Transport Roads & Maritime Services

GREEN TRUCK PARTNERSHIP

Technology study

Alternative fuels

Study summary

This study examines alternative fuel options. The potential benefits of alternative fuels in freight transport are discussed, as well as key limitations and barriers. Some case study examples of alternative fuels are also presented.

The *Green Truck Partnership* is designed to be a forum to objectively evaluate the merits of clean vehicle technologies and fuels by heavy vehicle operators. This technology study provides a high level overview of alternative fuel options for commercial vehicles.

1 Alternative fuel options

Automotive diesel is the dominant fuel source for commercial vehicles around the world, owing to the high energy density and reliable engine technology.

In Australia, diesel powers 95 per cent of all heavy vehicles (trucks and buses), and 54 per cent of light commercial vehicles (LCVs) including vans and utilities (ABS 2015). Petrol is also widely used for LCVs owing to its cheaper price (in Australia) and the common use of passenger car power trains in some LCVs.

Transport energy sources besides diesel and petrol are typically considered as “alternative” fuels, including other liquid and gaseous fossil fuels. They can broadly be categorised as:

- Biofuels (Biodiesel, ethanol, biomethane)
- Synthetic Fuels (diesel from coal/gas/shale)
- Natural Gas: either as compressed gas (CNG) or liquefied (LNG)
- Liquefied petroleum gas (LPG)
- Hydrogen
- Electricity.

Despite ongoing interest in alternative fuels over the last 30 years, no single alternative has established a significant market share across all segments. Natural gas is used in some public transport buses, and LPG in taxis and LCVs. Part of the reason for the continued dominance of diesel is that each alternative may entail a number of benefits but also disadvantages.

The *Green Truck Partnership* previously published five case studies on alternative fuels. This paper places them in the context of the other options.

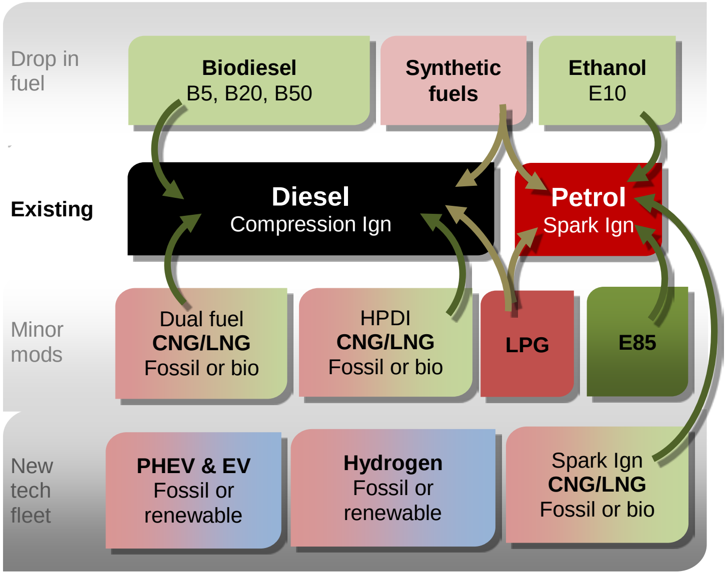
2 Reasons to consider this opportunity

The three main strategic drivers for alternative fuels are generally considered to be:

- Energy security
- Reduced greenhouse gas emissions (CO_2-e)
- Reduced pollution emissions (NOx, SOx, PM).

From an operator’s perspective, the case for switching often hinges on cost (or price stability), availability, and operational suitability. One of the main determinants of operational suitability is whether the alternative fuel can replace diesel (or petrol) directly, without engine modifications. These are referred to as “drop-in” fuels.

The figure below shows diesel and petrol as the conventional baseline (black and red), with drop-in fuels above the line and two levels of technology-dependence below it.



3 Alternatives

3.1 Biofuel

Biofuels depend on the chemical energy stored within biological matter (biomass), which is transformed into a usable fuel for transport. The interest in biofuels has driven rapid technological development and ambitious growth projections.

First generation biofuels are from conventional feedstocks (such as sugar cane and animal fats), and use well proven conversion technologies (such as fermentation).

Second generation fuels, sometimes referred to as “advanced biofuels”, are from non-food waste biomass, such as non-edible portions of plants and algae. Production methods include biochemical and thermochemical processes.

Third generation biofuels, currently in research and development (R&D), are envisioned as integrated biorefineries, able to produce not only biofuels, but also provide a range of products currently supplied by petrochemicals.

Biofuels represent less than one per cent of all transport fuel used in Australia in 2012-2013 (BREE 2014). However, globally, biofuels are expected to grow at 6.9 per cent per year, and could account for 5.8 per cent of all transport fuels in OECD countries by 2030 (AERA 2013).

3.1.1 Biodiesel

Biodiesel in Australia is technically fatty acid methyl ester (FAME) and typically comes from the oil and fats of plants and animals. It is rarely used on its own, but instead blended with conventional diesel at five per cent (B5), 20 per cent (B20) or even 50 per cent (B50). This makes it a drop-in fuel suitable for use with diesel engines unmodified.

However, high blends require specialised bulk delivery and storage. Price can be higher or lower than diesel, depending on market price of feedstocks, which can be volatile.

Biodiesel can be blended at up to five per cent without any additional labelling in Australia. The use of blends up to 20 per cent is generally accepted by most engine manufacturers, however it is important to check warranty and emissions compliance with your vehicle or engine manufacturer prior to implementing any biofuel program in the fleet.

3.1.2 Ethanol

Ethanol is a drop-in petrol substitute, and is widely available in low blend ratios (E5, E10 for example). It is produced in eastern states, often from waste sugar cane residues or waste starch.

Higher blend ratio E85 is available in limited locations, but requires engines specifically adapted to run on the fuel. The use of E10 will not affect warranties on most new vehicles, but compatibility can be checked via a range of websites.

In July 2015, NSW Fair Trading administered the Biofuels Act 2007, which mandates that two per cent of all diesel sold in NSW is biodiesel, and six per cent of all petrol sold is ethanol.

3.1.3 Biomethane

Other biofuels are making an impact internationally, such as biomethane, which is raw biogas (from landfill or anaerobic digesters) upgraded to high purity methane. This is effectively the same fuel as natural gas and can be used as a substitute in a suitable natural gas vehicle. However biomethane has not yet made an impact in Australia as a transport fuel.

3.2 Synthetic fuels

Synthetic fuels are manufactured from feedstock such as coal, gas and shale. These are then converted to a diesel or petrol drop in fuel. Demonstration and pilot plants have operated in Australia in the past, however they are not currently operational.

3.3 Natural gas

Natural gas is predominantly methane. It has been used as a transport fuel in Australia with varying success for decades. Whilst there have been large scale roll outs in bus fleets, broader adoption of natural gas remains limited.

Natural gas can be used as a heavy vehicle fuel in three main engine technologies: “dual fuel”, high pressure direct injection (HDPI), and dedicated spark ignition.

Dual fuel applications can substitute between 30 per cent and 70 per cent of the diesel, depending on the quality of the system and the operating cycle of the truck. HPDI technology replaces 95 per cent of diesel with gas, however involves substantially higher capital investment (and is not currently on sale in Australia).

Both systems have been shown to return a financial benefit in suitable operations, in previous case studies under the *Green Truck Partnership*. However, only the HPDI technology showed an energy and greenhouse gas (GHG) emissions benefit.

Natural gas cannot completely displace diesel in compression ignition engines. Instead, a dedicated natural gas engine requires spark ignition, and ideally a lower compression ratio of around 12:1 (less than diesel, but higher than petrol). In broad terms, a lower compression ratio means that the maximum possible thermal efficiency the engine can achieve is lower.

A previous case study under the *Green Truck Partnership* showed there is an economic benefit for spark-ignition gas engines, however those trials showed an energy and GHG emissions penalty.

Whatever engine technology is used, the gas must be stored on-vehicle as either a compressed gas (CNG), or cooled to a cryogenic liquid (LNG) at minus 161 degrees Celsius where the gas becomes a liquid. In both cases, the natural gas is injected in gaseous phase into the engine.

Spark ignition CNG trucks are available with typical original equipment manufacturer (OEM) warranties (such as three year, 100,000 kilometres, 2,000 hours). An aftermarket conversion of a truck with a dual fuel unit may not provide the same warranty (check with the supplier first); and the effect on emissions compliance needs to be checked with the state registration authority.

3.4 Liquid petroleum gas

Liquid petroleum gas (LPG) is predominantly propane and butane, and is a product of natural gas processing and petroleum refining. Australia has a significant indigenous supply and as such its strategic importance is highlighted by LPG's proponents.

Similar to natural gas, it can be used on its own (replacing petrol) or as a dual-fuel arrangement (supplementing either petrol or diesel).

The most common application is as a petrol replacement in passenger cars and light commercial vehicles, including Australian made cars and utilities. It has been used extensively in the taxi industry, but that market is shifting increasingly to imported petrol-electric hybrids.

A large market share more relevant to the *Green Truck Partnership* is utilities and vans with LPG conversions used extensively by tradespeople and couriers. However, in this segment LPG competes with diesel.

Comparisons of the only LPG model LCV available in the Green Vehicles Guide, the 2014 Ford Falcon Utility, shows the LPG model has a claimed 12 per cent CO_2 saving, and a 39 per cent annual fuel cost saving, over the equivalent petrol model.

LPG-diesel dual fuel conversion kits are available from aftermarket suppliers for vehicles ranging in size from small rigid trucks and four-wheel drives (4WDs), to prime movers. These have not been tested by the *Green Truck Partnership*.

As with any engine modification or fuel conversion, these systems alter the engine's exhaust emissions which the fleet operator is responsible for: ask the supplier to prove that the system continues to comply with emissions regulations, and what the implications are for engine warranty.

3.5 Hydrogen

Hydrogen's key difference is the lack of carbon in its molecular structure. As such, when burnt as a fuel, it produces no CO_2.

Hydrogen has an extremely high calorific value per unit of mass, however it's low density, even relative to other gaseous fuels, makes energy storage a challenge.

Hydrogen can be manufactured in a number of ways. Conventionally it is by carbon intensive processes. However, using renewable energy sources in its manufacture is considered technically feasible, and some have argued that Australia is well placed should this technology flourish (Garnaut 2015).

As a transport fuel, Hydrogen has been in development for a long time. It can be used as a dedicated combustion fuel in its own right; or as a diesel combustion supplement (hydrogen-diesel dual fuel); or in fuel cells to generate electricity for EV drivetrains. The current industry focus is on using it in fuel cell electric vehicles.

On-board hydrolysis of water, to make H_2 and O_2, referred to as Brown's gas or HHO, for use as a diesel supplement, has been a fringe technology for many years. The claimed benefits in this approach need to be rigorously and objectively analysed to ensure all inputs and outputs are included.

3.6 Hybrid electric vehicle, plug in hybrid electric vehicle and battery electric vehicle

Hybrid electric vehicles (HEVs), plug in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) utilise electrical energy, partially or exclusively, to propel the truck via electric motors.

The opportunities are twofold: electric motors are highly efficient at converting electrical energy into kinetic energy; and externally sourced electricity can be decarbonised with mature technologies which are currently available to the market (such as wind or solar generated GreenPower).

HEVs can also reclaim some of the kinetic energy traditionally lost when braking, via regenerative braking systems, to charge on board battery packs, which then drive the motor during acceleration or to power accessories. These electric motors provide only part of the work, with the majority typically handled by an internal combustion engine (ICE).

Green Truck Partnership tested a light duty rigid hybrid truck (GVM approximately 4.5 tonne), and found a 21 per cent improvement in fuel benefit, GHG benefit, and economic benefit.

PHEVs can utilise this same regenerative braking, but also use external energy sources (plug-in) to charge the battery packs, effectively displacing fuel energy. With this technology, more of the work can be handled by the electric motor, and less by the ICE. Taken to the extreme, some ICEs are completely decoupled from the drive train, and considered only “range extenders” or generators to charge the batteries.

BEVs take this one step further, and do away with the ICE altogether. All energy is via the batteries, charged externally and via regenerative braking. Advancements in battery technology have unlocked a number of lighter truck segments, and several bus types, using this technology.

The *Green Truck Partnership* published a case study of such a truck operating in three separate applications in Queensland, and found significant improvements in energy usage (73 per cent improvement), as well as 13-100 per cent improvement in GHG emissions, and 30-70 per cent improvement in energy cost per kilometre.

3.7 Alternative fuel comparison table

The below table provides a comparison of the main features of the alternative fuels discussed above.

As with all *Green Truck Partnership* studies, any operators considering the various technologies should consider their unique requirements, and conduct a whole-of-life analysis to find the most suitable fuel for their operations.

Alternative fuel category	Alternative fuel type & technology	Typical vehicle class	Availability	Fuel benefit L/100km or %	GHG g/km CO_2e or %	Economic benefit $/100km or %
Biofuel	Biodiesel ICE (CI)	LCV & HDV	B5, B20, B50, B100 available in bulk shipments	B20 0.688 ↑[6]	B20 247 ↑[6]	B20 1.81 ↑[6]
	Ethanol ICE (SI)	LCV	E5 and E10 eastern states. E85 limited.		E10 6-9%↑[1,2] E85 47%↑[1]	
	Biomethane ICE (CI, SI)	LCV & HDV	Not available in Australia	Refer Natural Gas (Similar)	60-90% ↑[8,9]	Insufficient Australian data
Synthetic Fuel	Synthetic Diesel ICE (CI)	LCV & HDV	Previous Trials (pilot plant now closed)	Marginal decrease ↓[1]	39% ↓[1]	Insufficient Australian data
Natural Gas	CNG ICE (CI, SI)	LCV & HDV	Specialised fleets and infrastructure (eg Bus)	HDV 3.12 DLE ↓[3]	LCV 11% ↑[1] HDV 392.1 ↓[3]	HDV 7.32 ↑[3]
	LNG ICE (CI, SI)	HDV	Limited specialised fleets and infrastructure	Dual Fuel 14% ↓[4] HDPI 0.18 DLE ↑[5]	Dual Fuel 1.7% ↓[4] HDPI 22% ↑[5]	Dual Fuel 4.1% ↑[4] HDPI 45% ↑[5]
LPG	LPG ICE (CI, SI)	LCV	High availability		10% - 12% ↑[1,12]	
Hydrogen	Hydrogen ICE (CI, SI) Fuel Cell/Elec	LCV	Limited pilot fleet and infrastructure	Bus (claimed for hybrid fuel cell) 40% ↑[10]	Sensitive to feedstock intensity	Insufficient Australian data
HEV, PHEV & BEV	Elec	LCV	High power availability	HEV 29-32% ↑[7] BEV 50%	HEV 21%↑[7] BEV (potential) 100% ↑[11]	HEV 21%↑[7]

Note:
The above data is for indicative purposes only. Individual fleet and duty cycles vary widely, and specific analysis should be performed before further investigation or financial decision.

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4. GTP 2014, *Liquefied Natural Gas (Dual Fuel)*
5. GTP 2014, *Liquefied Natural Gas (HPDI)*
6. GTP 2014, *B20 Biodiesel (Tallow Derived)*
7. GTP 2012, *Hybrid Technology (General Freight LPUD)*
8. Ricardo-AEA 2015, *Biomethane for Transport* (c.f. petrol, diesel)
9. Ricardo-AEA 2014, *Gaseous Fuels Report*
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11. Adelaide City Council 2011, *Tindo Fact Sheet*
12. *Green Vehicle Guide*

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5 Document control

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