Vehicle refuelling: a neglected emission source

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1 Introduction

Air quality in Sydney has improved since the 1980's as a result of strategies to reduce emissions from industrial, domestic and mobile sources. These strategies have targeted the most substantial and cost effective air pollution emission reductions available and included, for instance, banning back yard burning, introducing new industrial emission limits and the control of petrol vapour emissions when a road tanker delivers fuel to a service station.

Further improvements in regional air quality require more targeted actions that can address a larger number of smaller and lower intensity emission sources. Individually these sources may only make a small contribution to air pollution, however in aggregate they represent a significant portion of the air pollution in Sydney.

Notwithstanding the introduction of more stringent emission controls on motor vehicles, motor vehicles remain the single most significant source of urban air pollution in Sydney. As Sydney continues to grow new strategies are needed to continue to reduce emissions from motor vehicles, in addition to other source sectors.

The refuelling of motor vehicles warrants further investigation to inform future decision-making to address regional and local air quality and amenity issues, given the:

- significance of the emissions associated with the refuelling of motor vehicles;
- health effects of regional ozone formation;
- local health effects of VOC emissions;
- availability of technology to reduce refuelling emission by up to 95%; and
- successful uptake of this technology around the world.

2 Ozone formation in Sydney

In hot sunny conditions and in the presence of nitrogen oxides petrol vapours react to form ground level ozone, the principal component of photochemical smog.

Even though there is considerable year-to-year variation of ozone levels, Sydney experiences high ozone levels in summer months and faces long-term challenges in meeting the current national ozone standards. The high ozone levels in Sydney are a function of the intensity of emissions and the meteorology and geography of the region.

All Australian jurisdictions have adopted a one-hour ozone standard of 0.10 parts per million (ppm) and a four-hour ozone standard of 0.08 ppm to be achieved by 2008 (EPHC 1998).

The Sydney region currently exceeds the one and four-hour national standards each summer. From 1994 to 2004 the national one-hour ozone standard was exceeded on average 10 days per year, whilst the national four-hour ozone standard was exceeded on average 13 days per year. In 2004 the national one-hour standard was exceeded on 15 days, whilst the four-hour standard was exceeded on 16 days. See Figures 1 and 2.

Illawarra also exceeds national ozone standards but to a lesser extent than Sydney. The Lower Hunter region rarely exceeds national ozone standards.

The challenge of meeting the ozone standards is compounded by Sydney's forecast growth in population from 4.2 million in 2005 to 5.3 million by 2031. Additionally, a potential impact of global warming is the exacerbation of ozone formation, making national standards more difficult to achieve.

Consequently, continued reductions in VOC and NOx emissions are required. It is estimated that VOC emission reductions of around 30,000 tonnes per year, over and above business as usual reductions, will be needed for Sydney to achieve the current national ozone standards.

Figure 1: Exceedences of the one-hour ozone standard 1980 to 2004

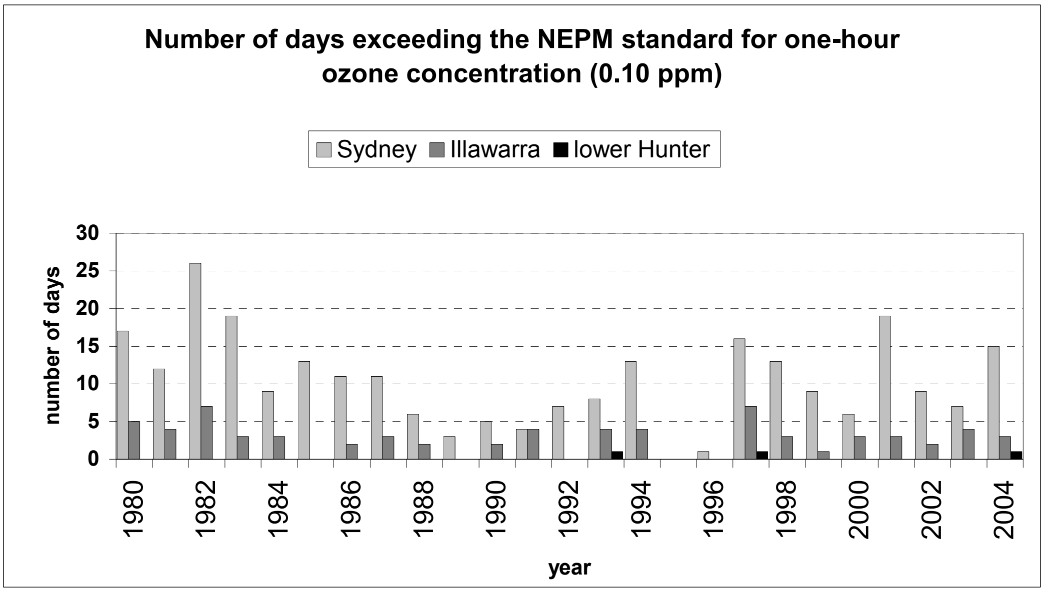
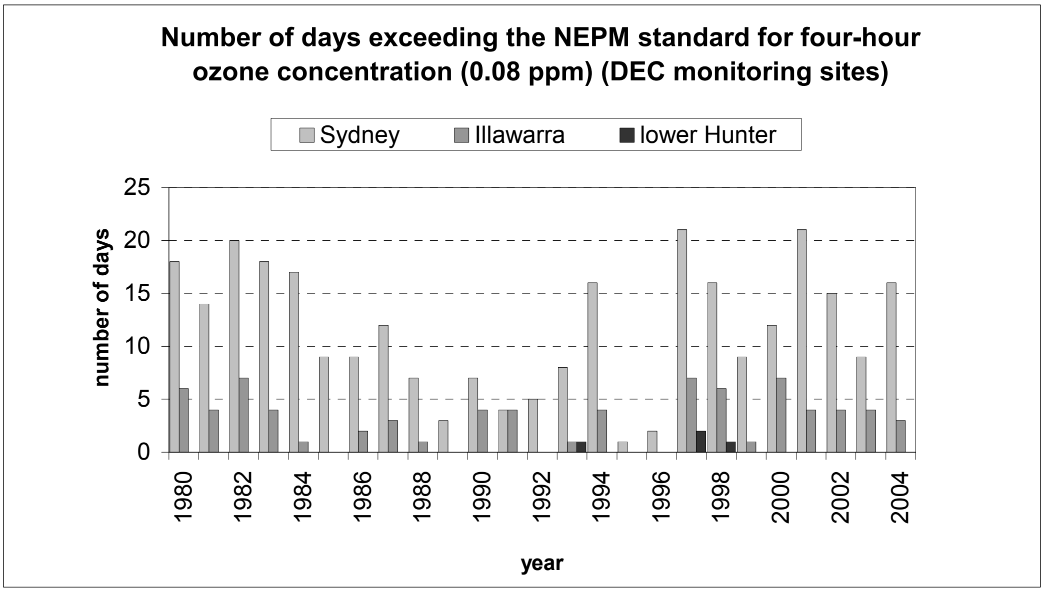


Figure 2: Exceedences of the four-hour ozone standard 1980 to 2004



3 VOC emissions from passenger vehicles

Australian emission inventories identify motor vehicle emissions as those that are directly associated with a vehicles' operation. Two types of emissions are generally accounted, namely exhaust and evaporative emissions. Evaporative emissions include both non-operational and running emission losses.

Volatile organic compounds are vented from a vehicle's fuel tank when refuelling takes place at a service station. However, Australian emission inventories attribute vehicle refuelling emissions to the commercial sector, as emissions emanating from a service station.

Whilst the inventory attribution of refuelling emissions may have a bearing on the implementation of the control technologies, for instance whether emissions are controlled in-vehicle or at the petrol pump, another consequence has been that refuelling emissions generally receive little attention as operational vehicle emissions.

This is not the case in the United States where refuelling emissions are classified as a mobile source emission and national rules require the fitment of technology to vehicles and service stations to control refuelling emissions.

Vehicle refuelling emissions have historically been small relative to exhaust or evaporative emissions. However, as vehicle emission controls are progressively tightened and fuel use increases, refuelling emissions represent a more significant and still growing source of VOC emissions.

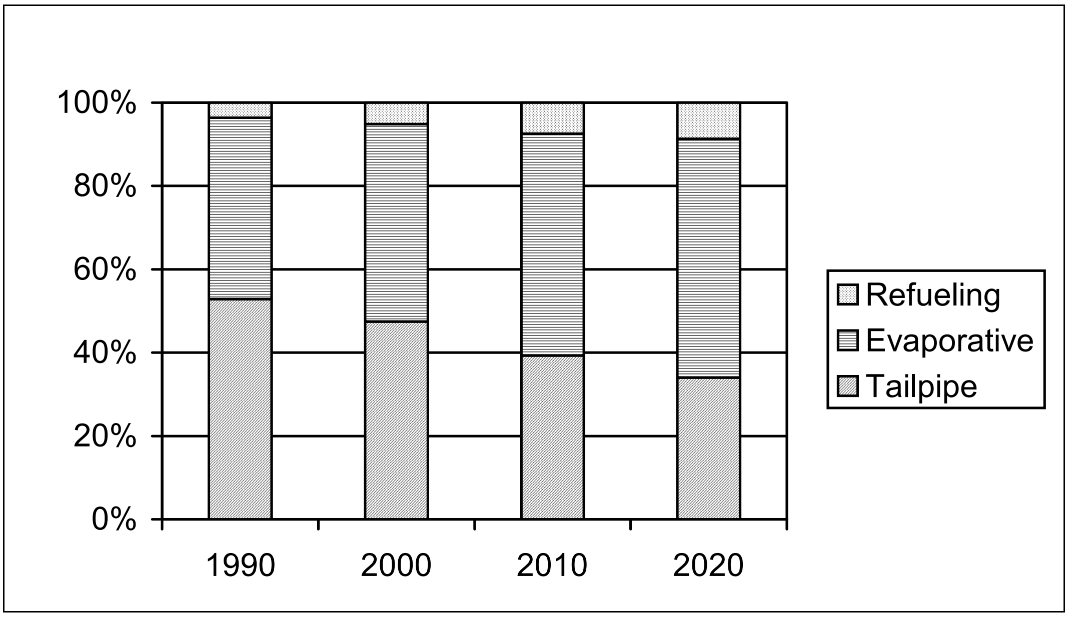
Data presented in the Bureau of Transport and Regional Economics' 2003 motor vehicle emission inventory estimates the inclusion of all VOC emissions attributable to vehicle refuelling would increase the estimated VOC total by 10 to 15% (BTRE 2003b).

4 Significance of refuelling emissions

In Sydney, refuelling emissions currently accounts for around 5,500 tonnes of VOC emissions per year, or about 3% of all anthropogenic VOC emissions.

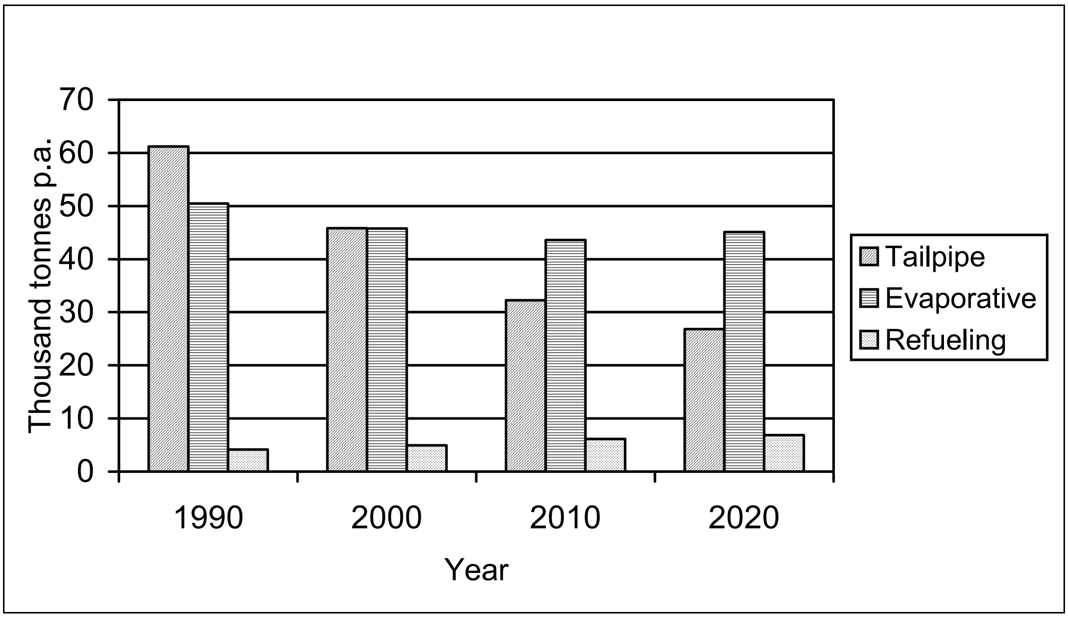
Exhaust emissions presently account for about 42% of all passenger vehicles VOC emissions. Evaporative emissions account for about 51%, and refuelling emissions account for about 7% of passenger vehicle VOC emissions. See Figure 3.

Figure 3: Source attribution of VOC emission from passenger vehicles in Sydney



However, it is estimated that total VOC emissions from passenger vehicles will decline by about 32% from 1990 to 2020 due to a tightening of vehicle emission standards. Exhaust emissions are projected to decline by about 56%, evaporative emissions are projected to decline by 10% and refuelling emissions will increase by 64%, from a low base, commensurate with growth in fuel usage at a rate of about 1.5 % per year (BTRE 2003b). See Figure 4.

Figure 4: VOC emissions from passenger vehicles in Sydney



Petrol vehicles contribute around 40% all anthropogenic VOC emissions in the Sydney air shed. This compares with emissions from industry sources contributing 10%, domestic emissions 40% and commercial sources 7.5%.

5 Health effects of refuelling emissions

Petrol vapour consists of a mixture of volatile organic compounds, many of which are both toxic air pollutants and contribute to the formation of ground level ozone, the principal component of photochemical smog.

Petrol evaporates inside a vehicle's fuel tank to fill the empty space above the fuel. As a vehicle is refuelled, the petrol vapours are pushed out of the tank by the incoming fuel and, unless captured, escape into the atmosphere out the top of the vehicle's fuel filler pipe. Some of the organic compounds are visible as a shimmery haze.

5.1 Ozone

Ozone is a highly irritating gaseous air pollutant, and exposure to concentrations found in Sydney can be harmful to people's health. Increases in levels of ozone have been associated with increased hospitalisations for respiratory diseases and mortality. Exposure to high concentrations of ozone may cause slight irritation to the eyes and nose. Very high levels of exposure over several hours can cause damage to the nasal airway lining and inflammatory reactions (Morgan et al 1998, WHO 2003).

Repeated exposure to ozone can make people more susceptible to respiratory infection, result in lung inflammation, and aggravate pre-existing respiratory diseases such as asthma.

Children active outdoors during the summer when ozone levels are at their highest are particularly at risk of experiencing such effects. Other at-risk groups include adults who are active outdoors (e.g. outdoor workers), and individuals with pre-existing respiratory disease such as asthma and chronic obstructive lung disease (NSW Health 2005).

During periods of high concentrations of ozone, hospital admissions for asthma and other respiratory conditions increase. The California EPA estimates that all cause mortality increases by 3% for every 0.04ppm increase in exposure to ozone (California EPA 2005b).

Ozone is known to have detrimental effects on plants and crop yields and has a damaging effect on materials including natural and synthetic rubber, surface coatings such as paints and varnishes and textiles. In combination with other pollutants it has been shown to damage metals and stone.

5.2 Neighbourhood and personal impacts of refuelling emissions

Volatile organic compounds in petrol vapour can also have direct health and amenity impacts within the vicinity of refuelling vehicles at a service station.

Benzene, for example, is a genotoxic human carcinogen and there is no absolutely safe level for benzene in ambient air. Long-term exposure to benzene has been linked with increased incidence of leukaemia.

In Australia, petrol contains a maximum of 1% benzene. Some other odorous and toxic air pollutants in petrol vapour include xylenes and toluene. As part of the Air Toxics National Environment Protection Measure all Australian jurisdictions have adopted annual health protective monitoring investigation levels for benzene, xylenes and toluene (EPHC 2004).

The emission of VOCs from vehicle refuelling at service station is related to the volume of fuel dispensed, and human exposure is related to a person's proximity to the emission source. Accordingly, the larger the service station and the closer a person is working or living to the vicinity of the forecourt, the higher the likelihood of encountering high concentrations of VOCs in ambient air.

Historically, service stations have been located close to residential and retail areas. In the middle and inner ring areas of Sydney it is not uncommon to find smaller service stations located adjacent to residential areas and public facilities. Higher volume service stations, are usually situated on major arterial roads, but can also be found adjacent to residential areas and public facilities.

The California EPA notes that benzene emissions from high throughput petrol stations may result in additional health risks above that of regional background levels. The Agency publishes a guide for evaluating and reducing air pollution impacts, and provides recommended separation distances for different sized service stations to avoid the siting of sensitive land uses (i.e. schools, homes or workplaces) too close to petrol stations (California EPA 2005a).

A recent Australian study has found that vehicle refuelling makes the most significant contribution to the population's exposure to benzene, accounting for 85% of the cohort's summertime exposure to benzene. The study also found that vehicle refuelling was associated with exposure to benzene concentrations of up to 3 orders of magnitude higher than typical ambient concentrations (Horton, Murray, Bulsara, Hinwood and Farrar 2006).

A range of other studies have also considered VOC emissions at service stations and the effectiveness of vapour control technology in reducing concentrations adjacent to service station forecourts and petrol dispensers. Papers include those by Uren (1996), Muir (2002), Gonzalez-Flesca, Vardoulakis and Cicolella (2002) and Cruze-Nunez, Hernandez-Solis and Ruiz-Suarez (2003).

6 Technology to control refuelling emissions

When refuelling at a service station, the primary source of VOC emissions are the vapours which are purged from a vehicle's petrol tank as the tank is filled. The volume of vapours emitted is equal to the volume of petrol dispensed into the petrol tank. Emissions also occur from spillage and drips from the filling nozzle however these are relatively minor compared with the volume of tank emissions.

There are two distinct technologies which have been developed to control refuelling emissions. One technology is integrated with the petrol pump and is known as Stage 2 Vapour Recovery (VR2). The other technology is fitted to a vehicle's fuel system and is known as Onboard Refuelling Vapour Recovery.

6.1 Stage 2 Vapour Recovery

Stage 2 Vapour Recovery (VR2) was developed in the early 1970's to capture petrol vapours that are vented into the atmosphere when a motor vehicle refuels.

VR2 systems generally use a pump to draw the vapour from the vehicle's petrol tank to the underground storage tank, ensuring that no vapour escapes from the space around the nozzle. This pumping system is calibrated to capture at least 95% of petrol vapours.

Variations on this technology exist, including a new system that converts the petrol vapour drawn from the vehicle back to liquid petrol. This system converts petrol vapour to saleable liquid petrol, at a rate of 1,000 litres of vapour to 1 litre of petrol. These new systems are reported to be considerably more cost effective than traditional VR2 systems (DEFRA 2005).

6.1.1 International uptake of VR2

The significance of air pollution associated with refuelling emissions was first recognised by the Californian Air Resources Board in the early 1970's. Over the next 20 years VR2 was mandated at a national level in Europe and the United States.

Since that time VR2 has become widespread across Europe, the United States and parts of Asia. All schemes to implement VR2 have been driven by the need to improve local and regional air quality. Many schemes, especially in densely populated areas, were initiated to improve local amenity and reduce exposure to air toxics.

United States
VR2 was first developed in California and mandated in San Diego County in 1972. Orange and Bay Area Counties followed soon after, introducing VR2 in 1973. 1990 amendments to the US Clean Air Act mandated VR2 in all ozone non-attainment areas from 1993. VR2 is currently in place in urban areas in 27 US states, and six states statewide.

Europe
VR2 is required in many areas of Europe, including Sweden, Switzerland, Germany, Denmark, Holland, Luxembourg, Austria, the Netherlands, Italy, France, Spain, Hungary, the Czech Republic and Slovenia. European countries have taken individual approaches to implementing VR2 and have not relied on any EU-wide model for implementation. The UK Government is currently proposing the implementation of VR2 across England, Scotland and Wales (DEFRA 2005).

Taiwan
Taiwan prescribed VR2 in 1997. In addition to improving regional air quality a significant aim of the program has been to resolve local amenity issues relating to exposure to VOC emissions in the immediate vicinity of service stations (Taiwan Environmental Protection Administration 2006).

A summary of a range of international schemes to implement VR2 is shown in Table 1 (Del Manso 2005 and DEFRA 2002).

Table 1: Summary of international schemes to implement VR2

State	Entry into Force	Timescale Years	Threshold (Litres per year)	% with VR2 (2004)
Austria	1993	5 years	None	99%
Czech Rep	Data unavailable			52%
Denmark	1995	5 years	<0.5 million	>90%
France	2001	18 months	<3 million	45%
Germany	1993	5 years	<1 million	100%
Hungary	Data unavailable			71%
Italy	1996	4 years	None	100%
Luxembourg	1992	4 years	<0.5 million	98%
Netherlands	1996	3 years	<0.5 million	100%
Sweden	1992	3 years	<0.1 million	90%
Switzerland	Data unavailable			100%
US (Clean Air Act)	1993	3 years	<0.5 million	Data unavailable
Mexico	Data unavailable			>90%
Taiwan	1997 & 2005	2006	None	>88%
Hong Kong	2005	3 years	None	NA
China (Beijing)	2004	Data unavailable		
UK **(proposed)**	2006	5 years	<3.5 million	3%

6.2 Onboard Refuelling Vapour Recovery (ORVR)

Onboard Refuelling Vapour Recovery (ORVR) is an in-vehicle emission control system that offers an alternative approach to VR2 for capturing refuelling emissions.

ORVR requires that a vehicle's tank and filling pipe be designed so that when the vehicle is refuelled, petrol vapours in the petrol tank are directed to a large activated carbon canister, which adsorbs the vapour, preventing the vapours venting out the filling pipe to the atmosphere. When in operation, the engine draws upon the petrol vapours from the carbon canister to be used as fuel.

In addition to requiring VR2 in ozone non-attainment areas the US Clean Air Act prescribes ORVR as a nation-wide program for the control of refuelling emissions. The US EPA intends to revise the VR2 requirements after ORVR equipped vehicles are in widespread use, which is expected to be some time after 2010.

Whilst ORVR is prescribed in the United States it is not prescribed under United Nations Economic Commission for Europe (UN ECE) vehicle standards and consequently is not required on vehicles sold into the European market. This has implications for Australia, as Australian vehicle design rules are tied to UN ECE vehicle standards.

Australia is a signatory to the UN ECE *1958 Agreement on Technical Prescriptions for Vehicles and their Component Parts*. The aim of the Agreement is to harmonise the Australian vehicle design rules wherever possible with the technical requirements of the UN ECE regulations, and to accept ECE compliant vehicles into our market. This harmonisation is important to fulfil WTO and APEC commitments and recognises Australia's small vehicle market in which about two thirds of new vehicles are imported.

The adoption of ORVR to control refuelling emissions in Australia would require amendments to Australian vehicle design rules and would take time and resources to achieve. ORVR is not prescribed under UN ECE regulations. There are also uncertainties relating to the legality of such a move under WTO regulation.

Significant emission abatement would not be realised until new national vehicle standards had been developed; until sufficient lead-time had been given to vehicle manufacturers; and a sufficient period for fleet turnover to taken place. In all, a 20 to 25 year time frame might be needed to achieve emission abatement comparable to that possible by implementing VR2.

7 Trial of refuelling vapour recovery equipment in Sydney

In 2004, the DEC in conjunction with Blacktown and Gosford City Councils trialled VR2 technology to evaluate the equipment under local conditions and as an option to reduce VOC emissions from service stations.

Four VR2 systems were installed at three council depots. All systems installed were tested for their operating efficiency three times during the trial. Monthly reporting by councils and two user surveys assisted DEC's evaluation of the trial.

The trial demonstrated VR2 equipment worked successfully and reliably under local conditions yielding emission reductions of over 1,500 kg of volatile organic compounds per year for the three council depots.

The user surveys indicated that the VR2 equipment was well received by users, especially when the environmental benefits were known. The overwhelming majority of respondents found the equipment easy to use compared to a retail service station pumps, and detected no or noticeably less odour at the VR2 equipped pumps compared to retail service stations.

8 Cost of implementing VR2

The cost of implementing VR2 is estimated to range between $15,000 and $290,000 per service station, depending on the size of the service stations and the timing of refurbishment (McLennan Magasanik Associates 2006). This includes the equipment's capital and installation costs, business disruption costs during refurbishment, and ongoing operating and compliance costs.

The actual additional costs to the service station of installing VR2 are dependent on the timing of the installation. If the installation of the VR2 equipment can be carried out at the same time as a major station refurbishment the incremental costs are significantly reduced.

Early adoption of VR2 would result in greater VOC reductions. This would need to be balanced against the need to allow industry sufficient time to employ the technology as cost effectively as possible. Consideration would also need to be given to mitigating the higher relative costs for smaller service stations to employ VR2, for example, by allowing them annual throughput-based exemptions or differentiated timeframes for compliance. This however would need to be weighed up against competitive neutrality principles.

9 Cost of VR2 on a cent per litre basis

The cost of implementing VR2 on a cent per litre basis was estimated for Sydney by assessing the cost of the measure on a net present value basis over a 15-year timeframe, which relates to the replacement rate of service station forecourts. This total cost was assigned to the total volume of petrol sales over the same period resulting in a levelised additional cost of petrol.

The highest additional cost results from the scenario where no stations are excluded from any VR2 requirement and a minimal timeframe for compliance is prescribed, for instance about 3 years. However, as the compliance timeframe is extended and opportunities for installing VR2 as cost effectively as possible increases, the cost per litre reduces significantly.

For instance it is estimated that requiring VR2 be installed at all service stations in Sydney would result in costs per unit throughput of less than ¼ of a cent per litre, ranging from 0.20 cents to 0.05 cents per litre over compliance dates from 2010 to 2020.

10 Conclusions

Emissions associated with the refuelling of motor vehicles are a significant and growing source of VOCs in Sydney. Whilst there has been a focus on exhaust and evaporative emissions from motor vehicles, vehicle refuelling emissions remain uncontrolled in Australia. However, this is not the case in the US, Europe and parts of Asia.

Ozone is an air pollutant that harms human health, vegetation and building materials. VOC emissions from service stations may also have adverse health impacts on people living or working in areas adjacent to vehicle refuelling.

Substantive reductions of both VOCs and oxides of nitrogen, the precursors to ozone formation, are required for Sydney to achieve national air quality standards.

Vapour recovery at the petrol pump is one of the biggest single actions available to reduce VOCs and deliver both regional and local air quality benefits and is considered best management practice for the control of petrol vapour at service stations.

States across Australia and the Commonwealth Government will need to consider these issues in managing air quality in the future.

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