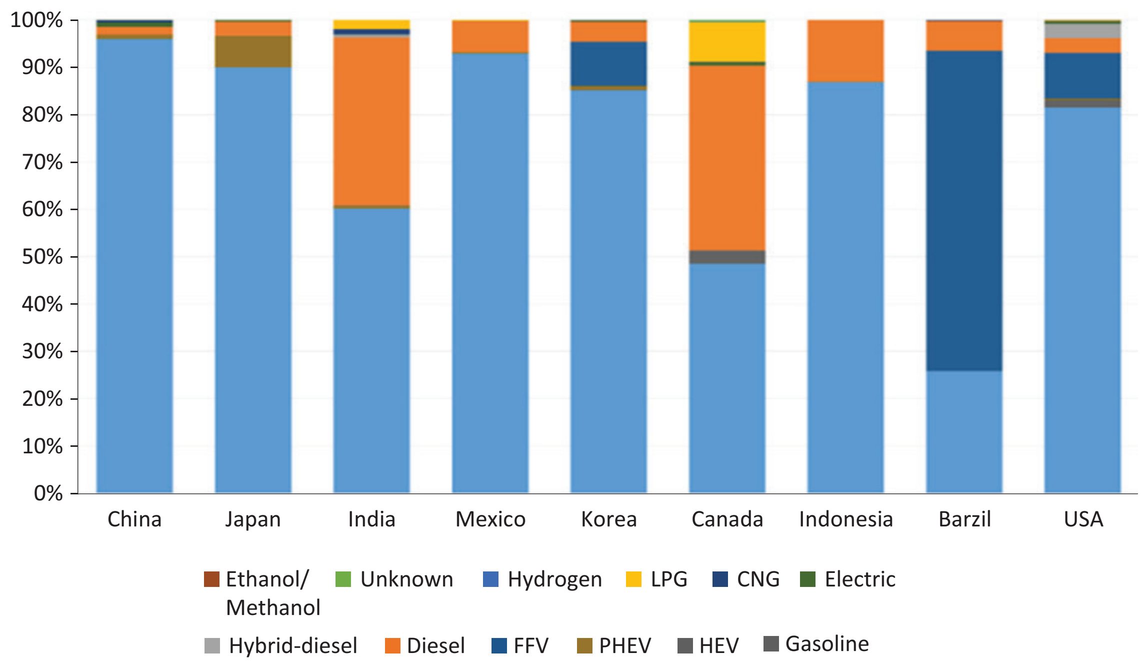

FIGURE 9: LDVs' breakdown by fuel type in operation in seven countries plus Brazil and the United States[26]

The Indian Government, headed by the Hon'ble Prime Minister, Narendra Modi has showed consent for the membership of Advanced Motor Fuels Technology Collaboration Programme noted as AMF TCP under the International Energy Agency (IEA) on May 9, 2018.[30] The principal objective of this acceptance is to step into the alternate fuel market to decarbonize the transport sector and enable global co-operation for the promotion of clean and energy efficient fuel. Raising the octane number of petrol has allowed the development of more efficient engine technologies with lower emissions. Fuel ethers also provide the possibility for this trend to continue.

Reduction of Scope 2 and Scope 3 Emissions

Total indirect GHG emissions from oil and gas operations are around 5200 million tonnes (Mt) of carbon dioxide equivalent (CO_2-eq.), 15% of the total energy sector GHG emissions.[31] Indirect emissions from oil are between 10% and 30% of its full lifecycle emissions intensity.[32] Tackling Scopes 2 and 3 emissions from oil and gas is one of the most viable and lowest cost options to reduce the total GHG emissions.

Recent LCA study done for France (ERG August 2023) has shown that use of oxygenated fuel can reduce carbon footprint up to 20% for high-octane blends. Largest GHG reduction is provided with maximum ETBE-blended gasoline. For a given oxygen level, adding ETBE increases GHG benefit up to 50% more benefit than ethanol-blended fuel. The results hold regardless of ethanol feedstock source.[33]

Since fuel ethers **are compatible with the existing refinery infrastructure, fuel supply and distribution system without additional investment**, they do not require any secondary distribution infrastructure (as they are produced at the source of the refineries themselves). Not only does this **provide cost-benefits for the refiner but also substantial reduction in scope 2 emissions** from additional distribution logistic and handling.

Fuel ethers can significantly contribute to the energy security and climate change agenda of the country directly impacting the reduction of Scopes 2 and 3 emissions. Since fuel ethers are compatible with the existing refinery infrastructure, fuel supply and distribution system without additional investment, they do not require any secondary distribution infrastructure (as they are produced at the source of the refineries themselves). Not only does this provide cost-benefits for the refiner but is also accompanied by substantial reduction in Scope 2 emissions from additional distribution logistic and handling. Access to a high-octane blending component is particularly valuable during refinery outages and distribution system disturbances when additional supplies are needed most. Fuel ethers reduce CO emissions by the same percentage as their content in petrol. Fuel ether, typically, 1-2%, in petrol typically leads to reduction of hydrocarbon emissions by 1%.[34] Another characteristic of fuel ethers is their capacity to raise the octane number in petrol, replacing less-desirable components. Using ethers allows refiners to substitute other components, which are more energy intensive to produce, and/or have less desirable environmental properties.

Improved Combustion and Other Environmental Considerations

Fuel ethers provide refiners with more blending options for volatile liquid fuels, especially for petrol engine fuels, due to low-vapour pressure (RVP). They also have a higher energy content, resulting in improved combustion, higher fuel efficiency (less energy needed per travelled mileage) and reduced GHG emissions. ETBE-blended gasoline can reduce GHG emissions up to 30% more than E10 compared to ethanol-free (or non-oxygenated) gasoline. India National Biofuels Policy Aspiration is to transition to complete E20 usage by April 2023 with full implementation by April 2025 (India's average ethanol blending level was 6.4% in 2019). However, there are potential challenges for higher blend options which need to be addressed before large-scale adoption.

» Higher ethanol blends can have a negative impact on the environment
» Higher reid vapour pressure (RVP), resulting in higher evaporative emissions, can lead to higher formation of ambient ozone
» Tailpipe aldehyde emissions can also increase which are not regulated
» Higher evaporative emissions lead to higher volatile organic compounds (VOCs) and higher secondary particulates formation which could negate the efforts being taken to reduce the particulate emission load from vehicles

If issues surpasses the benefits to reduce crude oil will trade off with environmental concerns which is not desirable. Vehicle technologies, infrastructure need to be designed and fuel specifications need to be defined appropriately. Achieving high RON with ether co-blending can play a crucial role to reduce this trade off. Most recently, the Environment Protection Agency in the US is dealing with a request from several governors of states to reject the current RVP waiver as the governors are concerned about the fact that the RVP waiver leads to higher air pollution in their states. On the EPA Website that request has been positively answered, consequently, the RVP waivers were removed.[35]

Reduced Import Dependence (Self-sufficiency)

Many of the challenges facing fuel suppliers and electricity generators were exacerbated with the onset of COVID-19. While advantages to India to an extent lower prices ease its fuel import bills it strained balance sheets and increased uncertainties over demand, affecting prospects for domestic energy investment and supply. Imports of crude oil in India increased to 20.04 million tonnes in May from 19.95 million tonnes in April of 2023.[36]

India imports around 84% of its crude oil needs and is the third-largest oil consumer and importer in the world. The financial implications of India's crude oil imports with increase in oil prices and decline in domestic oil production have been significant. With this dependence comes increased vulnerability to global events like the Russia–Ukraine war, decisions of OPEC countries, amongst others. To reduce this reliance, one of the globally accepted ways is to blend petrol with ethanol. By such blending, overall fuel demand falls while the efficiency of the vehicles using the blended-fuel does not suffer much. India's E20 targets are supported to this effect. Ethanol can be produced directly from agricultural crops or their waste. The resultant reduced demand for fuel could save India about $4 billion annually.[37]

While ethanol blending has several benefits which include curtailing dependence on imported fuel, conserving foreign exchange reserves, addressing environmental concerns, and boosting the domestic agricultural industry, there are a few considerations that need to be evaluated as the policy expands. Firstly, the challenge of food security, increased feedstock production, requires additional land and increases pressures on the domestic market to keep up with the demand. In the absence of the domestic market expansion, this gap will be met by extended import mandates which would in turn defeat the purpose of self-sustainability. In addition, there has been an increase in sugar cane cultivation (in lieu of expanding financial incentives for ethanol blending) which is a water-intensive crop. According to a report, producing 1 kilogram of sugar requires 1500–2000 litres of water, making it an unsustainable option. Secondly, there are also technical considerations of the impact ethanol-blended fuels can have on the environment. Higher reid vapour pressure (RVP) in ethanol-blended fuels results in higher evaporative emissions which can impact the ambient ozone. Tailpipe aldehyde emissions, which remain unregulated, can also increase. Similarly, higher evaporative emissions could lead to higher volatile organic compounds (VOCs) and possibly higher secondary particulates formation which can negate the efforts being taken to reduce the particulate emission load from vehicles. Lastly, ethanol production has its own infrastructural challenges of storage and transportation (since it is not directly produced at the refinery), which increases its Scopes 2 and 3 emissions. In this context, the benefits of EBP in reducing the crude oil will have a trade off with environmental concerns, which is undesirable.

In this context, fuel ethers are directly produced at the refinery and are widely available for import or local production in India. India currently produces more than 400 KTA of MTBE of which more than 50% goes into gasoline blending which is expected to further grow in the coming years.[38]

There are many significant players already producing ethers in the Indian market including leading OMCs, Indian Oil Corporation Limited, Haldia Petrochemicals, Hindustan Petroleum Corporation Limited, Bharat Petroleum Corporation Limited, and Reliance Energy. With the raw materials for ethers already available in India, the ability to meet the growing demand of fuel ethers, can be met domestically itself.

Case Study: Columbia Case Study and Report (Moves Modelling)

Through an assessment of the Columbia's blending programme, the model shows that oxygenating the same base gasoline with ETBE instead of, and in addition to ethanol results in significant reductions in all exhaust pollutants, followed by notable reductions in evaporative emissions.[5] Reductions in $PM_{2.5}$ (2–17%), VOCs (8–23%), CO (6–17%), NO_x (4–13%), SO_2 (13–26%) and air toxics were achieved. Besides replacing 10% ethanol with the equivalent amount of ETBE (oxygen basis) results in 21 kPa reduction in vapour pressure (RVP) and evaporative VOC emissions, leading to ozone and secondary PM formation. India can certainly benefit from this to improve its worsening air quality and achieve immediate results through incorporating ETBE in its gasoline blend. Refiners would be able to add, depending on the BOB up to 10%, more low-value streams such as C4 and C5.

TABLE 6: Total emissions (tonnes/year) by city scenario and pollutants (relative change in emissions with respect to E10 is shown in brackets)[5]

City	Pollutant	E10	E0	E8OX6	E5OX13	OX24
Bogotá	VOCs	108,935	104,536 (–4.0%)	100,073 (–8.1%)	96,758 (–11.2%)	89,012 (–18.3%)
	CO	1,644,299	1,710,345 (4.0%)	1,544,496 (–6.1%)	1,498,087 (–8.9%)	1,382,129 (–15.9%)
	NO_x	113,626	109,709 (–3.4%)	107,200 (–5.7%)	103,630 (–8.8%)	98,606 (–13.2%)
	$PM_{2.5}$	1,833	1,836 (0.2%)	1,759 (–4.1%)	1,694 (–7.6%)	1,600 (–12.7%)
	SO_2	359	346 (–3.7%)	309 (–13.8%)	299 (–16.7%)	268 (–25.5%)
Medellin	VOCs	73,378	67,246 (–8.4%)	67,000 (–8.7%)	64,841 (–11.6%)	58,512 (–20.3%)
	CO	1,266,684	1,315,326 (3.8%)	1,187,795 (–6.2%)	1,151,586 (–9.1%)	1,060,008 (–16.3%)
	NO_x	53,898	52,495 (–2.6%)	51,744 (–4.0%)	51,170 (–5.1%)	51,809 (–3.9%)
	$PM_{2.5}$	2,111	2,087 (–1.1%)	2,062 (–2.3%)	2,017 (–4.4%)	1,950 (–7.6%)
	SO_2	278	268 (–3.6%)	241 (–13.2%)	234 (–15.8%)	211 (–24.2%)
Cúcuta	VOCs	23,994	21,174 (–11.8%)	21,684 (–9.6%)	20,944 (–12.7%)	18,558 (–22.7%)
	CO	489,482	506,744 (3.5%)	458,073 (–6.4%)	443,715 (–9.4%)	406,733 (–16.9%)
	NO_x	9,988	9,666 (–3.2%)	9,548 (–4.4%)	9,419 (–5.7%)	8,968 (–10.2%)
	$PM_{2.5}$	442	427 (–3.3%)	419 (–5.2%)	397(–10.0%)	365(–17.2%)
	SO_2	86	83 (–3.9%)	74 (–14.3%)	72 (–17.2%)	64 (–26.3%)

TABLE 5: Key properties of the blend[5]

Blend	E10	E0	E80X6	E60X11	E50X13	E30X17	OX24
Year	2024	2024	2024	2024	2024	2024	2024
Oxygen (wt.%)	3.7	0	3.7	3.7	3.7	3.7	3.7
RON	89	84	93	93.6	94	94.9	96.1
RVP (kPa)	65	55	60.4	58.4	57.5	55.2	44.3
Sulphur level (ppm)	50	50	43	42	42	40	38
ETOH (%vol.)	10.6	0	7.8	5.8	4.9	2.9	0
ETBE (%vol.)	0	0	6.4	10.8	12.8	17.2	23.6
Aromatic (%vol.)	19.7	22	18.9	18.3	18.1	17.6	16.8
Olefin (%vol.)	16.1	18	15.4	15	14.8	14.4	13.8
Benzene (%vol.)	0.63	0.7	0.6	0.58	0.58	0.56	0.53
T50	213.7	222.4	209	205.9	204.5	201.3	196.8
T90	340.7	351.2	337.2	334.8	333.7	331.3	327.8
E200	43.2	36.5	45.2	47	47.7	49.3	51.5
E300	80.5	78.2	81.3	81.8	82.1	82.6	83.3

FINANCIAL VIABILITY AND SOCIAL IMPACT

Financial Viability (For Refiners and Consumers)

Fuel ethers have significant financial benefits to both the refiner and customer. At the refinery level, apart from providing refiners with more blending options for volatile liquid fuels, especially for petrol engine fuels, due to reid vapour pressure (RVP), fuel ethers are compatible with the existing refinery infrastructure, fuel supply and distribution system without additional investment (Figure 10). In addition, it also reduces the cost of production of fuel due to blending of low value, high volatile streams (C4+). A study is being executed with refiners in Singapore whose findings are awaited.

Several countries have chosen ethers over other blending components as ethers provide a better value proposition, in terms of both commercial and eco-friendly grounds. As a follow up to this report, the financial viability of ethers for the Indian market can be established by working directly with the Indian oil companies. This will need to be conducted at a national level with interventions from refiners, think tanks, and the government. The Asian Clean Fuels Association is happy to partner with refiners to curate this study.

At consumer level as well, fuel ethers translate to improved fuel efficiency, allowing cars to run longer distances with the same amount of fuel. This has significant benefits to consumers per km costs. It also reduces car maintenance costs by preventing engine damage through efficient combustion of petrol and limiting corrosion.

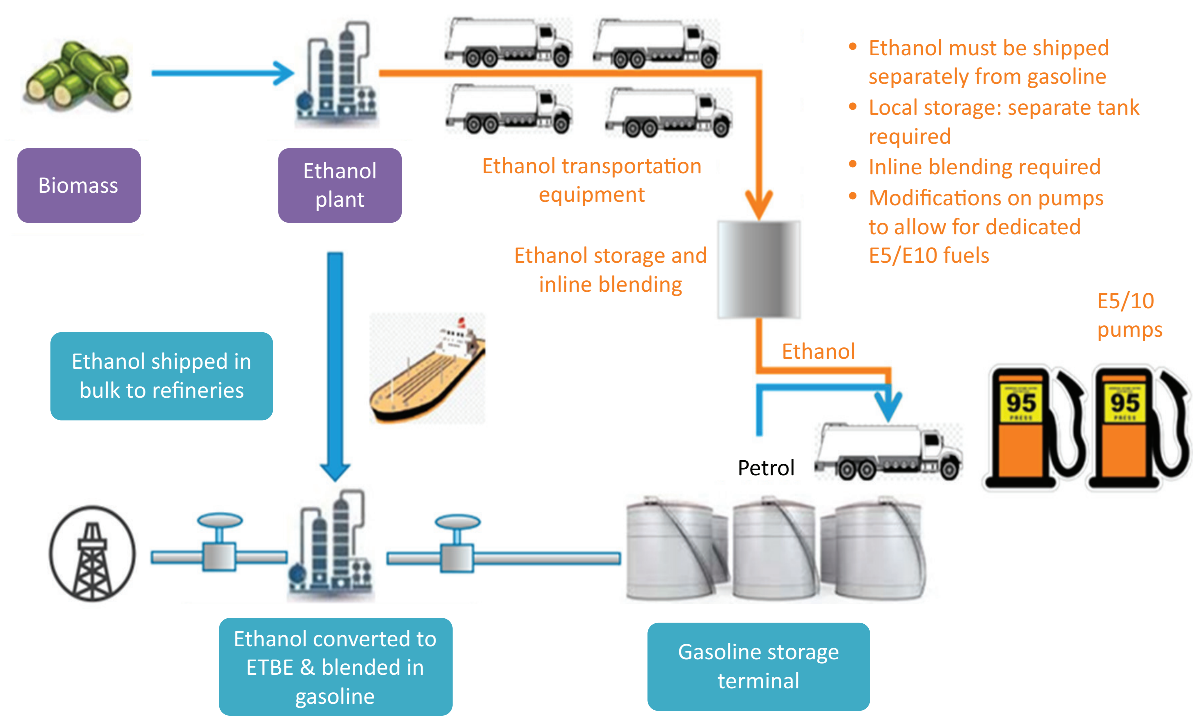

FIGURE 10: Ether and alcohols: upgrading to flexible MTBE/ETBE production at the refinery is ~10% the capital cost of direct ethanol blending infrastructure (Lyondell Basel presentation)

Food Security (Social Impact)

India's Ethanol Blended Programme has contributed significantly to the expansion of biofuels in the country. NITI Aayog's Roadmap for Ethanol Blending in India has highlighted, 'the recently approved interest subvention incentives for grain-based distilleries, the target of 20% blending of petrol in the country by 2025 thus appears feasible and within reach'. The Roadmap indicates, an estimated ethanol demand of 1016 crore litres based on expected growth in vehicular population. Modelling exercise on expected penetration of electric vehicles estimates the ethanol demand for petrol blending in the range of 722–921 crore litres in 2025.[39] The blueprint is a departure from the 2018 National Policy on Biofuels, which prioritized grasses and algae; cellulosic material such as bagasse, farm and forestry residue; and, items like straw from rice, wheat and corn. More recently, the adverse impact of ethanol blending on both food security and the environment has been receiving increased attention. Owing to an erratic monsoon season, there is an estimated shortage of 10–15% in sugar cane production for the next year which will put further pressure on food crops usage for biofuels. The long-term planning of the government involves the creation of sufficient capacities so that half of the requirement of 20% blending is catered by grains, predominantly maize and the rest by sugar cane.

As discussed in the previous section, Europe has categorized ETBE produced from bioethanol as a biofuel. With this categorization, ETBE, and fuel ethers can also be considered towards achieving India's biofuel policy, without curtailing food security for the nation.

CLEANER AIR: REDUCING THE IMPACT OF AIR POLLUTION

Health Impact of Air Pollution on India

Air pollution is one of the most pressing environmental concerns, with millions of premature deaths linked to it globally every year. India is one of the countries hit hardest by this problem, with some of the most polluted cities in the world. In 2021, New Delhi continued to be the world's most polluted capital city for the fourth consecutive year, with air pollution levels over 10 times the safe levels prescribed by the World Health Organization (WHO) for seven months in 2021. In addition, 11 of the 15 most polluted cities in Central and South Asia were also in India. In 2021, 35 Indian cities were listed under the worst air quality tag—Bhiwadi, Rajasthan topped this list and was followed by Ghaziabad, Uttar Pradesh.[40] Toxic air is one of India's primary health risks and is emerging as a major public health concern. The toll it takes on the economy is estimated at around USD 150 billion annually.[41]

Particulate matter of 2.5 microns or smaller ($PM_{2.5}$), one of the most dangerous air pollutants, comes from many sources including car engines, and its concentration in India's cities is among the highest in the world. Delhi has registered an annual $PM_{2.5}$ measure of 99.7 in 2023, 14.6% increase in toxic fine particulate matter compared with the previous year.[41] This has led to a reduction in life expectancy by as much as nine years and is a severe economic and social strain to the nation's capital. For Delhi specifically, transport has emerged as the highest source of air pollution (~38.80%). Delhi follows the same average E10 blending programme and is poised as one of the cities to move to the E20 mandate, announced in 2023. To improve the air quality further, ethers could be a consideration for cities like Delhi to be able to advance on air pollution improvements.

The Government of India has introduced several flagship policies to contain the effects of air pollution and improve air quality. The most significant of such initiatives is the National Clean Air Programme (NCAP) launched in 2019 aimed at improving air quality in over 100 Indian cities.[42] Under NCAP, the Government of India has prescribed a national level target of 20–30% reduction of particulate matter (PM_{10} and $PM_{2.5}$) concentration by 2024. These interim targets are in line with global experiences which highlight that city-specific actions led to 35–40% $PM_{2.5}$ reduction in five years for cities, such as Beijing and Seoul, whereas cities, such as Santiago and Mexico City have shown 73% and 61% reduction in 22 to 25 years for $PM_{2.5}$ and PM_{10} concentrations, respectively.

Reduction of Toxics and Pollutants

Curtailing the impact of air pollution and reducing the particulate matter has a direct correlation with fuel quality, as higher octane fuels emit fewer polluting particles.

Fuel ethers can play a significant role in helping India achieve its NCAP targets owing to the following:

» Fuel ethers lower the reid vapour pressure (RVP) when blended into gasoline. Lower total VOC, total toxics, NO_x, ozone formation.
» Reformate/aromatics content could be lowered to less than 25% (Bharat VI allows 35%).
» Aromatics are the primary source of $PM_{2.5}$ which leads to high increase of deaths/premature births. Ethanol leads in E10 to higher $PM_{2.5}$ generation than non-blended gasoline due to its cooling effect during combustion of the fuel. Fuel ethers in contrast lower the $PM_{2.5}$ formation due to improved combustion.

Conventional gasoline components like reformate, isomerate, etc. may not help in meeting the objective of 95 RON under BS VI scenario. They can be cancerogenic and drive PM and THC values up which in turn worsen the air pollution. With gradual stringent MS specs for lesser emission and higher engine efficiency, use of high RON fuels has become inevitable.

Figure 11 demonstrates the benefits of using fuel ethers and ethanol on emissions in comparison to regular petrol or Motor Gasoline (MG). A few critically important references are given below:

» When using the EPA Complex Model for simulating emissions of different blends applying the Bharat VI Standard:

» When 15% MTBE is added, total VOC has significantly decreased by 30% compared to E5 or E10; total toxics by 17%; total NOx by 2–3%

» When 11% MTBE is blended with 5% EtOH in gasoline, total VOC of blend decreased by 3%; total toxics by 13%

COMPLEX MODEL FOR VOC , NO_X, TOXICS, AND RON OCTANE
BHARAT VI PETROL VS UNOXYGENATED MG91

VOCs	OX15	E5	E10	E5OX13
Toxics	-19.5%	21.4%	19.9%	1%
NOx	-16.0%	-3.0%	-2.4%	-13%
Octane (RON)	-4.2%	-7.7%	-8.5%	-10%
	95.5	96	97	100

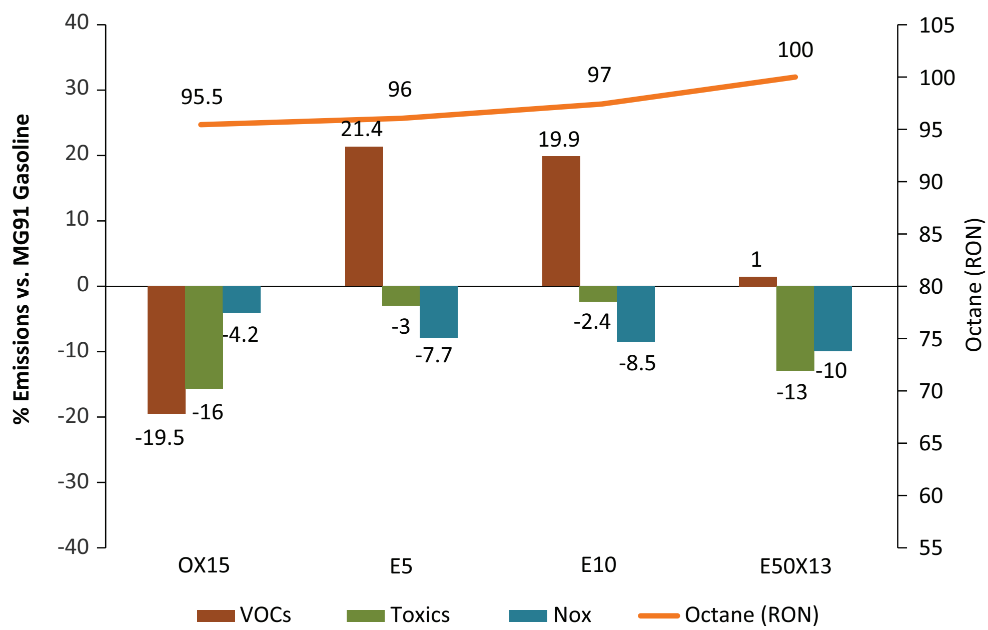

FIGURE 11 Cleaner Air & Less Air Pollution with ethers - Simulation of India Bharat VI with EPA COMPLEX Model[43]

Source: https://www.epa.gov/fuels-registration-reporting-and-compliance-help/complex-model-used-analyze-rfg-and-anti-dumping

Reduction in Reid Vapour Pressure

The addition of ethanol to a finished gasoline leads to increase in reid vapour pressure (RVP). For example, when E5 and E0 (being on-spec re RVP) are comingled, then the RVP of the mix in increased, and it potentially goes off-spec as shown in Figure 12.[44] The more ethanol is added the higher this increase becomes. There is no such anomaly with blends comprising fuel ethers. In contrast, fuel ethers decrease the vapour pressure of a finished gasoline with corresponding benefits for blending. VOCs are precursors to both atmospheric ozone 516 and $PM_{2.5}$ in the form of soluble organic aerosols. Butanes and pentanes must be reduced to meet RVP specifications with ethanol. Fuel ethers allow more of these low-cost components, thus improving refining margins.

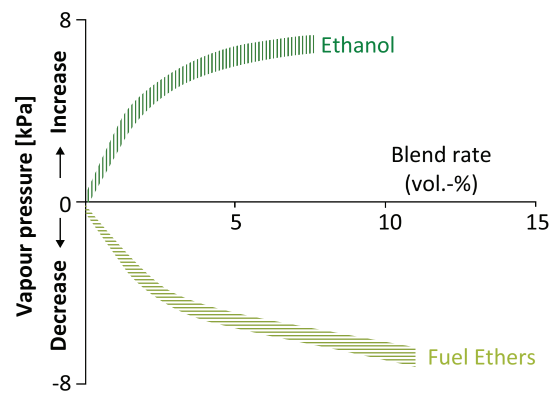

FIGURE 12: Reduction of vapour pressure[44]

Reduction in Evaporative Emissions

Principally, evaporative emissions occur through two processes: permeation and ventilation as illustrated in Figure.[44] Permeation takes place when organic gases permeate through the walls of fuel system components, like tanks, polymeric pipes, gaskets, and seals. Ventilation is the result of petrol evaporation, causing fuel escaping the tank through the vents. Blending gasoline with fuel ethers, reduces both types of evaporative emissions.

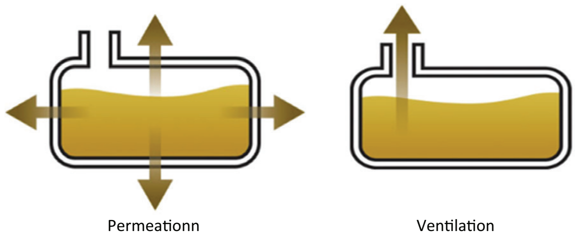

Figure 13 showcases the result of a test performed by Kautex-Textron, a German fuel tank manufacturer, with the following two different gasoline blends:[44,45]

- CARB II – 10% MTBE blended
- CARB III – 10% ethanol blended

In the first 21 weeks of the test, 10% MTBE-blended fuel was used in the fuel tank and from week 22, 10% ethanol-blended fuel was

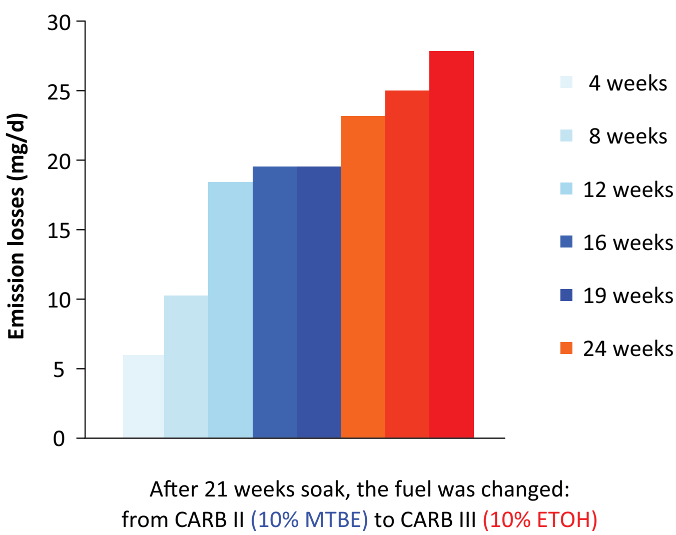

FIGURE 13: Permeation emissions reduction (30%) through fuel ethers[45]

used in the tank. With the CARB II specification, the fuel losses through permeation were at a maximum level of 20 mg/d (blue bars). When the fuel changed to CARB III, the permeation losses increased to 27–28 mg/d. **This results in 30% higher permeation from 10% ethanol-blended fuel as compared to 10% MTBE-blended fuel. Therefore, when RON is improved by adding MTBE in the finished gasoline, the permeation emissions are reduced by 30% as compared to ethanol-blended gasoline. This is a remarkable achievement, which leads to 30% less VOC emissions and therefore less ozone building. Air pollution and ozone building are major contributors to premature deaths and climate change. Avoiding these shall be the primary goal for policy makers when working on new legislative documents**.

RELIABLE FUEL QUALITY AT THE PUMP

Indian fuel quality standards have been developed and implemented to complement vehicle emission standards. These standards have evolved over the last two decades as India's commitments pertaining to clean fuels and air pollution have expanded.

India has officially transitioned to Bharat Stage (BS) VI vehicle emission standards. The BS VI regulation, effective as of 1 April 2020, contains new fuel specifications and standards for commercial gasoline and diesel to support the advanced emission control technologies that automakers are incorporating in BS VI vehicles.[46]

Under BS II, the octane number had increased to 88 and 93 for regular and premium, respectively. It was further increased to 91 and 95 for regular and premium, respectively, under BS III and beyond.[7] The octane number of petrol indicates the quality of fuel. The higher the octane number better is the quality. Here, quality refers to the rate of compression that fuel can withstand before igniting inside the combustion chamber of an engine.

Some parameters, like octane number, olefin content, and fuel density in gasoline, and cetane number in diesel influence the engine's thermal efficiency. Other parameters, like ethanol content in gasoline and polycyclic aromatic hydrocarbon content in diesel, have a direct effect on exhaust emissions.[47] That's the reason why most high-end performance cars use high-octane petrol. The high-octane fuel is suitable for engines with high-compression ratios. Usage of low-octane petrol in a high-compression engine will lead to knocking where the fuel burns even before the spark produced from the spark plug.

In comparison to fuel quality created through E5, E10, and E20 blending programmes where ethanol is hydroscopic and incompatible with gasoline and requires a phased separation; fuel ethers offer consistent and reliable fuel quality, with direct blending at the refinery itself. This also reduces quality issues (no impact comingling leading to off-spec fuel) and allows consistency in distribution (direct from refinery) to the pump sites.

No Requirement of Phase Seperation

Phase separation is the creation of two distinct phases from a single homogeneous mixture. The most common type of phase separation is between two immiscible liquids, such as oil and water. Fuel ethers and gasoline do not separate in contact with water in comparison with ethanol, where<1% water can cause E10 gasoline to go off-spec.48 Ethanol's strong affinity for water creates serious fungibility issues. Increased possibility of corrosion with both vehicle and fuel infrastructure facilities for higher ethanol blend which is not a case for ether. So utility parameters of fuel ethers shown in Figure 15.[48]

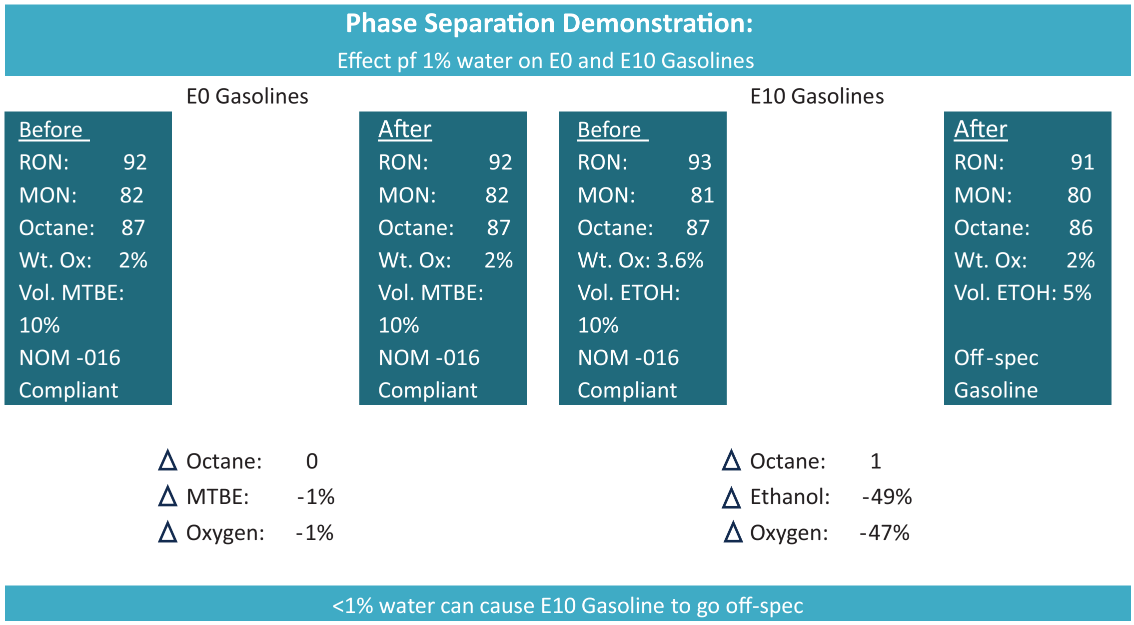

FIGURE 14: Phase separation demonstration: effect of 1% water on E0 and E10 gasoline[48]

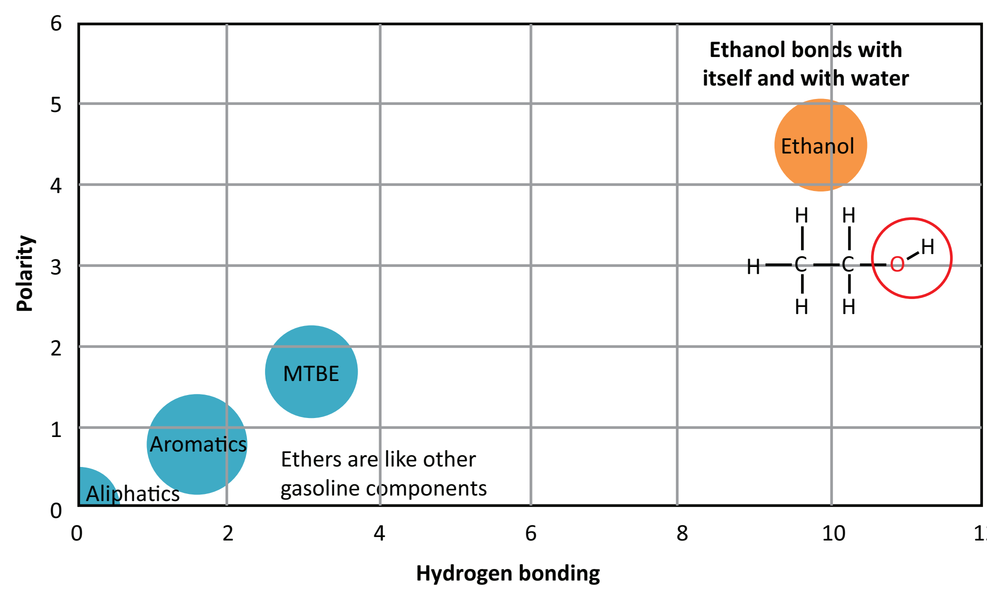

FIGURE 15: Solubility parameters of gasoline components—a comparison of ethanol and MTBE[48]

Compatible With Existing Infrastructure

Fuel ethers are compatible with the existing infrastructure at the refinery. Ethanol blending is not compatible with existing infrastructure and brings the following issue.

Ethanol necessitates changes to the normal product-handling practices in any distribution system. These necessary adjustments to protect gasoline quality adversely impact refiner/blender flexibility and cost.

Terminal and retail station modifications to enable ethanol blending results in significant additional costs. When/if considering converting an existing pipeline to dedicated ethanol–gasoline service, it is important to recognize that minimizing water and sediment would result in altered logistic practices that reduce pipeline capacity.

In comparison, fuel ethers can be splash blended at the refinery site, with no additional secondary distribution infrastructure needed. This also reduces **Scope 1** emissions from additional distribution logistics and handling for refiners.

No Comingling Effect

Ethanol–gasoline blends cannot be blended easily with pure hydrocarbon gasoline, since there is a reid vapour pressure (RVP) anomaly, for example, E5 and E0 (being on-spec re RVP) are comingled, then the RVP of the mix is increased, and can potentially go off-spec as shown in Figure 16.[49] There is no such anomaly with blends containing fuel ethers.

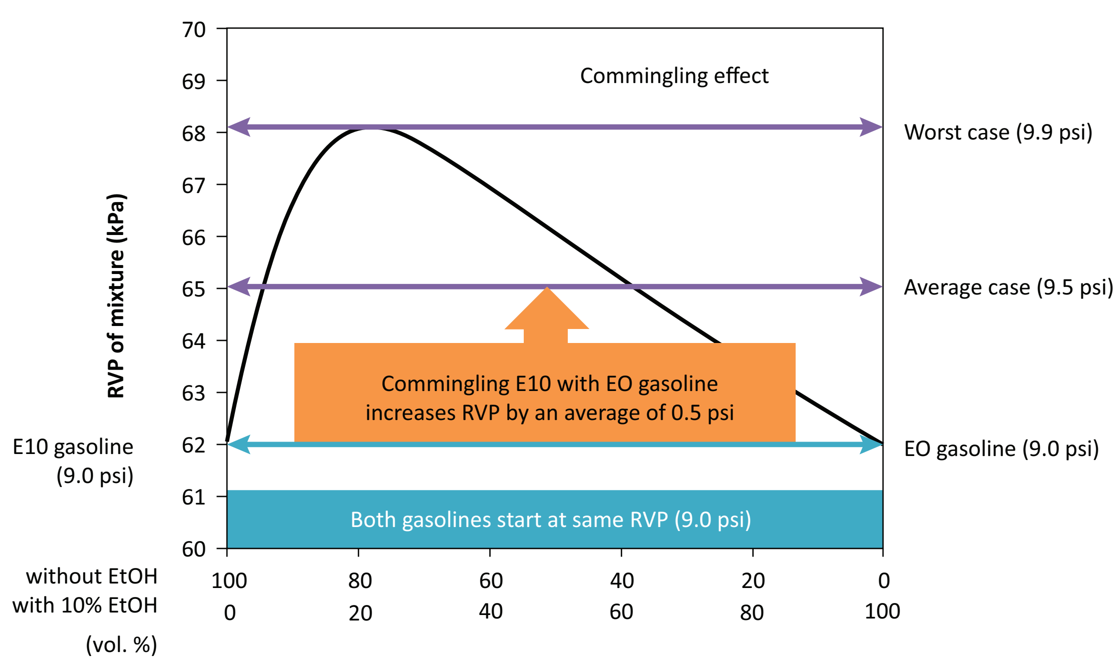

FIGURE 16: Commingling E10 gasoline with EO[49]

Fuel Efficiency Improvement

Figure 17 demonstrates the improvement in fuel efficiency and reduction in PM emissions by using MTBE. In 2015, the Ministry of Power, issued average fuel consumption standards for cars (applicable for the motor vehicle using petrol or diesel or liquefied petroleum gas or compressed natural gas which carry passengers and their luggage and comprising not more than nine seats including driver's, with the gross vehicle weight not exceeding 3500 kilograms tested). The standards relate the corporate average fuel consumption (in litres/100 km) to the corporate average curb weight of all the cars sold by a manufacturer in a fiscal year.[50]

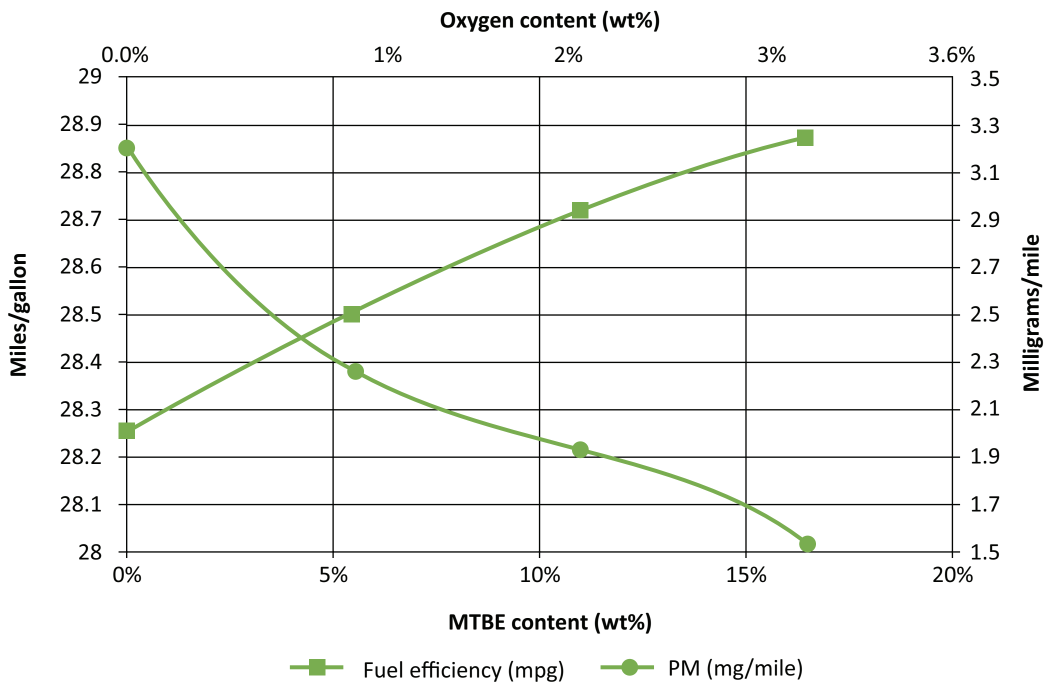

FIGURE 17: Fuel Efficiency and reduction in PM Emissions by using MTBE[50]

According to the first standard, the average weight of all cars was expected to be 1037 kg in 2016–17, and the average fuel consumption standard would have to be less than 5.49 km/100 litres for this average weight.[51] The second standard assumes car average weight of 1145 kg in 2022 and requires the average fuel consumption to be less than 4.77 litres/100 km at this average weight. In 2021, this value was revised to 1082 kg, notified vide S.O. 5020 (E) with the corresponding average fuel consumption of 4.89 litres/100 km. It is expected that these standards would lead to a reduction of 22.97 million tonnes of fuel consumption by 2025.[52]

Addressing Underground Storage Tank Challenges

In the 1990s, California was the only state that deselected MTBE because of groundwater contamination issues caused by leaking of underground storage tanks (USTs). Since then, several regulations governing have been put forward, storage of liquid fuels, providing requirements for the underground storage tanks and for monitoring of groundwater in both US and Europe. It should be noted that MTBE in groundwater has been identified as a past environmental problem, due to leaking underground fuel tanks in the US. However, current tank technology has largely eliminated this concern. After extensive industry testing to evaluate this issue, the United States Environmental Protection Agency (EPA) took no further action on health risks associated with such exposures.[53]

The California UST legislation has released a study which recommends several good practices which can help in ensuring safe storage of MTBE, and with it any liquid product at the station. Salient features of this study are as under:

- A double-walled system or if the tank is single wallet, a secondary containment should be installed.
- Usage of appropriate material to prevent corrosion/the tank should have cathodic protection to mitigate the risk.
- Equipped with a leak detection system.
- Regular monitoring of the tank and local monitoring of soil.
- Registration of the UST system with the local authorities.

The authors of the risk assessments of MTBE (2001), ETBE (2002), and TAME (2008) concluded that their use in petrol has no detrimental impact on human health, atmosphere, or environment. They are not classified as carcinogens, mutagens, or reproductive toxins.

The European regulations are regulatory revised and adequately enforced; this has played an important role in establishing good standards for USTs in the past 30 years.[54]

GLOBAL LEARNINGS

LEARNINGS FROM GLOBAL ADOPTION OF CO-BLENDED FUELS

ETBE and ethanol co-blending is commonly used across Europe. ETBE-blending percentage in RON 95 gasoline is 5.5%
in France, 4.9% in Slovakia, and 12.7% in Spain.

Europe has evaluated several steps to promote the production of ETBE. These can be replicated in India as well.
They include:

- Exploiting existing domestic MTBE production capacity which is converted into ETBE
- Couple bio with high-octane values
- Maintain maximum flexibility to face legislative changes and environment findings
- Easier, larger, and faster implementation of bio-mandates
- Avoid no-return investment in expensive and binding special logistics for ethanol direct blending
- Address ethanol air quality and compatibility drawbacks
- Facilitate fuel swaps among players and countries/regions
- Protect older vehicles owned by poorer people from ethanol compatibility issues

Several countries have also converted existing MTBE production units into ETBE units to encourage co-blending options. These include Austria (1), Finland (2), Italy (5), Poland (1), Spain (6), Belgium (2), France (2), Japan (2), Portugal (1), Sweden (1), Brazil (2), Germany (7), Netherlands (2), Romania (2), and USA (1).[54]

A science-based evaluation of sustainable and affordable octane improvers/oxyfuels is presented in **Table 5** which highlights the comparative edge of ethers over the other octane boosters including alcohols (ethanol and methanol).

Enhancing India's Biofuel Policy – Possible Future Options For India

India needs to evaluate benefits of adopting ethers along with alcohol from fuel quality from handling point of view. Upgrading fuel quality facilitates alignment with gasoline trade flows, ensuring better availability of common gasoline grades (no niche markets). Fuel ethers provide a unique opportunity to supplement the biofuel programme in India. A co-blended strategy can be reviewed which includes ethanol and ETBE-blended in gasoline. **In Table 6 it is shown how ethanol and ether can coexist under Bharat VI.[55] Fuel ethers can also be supplemented in areas where ethanol availability is low to compensate for additional raw material availability**.

TABLE 5 Quantitative comparison of octane improvers

Octane Improvers Options Quantitative and Qualitative Comparison																			
Category	Product		Oxygenates			Alcohols		Esters		N-Derivates N-Aromatics		Metal-based Metal-organics				Hydrocarbons Molecules		Blendstocks	
		RON	MTBE	ETBE	TAME	MeOH	EtOH	SBAC	DMC	AAPE	NMA	TEL	MMT	Ferro-cene	Toluene	Iso-octane	DIB	Alkylate	Refor-mate
Octane Boosting Effectiveness	bRON		121	123	110	140	128	117	110	528	360	22000	32000	20600	120	100	113	96	99
Costs Compative	"USD/1 Point RON Increase *- lowest ********* - highest"		**	***	**	*	**	*****	*****	*****	*****	*********	*********	*********	**	***	***	***	**
Bio-Derivatives	YES/NO		If Methanol -green, then YES	YES	NO	If Methanol -green, then YES	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Fuel Volumetric Contribution	%v/ RON-Point		3,0	2,8	4,5	1,9	2,5	3,4	4,5	0,2	0,4	0,0	0,0	0,0	3,1	8,3	4,0	11,9	9,1
World Capacity (magnitude order)	KT/Y		>30000	>4000	<500	>80000	>80000	630	<1000	<0,1	<10	<1	<10	<1	>30000	<1000	<1000	>50000	>100000
Amount of which direct blending into gasoline	%		90	100	100	6,4	90	<0,1	0	100	100	100	100	100	<0,1	100	30	100	100
Number of different manufacturers	#		>100	>20	<20	>100	>100	<20	<20	<5	<20	1	<5	<5	<100	<10	<10	>100	>100
Legal Limitation (Singapore)	%		≤22	≤22	≤22	≤3	≤10	n.a	n.a	n.a	n.a	0,0008	0,0008	0	42	n.l.	21	n.l.	67
Euro-VI Limit	%		≤22	≤22	≤22	≤3	≤10	0	0	[1]	[2]	0,0008	0,0008	[3]	35	n.l.	18	n.l.	56
"Engine-no-harm" Test Passed	Y/N		YES	YES	YES	YES	YES	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES
Metal Content	%m/m		0	0	0	0	0	0	0	0	0	64	25	30	0	0	0	0	0
Aeromatic Content	%v/v		0	0	0	0	0	0	0	100	100	0	0	0	100	0	0	0	63
Aromatics Content Contribution	Effect		Reduction	Reduction	Reduction	Reduction	Reduction	Reduction	Reduction	Increase	Increase	No Effect	No Effect	No Effect	Increase	Reduction	Reduction	Reduction	Increase
Olefin Content	%v/v		0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0,5
Oxygen Content	%m/m		18.15	15.66	15.66	49.94	34.73	27.55	53.29	7.99	0	0	0	0	0	0	0	0	0
Blending Volatility	kPa		55	28	10	782	220	1.33	7.4	9	0.04	0.027	(BP 232^{0}C)	(BP 249^{0}C)	2.8	31	14	26	23.7
Energy Density	MJ/L		26	27	28	15.8	21	30.5	16.9	31.5	38	n.r.	n.r.	n.r.	35.2	30.5	31.5	32	34
Toxic Emissions (Benzene, PM, ...)	Effect		Reduction 🟢🟢	Reduction 🟢🟢	Reduction 🟢	Increase 🔴	Increase ⚪	Increase 🔴	n.a	Increase 🔴	Increase 🔴	Increase 🔴🔴	Increase 🔴	Increase 🔴	Increase 🔴	Reduction 🟢	Increase 🔴	No effect	Increase 🔴
Engine/ vehicles Combustion Emissions			🟢🟢	🟢🟢	🟢	🔴	No Difference	🔴🔴	n.a	🔴	🔴🔴	🔴	🔴	🔴	No Difference	🟢🟢	🟢	🟢🟢	🟢
Need of Dedicated Supply Chain)			🟢🟢	🟢🟢	🟢	🔴	🔴	n.a	🔴	n.a	n.a	No Difference	No Difference	No Difference	🟢	🟢🟢	🟢🟢	🟢🟢	🟢🟢
Refinery (light HCs removal need)	Qualitative		🟢🟢	🟢🟢	🟢🟢	🔴🔴	🔴	No Difference	🔴	n.a	n.a	No Difference	No Difference	No Difference	🟢	🟢🟢	🟢	🟢	🟢

Density	T/m³		0.740	0.736	0.770	0.792	0.789	0.870	1.070	1.315	0.990	1.650	1.380	1.100	0.867	0.690	0.708	0.699	0.800
Octane Booster Need for 11 RON-Points increase	%v/v		2.999	2.84	4.545	1.923	2.500	3.448	4.545	0.227	0.368	0.005	0.003	0.005	3.125	8.333	4.000	11.905	9.091
	%m/m		2.989	2.816	4.706	2.049	2.652	4.017	6.422	0.402	0.490	0.010	0.006	0.007	3.630	7.790	3.821	11.286	9.726
Worldwide Fuel Charter		95	≤22%	≤22%	≤22%	≤3%	≤10%	0	0	0	0	0	0	0	≤35%	no limit	18	no limit	56
BS-VI Specification Limit			≤ 15	≤ 15	≤ 15	≤ 3	≤ 10%	0	0	-	-	-	-	-	≤35%	no limit			

TABLE 6: Ethanol and oxyfuels can co-exist under Bharat VI[55]

Comparison of options						
Refinery	**Octamax**	**Ethanol**	**MTBE**	**ETBE**	**TAME**	**Best option**
A (equipped with OCTAMAX)	Olefins	VLI & oxygen	VLI	✓	✓	ETBE because of greater increase in MS volume
B (petrochemical integrated)	S & olefins	Oxygen	VLI	✓	✓	TAME may be restricted as it requires to be added by 18% against max 15%) and hence ETBE forms more ideal solution
C (equipped with alkylation unit)	✓	✓	✓	✓	✓	Octamax is suitable by actual vol. swell, but due to LPG deficit, TAME is the better option.
D (normal configuration)	S & olefins	Oxygen	VLI	✓	✓	TAME may be restricted as it requires to be added by 19% (against max 15%) and hence ETBE forms more ideal solution.

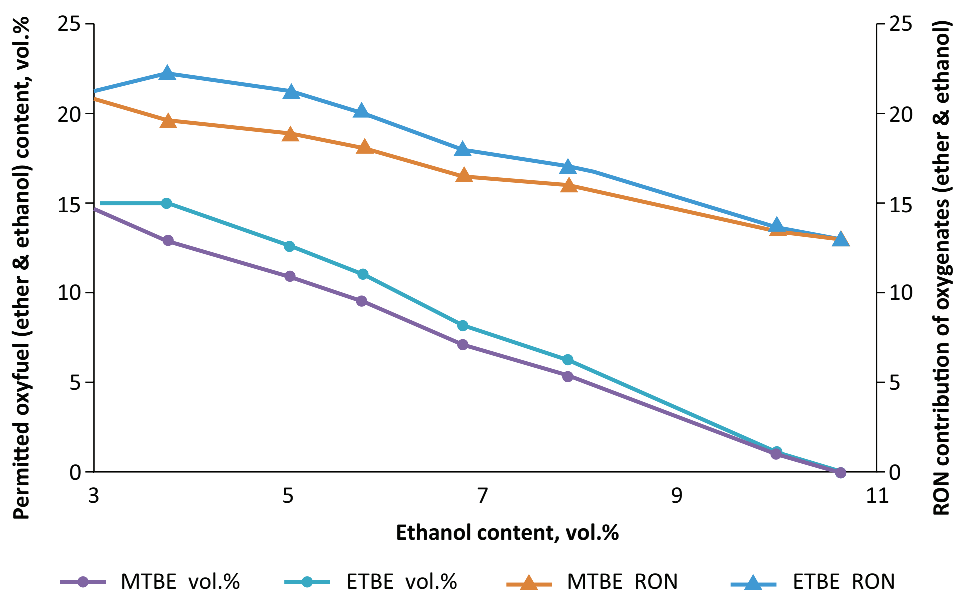

FIGURE 18 Oxyfuels allowed vs petrol ethanol content under current Bharat VI specifications[21]

Benefits of Co-blending Strategy

1. Increasing stringent technical and environmental specifications, required to fully exploit all beneficial characteristics of various blend stocks used by refiners to formulate finished fuels.

2. Several studies demonstrated that co-mixing different oxygenated blend stocks yields a better than linear blending performance via synergistic effects.
3. Chemical–physical properties leading to synergetic effect include polarity and hydrogen bonding effects.
4. Petrol specifications that benefit from the co-blending effect include volatility (BRVP), distillation curve (E70), octane performance (MON and RON) and water tolerance.
5. Co-blending also captures bio-components' well-to-wheels CO_2 saving potential.
6. Especially relevant the option to co-blending ethanol and ETBE, and bio/e-methanol based MTBE (as capacity is developed) considering the key role of bio-components to serve ambitious biofuels policy targets.
7. Oxyfuels can contribute to India's progress along the fuel quality curve, as shown in Figure 18[21] (based on EIA, HIS, Concawe, EEW Report).

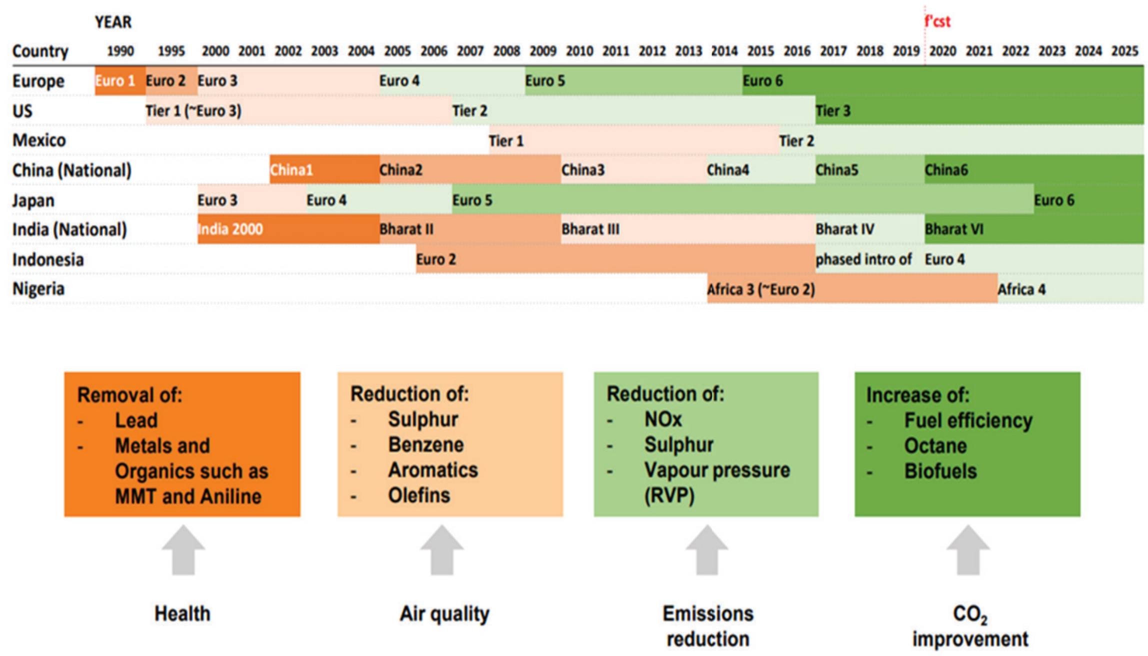

FIGURE 19 India's progress along fuel quality curve

During the course of this study, two stakeholder e-consultation meetings were conducted engaging Government and Industries in 2021 and 2022, respectively. The discussion points and the key recommendations suggested are given in Annexure. One of the reports was also submitted to MoP&NG in 2022.

KEY RECOMMENDATIONS

1. Indian refiners can increase ether content in gasoline (MS) to keep the overall cost of fuel low, meet BS VI specifications, produce ≥ 95 RON gasoline, and meet their sustainability targets.
2. Ethers can be used in conjunction with ethanol to get the best GHG benefit, reduce $PM_{2.5}$ formation and ozone depletion and increase octane.
3. As ethers like TAME, MTBE are already being produced domestically, this could be easier for India to ramp-up production of ethers and reduce import dependency.
4. Increased production of ethers can also lead to additional gasoline production due to usage of lower value refining streams (C4+) and therefore to improved use of imported crude and less crude oil import.
5. As with the adoption of ethanol which was initially introduced in ad hoc basis and then gradually expanded to E10 and E20 mandates, similarly, ethers can be adopted to demonstrate the benefits to refiners, customers, and automobile manufacturers.
6. There is no common standardization with respect to selection of additives for refiners. The mix is derived depending on the configuration of the refinery. Given this fluidity, a case for ether as oxygenate can be explored further for newer refineries and updates to existing refineries.
7. Fuel ethers are also part of the solution for the upcoming challenge to increase energy efficiency in transportation.
8. ETBE provides the opportunity for renewable ethanol production to grow further. Bio-methanol does the same for MTBE.
9. Advance R&D for renewable/waste-based generation of alcohols and ethers.

Key Actions Required from Policy Perspective

India is poised to move up in technology curve with newer engines, higher efficiency but with lesser use of petroleum gasoline. India has already introduced CAFÉ-1 regulation in 2018 and CAFÉ 2 in April 2022 towards increasing fuel and lowering CO_2 emission to 113 g/km. The inclusion of ether co-blending in India's biofuel policy can significantly benefit the air quality and reduce the associated issues/challenges of higher blending of ethanol.

To implement these recommendations a few policy changes would be required.

- **The automotive industry in India should have the adequate biofuel supply of higher RON in the next 3–5 years. If not, India not only would incur domestic supply challenges but also lose the export market as high-efficiency engines won't be able to operate with low RON gasoline.**
- **The government should consider introducing oxyfuels like ethers, namely, MTBE, ETBE, TAME along with ethanol blend target. Indian refineries can be encouraged to ramp up MTBE, ETBE,**

TAME production to meet domestic and export demand and to support balance of trade and energy security.

- **It is also highly desirable to adapt green fuels and e-fuels in broader perspective over merely biofuel by expanding the biofuel feedstock horizon and embracing other abundantly available wastes like MSW, plastic, and scrap tyres and CO_2 to make green and e-alcohols and embedding ethanol and methanol production under broader circular bio-economic industrial eco-system.**
- **The commercial viability of bio/green fuel production should be closely related to the commercialization of the by-products of bio/green fuel production.**
- **From a medium to long-term perspective, the biofuel policy should support advanced R&D for renewable ETBE and bio MTBE production technology innovation, fast scaling up, and commercialization. The biofuel policy needs to be conducive to make full use of bioethanol, bio and e-methanol, and domestic low-cost waste feedstocks for bio or green ether.**
- **One of the key enablers to facilitate adoption of ether-blended gasoline would lift the existing cap of (15 vol% cap on oxygenates in gasoline) and allow oxygenates up to 3.7 wt% oxygen limit in import and export of gasoline.**

In this connection, it is worth mentioning a recent case study undertaken by Stratas Advisors, in collaboration with Asian Clean Fuels Association (ACFA), to assess the premium price of imported gasoline for Australia. This considered the future demand conditions, availability of supply, and the refining capabilities required to meet the relevant fuel specifications. The study shows the possible scenario of the low RON gasoline (no-ether blended) becoming a 'boutique fuel' for Asia with supply availability for imports reduced by a factor of three times with a price premium to be paid of 3 US$ per barrel.
Each of the refineries has its specific blendstock. The overall cost-benefit analysis for different co-blending ratio of ethanol and ether needs to be performed for Indian refineries to quantify the degree of benefit to be accrued based on the blendstock composition. Additionally, rise of RVP associated with higher alcohol (ethanol) blending percentage limits the use of cheap and lighter hydrocarbons like C4 and C5, causing the gasoline more expensive. In contrary, co-blending of ether and alcohol to gasoline provides the opportunity of using C4/C5 hydrocarbons thus making the high RON gasoline cost competitive.

ANNEXURE

EVENT SUMMARY NOTE

SUMMARY

The Energy Resources Institute (TERI) in association with the Asian Clean Fuels Association (ACFA), a global consortium of leading petrochemical companies and FTI Consulting, a leading global business consulting firm, has launched the Report titled '*Enhancing India's Biofuels Program: Examining the role of Oxyfuels in India's Clean Fuel Transition*.'

ACFA is committed to advocating for the use of ethers in automotive fuels, aligning with contemporary vehicle technology and the pursuit of cleaner air. Through a collaborative effort with TERI, this report marks a pivotal stride towards fortifying India's biofuels initiative. By strategically integrating ethers as oxyfuels, India could substantially reduce its dependence on fossil fuel imports, fortify its trade balance, and accelerate the nation's transition towards a sustainable energy future.

The report was launched by various dignitaries including the **Shri Rajnath Ram, Advisor (Energy), NITI Aayog, Government of India; Shri Alok Sharma, Executive Director, Centre for High Technology (CHT),**

Ministry of Petroleum and Natural Gas, Government of India; Dr. Vibha Dhawan, Director General, TERI; Dr Clarence Woo, Executive Director, ACFA. The launch also saw the participation of other leading industry representatives from **Indian Oil Corporation Limited (IOCL), Hindustan Petroleum Corporation Limited (HPCL), Petroleum Planning and Analysis Cell, IIT Kanpur, Maruti Suzuki** and other **distinguished fellows from TERI. Prof Avinash Kumar Agarwal from IIT Kanpur, Dr (Prof) Anuradda Ganesh, Advisor, Cummins India Ltd** had also joined the stakeholder roundtable.

KEY ADDRESSES BY DIGNITARIES

The meeting began with the welcome address by **Dr. Vibha Dhawan, Director General, TERI**, where she reiterated the **Governments efforts towards finding cleaner solutions to India's energy demands** and the need to adjust India's strategy to look at integrating more biomass options. She had emphasized on exploring all types of sustainable biofuels using global successful models and India's own models.

Mr. Clarence Woo, Executive Director, ACFA provided the needed context for the report - assisting the government of India and the people of India in attaining an **optimized, economical, and balanced perspective towards policymaking on clean energy for India at a global stage**. He focused on the **need for ethers as a complimentary strategy to India's Ethanol mandate towards creating a 'total energy mix' to meet targets and improve air quality conditions**. Citing examples from Japan and France, he mentioned the potential of ethers as a domestic product improving the balance of trade, enhancing air quality, reducing air pollution by up to about 50%, and improving greenhouse gas emission reduction.

In his Keynote Address, **Shri Rajnath Ram, Advisor (Energy), NITI Aayog** shared that it was important that **all actors in the energy value chain are active in finding alternative solutions, to reduce the country's dependence on fossil fuels**. He highlighted the bold steps taken towards decarbonizing the economy, focusing on sources like hydrogen, bioethanol fuel, gasification, and compressed biogas, with a target of around 20% ethanol blending by 2025. He mentioned that the urgency of the search for environmental benefits and quality improvement is paramount, and **this report launch is the first step towards providing insights into the asset plan, cost analysis, and policymaking optimization for ethers**. Regarding policymaking, he reiterated the need to establish a firm foundation of independence to navigate the complexity of various systems for producing high-octane gasoline.

Shri. Alok Sharma, Executive Director, CHT, MoPNG also spoke about the various biofuels mandates that have been prioritized by the government including, Compressed Biogas and Sustainable Aviation Fuel. He spoke of the **potential of biomass gasification associated with bio-fermentation that can directly produce gas and improve ethanol production** – in line with meeting India's ambitious Ethanol mandate. He also mentioned the **need for various stakeholders to come together and discuss different strategies including ethers, to create complementary roadmaps for India** to achieve its clean fuels goals.

HIGHLIGHTS OF THE REPORT

The Principal Investigator (PI) Dr. Piyali Das, Senior Fellow and Area Convenor, Advanced Biofuel Division (ADB) at TERI presented the key highlights of the report:

» The report presents the case for including fuel **ethers to help enhance India's rollout of its ethanol-blending mandate**.

- **Co-blending ethers with ethanol will help get the best GHG benefit, reduce PM2.5 formation and ozone depletion, while increasing octane value**.
- **As fuel ethers** like MTBE **are being produced domestically**, this could be easier for India to ramp-up production of ethers **(MTBE as well as ETBE (referred to as" Easy-to-blend ethanol") and reduce import dependency**.
- Increased production of fuel ethers can also lead to **additional gasoline production** and to **improve the utility value of imported crude**.
- Fuel ethers provide the opportunity for India to **ramp up its biofuels production profile**.
- Oxyfuels can add value to India's clean fuels transition including **Energy Security & Trade; Financial Viability; and Cleaner Air**
- Fuel Ethers have several benefits at all levels:
  - **Refiners** - Reduce fuel production costs; Improves fuel blending options; Compatible with existing refinery infrastructure, fuel supply and distribution system; and Increases petrol production volume.
  - **Vehicle Manufacturers** - Compatible with existing as well as alternative power train technologies like hybrid cars; Improve fuel efficiency as much as 20%; Reduce vehicle emissions as much as 50%; In the Worldwide Fuel Charter, vehicle producers have indicated preference for ethers over other fuel components like ethanol; and Support vehicle producers in their sustainability targets.
  - **Consumers** - Improve fuel mileage; Improve engine performance; Reduce vehicle emissions; better air quality; Less car maintenance.

INPUTS FROM ROUNDTABLE DISCUSSION WITH STAKEHOLDERS AND NEXT STEPS

During the discussion on the report findings, several stakeholders (IOCL, HPCL IIT Kanpur, Cummins India. Maruti Suzuki, and others) presented their views on the report and provided valuable inputs for the next phase of work.

- There is a need to explore complementary strategies towards achieving India's E20 mandate given the challenge of on-ground ethanol production on a continuous basis.
- Standardization of fuel properties and blending percentages will be key and BIS can be an important stakeholder in this exercise.
- For a price sensitive market like India, Higher Octane fuels will have higher mark-ups. Cost analysis for such alternative strategies will need to be accounted for.
- A scope assessment for ethers capacity is needed to evaluate how much India can produce domestically.
- An economic study of the life cycle assessment of the cost of production of ethers should be considered as the next step for the development of a white paper. In other words, total cost of ownership for economic production of different ethers both by refinery and bio/green fuel producers needs to be carried out.
- There should be larger collaboration to carry out pilot projects to demonstrate the benefits of ethers in Indian condition. The Consortia needs to be formed with teams representing policy makers, OEMS, academic & research institutes (ether fuel production, engine testing and emission).

- Most of the secondary data are based on ether co-blending with gasoline/ petrol of other countries. Since the gasoline composition in India differs from the countries where ether co -blending is a reality, the co-blending data needs to be generated for Indian gasoline blend stocks. All other aspects need to be optimized too for Indian condition
- In addition to the study of co-blending of ether in gasoline , similar studies should also be undertaken for co-blending of ether in Diesel
- India needs to generate authentic Pilot data for ether co-blending and see its emission benefit on ground and these activities need not wait till green ethanol infrastructure is established in full capacity in India. This is the right time to conduct detailed study on prospect of ether co-blending in gasoline and diesel.
- A detailed road map should be developed on how ether can be integrated in India's cean/biofuel strategy and its contribution towards achieving net zero emission in transport
- Clean fuel strategies for India should also consider customer awareness on fuel efficiency to increase uptake.
- TERI can take a lead in developing Phase II project with consortia partners and discuss this further with Government bodies and concerned Ministries like NITI Aayog, MoP&NG, BIS and MoRTH for funding support. ACFA shown keen interest in supporting further policy studies also sharing global study reports and findings.

CONCLUSION

The report highlights the benefits of considering the introduction of oxyfuels like ethers (MTBE, ETBE, TAME) with the ethanol blend target. This inclusion will allow Indian refineries to ramp up production of ethers to meet domestic and export demand. India may face domestic supply challenges and lose out on a substantial export if it does not secure adequate biofuel supply of higher RON in the next 3–5 years. From a medium to long-term perspective, the biofuel policy should support advanced R&D for scaling and commercialization of renewable ETBE and bio-MTBE production technology innovation. Fuel ethers is an important complementary and supportive gasoline component to help achieve fuel ethanol success and accelerate the process of reducing emission in transport Sector.

VIRTUAL DISCUSSION I TERI REPORT ON 'MULTIFUEL OPPORTUNITY FOR INDIA' I CURATED BY ACFA AND FTI – POST E-CONSULTATION NOTE-2022

Context

As India enters its G20 presidency this year, focus on India's decarbonization efforts amid its increasing energy demand, is under the spotlight. India is making strides in creating the right energy mix, one which not only ensures energy security but aligns with our net zero commitments. In this context, the Asian Clean Fuels Association (ACFA) and FTI Consulting, in partnership with The Energy Resource Institute (TERI), hosted a virtual discussion around its latest report: 'Multifuel Opportunity for India' to reiterate the role of Fuel Ethers can play, towards expanding towards India's import substitution goals and impacting India's technological advancements in creating low emission and cleaner fuels.

eConsultation – Objectives and Participants

ACFA organized a multi-stakeholder consultation to enabled deeper discussions on the report findings:
The keynote address was delivered by:

» Mr. Ramakrishna YB, Member - Working group on Biofuels at Ministry of Petroleum and Natural Gas, Govt. of India

The eConsultation was attended by large oil and gas manufacturers including:

» Adani Total Gas
» Hindustan Petroleum Corporation Limited
» Nayara Energy Limited

and other think tanks in the energy space including,

» Centre for High Technology (Ministry of Petroleum and Natural Gas)
» The Energy Resource Institute (TERI)

Members form the Asian Clean Fuels Association (ACFA) including,

» LyondellBasell Industries
» Saudi Basic Industries Corporation (SABIC)
» Evonik Industries AG
» Saipem
» ECOFUEL

The conversation was curated by:

» FTI Consulting

Key Discussion Points

» **In his keynote address, Mr. Ramakrishna YB laid emphasis on the Government of India's ongoing work in the space of alternate fuels and ethers.**
    - Energy transition is a government priority specifically since global commitments announced at COP26
    - Emphasis on energy transition began for India in 2003, with a focus on Ethanol Blending. In the last 10 years, large emphasis has been put on low carbon alternates, particularly ethanol. A policy and

new programmes are in place to implement this focus. Targets for the blending programmes have progressed
    - 2014 – 1.4% (announced even before blending had begun)
    - 2022 – 10% (achieved 5 months in advance)
    - 2026 – 20% (roadmap developed and underway)
    - 2030 – 30% (target announced)
- Advances in ethanol blending have been significant because of the availability of feedstock. Both 1st generation and 2nd generation ethanol production developed:
    - 1st generation – use of different kinds of starch and sucrose
    - 2nd generation – use of different kinds of inedible feedstock, waste, agricultural residue, and urban capture (converting terrain gas)
- Commercialization of technologies that are carbon neutral will be very important in achieving goals ahead.
- SATAT (Sustainable Alternative Towards Affordable Transportation) programme – targeting 5000 commercial blends through conversion of different wastes – Solid waste, Animal waste, and other organic waste converted into compressed biogas. Target of this programme is 15 million metric tonnes of biogas.
- As the Energy transition roadmap is developed for next 15-20 years, fuel requirement in India will also increase. Alternates to fuels are being actively discussed including natural gas, hydrogen, and blends.
- Challenges in clean energy
    - Conversion technology development and adoption
    - Commercialization of technology
    - Use of natural resources – waste management
    - Uncertainty of energy mix – relevance of methanol, Hydrogen and other new fuels will remain to be seen
- In this context, the fuel ether development is important – not only evaluating its advantages but also exploring ways for its commercialization and adoption

» **Dr. Piyali Das, Senior Fellow at TERI, shared highlights from the ongoing TERI report – Multifuel opportunity for India. A few key highlights from the report were discussed including:**

- Fuel ethers contribution towards India's import substitution goals
- Fuel ethers towards reduction of GHG emissions
- Impact of India's technological curve towards its societal + environmental goals
  (Newer engines are more efficient, require less fuel, emit less GHGs)
- Policy imperatives, economic considerations of combining ethers and ethanol
- Proposition for refiners
  (Detailed report shared with this note)

» Clarence Woo, Executive Director, Asian Clean Fuels Association went on to share Global successes of MTBE/ETBE usage by petrochemical companies, particularly in larger markets, sharing perspectives of its possible usage in India

- A few important points were raised by the stakeholders' present –
  - Using the example of France where ETBE ethers are credited to be able to maintain GHG targets and are seen as complimentary efforts, India can also view ethers as alternates from a policy perspective, contributing to lesser GHG emissions
  - Even though Indian automobiles are an average of 5-10 years old, there will be no challenges of uptake of blended fuels and ethers (experience from Indonesia) – in fact ethanol blended fuels are facing challenges including possible corrosion. With the blended ethers fuel this can be further negated. Further, ethers can also stabilize and reduce impact of GHG emissions and adds to gas equality and improves engine performance
  - Areas that can improve the report:
    - Many of the advantages of ethers blended ethanol will be helpful to be brought out more clearly in the report, including commercial viability
    - With government of India strong focus on ethanol, additional components being brought into the mix will need to be evaluated in depth
    - Cost analysis will be very important
    - Supply and demand imbalances also need to be evaluated

Way Forward

- To explore potential collaborations with oil majors – sharing data on developments with respect to fuel ethers and facilitating two-way knowledge transfer relationship
- Share the detailed presentations and the eConsultation summary with all participants
- Adapt insights from the eConsultation into the TERI report being developed

VIRTUAL DISCUSSION | TERI REPORT ON 'MULTIFUEL OPPORTUNITY FOR INDIA' | CURATED BY ACFA AND FTI – POST E-CONSULTATION NOTE-2021

April 30, 2021

To,
Mr. Tarun Kapoor
Secretary,
Ministry of Petroleum and Natural Gas
New Delhi

Subject: Submission from Asian Clean Fuels Association (ACFA) - Recommendation for India's Clean Fuel Roadmap – Beyond BS-VI

Dear Shri Tarun Kapoor,
I am writing on behalf of the Asian Clean Fuels Association (ACFA), to appraise you about a multi-stakeholder e-Consultation that was organised on Tuesday, April 20, 2021, bring together government and industry participants to discuss India's Clean Fuel Roadmap – Beyond BS-VI.
The e-Consultation witnessed participation from 10 stakeholders, and covered a number of important areas, namely:

a) Global learnings from ethanol blending programmes
b) Importance of a multi-clean fuels' strategy for India
c) Make-In-India and Oxygenate Exports
d) Need for economic research to guide Clean Fuels Roadmap for India

We would like to request for a meeting with you or a nominated officer to discuss this submission.
Thanking you,

Sincerely,
Rakesh Aulaya
(On behalf of Asian Clean Fuels Association/ACFA)

India's Clean Fuels Roadmap and 'Oxygenates for India' Plan-Post Consultation Note 2021

Background

India has come a long way in improving tailpipe emissions from vehicles from the nationwide introduction of Bharat Stage I emissions standards in 2000 to implementing BS-VI amidst the pandemic and the country-wide lockdown in 2020. With a huge increase in motor vehicle numbers and traffic as well as air pollution, there is now a need for continuous improvement in fuel efficiency and quality standards, in conjunction with emission-oriented outcomes. With a focus on stringent fuel quality standards worldwide, countries are now adopting an ecosystem approach to policy making and preparing roadmaps for multiple fuel oxygenates, based on the long-term impact of economic cost, production capacity, feedstock availability, air quality, and fuel quality harmonization across regions.

The adoption of Euro emission standards for on-road vehicles has driven fuel policy in several of the Middle East and Asian countries. Thailand, Vietnam, Indonesia, Philippines, and China have adopted specific biofuels as they moved towards higher fuel standards—but have faced challenges on that road and some are now switching course to fuel oxygenates, or a multi-fuel policy.

India's draft National Auto Fuels Policy needs an urgent review if the country is to move towards faster adoption of cleaner transport fuels, meet transport demand, and achieve lower emission targets – in line with its global commitment to sustainable transport and climate change. Auto manufacturers and transport fuel suppliers/refineries have legitimate views on the challenges of some clean fuels for India.

Multi-Stakeholder e-Consultation – India's Clean Fuels Roadmap Beyond BS-VI

To support the above objectives, ACFA organized a multi-stakeholder consultation on 'India's Clean Fuels Roadmap beyond BS-VI'. The discussion drew on the various challenges currently being faced by countries in the Asia Pacific region to meet their E10 and E20 ambitions and work towards a multi-fuel roadmap that offers a level playing field for other oxygenates to co-exist to achieve better fuel economy, lower emissions, address supply and energy security challenges, seek export revenue generating opportunities and meet national climate commitments.

The consultation on April 20, 2021 was represented by Indian policy makers, industry representatives, and third-party, national, and international experts from:

PARTICIPANTS

1) Centre for High Technology, Ministry of Petroleum and Natural Gas, Government of India
2) Department of Chemicals & Petrochemicals, Ministry of Chemicals and Fertilizers, Government of India
3) Haldia Petrochemicals
4) Petroleum Conservation Research Association (PCRA)
5) Society of Indian Automobile Manufacturers (SIAM)
6) The Energy and Resources Institute (TERI)
7) LyondellBasell Industries
8) Saudi Basic Industries Corporation (SABIC)
9) Evonik Industries AG

10) FTI Consulting
11) Centre for High Technology, Ministry of Petroleum and Natural Gas, Government of India
12) Department of Chemicals & Petrochemicals, Ministry of Chemicals and Fertilizers, Government of India
13) Haldia Petrochemicals
14) Petroleum Conservation Research Association
15) Society of Indian Automobile Manufacturers
16) The Energy and Resources Institute
17) LyondellBasell Industries
18) Saudi Basic Industries Corporation (SABIC)
19) Evonik Industries AG
20) FTI Consulting

The e-consultation evaluated the following questions as part of the discussions:

a) What should India's Clean Fuels Roadmap look like? What is the role of Oxygenates in the roadmap?
b) Will the current fuel Oxygenate options be enough to address the issue of gasoline fuel quality and moving beyond BS VI?
c) Can the current fuel Oxygenate economy be able to sustain itself without subsidy support? What about consumption centres that are far from production centres?
d) How can India better achieve its emissions and engine performance targets?
e) How have higher RON fuels and BS-VI impacted refiners and automobile manufacturers?
f) What are the Challenges of a strategy based on a single-clean fuel and contribution of forex earnings from non-alcohol oxygenates?
g) What is the global experience with E10 targets?
h) Is there a 'Make-In-India' and export potential for fuel oxygenates?

Discussion Points at the e-Consultation

1. **Impact of BS-VI implementation on refiners, automobile manufacturers, and of mandating Ethanol blended fuels / advancing E20 targets to curb emissions**

   a) To meet the stipulated fuel quality for **BS-VI** fuels, and emission standards, Indian refineries have undergone major upgrades. De-sulphurisation technologies along with octane-boosting units have been installed or augmented with large investments.
   b) However, fuel quality and vehicle technology go together for a cleaner transport ecosystem. Automobile manufacturers including their association SIAM, said: "there have been significant engine technology changes and more must be done if India desires to move to E10, and then E20 blending by 2025." Given the E20 roadmap but erratic availability of E5 (current blending rates are 5-8% in most areas), challenges of blending, storage, and transportation of ethanol, manufacturers face dilemmas on introducing structural changes in vehicles.
   c) Engine design changes are expensive, and BS-VI has already driven significant engine design and product-mix changes (for instance a move away from diesel, for Maruti-Suzuki).
   d) If E10 and E20 need to be planned for, there needs to be reliable availability of those fuels; if E0 is used instead (no ethanol blending) and no oxygenate alternatives (e.g. ethers) are used either,

resulting in low RON numbers, then engines suffer risk both knocking, with related damages, as well as energy efficiency losses

e) There is a strong need to explore multiple oxygenates (alcohols and ethers) with higher energy content, manufactured locally in India, and address the supply constraints with a long-term and planned approach for the ecosystem. Manufacturers (including SIAM,) have said they are supportive of the govt roadmap but urge a focus on and guarantee of consistent availability of the newer targeted fuels blends—E10 and beyond. A multi-clean fuels national policy would help address this.

2. Challenges of a strategy based on a single-clean fuel and contribution of forex earnings from non-alcohol oxygenates

a) A "single fuel only" policy approach depending on ethanol alone may face limitations due to feedstock availability, dependence on imported technologies, and distance from refineries to fuel blending locations. Higher subsidies alone will not provide a reliable and holistic commercial clean fuels policy view and may even lead to a trade deficit.

b) With the world's fuel and engine ecosystems moving towards higher octane ratings, it will be important for India to align itself to look at alternatives to achieve higher octane fuels that behave and combust predictably to ensure higher fuel efficiency. Haldia Petrochemicals inferred: "that they are keen to explore MTBE blending to achieve higher octane ratings". There is a need for alternate fuel oxygenates that can support domestic consumption and be a potential exports/forex earner.

3. What are the global experiences with ethanol-blend targets from across the world and India?

a) Countries like China that implemented fuel ethanol programs in the early 2000s have now switched course due to increased concerns on availability, including 'food vs fuel' issues and debates. Economic cost, production capacity, and resource management are barriers leading countries like the Philippines, Vietnam, and Indonesia to pull back on their plans.

b) Thailand had planned to make gasohol E20 the primary fuel for motorists but has now postponed it indefinitely because of higher biofuel prices, creating a financial burden for the Oil Fuel Fund.

c) Japan and Indonesia have carried out extensive assessment studies on the use of ethanol-blended fuel and identified concerns over ethanol direct blending and increased costs to refiners. Department of Chemicals and Petrochemicals (in our consultation) suggested: "exploring Japan's feasibility structure on the usage of ethers."

d) Brazil, a leading global producer of ethanol, also introduced flexible fuel vehicles (FFVs) to address availability concerns. These can work on any ethanol-petrol blend. TERI (in our consultation) suggested: "a similar approach like Brazil could be explored in India."

e) Centre for High technology said: "considering the growing demand for motor vehicles, biofuels are important for India, apart from Electric vehicles". To promote ethanol as a fuel, the Government of India has approved a modified scheme for interest subvention for ethanol production, expanding the scheme to include grain-based distilleries and not just molasses-based ones So far the blending rates are 6-8 % and up to 10% would not be a problem, however concrete pathway for E20 is underway.

4. Importance of a national clean fuel's roadmap, with multiple oxygenates (alcohol and ether-based)

a) ACFA discussed the the use of multiple fuels oxygenates / coexistence of ethers like MTBE and ETBE to help improve air quality, meet fuel quality, and fuel efficiency standards that help the entire ecosystem of consumers, automobile manufacturers, and fuel oxygenate producer. ACFA also made a recommendation that it is imperative to have a multi-stakeholder approach involving all relevant party views across sectors like agriculture and petrochemicals in a coherent and cogent manner to work closely with the government to make enabling policies. India already has a growing capacity of 740 kt/yr, which is already half of ethanol consumption. This means that MTBE/ethers can have an equivalent positive impact on India since it is domestically produced. The policies need to offer a level-playing field for the existence of current and new fuel blends to aid the maturity of the eco-system, growth of diverse sectors and meet climate ambitions too.

b) ACFA recommended that India should finalize a Clean Auto Fuels roadmap beyond BSVI, taking a view of all oxygenates options (rather than a single fuel type approach) and a realistic view of the blending implementation and domestic supply challenges. The reasons for this were:

i. **Fuel quality and economy**
India needs to harmonize auto fuel standards with global standards as articulated in the Automotive Mission Plan (AMP 2026). This will require a conscious path towards higher RON (moving from 91 to 95, and subsequently to 98 and beyond, to 102 as in Europe), and higher-octane fuels in line with market maturity.

ii. **Ethers are important oxygenates for improving octane**
India should consider other oxygenates along with alcohol-based oxygenates in their roadmap to move towards high-quality clean fuels. It is important to seek advantage of higher energy fuels in the mix as consumer demand rises. Moving away from the single-fuel alcohol-only based oxygenates policy will help improve the quality of the air Indian's breathe by reducing vehicle emissions and enable cleaner-burning petrol, while also increasing engine efficiency and performance.

iii. **Air Quality**
Research studies across the world suggest that volatile organic compounds (VOCs) from vehicle exhaust, fuel evaporation and permeation have been major contributors to India's air pollution issue. This in ACFA's view can be checked with higher Oxygenate use in fuels. By increasing the fuel oxygenate use (Ethers), Auto OEMs can comply with Corporate Average Fuel Efficiency (CAFÉ) norms with regards to CO_2 emissions reduction and compliance targets.

iv. **Fuel quality harmonization across the regions**
Due to the cyclic volatility of indigenous feedstock, land availability, logistics compatibility, ease-of-transport, storage, and production for the refineries, fuel harmonization continues to be an obstacle with a single-fuel policy -- an issue that has aggravated further due to the pandemic. Ethers demand lower investments and UST (storage tank) modifications; control of fuel quality is also easier. This ease of logistics will ensure consistent blends and uniform availability across

the country. The technical calibrations of vehicles will also be better managed by automobile manufacturers, and issues of knocking and corrosion will be avoided.

5. Make-In-India' and forex revenues from oxygenate exports

a) With the right support and a level-playing field, India could emerge as an international production hub, playing an important role in the global supply chain for clean fuels. This is even more important for the country given the economic constraints now due to the pandemic. A multi-clean-fuel policy will add to energy security and stability.

b) India gets significant foreign-exchange export earnings from fuel oxygenates. This growing domestic production of Ethers (MTBE and ETBE) should be supported for forex earnings and meet onshore demands. MTBE produced and used in gasoline blending in India will reduce gasoline imports. MTBE/ethers are known to increase gasoline production volume by as much as 15%

c) With the increasing demand for gasoline and a focus mainly on subsidies and incentives for a single fuel oxygenate/additive in India i.e. Ethanol, it is difficult to make a rational economic comparison between all other Oxygenates. A uniform set of subsidies from the government is important to assess return on investments, planned production capacities and ensure there is no trade deficit.

Way Forward

As the way forward, the participants discussed the need to conduct economic research on the production, supply, and forex earnings capacity, of different oxygenates (alcohol-based as well as ether-based). This is to ensure a level playing field to all oxygenates contributing to the growth of different sectors like agriculture and petrochemicals rather than the current skew towards single fuel government policy that limits India's options into the future of a clean multi-fuel strategy that enables the use of cleaner automotive fuels based on the principles of sound science, cost efficiency and sustainability of the environment.

ACFA would like to propose a jointly commissioned study, with the Government of India, with a national research partner e.g. TERI. It would be great to have the support of the Government of India in such an economic study.

Addendum

We would like to share below a very relevant example of how French refiners, looked to fulfil their E10 obligations, by adopting, an alternative fuels strategy with effective results:

» Co-blending ETBE and ETOH-DB were looked at to exploit the superior octane performance of ETBE and reduce ethanol's high blending volatility issue.

» They agreed upon a common "BOB" formulation, containing ETBE, which helps to not only improve fuel swaps but also allows refineries the flexibility to consider blending of different percentages of ethanol to yield either "E5" or "E10" as per need.

» This process enabled Octane-upgrade that was fully bio but very low octane naphtha (from HVO process) with high-octane fossil MTBE to produce almost fully bio-finished 95RON gasoline.

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GLOSSARY

- **ETBE –** Ethyl tert-butyl ether is an oxygenated gasoline fuel component and ether that offers more benefits than ethanol as a blending additive.
- **MTBE –** Methyl tert-butyl ether is a flammable liquid that has been used as an additive for unleaded gasoline since the 1980s.
- **TAME** – Tert-amyl methyl ether is an ether used as a fuel oxygenate. It is added for three reasons: to increase octane enhancement, to replace banned tetraethyl lead, and to raise the oxygen content in gasoline.
- **TAEE** – Tert-amyl ethyl ether is a chemical substance that belongs to the group of fatty acid esters. It is used as an additive in gasoline fuels as an oxygenator and solvent in organic chemistry.
- **RON** – Research octane number (RON) is the most common octane rating, determined by running the fuel in a test engine with a variable compression ratio under controlled conditions and comparing the results with those for mixtures of iso-octane and n-heptane.
- **Octane Number** – Octane number is a standard measure of a fuel's ability to withstand compression in an internal combustion engine without detonating. The higher the octane number, the more compression the fuel can withstand before detonating.
- **E20** – E20 (20% ethanol blended) petrol is a mixture of 20% anhydrous ethanol with 80% motor gasoline fuel volume by volume.
- **EBP Programme** – The Ethanol Blended Petrol Programme was launched in 2003 with an aim to promote the use of renewable and environmentally friendly fuels and reduce India's import dependence for energy security. Starting with 5% blending, the government has set a target of 10% ethanol blending by 2022 and 20% blending (E20) by 2030.
- **OMCs** – These are the public sector oil marketing companies (OMCs) like Indian Oil Corporation Limited (IOCL), Hindustan Petroleum Corporation Limited (HPCL) and Bharat Petroleum Corporation Limited (BPCL).
- **GHG** – Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of radiation emitted by the earth's surface, by the atmosphere itself, and by clouds. This property causes the greenhouse effect.
- **CAGR** – Compound annual growth rate (CAGR) is a way to measure how an investment or business has grown over a specific period. It considers the effect of compounding which means that the growth builds upon itself.
- **Total VOCs** –Total volatile organic compounds or TVOCs is a term used to describe a group of compounds that are present in emissions or ambient air. VOCs typically are industrial solvents, such as trichloroethylene; fuel oxygenates, such as methyl tert-butyl ether (MTBE); or by-products produced by chlorination in water treatment, such as chloroform.
- **Commingling Effect –** Commingling of fuel is the blending or mixing of different batches or grades of fuel, either to mix similar products together for transport and storage or to create a new product with specific performance characteristics. This is a common practice in the oil and gas industry, particularly in the refining and distribution of gasoline, diesel, and other refined products.
- **E3, E5, E10 Series –** Similar to India's ethanol blending targets, Japan's energy policy had set three targets of blending at 3% (E3), 5% (E5) and 10% (E10) ethanol blending by 2020.
- **NO_x** – Nitrogen oxides (NO_x) act as indirect greenhouse gases (GHGs) by producing the

tropospheric greenhouse gas 'ozone' via photochemical reactions in the atmosphere.

- **THC** – Total hydrocarbon content (THC) is used to describe the quantity of the measured hydrocarbon impurities present. Usually expressed as methane equivalents.
- **BS Framework** – India has adopted Bharat Stage (BS) Emission Standards since 2000, modelled on EU norms. The BS Standards regulate tailpipe emissions of air pollutants including particulate matter, SO_x, and NO_x as well as carbon monoxide, hydrocarbons, and methane. They have been developed for all vehicle categories and apply to vehicles manufactured since April 2020.
- **BS-VI** – In April 2020, India leapfrogged from BS IV to the implementation of BS VI, with current standards similar to Euro 6 norms.
- **RVP/RVOP Value** – Reid vapour pressure (RVP) is a measure of volatility and is defined as the pressure at which a hydrocarbon liquid will begin to flash to vapour under specific conditions. They are sometimes specified by crude oil purchasers, particularly if the crude is to be transported by tanker or truck prior to reaching a processing plant.
- **OECD** – The Organization for Economic Co-operation and Development is an intergovernmental organization with 38 member countries, founded in 1961 to stimulate economic progress and world trade.
- **G20 –** The Group of Twenty (G20) is the premier forum for international economic cooperation. It plays an important role in shaping and strengthening global architecture and governance on all major international economic issues. India holds the Presidency of the G20 from 1 December 2022 to 30 November 2023.
- **2G Ethanol** – First-generation (1G) bioethanol is one of the most used liquid biofuels in the transport industry. It is generated by using sugar- or starch-based feedstocks, while second-generation (2G) bioethanol is generated by using lignocellulosic feedstocks. With an objective to augment ethanol supplies, the government allowed procurement of ethanol produced from other non-food feedstock besides molasses, like cellulosic and lignocellulosic materials including petrochemical route.
- **Worldwide Fuel Charter –** The Worldwide Fuel Charter was first established in 1998 to promote greater understanding of the fuel quality needs of motor vehicle technologies and to harmonize fuel quality world-wide in accordance with vehicle needs. It provides recommended fuel specifications for a range of grades of gasoline and diesel fuel for use with engines designed for different levels of emission control.
- **Bioether** – When the alcohol obtained from biomass is used in the production of MTBE, ETBE or TAME, it is considered as a 'Bioether'.
- **IIEA –** The International Energy Agency is a Paris-based autonomous intergovernmental organization, established in 1974, that provides policy recommendations, analysis and data on the entire global energy sector. The 31-member countries and 13 association countries of the IEA represent 75% of global energy demand.
- **AMF TCP –** Advanced Motor Fuels Technology Collaboration Programme – Established in 1984, AMF has a strong international network that serves to foster collaborative research, development, and deployment (RD&D) and to provide unbiased information on clean, energy-efficient, and sustainable fuels and related engine and vehicle technology.
- **LDV –** LDV stands for light-duty vehicle
- **Scope 1 Emissions** — This covers the greenhouse gas (GHG) emissions that an organization makes directly, for example, while running its boilers and vehicles.
- **Scope 2 Emissions** — These are the emissions an organization makes indirectly – like when the electricity or energy it buys for heating and cooling buildings, is being produced on its behalf.
- **Scope 3 Emissions** — In this category go all the emissions associated, not with the organization itself, but that the organization is indirectly responsible for, up and down its value chain. For example, from buying products from its suppliers, and from its products when customers use them. Emissions-wise, Scope 3 is nearly always the big one.

- **$PM_{2.5}$** – PM stands for particulate matter (also called particle pollution): the term for a mixture of solid particles and liquid droplets found in the air. $PM_{2.5}$ includes fine inhalable particles, with diameters that are generally 2.5 micrometres and smaller.
- **NCAP –** National Clean Air Programme, launched in 2019, is India's flagship programme for better air quality in 122 cities with a five-year action plan. The NCAP targets to achieve 20% to 30% reduction in concentrations of PM_{10} (particulate matter of diameter between 10 and 2.5 micrometres) and $PM_{2.5}$ (particulate matter of diameter 2.5 micrometres or less) by the year 2024, keeping 2017 as the base year for comparison of concentration.
- **Oxyfuels** – Oxyfuels and oxygenates are chemical compounds/hydrocarbons added to fuels which contain at least one oxygen atom in their chemical structure. These are usually employed as gasoline additives to reduce carbon monoxide and soot and related polyaromatic hydrocarbons (PAHs) and nitrated PAHs. The most widely used oxyfuel/oxygenates are alcohols and ethers.
- **Olefin Content** – One of the major components of gasoline are olefins (alkenes), along with a mixture of other hydrocarbons, including paraffins (alkanes), naphthenes (cycloalkanes), and aromatics, and oxygenates [16]. Olefins are hydrocarbon compounds with one or more carbon double bonds.
- **Cetane Number** – Cetane number is an indicator of the combustion speed of diesel fuel and compression needed for ignition. It plays a similar role for diesel as octane rating does for gasoline.
- **Polycyclic Aromatic Hydrocarbon** – A polycyclic aromatic hydrocarbon (PAH) is a class of organic compound that is composed of multiple aromatic rings. The simplest representative is naphthalene, having two aromatic rings and the three-ring compounds anthracene and phenanthrene.
- **Corporate Average Curb Weight** – Bureau of Energy Efficiency, Government of India has adjusted the average car weight for the 2022–23 standards to 1087 kg from the originally proposed 1145 kg.
- **Distillation Curve –** The petroleum-derived automotive fuels in the market today have different characteristics from those that were available a decade ago, mainly due to the promotion of the use of biofuels. However, the study of their distillation curves remains a basic test for their quality control.
- **Well-to-wheels CO_2** – Well-to-wheel emissions include all emissions related to fuel production, processing, distribution, and use. In this case, the term includes all CO_2 emissions across the value chain.
- **Ethanol/ETBE BOB** – For refiners producing motor gasoline containing ethanol or ether ETBE, an important consideration is the production and properties of the hydrocarbon blendstock prior to oxyfuel blending. This is termed as a blendstock for oxygenate blending (BOB). This hydrocarbon blendstock must be produced with properties that are appropriately adjusted in order to take into account any changes that will occur after the oxyfuel has been added.
- **CAFÉ 1** – The Corporate Average Fuel Economy (CAFE) norms are primarily designed to increase fuel efficiency, which, in turn, will lower an organization's overall CO_2 footprint. CAFE regulations in India came into force from April 1, 2017. Under this, average corporate CO_2 emission must be less than 130 g/ km till 2022 and below 113 g/km thereafter.
- **CAFÉ 2** – As per CAFÉ II that is in effect since April 2023, the target for average corporate CO_2 emission has been lowered to 113 g/km. While BS VI norms limit the emissions of pollutants like hydrocarbons, sulphur and oxides of nitrogen, CAFE norms deal with overall fuel consumption, specifically the quantity of fuel consumed.

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