Identifying and Controlling the "Silent Threat" in BS7 – Evaporative and Refueling Emissions

Executive Summary

Throughout India, petrol-fueled internal combustion engine (ICE) vehicles emit non-exhaust evaporative and refueling volatile organic compound (VOC) emissions at levels which significantly exceed tailpipe exhaust emission. The Economic Times of India has called evaporative and refueling emissions the "silent threat"[1]. This is because **during periods of heat waves, when air quality is often most unhealthy and severe, petrol-fueled ICE vehicles in India can have emissions of evaporative nonmethane hydrocarbons (NMHC) that are up to 30 grams per vehicle per day, which is 15x higher than the current BS6 evaporative emission certification standard (2.0 g/day) and 13x higher than the BS6 exhaust NMHC emission standard (68 mg/km).**

Evaporative emission standards in India have remained unchanged since the implementation of Bharat 4 in 2017 and Bharat 6 in 2020, both of which are equivalent to Euro 4, resulting in India evaporative emission control systems that are outdated, undersized, and not effective. Over the same time period, the sale of petrol-fueled ICE vehicles in India has increased by 81% to 3.26 MM annually (with petrol ICE representing more than 65% of all new car sales (Figure 1))[2], and India has increased the volume percentage of ethanol required to be blended into petrol up to a minimum of 20% (E20). The in-use vapor pressure of E20 sold commercially (up to 70 kPa)[3] is a higher vapor pressure than that of E0 petrol (up to 60 kPa)[4] and also higher than the fuel to which vehicles are certified for evaporative emissions under BS6 (60-65 kPa)[5]. This disparity between certification and in-use vapor pressure increases evaporative emissions in-use, whether the vehicle is parked or operated. The current situation in India is petrol-fueled ICE vehicles are more prevalent, are operating on higher vapor pressure fuels, and these vehicles are technology laggards with outdated and insufficient evaporative emission control systems. This is leading to high in-use evaporative emission rates that contribute significantly to non-methane volatile organic compounds (NMVOC), which are primary precursors for the formation of ozone (O_3) and secondary organic aerosol ($PM_{2.5}$). These air pollutants contribute to smog formation, haze and increased public health risks**.**

As India evaluates options for BS7, it is important to consider the unique circumstances in India that warrant a different approach than simply following Euro 7, which is the weakest evaporative emission standard when comparing against the standards implemented in the other major automotive producing countries that desire to improve air quality (US, Canada, Brazil, China). Euro 7 applied in India would not be sufficient to mitigate the high in-use evaporative emissions that occur due to the unique circumstances in India such as; higher temperatures, higher in-use fuel vapor pressure, and a longer time horizon for the continued sale of ICE vehicles. **At a minimum, India should implement evaporative and refueling emission standards and limits equivalent to Brazil (0.05 g/L refueling emissions limit (ORVR) and a hot soak + 48-hr diurnal emission standard of 0.50 g/day). These standards would reduce evaporative and refueling emissions by more than 92% during all possible in-use conditions and retain the valuable fuel vapor on the vehicle to be burned in the engine as fuel, saving consumers on fuel costs and reducing their exposure to air toxics found in petrol, such as benzene.**

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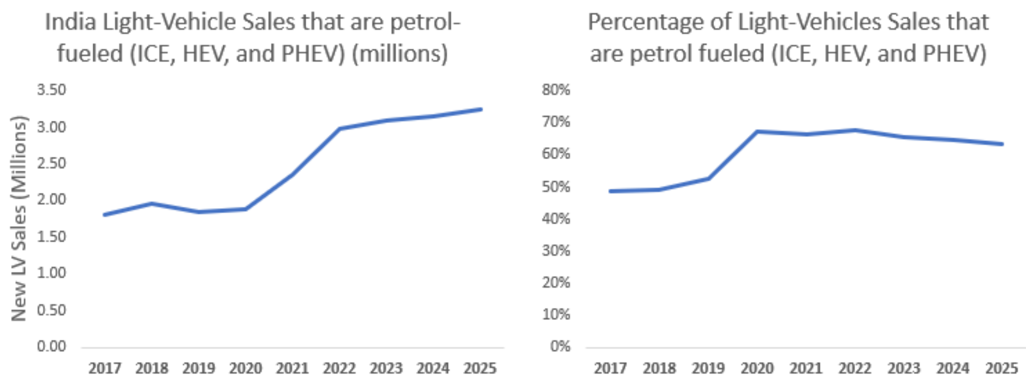
[1] Unveiling a silent threat: Need to tackle refuelling emissions for cleaner air, ET Auto (indiatimes.com)
[2] S&P Global, Mobility and Energy Future, Inflections Scenario, August 2024
[3] IS 17021:2018
[4] IS 2796:2017
[5] IS 17943:2022

Figure 1. Sales trends of light-vehicles that are petrol fueled (ICE, HEV, PHEV)[2]



1. Background on Evaporative Emissions Regulations and Control Technology

Tailpipe NMHC emissions consist of unburned or partially burned fuel vapors, whereas evaporative NMVOC emissions consist of volatilized fuel vapors that escape during refueling, as running losses during vehicle operation, by permeation of vapors through fuel tanks and supply lines, and as diurnal fuel tank breathing losses during parking events. While regulations have been implemented in the United States, Canada, China, and Brazil to reduce evaporative NMVOC emissions to help meet strict air quality standards, less effort has been made to regulate and reduce evaporative and refueling NMVOC emissions in Europe and India. **Euro 7 was the most recent example in a long history of European legislation choosing to not prioritize control of evaporative emissions, where European co-legislators rejected the European Commission's proposal to adopt a refueling emission standard and a more stringent evaporative emission standard.** Only a slight reduction was made to the diurnal evaporative emissions limit (reduction from 2.0 g to 1.5 g), which in practical application will lead to no further changes in control technology. Euro 7 continues to place Europe as the least stringent evaporative emission standard in comparison to other countries that prioritize improving air quality. Table 1 provides a comparison of global evaporative emissions standards, which clearly shows that **Europe and India lag far behind other regions in terms of limits that have been demonstrated to be both achievable and cost-effective**.

Even though India has historically followed European emission standards through United Nations Economic Commission for Europe (UNECE) agreements, **India should evaluate their unique air quality challenges and ambient conditions which are different than Europe**. It should be noted that both Brazil and China made the policy decision to develop their own evaporative emission standards and shift from their history of following European standards due to their unique air quality challenges and circumstances and recognizing that the continued weakness of the European standards was insufficient to solve their challenges. Table 2 shows the progression of Euro standards with respect to evaporative and refueling emissions, demonstrating the minimal progress since Euro 4.

Table 1; International comparison of current evaporative and refueling emission standards.

Emission Standard	India BS 6	Europe Euro 7	USA Tier 3	Brazil PL 7	China 6b
Evaporative (hot soak + diurnal)	1-day 2.0 g	2-day 1.5 g	2-day & 3-day 0.30 g	2-day 0.50 g	2-day 0.70 g
On-board Refueling	None (Stage II)	None (Stage II)	0.20 g/gal (~0.05 g/L)	0.05 g/L	0.05 g/L

Table 2; History of evaporative emission limits from Euro 4 to Euro 7.

Standard	Ethanol in Certification Test Fuel (%)	Category M1 Diurnal Evaporative Emissions Limit (g/day)	Category M1 Refueling Emissions Limit (g/L)
Euro 4	0 (E0)	2.0 – 24-hr	None
Euro 5	5 (E5)	2.0 – 24-hr	None
Euro 6	5 (E5)	2.0 – 24-hr	None
Euro 6d	10 (E10)	2.0 – 48-hr	None
Euro 7	10 (E10)	1.5 – 48-hr	None

ICE vehicles incorporate an evaporative emission control system in the form of an activated carbon canister designed to adsorb petrol vapors from the fuel tank and utilize them in the engine for combustion, rather than being released to the atmosphere. In the US, Canada, China and Brazil, stringent evaporative emission regulations have driven advancements in the design of these systems to better capture emissions from refueling, vehicle operation, and at least two days of diurnal vapor generation while parked. In other regions, including Europe and India, these canister systems remain undersized—being designed to control for only one or two days of diurnal vapor generation—and therefore lack the capacity to control emissions during refueling, parking events beyond two days, or during off-cycle conditions such as heatwaves.

In addition to undersized on-vehicle activated carbon canisters, Europe and India also currently rely upon Stage II vapor recovery systems installed in petrol stations to control the refueling portion of evaporative emissions. Stage II systems utilize passive or active vacuum-assisted fuel dispensers to capture and return vapors to underground bulk storage tanks during refueling. In Europe, the certification requirement for the efficiency of a Stage II system is 85%, as established in Directive 2009/126/EC[6]. However, the certification efficiency only applies to the capture of vapors by the nozzle at the nozzle/fill pipe interface at time of certification and does not address efficiency losses that occur due to malfunctioning equipment, vapor leaks in the system, or the release of vapors from the underground storage tank vent stack that occur in operation.

Early US Environmental Protection Agency (US EPA) studies estimated in-use efficiency of Stage II systems to be between 62%–92%[7] depending upon the frequency and rigor of maintenance and inspection; a more recent California Air Resources Board (CARB) study estimates Stage II efficiency to be around 71%[8]. To remain effective, Stage II systems require at least annual inspection and maintenance, the requirements for which are not as comprehensive in Europe or India as those established in the US[9]. Stage II vapor recovery is not required by the US EPA anywhere in the US and it has been removed in all areas except California. California technology has morphed from a limited to Stage II program to a more comprehensive Enhanced Vapor Recovery (EVR) program which addresses other sources of emissions from petrol dispensing and storage of gasoline, including additional controls to prevent vapor venting from underground storage tanks by maintaining tank pressures within certain limits[10]. Considering estimated Stage II efficiencies in the US of 71% and the estimated Stage II implementation in Europe of 72% of all petrol stations[11], the actual efficiency of overall refueling emissions control in Europe is likely between 50%–60%. **The implementation rate and efficiency of Stage II in India is not well documented, so it is unknown if Stage II is effectively controlling refueling emissions in India.**

[6] Directive - 2009/126 - EN - EUR-Lex (europa.eu)
[7] 2000MSM2.PDF (epa.gov)
[8] GDF Emission Factor Umbrella Document (ca.gov)
[9] CP-201: Cert Procedure for GDF using UST (ca.gov)
[10] Test Procedure: 2003-10-08 TP-201.2B Flow and Pressure Measurement of Vapor Recovery Equipment (ca.gov)
[11] Evaluation of Directive 1994/63/EC on VOC emissions from petrol storage & distribution and Directive 2009/126/EC on petrol vapour recovery - Publications Office of the EU (europa.eu)

To overcome the limitations of Stage II systems, regulations in the US, Canada, China, and Brazil require petrol ICE vehicles to be equipped with Onboard Refueling Vapor Recovery (ORVR) systems. In ORVR-equipped vehicles, a seal is formed inside the vehicle's filler neck during refueling to prevent the escape of fuel vapors, which are directed to a larger carbon canister system. In the US, over 25 years of data on ORVR implementation demonstrate that it can reliably capture at least 98% of evaporative NMVOC refueling emissions throughout the useful life of the vehicle[12]. While Stage II systems must be replaced periodically and incur annual operational costs, ORVR systems require no maintenance and can be installed on new vehicles at a cost of €10–€20 (₹920 - ₹1,40) per vehicle[13]. During vehicle operation, fresh air is intermittently drawn through the ORVR canister to remove the adsorbed fuel vapor from the activated carbon. The stripped vapor is then fed to the engine for combustion, providing additional fuel savings that can offset a significant portion of the canister installation cost over the life of the vehicle. In comparison, the European Commission estimated the cost of implementing and maintaining Stage II to be €1200–€1600 per dispenser annually, assuming a useful life of eight to ten years for the equipment.

Regulatory decisions regarding evaporative emission control technologies and strategies are dependent upon accurately modeled estimates of evaporative NMVOC inventories. As a primary driver of evaporative processes, precise temperature input is vital to the accuracy of inventory estimates since evaporative emissions exhibit a non-linear dependence on temperature. However, evaporative emission inventories, including those used for regulatory decisions in Europe and India, are often developed using average annual or seasonal temperature profiles that fail to capture extreme temperature events such as heatwaves, which research suggests are increasing in frequency, duration, and intensity in India in response to climate changes[14]. This has historically led to the belief that evaporative emissions from vehicles are of the same magnitude as exhaust emissions; in reality, the evaporative component can be significantly larger when considering refueling emissions and increased evaporative emissions due to higher ambient temperatures. As shown in Figure 2 and 3, during periods of heat waves, when air quality is often most unhealthy, petrol-fueled ICE vehicles in India can have emissions of evaporative nonmethane hydrocarbons (NMHC) that are up to 30 grams per day, which is 15x higher than the current BS6 evaporative emission certification standard (2.0 g/day) and 13x higher than the BS6 exhaust NHMC emission standard (68 mg/km).

2. Evaporative Emissions Modeling Methodology

The evaporative emissions model consists of MATLAB modules which calculate per-vehicle emission factors for diurnal, running loss, hot soak, permeation, and refueling sources. The frequencies and durations of driving and parking events, average trip numbers and distances, and average vehicle speeds were obtained from COPERT, which were developed for use in Europe and modified for application to India. For each scenario, inputs were adjusted to reflect India automotive evaporative emissions standards. Running loss, permeation, and hot soak rates were derived from methodologies applied in EPA MOVES3 model[15]; diurnal and refueling emissions were determined by methods described by Dong et al[16]. For all scenarios, in-use ethanol was set at 20%, 70 kPa vapor pressure. Diurnal soak requirements used for canister sizing were one day for BS6; canister sizing for the BS7 scenario was based on implementation of a 0.05 g/L refueling limit (ORVR) and a 0.50 g/day 48-hr hot soak + diurnal evaporative emission limit (representing the European Commission's November 2022 proposed evaporative requirements). The full vehicle hot soak + diurnal emissions limits were 2.0 grams for a 24-hour test for BS6 and 0.50 grams per day for a

[12] Summary and Analysis of 2000-2015 Model Year IUVP Evaporative and Refueling Emission Data (sae.org)
[13] Microsoft Word - ORVR_v4.docx (theicct.org)
[14] More frequent heatwaves in India are putting lives at risk | World Economic Forum (weforum.org)
[15] Overview of EPA's MOtor Vehicle Emission Simulator (MOVES3) (EPA-420-R-21-004, March 2021)
[16] Full article: Modeling cold soak evaporative vapor emissions from gasoline-powered automobiles using a newly developed method (tandfonline.com)

48-hr test for BS7, with the BS7 scenario aligning with current Brazilian PROCONVE L-7 standards. Canister purge volume was determined using the shortest drive cycle time from the New European Driving Cycle (NEDC) for BS6 (60 min) and the World harmonized Light vehicle Test Procedures (WLTP) for BS7 (31.8 min) using methods described by Dong et al. Evaporative emissions exhibit a linear relationship with fuel tank volume, and an average fuel tank capacity of 60 L was used. Carbon aging was accounted for by reducing the adsorption capacity of the carbon in the canister by 16% for the BS6 scenario and 7% for the BS7 scenario, which represents the adoption of more durable carbon and the inclusion of aging procedures to ensure enhanced durability beginning with Euro6d standards.

For each scenario, the model requires a base running loss and leak rate which reflect control measures, such as heat shielding designed to insulate fuel tanks and lines from radiative road surface heat during use, and on-board diagnostics designed to alert the driver of leaks in the fuel system. The base rate is then adjusted according to ambient temperature and fuel Reid Vapor Pressure (RVP) to determine actual loss rates. Since India does not currently have a running loss emission standard or leak standard, emission factors for running loss and leaks were taken from conservatively low MOVES model estimates for an enhanced or Tier 1 US vehicle for the BS6 scenario (0.72 g hr^{-1}) and Tier 2 vehicles for the BS7 scenarios (0.23 g hr^{-1}). Stage II efficiency was estimated as 60.35% based on the product of CARB's estimated in-use efficiency in the US of 71% and assuming a conservatively high 85% implementation of Stage II in petrol stations throughout India (no documentation could be found on actual implementation rate and in-use efficiency). Temperatures were selected to represent a heat wave period in Delhi from April to July, 2022, which coincided with significant unhealthy smog events.

3. Evaporative Emissions Modeling Results

The evaporative emissions modeling result for the heat wave period in New Delhi, India from April-July 2022 are shown in Figure 2 below. In both scenarios, an in-use fuel vapor pressure of 70 kPa was utilized to represent the highest vapor pressure allowed for in-use E20 fuel. For the current BS6 scenario, which is representative of current BS6 vehicles in India, the combined evaporative and refueling emissions rate exceeds 30 grams per vehicle per day during the hottest heat wave periods and, at a minimum, is 10 grams per vehicle per day. Figure 3 compares these maximum in-use emissions rates to the current BS6 evaporative emission certification limit (2.0 g/day) and the BS6 NMHC exhaust limit (68 mg/km). Using the average annual driving rate in India of 12,000 km[17], a vehicle is driven an average of 33 km/day, resulting in an average NMHC exhaust emission of 2.2 g/day. Unlike evaporative emissions which increase exponentially with temperature, exhaust emissions are not influenced by the ambient temperature. As shown in Figure 2, **during periods of heat waves, when air quality is often the most unhealthy, petrol-fueled ICE vehicles in India can have emissions of evaporative nonmethane hydrocarbons (NMHC) that are 15x higher than the current BS6 evaporative emission certification standard (2.0 g/day) and 13x higher than the BS6 exhaust NHMC emission standard (68 mg/km).** This clearly demonstrates that the current canister systems for BS6 vehicles are undersized and do not effectively control the evaporative and refueling emissions at higher temperatures and higher vapor pressures of E20 fuel.

If BS7 were to adopt a refueling emission standard of 0.05 g/L (ORVR) and a 48-hr hot soak + diurnal evaporative emission limit of 0.50 g/day, the combined evaporative and refueling emissions rate can be reduced by 92% to less than 2.5 grams per vehicle per day across all temperature conditions. The canister systems to meet these standards can be produced in India and implemented by OEMs cost-effectively, as has been demonstrated for decades in the US, Canada, China, and Brazil. Most recently, Brazil has demonstrated the effectiveness of a similar standard for E22 and E22/E100 flex fuel vehicles.

[17] Drive 12,000km a year? Cheaper to call cab - Times of India (indiatimes.com)

Figure 2. Comparison of daily evaporative and refueling emission rates for a current BS6 standard and an optimal BS7 scenario

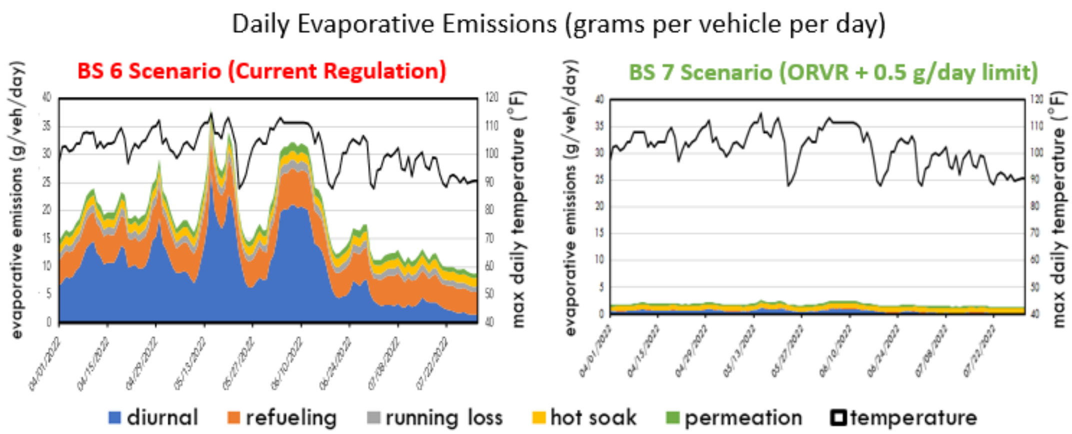
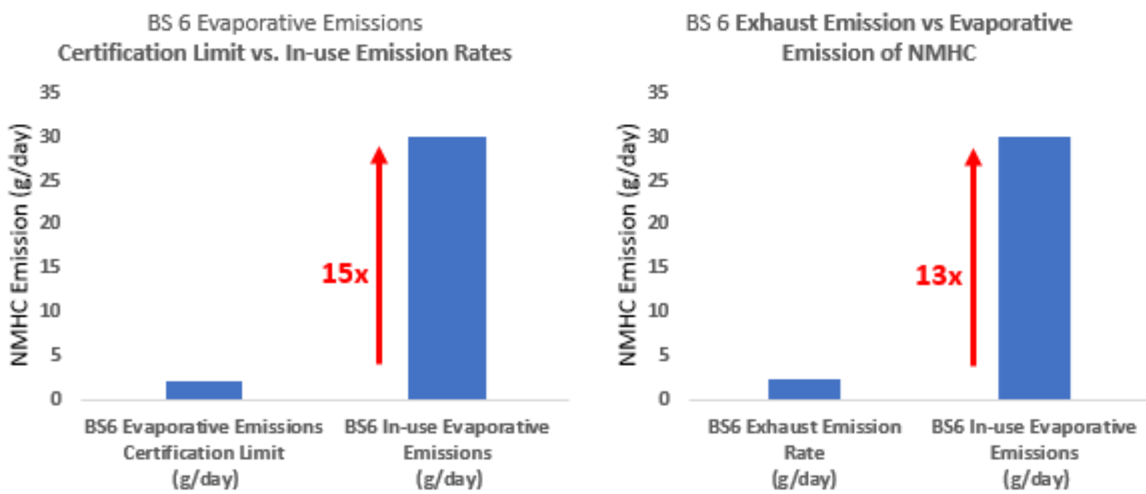


Figure 3. Comparison of daily evaporative and refueling emission rates to current BS6 certification standards for evaporative and exhaust non-methance hydrocarbons (NMHC)



4. Conclusion and Recommendations

There are unique situations in India that warrant a different approach than Euro 7 for the control of evaporative and refueling emissions. These include (1) a large and growing proportion of petrol fueled light duty vehicles, representing more than 3.2MM vehicles per year and 65% of new car sales (2) promotion of E20 fuels that have a higher in-use vapor pressure leading to higher evaporative and refueling emission rates under all in-use conditions (3) significantly higher ambient temperatures and increasing prevalence of heat waves due to climate change leading to higher in-use evaporative and refueling emissions (4) a longer time horizon for the continued sale of petrol/ethanol fueled ICE vehicles than Europe and (5) a strong need and desire to improve air quality for all Indian citizens.

Europe has a long history of not prioritizing and not advancing evaporative emissions control to improve air quality, while other regions of the world, including US, Canada, China, and Brazil, have all significantly advanced evaporative and refueling emissions control. It should be recognized that both China and Brazil made the policy decision to not follow European standards due to their desire to improve air quality and recognition that the European standards were insufficient. **At a minimum, India should implement evaporative and refueling emission standards equivalent to Brazil (0.05 g/L refueling limit (ORVR) and a 48-hr hot soak + diurnal limit of 0.50 g/day). This would reduce evaporative and refueling emissions by more than 92% during critical in-use conditions and retain the valuable fuel vapor on the vehicle to be burned in the engine as fuel, saving consumers on fuel costs and reducing their exposure to air toxics found in evaporative emissions of petrol, such as benzene.**

Other options to consider to adapt the evaporative and refueling test procedures to be more relevant to India conditions include (1) a higher diurnal temperature range (40°C or higher), such as implemented by the California Air Resources Board (CARB) to reflect conditions more representative of worst case in-use conditions for evaporative emissions when air quality needs to be controlled most (heat waves) (2) a three-day (72-hr) diurnal to reflect multi-day parking events and (3) increasing the vapor pressure of the certification fuel to 70 kPa to match the vapor pressure encountered in-use for E20 splash blends.