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Aftertreatment Technologies in Automobile Sector: Opportunities for Home-Grown Technology Creation and Start-ups

A Policy Perspective

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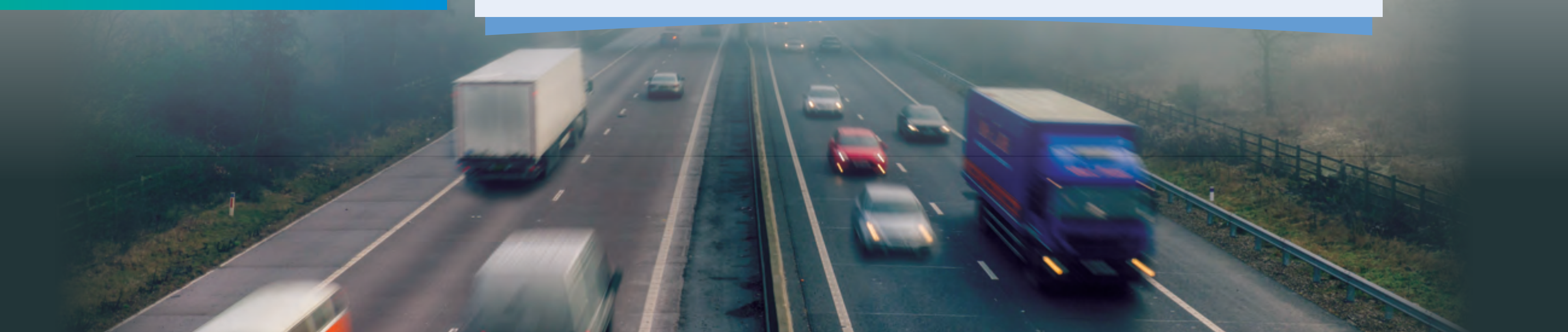
1. Introduction

The introduction of BS-VI fuel standards in India is a significant step to reduce vehicular exhaust emissions. This is effective only if vehicle engines are equipped with advanced aftertreatment technologies. These aftertreatament systems are designed to control Carbon monoxide (CO), Nitrogen oxides (NO)x, Hydrocarbons (HC), Particulate matter (PM2.5), and Black Carbon (BC) emissions. The aftertreatment systems major components are highly sophisticated filters and catalysts to control each of the pollutants. Regulations that are evolving and becoming more stringent for emission norms are driving the research and innovation for building more advanced filters and catalysts. A few firms globally are controlling majority of the aftertreatment components. India is positioning itself globally as one of the active players in the automotive sector. Indian manufacturer's dependence on majority of the aftertreatment components effects its global competitiveness.

This policy bulletin situates itself in this context. The bulletin covers some salient aspects of the exhaust aftertreatment systems, their global market scenario, and technology profiling based on patent analysis. Through this background and analysis, the bulletin identifies the gaps and challenges in the technology portfolio of aftertreatment systems in the Indian context. Based on these challenges, policy suggestions for the creation of home-grown technology, and start-up opportunities are identified.



2. Aftertreatment Systems

Pollutants emitted from the vehicular tailpipe (Tailpipe emissions) are a serious threat to human and environmental health. The combustion of petroleum-based fuels results in the release of noxious chemicals into the air. Due to incomplete combustion in the engine, there are several combustion products released (Figure 1). Among all these products, HC, CO, and NO_x are the major pollutants.CO reduces the flow of oxygen in the bloodstream and is particularly dangerous to a person with heart disease. CO_2 does not directly impact human health, but it is a "greenhouse gas" that traps the earth's heat and contributes to the potential for global warming [1]. NO_x is the major pollutant that acts as a precursor for tropospheric ozone (O_3) formation as well as results in several allergenic diseases. HC is responsible for soot formation and particulate matter ($PM_{2.5}$), which has negative consequences on human health.

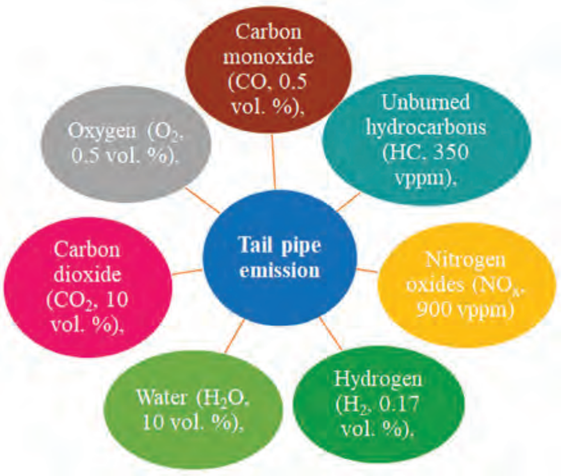


Figure 1.Various products of tail pipe emission

An aftertreatment system is a method or device for reducing harmful exhaust emissions from internal-combustion engines. In other words, it is a device that cleans exhaust gases to ensure the engines meet emission regulations. The mechanism of fuel combustion and exhaust emissions largely relies on the properties of the fuel and also the geometric profile of the chamber itself. Many approaches are used to reduce the amount of emission from engine exhaust to the atmosphere. An integrated approach of considering both 'internal factors' that result in better engine combustion and 'aftertreatment' technologies that can reduce already borne pollutants in the exhaust stream is mandatory for emission reduction from engines. The internal factors include factors that influence the combustion chamber and fuel delivery systems. The aftertreatment systems are used to reduce NO_x, CO, PM, and BC emissions. Balancing the factors is highly challenging as some conditions favor the reduction of these emissions, while some conditions lead to an increase in the emissions. An amalgamation of the internal factors and aftertreatment technologies in engines is a bigger contest in modern engine technology. Thus, exhaust emissions and mitigations are intricate. Nevertheless, the rigorous rules on modern exhausts paved the way for the incorporation of both internal factors and aftertreatment technologies for attaining compliant levels of exhaust emissions, which shows that the emission standards and engine technology are closely linked.

The Indian Government's Bharat Stage (BS-VI) norms require vehicles to be equipped with advanced aftertreatment technologies. The use of high-quality conventional fuels possesses a greater effect on directly reducing emissions. Furthermore, sulphur fuel content plays a critical role in emissions. This reduction in sulphur fuel content will aid in the effective functioning of the advanced aftertreatment technologies which are equipped in BS-IV and BS-VI vehicles. Since, fuel sulfur content has a direct effect on both the performance and durability of aftertreatment systems, modern aftertreatment technologies are more effective with sulfur fuel content below 10 ppm, as required in BS-VI vehicles.

3. Exhaust Aftertreatment Systems: Global Scenario

Meeting the stringent limits of NO_x and soot emissions requires a catalytic system with great complexity, size of units, and the number of units, as well as increased fuel consumption. Thus, an after-treatment device for a vehicle requires the use of an integrated catalyst technology for the reduction of individual emissions of exhaust gas. Various countries have undertaken several initiatives for combatting air pollution due to vehicular emissions.

They are becoming more stringent as they connect strongly with customer demand, SDG goals, and climate change concerns. These regulations are framed under the overall clean air initiatives. Europe and U.S.A. have stringent regulations for tailpipe emissions which are being adopted by other emerging economies. Europe has currently EURO 6 norms and the USA has Tier-III norms. India's BS-VI norms are largely based on European regulations[2]. It is not fully equivalent as such with EURO-VI norms which are more stringent. India however, has set higher vehicular standards in comparison with China

Figure 2. Automotive Exhaust Aftertreatment System-Growth rate, by region (2022-2027)

The global market scenario for aftertreatment technology is illustrated in Figure 2. Major export destinations from emerging economies of automobiles such as India are compelled to include sophisticated Aftertreatment systems in modern engines to comply with BS-VI norms and also make their vehicles export ready.

Due to the severity of the emission norms, the projected growth of aftertreatment systems market in Asia-Pacific countries, particularly India, Japan, and South Korea is higher. The projection is higher in most of the European countries as well as in North America [3]. *Thus, the market scenario for exhaust aftertreatment systems depends on the severity of the emission norms.*

4. Core Components of Aftertreatment Technology

There are five core components of aftertreatment technology on which all the technologies have been based (Figure 3). The representative technologies devoted to the reduction of NO_x under lean-burn operation conditions are selective catalytic reduction (SCR) and the lean NO_x trap (LNT), while soot removal is mainly performed by diesel particulate filters (DPF) (Figure 4). These devices are normally used in sequence, or a combination of them has been proposed to overcome the drawbacks of the individual devices. Various new combined technologies have been introduced for NO_x removal (i.e., LNT–SCR) and the simultaneous removal of NO_x and soot, like SCR-on-filter (SCRoF), in series LNT/DPF and SCR/DPF, and LNT/DPF and SCR/DPF hybrid systems[4].

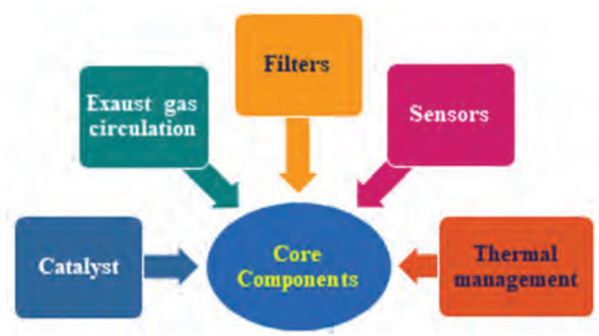


Figure 3. Core components of Aftertreatment systems

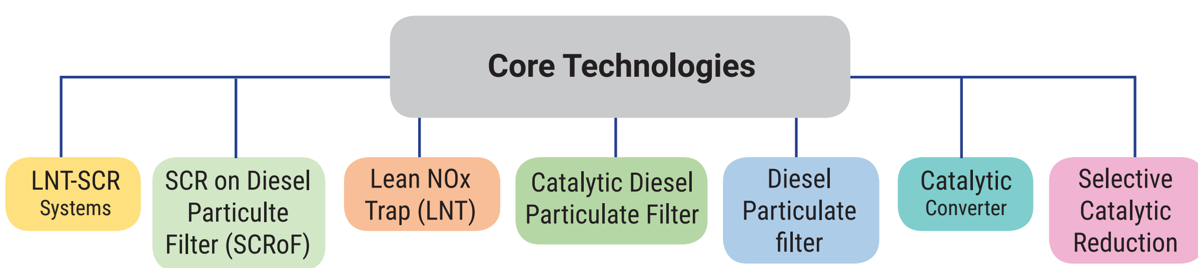


Figure 4. Core Technologies of Aftertreatment systems

5. Technology Profiling of Aftertreatment Technology

As this is a cutting-edge area, technologies are fiercely protected by patents at every stage of the technology development cycle. Hence patenting analysis provides a deep understanding of the technology development, firms dominating these technologies, how technology is shifting, etc. Evolutionary study of patent data shows significant increase of patents in aftertreatment technology from 2001 onwards (Figure 5). Among five technologies, SCR has a significantly higher number of patents followed by DPF, and DOC. EGR and Lean NO_x trap do not show any significant change. Increasing regulations are making more stringent the emission norms globally. The Paris Agreement, Net Zero emission targets, and increasing concern for climate change, air pollution are pushing for more stringent emission norms [5]. We already observe that there is active consideration to replace Euro-VI and US Tier-III norms with more comprehensive emission standard Euro-VII and equivalent norms in US. Patents growth signifies the increasing research and innovation in aftertreatment systems globally as they are the most representative indicator of invention in high technologies. Thus this growth is not surprising. It is also not surprising to see the growth of SCR based patents as they are most effective in reducing NO_x emissions.

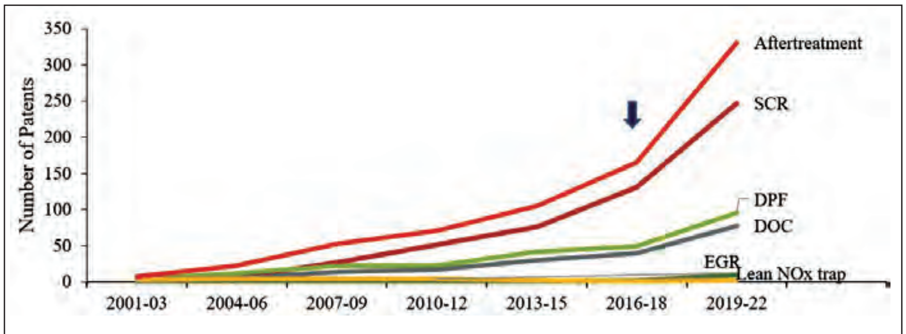


Figure 5. Timeline representation of Aftertreatment technologies

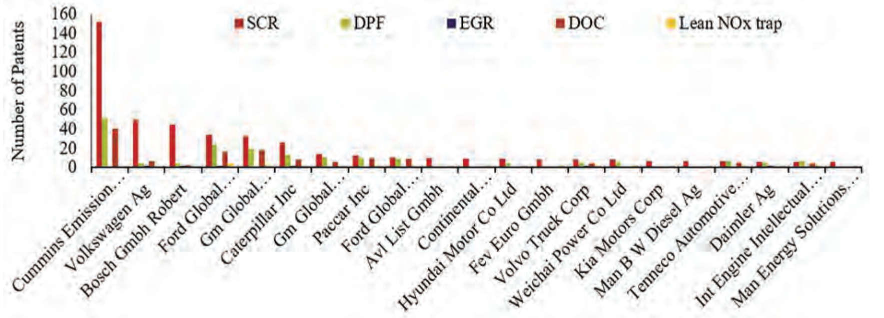


Figure 6. Technology profiling based on the Assignee name (2001-22)

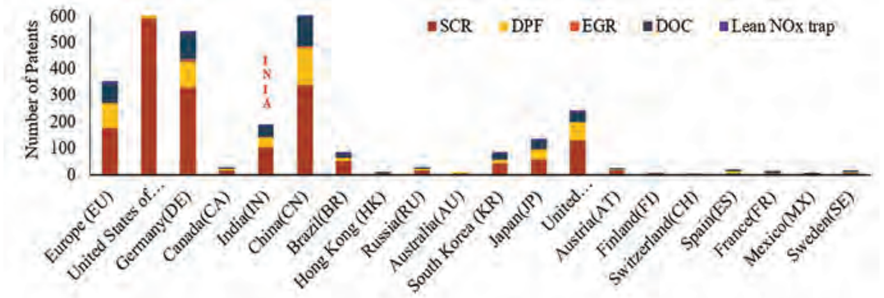


Figure 7. Technology profiling based on patenting countries (2001-22)

The top 20 assignees show a highly skewed distribution and concentration in select OECD economies (Figure 6). SCR is the area of maximum patenting followed by DOC, DPF and EGR. Only a few firms are actively involved in patenting in Lean NOx trap. This provides an indication of firm's strategic patenting choice concentrating on technologies wherein market demand is highest. Most of the firms are major engineering MNC or automotive firms having global presence Cummins is the leading firm for patenting this technology underscoring the competitive edge it has in this technology. Among the top 25 countries, the US is the leading country with 1182 numbers for patenting aftertreatment technology (Figure 7). This signifies that research on aftertreatment technology is most intense in this country. India is in the 7^{th} position with a total number of 186 patents in aftertreatment technology and specifically in SCR technology. Patenting shows Indian firms are developing innovation capability in this area.

6. Aftertreatment Systems and India: A brief of India's Automotive Sector

India's automotive industry is very dynamic and competitive. The global and Indian firms compete strongly in the domestic market and also have a global presence. The Automotive Market was valued at USD 100 billion in 2021 and is expected to reach USD 160 billion in 2027, registering a compounded annual growth rate (CAGR) of 8.1% over the forecast period (2022-2027).The rapid urbanization in India has led to increase in mobility and over 60% of the Indian population prefer road transport. India having the second largest road network in the world and with maximum percentage of population travelling by road, the automobile industry in India is the major sector that contributes to the growth of the Indian economy. This growth opens up the opportunity for large-scale production of automobile components in India.

India is the 4th largest producer of Automobiles in the world, with an average annual production of more than 4 million motor vehicles. The Electric Vehicle (EV) market is estimated to reach Rs. 50,000 crores (USD 7.09 billion) in India by 2025.Share in Gross Domestic Product (GDP) is 7.1% and in India's exports is 4.7%. Various government initiatives have been taken to strengthen this sector. Figure 8 gives a schematic diagram of this policy initiatives.

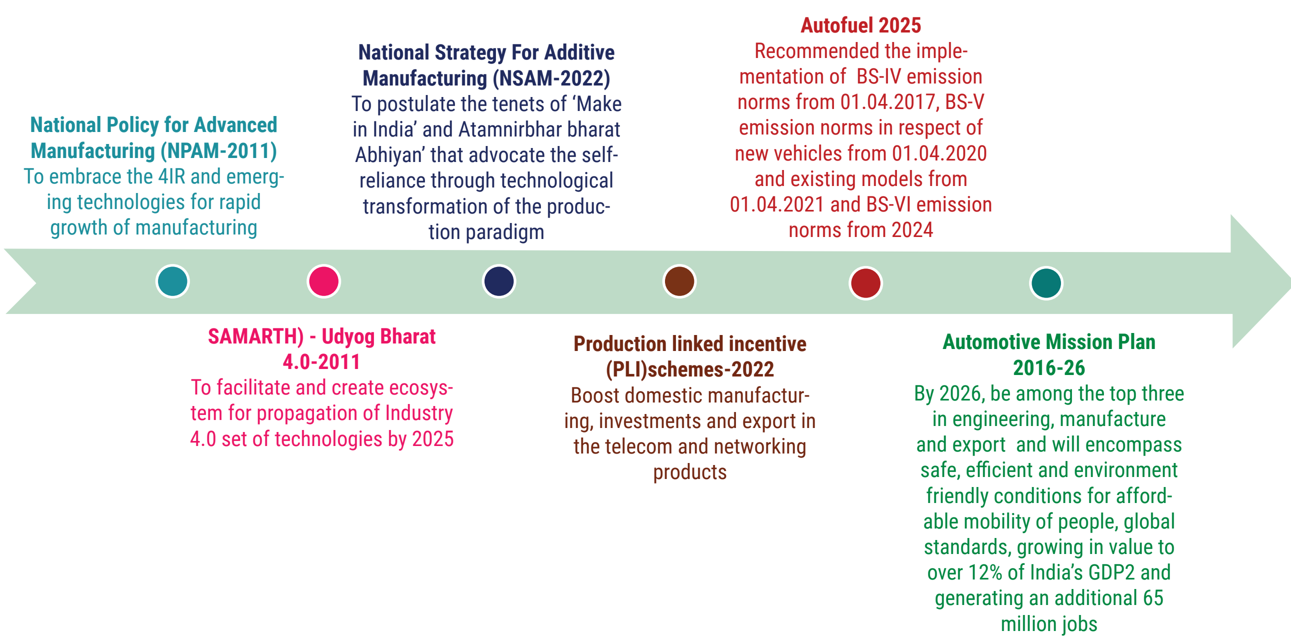


Figure 8. Timeline representation of Indian automotive core policies

The standards for reduction of emissions of each pollutant in BS-VI norms is given in Figure 9 for both gasoline and diesel engines. The norms are compared with BS-IV norms.

As seen in Figure 9, BS-VI imposes stringent norms for NO_x and $PM_{2.5}$. This eventually requires advanced aftertreatment technologies in exhaust systems of BS-VI engines.

Table 1: BS-IV and BS-VI emission limits for pollutants

BS Standards	Pollutant emission limits (g/kWh)				Sulfur content (ppm)
	CO	HC	NO_x	PM	
BS-IV	1.50	0.46	3.5	0.02	50
BS-VI	1.50	0.13	0.40	0.01	10

The incorporation of BS-VI and export orientation has pushed the need for incorporating sophisticated aftertreatment systems. The import and export statistics of aftertreatment technology are shown in Figure 9. From export/import data under aftertreatment technology, class indicates that India exported only single technology belonging to HSN code 87089900 while importing a higher number of technologies from China followed by Germany and Brazil.

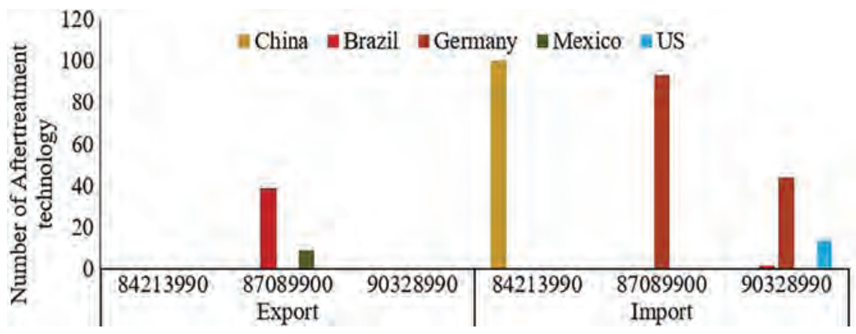


Figure 9. India Export and Import data of aftertreatment technology (HSN code 84213990, 87089900, and 90328990 signify Filters, Devise, and control units respectively)

7. Challenges

As the regulations for abatement of vehicular emissions becoming more stringent globally, India's move towards BS-VI norms is anticipated to reduce the exhaust emissions to a greater extent. This decision will limit gasoline and diesel fuels to 10 parts per million of sulphur, carrying India into streak with the global leaders in fuel sulphur standards. Many cities in India are following stringent emission standard rules and Delhi has already adopted BS VI from 2018 onwards. In order to be in compliance with the BS-VI emission norms, the modern engines require being equipped with advanced aftertreatment technologies as discussed in earlier sections. From an environmental and health perspective, the BS VI emission norms would better serve to reduce PM and NOx emissions from vehicles. However, from consumer perspective, engines would be more expensive by the implementation of BS VI norms, as the requirement of SCR systems as well as real-world driving tests is cost-effective.

India does have indigenous technology available to cap NO_x emissions (Central Pollution Control Board (CPCB).The indigenous technology for SCR adaptable to both low and high levels of NO_x emissions developed by ACC's R&D (research & development) Division at Thane. To meet NO_x emission norms, an SCR or SNCR (Selective Non-Catalytic Reduction) system needs to be installed in some units. These technologies are not yet proven under indigenous conditions. Meeting NO_x emission norms with SCR using ammonia may not be feasible, and storage of ammonia may cause hazards. Aside from the market demand, there are a lot of technical requirements for aftertreatment technologies to comply with the emission norms.

SCR systems are miniaturized chemical plants that require high temperatures to function optimally, which can be achieved only when the vehicle is operating on the highway. Further at low ambient temperatures, the air pollutants disperse widely and therefore, the dependence between vehicular emissions and temperature should be accounted for in the emission norms. As per BS V1 norms, most of the tests are performed using CD or PEMS. But with these tests it is difficult to quantify the effect of ambient temperature on vehicular emissions. Hence, implementing novel technologies to overcome the above tasks is of substantial importance.

Since, the BS-VI emission standards is aimed at achieving 10 ppm fuel sulfur content, any use of sulfur above than this limit will reduce the pollutant control efficiency of the aftertreatment systems. Therefore, BS-VI diesel vehicles can tolerate the sulfur content of 50 ppm with the BS-IV standards upto a small extent and in long-term, this might lead to several risks. *Since, fuel sulfur content has a direct effect on both the performance and durability of aftertreatment systems, modern aftertreatment technologies are more effective with sulfur fuel content below 10 ppm.*

The BS-VI emission control standards for light and heavy duty vehicles differ mainly in terms of aftertreatment technologies. The BS-VI compliance approaches for light and heavy duty vehicles are summarized in Table below.

BS-VI Compliance approaches for diesel and petrol vehicles

Light and Petrol	Heavy-duty (Diesel)
• Smaller and medium-sized engines (< 2 litres) use LNT, DOC and DPF for NO_x control. • Larger engines use DOC+DPF+SCR components. • Few manufacturers utilize only EGR without any aftertreatment for NO_x control and for medium and large engines, DOC + DPF is used.	• DPFs required with PM standard. • Zeolite SCR catalyst should be used. • No EGR is offered.

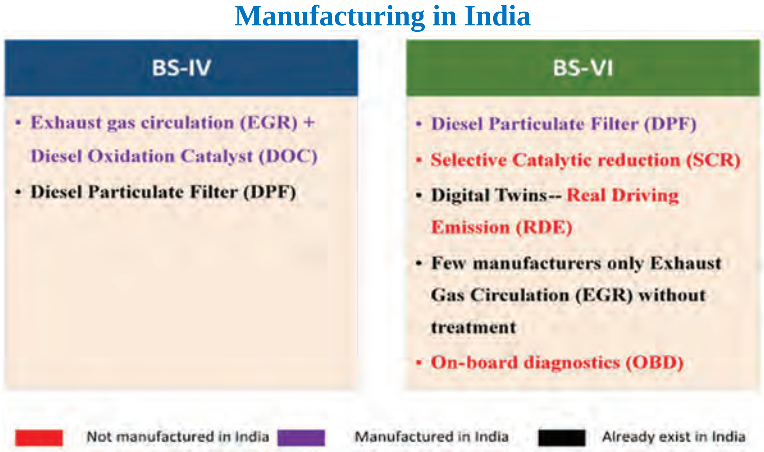
8. Opportunities and Policy Suggestions

The demand for advanced exhaust aftertreatment systems is expected to be driven by the increase in the production of automobiles. The global automobile industry has regained its growth from its drop during the Covid pandemic, where ~ 66.7 million automobiles were sold in 2021. The automotive revenue pool is forecasted to increase up to 30% in 2030 when compared to 2015. A recent perspective by McKinsey has reported that cash-rich high-tech companies and start-ups will be the key players in the automotive revolution. Also, these tech players will initially focus on only specific segments which are more attractive economically as well as in terms of market trends. These new entrants are expected to have more influence with consumers and regulators and leverage the aftertreatment systems market demand. This also gives opportunity to Indian automotive manufacturers to indigenously design the aftertreatment systems in a cost effective manner.

As per the new emission norms, availability of clean fuel will be one of the greatest challenges for compliance. Any steps to reduce NO_x will invariably translate into increase in CO_2 emissions. Thus, despite testing activities, the aftertreatment technologies for BS VI compliance require a robust approach to balance both NO_x and CO_2 levels.

With more than 60% of BS-IV vehicles on road, emissions can be reduced by retrofitting of few of the components of BS-VI engines in BS-IV engines. This requires high-end technologies and starts-ups can play a crucial role in such retrofitting mechanism. This will eventually aid in achieving circular economy and reducing emissions from BS-IV vehicles. The table below highlights some key areas of aftertreatment system manufacturing status in India.

Aftertreatment Components: Status of Manufacturing in India



It is estimated that more than 56 percent of vehicles in India have BS-IV engines. Around 12 percent of engines are operating under BS-III norms. India has taken a huge leap by moving from BS-IV to BS-VI fuel. This is unfortunately not helping significantly in controlling major tailpipe emissions as only 30 percent or so vehicles with BS-VI norms *have suitable Aftertreatment systems compiling with BS-VI fuel.* There is a huge opportunity space for developing Aftertreatment systems for vehicles with BS-IV and BS-III norms. The key enablers can be startups with incentivization and technology support and mentoring to develop cost-efficient Aftertreatment systems for these engines. They will not face the technology entry barrier of patents that surrounds Aftertreatment systems for BS-VI systems controlled by major vehicle and component manufacturers. India will have the opportunity to export to a large number of low-income, developing, and emerging economies these systems.

At the higher end i.e., for BS-VI vehicles, dedicated incentives like product-linked schemes can be explored for developing Aftertreatment systems in India. Innovations from start-ups may aid in the ecosystem at the technological forefront of BS-VI vehicle standards through new-age technological surges. Incentives for such start-ups should be given by the government and collective ideas from the manufacturers and start-ups should be incorporated into designing aftertreatment systems of vehicle engines.

9. References

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