Public Executive Summary

Cleaner Alternative Technologies to Diesel for New Vehicles in Singapore

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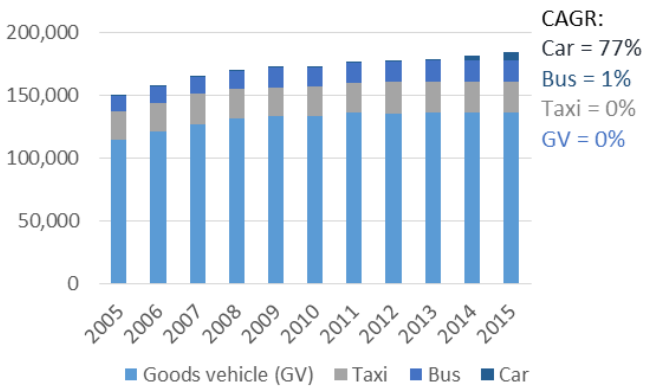
Introduction and Singapore's context

Despite the versatility and efficiency of diesel engines, diesel vehicles are known to emit higher particulate matter (PM) and nitrogen oxides (NOx) emissions than petrol vehicles, which is a challenge for ambient air quality. Long-term exposure to diesel exhaust may cause lung cancer and chronic respiratory symptoms. NOx contributes to smog, acid rain and climate change. Emissions of black carbon and greenhouse gases like carbon dioxide (CO_2) also contribute to global climate change.

Diesel vehicles in Singapore (ST File 2016)

Cities like Paris, Madrid, Athens and Mexico City have taken drastic actions to phase out or reduce diesel vehicles to improve air quality. This study was commissioned to independently examine the feasibility of technology options for new vehicles in Singapore, with the objective of reducing air emissions from diesel vehicles.

In Singapore, the government has embarked on a national vehicle emissions reduction programme. While diesel emission standards can help reduce emissions from new vehicles, many existing diesel vehicles remain high emitters. Replacing older diesel vehicles with ones that can meet the latest Euro VI emissions standard will help improve ambient air quality to some extent.



Singapore diesel vehicle population by vehicle type, 2005-2015. CAGR = compound annual growth rate (LTA 2016)

Presently, 1 in 5 vehicles on our roads use diesel. Goods vehicles and buses contribute the bulk of diesel air emissions due to their large population and higher emissions per kilometre travelled. These vehicle types deserve more emphasis. Although diesel cars and taxis contribute far less, the number of diesel cars is rising rapidly and should also be monitored.

A general move away from diesel to cleaner alternatives where feasible will lead to better air quality and health for everyone.

Analysis of alternative technologies

Various alternative fuels and powertrains that have the potential to reduce air pollutant emissions have been identified from recent literature. Alternative vehicle drivetrains that could replace diesel vehicles are:

- Conventional petrol – Vehicles that use petrol fuel in spark-ignited engines, widely used in passenger cars and some light goods vehicles.
- Electrification – Vehicles that rely in part or fully on electric drives for propulsion, such as hybrid, plugin hybrid (PHEV) or battery electric vehicles (EV).
- Hydrogen fuel cell – Vehicles that use a fuel cell in place of an engine. Usually these vehicles operate on hydrogen fuel.
- Natural gas – Vehicles that use compressed (CNG) or liquid natural gas (LNG) for fuel, with either a spark-ignition or compression-ignition engine.

Renewable fuels like biodiesel and renewable diesel are available alternatives to oil-based fuels like diesel that have the potential to reduce air emissions. They are produced from feed stocks such as vegetable oil, animal fat, or algae.

- Biodiesel – Also called Fatty Acid Methyl Esters (FAME), it can be used in its pure form or more commonly blended with diesel fuel.
- Renewable diesel – Also known as Hydrogen-Derived Renewable Diesel, it is chemically similar to diesel fuel and can be used directly to displace diesel fuel. That is, it is a "drop in" replacement fuel.

Combustion of renewable (left) and conventional fossil fuel-based diesel (right) (Neste, 2016)

Tables 1 and 2 show summaries of the cost and benefits of these technology options.

Discussion and recommendations

The incumbent technology – diesel engines – is a strong contender in many ways, given its availability for many applications, lower cost, durability, reliability and long driving range. The technologies evaluated are compared in Table 3. Recommendations for different diesel vehicle types are shown in Table 4.

Vehicle electrification is found to be a more expensive, but promising technology that can be pursued for many vehicle types, except for those that demand long travel ranges. Taxis can be converted to petrol hybrids today, as some already are. Hybrid or electric options for buses are commercially available, and this option can be considered especially for public buses that travel along predictable and shorter routes. Field trials, like the current e-bus trial operated by Go-Ahead Singapore are helpful to assess their suitability in the local traffic and climate conditions.

Renault Maxi ZE electric vans are to replace some of Singapore Power's service van fleet (Tan, 2016)

The options are limited for very heavy goods vehicles, for which one can consider the use of renewable diesel. This alternative fuel option can be pursued for all vehicles types. **Renewable diesel** is viable as a "drop-in" fuel replacement but requires further study on its overall environmental impact. Stringent requirements and monitoring of the use of sustainable feedstock like waste and residues would be needed.

In addition to technical feasibility, there are known **barriers to the adoption of alternative technologies**, such as lack of information, capital, or after-sales support. These would have to be addressed in order for these technologies to gain market traction. To better assess the impact of the technologies for specific vehicle types, further studies are recommended to understand **vehicle usage patterns** in the local context. A review of Singapore **vehicle fleet dynamics** is also recommended to better understand the timing of emissions reductions that can be achieved.

Finally, **policies to address the existing diesel fleet**, especially the older, more polluting vehicles, are recognised to be complementary and essential in reducing diesel emissions. Existing Initiatives by the Government to encourage cleaner vehicles, such as the Early Turnover Scheme (ETS) for commercial diesel vehicles have been helpful towards this objective. The ETS has encouraged the early replacement of about 24,000 commercial diesel vehicles to cleaner models since its commencement in April 2013. (NEA 2016) The BlueSG EV car-sharing scheme helps to reduce the usage of taxis, which mostly run on diesel, and reduce diesel emissions. Other policies to consider include vehicle inspection programmes, retrofitting schemes, education programmes, and pollution tax.

Technology	Benefits	Costs	Issues	Commercial status
Diesel	(Baseline technology)	(Baseline technology)	Heavy emitters of pollutants and greenhouse gases (GHG)	Commercial for all vehicle types
Petrol	Modest reductions in emissions	Lower vehicle cost, Higher fuel cost	Less fuel efficient, Not for heavy towing applications	Commercial for cars and vans
Hybrid, plugin hybrid	Reduced emissions, Increased efficiency	Increased cost (1.2-1.7x)	Battery life uncertain, PHEV requires charging infrastructure and time	Commercial in almost all vehicle types except very heavy goods vehicles (VHGV)
Battery electric (EV)	Zero tailpipe emissions, Lower GHG, Large increase in efficiency	Increased vehicle cost (2x), Requires charging time	Limited range (< 160 km), Battery replacement might be necessary, Charging infrastructure currently lacking, End-of-life options for battery uncertain, Need to train maintenance staff	Commercial for cars and buses, Early market introduction for others, except VHGV
Hydrogen fuel cell	Zero tailpipe emissions, Large increase in efficiency, Long range	Increased vehicle cost (2-3x), High hydrogen fuel cost (6x diesel fuel), 4x fuel storage volume	~half lifetime of diesel engines, Hydrogen refuelling infrastructure lacking	Early market introduction for cars, demonstrated for buses and trucks
Compressed or liquefied natural gas (CNG/LNG)	Nontoxic	Increased vehicle cost (1.2-1.36x), 6-15% less efficient, 2-4x fuel storage volume, Shorter range.	Little reduction in tailpipe emissions, Risk of methane (GHG) leakage, Refuelling infrastructure lacking, High pressure tank needs periodic inspection	CNG is a mature technology, commercial in almost all vehicle types, LNG used in cars, heavy goods vehicles, buses, 4 CNG stations in Singapore

Table 1. Summary of alternative powertrains benefits, costs, issues and commercial status

Technology	Benefits	Costs	Issues	Commercial status
Biodiesel	Lower CO and PM emissions, Lower visible smoke, Nontoxic, Biodegradable	May increase NOx emissions, Lower energy content and power, More costly to produce (2-3x)	Sustainability of palm oil feedstock, Net change in GHG emissions uncertain, Not all vehicles support use of biodiesel	Widespread production
Renewable diesel	Lower emissions, "Drop-in" replacement fuel	More costly to produce (1.9x), Slightly lower energy content	Sustainability of palm oil feedstock, Net change in GHG emissions uncertain	In production

Table 2. Summary of alternative fuels benefits, costs, issues and commercial status

Technology	Air emissions	Purchase cost	Operating cost	Infrastructure cost	Travel Range	Fuel storage volume	Refuel time	Commercial availability[1]
Petrol	●○○○	●●●●	●●●●	●●●●	●●●●	●●●●	●●●●	●●●○
Diesel	○○○○	●●●●	●●●●	●●●●	●●●●	●●●●	●●●●	●●●●
Petrol hybrid	●●○○	●●●●	●●●●	●●●●	●●●●	●●●●	●●●●	●●○○
Diesel hybrid	●●○○	●●●○	●●●●	●●●●	●●●●	●●●●	●●●●	●●○○
EV	●●●●	○○○○	●●●○	●○○○	○○○○	●●○○	○○○○	●●○○
Fuel cell	●●●●	●○○○	○○○○	○○○○	●●●●	●○○○	●●●●	○○○○
CNG	○○○○	●●●○	●●●○	●○○○	●●●○	●○○○	●●●●	●○○○
LNG	○○○○	●●○○	●●●○	○○○○	●●●●	●●○○	●●●○	○○○○
Biodiesel	●○○○	N.A.	●●○○	●●○○	●●●○	N.A.	●●●●	●●●○
Renewable diesel	●●○○	N.A.	●●○○	●●○○	●●●●	N.A.	●●●●	●●●○

Table 3. Relative comparison of alternative technologies to diesel. More black dots indicate that the technology option performs better compared to other alternatives.

Alternatives to diesel	LGV	HGV	VHGV	Buses	Taxis	Cars
Petrol	○				○	○
Hybrid/plugin hybrid	●	●		●	●	●
Battery electric	●	●		●	○	●
Hydrogen fuel cell	○	○		○	○	○
CNG	○	○		○	○	○
LNG		○	○	○		
Biodiesel	○	○	○	○	○	○
Renewable diesel	●	●	●	●	●	○

Table 4. Applicable (○) and recommended (●) alternative technologies for different types of diesel vehicles in Singapore.
LGV = light goods vehicles, HGV = heavy goods vehicles, VHGV = very heavy goods vehicles

[1] Commercial availability of various technologies is shown for light goods vehicles only.