Understanding red fleet carbon emissions

Literature review Fire and Emergency Report #212

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1 Introduction

Fire and Emergency New Zealand (Fire and Emergency) has set out how they will reduce their fleet emissions through their Climate Response Strategy 2022-2030. The Climate Response Strategy aligns with all of government directions under the Carbon Neutral Government Programme (CNGP). The CNGP requires all government agencies to:

- Measure, verify, and report their emissions annually
- Set gross emission reduction targets and long-term reduction plans
- Offset remaining gross emissions from 2025 to achieve carbon neutrality.

As part of their Climate Response Strategy, Fire and Emergency has made a commitment to become environmentally sustainable by outlining how they will manage their carbon footprint. The Strategy also describes how Fire and Emergency will respond to the challenges of climate change through to 2030, with a particular focus on reducing emissions.[1] One of the challenges Fire and Emergency faces is management of their red fleet, which is the largest contributor to their total emissions. This report provides a review of the literature on managing red fleet emissions. It presents the relationship between emissions and the red fleet, and a summary of what other fire and emergency authorities are doing internationally to manage this challenge.

1.1 Targeted literature review

To understand the relationship between heavy-duty red fleet vehicles (fire appliances) and carbon emissions, we conducted a targeted review of the literature on how red fleets impact the environment and carbon emissions globally. We also explored how other fire and emergency authorities are dealing with reducing the carbon emissions of their red fleets. The countries and jurisdictions identified were Australia, the United Kingdom (UK), the European Union (EU), the United States of America (USA), and Canada. This literature review addresses:

- How heavy-duty red fleet vehicles impact the environment and carbon emissions
- How other fire and emergency authorities are attempting to reduce their red fleet emissions.

This targeted literature review explored the environmental and carbon emission impact of red fleets using the following sources:

- The fire and emergency authorities of New Zealand, Australia, the EU, the USA, the UK, and Canada.
- The Web of Science, Google Scholar, and Scopus.
- Grey literature published outside of academic or commercial sources. The decision to include grey literature was in account of the limited available literature related to certain topics.

[1] Fire and Emergency New Zealand (2022) Climate Response Strategy 2022—2030, https://www.fireandemergency.nz/assets/Documents/Fire-season-and-permits/FENZ-Climate-Response-Strategy-Sept-2022.pdf

2 Understanding red fleet carbon emissions

2.1 How does the red fleet contribute to emissions?

The Fire and Emergency red fleet comprises the main front line incident response vehicles but are also the largest contributor to total Fire and Emergency emissions. Fire and Emergency and New Zealand's other heavy-vehicle fleets make up four percent of national total greenhouse gas emissions (Energy Efficiency and Conservation Authority, 2022).

The red fleet generates emissions when responding to and idling at incidents, through operational use at incidents, during non-operational travel, and during general use of the fire appliance for training. Diesel fuel has the highest impact on fleet emissions (Waka Kotahi, 2022). This research also found that heavy-duty articulated trucks have a high impact for both particulate matter and nitrogen dioxide emissions, although a high level of uncertainty is associated with the measuring of emissions from these trucks.

Greenhouse gases (in the form of carbon dioxide) are generated when diesel fuel is burnt to produce energy that powers the red fleet. Greenhouse gases in the atmosphere contribute to climate change. This process also releases nitrogen oxides, particulate matter, and sulphur dioxide. These three pollutants contaminate the air and have negative health consequences (Reşitoğlu, 2014). Therefore, red fleet emissions not only result in negative environmental outcomes, including climate change, but can contribute to negative health outcomes While these negative health outcomes mostly impact fire and emergency staff, they also adversely affect the general community.

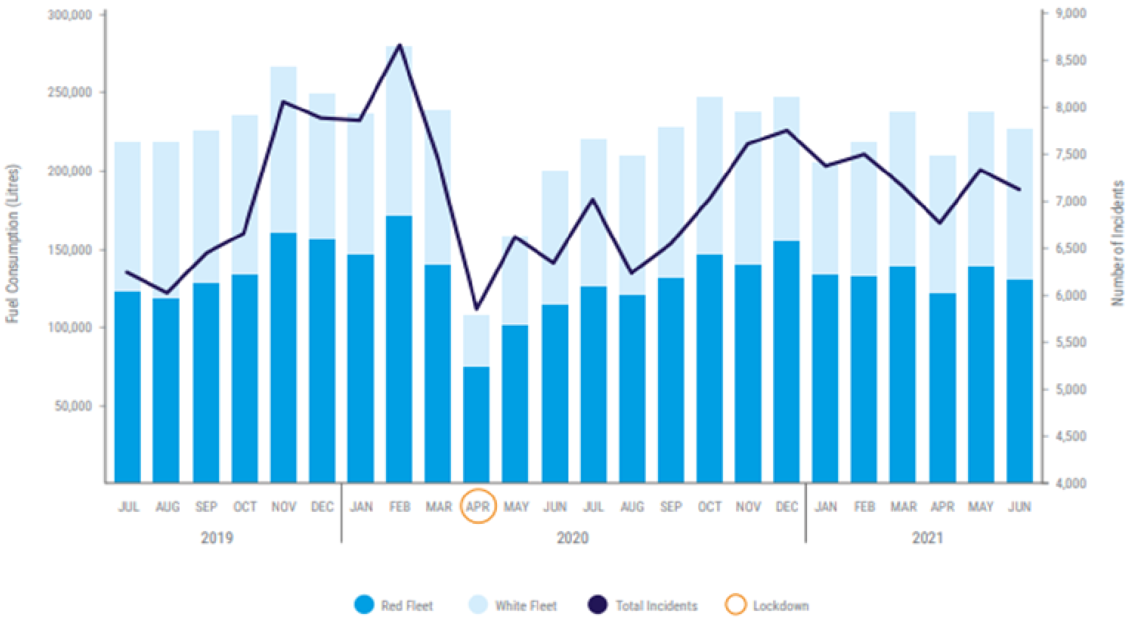
Diesel accounted for 43.4 percent of total Fire and Emergency emissions

As of March 2023, Fire and Emergency had a total of 1,274 heavy vehicles in their red fleet, all of which were fuelled by diesel.[2] In 2018/19, it was estimated that diesel accounted for 43.4 percent of total Fire and Emergency emissions (red and white fleet). Of this the red fleet accounted for 24.6 percent of total Fire and Emergency emissions.

Total Fire and Emergency emissions from the red fleet are also directly connected to the number of incidents that Fire and Emergency responds to each year, as presented in Figure 1. This adds an additional layer of complexity to managing red fleet emissions.

[2] Heavy-duty vehicles (HDVs) include vehicles with a Gross Vehicle Mass (GMV) greater than 3,500 kilograms (Waka Kotahi, 2022).

Figure 1 Vehicle fuel consumption and incident counts (July 2019-July 2021)



Source: Fire and Emergency Climate Response Strategy 2022-2030

As climate change worsens and extreme weather events (droughts, floods, cyclones, and wildfires, etc.) continue to become more frequent and more severe, the number of incidents that Fire and Emergency need to respond to will increase. This means emissions from the red fleet, in its current structure and setting, will also increase. This places further pressure on Fire and Emergency to reduce red fleet emissions. This is a problem facing fire and emergency services globally.

Widening the research to include other heavy-duty vehicles

There is, however, limited research globally and domestically on fire and emergency service vehicle emissions. Bluett (2016) identified that research on emissions from heavy-duty vehicles was one of the three most significant gaps in the current remote sensor device (RSD) database.[3] Due to this limitation, we needed to widen the review of the literature and include research on emissions from heavy-duty vehicles, which the fire and emergency red fleet falls under.

There are a range of factors that influence heavy-duty vehicle emissions. Some of these factors are better articulated in the available literature than others. Clark et al. (2011) identified the following parameters affecting emissions from diesel engines: vehicle class and weight, driving cycle, vehicle vocation, fuel type, engine exhaust aftertreatment, vehicle age, and terrain travelled.

Vehicle class and weight has a significant impact

Vehicle class and weight have a significant impact on the level of emissions from a heavy-duty vehicle. The Fire and Emergency red fleet consists of 1,372 heavy-duty vehicles. Clark et al (2011) found that "higher truck classes are heavier and, thus, produce more regulated emissions." If two vehicles employ the same engine, with all else equal, the heavier vehicle (or higher class) will

[3] An RSD measures exhaust emissions by absorption spectroscopy without interference with the vehicle or its driver. It is often used to track vehicle emissions over time in New Zealand (see Bluett (2016) for example.)

demand more energy, and thus produce more emissions. Clark et al (2011) also note that higher fuel consumption implies higher emissions, with the relationship between weight and fuel consumption professionally researched and established.

The type of fuel used also impacts the level of emissions

The fuel used in the combustion process also impacts the level of emissions. There are alternatives to diesel that can reduce emissions (including compressed natural gas, liquefied petroleum gas, and various alcohols.). These alternatives, however, require vehicle modifications that can be costly.

In addition, Clark et al (2011, as cited in Lange et al and Green et al) stated that diesel additives can also have a positive impact on reducing emissions. The most common additive is a cetane number enhancer, with results indicating that fuel with a higher cetane number ignites earlier and may use less fuel for the same power output. Clark et al (2011, as noted by Brown) also noted that a high-quality, fully reformulated diesel combined with exhaust aftertreatment is the most beneficial and cost-effective solution for reducing emissions.

Exhaust aftertreatment systems have also been shown to reduce carbon dioxide in heavy-duty, diesel-powered vehicles. There are three types of systems: diesel oxidation catalyst, particulate traps, and continuously regenerating traps.

Modifications and future purchases of vehicles will need to consider and abide by new and emerging legislation. Coming into force in October 2023, the Vehicle Exhaust Emissions Amendment Act 2023 will require vehicles to abide by Euro 6/VI and similar standards for the exhaust of light and heavy motor vehicles (Ministry of Transport, 2023).

The age of the vehicles also affects emissions

The age of a vehicle also affects emissions, at two main levels: engine deterioration and improved technology. The available research indicates that as a vehicle ages, and its engine deteriorates through continued use, the engine will produce higher emissions. Secondly, new and emerging technologies will produce lower emissions than those of the past, because they are subject to stricter and more extensive emissions related policy and regulation. Therefore, the older the fleet, the more unlikely it is to have the most recent emission reducing technology. This is the situation for the current Fire and Emergency red fleet which has an average age of 15-20 years, although funding has been received to upgrade it.

The literature reveals that many parameters and factors contribute to the level of emissions from heavy-duty vehicles. This suggests that there are also a variety of methods, or technologies available, to help reduce emissions. But importantly, the most effective way to achieve emissions reduction will result from a transition away from diesel-powered vehicles to a combination of electric vehicles, hybrid electric vehicles, and hydrogen electric vehicles. However, at present these options are limited or unavailable for heavy-duty vehicles.

Cunanan et al (2021) suggested that “diesel engines will remain an important technology in the short-term, due to existing infrastructure and lower costs, despite high emissions, while battery-electric heavy-duty vehicle technology and hydrogen fuel cell heavy-duty technology will be slowly developed to eliminate barriers.”

They presented a qualitative summary of the advantages and disadvantages of the three powertrains studied for heavy-duty vehicles (as presented in Figure 2**Error! Reference source not found.**). Battery and fuel cell technologies had the most positive impact on emissions. However, these technologies come at a considerable cost.

Advantages and disadvantages between battery and fuel cell heavy-duty vehicles vary. For example, while battery electric vehicles require less infrastructure investment than fuel cell vehicles, fuel cell vehicles have much faster refuelling times (2.85-20 hours vs. 16.67 minutes.). This research paper acknowledged recent growth in technological developments in battery-electric and fuel cell electric heavy-duty vehicles that have shown positive results.

Figure 2 Advantages and disadvantages of the three powertrains

Technology	Advantages	Disadvantages
Diesel	Lowest vehicle cost. No infrastructure investment required. Long range and high payload. Faster refueling time than BEVs. Large market with widely available parts and vehicles.	High greenhouse gas emissions Source of local air pollution (high tailpipe emissions). High refueling and maintenance cost. Low energy efficiency.
Battery	Reduces greenhouse gas emissions. Reduces local air pollution (no tailpipe emissions). Lower refueling and maintenance costs than ICE vehicles. Higher energy efficiency than ICE. Less infrastructure investment required than FCEV.	Infrastructure investment required. Higher vehicle cost than diesel. Long recharging time. Limited range. Limited cargo weight and size due to large battery.
Fuel cell	Reduces greenhouse gas emissions. Reduces local air pollution (no tailpipe emissions). Higher energy efficiency than ICE. Faster refueling time than BEVs. High specific energy.	High initial hydrogen fuel cost. Heavy infrastructure development required. Highest vehicle cost compared to diesel or battery. Slow FCEV development.

Source: A review of heavy-duty vehicle powertrain technologies: Diesel engine vehicles, battery electric vehicles, and hydrogen fuel cell electric vehicles (Cunanan et al, 2021)

Although these developments are positive, they have been focused on heavy-duty vehicles more broadly. At present these technologies are limited in their application for Fire and Emergency.

2.2 Technologies for reducing heavy-duty vehicle emissions

Reducing emissions from heavy-duty vehicles is a complex challenge. The challenge is compounded when trying to achieve emissions reductions for fire and emergency red fleets. The most significant barrier is the cost of alternative fuel vehicles. The upfront costs for central and local Government and for fire and emergency service departments are substantial, especially within fiscally constrained budgets as is the case for Fire and Emergency.

Idle reduction technology

Idling occurs when the engine is running but the vehicle itself is not in motion. For fire and emergency service vehicles this can occur, for example, at the station, at incidents, during stand-by periods, or when responding to/during a fire. While idling, vehicles continue to emit greenhouse gases into the atmosphere, contributing to climate change.

Fire and emergency service vehicles spend a notable proportion of time idling. Zheng et al (2018) found over the course of their study period (May 1, 2018, to June 4, 2018) that, overall, idle time made up 41.9 percent of total engine time on average, per incident.

Rahman et al (2013) identified that during idling the engine is not running at an ideal temperature and the combustion of the fuel is incomplete, which leaves fuel residues in the exhaust resulting in an increase in emission levels. They also noted that the fuel consumed during five miles of driving is the equivalent to just ten minutes idling, and ten minutes of idling per day will consume more than twenty-seven gallons of fuel per year.

Not all instances of idling are avoidable. However, some are and so the levels of emissions from idling can certainly be reduced. For this reason, research into, and the implementation of, idling reduction technology has received considerable attention across fire and emergency service departments internationally. Although not the most optimal solution to reducing emissions, it is an important available avenue in doing so.

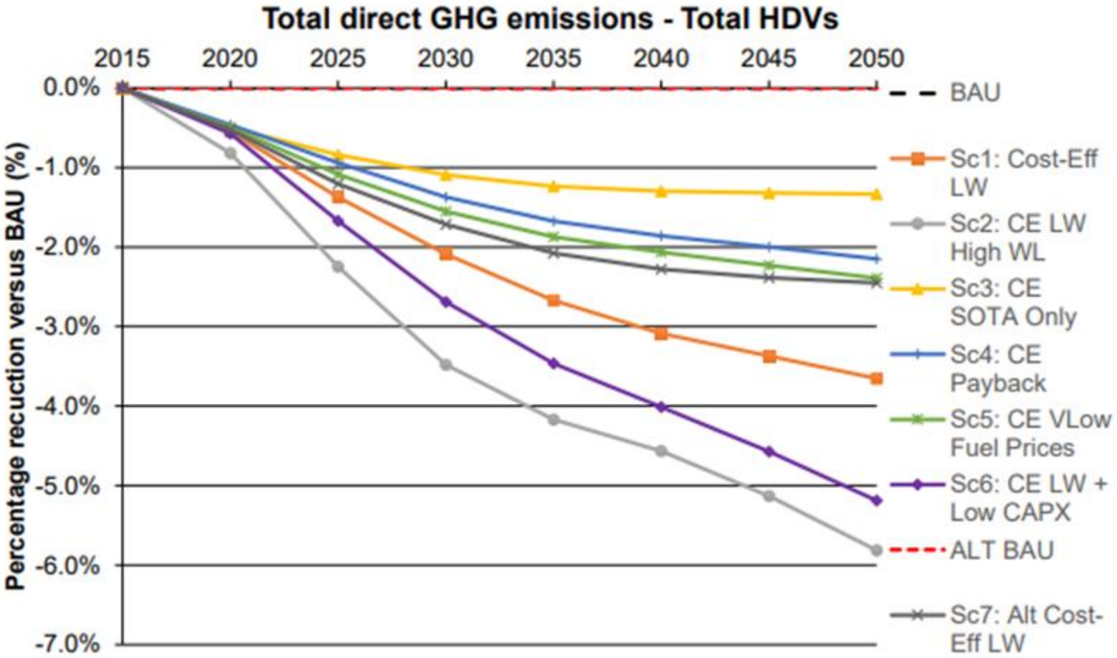
Zheng et al (2018) conducted a study to determine the value of APUs. Zheng et al (2018, citing Frey and Kuo) found that although APUs run on diesel, their fuel use and emissions of carbon dioxide (GHG) were 36 to 47 percent lower when compared to the main engine. In their own study, they found that the implementation of an APU in a fire truck can correspond to fuel and maintenance saving costs of US$221 per year. Importantly, an APU can reduce greenhouse gas emissions by 420.1 kilograms in CO_2 equivalents per year.

Owens and Laughlin (2016) found that in a case study of the Poulsbo Fire Department, in the USA, an APU installed on a fire truck reduced diesel fuel use by 77 percent. The study also noted that seven hundred hours of main-engine idling were eliminated per year for a typical fire pumper truck. Unfortunately, this study was unable to collect sufficient data on the reduction in GHG emissions. However, it is implied that reduced fuel consumption and idling time will contribute to this.

Light weighting for heavy-duty vehicles

RICARDO-AEA (2015) undertook an assessment into potential light weighting as a means of improving the energy efficiency and overall CO_2 (GHG) emissions from heavy-duty vehicles. Lightweighting is a process of reducing weight from a component, part, or overall vehicle to improve fuel efficiency, which consequently reduces emissions impact. This can, for example, include shifting vehicle components from one metal to another (i.e. steel to aluminium). It explored the benefits of cost-effective uptake of light weighting across various heavy-duty vehicle types. Figure 3 below presents a summary of the yearly change in projected CO_2 emissions, compared to business as usual, from all heavy-duty vehicles in the EU fleet.

Figure 3 Change in projected direct emissions from all heavy-duty vehicles in the EU fleet



Source: Light weighting as a means of improving heavy-duty vehicles energy efficiency and overall CO_2 emissions (RICARDO-AEA, 2015)

It is evident that, across different scenarios, light weighting of heavy-duty vehicles can positively impact the total direct GHG emissions produced. For example, in the baseline scenario (Sc1: Cost-Eff LW), emissions were estimated to be reduced from heavy-duty vehicles in the fleet by around 2.1 percent by 2030 and almost 3.7 percent by 2050. This equates to 6.6 megatonnes less total heavy-duty vehicle emissions (CO_2) in 2030.

Improved incident responses/reduced unwanted callouts

Every year fire and emergency services globally respond to a substantial number of unwanted callouts, whether they be false alarms, unnecessary calls, or malicious activity. For example, Fire and Emergency responds to over 20,000 false alarm calls every year (Fire and Emergency, 2023). And in some areas, more than 50 percent of callouts are unwanted alarms. These high numbers are not atypical internationally. For example, in Norway, in 2016 approximately 60 percent of emergency dispatches were false or unnecessary. In Denmark the equivalent figure was 44 percent (Gjøsund et al, 2018).

The impact of these unwanted callouts is severe. In an earlier report BERL (2019) highlighted the economic impact of unwanted false alarms which also have a significant impact on emissions. Red fleet vehicles are often deployed for unwanted alarms. As highlighted in Figure 1, with more callouts comes higher fuel consumption, leading to further emissions.

In the Climate Response Strategy, the opportunity to reduce unwanted callouts and emissions was identified as a particular direction Fire and Emergency will take. “We will explore how we respond to incidents, and use our fire appliances generally, with the aim of identifying efficiencies in the way we use our vehicles without compromising the effectiveness of our response.”

BERL (2019) identified the following strategies that have been applied or considered internationally when approaching the issue of unwanted callouts:

- Upgrade to analogue addressable fire alarm systems
- Promote the use of appropriate, approved, and correctly located detectors
- Encourage the replacement of single type detectors (usually smoke) with multi- sensors which detect more than one fire sign
- Prevent malicious alarm activations by using protective covers over approved Manual Control Points and sensors with adequate signage, supported by CCTV where required
- Promote the use of localised alarm sounding, and Alarm Acknowledgement Facilities (hush buttons) in multi apartment buildings
- Implement more rigorous maintenance of the alarm system, better control of contractors, and thorough inspections. This is to confirm that maintenance has been performed correctly and that the alarm system has not been tampered with (both to prevent unwanted alarms and to ensure lifesaving equipment is functional)
- Improve data collection and national databases to enable proper analysis of the causes and patterns of unwanted alarms
- Highlight the economic cost of unwanted fire alarms
- Improve call back procedures and alter responses to mitigate the impact of unwanted alarms while maintaining life safety
- Ensure there is communication and cooperation between Fire and Emergency and the alarm industry, and
- Implement measures to align the incentives of building owners and managers and the alarm industry with those of Fire and Emergency. Successful strategies include networking events, cooperating on policy creation, and information sharing.

Though not modelled, it is implied that reducing the number of unwanted callouts would have a major impact on reducing red fleet emissions.

3 How do authorities tackle net zero carbon targets?

Many global authorities, New Zealand included, are targeting carbon neutrality within the next decade. In New Zealand's case, government agencies are expected to be carbon neutral by 2025. However, achieving this is challenging.

A reduction in red fleet emissions must occur without compromising the ability of Fire and Emergency to protect, help, and serve the community. At present, there are few alternatives available to replace the red fleet's high emitting vehicles. In contrast, vehicles in the white fleet (e.g., hatchbacks and, SUVs), can be replaced by a range of hybrid or fully electric vehicles.

Replacing old vehicles included in the red fleet with newer models, by default, will reduce emissions generated from the fleet. It is widely researched that older vehicles contribute more to emissions, and with increased regulatory requirements, newer vehicles abide by tighter emission standards. That means that a reduction in red fleet emissions does not need to occur only by replacing the fleet with electric or hydrogen fuel cell heavy-duty vehicles but can occur by replacing older vehicles with newer ones as well. Currently there are few instances where fire and emergency departments have replaced their red fleet vehicles with low-emission alternatives. This landscape is changing however (see section 4).

Limited transition to lower emission red fleets globally

Momentum in the development of low to zero emission heavy-duty red fleet vehicles is building globally. The demand for such vehicles from fire and emergency departments, growing regulatory and emission requirements, and fast developing improved technology is driving this. Current adoption of low to zero emission heavy-duty vehicles across fire and emergency departments is still limited at present. Requirements vary significant from country to country and department to department which makes producing these vehicles at scale difficult. These requirements include operational aspects of the vehicle, as well as regulatory requirements in place in different nations.

Rosenbauer, an Austria-based manufacturer, has been one of the leading producers of electric/hybrid electric heavy-duty fire trucks. A few fire departments in Australia and the US have purchased these trucks for their fleet. A key barrier to further widespread uptake of the hybrid electric trucks produced by Rosenbauer is their price. The trucks can cost nearly double that of a traditional heavy-duty, diesel engine fire truck, at approximately US$1.6 million/NZ$2.6 million (Van Oot, 2023). Gagnon (2023) stated that higher up-front costs is a unique challenge facing owners of heavy-duty vehicles who want to electrify them. Access to charging infrastructure and the strain on the local electric network is also another challenge. There are also mass weight concerns for the low to zero emission alternatives currently available. New Zealand roads have axle mass restrictions to preserve and protect the road infrastructure which means imported vehicles must abide by these limits.

For a more detailed review of the transition to low to zero emission heavy-duty vehicles, please see section 4.

United Kingdom (UK)

The United Kingdom (UK) has set a target to achieve net zero emissions by 2050. This requires lowering emissions by 68 percent by 2030 compared to 1990 levels (Zemo Partnership, 2021). In reaching this target the current government released the Transport Decarbonisation Plan in 2021. Included in this was a commitment that new diesel and petrol cars and vans will no longer be sold from 2030.

There is a lack of recognition, however, as to what might be done to reduce emissions from heavy-duty vehicles. The plan points towards an opportunities study, conducted by Zemo Partnership (2021), that identified policy choices available for governments to encourage and support this transition for heavy-duty vehicles. But there was a clear focus on heavy-goods vehicles. However, specific actions are being undertaken by fire and emergency service departments in the UK to reduce emissions which are outlined below.

London Fire Brigade

The London Fire Brigade are taking concerted action to decarbonise their fleet in line with the emission target of making London net zero carbon by 2030. The London Fire Brigade (2022) has since begun work with Emergency One to build a Zero Emission Capable Pumping Appliance (electric-hybrid fire engine). This brigade is arguably leading the way forward for emissions reduction across the United Kingdom. Ninety-six percent of the Brigade's buildings have electric vehicle charge points, and three fire stations have publicly accessible rapid charging facilities.

The Brigade are also assessing the use of hydrogenated vegetable oil in existing fire engines. It is expected that this could reduce carbon emissions by 24 percent from fleet fuel consumption. This was supported in the above opportunities study conducted by Zemo Partnership (2021), where they stated that hydrotreated vegetable oil should be considered as a possible alternative for reducing GHG.

Oxfordshire Fire and Rescue Service

Ulemco (2022) identified that zero emission battery electric fire tenders, in combination with hydrogen fuel cells, will meet the current operational and emission requirements of the Oxfordshire Fire and Rescue Service. For Oxfordshire Fire and Rescue Service, the best option for transitioning to a zero-emission fleet would include a combination of electric power and onboard hydrogen fuel storage. This would also feature a 220-kWh battery with a fuel cell range extender and eight kilograms of hydrogen to meet driving and pumping requirements.

United States of America (USA)

The USA Environmental Protection Agency (EPA) announced a proposal to revise existing standards to reduce GHG from heavy-duty vehicles in model year 2027, and to set new and more stringent standards for model years 2028 through 2032.[4] This proposed programme, known as "Phase three

[4] Regulations for Greenhouse Gas Emissions from Commercial Trucks & Buses, the United States Environmental Protection Agency (EPA) https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-greenhouse-gas-emissions-commercial-trucks

greenhouse gas," builds upon the success of two previous rules, Phase one[5] greenhouse gas and Phase two[6] greenhouse gas.

These rules acted collectively to reduce GHG from heavy-duty vehicles and engines. Phase three greenhouse gas standards would apply to heavy-duty vocational vehicles and is called the Clean Truck Plan.[7]

In California, the Carl Moyer Program provides funding for fire apparatus (or fire trucks). The funding enables the replacement of an older, more polluting vehicle with a vehicle that has an engine certified to the 2010 emissions regulations or clean California emission standard (California Air Resources Board, n.d.). Since its establishment in 1998, the programme has delivered almost $1 billion in equipment. It continues to provide over $60 million annually in grant funding to clean up older polluting equipment throughout California.

Multiple departments across the USA have also added zero-emission electric fire trucks into their fleet. For example, the Madison Fire Department and Portland Fire and Rescue added a Pierce Volterra zero-emissions pumper to their fleet (Pierce, n.d.). The Charlotte Fire Department has made an order for an electric fire truck to be housed at their all-electric firehouse that is set to open in 2024 (Worford, 2022). The Los Angeles City Fire Department (LAFD) acquired a hybrid electric fire truck (DeMuro, 2022).

3.1 How are Australian fire and rescue services tackling fleet emissions?

Australia's transport sector accounted for 19 percent of total emissions in 2022 (Department of Climate Change, Energy, the Environment and Water, n.d.). Plans, strategies, and approaches to reducing emissions vary from state to state. At a national level though, they are governed by the National Electric Vehicle Strategy, among other initiatives and strategies (Department of Climate Change, Energy, the Environment and Water, 2023). This strategy encompasses a significant amount of support to encourage the uptake of electric vehicles nationally in terms of resourcing, infrastructure, and initiatives. It also leverages a range of initiatives that are already in place in different states. It is evident that the shift towards adopting electric vehicles is of high priority.

As approaches and strategies vary from state to state, some have made much more significant progress than others. In particular, the ACT Government added a Rosenbauer plug-in hybrid electric fire truck to its fleet (ACT ESA, 2022). They also agreed on a partnership with Volvo Group Australia to co-design and develop net zero emission operational service vehicles from 2022. This partnership builds on an almost $13 million vehicle replacement program for ESA. And it allows current leading edge zero and low emission technology to be incorporated into the critical design requirements for emergency service vehicles. These steps taken by the ACT ESA are driven by their efforts and commitment to achieve a net zero emissions future by 2045 (ACT, 2022).

The New South Wales (NSW) fire and rescue service has also made strong commitments to reducing GHG emissions. In 2022 they committed to a plan to reduce emissions by introducing energy-

[5] Phase one Greenhouse Gas Rule for model years 2014-2018.
[6] Phase two Greenhouse Gas Rule for model years 2019-2027.
[7] EPA's Clean Truck Plan, https://www.epa.gov/regulations-emissions-vehicles-and-engines/clean-trucks-plan

efficient improvements to their facilities, and maximising renewable energy generation. They are also minimising their carbon impact by transitioning their passenger fleet to efficient hybrid and electric vehicles.

Queensland Fire and Emergency Services (QFES) have added three electric vehicles to their fleet (Credentino, 2023). This is a new pilot program aimed at reducing emissions and supporting the state's zero emissions vehicle strategy. But these additions were only for what would be the equivalent of the Fire and Emergency white fleet. However, QFES did also recently place its first order with Volvo Group Australia for its first heavy-duty vehicle electric truck (Volvo Group, 2023). Underpinning Australia's fire and emergency services approach to reducing their fleet emissions is a government-led approach built on industry partnerships.

4 Transitioning the fleet to electric heavy-duty vehicles

Heavy-duty vehicle fleets are significant contributors to emissions around the world. For many nations, authorities, or departments that are striving to achieve emission targets and carbon neutrality, there is an urgent need to address the level of emissions from heavy-duty vehicle fleets. This is a complex challenge. Emissions from heavy-duty vehicles are classified as harder-to-abate. Technologies are available that directly or indirectly act to reduce/minimise emissions generated from heavy-duty vehicles. However, the impact of these options, although still positive, are of smaller scale compared to purchasing new, low or zero emission heavy-duty vehicle alternatives that will immediately and notably reduce Fire and Emergency fleet emissions emissions.

The most impactful approach to tackling this challenge would result from a transition of the heavy-duty vehicle fleet to fully electric, hybrid electric, or hydrogen fuel cell heavy-duty vehicles. At present, there are limited available options for transition to a zero or low emission heavy-duty vehicle, let alone a fire and emergency service specific vehicle. Although, this is rapidly changing. Technology is developing quickly, pressure continues to mount from government, society, and institutions, and demand is growing globally. The market for zero to low emission heavy-duty red fleet vehicles will match this changing landscape.

In account of a lack of literature on electric or hybrid electric heavy-duty vehicles specifically designed for a red fleet, the following review also considers alternative heavy-duty vehicles more broadly, not only those applied in a fire and emergency service setting.

4.1 Current landscape

Adoption of low or zero emission red fleet vehicles globally

Low or zero emission heavy-duty vehicles for a red fleet have specific requirements that vary from department to department and from country to country. To meet these requirements, each vehicle needs to be tailored and modified in a particular way. This means manufacturing large numbers of such vehicles difficult with very low economies of scale.

Momentum is building in this market, mostly within the last few years. A partnership between Rosenbauer and Volvo led to the development of an electric fire truck in 2021, that being with Rosenbauer's design and Volvo's drivetrain. Furthermore, in 2023, Rosenbauer recently launched an all-new electric fire truck in the US, the Rosenbauer RTX (Fortune Business Insights, 2022). In 2023, SCANIA also developed a hybrid solution for industrial and marine purposes, perfectly suited for airport fire trucks. Such alternatives offer improved torque, lower total lifetime operating costs, and reduced noise pollution. There are a few examples, (Bleakley (2023), DeMuro (2022), and Edwards (2023)), where fire and emergency services have shifted to some extent to a low or zero emissions red fleet. But these vehicles come at a significant upfront cost, even without including the supporting infrastructure that is required. Between these examples, the cost of an electric fire truck is approximately upwards of US$1.5 million. This high upfront cost poses a challenge in shifting an entire heavy-duty vehicle fleet to zero or low emission alternatives.

4.2 The cost of the transition

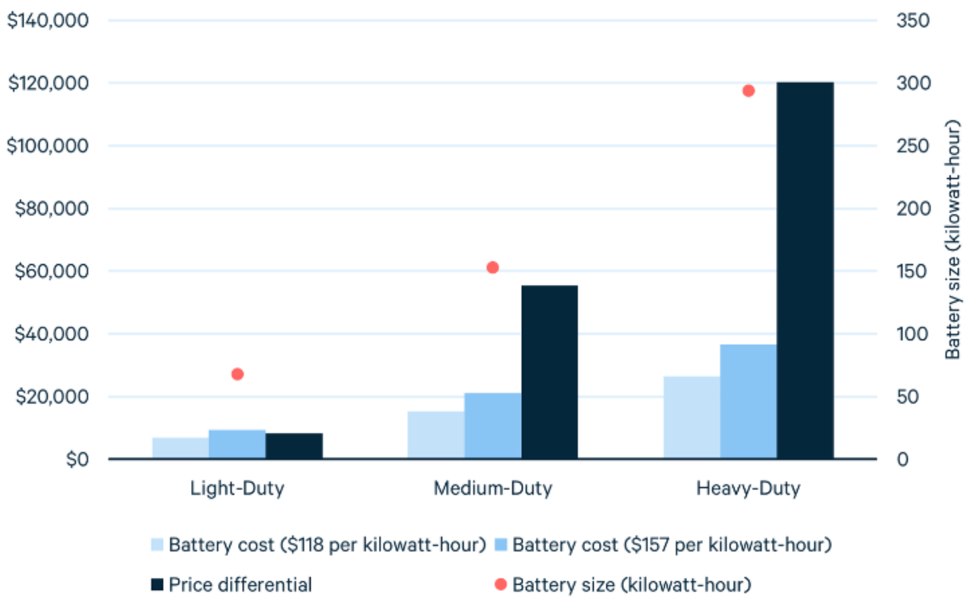
Although the broader market for low to zero emission heavy-duty vehicle alternatives is growing, the cost for authorities, departments, and governments remains high. The price of an electric battery and fuel cell storage is the key factor distinguishing between the price of traditional diesel heavy-duty vehicles and low to zero emission alternatives. But the last few years has seen significant developments. It is expected that as market demand grows and technology improves, this high upfront cost will decline.

The following section first explores the driver of current high upfront costs, which is then weighed up against the lower total lifetime operating costs. This is followed by a review of the literature and research on the potential future outlook for this market, highlighting when price parity between heavy-duty vehicle alternatives could be achieved.

High upfront costs

There are various elements that contribute to the high upfront costs of low to zero emission heavy-duty alternatives at present compared to traditional diesel heavy-duty vehicles. For starters, economies of scale, that is the cost advantage which firms can gain from producing at scale, is low due to the currently limited demand. There is also limited competition in this market at the moment with the start-up costs associated with the development of electric vehicles potentially further deterring new entrants. But the underlying driver that separates the cost of electric or hybrid electric heavy-duty vehicles to their diesel counterparts is the cost of batteries, while for hydrogen fuel cell heavy-duty vehicles, it is the fuel cell storage. For heavy-duty vehicles, this issue is further pronounced. To put it simply, the bigger the battery, the more expensive the vehicle, and batteries scale with the size required. Therefore, heavier and larger vehicles require a much larger battery, and thus the price of the batteries for heavy-duty electric vehicles is higher (Figure 4).

Figure 4 Price differential and battery cost across vehicle type



Source: Why are electric truck prices so high? (Spiller, 2023).

This similarly is the case for hydrogen fuel cell heavy-duty vehicles. The larger the vehicle, the more fuel cell storage that is required, and the cost of such fuel storage increases with scale.

Lifetime operating costs

It is widely recognised that the lifetime operating costs of low to zero emission heavy-duty vehicles outweighs that of their diesel counterparts. Heavy-duty diesel vehicles, on average, have higher fuel and maintenance costs, compared to low to zero emission heavy-duty vehicles alternatives. Cunanan (2021, citing Pelletier et al (2014)) states that battery electric vehicles have maintenance costs 20-30 percent lower than diesel-powered vehicles. A vast amount of research (Fortune Business Insights (2023), Burnham (2021), Wang (2022), and Propfe (2012)) confirms this. In the fire and emergency service setting, Pair (2023) quotes CJ Stegink, who stated that a single engine in their red fleet used roughly $6,300 in fuel costs and cost roughly $5,300 in preventative maintenance. But for an electric engine, these costs could shrink to $150 and $1,500, respectively.

Such findings for heavy-duty vehicles are well researched. The challenge in this regard is not the lifetime operating cost, rather the total cost of ownership. Total cost of ownership is often summarised as the initial purchase cost plus the lifetime operating costs. Although low to zero emission heavy-duty vehicles have much lower operating costs compared to their diesel counterparts, the current high upfront purchase costs makes the total cost of ownership between the vehicles favour diesel vehicles. This is shifting as momentum in the market builds with price parity likely to be achieved in the coming decade.

4.3 Future outlook

New Zealand has set in law the overarching target for net zero greenhouse gas emissions by 2050 (Ministry for the Environment, 2022). Responsible for 17 percent of gross emissions in New Zealand, the transport sector is a core component in this transition. A key action in the Emissions Reduction Plan (2022) for the transport sector is to begin work decarbonising heavy transport and freight.

Such overarching target and vision for a zero emissions future is one shared by many governments globally. To achieve this and reduce emissions from the transport sector, governments around the world are introducing regulations and policy that either limits emissions from the transport sector or encourages/incentivises the adoption of electric or hybrid electric vehicles. A particularly impactful commitment in this sector was reached at the United Nations Climate Change Conference (COP26) in 2021, with the United Kingdom announcing a ban on the sale of all internal combustion engine vehicles by 2040 (Government United Kingdom, 2021). Over 20 countries have pledged to this commitment, with New Zealand being one of the signatories.

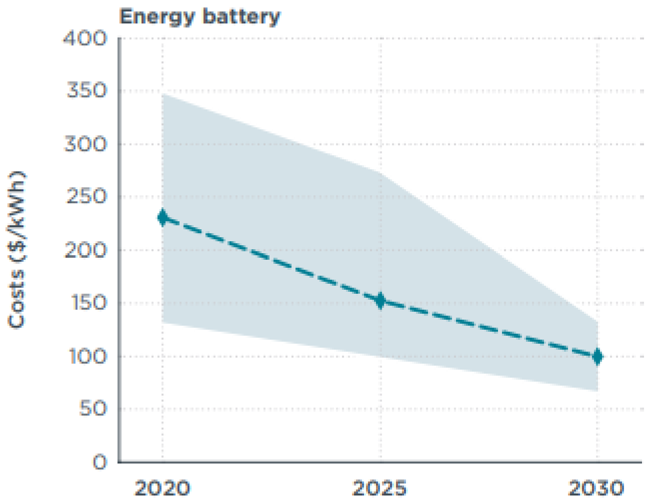
This target, in unison with the overarching target of a zero emissions future by 2050, puts New Zealand on a timeline, as is the situation with many countries. Consequently, this has quickly accelerated the need to electrify the transport sector. Technological developments and the development of low or zero emission alternatives will continue to be driven by policy/regulations and mounting demand. This puts the price of electric and hybrid electric vehicles, particularly heavy-duty vehicles, on a downwards slope.

The cost of batteries for electric vehicles is rapidly declining

As previously mentioned, the cost of the battery for an electric or hybrid electric vehicle is significant and increases in accordance with the size of the vehicle and the distance it is required to travel. Thus the current cost for a heavy-duty electric or hybrid electric vehicle is significantly high and notably outweighs that of a diesel heavy-duty vehicle. Up until relatively recently demand for these alternatives was limited. What is very evident though is the push from government, industry, and businesses to meet emission targets.

It is clear that battery costs for electric vehicles are expected to decrease considerably with an overall increase in the penetration of electric vehicles in the market, plus technological developments. Nair (2022) acknowledges that battery, motor, and power electronic costs are decreasing more rapidly than predictions made in the past. Sharpe (2022) expects that battery pack costs for heavy-duty vehicles will significantly decrease over the next decade, dropping to $100/kWh by 2030, as opposed to the average reported cost in 2020 of $240/kWh (Figure 5).

Figure 5 Zero-emission heavy-duty vehicle manufacturing costs of an energy battery

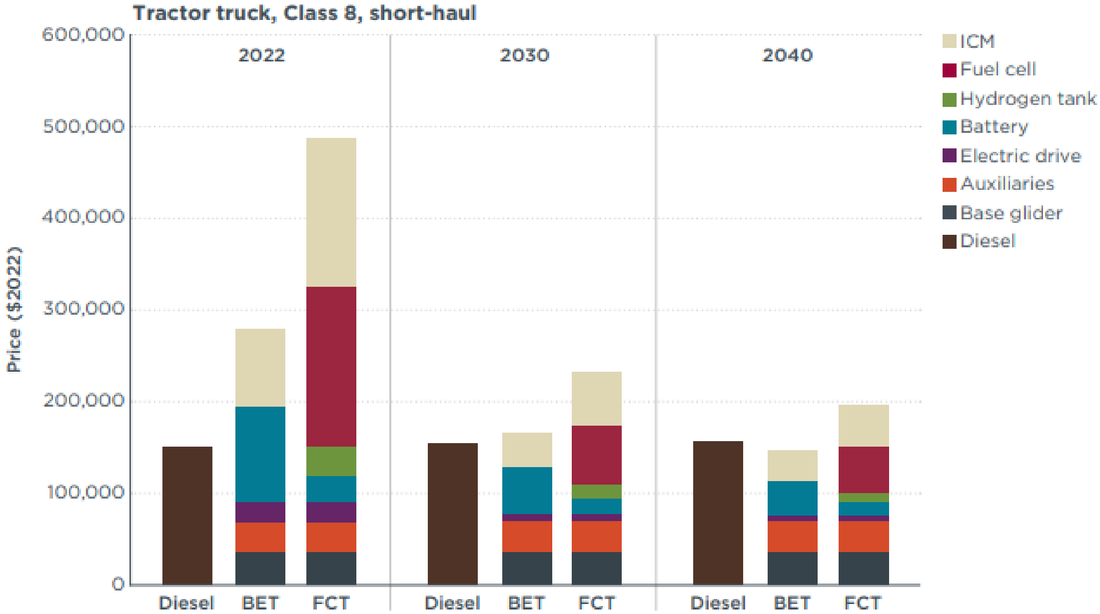


Source: A meta-study of purchase costs for zero emission trucks (Sharpe, 2022)

Sharpe (2022, citing Anculle (2021)) states that for battery-electric trucks, the entire electric propulsion system can account for roughly 85 percent of vehicle costs, with the battery pack itself accounting for roughly 60 percent. Therefore, the reduction in the cost of batteries for heavy-duty electric vehicles will significantly contribute to enabling price parity between battery-electric and diesel trucks (Xie, 2023). This is depicted in Figure 6, where it reflects that the battery packs and indirect cost multipliers (ICM) account for 28 percent and 30 percent of the total cost of battery electric trucks (BET) in 2022.[8]

[8] Indirect cost multipliers (ICM) account for additional expenses, such as research and development, overhead, marketing and distribution, and warranty expenditures, as well as for-profit markups.

Figure 6 Estimated retail price of a short-haul tractor truck (class 8) by components



Source: Purchase costs of zero-emission trucks in the United States to meet future Phase 3 GHG standards (Xie et al, 2023).

However, by 2040, as the price of a battery decreases for electric trucks, as with the ICM, the estimated retail price of a class 8 short-haul vehicle is below the diesel counterpart. Although not a perfect representation of a red fleet heavy-duty vehicle, this analysis confirms the broader trend occurring in this market. Battery prices are expected to fall drastically within the next decade, and other factors (captured in the ICM), such as profit markups and overhead, will continue to fall with increased market penetration, demand, and continued pressure from policy and regulations.

Hydrogen fuel cell trucks prices also expected to decline

The market for heavy-duty hydrogen fuel cell vehicles is in a similar state as that for electric or hybrid electric heavy-duty vehicles, although less researched at the moment. The market is rapidly growing and developing. Figure 6 indicates that average price for a fuel cell truck (FCT) is expected to decline significantly between 2022 and 2030. However, it also reveals that in 2022, the price of an FCT was much higher than that of a BET. This is mostly due to the price of a fuel cell outweighing that of a battery.

The uptake of hydrogen fuel cell fire trucks globally has been even more limited than the uptake of electric or hybrid electric fire trucks. An important step was taken in the UK though, with a $3.9 million project aimed at developing hydrogen-powered vehicles for the emergency services and councils announced.

Achieving price parity within two decades

Electrifying the transport sector is a key focus of governments around the world and this focus has accelerated technological developments and the adoption of low or zero emission alternatives. It is clearly evidenced across literature that the cost of a battery or fuel cell storage, the leading contributor to the currently high upfront costs of low to zero emission heavy-duty vehicles, is declining considerably. The underlying question here is when will these alternatives reach or surpass price parity with heavy-duty diesel counterparts.

The US Department of Energy estimated that price parity would be achieved at battery costs of $100/kWh (VTO, 2022). Sharpe (2022) presents the findings from a range of literature which suggests that the average cost of a battery will reach $100/kWh by 2030. Similarly, Xie (2023) finds that the upfront cost parity for most truck segments between battery electric trucks and their diesel counterparts will be achieved in the late 2020s or early 2030s. Andrew (2022) also states that electric trucks will only be competitive once batteries reach $100/kWh, with this likely to occur within the next ten to twenty years. While a recent study by the US Department of Energy, estimates that electric medium- and heavy-duty trucks will a cost parity with their diesel equivalents by 2035 (Sickels, 2022).

In summary, the literature indicates that price parity will likely be achieved within the next decade.

5 Concluding remarks

The market is growing and developing rapidly

The transport sector is New Zealand's largest contributor to total energy sector emissions (MBIE, 2021). The heavy-vehicle fleets alone contribute four percent of New Zealand's total GHG emissions (Energy Efficiency and Conservation Authority, 2022). To meet commitments and targets within the Climate Response Strategy and more broadly, targets set by the New Zealand Government, Fire and Emergency must seek to navigate and address the challenge of reducing emissions from the red fleet.

The most impactful approach to reducing red fleet emissions would result from a transition to low or zero emission heavy-duty vehicle alternatives. At present, the market for these alternatives is limited. Globally there has only been a few cases where fire and emergency departments have adopted electric or hybrid electric fire trucks. This landscape is changing rapidly though, particularly in the last few years.

Regulations and policy driven by government and industry has put significant pressure on the electrification of the transport sector. A key development occurred at COP26, with the UK announcing a ban on the sale of all internal combustion engine vehicles by 2040, with New Zealand one of the signatories pledging to this commitment.

Technological developments will continue to drive overall developments in this market as well. It is expected that the prices of electric vehicle batteries and hydrogen fuel cell storage will continue to decrease, with price parity achieved in the coming decade. This is the result of a combination of technological developments, pressure from regulations and policy, and overall growth in demand, which has increased rapidly the last few years.

5.1 Approaching reducing red fleet emissions

Managing and reducing emissions from the red fleet will need to be a gradual transition, including a combination of immediate measures, with smaller impacts to the level of greenhouse gas emissions and scoping and developing a longer-term strategy to adopt low to zero emission heavy-duty vehicles. This will include developing a strong relationship with an appropriate provider, and long-term backing by the government. To effectively reduce emissions from the red fleet, adequate resourcing/investment will need to drive the transition.

To tackle net-zero carbon targets, transport authorities in New Zealand and internationally have employed various strategies and measures which include but are not limited to:

- Introducing exhaust emissions standards: i.e., authorities implement regulations that require vehicles to meet specific exhaust emissions standards. For example, the Ministry of Transport in New Zealand drafted the Land Transport Rule: Vehicle Exhaust Emissions Amendment 2023, which introduces Euro 6/VI and similar standards for light and heavy motor vehicles.
- Transitioning to low-emission vehicles: i.e., authorities encourage the adoption of low-emission vehicles, such as hybrid or fully electric vehicles, especially for the white fleet (e.g., hatchbacks and SUVs). In some cases, fire and emergency departments have started replacing heavy-duty

vehicles with low-emission alternatives. However, the high upfront cost of such vehicles, road weight restrictions, and the significant supporting infrastructure required, remain major barriers to widespread adoption. Government programmes are an important means of accelerating these initiatives. The Carl Moyer Program in California is a strong example how a program can effectively help resource the transition away from older, more polluting vehicles. A domestic example includes the Carbon Neutral Government Programme (CNGP) (Ministry for the Environment, 2022).

- Partnerships and co-design: i.e., partnerships between emergency service agencies and vehicle manufacturers are formed to co-design and develop net-zero emission operational vehicles. For example, the Australian Capital Territory Emergency Services Agency has partnered with Volvo Group Australia to develop zero-emission emergency service vehicles.
- Setting ambitious emission reduction targets: i.e., authorities set ambitious targets to reduce emissions from the transportation sector. The EU has proposed more stringent CO_2 emission targets for new heavy-duty vehicles, aiming for significant reductions by 2040. The United Kingdom has also set a target to achieve net-zero emissions by 2050 and plans to ban the sale of new diesel and petrol cars and vans from 2030.
- Monitoring and reporting: i.e., authorities establish monitoring systems to track CO_2 emissions from heavy-duty vehicles. The European Environment Agency monitors emissions from heavy-duty vehicles in the EU, and EU member states and manufacturers are required to report data related to these vehicles.
- Idling reduction technology: Fire and emergency service vehicles often spend considerable time idling, contributing to emissions and fuel consumption. Adding auxiliary power units (APUs) can help reduce idling by providing an alternative power source for heating, air conditioning, and electricity while the vehicle is parked. APUs can significantly reduce fuel consumption and emissions during idle periods. However, this technology adds additional weight to vehicles. In the case of Fire and Emergency service vehicles, that are already close to weight limits on New Zealand roads, idle reduction technology may need to be partnered with light-weighting modifications.
- Improved incident responses and reduced unwanted callouts: i.e., authorities focus on improving incident response processes to minimise unnecessary callouts and false alarms. Unwanted callouts result in increased fuel consumption and emissions. By reducing these incidents through better systems and technologies, authorities can decrease emissions associated with unnecessary vehicle deployments.

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