

*Calculating, reporting and reducing greenhouse
emissions in the Australian trucking industry*

a case study of Rocky's Own Transport Company

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List of abbreviations

AGO	Australian Greenhouse Office
CO	carbon oxide
CO ₂	carbon dioxide
CNG	compressed natural gas
COPERT	computer program to calculate emissions from road traffic
CORINAIR	(European) coordination of information on air emissions
CRT	Continuously Regenerating Technology
CVS	constant volume sampler
DCC	Department of Climate Change (2009 and prior)
DCCEE	Department of Climate Change & Energy Efficiency (2010)
DE	diesel-ethanol blend - not in text - delete??
DME	dimethyl ether (a diesel fuel alternative)
DPF	diesel particulate filter(s)
EGR	exhaust gas recirculation device
ETS	emissions trading scheme
GJ/m ³	Gigajoules per cubic metre
GPS	global positioning system (satellite tracking)
HC	hydrocarbons
HDDE	heavy-duty diesel engine
hp-hr	horsepower-hour
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
kg CO ₂ -e	kilograms of carbon dioxide equivalents
L	litre
LNG	liquid natural gas
LNT	lean NO _x trap
LPG	liquefied petroleum natural gas
Mt	million tonnes
NGERS	(Australian) National Greenhouse Emissions Reporting Scheme
NO _x	oxides of nitrogen / nitrous oxide
NTA	National Transport Authority
NGA	National Greenhouse Accounts
O ₂	oxygen
OSCAR	Online System for Comprehensive Activity Reporting
PEMS	portable emissions measurement system
PM	particulate matter
PPM	parts per million
ROTC	(the) Rocky's Own Transport Company
SCR	selective catalytic reduction
ULS	ultra-low sulphur (diesel)
VOC	volatile organic compounds

Executive summary

The transport sector is a key contributor to the global greenhouse gas emissions burden. However, understanding and accurately calculating emissions from transport activities is challenging due to the size and complexity of the sector. For example, the road freight industry alone comprises numerous different vehicle classes, trip types, driving and traffic situations, each of which can affect emissions across a range of pollutant categories such as gases, smoke and particulates.

In Australia, accurate reporting of emissions in the road transport sector is essential for several reasons. The first is to ensure that accurate data are inputted into the national greenhouse accounts, since these may be used to inform low-carbon policy development in the sector. The second is to ensure that those corporations who are obligated to report emissions under NGERS (the National Greenhouse Emissions Reporting Scheme) are able to have confidence that these data adequately reflect their contribution to greenhouse gas pollution. The third and most compelling reason is that a detailed understanding of the key influences on emissions from road freight fleets will help identify opportunities for emissions reductions within the sector.

This research project was undertaken at the request of the Rocky's Own Transport Company (ROTC), a road-freight company headquartered in central Queensland. The project focussed on assisting ROTC to better understand, calculate, report and reduce their scope one emissions under NGERS.

The report is arranged into six sections:

1. background and aims;
2. a review of ROTC's operations, including profiling of the fleet; an analysis of fuel consumption patterns and other information relevant to emissions calculations; and trialling of the emissions outcomes (i.e., the reportable quantities) using different NGERS reporting options;
3. a review of the published information currently available with regard to emissions studies (particularly those with application to heavy-duty diesel engines and Australian settings);
4. information on how emissions can be reduced, including via regulatory and policy trends, new technologies for measuring emissions, and the latest advances in engine development (such as after-treatment options) and diesel fuel blends and alternatives;
5. a summary of the existing research gaps and areas for priority study; and
6. recommendations to enable ROTC (as well as Australian road freight companies in general) to better understand and reduce their greenhouse gas emissions.

Key findings: profiling ROTC operations and emissions

Company profile

The Rocky's Own Transport Company (ROTC) is a road freight business headquartered in central Queensland with depots located nation-wide. ROTC operates a fleet of 117 trucks and is engaged in explosives and dangerous goods transport, as well as a mixture of other freight categories. A conservative estimate would put the average distance travelled by each of ROTC's assets at 1,000km per day. The corporation currently consumes between 7-8 million litres of diesel annually; this is predicted to exceed 10 million litres by approximately 2015. Around 60% of fuel product is moved through the company's bulk tanks at the depots; the remaining fuel is sourced from commercial outlets, and almost half of this volume is purchased in central Queensland.

ROTC implements a number of proactive strategies that assist them to be efficient, cost-effective and lower-carbon in their operations. These include the use of high-performance diesel in preference to the standard product, an intensive asset management programme which minimises ageing within the fleet, and a focus on good driving behaviour. This combination of initiatives makes it likely for ROTC's operations to be more carbon-efficient than others in the Australian road transport sector. For this reason, as well as the need to reduce the future costs associated with a carbon price, ROTC is particularly interested in the way(s) to most accurately report greenhouse gas emissions under the National Greenhouse and Energy Reporting Scheme (NGERS).

ROTC already holds an extensive dataset on the performance of their trucks, as Global Positioning System (GPS) devices are fitted to all fleet assets. This includes information that could be used to link factors such as journey type and driving behaviour with fuel consumption. Unfortunately, the system is currently unable to provide information about emissions, though this may later become available pending technological advances and/or further development of the software. Nevertheless, the existing data are still valuable, particularly where they can be combined with fuel consumption records: this will allow ROTC to identify those journeys (e.g., different permutations of drivers, route, vehicle, load and climate) which are most costly in terms of diesel usage, and are therefore the most emissions-intensive.

Options for emissions reporting

ROTC has been identified as a corporation that is required to report emissions under NGERS. Currently, ROTC fulfils this obligation using the default 'Method 1' option. This methodology results in a total of 2,692 tonnes CO₂-equivalent emissions for every one million litres of diesel fuel used. The calculations under Method 1 are relatively straightforward, and there are few ways in which ROTC can adjust the worksheet to more accurately reflect their operations. On the other hand, information from ROTC and its fuel supplier shows that there is a strong case for using an alternative reporting option, such as NGERS Method 2. This involves a closer inspection of the quantities of fuel purchased (including variability and consumption patterns across different supply regions and supply dates) and obtaining fuel specifications data from the manufacturer to ascertain the energy, density and carbon content of different batches. Where these data are compliant with the relevant sampling and testing standards, the information can then be used to adjust the default emissions factors. In turn, this generates new emissions values based on the specific nature of the fuel as consumed by ROTC.

Modelling based on one million litres' annual consumption of standard diesel product shows that the use of Method 2 can result in reported emissions savings of between 1.43 - 3.03%, equal to approximately 39 - 81 tonnes CO₂-equivalent annually, when compared with the default reporting option. At a yearly consumption of 10 million litres and a carbon price of \$60/tonne¹, this represents an annual saving of up to \$48,600. The modelling also highlighted variability amongst the fuel characteristics of different supply regions and supply dates, which resulted in emissions differences of 0.69% and 1.30%, respectively. Unfortunately, it was not possible to get comparable data from major Australian fuel manufacturers other than the company supplying ROTC. However, as all fuels available for sale in Australia must fall within a minimum-to-maximum density range, further modelling was undertaken on the worse-case (maximum density) and best-case (minimum density) fuels possible under the Australian standard. Under Method 2, this showed a saving of 0.73% or 4.2%, respectively, when compared with the NGERs default option.

The NGERs Method 3 is similar to that of Method 2, except that Australian standards are used for sampling. It is not clear how Method 3 can offer an additional benefit compared with Method 2 in terms of more accurately reporting emissions from ROTC's operations.

Method 4 is unique amongst the NGERs reporting options in that it is based on direct monitoring of actual emissions, rather than estimates created from a combination of fuel consumption and emissions factors. This is important because the emissions factors that are currently used in the National Greenhouse Accounts appear to be largely based on European case studies, which might poorly reflect Australian trucking conditions. For ROTC, the advantage of Method 4 is therefore the ability to accurately record emissions that properly reflect the largely rural and regional Australian context in which the company operates. However, the Method 4 option requires robust and comprehensive data on emissions, and these are not currently available for ROTC. The necessary information could be provided by dynamometer studies, but these are complex, time consuming and expensive. More attractive options may include the use of constant-volume sampling (CVS) and/or portable emissions measurement devices (PEMS), though both these are also likely to represent a considerable investment in both time and capital.

In summary, the Method 2 reporting option appears to be the most favourable method for ROTC to reduce their reportable emissions in the short term. Correspondence received from the Department of Climate Change and Energy Efficiency (DCCEE) indicated that the Method 2 option should be appropriate for ROTC. Method 2 will also assist ROTC to better understand – and therefore potentially reduce – their greenhouse emissions burden. For example, this could include the company learning more about carbon-intensive driving behaviours and journey types, with a view to reducing or eliminating them in future. Transitioning from the default (Method 1) to Method 2 option would require ROTC to more closely investigate their fuel consumption records, and marry these with the fuel specifications data available from their manufacturer on a quarterly basis. A template spreadsheet has been developed for this purpose and is provided as an attachment to this report. However, the Method 2 reporting process could also be further streamlined by identifying and addressing the inconsistencies between the reporting styles used in-house, by the fuel supplier, and by NGERs.

¹ A price on carbon is yet to be established in Australia, but ROTC are under financial advice to use a \$60/tonne figure in business planning.

In the longer term, ROTC may wish to consider the value of installing direct emissions measurement devices (e.g., PEMS) onto ‘representative’ trucks in their fleet, and to then consider reporting under Method 4. This decision can be informed by the existing literature on trucking emissions. For example, where published data can support the idea that ROTC’s operations are likely to result in substantially less carbon emissions, then the trade-offs between the purchase cost of direct measurement technology, versus the possible savings under an emission trading scheme, will become more apparent. For this reason, a summary of the existing information on the factors influencing emissions from the diesel trucking industry is provided in section two of this report.

Key findings: review of emissions literature

The second section of this report provides an introduction to the current research being conducted on emissions testing, calculations and reporting for the road transport sector. This information is critical in helping to understand (and evaluate) the calculation of emissions factors in the Australian road transport industry. Wherever possible, the review was based on recently-published and peer-reviewed articles; these showed that this research field is complex, with an extensive set of studies already available. It was outside the scope of this project to comprehensively review all aspects of emissions work. However, the review has shown that knowledge on the emissions generated specifically by heavy-duty diesel vehicles is far from complete, despite a stronger focus on this class in recent years.

Significant progress has been made in emissions modelling for road transport. The two main approaches for emissions calculations are the macroscale (or bottom-up) and microscale (or top-down) options. Currently, the CORINAIR-COPERT approach to emissions factors and reporting is the preferred model used throughout Europe; it also provides the basis for estimates calculated by the Intergovernmental Panel on Climate Change (IPCC) (Zachariadis and Samaras, 1999). Variations and revisions of this methodology have also been adopted in the US and a number of other nations (including in the Australian National Greenhouse Accounts).

A number of approaches exist to observe and calculate emissions from transport vehicles. One of the most commonly-used methods is laboratory-based vehicle testing using dynamometers. However, this is difficult for heavy-duty diesel engines (HDDEs) due to weight and cost restrictions, so dynamometers are typically restricted to regulatory compliance-checking for this vehicle class. Remote sensing using an infrared or ultraviolet spectroscopy unit mounted on a roadway is also useful for measuring emissions, but can only provide instantaneous data. The technique is therefore often limited to high-volume traffic scanning to detect high-emitting vehicles. Thirdly, on-board diagnostic systems have been developed over time and now provide not only a range of vehicle performance indicators, but also baseline data about emissions. Ongoing development of these systems (including combining them with direct emissions sampling devices) is likely to provide significant benefits to the understanding of emissions from HDDEs. Vehicle emissions can also be estimated from secondary sources such as inventory data, but these must be interpreted carefully to avoid unreliable figures.

For HDDEs specifically, the key influences on emissions include factors such as the types and properties of fuels and oils; vehicle and engine characteristics (e.g., class and after-treatment technologies); vehicle maintenance and age; the trip type(s); driver behaviour; and driving scenarios (including traffic, terrain and climatic conditions). Although most of these parameters are already

incorporated into the CORINAIR-COPERT emissions methodology, specific information on the role of these in influencing emissions from heavy-duty diesel vehicles is scant. Furthermore, the Australian trucking environment features vastly different journeys types, climate, engines and fuels, compared with the scenarios used to generate the European-based CORINAIR-COPERT and/or IPCC methodologies. Thus, there is a strong case for re-examining how well the existing methodologies can be applied in Australia. However, this continues to be frustrated by the lack of information about the influences on emissions from HDDEs in general, as well as a lack of data specific for Australian operations.

Key findings: reducing carbon emission from road transport

Emissions from the global road transport industry continue to rise, largely because growth in the sector (the number of vehicles and the distance travelled by them) is outstripping the efficiency gains provided by technological advancements, fuel improvements and alternatives, and behavioural changes.

The introduction of increasingly more-stringent emissions regulations (e.g. EURO V and VI) will continue to drive a strong focus on emissions measurement and emissions reductions. The new tools and technologies for the road transport sector include those for mapping emissions, direct sampling of emissions during real-world driving, and on-board diagnostics to assist in achieving best vehicle performance. Another key area is engine development for emissions control. The 'next wave' of engine evolution is likely to involve thoroughly advanced engines with electronic engine management, two-stage turbocharging, high peak cylinder pressures and high pressure common-rail fuel injection capability, as well as ongoing developments in Exhaust Gas Recirculation (EGR), Selective Catalytic Reduction (SCR) and Diesel Particulate Filter (DPF) devices. Each of these have advantages and disadvantages, and result in reductions in different kinds of emissions categories (e.g., NO_x, particulates). In fact, most new HDDE technologies appear to offer a trade-off between emissions savings on the one hand, but emissions increases (in other categories), penalties to fuel economy and engine durability and high cost barriers, on the other. Hence so careful consideration must be made before adopting a particular technology for emissions reductions. The appropriateness of each technology must be considered with respect to cost, availability, and durability; performance (with respect to emissions); and appropriateness for the transport application in the Australian operating environment (e.g., climate, trip type).

The development of alternative fuels (including diesel blends) is a further way by which emissions from HDDE activities can be reduced. Most current research effort is being directed toward the development of biodiesels, alcohol-based blends and gases (such as CNG or LNG). Each of these can result in substantial reductions in greenhouse emissions (e.g., up to 95%), so their potential use by trucking companies should be explored further. However, in ROTC's case, this is only possible notwithstanding problems with the explosives carrying code and issues with engine warranties. Other remaining options for emissions reduction include optimising trips, routes and loads, and driver education programmes.

Research gaps

The calculation of accurate emissions factors is dependent on the rigorous collection of a range of information about the performance of engines, after-treatment technologies, fuel blends and driving conditions. A large body of data is already available. However, most studies are not specific to HDDEs, and Australian work is almost non-existent. Furthermore, as the Euro regulations and/or the Australian Design Standards become progressively more stringent, a wider and more sophisticated array of technologies will come to the market. This represents a considerable testing and reporting burden, particularly given that accurate emissions factors are not yet available for many of the pre-existing technologies.

A number of priority research areas have been identified as important in refining the emissions factors used under the COPERT-CORINAIR, IPCC and other national methodologies. By far, the most important of these is the validation of laboratory data by collecting real-time data from vehicles in real-world driving conditions. For this reason, the ongoing development and much wider adoption of PEMS and other on-board systems and samplers is expected to feature in emissions studies into the future.

Recommendations

Clearly, it is very important for ROTC (and others) to be able accurately report their scope 1 emissions under NGERS. However, it is equally important for ROTC to continue to be proactive in reducing their emissions overall. A mix of technological, operational and behavioural changes can be used by ROTC in response to the pressures of changing emission regulations, carbon reporting and customer environmental awareness. Of these, the key activities include:

- transitioning to the NGERS Method 2 for annual emissions reporting and working with the fuel manufacturers to identify more streamlined ways of gathering the necessary data;
- finding ways to add value to the existing GPS datasets already held by ROTC;
- exploring the role of different engine technologies (after-treatment options) in further reducing emissions from the fleet;
- evaluating options for the use of diesel fuel alternatives or fuel blends; and
- considering the value of installing portable emissions measurement (or similar) devices on representative trucks to capture real-time, real-world emissions data.

These initiatives will not only help ROTC to understand and reduce both their reportable and actual emissions burden, but will also provide much-needed baseline data relating to emissions from HDDEs in Australian settings.

1 Background and aims

1.1 Study context

The global road transport industry, and heavy-duty diesel road-trucking businesses in particular, have a critically important role to play in transiting the world to a lower-carbon future (BHC, 2006). Carbon emissions from transport are increasing faster than those from any other sector worldwide (Trodahl et al., 2007), and of the total transport emissions, around 80% arise from road-based activities (Symeonidis et al., 2004). Road transport also accounts for around 50% of all NO_x emissions, 90% of all lead emissions, 30% of all volatile organic compounds and nearly all carbon monoxide in urban areas (e.g., Symeonidis et al., 2004). Within the road transport sector, heavy-duty diesel engine (HDDE) trucks are responsible for the major contributions of NO_x and sulphur compounds, as well as up to 75% of particulate matter (Symeonidis et al., 2003, Symeonidis et al., 2004). In fact, HDDEs account for a similar quantity of NO_x emissions as do passenger cars, despite there being far fewer of them worldwide (Symeonidis et al., 2004).

In Australia, the transport sector is likely to be a key area of focus for national emissions reductions. The country has vast distances that must be travelled to achieve freight deliveries, and it currently relies heavily on carbon-intensive transport modes (e.g., road compared with rail). Not surprisingly, the Australian Greenhouse Office (AGO) has acknowledged the transport sector as one of the 'strongest sources of emissions growth in Australia', with emissions increasing over 26% (or 14.2 Mt CO₂-equivalent) during the period 1990-2007 (AGO, 2009) (Figure 1). Consequently, when the national Emissions Trading Scheme (ETS) was proposed in 2009, it included the activities of the Australian transport sector. Although the Scheme was voted down by parliament, the possibility of a carbon price remains on the national agenda. If introduced, an ETS would have significant impacts on the Australian transport sector, with supply-chain effects expected to filter through to the wider business world and all Australian communities, since these are heavily dependent on road transport.



Figure 1 Trend in total emissions from the Australian transport sector, 1990-2007. Source: reproduced from the AGO (2009, p. 6).

The introduction of any Emissions Trading Scheme will require a rigorous and accurate emission reporting system to be in place. The Australian government has already developed a system for estimating emissions, documented in the National Greenhouse Accounts (NGA). For the trucking

industry, scope one emissions² are largely based on fuel consumption, which account for greater than 90% of the total energy usage of most transport companies (ATA, 2008). For example, in 2008-09, all Australian corporations with operations that emitted 125 or more kilotonnes CO₂-equivalent per year were required to participate in the National Greenhouse and Energy Reporting System (NGERS). This is roughly equivalent to 46.30 megalitres of diesel consumption; a relatively conservative figure from the perspective of many Australian road transport companies (ATA, 2008).

For the trucking industry, there are three main options under NGERS for the estimating emissions: the NGA default method, or two variations that involve collecting additional fuel specification data and adjusting the NGA emissions factors accordingly. A fourth reporting option also allows for the opportunity to monitor and report emissions directly. At present, many Australian corporations are automatically assessed under Method 1 (the default). However, given the current focus on transiting Australia to a less carbon-intensive future, more information is clearly needed for transport businesses regarding:

- how to calculate and report their carbon emissions accurately;
- what the implications of emissions are with respect to economic costs; and
- the ways in which reductions in carbon emissions can be made.

This presents a strong case for Australia's road trucking companies to consider moving away from the default methodology and to instead adopt one of the alternative NGERS reporting options. The reason for this is that the alternative options will provide additional understanding and information about the nature of carbon emissions from road transport activities and how they might be reduced. It also provides a way to test the accuracy of the default reporting option under NGERS.

1.2 *Project aims*

This project examines the key factors that are relevant to emissions calculations and reporting in the Australian road freight transport sector, using a case study from central Queensland. The key objectives are:

- to profile ROTC as an example of a typical Australian road-transport company;
- to provide worksheet modelling to illustrate the differences in reportable emissions under different NGERS reporting approaches;
- to review current scientific literature in order to identify the key influences on emissions (particularly in the context of heavy-duty diesel trucking in Australia);
- to describe how emissions may be reduced through current and future regulatory changes, emissions measurement technologies, vehicle and engine developments and diesel fuel alternatives;
- to identify existing research gaps in road-transport emissions ; and
- to describe the way(s) in which emission from HDDE trucking operations can be reduced and/or more accurately reported.

² emissions generated on-site.

2 Rocky's Own Transport company: profile, emissions and reporting options

The Rocky's Own Transport Company (ROTC) is a road freight business headquartered in central Queensland. ROTC operates depots in Central Queensland (Yarwun, Rockhampton & Biloela), south-east Queensland (Brisbane-Rocklea and Helidon) and Western Australia (Kalgoorlie). Approximately 60% of ROTC's routine business is explosives and dangerous goods carrying for the mining industry, with ROTC being one of only three Australian companies to do so. This requires special precautions and can limit the nature of the vehicle and its fuel load. The remaining operations include a number of other freight categories, including carry of refrigerated goods and military supplies.

2.1 *Fleet & engine details*

ROTC operates a fleet of 117 trucks, comprising 83 prime movers (of which 74 are Kenworth K or T series) and 34 body trucks. The average age of the fleet is 3.2 years (range 138 days - 17.5 years), if taken from the date that each asset began in-service. Each B-double carries 35 tonne, whilst the body trucks vary between 6, 8 or 12 tonne maximum. The vehicles travel fully loaded wherever possible.

All vehicles have heavy duty Cummins ISX CM871 EGR diesel engines. Full engine performance data are already available for the ISX600 signature series, including information on the expected operating temperatures, pressures and flows across different speed, power and torque scenarios (Cummins 2007). The 'EGR' suffix on this engine model indicates that a cooled Exhaust Gas Recirculation device is fitted to meet the Australian Design Rules ADR80/02 emissions standard (Cummins Cummins South Pacific, 2010). The EGR uses a small amount of exhaust gas (around 15% of emissions) and recirculates it in the cylinder. This reduces the oxygen content of the fuel mixture, which cools the combustion flame temperature and directly reduces NO_x emissions (Cummins Cummins South Pacific, 2010). More detailed information on EGR systems and their benefit in reducing emissions is provided in section 4.4.

2.2 *'Typical' journeys*

ROTC operates a wide-ranging business with a mix of explosives carrying and other freight types. A conservative estimate of the average daily distance travelled by an individual asset is 1,000km. For example, in Queensland, a regular 640km shuttle route is travelled between Rockhampton and Brisbane, with driver change over at the mid-way point (Apple Tree Creek). This route is travelled six nights each week with eight trucks at each end. Following this run, trucks at the northern end are used in an additional 700km route from Rockhampton to Yarwun, through to Blackwater or Middlemount before returning. This results in trucks reaching 1,300 – 1,350km daily. A further six assets complete a run from Yarwun to various service points in the Bowen Basin (Central Queensland), travelling 1,000 – 1,100km per day.

ROTC also conducts nation-wide freight carrying. Examples include:

- trucks travelling from Helidon (in the Lockyer Valley of south-east Queensland) to destinations around the country, including to Kalgoorlie's Granites Mine (Western Australia). This return trip of 7,200 takes 7 days; and
- milk delivery to the Northern Territory, which is a 9,400km return journey that takes 9 days.

2.3 *Asset management (maintenance and replacement)*

ROTC implements a suite of asset replacement and/or maintenance checks in order to maintain an efficient fleet. The service intervals for all assets are:

- A service (8,000 – 12,000 km);
- B service (18,000 – 22,000 km); and
- C service (90,000 – 110,000 km).

Tyres on all vehicles are changed as follows:

- Steer tyres: 60-70,000 km;
- Drive tyres: 150,000 km; and
- Trailer tyres: 250,000 km.

The warranty life of the engines is typically one million kilometres, but a mid-life warranty check occurs at approximately 500,000 km, whereby the engines are fully overhauled and the warranty is extended to 1,200,000 km. Most assets are retired from the fleet when they reach expiry of the extended warranty period (currently, between 4 – 5 years).

2.4 *Driver profiles*

All ROTC drivers must be over 25 and have a minimum of four years B-double experience. On commencement, operators receive 1 – 2 days of fatigue management driver training and an additional four days of training for dangerous goods and explosives carrying.

2.5 *Fuel use (consumption & product type)*

During 2008-09, ROTC consumed approximately 7,501,300 litres of diesel across its national operations, not including South Australia. The business has experienced steady growth in fuel consumption since 2001, and annual diesel consumption is predicted to exceed 10 million litres by 2015.

ROTC has a preference for premium diesel products, and is currently supplied with 'Ultimate' diesel from BP Fuels Australia. This is important with respect to emissions, since fuel products with different chemical properties are associated with different fuel economy, and may create different emission profiles as they are consumed (burnt). According to BP fuels, use of the 'Ultimate' fuel will produce significantly lower carbon emissions without the need for engine modifications. The expected economy gains for passenger vehicles are 1-2%; tests are ongoing for trucks but preliminary results suggest a similar figure (BP Fuels Australia, pers. comm.). Existing studies with passenger cars, sports utility models and light commercial vehicles have shown that reductions in exhaust emissions, including carbon monoxide, unburnt hydrocarbons and particulates categories, when compared with regular diesel (BP Fuels, Undated). However, it is not clear if these savings are achieved through the reduced fuel consumption, or if the fuel actually produces fewer emissions

on a litre-for-litre basis when compared with standard diesel³. The product achieves better fuel economy via the use of an additive to keep the nozzles and injectors clean, thus increasing engine performance. This additive is the main compositional difference between Ultimate and the regular product.

Ultimate fuel is generally available at specialist outlets and is supplied to the bulk tanks at ROTC depots where possible. However, there are occasions where the Ultimate product is not available to ROTC. For example, supplies of Ultimate were temporarily suspended by BP during late 2009, due to difficulties in storing and handling the formula. This was rectified in mid-2010 with the introduction of a modified formula already being used in New Zealand and China.

2.6 Fuel use (by supply region)

Differences in fuel quality and characteristics across supply regions is an important consideration in understanding fuel use and likely greenhouse emissions by the Australian road transport sector. In Australia, supply regions for fuel distribution are based on 'cloud point' (Figure 2). According to the Department of Climate Change and Energy Efficiency (DCCEE), all diesel sold around Australia is understood to be relatively homogenous with respect to energy content (DCCEE, pers. comm.). However, energy content is a key influence on emissions, and even modest differences in fuel characteristics can result in quite different emissions outputs. Consequently, when calculating emissions from road transport activities, it is useful to describe not only the total consumption and product type, but also to understand the profile of supply regions from which the fuel originates.



Figure 2 Australian supply regions for fuel distribution (based on cloud point). Source: (Standards Australia, 1998)

³ This aspect is particularly important when considering the overall ability of the Ultimate product to reduce emissions across the ROTC fleet, because the NGERS reporting worksheet is based on total volume of fuel consumption.

To conduct this exercise, ROTC's fuelling records for the 2008-09 financial year were obtained from a combination of:

- 'datafuel' reports, showing consumption of fuel from bulk tanks at Wacol, Helidon, Rocklea and Rockhampton; and
- the BP online database, which is made available to bulk customers by the manufacturer. This reflects all BP product types that are purchased with the corporate cards carried by ROTC drivers (i.e., all other fuel consumption other than the bulk tanks).

The analysis demonstrated that for 2008-09 (refer Table 1 and Table 2):

- bulk tanks constitute about 60% of the ROTC supply;
- 'Ultimate' diesel accounted for slightly more than 40% of consumption, with the ultra-low sulphur (ULS) diesel and the 10PPM G10 diesel products accounting for almost all remaining supply; and
- the Central Queensland supply region is the most heavily used, supplying almost 48% of fuel. Another quarter of supply is sourced from south-east Queensland, whilst South and Western Australia supply a further 15%. Less than 2% of fuel is sourced from other regions.

An error of approximately 10,000L was detected between the card fuel purchases by product and by supply region, but this reflects the difficulties in identifying product type and/or region on some items. A discrepancy of some 212 – 220,000 litres was also detected between the ROTC-reported consumption (for NGERs purposes) and that which was consumed via the bulk tank and corporate cards combination for the same period. However, this variation is less than 3%, and may be partly explained by ROTC not reporting the consumption from South Australia in the NGERs worksheet (this accounts for approximately 428,000 litres)⁴.

The implications of this breakdown of total fuel consumption, consumption by product type, and consumption from different supply regions, on overall greenhouse emissions from ROTC is modelled in section 2.8.

⁴ Under NGERs, ROTC only reports fuel consumed in Western Australia and Queensland, since these states are where the key Facilities are operated. The SA component of fuel use is considered immaterial.

Table 1 Consumption patterns for ROTC – by product type; 1 July 2008 to 30 June 2009.

Product	Fuel consumed (litres)	Proportion of total (%)
<i>Ultimate diesel (card purchase)</i>	8,129	
<i>Ultimate diesel (bulk tanks)^</i>	3,089,507	
Total Ultimate diesel	3,097,636	40.10
10ppm Diesel (G10)	2,654,163	34.36
<i>ULS ((card purchase)</i>	427,634	
<i>ULS (bulk tanks)^</i>	1,519,914	
Total Ultra low sulphur diesel	1,947,548	25.21
Ultimate unleaded	10,188	0.13
UMS	9,558	0.12
Unleaded with ethanol	4,110	0.05
Premium unleaded	777	0.01
Bottled gas	200	0.00
Oil	0	0.00
<i>Subtotal (Bulk tanks)</i>	4,609,421	59.68
<i>Subtotal (Card purchases)</i>	3,114,759	40.32
TOTAL	7,724,181	100.00

^ Ultimate diesel was only supplied to Rockhampton bulk tank for 2008-09.

Table 2 Consumption patterns for ROTC – by fuel supply region; 1 July 2008 to 30 June 2009.

Prefex	Region	Fuel consumed (litres) [#]	Proportion of total (%)
	<i>Central Queensland (Bulk tanks)^</i>	3,089,507	
	<i>Central Queensland</i>	705,724	
QC	Total Central Queensland	3,795,231	49.20
	<i>Queensland South (Bulk tanks)^^</i>	1,519,914	
	<i>Queensland South</i>	448,119	
QS	Total South-East QLD /Northern NSW	1,968,033	25.51
WAS	Southern Western Australia	738,189	9.57
SAS	Southern Australia	427,999	5.55
VIC	Victoria	180,959	2.35
AUN	Northern Australia	161,412	2.09
QCN	Central & North Queensland	147,816	1.92
WAC	Central Western Australia	147,375	1.91
NSW	New South Wales	117,447	1.52
AUC	Central Australia	21,093	0.27
QFN	Far North Queensland	6,478	0.08
--	Elsewhere	2,030	0.03
	Subtotal (Bulk tanks)	4,609,421	59.75
	Subtotal (Card purchases)	3,104,641	40.25
	TOTAL	7,714,062	100.00

on BP cards, unless otherwise stated; ^at Helidon, Rocklea & Wacol; ^^ at Rockhampton.

2.7 *Fleet movements*

ROTC monitors their fleet movements through an extensive satellite-tracking system based on Global Positioning System (GPS) technology fitted to each vehicle. This system provides for the collection of key statistics regarding freight load and type, road terrain, driving patterns and behaviour and refuelling locations. Since many of these factors are important in influencing the overall fuel economy of different freight routes, these data could provide useful information for emission calculations. With this in mind, preliminary investigations were conducted on the nature and extent of data held by ROTC's on-line system (GPS online hosted by Industree Ltd), and the possible role of this information in emissions calculations and reporting.

The key information that is currently available includes:

- position (latitude/longitude);
- total distance travelled (km);
- journey start and stop (e.g., movement halted);
- fuel consumption (total litres) and fuel economy (km/litre and litres/100km);
- speeding events;
- excessive RPM events (over-revving);
- hard braking events;
- hard cornering events;
- harsh terrain;
- rollover risk (excessive lateral movement);
- use of seatbelt and parking brake; and
- use of breakdown and emergency functions.

There are also a number of other statistics that could be determined from the original data, such as:

- profiles for the proportion of journeys spent in particular speed brackets (e.g., 0-20km/h; 21-60km/h, 61-80km/h and so on);
- profiles for the proportion of journeys spent in particular RPM brackets; and
- profiles of the time spent stationary (e.g., the number and length of vehicles stops of <5 minutes, 5-20 minutes, 20-60 minutes and so on).

Each of these could be calculated as a percentage of the journey with respect to both time (minutes) and space (kilometres). There is currently no provision in the system for instantaneous fuel consumption figures or remaining fuel values at a given point in the journey, though this functionality may be added in the coming years (GPS online, pers. comm.).

There are two key points that govern whether these GPS data can be used to achieve more accurate calculation and reporting of greenhouse emissions. Firstly, given the huge variability in the types of journeys undertaken by ROTC during the year, the datasets must be very specific and there must be an adequate number of replicates to enable isolation of one study parameter at a time. This is the only way to accurately measure the influence of a particular variable on fuel consumption. It is not clear that this level of information is currently held in the ROTC dataset.

Secondly, and most importantly, the GPS data do not reflect direct changes in emissions: they reflect changes in fuel consumption. As the NGERS default method already uses fuel consumption figures

to estimate greenhouse emissions, the GPS data can't be used directly to provide an argument to change the emissions factors. Rather, any argument for change must include information on actual emissions and how these compare with existing (mostly European) studies. Instead, the current value of the existing GPS data appears to be that they can be combined with fuel purchasing records to provide a more detailed picture of fuel consumption patterns. This may help ROTC to more easily identify those journeys (e.g., different permutations of drivers, route, truck, vehicle, load and climate) which are most costly in terms of diesel usage, and are therefore the most intensive (and expensive) with respect to greenhouse gas emissions overall. This exercise seems best done by collaboration between ROTC and Industree staff, given that intimate knowledge of the GPS software and of ROTCs operations is required.

2.8 Emissions reporting options

ROTC has already been identified as a corporation that is required to report its emissions under NGERs. Currently, ROTC fulfils this obligation use the default method via the Online System for Comprehensive Activity Reporting (OSCAR) tool. However, the current NGERs methodology also has provision for corporations to monitor and report their emissions through one of three other methods (DCC, 2008). Choosing between these methods is important, as it can help to report emissions more accurately, thus avoiding under- or over-estimation. The purpose of this section is therefore to examine the likely outcomes if ROTC were to report their scope one emissions using alternative NGERs methods.

2.8.1 Method 1

The Method 1 option is the NGA default method. ROTC currently uses this method to report its scope one emissions (i.e., direct emissions of carbon dioxide, methane and nitrous oxides), based on figures relating to:

- the transport sector;
- diesel oil;
- Euro IV standard design heavy vehicles;
- combusted usage; and
- AAA criteria.

From these, the total emissions are calculated based on total diesel consumption, using the default worksheet factors, as follows:

- Energy content factor: 38.6
- Emissions factor: 69.2

These factors reflect the national average factors for emissions from standard diesel fuels, as determined by the DCC. Using the Method 1 reporting option, the emissions from one million litres of diesel fuel consumption is calculated at 2,692.35 tonnes CO₂-equivalent (Table 3).

Table 3 Emission calculations using Method 1 (the NGERS default method) for one million litres of diesel fuel

Emission factors	
<i>Default Energy Content Factor (GJ/kL)</i>	38.6
<i>Default Emission factor (kg CO₂^e/GJ)</i>	69.20
Emission outputs	
CO ₂	2671.12
CH ₄	1.93
NO _x	19.30
Total	2692.35

2.8.2 Method 2

Method 2 provides for a “facility-specific method using industry sampling and Australian or International standards or equivalent for analysis of fuels and raw materials to provide more accurate estimations of emissions at facility level” (DCC, 2009). Under Method 2, the default emissions factors can be changed to reflect different fuel characteristics, providing that the source data are generated using relevant Australian or International analytical standards. Method 2 therefore offers ROTC the ability to calculate emissions that are more closely modelled on the kinds of fuel(s) used in their operations. For example, this could account for the differences in the use of Ultimate compared with standard diesel, as well as for differences in fuel quality by supply region.

To change emissions values in Method 2, the corporation must follow the NGA’s Section 2.44 “General requirements for sampling” and 2.45 “Standards for analysing samples of liquid fuels” (NGAF 2007). This requires the re-calculation of emissions factors using functions of the fuel density, energy and carbon content values. Fortunately, fuel specification data (i.e., density, energy and carbon content) are already available for some products on a quarterly basis (by request from BP Fuels). These figures satisfy the additional NGERS rules:

- Under Section 2.44: sampling must be undertaken quarterly; and
- Under Section 2.45: figures tendered from Industry must be created by sampling done in accordance with the Australian or International Standards.

For the latter, BP makes their determinations using industry standards based on ISO, ASTM and IP methods for sampling tanks to get a representative sample. Specifically, the testing involves:

- Calorific value: ASTM D4868 (which gives equivalent results to ASTM D240);
- Density: ASTM D4052 (equivalent to ASTM D1298). Here, the quoted density is the average of all batches produced by the BP refinery and imported for the period in question; and
- Carbon content: ASTM D5291 (BP Fuels Australia, pers. comm.)

Data from BP shows that the typical densities for Australian fuels do vary, though the difference is slight. For example, BP supplied specifications⁵ show the density of unleaded, premium unleaded

⁵ Based on (British Standards) BS2869 Part 2: *Fuel oils for non-marine use. Specification for fuel oil for agricultural and industrial engines and burners.*

and ultimate petrol at 0.73, 0.75, and 0.755 kg/L, respectively⁶. Thus, premium blend (higher-octane) products generally have higher energy contents due to their higher density. BP fuel engineers were also able to provide data on the required variables, based on the fuel batches supplied to all Australian fuel regions⁷.

Using this information, corrected emissions factors can be prepared. A fully worked example of this, based on for ROTC's Queensland operations, July-December 2008, using information on the BP standard diesel product⁸, is provided in Appendix A. The key amendments are:

- revision of the energy content from the default 38.6 GJ/m³ to 38.41 GJ/m³; and
- revision of the emission factor from the default 69.20 to 67.39.

Using these revised factors, it is possible to create a new NGERS worksheet using the Method 2 reporting option. This results in a reported emissions saving of between 1.43 – 3.03%; equivalent to approximately 39 – 81 tonnes CO₂-equivalent for an annual diesel consumption of one million litres (Table 4 and Figure 3).

It is also important to note the variability in the BP fuel content amongst different supply regions, and from date to date. For example, the modelling also shows that:

- fuel differences between the SA/WA and the SEQ/CQ supply regions amount to 0.69%; and
- fuel differences across supply periods, in the same supply region, amounts to 1.30%.

It is unclear how variable Australian diesel fuels are across manufacturers: unfortunately, it was not possible to get comparable data from major Australian fuel suppliers other than BP. However, entering the maximum and minimum values possible for fuels sold under the current Australian standards into the Method 2 calculations that:

- the best-case fuel sold in Australia (i.e., that with minimum density) would achieve savings of 4.2% of total emissions compared with the default reporting option, or roughly equivalent to \$6,800 for every million litres consumed; and
- the worst-case fuel (i.e., that with maximum density) would achieve a saving of 0.73%, or roughly \$1,200 for every million litres consumed (Table 4 and Figure 3).

These figures have been calculated using an *assumed* average carbon content of 86%: this value could not be substantiated from literature, but was discussed in conversations with fuel technicians from three different Australian suppliers.

In summary, to report regularly under Method 2, ROTC would need to:

1. identify the total fuel consumed from different regions of Australia on a quarterly basis; and
2. approach BP for data on those batches and enter them into the worksheet, along with the details of the total fuel consumed from each batch.

Correspondence from the Department of Climate Change and Energy Efficiency (DCCEE) shows that the Method 2 option should be an acceptable choice for ROTC. However, the success of this

⁶ Values for imported fuels supplied into Australia (e.g., in the far north) may also differ due to different refining process (BP Fuels, pers. comm.).

⁷ BP uses the regions similar to the Australian cloud points, except that the Central and South Australian regions are combined.

⁸ Period data were unavailable for the BP Ultimate product.

reporting method depends on getting data from BP in a timely fashion and ensuring that the data sampling and/or analysis techniques used by BP continue to conform to the NGERs requirements. Furthermore, the NGER determinations require that the submitted emissions values should be provided to within a 95% confidence level. Thus, where small amounts of fuel are purchased 'once-off' in a region, a decision would need to be made as to whether to treat these as a separate event, or for an average figure to be calculated (i.e., they are incorporated into the reporting for another supply region). ROTC would also need to decide what level of detail will be incorporated into Method 2, such as either (a) differences in fuel specification by region and/or (b) differences in fuel supplied in different time periods. Both these would result in lower reported emissions than the NGERs default method, but spending extensive time on even more detailed modelling (e.g., both factors together) may not be useful, since it is likely to result in progressively smaller increments in emissions reductions.

The Method 2 option is slightly more time-consuming than Method 1, but a template worksheet would help make this exercise straightforward, only requiring that the specific figures for each fuel batch be obtained from BP and then entered into the calculation. A template spreadsheet has been developed for this purpose and is provided as an attachment to this report. It was a lengthy task to categorise the consumption of ROTC by product type and supply region, and this was made more time-consuming by differences between the BP online, datafuel and NGERs figures and reporting styles. For 2008-09, a variation of some 3% was detected between the NGERs reported totals versus the consumption that could be tracked through BP online and datafuel. This is only a small variation, but it is worth noting since this could eclipse the gains afforded by switching between the NGERs Methods 1 and 2. Further work by ROTC could focus on addressing this problem and further streamlining the reporting process.

Table 4 Comparison of NGERs Method 2 reporting options, including supply-region and supply-date iterations; based on 1,000,000 litres diesel consumption.

	BP Diesel				Standard Australian Diesel	
	WA & SA supply regions*	SEQ and Central QLD supply regions^	SE QLD Supply Region (Jun-Dec 2008)	SE QLD Supply Region (Jan-Jun 2009)	Minimum density threshold [#]	Maximum density threshold [#]
Average Density (kg/m ³)	840	835	835	838	820	850
Average Energy (GJ/kL or GL/m ³)	38.6	38.6	38.41	38.53	38.6	38.6
Average Carbon Content	86.4	86.3	85.5	86.35	86	86
Revised Energy Content Factor (GJ/kL)	38.6	38.6	38.41	38.53	38.6	38.6
Revised Emission factor (kg CO ₂ -e/GJ)	68.20	67.72	67.42	68.12	66.27	68.69
Emission Outputs						
CO ₂	2635.59	2613.89	2589.66	2464.80	2558.01	2651.60
CH ₄	1.93	1.93	1.92	1.93	1.93	1.93
NO _x	19.30	19.30	19.21	19.27	19.30	19.30
Total	2653.82	2635.12	2610.79	2646.00	2579.24	2672.83
Savings (compared with amounts calculated using Method 1)						
Tonnes of emissions saved	38.53	57.23	81.56	46.35	113.11	19.52
Proportion of Emissions Saved	1.43%	2.13%	3.03%	1.72%	4.20%	0.73%
Dollars saved (\$60/tonne)~	\$2,311	\$3,433	\$4,893	\$2,781	\$6,786	\$1,171.19

*Based on average data from the BP Kwinana refinery. Data were identical for the first and second halves of both 2008 and 2009.

^Based on average data from the BP Bulwer refinery. Data were identical for the first and second halves of both 2008 and 2009.

Based on AS3570 (Australian Standard for Automotive Diesel Fuel) under the 2001 Amendment – using minimum or maximum limits for density at 15°C to meet specifications for sale; the NGERs standard value for energy content (38.6 GJ/Kl); and an assumed average carbon content of 86% (reflecting discussions with a number of fuel technical specialists from key Australian suppliers).

~ ROTC are under advice to factor a \$60/tonne carbon price into their business plan.

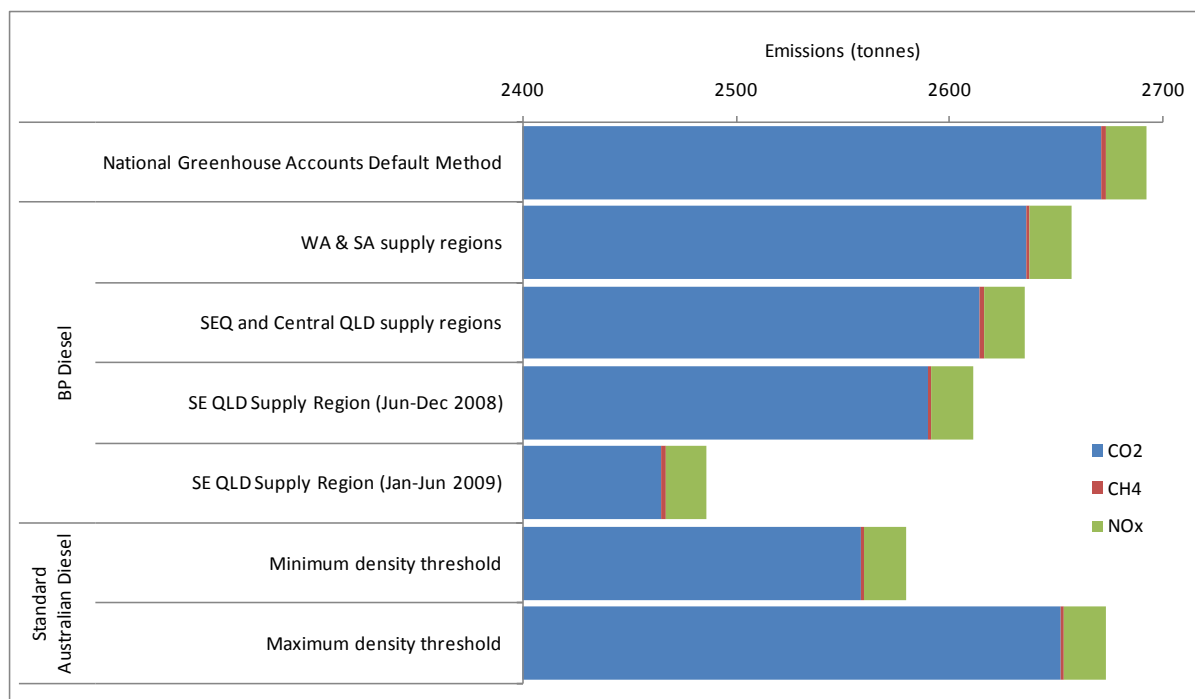


Figure 3 Comparison of the reportable emissions associated with one million litres of diesel fuel consumption under different NGERs reporting options.

2.8.3 Method 3

The Method 3 option relates to ‘a facility-specific method using Australian or international standards or equivalent for [both] sampling and analysis of fuels and raw materials’. That is, the method is essentially similar to Method 2, except that Australian standards are used for sampling. It is not clear how Method 3 can offer an addition benefit over Method 2 with respect to more accurately reporting emissions from ROTC’s operations.

2.8.4 Method 4

The NGERs Methods 1-3 provide *estimates* of scope one emissions, as generated from emissions factors, whereas method 4 monitors *actual* emissions. Method 4 is therefore an important inclusion in NGERs, since the emissions factors used in Methods 1 through 3 are largely based on European case study data, originally collected for use in the CORINAIR project (described in section 3.1). These may reflect very different test conditions (e.g., short-distance haulage trips, multiple cold starts, lower average transport speeds, older engines, different fuel types, and the influence of climate on vehicle performance) compared with the real-world trucking environment in Australia. Thus, although considerable effort is being spent to ensure laboratory studies have relevance to real-world driving cycles in general (Ntziachristos et al., 2003), it remains unclear how well these emissions factors can be transferred to Australian settings.

Method 4 under NGERs provides corporations with the opportunity to undertake direct observations of their emissions, but requires that data are robust and comprehensive – with consideration of

relevance, completeness, consistency, transparency and accuracy (DCC, 2009). Consequently, data collected for use in Method 4 would need to be compliant with existing Australian and/or international standards, for example:

- ISO 16183:2002 Heavy duty engines: measurement of gaseous emissions from raw exhaust gas and of particulate emissions using partial flow dilution systems under transient test conditions. This ISO is applicable to heavy-duty engines for commercial vehicles primarily designed for road use; and
- ISO/PAS 3930:2009 Instruments for measuring vehicle exhaust emissions: metrological and technical requirements; metrological control and performance tests, which specifies the nature of the instruments used to measure CO, CO₂, hydrocarbons and O₂.

Unfortunately, these data are not currently available for ROTC, and the studies needed to generate them are likely to be expensive and complicated. Most direct emissions-observations are typically attempted in laboratory steady-state conditions using dynamometers. This type of work generates emissions maps for different engine types, which assist in calculating overall emission factors for groups of vehicles (e.g., a company fleet). These tests are very complex, incorporating elements such as power and acceleration simulations; equations for rolling and air resistance; power demand from the auxillary and transmission engine components; gear box losses; road gradients; loading; and numerous error and correction functions (Sturm and Hausberger, 2005b, Zachariadis and Samaras, 1999). Dynamometer tests are therefore costly and time-consuming, and are consequently often relied on only for regulatory procedures aimed at compliance-checking for new vehicles and new emissions standards (Frey et al., 2001). There are number of other options by which road transport companies can collect emissions data, including constant-volume sampling (CVS) methods and/or portable emissions measurement devices (PEMS). These are discussed in further detail in section 4.3 below, but again, both represent a considerable investment in time and capital.

In the short term, the Method 2 option appears to be the best way for ROTC to reduce their reportable emissions, as well as to better understand and reduce their greenhouse burdens. In the longer term, ROTC may wish to consider the value of introducing direct emissions measurements onto 'representative' trucks in their fleet. This would be useful not only in accurately reporting annual emissions, but also in helping the company learn more about carbon-intensive driving behaviours and journey types, with a view to reducing or eliminating them in future.

3 Review of emissions literature

The section provides a review of the current literature on emissions from the road transport sector. The review has three main purposes:

- to describe the key influences on emissions in road transport (and from heavy-duty diesel engines in particular), including how important these are in the Australian context;
- to comment on the ‘case for change’ in terms of accurately calculating greenhouse emission factors from the Australian diesel-trucking industry; and
- to consider how this evidence could help ROTC (and other companies) to determine ways to more accurately report, as well as reduce, their greenhouse gas emissions.

3.1 *Methods for calculating emissions factors*

For the road transport sector, there are a large variety of tools to calculate and report greenhouse gas emissions. These differ with respect to the basic assumptions on which the calculations are based, as well as the way(s) in which emissions are described. For example, emissions can be expressed on a per-kilometre basis (e.g., g/km) or per unit of fuel consumption (g/L) (Kousoulidou et al., 2010). For heavy-duty diesel vehicles, engine emissions can also be expressed as grams per hour per kilowatt of power (g/hr/kW). This is particularly useful since it accounts for the vast number of engine, vehicle and transmission combinations that are possible (Samaras, 1999). Symeonidis et al. (2004) summarised the two main approaches for undertaking emissions calculations:

- the macroscale (or bottom-up approach), where data relating to national fleet composition and fuel consumption statistics are combined with estimations of annual mileage and road and traffic conditions to provide overall emissions estimates; and
- the microscale (or top-down approach), where analyses are conducted at much higher spatial and temporal resolutions (such as emissions from a particular urban area over one hour).

During the 1990s, there was significant progress in the way in which emission modelling for road transport was conducted (Zachariadis and Samaras, 1999). This work has resulted in a situation whereby emissions can now be modelled from the local or regional level through to national and global trends. Most emissions tools are also periodically revised, which means that care needs to be taken to ensure that the latest version is in use.

Currently, the most well-used methodology for emissions calculations in road transport is the “coordination of information on air emissions” (CORINAIR) method, developed under the framework of the European Commission (Zachariadis and Samaras, 1999). CORINAIR provides the basis for the Emission Inventory Guidebook used by the European Environment Agency and the European Monitoring and Evaluation Programme, and is considered ‘the best available starting point for work on consistent national emission estimates’ (EMEP, 2009). The process involves calculating emissions from information such as fleet composition, vehicle age, known fuel consumption, and estimates of the average kilometres driven by each vehicle, combined with traffic and driving conditions (Symeonidis et al., 2003). These data are manipulated by a computer program (COPERT) in order to provide estimates of CO, CO₂, NO_x, volatile organic compounds (VOCs) and particulate

matter (PM), each based on fuel consumption (Kousoulidou et al., 2010). Importantly, the document also provides a plan for regular work programmes to review and improve the inventory methodology.

The emission calculation method used by the Intergovernmental Panel on Climate Change (IPCC) has more global application than does the CORINAIR approach, and is thus used by many non-European countries as the default methodology (Salt and Moran, 1997). A key difference between the IPCC approach and that of CORINAIR is that the former focuses only on anthropogenic emissions; whereas CORINAIR also includes natural emissions. For the road transport industry, this becomes important in (for example) calculating emissions factors for biofuels. However, in many cases, the IPCC methodology uses the original source data contained in the CORINAIR or other comparable systems (Salt and Moran, 1997).

In Australia, emissions of greenhouse gases are estimated through the National Greenhouse Accounts (NGA) factors, as developed by DCCEE (2010). Precise methods for calculating emissions through the NGA are taken from:

- the *National Greenhouse and Energy Reporting (Measurement) Determination 2008*
- the *National Greenhouse and Energy Reporting (Measurement) Amendment Determination 2010 (No.1)*; and
- the *National Greenhouse and Energy Reporting (Measurement) Technical Guidelines June 2010*.

According to DCCEE (2010, p. 5), these national methods ‘are consistent with international guidelines and are subject to international expert review each year’. The guidelines draw on key information from the Intergovernmental Panel on Climate Change (e.g., 2006 IPCC Guidelines for National Greenhouse Gas Inventories by Eggleston et al.) as well as other sources such as the United States Environmental Protection Agency (US EPA).

Models for emission factors are also used in conjunction with emissions inventory tools, such as the COPERT (I and II) and Artemis models which are used in most of the European Union as well as much of Central and Eastern Europe; and the MOVES and NONROAD models in the United States (Symeonidis et al., 2004). More recently, the US models are being superseded by MOBILE. This differs from COPERT in a number of ways, including in the source data and how the influence of low ambient temperatures and cold starts are treated (Zachariadis and Samaras, 1999). In Australia, the TRUCKMOD model has been used to simulate emissions from the national road freight fleet. TRUCKMOD works by profiling the age of the vehicles, their freight tasks(s) and fuel consumption to provide emissions estimates for the period 1991 to 2015 (BTCE, 1996).

3.2 *Collecting vehicle emissions information*

There are several ways to collect emissions information from road vehicles. An excellent plain-language review of each of these options, including their respective advantages and disadvantages, is already provided by Kousoulidou (2010) and McKinnon & Piecyk (2009). One of the most commonly-used methods is laboratory-based vehicle testing, where trucks are placed on a dynamometer (rolling road) and examined for their fuel consumption at varying combinations of

speed, tare, vehicle dimensions, loads and (Euro) engine standards. Emissions are later determined from standard ratios based on fuel consumption. Dynamometer studies can be undertaken on the engine or the chassis, and in both steady-state and transient conditions. However, the use of dynamometers has proved difficult in heavy-trucking applications, due to costs and the physical constraints of having such heavy vehicles on the rolling parts of the testing apparatus.

Dynamometer studies also focus on direct engine-testing, which tends to be unsuitable, since it fails to account for the after-treatment systems which are now being fitted to the exhausts of all diesel vehicles as a result of the Euro IV and V emissions standards. Finally, dynamometer studies are restricted because the data from the laboratory tests can only mimic actual driving environments. Unfortunately, many laboratory studies fail to accurately reflect the nuances of real-world driving, such as the accelerating phase (Jayaratne et al., 2010).

Remote sensing is an alternative way of collecting emission information, and is achieved via an infrared or ultraviolet spectroscopy unit mounted on the roadway (often, near tunnels). Remote sensing is often employed for applications such as identifying individual high-emitting vehicles (e.g., by combining the technology with registration number recognition software). It is also a good way to assess the value of maintenance programmes, since it offers the ability to scan thousands of vehicles per day. However, the data collected by remote sensing can only reflect instantaneous emissions, and thus cannot describe emissions patterns over a journey (Kousoulidou et al., 2010).

A third option for measuring emissions is via the use of on-board instruments and/or sampling devices. On-board systems were originally developed with the aim of monitoring a range of vehicle performance indicators, such as fuel economy and driving patterns (hard braking, heavy acceleration) (Gense et al., 2006). However, the technology has now progressed to include emissions-related components. For example, in HDDEs, most on-board systems now provide baseline data about the performance of the catalytic converter, fuel injection system, particulate traps and after-treatment systems. Unfortunately, improper calibration and electrical failures can be weakness of on-board devices. Furthermore, the information is usually acquired for diagnostic applications (e.g., to detect and correct engine malfunctions), rather than specifically for emissions monitoring. However, in future, on-board instruments are likely to be coupled with real-time sampling of emissions and involve the use of on-board emission control technology. This will provide valuable, rigorous and real-world data about emissions, and the influence of different driving patterns, engine types and road traffic and conditions, in order to substantially decrease emissions from road vehicles (Samaras et al., 1993). These possibilities are discussed further in sections 4.3.2, 4.3.3 and 4.3.4.

Where emissions cannot be directly tested from vehicles, inventory data can also be compiled from secondary sources, such as:

- operator surveys or national traffic surveys – where companies are sampled to collect information about total fuel usage and total distances travelled. These data are used to calculate fuel efficiencies, which are then converted to emissions using standard fuel-to-CO₂ estimates. Here, the accuracy of the fuel efficiency data is particularly important (and complex), since this must reflect a range of underlying influences such as fuel and engine type, and operating and driving conditions;
- records of diesel fuel purchases – unfortunately, this cannot discriminate between different vehicle types, and so must be combined with other survey data in order to calculate the relative contribution of road freight operations, and different vehicles within this; and

- national atmospheric emissions inventories – these house information on emissions from all sources and can be used in combination with the above methods to get a more accurate picture of emissions.

However, secondary data such as those listed above must be interpreted carefully. For example, one problem is the interdependence between total fuel consumption, the consumption rate(s) of particular vehicles, the number of vehicles in each category and the average annual driving distance (Zachariadis and Samaras, 2001, p. 468), which can lead to confounding of the data. Zachariadis et al. (2001) has also showed that estimates of vehicle-kilometres are often unreliable, and this can lead to similarly unreliable energy efficiency and fuel consumption figures.

3.3 *Key influences on emissions from diesel vehicles*

The variability in greenhouse gas emissions from diesel engines can be sourced from a number of key factors, including:

- types and properties of fuels and oils;
- vehicle and engine characteristics (e.g., class and the use of after-treatment technologies)
- vehicle condition (maintenance history) and production year (age);
- trip type (including annual mileage, average speeds and the extent of stops and idling);
- driver behaviour; and
- driving scenarios (traffic, terrain and climatic conditions).

Most of these parameters are already incorporated into the COPERT methodology (Zachariadis and Samaras, 1999). However, specific information on the role of these factors in influencing emissions from heavy-duty diesel vehicles is scant, particularly when compared with studies done on gasoline-powered passenger cars (Clark et al., 2002). For example, Sturm & Hausberger (2005a) claimed that less than 1% of the data available during the mid 2000s was related to HHDEs, despite this class being acknowledged as key polluting vehicles. The following section of this report describes the current information on factors influence emissions from diesel vehicles.

3.3.1 Fuel and oil

Fuel characteristics are crucial in influencing emissions from HDDE, and section 2.8 of this report has already demonstrated the direct effects that fuel qualities can have on emissions. Changing the fuel characteristics can also have flow-on effects, such as changes in injection timing, which helps to improved the combustion process and therefore further reduce emissions (Sturm and Hausberger, 2005b). There are ongoing improvements in fuel quality in both the US and Europe, driven largely by new emissions legislation. Here, the key changes are sulphur and aromatic content, which can both minimise particulate emissions (Ntziachristos and Samaras, 2003, Samaras, 1999). This kind of fuel optimisation is particularly advantageous because any gains achieved at the refinery can be applied to many different engines and vehicles, regardless of the current technologies in use. Fuel changes can also be rapidly introduced and adopted in the marketplace, whereas engine technologies may take up to a decade (Samaras, 1999).

For diesel fuels, early work by Westerholm & Egeback (1994) showed that the most important parameters for moderating emissions included density, 90% distillation point, final boiling point,

specific energy, aromatics and PAH contents. In 2003, Ntziachristos et al. concluded the most significant emissions differences are present between fuels of different surface tensions and blends. Here, reduced surface tension and cetane content appeared to improve CO₂ output and fuel consumption; whereas increased density and viscosity were linked with increased particulate matter (Ntziachristos et al., 2003). Sturm & Hausberger (2005b) have also shown that the main fuel properties affecting emissions in heavy duty vehicles are the cetane number, total and poly-aromatics content, back-end distillation, density, sulphur content and oxygenates. These kinds of variables can impact both engine-out emissions, as well as emissions resulting from after-treatment technologies. However, within these, there may be different effects for different emissions categories. For example, fuel sulphur content only impacts the emissions of particulates (Sturm and Hausberger, 2005b); whilst oxygenated fuel can reduce both the number and mass of diesel particulates by approximately 20% (Ntziachristos et al., 2000). Most recently, Lim et al. (2007, p. 1831) noted that emissions from heavy-duty diesel buses were ‘strongly dependent on fuel parameters such as fuel sulphur content, density, distillation point and cetane index’.

With respect to oils, Zielinska et al. (2004) conducted one study and concluded that diesel engines experience fewer problems with emissions from unburned lubrication products than do other engine types. Otherwise, in general, there is appears to be paucity of information on the role that of engine oil (lubricants) play in influencing emissions from HDDEs.

3.3.2 Vehicle and engine characteristics

Even within a specific type of vehicle, emission factors can vary substantially depending on a variety of parameters. The parameters that most heavily affect emissions include vehicle class and weight, driving cycle, vehicle vocation, engine exhaust after-treatment, vehicle age and engine control effects (e.g., injection timing strategies) (Clark et al., 2002). In addition, tare weight reduction naturally offers fuel efficiency gains (e.g., around 2% savings) and these are closely associated with emissions reductions (Malone, 2008).

Most early (i.e., pre-2000) work on emission reductions was achieved through improved engine and vehicle design. This included optimisation of the fuel-air mix, higher fuel injection pressures and electronic engine control (Samaras, 1999). More recently, emissions from HDDE vehicles have changed dramatically, due largely to the introduction of the Euro standards and the emergence of new engine technologies. However, this has not always corresponded with emissions decreases. For example, the introduction of the Euro I standard for rigid trucks actually resulted in almost 20% increased emissions (as grams of CO₂/km) from pre-1993 models, although later iterations (Euro II, III and IV) were linked with modestly decreased values (Zanni and Bristow, 2010). For articulated trucks, introduction of the Euro standards resulted in a 40% increase in emissions, and even incremental improvements in the latest Euro IV and V standards have not recovered that gain. Largely, these initial increases in both rigid and articulated vehicles occurred because the earlier models had much smaller size and weight, which weren’t entirely compensated for by advancements in engine technology (Zanni and Bristow, 2010). Most recently, after-treatment technologies have featured heavily in work with HDDEs. A summary of these and how they might influence emission reductions in the future is provided in Section 4.3.

3.3.3 Vehicle maintenance and age

Vehicle age can influence emissions in a number of ways: first, as mileage increases, natural wear and tear deteriorates the engine, thus producing higher emissions. Secondly, the effects of an ageing fleet can also mean efficiency losses in emissions control systems. Thirdly, ongoing changes in technologies mean that aged vehicles have higher emissions compared with those that are new-to-market (Clark et al., 2002). For this reason, the age structure of a fleet becomes particularly important when considered in the context of the ongoing maintenance schedule, and the rate at which new technological advances (including new fuels) are coming to market (Zachariadis et al., 2001). The latter can include technologies designed for retrofit applications, as well as those limited to new models.

The FOREMOVE model is already available to examine the link between the deterioration of older vehicles and emissions (Zachariadis and Samaras, 1999). One study has already shown that even modest aging can contribute to real difference in emissions outputs: Graham et al. (2008) reported that a Freightliner vehicle had statistically significantly higher emissions (methane and NO_x) in comparison with an identical make that was only five years younger. Symeonidis et al. (2003) also claimed that older and less frequently maintained vehicles would emit more pollutants than newer, well-maintained models. However, other work supports the idea that diesel engines deteriorate little in their first half-million kilometres, before rebuilds are attempted. For example, Sturm & Hausberger (2005a) assessed the effect of engine deterioration on emissions, using information from steady-state tests on Euro II in the Netherlands and Germany. They concluded that engine deterioration effects, even in worse-case scenarios, were likely to be marginal; they also commented that the on-board diagnostic systems in later-model vehicles (Euro IV, V) could help to correct any emissions rises due to engine wear and tear and performance irregularities over time.

Sturm & Hausberger (2005a) also studied the impacts of vehicle maintenance on emissions. Here, the authors showed that emissions reduction of 7-8% could be achieved, but that this varied widely according to the emitted components (e.g., NO_x compared with CO), and between different vehicle standards (e.g., Euro I or II). Thus, whilst individual vehicles can experience quite dramatic emissions reductions due to maintenance (particularly those that are in poor condition initially), overall effects across a fleet are likely to be relatively low (e.g., a few percentage points). Furthermore, these gains would even smaller where fleets regularly undergo routine maintenance. It is for this reason that fleets undergo regular inspection and maintenance programs in industrialised countries tend to realise a fraction of the emissions reductions that are theoretically possible (Samaras, 1999).

3.3.4 Trip type (length, speed, stops and idling)

Symeonidis et al. (2003) noted that vehicle usage is a large source of uncertainty in emissions calculations. The nature of the trips undertaken by HDDE vehicles can influence emissions in a number of ways. For example, the trip type will reflect the number of cold-starts that are required during a journey, as well as the extent of engine idling. The importance of incorporating cold-starts into emissions calculations was recognised as early as the 1990s (Joumard et al., 1994). According to the COPERT model, an engine is considered as cold-start when the water temperature of the cooling system is less than 70°C (Zachariadis and Samaras, 1999). Here, the time (and hence distance) required to warm the engine depends on driving behaviour and ambient conditions (Eggleston et al., 1991). However, for engines with after-treatment devices, cold starts can also include the trip

fraction that is travelled with cold catalyst (Zachariadis and Samaras, 1999). Cold starts occur under many different types of driving conditions, but are most likely in urban settings and occur quite independent of vehicle age (Eggleston et al., 1991).

Idling emissions refer to fuel consumption and emissions created by idling during long-haul trips, particularly where additional energy is used to air-condition the cab during driver rest periods (Khan et al., 2009). Other reasons for idling include driver habit, to keep the engine warm and to maintain battery voltages. Despite the emergence of 'anti-idling' legislation, a recent study by Khan et al. (2009), concluded that a comprehensive database is not yet available to describe the impacts of idling on emissions. The effects of engine speed and running accessories (such as cooling fan, air compressor, air-conditioning and alternator loads) on idling emissions is particularly unclear: in a Cummins engine, for example, engaging the air conditioning had only a modest effect on fuel consumption (and emissions), contrary to expectation (Khan et al., 2009). Meanwhile, an earlier study had demonstrated that of the 12% of emissions created by idling, with up to 9% were due the auxillary power unit (Malone, 2008). These contrasting findings are a key problem when working to estimate emissions across different journey types. For example, though trips in urban and rural areas may have equal distance, the long idling periods due to traffic congestion in the urban setting may contribute to much higher trip emissions when compared with highway driving.

Similarly, the proportion of trip time that a vehicle spends in particular speed ranges is also exceptionally important to the emissions factors, because exhaust emission factors vary with vehicle speed (Kousoulidou et al., 2010). For example, lower engine speeds in heavy-duty diesel engines are linked with lower combustion efficiency, thus creating higher particle emissions (Wang et al., 2003). This means that emissions profile of rural-regional long-haul trips may be quite different to those of smaller-scale journeys in urban environments. For example, the methodology used in the 1999 version of CORINAIR 1991 involved CO₂ emissions factors for HDDEs⁹ that were more than twice as high in urban environments as they were in rural conditions (e.g., 51.4 g CO₂/km compared with 22.2 g/km), and three times higher than for highway driving (14.2 g/km) (Eggleston et al., 1991). However, this was not the case for all pollutants; factors for NO_x were generally comparable across all scenarios (Eggleston et al., 1991). The availability of transit lanes, one-way traffic lanes and traffic lights have also been explored as potentially important to emissions, since each of these also influence speed, stop rate and/or stop duration (Sturm and Hausberger, 2005a).

Lastly, it is worth noting that the seminal Greek studies – from which much of the CORINAIR-COPERT, IPCC and subsequently, the Australian emissions factors have been derived – use trip lengths ranging between 10km to 15km (average 12.4km). Clearly, this is not comparable to the average length of long-haul journeys undertaken in Australia, but it seems that the precise implications of such different trip types have yet to be properly examined.

3.3.5 Driving environment (terrain and ambient conditions)

Lim et al. (2007, p. 1831) noted that emissions from heavy-duty diesel vehicles were strongly influenced by driving conditions. These factors may include the impacts of terrain (also known as

⁹ For HDDEs exceeding 16 tonnes

grade, gradient or altitude effects) and a number of ambient conditions that affect engine performance and fuel economy, including temperature, humidity, barometric pressure and wind.

Road gradient was acknowledged as important influences in early work on emissions, which is unsurprising given that increased fuel consumption naturally occurs when a vehicle is operated at higher power (such as uphill driving) (Lim et al., 2007, Zachariadis and Samaras, 1999). The extent of emissions created by road gradient changes may be remarkable: for example, driving altitude and road slope were shown to contribute as much as 50% to overall emissions (Joumard et al., 1994). Despite this, the original versions of the CORINAIR methodology did not include their influence, due to a lack of data (Eggleston et al., 1991). It is unclear what recent progress has been made to remove the uncertainties in this area. Work by Sturm and Hausberger (2005b, p. 146) has since shown that the effects of gradient can be substantial: for example, a 6% gradient has been linked with 100% to 350% increases in both fuel consumption and NO_x emissions, compared with driving on a flat road. The degree of road sinuosity (winding) has also been examined for its role in affecting speed and driving behaviour, and have micro-scale terrain parameters such as speed bumps and roundabouts (Sturm and Hausberger, 2005a). However, the latter appear to exert influence on emissions mostly through their impact on driving speed, rather than loading on the engine. Most recently, Kousoulidou et al. (2010) collected data on emissions and noted that a number of altitude values (e.g., minimum, maximum and average) were important parameters.

The effects of ambient temperature on emissions appear to be greater in gasoline, rather than diesel-fuelled vehicles (Zielinska et al., 2004). However, over long-haul journeys, it has been demonstrated that emissions of CO₂ increase with cooler ambient temperatures. For example, Graham et al. (2008) reported that cold temperature operations (e.g., 10°C compared with 20°C) were linked with average CO₂ increases of 5%, NO_x increases of 40% and methane decreases of 40%. However, the study was done with a single vehicle only. The authors also noted that warmer climates (e.g., tropical Queensland) could be important in determining how long an engine takes to become warm enough to reduce emissions profiles. In 1991, Eggleston et al. noted that an acute information gap on influence that cold starts have on emissions: this gap is still being acknowledged nearly a decade later.

3.3.6 Driver behaviour

Driver behaviour significantly affects vehicle emissions, but few studies have focussed specifically on this factor. Two exceptions are Malone (2008), who estimated that driver training and monitoring measures could save almost 4% of the emissions in the Canadian freight truck industry; and Kousoulidou et al. (2010), who confirmed that aggressive driving behaviour produces more vehicle emissions than normal driving behaviour.

3.4 Emissions factors in the Australian trucking industry – a case for change?

Clearly, one of the most important potential problems with applying the CORINAIR and/or IPCC methodologies is that emissions factors developed for European (or other) settings may not be directly applicable to Australian environments. Kousoulidoua (2010, p. 9) has already acknowledged that emissions from road vehicles can change dramatically due to various climatic and terrestrial conditions, and that ‘tailpipe pollutant concentrations may range by order of magnitudes depending on vehicle operation’. The UK experience has already shown that it is very difficult to compile an accurate and consistent set of data relating to trucking emissions, because average values and data trends being very much dependent on the base information on which calculations are done (McKinnon and Piecyk, 2009). Similarly, a Canadian study by Graham et al. (2008) has produced emission factors for diesel and gas vehicles that were substantially lower than those recommended by the IPCC methodologies. This kind of work can lead to the ‘radical revision’ of estimates in some countries, which makes it difficult to build confidence in the data, as well as to establish appropriate low-carbon policies for the transport sector (McKinnon and Piecyk, 2009, p. 3741).

Most of the original methodology on emissions from road transport has been developed from international research conducted in Europe and the United States. There is exceptionally little research from Australian-based trials, with only a few notable exceptions (e.g., Nelson et al., 2008). The brief review of literature provided above shows that this could potentially lead to inconsistencies, because of the role that different fuel characteristics, driving conditions (e.g., climate, gradient) and trip types can play in influencing emissions. Furthermore, the explanation of emissions factors described in the European Emissions Inventory Guidebook includes a disclaimer that anyone applying these factors to other countries must first establish the role of rural and urban driving cycles (i.e., trip types) in influencing emissions (European Environment Agency, 2007). This is a key point given that the average distances and trip lengths undertaken in Australia have little in common with those of European nations. This problem is also made more acute by the lack of a universally agreed-upon definition of ‘trip length’ in the current methodology (Sturm and Hausberger, 2005a).

The Australian trucking industry features the use of heavy-duty diesel engines in a range of different models, ages and service histories. The country has tropical, subtropical, temperate and desert operating environments. The industry is typically characterised by long-haul journeys, with high proportions of highway driving, particularly where companies operate from regional destinations. Therefore, the application of the existing CORINAIR-COPERT emissions standards to Australian conditions may not result in accurate emissions reporting: potentially, this could result in either under- or over-estimation, depending on the different journey factors. However, in the absence of rigorous Australian datasets, this issue seems unlikely to be addressed in the near-term.

4 Reducing emissions from road transport

4.1 *Global emissions trends*

Total emissions from the global road transport industry continue to rise: growth in the number of new vehicles, as well as in the annual mileage driven is currently outstripping any reductions in emissions that are achieved through technological advancements, fuel improvements and/or diesel alternative, and increasingly more stringent emissions regulations. Upward trends in emissions are also linked with the problem that technological advancements provide greater efficiency, thus allowing road transport to become cheaper, in turn driving further growth in the sector (Zanni and Bristow, 2010). For example, modelling done by the Bureau of Transport and Regional Economics (BTRE) has shown that by 2020, the Australian transport sector will produce base-case emissions that are 78% higher than 1990 levels (or 106.3 million tonnes CO₂-equivalent) (BTRE, 2005). Certainly, Australia has experienced growth in overall freight activity, and this has been combined with a modal shift towards trucking (compared with rail) due to its flexibility and speed (Kamakaté and Schipper, 2009). However, Kamakaté & Schipper (2009) have also suggested that the carbon intensity of the Australian trucking industry is falling, largely through load increases per vehicle and due to improvements in individual truck efficiencies.

The influence of regulatory, technological, logistical and behavioural changes in reducing the carbon-intensity of the Australian road transport sector should not be underestimated. For example, Zanni & Bristow (2010) estimated that emissions growth in London could be halved by 50% by 2050 through a combination of these measures. This section therefore provides a summary of the key areas through which emissions reductions are likely to evolve, including:

- advanced technologies (e.g., improvements in emissions monitoring and mapping, and innovation in engine and vehicle design);
- fuel improvements and/or alternative fuels and blends; and
- other options, including best management practices (Ang-Olson and Schroerer, 2002).

4.2 *The role of regulations in reducing emissions*

New government policies on transport, road and traffic planning and carbon pricing will be of obvious importance in reducing emissions from the road transport sector. For example, Sturm & Hausberger (2005a) suggested that emissions from the heavy duty transport sector could be reduced by:

- legislation that obliges manufacturers to develop cleaner vehicles and/or engines (this would also prompt the evolution of better testing procedures, since new technologies must be evaluated and validated in real-world applications);
- transport and traffic planning measures (which would also stimulate a better understanding of how traffic factors and road infrastructure influence emissions); and
- financial measures (e.g., incentives) to encourage the transport industry to move toward cleaner operations.

Zanni & Bristow (2010) also listed logistics and infrastructure solutions (focussed on more efficient goods delivery modes), traffic restrictions and regulations, and driver training and information packages as the key pathways by which emissions can be reduced.

Emissions regulations (vehicle design standards) have the ability to dictate precisely the level at which an engine or vehicle must perform: these rules will strongly influence the nature of emissions reductions in road transport operations. Johnson (2008) recently reviewed the recent regulatory developments to reduce diesel emissions. The current focus is on the European Union, where Euro V regulations have already been introduced, with Euro VI due in 2014. Generally speaking, new iterations of the Euro standards are linked with progressively more stringent emission controls. However, Zanni & Bristow (2010) noted that the emissions factors from heavy-duty articulated goods vehicles have steadily declined with the introduction of more stringent Euro standards, but that the rate of reduction is slowing. For example, that change from pre-1993 to Euro I provided a 42% decrease in grams of CO₂/km, but subsequent iterations of Euro have been 12%, 3% or nil net effect (up to Euro IV).

Moreover, emissions reductions are not being experienced across all pollutant categories. For example, the Euro V emission limits differed from the previous Euro IV only with respect to NO_x (Table 5 and Table 6). Furthermore, in the mid-2000's, international research was focussed on characterising particle emissions, particularly their size and number (Ntziachristos and Samaras, 2003). This work showed that regulations for particle emissions should not necessarily be focussed on mass (i.e., the amount produced), but instead, the nature of the emissions (e.g., particle size distribution and the chemical features of the particles) (Burtscher, 2005). Subsequently, the particulate matter levels that are anticipated for Euro VI are in fact higher than those of Euro V for transient cycles (see Table 5), with the newer regulations instead being focussed on hydrocarbons, smoke and NO_x matter.

Future changes to emissions regulations will include the US regulations becoming more stringent, although these are based on different transient test cycles than are the Euro figures (Johnson, 2008). Changes in emissions regulations may also lead to existing technologies and existing fuel alternatives being re-evaluated for their role in emissions reductions efforts (Johnson, 2009). Recently, Guarieiro et al. (2009) noted that emissions reduction may be more effectively achieved by improvements in fuel consumption, rather than in emissions controls. Strangely, worldwide, fuel economy is not regulated: this has instead been left to market forces (Samaras, 1999). There is now a potential problem in increasingly tough emissions restrictions leading to decreased fuel economy, due to of additional weight, changed exhaust pressures and additional consumption needed to power (e.g., catalysts or filter regeneration burns) (Samaras, 1999). The HDDE transport industry now appears to be on the point of achieving diminishing returns in the area of reducing diesel exhaust gas emissions, and this may trigger a re- focus back on fuel economy (Guarieiro et al., 2009).

Table 5 Comparison of emissions limits for heavy-duty diesel vehicle across different Euro standards and/or Australian Design Rules (as compiled from the Australian Design Rules 80/03). Values are for transient cycle tests (European Union). Note: Euro II (1997) and Euro I (1993) emissions standards and those enforced by the Economic Commission for Europe (ECE) in the pre-1990s are not provided.

Euro Standard	III	IV	V	VI [^]
Australian Design Rules	80/01	80/02	80/03	80/04
Year operational	2000	2005	2008	2013
CO (g/kWh)	5.45	4.00	4.00	4.00
Hydrocarbons (g/kWh)	0.78	0.55	0.55	0.16
NO _x (g/kWh)	5.00	3.50	2.00	0.50
Particulate Matter (g/kWh)	0.16	0.03	0.03	0.40
Smoke (m ⁻¹)	0.80	0.50	0.50	0.01

[^] anticipated/planned.

Table 6 Comparison of emissions limits for heavy-duty diesel vehicle across different Euro standards and/or Australian Design Rules (as compiled from the Australian Design Rules 80/03). Values are for steady-state (stationary) cycle tests (European Union).

Euro Standard	III	IV	V	VI [^]
Australian Design Rules	80/01	80/02	80/03	80/04
Year operational	2000	2005	2008	2013
CO (g/kWh)	2.10	1.50	1.50	0.50
Hydrocarbons (g/kWh)	0.66	0.46	0.46	0.13
NO _x (g/kWh)	5.00	3.50	2.00	0.40
Particulate Matter (g/kWh)	0.10	0.02	0.02	0.01
Smoke (m ⁻¹)	NA	NA	NA	NA

[^] anticipated/planned January 2013

4.3 New & advanced tools and technologies

4.3.1 Mapping emissions

Regional emissions maps can be very useful in identifying areas associated with high emissions. For example, maps that are generated from emissions inventory data can track a particular pollutant and vehicle type for a specified road section and/or period (Symeonidis et al., 2004, Symeonidis et al., 2003). Thus, when these are combined with Geographic Information Systems (GIS) techniques, it is possible to visually identify particular road sections or time periods that are associated with higher emissions (see example in Figure 4). In turn, this can be used in decision-making by road-transport companies to avoid high-emission 'hotspots' such as heavy acceleration periods (Frey and Unal, 2002). They could also be used for planning by national and state transport authorities. However, this kind of approach requires specific and detailed emissions inventory data: it is not clear that these are currently available in Australia.

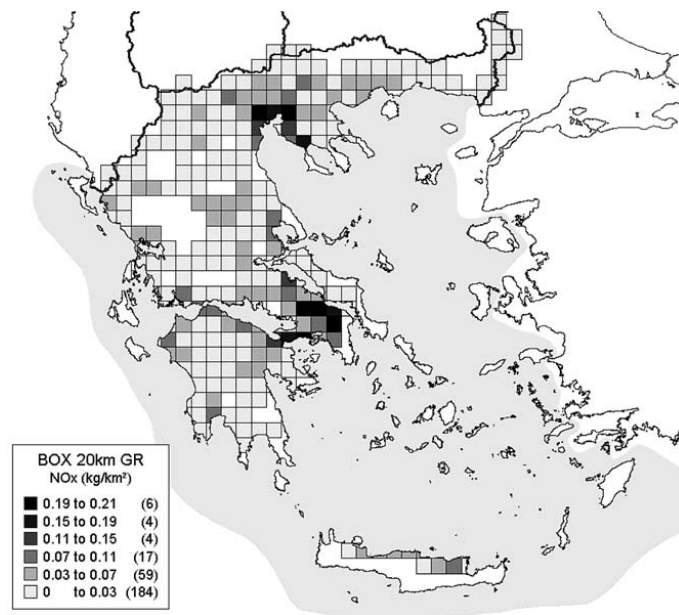


Figure 4 An example of an emissions map generated from inventory data combined with Geographic Information Systems (GIS) techniques. Source: reproduced from Symeonidis et al. (2004, p. 420).

4.3.2 Constant-volume sampling (CVS)

Constant volume sampler (CVS) systems were being developed as early as 1987. These small on-board devices are designed to capture a representative subsample of the exhaust gases created during a test drive, and thus enable direct measurement of emissions (Potter, 1987). The exhaust gases and particulates are transferred through tubing and collected either in a sample bag, or on filter paper. The exhaust sample is then analysed (e.g., via infra-red or gas chromatography techniques) to determine the pollutant concentrations. More modern designs have allowed for the entire volume of the exhaust product to be captured in laboratory settings, but field studies continue to rely on sub-sampling (Graham et al., 2008). The use of CVS systems for emissions work is well-regulated: indeed, they are now regarded as the standard reference procedure for direct emissions monitoring. A key benefit of this is the easy comparison of results across studies (Ntziachristos et al., 2003). However, some of the unresolved challenges with CVS include:

- how to achieve representative sampling and avoid artefacts (especially for aerosols) (Ntziachristos et al., 2003);
- how to account for uncontrolled parameters including dilution conditions (how much raw exhaust product is used) and the design of the transfer line (which carries the sample from the exhaust to other parts of test equipment) (Ntziachristos et al., 2004); and
- how to minimise changes in the fractions of volatiles and condensation and coagulation of particles (Burtscher, 2005).

Thus, CVS technologies are still developing, with a focus on achieving greater sophistication in the characterisation of exhaust particles and better reproducibility (i.e., confidence in the results) (Ntziachristos et al., 2004).

4.3.3 On-board technologies

On-board diagnostic tools that detect problems with engine (and therefore emissions) performance are already widely available. However, future advancements in emissions control via on-board systems are likely to involve closer relationships with engine management systems and with telemetry-based communications technologies. For example, the latter could include in-vehicle Controller Area Network (CANbus) technology, which could be integrated with the satellite-tracking systems already in use by companies such as ROTC (Industrea, pers. comm.). This would allow for emissions and vehicle performance to be collected and analysed in real-time. However, there are three elements that currently govern the use and applications of such monitoring devices: the bandwidth, cost of data traffic, and internal storage capacity. Currently, many systems are limited by bandwidth and cost-effectiveness restrictions, meaning that only summary values for performance (such as one log per twenty second) can be recorded. Wide adoption of this technology will also ultimately depend on overcoming the perception that introducing such technology would cause undue risk (because it potentially allows for changes to be made to the engine in real-time) (Industrea, pers. comm.).

4.3.3.1 Portable emission measurement systems (PEMS)

The limitations of dynamometer and remote-sensing technologies in accurately assessing emissions from HDDE vehicles has already been discussed in section 3.2: a key problem here is the inability to properly reflect real-world driving conditions over the entire length of a journey. This challenge has meant that on-board measurement of tailpipe emissions is rapidly becoming a preferred approach for emissions studies (Frey and Unal, 2002).

Portable emission measurement systems (PEMS) are on-board devices that allow for emissions measurements and data logging in real-time. They are thus very useful in validating existing emission factors and/or develop new methods for emissions calculations (A/Prof Leon Ntziachristos, pers comm), as well as in supplementing the data dynamometer studies (Kousoulidou et al., 2010). Frye et al. (2009) has already recommended the updating of basic emissions information as soon as PEMS data becomes available for heavy-duty diesel trucks, since this will achieve greater accuracy. In addition, where PEMS can be combined with other on-board diagnostic and measurement tools (e.g., CanBUS), they can allow for emissions to be linked with driving speed; acceleration, cruising and deceleration; engine RPM and other parameters (Kousoulidou et al., 2010, Frey and Unal, 2002). Such data are particularly useful in estimating emissions from particular road sections or routes: this has obvious advantages in avoiding high-emissions routes in the future. It also means that there will be a renewed focus on driver behaviour as a key way of reducing emissions (Frey et al., 2001)

The key advantages of PEMS are the ability to account for emissions across a range of driving conditions, including preconditioning, urban driving, low load driving, rural and motorway driving and cool down (engine off). PEMS can characterize emissions during idling, cruising, accelerating and decelerating modes (Kousoulidou et al., 2010). The system can provide for continuous measurement (second-by-second basis). Portable instruments that allow for on-board measurement of tailpipe emissions during actual driving have been under investigation for some time (Frey and Unal, 2002). These studies need to consider aspects such as vehicle and route type, driver,

instrument deployment, and how to measure uncontrolled factors that could influence emissions (i.e., get a sense of likely artefacts in the data) (Frey and Unal, 2002). For example, studies with portable instruments have already shown that emissions can be substantially influenced by short-term events; and that some modes (such as idling) may have much lower emissions than previously thought, when compared with others (such as acceleration) (Frey et al., 2001). On-board sampling techniques are also being developed for use in direct emission sampling during laboratory studies. Earlier technologies included the OEM-2100, which had the approximate size of a shoe box, weighed 30 kg and could be installed on a passenger seat in 15 minutes (Frey et al., 2001). More recently, new technology has been commercialized as the Dekati FPS-4000 sampling system (A/Prof Leon Ntziachristos, pers comm).

PEMS did not achieve good market penetration during the 2000s, largely because of cost restrictions. However, the technology has now advanced and Kousoulidou et al. (2010, p. 16) claim that PEMS are ‘relatively simple, inexpensive ... can be installed easily in a wide variety of vehicles ... are designed for measuring in-use emissions during real-world on-road operation under any ambient conditions, traffic conditions, and operational/duty cycles ... [the installation is] typically reversible, and no modifications are necessary in many cases’.

4.4 *Engine development (emissions control devices)*

As early as 1996, the Australian TRUCKMOD model showed that uptake of advanced vehicle technologies was expected to create a significant reduction in emissions, whereas retiring less fuel-efficient vehicles from the Australian fleet was a high-cost and comparatively lower-return option (BTCE, 1996). Fuel and engine modifications have since been confirmed as the key pathway to achieving ongoing emissions reductions in HDDEs into the future (Samaras, 1999).

For diesel engines, the key challenges in emissions reduction are the ways in which to address NO_x and particulate matter. This is particularly problematic because reducing either component typically involves a change in chemistry, which ultimately leads to increases in carbon monoxide (CO) and unburned hydrocarbons. It is also difficult to achieve emissions reductions without experiencing a penalty on fuel economy. There has been remarkable progress in clean-engine technologies in recent years, but only a proportion of this work has been centred on heavy-duty applications. For HDDEs, engine advances tend to be conservative and/or incremental, because of concerns about fuel economy, reliability, durability and cost (Johnson 2008). Nevertheless, there are two broad categories of emissions-reductions technologies that can be applied to heavy-duty diesel vehicles:

- internal engine measures, where developments in the combustion system help to reduce ‘engine-out’ emissions; and
- after-treatment technologies, which focus on the optimising exhaust gas composition in the post-combustion phase (Gense et al. 2006).

Each of these are discussed in more detail below.

4.4.1 Internal technologies

Recent developments in internal engine technologies have included:

- advances in fuel injection systems. Here, higher pressures and multiple-precision injection are being used to help achieve optimal fuel gas mixing. This results in improved fuel consumption, and therefore, reduced emissions (Gense et al., 2006);
- increased flow-range turbocharging. This addresses the need to have high boost pressures in order to minimise particulate emissions, particularly in heavy-duty engines operating at high loads. Next-generation turbocharging is likely to focus on the use of two turbochargers of different sizes are connected in series; this technology is already being adopted in Europe (MAN Diesel and Turbo 2010);
- homogenous charge compression ignition (HCCI): this uses a premix of air, fuel and combustion and compresses it until it auto-ignites. The compression allows for lower peak temperatures, and leaner mixtures, thus giving lower NO_x and particulate emissions. However, the technology is not yet fully feasible for road applications where a range of engine speeds and loads may occur. There are also some issues with durability and cost (Penton Media 2008); and
- combustion control using new sensor technology. This involves the development of sensors that can provide direct feedback to the vehicle control system, thereby allowing for engine adaptations and better on-board diagnostics. This technology remains in its infancy (Gense et al., 2006).

4.4.2 Aftertreatment technologies

One of the key problems in reducing emissions through internal engine measures is that it is very difficult to achieve NO_x reductions without simultaneously increasing fuel consumption (and therefore, emissions in other pollutant categories) (Gense et al., 2006, p. 13). Thus, as the Euro standards become more stringent for NO_x and particulates, gains through internal technologies (such as EGR) will not be sufficient to achieve the target emissions. As a result, after-treatment technologies have a critically important role in helping to reduce NO_x emissions.

After-treatment technologies refer to a number of different devices that may be fitted to the exhaust system to minimise emissions. The key after-treatment technologies that can be applied under the Euro VI regulations are summarised in Table 7 below.

Table 7 Summary of the new after-treatment technologies for NO_x and particulates control in heavy-duty diesel vehicles. Source: adapted from Gense et al. (2006).

Name	Mode of operation	Advantages and disadvantages
Diesel Particulate Filter (DPF) technologies	Previously only for retrofit, filters are now available in factory fits	Used on engines with cooled EGR
- Closed DPFs	Ceramic or metal materials well suited to trapping soot particles	Filters become blocked unless soot is burned off (400-550°C), fuel consumption increases
- Open-flow DPFs	Can achieve lower fuel consumption	Lower soot trapping efficiencies
- Others	Ceramic Fibre, Ceramic Foam and Electrostatic Filter	Niche applications only
Particulate Filter Regeneration	Periodically regenerates the filter substrate to maintain efficiency	Difficult under low driving speeds, regular stop/starting and cold climates
Continuous NOX reduction		
- Lean NOX catalysis	Hydrocarbon is delivered from the engine or from exhaust fuel injection to achieve NOX reduction (.e., NOX becomes nitrogen, water and carbon dioxide)	Poisoning by fuel and oil sulphur, poor durability
- Selective Catalytic Reduction (SCR) with ammonia	Liquid urea (or alternative such as ammonium carbamate) is injected into the exhaust, and hydrolyses to form ammonia and CO ₂ , these then interact to achieve chemical NOX reduction	Performs best at low temperatures; but becomes temperature limited at 200°C, difficult to package on smaller vehicles, on heavy trucks, urea tanks require refilling almost as often as diesel tanks.
- NOX storage with periodic reduction	A rich gas mixture is used to remove NOX that has been temporarily stored and released	Temperature sensitive, performance in high-mileage engines (which are typical of heavy duty vehicles) is not clear.

4.4.2.1 Diesel Particulate Filters (DPFs)

Diesel Particulate Filters (DPFs) or traps work on the principle of introducing a porous barrier in the exhaust system. The key challenges with these products are careful design to avoid pressure losses, durability, and regeneration (Samaras, 1999). Since particles accumulate with time, they must be burned off: where this cannot be achieved through existing exhaust gas temperatures, other processes must be added to the system to achieve burn. These include the use one or a combination of auxiliary burners, fuel additives, catalytic coatings and oxidation by NO₂ (Samaras, 1999). However, where burning (regeneration) is done inappropriately, then the level of emissions reduction is

compromised and filters can be destroyed. If active regeneration is needed, a catalyst temperature of 220-250°C is necessary to burn hydrocarbons (Johnson, 2009).

DPF technology is now in a stage of optimisation and cost reduction (Johnson, 2008), with the products becoming increasingly sophisticated and efficient achieving up to 99% trapping of particulates (Sturm and Hausberger, 2005a, p. 53). Unfortunately, DPFs remain sensitive to ash emissions, because of additives used in lubrication oil (Sturm and Hausberger, 2005b). The use of DPFs in new vehicles is particularly advantageous, since retrofit of DPF usually leads to fuel economy penalty of between 1% and 3%. All U.S. truck engines have been fitted with platinum-based DPFs since January 2007 (Johnson, 2008), and aluminium titanate is also being considered, but cordierite remains the preferred substrate for heavy-duty applications (Johnson, 2009). These new filter materials and architecture (design) are likely to bring even greater reductions in PM emissions, but these need to be carefully considered in light of the cost barriers (Johnson, 2009).

4.4.3 EGRs and SCRs

In recent years, engine technologies have essentially shifted into two groups: the use of cooled exhaust gas recirculation (typically combined with open-flow DPF); or the use of selective catalytic reduction (Gense et al., 2006). Both technologies are useful in reducing emissions, but each has advantages and disadvantages.

Exhaust Gas Recirculation (EGR) devices work on the principle of depriving the engine of oxygen. This is achieved by capturing some of the exhaust gas and recirculating it back into the combustion chamber, resulting in the engine intake consisting of fresh air as well as the CO₂-rich exhaust product (Zheng et al., 2004). As this reduces the oxygen ratio in the cylinder, the peak combustion temperature is lowered, which dramatically reduces NO_x formation (Sturm and Hausberger, 2005b, p. 91). Where the exhaust gas is recycled directly, the process is known as hot EGR; alternatively, a cooled EGR system pre-cools the captured exhaust before reintroducing it. Cooled EGR offers further reduction in the combustion temperature, and thus reduces NO_x more effectively than the hot- EGR process (Zheng et al., 2004). EGRs can also be external (high- or low-pressure) and internal.

Unfortunately, there are a number of drawbacks with EGR systems. First, the implementation of EGRs in modern diesel engines is made difficult because of turbocharging (Zheng et al., 2004). Recirculation of the exhaust gas can also produce negative effects on the engine: for example, EGRs can create increased wearing of the piston-cylinder in diesel engines, and heavy use can result in energy efficiency losses and instability (Zheng et al., 2004). In addition, engine oils can become contaminated and/or degraded by the exhaust products used in the EGR, such as soot and particulates. For example, Aldajah et al. (2007) showed that engine oil degradation in a Cummins M-11 engine was accelerated by extra 3-8% when an EGR system was used; although this did not necessarily correspond with increased abrasive wear on the engine parts. Finally, high-pressure EGR systems are susceptible to fouling and corrosion (Sturm and Hausberger, 2005b, p 136).

More recent work in engine technologies has focussed on the use of Selective Catalytic Reduction (SCR) systems, which are typically based on urea. According to Koebel et al. (2004), urea-based SCR is widely considered to be the most promising way to reduce NO_x in heavy-duty diesel engines, and

these devices have been particularly well investigated by the German trucking industry. Urea-based SCR works by injecting dissolved urea into the exhaust, which begins a chemical reaction (the hydrolysis process) to remove NO_x . Here, the mix is converted into CO_2 and NH_3 (ammonia), and the ammonia product is then used to chemically reduce NO_x over a catalyst, thus creating N_2 and water. SCRs are temperature dependent, but can reduce NO_x emissions by more than 65% (Sturm and Hausberger, 2005b). In the past, SCR catalysts have been based on ceramic materials, but new developments in the Japan, US and European markets have witnessed the introduction of zeolite (e.g., copper or iron-based silicate minerals) or vanadia catalysts (Johnson, 2009, Johnson, 2008). In the future, hydrocarbon-based systems (HC-SCRs), may also provide for effective and low-cost NO_x reduction. HC-SCRs use fuel instead of ammonia to achieve the desired reaction, but work on this technology remains in its infancy (Johnson, 2009). There has also been recent interest in combining lean NO_x traps with SCR: this involves storing the ammonia that is generated in the trap, and using it in a downstream reaction to increase system efficiency (Johnson, 2008).

However, like EGRs, SCR systems are not without their limitations. Early-design SCRs had size and weight restrictions which rendered them suitable only for larger diesel trucks, though these have now been addressed. Many SCR systems are complex, requiring tank sensors to detect the urea level, temperature and quality, as well as the engineering of freeze-thaw expansion zones in the tanks (Johnson, 2009). As of the performance of SCR is temperature-dependent, the systems are less effective after cold-starts or during long idle-running times. There are also issues around inconvenience and regulatory compliance, since drivers need to periodically fill the urea tank to ensure it does not run dry (thus creating an emissions plume). Some systems require large volumes of catalyst and can be vulnerable to tampering. There is also a considerable challenge in ensuring the correct dosage rates are applied whilst driving. For example, urea has poor lubrication properties and this can lead to excessive wear, eventually causing incorrect injection quantities (Sturm and Hausberger, 2005b). It is also necessary for urea concentrations to be adjusted according to exhaust gas temperatures and the amount of NO_x exiting the system (Koebel et al., 2004). Finally, the expected price stability of urea into the future is also of concern, because of the volatility associated with the agricultural markets for fertiliser.

Both the EGR and SCR technologies will continue to evolve. However, ongoing changes to the Australian Design Rules as well as the Euro standards will be critical in influencing the types of technologies that are adopted in the market. For example, most major engine manufacturers met the Euro IV regulations by using EGR in combination with DPFs, despite the fact that this increased the running costs of vehicles. In contrast, the Euro V regulations – which had particularly stringent NO_x regulations – appeared to encourage the use of SCR (Gense et al., 2006). In Australia, Cummins has committed to the use of EGR as its core emissions reduction technology: this will be combined with Continuously Regenerating Technology (CRT) to traps and oxidize soot before turning it to ash (ATN, 2010). However, Cummins have also advised that SCR will be used in combination with EGR and common-rail fuel systems closer to 2014, subsequent to the next emissions changes under ADR80-03 (Cummins, pers. comm.).

4.4.4 Future directions

According to Johnson (2008), the current emphasis for engine developments in the US, European and Japanese markets is on low-temperature operations, reducing secondary emissions (e.g., ammonia and acids) and system optimisation. The next wave of engine evolution is therefore likely to involve thoroughly advanced engines with electronic engine management, two-stage turbocharging, ongoing developments in EGR and SCR, high peak cylinder pressures and high pressure common-rail fuel injection capability (Johnson, 2009). Post-2010, emissions studies are also expected to rely on improvements to traditional diesel engines, to address the problem that most fuel consumption in HHDEs is expended under high-load conditions (Johnson, 2009). Fortunately, this means transport companies can look forward to better fuel economy and emissions performances, as well cost decreases over time due to technical progress and mass production (Genese et al., 2006).

4.5 Other technological measures

There are a number of other measures that may assist in overall emissions reductions, including improved aerodynamics, tyre inflation control, wide-base tyres, tare-weight reduction, low-friction lubricants, reduce engine idling, start and stop technology, and the potential diffusion of electric-powered freight vehicles (Zanni and Bristow, 2010) (2002). In most cases, the individual contribution of each of these for emissions reductions in HHDEs remains unclear. An exception to this is aerodynamics (e.g., body shape, gap between prime mover and load, and sideskirts) and tyre inflation, which have been shown to result in reduced fuel consumption in the order of 30% (Ang-Olson and Schroeder, 2002).

4.6 Fuel alternatives and blends

The use of alternative and/or low-carbon fuels has good potential for emissions reductions (Samaras, 1999) (Kamakaté and Schipper, 2009). For example, Frey et al. (2009) conducted an urban case study and noted that even modest use of alternative fuel and propulsion technologies would result in 3-14% reduction in emissions. Similarly, the use of biofuels results in almost zero emissions of sulfates, and only a small CO₂ contribution, even when whole-of-lifecycle aspects are considered (i.e., production, processing and use of biofuels) (Carraretto et al., 2004). The existing range of diesel-fuel blends and alternatives available for use in the road transport sector, including biofuels, oxygenated fuels and CNG, LPG or LNG, and range and the availability of these is likely to increase as the transport sector is driven to create better carbon efficiencies.

However, a key consideration with any fuel alternatives and/or blends is the need to make engine modifications, run a hybrid vehicle or undertake specific fuel processing. For example, some products can be burned directly, but many require modification (such as transesterification, where fats are converted using an alcohol-based chemical process) for use in diesel engines (Coronado et al., 2009). Another important note (at least for ROTC), the that current Australian Code for the

Transport of Explosives by Road and Rail (AEC3)¹⁰ limits the use of particular fuel types when explosives are carried in sufficient quantities to be considered high-risk (category 3) loads (Safework Australia, pers. comm., and see Appendix B and C). In past years, many Australian explosives carriers have chosen to limit their operations to commercially available diesel motor fuel, thus limiting their ability to reduce emissions by exploring alternative fuels. However, the preference for standard diesel appears to be largely a safety precaution, since technical compliance with the AEC3 only requires that vehicles are compression ignition and powered by a combustible liquid: this allows for the possibility of a number of alternate fuel blends (Safework Australia, pers. comm.). For example, the National Transport Commission appears to be trialling biodiesel alternatives and it is possible that government incentives may become available to encourage the adoption of these, if they can be validated in real-world applications. Some of the diesel alternatives that may be considered as part of an overall strategy for emissions reduction are summarised below., not all of these fuels may be appropriate for use with explosives carrying.

4.6.1 Biodiesel (not including alcohol-bases)

Biodiesel has been one of the most closely-studied of the diesel fuel alternatives (Di et al., 2009), and studies on biodiesel continue to increase due to the role that biofuels are expected to play helping to address emissions from road transport (Lapuerta et al., 2008). Biodiesel can be defined as fuels created from methyl esters of vegetable oil (Carraretto et al., 2004). Essentially, biodiesel can be based on plant oils, animal fats, or recycling cooking oils, with typical examples being canola, soy and a host of other products including castor, rapeseed, sunflower and other vegetable oils (Karabektas, 2009, Yanowitz and McCormick, 2009) as well as biomass and biogas (Coronado et al., 2009). Many of these are advantageous in being renewable, locally available, cheap and less polluting (Karabektas, 2009). They also offer cold-weather operability and in some cases, performance benefits (Yanowitz and McCormick, 2009). Biodiesel can easily be used in heavy-duty vehicles without operating complications, and standards are already in place for the use of biodiesel intended for use in fuel blends (e.g., ASTM D6751 for the USA, or EN14214 for European nations) (Yanowitz and McCormick, 2009). However, care must be taken to ensure proper storage (Sturm and Hausberger, 2005b).

Biodiesel is very attractive in terms of emissions, however, it is difficult to generalise these effects, because the nature and extent of these gains is variable according to different pollutants (emissions categories), engine type, speed and load scenarios and ambient conditions, as well as simply the origin and quality of the biodiesel product and its blend ratio (Lim et al., 2007). Usually, however, the high oxygen content of biodiesel improves the combustion properties of the fuel, and thus the level of CO emissions (Karabektas, 2009). Guarieiro et al. (2009) examined 45 different fuel blends and reported CO₂ decreases in the range 5-24% at high speeds. Studies on North American HD diesel engines showed that a 20% biodiesel blend both reduced CO and particulate matter emissions by 10-

¹⁰ AEC3 (3rd edition), 2009.

20%, regardless of the model (year of manufacture) or fuel injection type (Yanowitz and McCormick, 2009). Biodiesel blends can also reduce hydrocarbon emissions (Di et al., 2009).

Unfortunately, since NO_x emissions are linked to the oxygen content, the use of highly-oxygenated fuels biodiesel typically results in higher NO_x emissions (Graboski et al., 2003). The NO_x behavior of biodiesel blends is complex, as the effects of biodiesel on NO_x vary with driving cycle (Yanowitz and McCormick, 2009). Nevertheless, according to Lapuerta et al. (2008), around 85% of the existing papers agree that there is an increase of NO_x emissions when using biodiesel. Yanowitz & McCormick (2009) considered two principal reasons for this: one, as a result of timing changes linked with fuel injection and/or combustion, and the other, a result of the inherent combustion properties of the biodiesel itself. Emissions increases due to the former can be addressed through engine design and calibration (Yanowitz and McCormick, 2009). It has also been suggested that the characteristics of the injected fuel – parameters such as droplet size, evaporation and viscosity, amongst others – can help to explain the NO_x increases for biodiesels (Lapuerta et al., 2008).

Biodiesel also has other disadvantages: one is the penalty in fuel economy, another is that the long-term effects of biodiesel use on engines is poorly known (Lim et al., 2007). The use of vegetable oils can be linked with eventual engine failure, since the chemical composition of such oils does not necessarily make them suitable for use in diesel engines (Karabektas, 2009). At low temperatures, the properties of biodiesel are less favourable than those of diesel oil (Carraretto et al., 2004): whilst biodiesel fuels have higher lubricity (e.g., lubrication properties) than conventional fuels, they can also result in deposits that can degrade engine parts and/or clog filters (Lim et al., 2007). Also, the use of biodiesel may be associated with by-products and deposits that can affect tanks, fuel systems and filters (Carraretto et al., 2004). Biodiesel has also been associated with lower effective performance (reduced torque and power), although Lapuerta et al. (2008) concluded that this is only true for full-load conditions or at full acceleration, and that it may be quite small overall (e.g., 3-5%).

Unfortunately, another problem is that many recent technological advancements (such as common rail and electronic fuel injection) appear to have made little progress in designing engines that are better adapted for biodiesel (Yanowitz and McCormick, 2009). The impacts of biodiesel on the functioning and longevity of new emission control technologies (e.g., particle filters and catalysts) are also unclear (Yanowitz and McCormick, 2009). For example, it appears that biodiesel can accumulate in engine lubricants if the injection timing is adjusted to divert fuel to these applications. This remains an area for future research.

initial arrangements under the proposed Australian emission trading scheme were for the combustion of biofuels to be granted a zero Scope 1 emission rating (ATA, 2008); and the European 'Biofuels Directive' nominated that 5.75% of fuel used by 2010 should be biodiesel. Despite this, Yanowitz & McCormick (2009) have reported that less than 1% of the total fuel use of the USA and Europe is represented by biodiesel. A possible reason for this is the 'uncertainties [that] still exist about the real potentialities of biodiesel as a substitute of diesel oil ... the results reported in the literature seem to be often restricted to the specific analyses and scenarios (Carraretto et al., 2004, p. 2196). For example, Sturm & Hausberger (2005a) reported that results were very uneven between different studies. However, according to Karabektas (2009), the variability in results from biodiesel trials may be at least partly attributed to engine modifications, the fuelling method (neat compared with diesel blend), as well as the test procedures and test conditions. Certainly,

information on biodiesel remains difficult to summarise, given the variety of possible combinations of feedstocks, different engine technologies, and driving conditions that can (and have been) tested (Lapuerta et al., 2008). For example, the existing trials on biodiesel have included those for on 2-20% blends, but sometimes including pure biodiesel fuels, depending on the source product (Coronado et al., 2009).

4.6.2 Alcohol-based blends (ethanol, methanol)

Alcohol-based fuels have a number of advantages when compared with diesel:

- low viscosity, therefore being easily to inject and mix with air;
- less emissions, because of the high oxygen content and lower combustion temperature; and
- high evaporative cooling; thereby allowing better engine efficiency (Sayin, 2010).

However, alcohols seem less well suited to diesel blends than other fuels such as biodiesel, and this means that specially designed engines or ignition improvers are generally required (Samaras, 1999). The lubricity and viscosity of the fuels are also important considerations, since these will affect the durability of the diesel engines in which they are used (He et al., 2003).

Diesel-ethanol (DE) and diesel-methanol blends of 5, 10 and 15% blends (by volume) have been commonly trialled (Domínguez et al., 2005, Sayin, 2010), but some studies have involved blends of up to 25-30% (e.g., Huang et al., 2009).

Like biodiesel, alcohol blends are advantageous in terms of emissions: one study has shown that CO₂ emissions could be cut by almost one-third by an ethanol blend containing 83-94% diesel, 5-15% ethanol, 1-3% additive and a small quantity of cetane improver (Ahmed, 2001 in He et al. 2003). However, the change in emissions profile created by the use of ethanol blends is dependent on engine operating conditions, the ethanol content (blend ratio), and whether additives and ignition improvers have been used (He et al., 2003). For example, DE blends perform differently under different load situations: at thigh loads, blends reduce smokes, NO_x and CO₂; but these gains are not as obvious at low loads (He et al., 2003). Other studies have shown that DE blends result in decreased smoke and PM emissions, with variable effects on CO, NO_x and HC emissions (Di et al., 2009), whilst the use of additives and/or cetane improver to keep the blends stable may reduce particulate emissions (He et al., 2003).

In terms of disadvantages, the development of ethanol blends has languished because of problems with poor fuel economy and low ignitability (He et al., 2003).

Methanol is a slightly different product that can be obtained from many materials where decomposition results in CO and hydrogen products (Sayin et al., 2009). These include feedstocks such as natural gas (a major source), wood; and agricultural, waste and municipal biomass. Methanol has a lower energy content than diesel fuel, and so more product is needed (compared with diesel) to supply the same amount of power (Sayin et al., 2009). However, methanol extracts heat as it vaporises, which lends it to have a cooling effect, thus reducing NO_x emissions (Sayin et al., 2009). It has poor ignition behaviour due to its low cetane number (cetane being a measurement of the combustion quality of a fuel). This can cause ignition delay but has benefits in being safer to transport and store (notwithstanding the lower flash point) (Sayin et al., 2009). Phase separation can

also occur when methanol and diesel are blended; this can be overcome by user a mixer inside the fuel tank (Sayin et al., 2009).

Studies on DE and methanol-diesel have been undertaken to check effects of the blends on performance and exhaust emissions: both blends were shown to increase brake-specific fuel consumption and NO_x emissions (non-turbocharged engines), whilst smoke, carbon monoxide and hydrocarbons decreased (Sayin, 2010).

4.6.3 Gas

Gas alternatives for some HDDEs include compressed or liquefied natural gas (CNG or LNG) and hydrogen blends. CNG compares favourably with like-purpose diesel engines during the Euro II era, but performance can be quite variable in emissions performance depending on manufacturer, trip type and test cycle (Sturm and Hausberger, 2005b). For this reason, and because of the lower volume of production, calculated emissions factors for gases are often laborious and expensive (Sturm and Hausberger, 2005b). Nevertheless, Graham et al. (2008) reported that the use of gas can reduce tailpipe emissions by 10-20% when compared with diesel fuel. Jayaratne et al. (2010) also reported that the emissions rate from diesel buses were about 15-20% greater than for buses run on CNG, regardless of speed. Natural gas heavy-duty vehicles (NGVS) feature much lower particulate matter emissions, but have additional costs due to extra engine components, specialised fuel bottles/body reinforcing and maintenance costs (Gense et al., 2006). The use of natural gas also requires the replacement of a standard diesel engine with a spark ignition gas engine, which have complex refuelling systems and large tank size requirements (e.g., four times the size of traditional diesel tanks) (Samaras, 1999). There must also be gas readily available at existing fuelling stations before this fuel to be considered as a viable alternative to diesel.

Liquified petroleum gas (LPG) is also cleaner fuel, but has low efficiency, and this must be considered in the wider context in greenhouse gas emissions (Samaras, 1999).

4.6.4 Other

- Dimethyl ether (DME) fuel is produced from sources such as natural gas, coal or biomass, but has very low particle emissions and does not require after-treatment (Samaras, 1999). DME is liquid at low pressure, and can be used by diesel engines, but work on the fuel is still in the experimental stages (Samaras, 1999).
- Studies of the use of electric-propelled cars (e.g., advanced plug-in hybrids) in the freight industry are in their infancy and more research needs to be focussed on this area (Frey et al., 2009).

4.7 Emissions modelling for alternative fuels

Using the NGERs default emissions factors, estimates for one million litres of fuel (or equivalent) show that a switch to pure biodiesel could reduce emissions (and thus carbon costs) of the ROTC fleet by more than 95%, whilst CNG would achieve a one-fifth reduction (Table 8).

Table 8 Scope 1 emissions comparisons for standard diesel, biodiesel and CNG fuels. Calculations are based on NGERS default emissions factors.

Conventional Diesel [#]	Calculations	Emissions
<i>Kilolitres or GJ/m³</i>		<i>1,000</i>
CO ₂ (tonnes)	KL x 38.6 x 69.2 / 1000	2671
Methane (tonnes)	KL x 38.6 x 0.05 / 1000	1.93
Nitrous oxide (tonnes)	KL x 38.6 x 0.5 / 1000	19.3
TOTAL Emissions		2692
Biodiesel [^]	Calculations	Emissions
<i>Kilolitres or GJ/m³</i>		<i>1,090</i>
CO ₂ (tonnes)	KL x 34.6 x 0 / 1000	0
Methane (tonnes)	KL x 34.6 x 1.2 / 1000	45
Nitrous oxide (tonnes)	KL x 34.6 x 2.2 / 1000	83
TOTAL Emissions		128 ↓95.2%
CNG ^{^^}	Calculations	Emissions
<i>Kilolitres or GJ/m³</i>		<i>1,000,000</i>
CO ₂ (tonnes)	[39.3 x 10 ⁻³ GJ/m ³] x 51.2 / 1000	2012
Methane (tonnes)	[39.3 x 10 ⁻³ GJ/m ³] x 2.1 / 1000	82
Nitrous oxide (tonnes)	[39.3 x 10 ⁻³ GJ/m ³] x 0.3 / 1000	12
TOTAL Emissions		2106 ↓21.7%

Euro V diesel oil in transport applications; ^ for transport applications, based on the assumption that specific fuel consumption for biodiesel is approximately 9% higher than conventional diesel on a volume basis (Lapuerta et al., 2008); ^^heavy duty vehicles, transport applications, and assuming that the energy value of one cubic metre of CNG is similar to the energy value of one litre of diesel.

4.8 Other options for emissions reduction

Clearly, optimising vehicle routing for supply/delivery can help to reduce fuel consumption and therefore emissions. In urban freight scenarios, this can generate substantial savings, but the gains may be much less over long-haul journeys (Zanni and Bristow, 2010). Better matching of truck size and capacity to the cargo load and type also offers the ability to reduce emissions (Kamakaté and Schipper, 2009).

Knowledge on driving behaviour and traffic situations will also continue improve in the future (Sturm and Hausberger, 2005a). McKinnon & Piecyk (2009) also acknowledged the opportunity to use telemetry applications and data to help model more accurately, the relationships between road and traffic conditions and emissions. For example, real-time monitoring of vehicle location, speed and instantaneous fuel consumption (as opposed to trip-averaged fuel efficiency) would enable operators to identify high-emissions journeys and behaviour. Thus, the existing datasets held by Industree, and those that may become available in the future, should allow ROTC to use them as tools to monitor the overall fleet performance, begin driver education, and identify further ways to reduce high-emissions practices and journeys.

5 Research gaps and priority areas

According to McKinnon & Piecyk (2009), ‘the carbon auditing of freight operations is a relatively new science, with methods of data collection and manipulation still evolving’. As early as 1991, the CORINAIR working group noted that significant challenges were associated with calculating road emissions calculations, due to the environment whereby technological advances in engine and fuel performance combine with changed road surfaces and dynamic traffic conditions to result in substantial differences in emissions outputs. Thus, estimating emissions from road traffic is a task that will require frequent updating, given the large and rapid changes in this sector over short time periods. Default emissions factors continue to be adjusted as new information comes to hand. However, there has also been the suggestion that as technology improves, and emissions become fewer, they will be harder to accurately/precisely sample and test (Sturm and Hausberger, 2005a).

In 1991, the CORINAIR working group identified research and methodological deficiencies around:

- descriptions of, and corrections for, different driving behaviour (e.g., average trip distance and number of trips per day);
- corrections for local differences (e.g., regional terrain, climatic conditions and speed limits); and
- the influence of cold-starts on emissions, especially in heavy-duty vehicles.

Since then, Ntziachristos & Samaras (2003) and Ntziachristos et al. (2004) have identified a number of further areas in which research should be prioritised. Of these, the most relevant to HDDEs include:

- better understanding of the number and size of particles (which can help to distinguish diesel emissions from other sources) and how to control them);
- cold-start modelling (including introducing a new emissions test at -7°C);
- estimations of the heavy metal content of exhaust emissions due to fuel, lubricant and engine attrition;
- independent estimations, e.g. nation-wide surveys, of the total annual mileage driven on the different road classes by different vehicle categories;
- methodology and statistical input for estimating the spatial allocation of vehicle emissions and trip statistics; and
- statistical calculation of total uncertainties for the estimation of emissions.

Most recently, Kousoulidou et al. (2010) called for the prioritisation of research effort in the areas of:

- NOX emissions from new truck technologies (e.g., emissions factors specific for Euro V vehicles that will be fitted with SCRs and DPFs);
- cold-start studies (for VOCs; and
- methane production from the use of compressed natural gas (CNG).

The importance of cold-start emissions is a clearly a recurring theme in these lists. However, perhaps the most outstanding research gap is the real-world validation of existing emissions studies.

Prior to 2000, much discussion was focussed on the use of steady-state versus transient test cycles in developing emissions factors, and the trade-offs between real-world applicability and the demands of ongoing testing (Samaras, 1999). A decade later, this is still the largest problem restricting emissions studies. Unfortunately, the cost of dynamometer studies (particularly for heavy vehicles) often precludes the use of large test sets, and this leads to poor rigour in the datasets. Moreover, figures are only representative when the vehicles are driven under similar driving conditions to those used in the tested driving cycle. Whilst this can be improved through studies that involve careful design of the test profile (e.g., starts, stops, constant speed cruises, and acceleration)(Kousoulidou et al., 2010), real-world validation is still needed. Despite this, real-world studies appear to be rarely completed (Frey and Unal, 2002).

The challenges facing those people studying vehicle emissions are compounded by frequent changes in vehicle regulations, and thus the number of new technologies reaching the market. Sturm & Hausberger (2005a) have already acknowledged that the high technical standards that will be brought about by iterations of the current Euro emissions regulations will mean a widening gap between the capabilities of approved emissions tests, and real-world emissions behaviour. There have also been periodic changes in the standard test cycles through which emissions factors are calculated; this can make it difficult to compare across years and get a sense of how technologies and test patterns are travelling. This problem may be addressed in part by the European Commission, who have adopted a World Harmonised Transient Cycle (WHTC), an attempt at using consistent test cycles across all countries (Johnson, 2008).

If effective policies are to be developed to reduce the carbon- ntensity of the road-transport sector, then ongoing refinement of study methods, as well as the collection of reliable and realistic data across many different driving conditions, is essential (Zachariadis and Samaras, 2001). In future, this is likely to mean a much wider use of PEMS and other on-board systems and samplers that can be used during actual driving. Unfortunately, it is not clear that such studies are being actively pursued in Australia.

6 Recommendation: ROTC's lower-carbon future

A mix of technological, operational and behavioural changes can be used by ROTC in response to the pressures of changing emission regulations, carbon reporting, and growing environmental awareness by the customer base¹¹.

Advances in engine technologies and fuel reformulations to achieve greater efficiencies have always been a part of the road transport business. However, companies such as ROTC should look forward to even deeper cuts in emissions, driven by the economic trigger of emissions trading schemes and increasingly more stringent emissions standards. For example, correspondence with Cummins shows that the EGR truck model currently used by ROTC is compliant with the exhaust emissions set by the 2008 version of the Australian Design Rules (ADR 80/02), which allow for a ceiling of 0.1 grams of particulate matter/hp-hr, and of approximately 3 grams NO_x/hp-hr. In contrast, emissions standards will change substantially under the 2011 version of the rules (ADR80/03) with vehicles expected to perform in the range of < 0.01 grams for particulate matter and < 2.5 grams of NO_x. Further rulings to enhance emissions performance are expected in the 2015 revision. The rapid fleet turnover already achieved by ROTC will therefore help to ensure that these new technologies are readily incorporated into the fleet. However, these new technologies may be accompanied by fuel consumption penalties, and the net change in emissions resulting from these cleaner, but less fuel-efficient models is unclear. Furthermore, unless ongoing research on these new technologies is available to inform and refine the calculations of emission factors under NGERs (and other methodologies), then it seems unlikely that engineering advancements alone will provide a reduction in reportable greenhouse gas emissions.

ROTC is also likely to benefit from the growth in online fuel and emissions databases, such as that provided by BP. The information contained in these reports is useful and helps to provide the case and evidence for reporting under NGERs Method 2. Currently, however, there is no quick method of translating this information into a format ready for OSCAR. Thus, a working relationship between fuel suppliers, transport companies and the DCCEE could help to further refine and streamline reporting.

In summary, ROTC can achieve further reductions in emissions, as well as more accurate reporting of those emissions, by:

1. transitioning to the NGERs Method 2 for annual reporting, including working with the fuel manufacturers to identify more streamlined ways of gathering the necessary data;
2. working with their satellite-tracking technicians to create more value from the existing GPS datasets. This will allow a deeper understanding of the key influences on fuel consumption and therefore, greenhouse emissions across the fleet. For example, future work could involve:
 - setting benchmarks and monitoring performance (e.g., for individual staff and for different vehicles);

¹¹ Scope 1 emissions only, options for reducing scope two (e.g., electricity consumption and disposed paper) or scope three emissions have not been considered as part of this report.

- identifying and minimising journeys with poor fuel economy, high carbon emissions and low profit margins, including reconsidering the use of those freight routes that appear to be more carbon-intensive; and
 - explore further the development of GPS and associated systems (e.g., CANbus) for emissions measurement and controls;
3. working with engine manufacturers to assess the suitability of different engine technologies (e.g., SCR versus EGR) for their ability to further reduce emissions from the ROTC fleet;
 4. evaluating options for diesel alternatives and/or blends (e.g., biodiesel). Given the logistical challenges associated with rescheduling fleet runs, the separation of the fleet into trucks that can, or cannot, handle explosives is non-viable. Rather, ROTC needs to have the ability to have any truck in the fleet available for a mix of freight purposes, including explosives carrying. Notwithstanding this, it is possible that changes to the explosives code and/or new development in fuel alternative will provide an option that is both less carbon-intensive and also suitable for explosives-transport applications;
 5. considering the value of installing PEMS or similar devices on representative trucks as part of a R&D program designed to capture real-time, real-world emissions data.

This combination of activities will help to reduce the actual and reportable emissions from ROTC operations, as well as help to improve business efficiency and profits. Furthermore, ongoing work by ROTC will help to provide the first baseline data relating to real-world emissions from HDDEs in the Australian transport sector.

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Appendix A

Calculations for revised emissions factors for BP standard diesel product, as supplied to ROTC Queensland operations, July-December 2008.

$$E = (Q \times EC \times EF) / 1000$$

Where E = emissions (CO₂-e tonnes)

Q = quantity of fuel (kilolitres)

EC = energy content (Gj/m³)

EF = carbon dioxide emission factor (CO₂-e Gj)

1. Firstly, the EC (energy content) of the fuel changes from the default value of 38.6 GJ/m³, to the BP specification of **38.41** GJ/m³
2. Secondly, the standard EF (carbon dioxide emission factor) has a default value of 69.2, but can be altered using the method allowed for in section 2.43 of the National Greenhouse and Energy Reporting (Measurement) Determination guideline (2008), as follows:

$$EF = (Ca/100) \times OF \times 3.664 \quad [Ca = \text{Carbon in the fuel} \quad OF = \text{oxidation factor } 0.99]$$

$$\therefore EF = (85.5/100) \times 0.99 \times 3.664$$

$$\therefore EF = 3.1$$

To express EF in terms of kg CO₂ per Gj, the following formula is used:

$$EF = EF / (EC/C) \quad [\text{where } C = \text{fuel density, kilograms per kilolitre}]$$

$$EF = 3.1 / (38.41/835)$$

$$EF = 67.39$$

Appendix B

Excerpt from the Australian Code for the Transport of Explosives by Road and Rail Third Edition (AEC 3)

Definitions - Combustible liquid - means a combustible liquid within the meaning of AS 1940;

“Flammable liquids” are liquids, or mixtures of liquids, or liquids containing solids in a solution or suspension (such as paints, varnishes, lacquers, etc; but do not include substances which, on account of their other characteristics, have been included in other Classes), which give off a flammable vapour at or below 60°C closed-cup test (corresponding to 65.6°C open-cup test), normally referred to as the flashpoint.

This also includes:

- (a) liquids offered for transport at temperatures at or above their flashpoint; and
- (b) substances transported or offered for transport at elevated temperatures in a liquid state, which give off a flammable vapour at temperatures equal to or below the maximum transport temperature;

“Flashpoint” means the lowest temperature, corrected to a barometric pressure of 101.3kPa, at which application of a test flame causes the vapour of the test portion to ignite under the specified conditions of a test;

Additional Requirements for Special Vehicles

(1) The requirements of this Section apply only to vehicles carrying explosives in a quantity sufficient to qualify for inclusion in **Category 3**, and do not apply to vehicles registered by the Department of Defence.

- (2) Road vehicles must be approved, and comply with the following requirements:
- A. the vehicle engine must be a compression ignition engine which uses a combustible liquid as a fuel; and
 - B. the vehicle fuel tank may be located to the front or rear of the vertical firescreen, but if located to the rear of the firescreen, it must be:
 - C. mounted below the horizontal firescreen;
 - i. protected so that the likelihood of accidental damage is minimal; and
 - ii. designed to prevent accumulation of spilt fuel on any part of the vehicle.

Appendix C

Excerpt from the Australian Standard 1940 - 2004: The storage and handling of flammable and combustible liquids

DEFINITION - Combustible liquid – Any liquid, other than a flammable liquid, that has a flash point, and has a fire point that is less than its boiling point.

For the purpose of this standard, combustible liquids are divided into two classes as follows:

Class C1 – A combustible liquid that has a flash point of 150°C or less.

Class C2 – A combustible liquid that has a flash point of greater than 150°C.

Notes:

1. The boiling point is that point at which it is no longer possible to achieve the rate of temperature required by ISO 2592 for the determination of fire point.
2. ISO 2592, IP 36 and ASTM D92 are technically equivalent test methods for the determination of flash and fire point by Cleveland open cup tester.

Flammable liquids – Liquids or mixtures of liquids, or liquids containing solids in a solution or suspension (e.g. paints, varnishes, lacquers, etc; but not including substances otherwise classified on account of their dangerous characteristics) which give off a flammable vapour temperatures of not more than 60.5°C, closed-cup test, or not more than 65.6°C, open-cup test, normally referred to as the flash point.

This class also includes -

- (a) liquids offered for transport at a temperature at or above their flash point; and
- (b) substances that are transported or offered for transport at elevated temperatures in a liquid state and which give off a flammable vapour.

Class 3 Flammable Liquids are divided into 3 packing groups as follows and as summarised in Table 9.

- PGI – high danger; initial boiling point $\leq 35^{\circ}\text{C}$.
- PGII – medium danger; flash point (closed cup) $< 23^{\circ}\text{C}$; initial boiling point $> 35^{\circ}\text{C}$.
- PG III – low danger; flash point (closed cup) $\geq 23^{\circ}\text{C} \leq 60.5^{\circ}\text{C}$, initial boiling point $> 35^{\circ}\text{C}$.

Table 9 Hazard groupings based on flammability

Packing Group (PG)	Flash Point (closed-cup)	Initial boiling point
I	–	$\leq 35^{\circ}\text{C}$
II	$< 23^{\circ}\text{C}$	$> 35^{\circ}\text{C}$
III	$\geq 23^{\circ}\text{C} \leq 60.5^{\circ}\text{C}$	$> 35^{\circ}\text{C}$

Note: Reference should be made to the ADG Code

Flashpoint - the lowest temperature, corrected to a barometric pressure of 101.3 kPa, at which application of a test flame causes the vapour of the test portion to ignite under the specified conditions of test.

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