LIFE CYCLE EMISSIONS FROM CARS USING AVAILABLE FUELS - THE AUSTRALIAN SITUATION

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ABSTRACT

Of the Australian passenger fleet of 10.4 million vehicles, Liquefied Petroleum Gas (LPG), which is readily available throughout the country, powers 225,700. Australia also has an equivalent number (295,700) of diesel vehicles under 3.5 tonnes, primarily four-wheel drive vehicles [1].

The full fuel cycle of atmospheric emissions (known as exbodied emissions) incorporates emissions involved in manufacturing and transporting the fuel, as well as the emissions involved in combusting the fuel. Exbodied emissions of dedicated OEM LPG cars are less than those of equivalent cars using unleaded petrol for greenhouse gases, hydrocarbons, oxides of nitrogen, and particulate matter. Diesel vehicles emit less greenhouse gases and carbon monoxide, but more particulate matter.

As standards decree lower emission limits, vehicle manufacturers and catalyst manufacturers will find it harder to comply. This means that it will be harder to optimise a vehicle to produce low emissions for two separate fuels. We conclude, however, that dedicated LPG vehicles will be able to maintain both lower tailpipe emissions, and lower exbodied emissions, than petrol vehicles.

INTRODUCTION

Beer et al. [3] studied the full fuel-cycle of greenhouse gas emissions from alternative fuels in Australian heavy vehicles, whereas Beer et al. [4] extended the methodology to examine the use of ethanol in light vehicles. This study examines other light vehicle fuels, especially LPG, which has been used as an automotive fuel in Australia since the 1960s. It is the most widely available "alternative fuel" in this country, and it has been claimed [2] that Australia has the best refuelling infrastructure in the world. There are over 3,500 service stations over the whole length and breadth of Australia that are equipped with LPG dispensing systems, allowing vehicles operating on LPG virtually unrestricted travel through Australia.

This paper examines LPG (on a mass emissions per kilometre travelled basis) with respect to its life-cycle emissions of greenhouse gases and particulate matter when used as a fuel in Australia for light vehicles. The emissions of other pollutants may be found in Beer et al. [4]. The use of LPG as propane, as autogas (propane and butane) and as a propane-butane plus olefins mixture (represented as LPG QLD) is examined in two vehicle types: second generation (2G) LPG vehicles that have electronic control, and third generation (3G) LPG vehicles that combine advanced fuel injection technologies with advanced electronic management features. Anyon [1] in Appendix A provides more details as to the differences between first, second, third and fourth (future) generation LPG technologies. The emissions are compared to those of petrol, diesel and compressed natural gas (CNG) vehicles.

METHODOLOGY

The study uses the international standards framework for conducting life-cycle analysis contained in the ISO14040 series [7]. A full fuel-cycle analysis of emissions takes into account not only direct emissions from vehicles but also those associated with the fuel's: extraction; production; transport; processing; conversion and distribution. Fuels are compared on the basis of the mass of emissions per kilometre of distance travelled. This figure, though environmentally more meaningful, is subject to greater variability than the mass of emissions per unit energy. Both upstream (pre-combustion) emissions and downstream (tailpipe, or combustion emissions) are considered. We use the term "exbodied emissions" to refer to the cumulative upstream and downstream full fuel-cycle emissions.

International results were used to supplement the small amount of available local data on tailpipe emissions for the majority of the fuels studied. The aim of the study is to examine how the vehicle and fuel mix determines and characterises the greenhouse gas and particulate matter emissions.

For comparison, we normalise to a large family vehicle of mass 1,594 kg, and a common test cycle (ADR79/01 also known as the Euro3 Drive Cycle or EDC). Data sets used for the study are the Australian CVES [5] and the European Emission Testing Program data, EETP [9].

The CVES study provides data on unleaded petrol (ULP), some data on premium unleaded petrol (PULP) in ULP vehicles, and LPG data. It is based on a range of vehicle sizes from small 4 cylinder vehicles up to light commercial vehicles and recreation vehicles. It also has a mix of European, Asian and Australian built vehicles.

The EETP program gives data on PULP vehicles conforming to Euro4 emission standards, 3rd generation LPG vehicles, a compressed natural gas (CNG) vehicle and a range of new diesel vehicles. The two data sets share a common test cycle (ADR79/01) but no identical vehicles were used in both tests, and the average size of vehicles tested in the European data set is smaller than that used in the CVES data set. To make a fair comparison, the emissions measured in the EETP data set can be adjusted to account for heavier vehicles used as the baseline for this study. To achieve this, the relationship between vehicle mass and CO_2 emission was established for the two tests (i.e. CVES and EETP). The results indicate that the carbon dioxide emissions (CO_2-e) to be expected from a typical Australian family car of 1,594 kg mass undergoing the ADR 79/01 drive cycle, are 242 g/km for a petrol vehicle, 195 g/km for a diesel vehicle, and 217 g/km from an LPG vehicle. The inferred fuel energy loads to which these emissions correspond are 3.54 MJ/km, 2.81 MJ/km and 3.56 MJ/km respectively.

RESULTS

Details of the upstream emissions are given in Beer et al. [4]. This section summarises the tailpipe emissions. Table 1 presents carbon dioxide emissions from European testing results for Euro2, 3 and 4 petrol and LPG cars [1] as well as Euro4 diesel cars [8]. Figures 1 and 2 summarise both the tailpipe and upstream emissions of CO_2-e and PM.

There are few data available on the emissions of methane (CH_4) and nitrous oxide (N_2O) from LPG vehicles. Weeks et al. [11] examined 76 vehicles from the Australian in-service passenger fleet and tested them according to the ADR 37/00 drive cycle. The results of this testing program are given in Table 2 for methane and nitrous oxide, along with the default emission values recommended by the Australian National Greenhouse Gas Inventory Committee (NGGIC). It is noticeable that the emissions depend on the pollution control device fitted to the car. For both LPG and ULP, the use of three way catalysts produces the largest emissions of nitrous oxide, but the lowest emissions of methane. When catalysts are used then the emissions from LPG vehicles are always less than those from petrol vehicles. By contrast, an ADR 37 vehicle that lacks a catalyst emits similar amounts of methane and nitrous oxide whether petrol or LPG powers it.

Table 3 reproduces the measurements of N_2O given in the final report of the EETP programme [8]. The document notes that nitrous oxide emissions are generally very low, and often under the detection limit of the instruments that were used. It is noteworthy that the EETP emissions are substantially lower than those of Table 3. It is not clear whether the reason for this lies in catalyst technology, fuel differences or the different drive cycles.

	Mode	Car Type	Drive cycle	CO_2
Petrol	Euro2	Vauxhall Vectra	ADR 79/00	199
LPG	Euro2	Vauxhall Vectra	ADR 79/00	170
LPG/Petrol ratio	*Euro2*	*Vauxhall Vectra*	*ADR 79/00*	*0.85*
Diesel	Euro3	Vauxhall Vectra	ADR 79/01	162.1
Petrol	Euro3	Vauxhall Vectra	ADR 79/01	179.1
LPG	Euro3	Vauxhall Vectra	ADR 79/01	158.7
LPG/Petrol ratio	*Euro3*	*Vauxhall Vectra*	*ADR 79/01*	*0.89*
Diesel	Euro4	EETP dual-fuel	EDC	161.5
Petrol	Euro4	EETP dual-fuel	EDC	197.9
LPG	Euro4	EETP dual-fuel	EDC	174.2
LPG/Petrol ratio	*Euro4*	*EETP dual-fuel*	*EDC*	*0.88*
Diesel	Euro4	EETP dual-fuel	Artemis	170.9
Petrol	Euro4	EETP dual-fuel	Artemis	193.4
LPG	Euro4	EETP dual-fuel	Artemis	172.6
LPG/Petrol ratio	*Euro4*	*EETP dual-fuel*	*Artemis*	*0.89*

Table 1: Euro2 (Vauxhall Vectra) emission results (g/km)

Emission control	Gas	LPG	ULP
3-way catalyst	CH_4	34	24
no catalyst	CH_4	97	107
NGGIC	CH_4	87	100
3-way catalyst	N_2O	12.9	43
no catalyst	N_2O	5.3	4.5
NGGIC	N_2O	7.9	25.0

Table 2 Methane and nitrous oxide emission rates (mg/km) – ADR 37/00

As part of the European Test Programme of 2003, the particulate matter emissions from a Nissan Primera were tested. A petrol, diesel and LPG vehicle were examined at the TUV Rheinland testing facility in Germany. Particle concentrations were measured using an

Electrical Low Pressure Impactor (ELPI) that enables real time particle size distribution and concentration measurements in the 30 nm to 10 µm a size range. To compare Euro4 vehicles on this basis, we converted the unpublished ELPI data from TUV to mass data. The results are given in Table 4.

	Diesel	**LPG**	**PULP**
EETP (CADC)	5.99	1.98	2.14

Table 3 Nitrous oxide emission rates (mg/km) – Artemis Drive Cycle

The emissions of PM10 particulate matter from the LPG vehicle are always well below the emissions from petrol and diesel vehicles. The LPG emissions under the Artemis drive cycle (CADC) were particularly low, being one thousandth of the equivalent petrol emissions.

Drive cycle	Diesel emissions (g/km)	Petrol emissions (g/km)	LPG (Autogas) emissions (g/km)
ADR 79/01	1.69	7.36×10^{-2}	9.16×10^{-3}
ADR 79/00	3.67	2.93×10^{-2}	2.06×10^{-3}
Artemis	0.434	2.72×10^{-2}	2.67×10^{-5}

Table 4: PM10 emission results for a Nissan Primera (unpublished TUV data)

Figures 1 and 2 indicate that on a full-fuel cycle basis, exbodied LPG (propane and autogas) emissions are below those of equivalent petrol emissions for greenhouse gases and for particulate matter. On the basis of the LPG emission factors given in Watson and Gowdie [1], the same results would hold for autogas with olefins. Although not presented in this paper, it is worth mentioning how the fuels compare to each other in terms of exbodied CO, HC, and NO_x emissions. LPG produces higher CO emissions than petrol, diesel, and CNG. Petrol and diesel have the highest NO_x emissions and diesel displays the lowest hydrocarbon emissions. LPG has comparable HC emissions to CNG, and they are lower than petrol. Details of the calculations are provided in Beer et al. [5].

CONCLUSION

Exbodied emissions of dedicated OEM LPG cars are less than those of equivalent cars using unleaded petrol for greenhouse gases and particulate matter. There is, however, a large uncertainty associated with these particulate matter results. Data are very scarce and the results had to be inferred. Where data are more abundant, there is a large variability in the results. In many cases one high-emitting vehicle can skew the final result.

As the ADR specifications decree ever-decreasing emission limits, vehicle manufacturers and catalyst manufacturers will find it harder to comply. This means that it will be harder to optimise a vehicle to produce low emissions for two separate fuels. We conclude, however, that dedicated LPG vehicles will be able to maintain both lower tailpipe emissions, and lower exbodied emissions, than petrol vehicles.

We recommend that as new, dedicated OEM LPG vehicles become available, the certification test information be extended. Determination of the environmental impacts of such vehicles, relative to the equivalent petrol vehicle, will also require knowledge of particulate matter emissions, emissions of non-CO_2 greenhouse gases (i.e. methane and nitrous oxide) and emissions of air toxics.

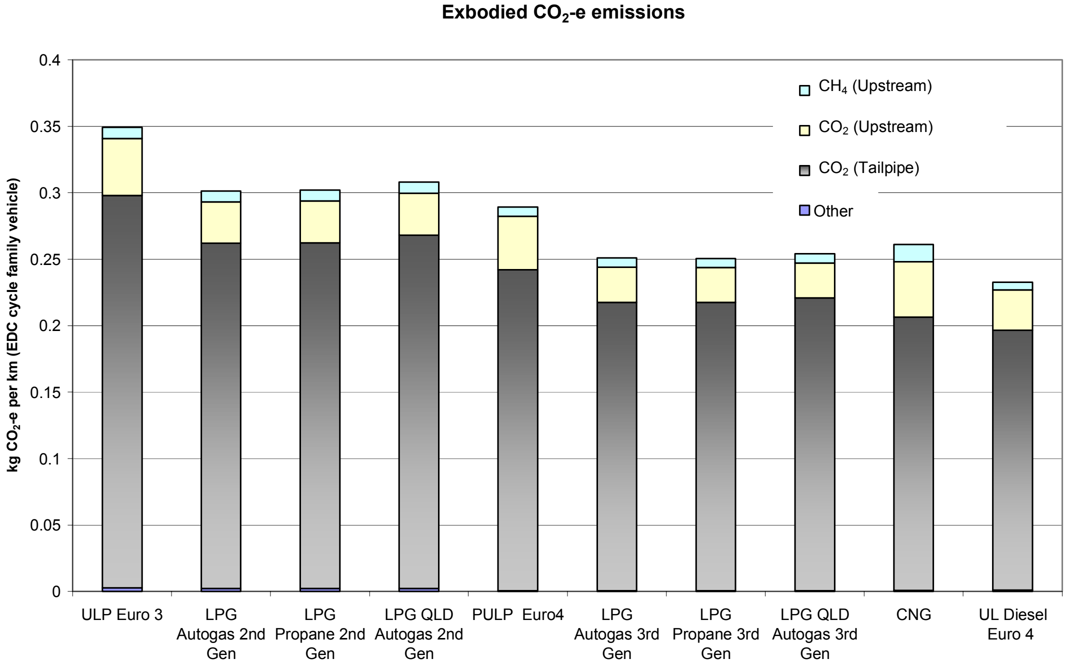

Figure 1: Exbodied greenhouse emissions from LPG vehicles (European Drive Cycle)

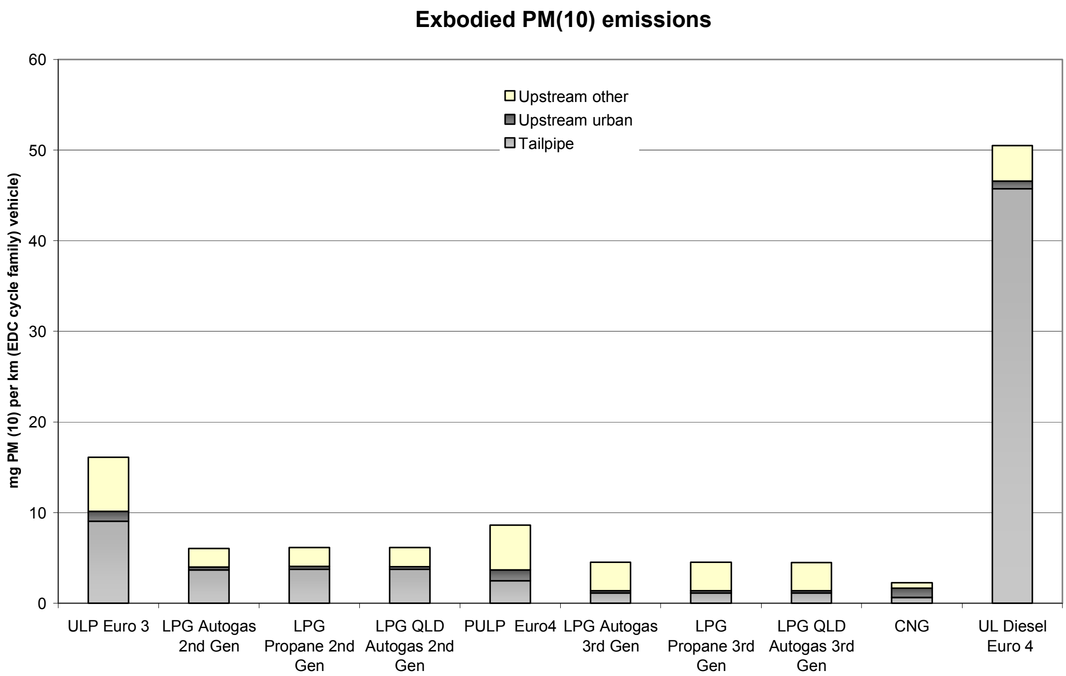

Figure 2: Exbodied particle (PM10) emissions from LPG vehicles (European Drive Cycle)

ACKNOWLEDGEMENTS

We acknowledge that assistance and the support of the Australian LPG Association (ALPGA) in obtaining the data and in providing financial support.

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