

Heavy Trucks

HIGHLIGHTS

■ **TECHNOLOGY STATUS** – This brief covers powertrain technologies for trucks with a gross vehicle weight greater than 3.5 tonnes, in light of reducing greenhouse gas emissions in the transport sector. While the performance of trucks varies considerably in different countries and even across similar truck classes in the same country, average efficiency has steadily improved by 0.8 – 1% per year over the last 40 years [1]. However, in some countries where increasingly stringent air quality emission standards have been in force, like in the UK and other European countries, this has not necessarily been the case. Since 1990, efficiencies in the UK have not improved consistently. Rigid vehicles are now around 12.5% less efficient than in 1993 due to the impacts of vehicle adaptation to comply with the Euro emission standards (and also a shift to larger vehicles). In comparison articulated vehicles have improved by around 10% over the same period [1]. Over the next ten years new trucks predicted to improve efficiency at around 0.5% per year [2]. Fuel use is still approximately 80% diesel, however modifications to various components of the combustion engine powertrain have proven effective in greenhouse gas reduction, and it is believed there are significant gains still to be made. Natural gas trucks, biofuels and - to a lesser extent - electric trucks, have begun commercial market uptake in some suitable applications, but their overall contribution remains negligible.

■ **PERFORMANCE AND COSTS** – In the medium to long term, current engines could improve their thermal efficiency by approximately 25% on today's average (21 – 32 l/100km for typical rigid and articulated vehicles respectively). Some of the technological improvements discussed below show how this can be done at relatively little cost. More information is needed on technology costs, but many of the improvements appear likely to be relatively cost-effective. Logistic systems to ensure better use of trucks, and shifts to larger trucks in some cases, can provide additional system efficiency gains, and may also be cost-effective [3]. For the larger emissions savings however, costs remain very high and are heavily influenced by the drive cycles of the vehicles. Dual fuel vehicles, which substitute natural gas for diesel, run at similar efficiencies to conventional vehicles but with lower emissions. Hybrids save between 7 - 20% on fuel use dependent on drive cycle, whilst full electric trucks - given urban delivery cycles - can achieve 70% savings. Recent studies have shown that the price premium for gas powered dual fuel and dedicated gas vehicles is around €27k, while hybrid and electric trucks cost around €50k and €100k more than conventional diesel trucks respectively.

■ **POTENTIAL AND BARRIERS** – Considerable fuel savings could be obtained from the current diesel engine fleet if all trucks were to achieve the fuel efficiency of today's newer models. The International Energy Agency (IEA) - in its BLUE Map scenario with a 50% global CO₂ reduction by 2050 against 2005 levels – projects that on a global scale diesel use for road freight will be nearly halved by 2050, leaving hydrogen, electricity, gas and in particular biofuels to meet remaining demand. The technologies which use these alternative fuels will likely develop initially in their own niche applications where they are more economical. Deployment of biofuels will prosper in sustainable feedstock farming. Hydrogen and dual fuel natural gas engines will prevail initially in instances where trucks have repetitive drive cycles and can return to a central point to refuel. A recurring difficulty for hydrogen, dual fuel and electric trucks will be on-board energy storage, which requires large energy storage units and competes with payload; this damages the economics of the technologies when considered over their lifetime.

TECHNOLOGY STATUS - Heavy trucks are defined in this brief as vehicles with a gross vehicle weight, or GVW, greater than 3.5 tonnes. This definition spans the diverse makeup of heavy trucks particularly for vocational applications such as in construction (mobile cranes, cement trucks, tipper trucks) and municipal utility vehicles (e.g. refuse vehicles, road sweepers). However, the focus of this brief is on the largest energy consuming area, which is heavy trucks used in freight transport.

Trucks are composed of rigid and articulated vehicles. A rigid truck consists of a truck with the cab and body integrated on a single fixed chassis. An articulated truck consists of a tractor unit and semi-trailer (plus possible additional trailers) that carries the payload (or vocational auxiliary equipment). A 'road train' is the term used to describe a combination of a rigid (or articulated) truck and drawbar trailer.

Engine technologies across Europe, USA and Japan are very similar in terms of engine displacement, fuel injection equipment and after-treatment [4]. These three markets are also likely to make the most advances in engine technologies, as they are subject to the toughest emissions or fuel-related legislation on heavy trucks, particularly in Japan [1].

The following sections are defined by the major technologies currently deployed or available in the future for improving the efficiency and emissions performance of heavy trucks. Beneath each technology heading, the current state of the art technologies are described, or where a technology is close to market, its potential is discussed.

■ **Conventional gasoline / diesel ICE** - E-Tech-DS briefs T01 and T02, on advanced gasoline and diesel technologies respectively, cover the current status of

conventional Internal Combustion Engines (ICE). In this brief we consider applications specific to heavy trucks which improve fuel economy. Current state-of-the-art ICEs in heavy trucks use a **common rail** for fuel injection. This is a high pressure fuel rail which has the benefit of increasing the pressure and precision of fuel injection, improving overall combustion efficiency. Alternatively **unit fuel injectors** are used. These reduce the need for maintaining pressure in fuel pipes by having their own individual pumps, which when controlled electronically, can meet the accuracy and pressure of injection of the common rail. **Turbo-compounding** is used to recover energy from exhaust gases, converting it from pressure to rotary motion, and increasing drive with no change to fuel consumption. This is achieved using an additional exhaust turbine to deliver power to the crankshaft via mechanical gears and a hydraulic coupling. **Twin-turbocharging** in series are also incorporated, which compress air intake at combustion, increasing its pressure and temperature for higher efficiency. One turbocharger is used for higher speeds, and the other for lower speeds. If the pressure in the turbocharger is not right for the vehicle speed, then this can lead to high exhaust pressure and pumping losses which means lower power output. To avoid this and optimise the efficiency of the turbochargers in the twin turbocharging series, **Wastegated** or **Variable Geometry Turbos** (VGTs) can be used. Wastegated turbochargers regulate the pressure in turbocharger systems by diverting exhaust gases. VGTs meet the most efficient dimensions for the turbocharger by modifying the inlet area to alter its aspect ratio.

■ **Biofuel vehicles** - On top of potential improvements from engine efficiency, the design of the truck and the way in which it is driven, fuel switching also offers considerable CO₂ savings. The most practical alternative fuel option for trucks is advanced biofuels [3]. Advanced biofuels are derived from sustainable feedstocks which do not compete with food crops and have a low nutrient input per area farmed, such as woody/grassy biomass and algae. These fuels can be incorporated into current combustion engines with relative ease.

■ **Hybrid vehicles** - This category covers electric hybrid, hydraulic hybrid and mechanical hybrid technologies which recover braking energy. Such systems can achieve 20-30% energy savings on urban, stop-start routes, but just 4-10% for longer haul or regional distribution duty cycles [4]. **Electric Hybrids** use an electrical brake energy recovery and storage system. They require a generator and a battery or ultra-capacitors, which are typically designed to outlive the vehicle. If the vehicle is able to run on electricity alone for any distance, then it is also necessary to reconfigure ancillary functions so they are not reliant on the diesel engine. This technology has emerged despite its high cost because of the large benefits for particular drive

cycles. Most large truck manufacturers are now developing electric hybrid engines for rigid vehicles and several hundred such trucks are currently in service [1]. **Hydraulic Hybrids** use a hydraulic pump and accumulator to convert braking energy into power output. The hydraulic system has good power density, although the accumulator has poor energy density. This technology is attractive due to expected lower capital costs and smaller form-factor compared to electric-hybrids. A prototype is being tested by the parcel carrier UPS [1]. **Mechanical Hybrids** use kinetic flywheel technology that provides a balance of power and energy density ideally suited to brake energy recovery on conventional powertrains [4]. Whilst relatively undeveloped in this application, the technology won the Low Carbon Vehicle Partnership Technology Challenge in 2010 in the UK for its ability to be retrofitted to heavy trucks or buses and save around 20% of emissions during urban stop-start operation [5].

■ **Plug-in hybrid electric vehicles** - Plug-in hybrid electric heavy trucks use electrical energy stored in batteries to drive an electric motor to power the vehicle or supplement engine power. When electrical energy is being used, this offers zero tailpipe emissions. This has local air quality benefits, and average emissions produced upstream at power plants are lower than those from a conventional ICE running on diesel, due to greater efficiency of conversion in power stations compared with ICEs [6]. Benefits can reach 20% for short drive cycles, or 7% for longer haulage [4]; downsides are that the incorporation of a battery leads to less space for the payload, and staff require training on handling high voltage vehicles.

■ **Battery electric vehicles** - The vehicle is driven by an electric motor powered by batteries which are charged from mains electricity or dedicated charging points. The vehicle has no other power source other than the battery. Electric heavy trucks can offer zero tailpipe CO₂ emissions, however while lower CO₂ will be emitted during electricity generation, the well-to-wheel benefit of this technology will be influenced by the fuel source used to generate electricity, as with Plug-in hybrid electric vehicles. Overall emissions on certain drive cycles can be 40% lower, leading UPS and others to introduce electric trucks into their fleets on drive cycles where these savings are highest [7]. However, due to the limitations of current battery technology, electric commercial vehicles are currently limited to 12t [4] and used in urban/local distribution applications.

■ **Hydrogen fuel cell vehicles** - Fuel cells convert the chemical energy of hydrogen into electrical energy that can be used to power the vehicle. A hybrid Polymer Electrolyte Membrane (PEM) fuel cell system is used as the prime mover for the vehicle [4]. As with electric trucks, hydrogen fuel cell trucks produce zero tailpipe pollutant emissions. However, overall emissions depend on the source and production method of

hydrogen. Again, payload capacities are reduced because of the need for hydrogen storage and batteries. Further, no hydrogen distribution network exists and on-site production has significant diseconomies of scale [6]. For this reason its use for trucks is likely to be very limited in the short term, whilst it may advance in applications for buses or on-site vehicles which use a central depot where hydrogen could be produced or stored. A separate ETSAP brief T07, “Automotive Hydrogen Technology”, covers this topic in more detail.

■ **Dual fuel vehicles** - These are systems which enable a diesel engine to run primarily on gas using diesel as a liquid spark plug. Liquefied or Compressed Natural Gas (LNG/CNG) is typically used, and substitutions are of 50 – 90% gas depending on level of system integration [4]. The lifecycle GHG emission benefits of dual fuel vehicles are around 10 - 20% depending on its control system – using the engine’s Electronic Control Unit (ECU) will yield better results [4]. Similarly to hydrogen fuelled trucks, these systems would be most effective where a complete infrastructure is not required, and the gas is readily available. Further life cycle emissions savings are possible if biogas is blended into the fuel – see E-Tech-DS brief S05 on Biofuels Production for more detail. The main disadvantages of LNG or CNG are that the tanks displace payload space, and the technology adds complexity and cost to the overall system. Their range running on gas is also limited as the gas has a relatively low energy density [8]. However, since they can also run 100% on diesel their overall range is not limited. These vehicles should not be confused with 100% dedicated natural gas vehicles, which tend to use less efficient spark ignition engines compared to diesel engines, and perform similarly on emissions. See the ETSAP Brief T03 (Automotive LPG and Natural Gas Engines) for more details.

In addition to engine and fuel technologies, other auxiliary devices and systems are important to improve efficiency and reduce emissions (i.e. greenhouse gas and other pollutants).

■ **Air quality improvements** - Three systems are prevalent in modern heavy trucks for limiting emissions of air quality pollutants (NO_x and PM): Diesel Particulate Filters (DPF), Exhaust Gas Recirculation (EGR) and Selective Catalytic Reduction (SCR). The three can be used together for maximum improvement in air pollution, although there is an associated fuel penalty. A recent study by Ricardo estimates this fuel penalty to be around 3%; however, with improvements in technology, this fuel penalty is expected to disappear in time [4].

■ **Auxiliary loads and equipment** - A first step to reducing GHG emissions is reducing the load on the engine of the auxiliary systems such as coolant and oil pumps, air conditioning and cooling fans. The level of

savings that can be achieved vary from 0.7 - 4% depending on the auxiliary, the type of drive and the vehicle application [4]. For instance, **electrically driven pumps** will result in 1 - 4% CO₂ savings over variable mechanical pumps through matching requirements of coolant to the engine’s demand. However, mechanically driven systems are seen as more durable. Similarly, **variable speed oil pumps** can vary flow speed to requirement to optimise oil flow and oil pump power consumption, saving 1-3% of CO₂ emissions. However, they suffer the downfall of reliability against the mechanical system, and with such an integral device the consequences can be severe [4]. Current truck airbrake systems simply dump excess pressure when the air tanks are full, although the compressor keeps running. **Air compressors** with an electric/air actuated clutch can disconnect the compressor in idle times or when it is not required, which for long-haul truck work can be up to 90% of the time. Controllable air compressors can achieve an average of 1.5% CO₂ reduction [4]. **Electric power steering, A/C compressors, engine cooling fans and fuel pumps** can also achieve savings of up to 8%. Savings are most profound with long haul journeys, although full electrification can be quite costly [4]. Vehicles with **refrigeration** for temperature controlled transport can add 15 - 25% to fuel consumption. Such vehicles account for approximately 7% of rigid and 10% of articulated trailers in the EU, and a large proportion of activity too [4]. Other auxiliary equipment, such as the power take off (PTO), auxiliary power unit (APU), battery-powered and direct plug-in electrical power supply can also add to energy consumption.

■ **Weight and drag reduction** - Lightweight materials can help reduce fuel consumption through increased payload and fewer vehicle journeys, or by lighter vehicles and trailers. These bring benefits of 1 - 2% per ton of weight saved equating to 1.7% on volume limited goods (i.e. lighter vehicle) and 4% for weight limited applications, i.e. fewer journeys [4]. Savings are greatest in urban applications, where reduced weight contributes to reduce wasted energy in stop-start duty cycles. Barriers include the cost of lightweight materials such as aluminium, and also higher lifecycle emissions due to the energy intensive manufacturing process [4]. Light-weighting measures will reduce the relative savings of the regenerative braking technologies mentioned above; however the overall energy use will be lower because less energy is needed to power the truck, a saving with no efficiency penalty unlike if it were recovered later.

■ **Aerodynamic aids** - Vehicles and trailers across all regions have aerodynamic design elements; however it is in Europe that the largest numbers of aerodynamic aids are standard fit. The most widely available option is cab roof air deflectors. These are available across all markets and typically save up to 2.4% of fuel consumption. Up to a 0.7% saving can be achieved for

air dams, up to 0.5% for side edge turning vanes, up to 4.8% for cab roof fairings and up to 0.6% for cab collars or side extenders. Most aerodynamic options pay back within two years [5], though the absolute level of benefit is very dependent on duty cycle with greatest benefit for those vehicles with large proportions of high speed running (where very significant total savings are achievable). For vehicle and trailer body types that are irregular, highly dependent on load (e.g. flat-bed) or constrained to a particular form (e.g. tankers, container transport) the potential for aerodynamic savings is lower.

■ **Low rolling-resistance tyres** - There are also opportunities for efficiency gains through the wider introduction of low rolling-resistance tyres (up to 5%) [9]. For further details refer to ETSAP brief T18 "Weight and drag reduction –automotive".

■ **Operational efficiency** – A variety of IT systems and measures are capable of improving operational efficiency such as intelligent transport systems, telematics and intelligent routing. Non-technical measures such as improved loading practices or use of larger vehicles can have marked effects too.

PERFORMANCE AND COSTS – Heavy trucks consumed around 500 Mtoe in 2007, or 23% of global energy used for freight and passenger transport [3]. Most of this fuel consumption is in the form of diesel because of its high energy density per litre. The variation in energy and CO₂ intensity of trucking in different world regions is displayed in Figure 1.

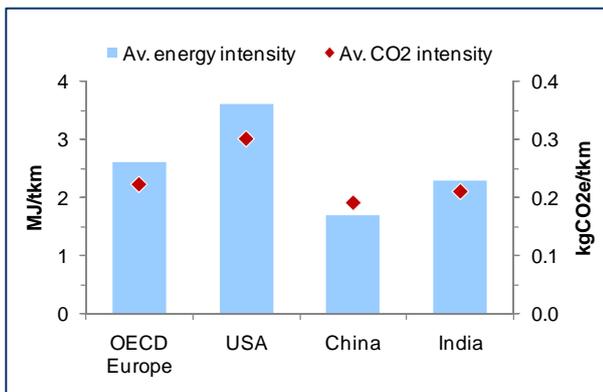


Figure 1 – Energy and CO₂ intensity of trucking [3]

Truck powertrains rely almost exclusively on efficient diesel engines, but further significant improvements to today's vehicles may still be possible. For example, in the United States where the thermal efficiency of truck engines is currently around 40% to 42%, this could potentially be raised to 50% or even 55% [10]. This would require the application of a range of incremental technologies affecting different aspects of the vehicle's design and operation, including the recovery of energy from exhaust gases and hybridisation as discussed

		Energy/CO ₂ savings	
		Lower	Higher
Cost per unit of fuel/CO ₂ saving	Lower	<ul style="list-style-type: none"> - Idling control devices - Lower rolling resistance tyres 	<ul style="list-style-type: none"> - Improved diesel powertrains - Retrofit package including aerodynamics
	Higher	<ul style="list-style-type: none"> - Hybridisation of long-haul trucks - Reduce vehicle empty weight 	<ul style="list-style-type: none"> - Hybridisation of local delivery trucks - Advanced power trains (e.g. fuel cell) - Biofuels, LPG, CNG

Figure 2 - Relative costs of technologies [3]

above [4]. Further advances can also be made through modifications to the vehicle body (i.e. weight reduction, aerodynamics, low rolling resistance tyres, etc.). Information on fuel consumption savings and costs for modern heavy truck technologies is scarce and dispersed as no comprehensive studies are available. However, Figure 2 gives a good indication of cost effectiveness. To give perspective, a recent study by AEA showed that the price premium for gas powered dual fuel and dedicated vehicles was around €27k [10], while hybrid and electric trucks cost around €50k and €100k more than conventional diesel trucks respectively [11]. There is some detailed cost information on retrofit technologies, i.e. aerodynamic kits and changes to the auxiliary power units. Two recent studies have been conducted in Canada by Energy and Environmental Analysis [10] and the Rocky Mountain Institute [12]. The results indicate that nearly all aerodynamic kit and auxiliary power units can easily pay for themselves within three years at a market fuel price of US \$1.00/l. It follows that such changes are cost effective and have no abnormal barriers to market.

POTENTIAL AND BARRIERS –

■ **Role of legislation** – The primary EU approach to control of emissions from heavy duty vehicles (HDVs) has been to directly regulate emissions standards for new vehicles. A series of progressively stricter emissions standards have been introduced since 1999, moving from 'Euro III' through to 'Euro VI' which will become mandatory for manufacturers in 2013.

However, these Euro standards only address emissions that affect air quality, not CO₂ or other GHGs (and in fact resulting in a reduction of fuel efficiency). CO₂ emissions cannot be addressed as easily through limits on vehicle emissions. Research is underway on

developing legislation to address CO₂ emissions from HDVs, but it remains behind cars and vans.

In addition to the Euro emissions standards, the EU has introduced directives on driver training, government procurement and road user charging, all of which have an influence on HDV emissions. The EU's Intelligent Energy Europe programme has run an information and behaviour change programme called 'STEER' since 2005. Further, the Clean Vehicle Directive requires that energy and environmental impacts linked to the operation of vehicles over their whole lifetime are taken into account in purchases of road transport vehicles, which will drive demand for clean technologies and resulting cost reduction [12].

Outside the EU, the SmartWay best practice program in the US aims for a saving of 33 - 66 million tonnes of CO₂ per annum by 2012 [4]. The US has also just announced the forthcoming introduction of CO₂/fuel efficiency standards for medium and heavy duty vehicles. In Hong Kong, a 30 - 100% reduction in registration tax is applied to vehicles that meet Euro 5 standards. The Japanese Government has also set vehicle emission standards for HDVs, which requires an average 12% improvement in fuel efficiency across multiple HDV classes by 2015 [4].

■ **Market Potential and Prospects** – By 2030, it is predicted that new heavy trucks in the US could improve efficiency by around 30 - 40% on current levels [3] (recent work suggests lower potential in the EU [1]). This includes improved engines/powertrains, light-weighting, better aerodynamics and better tyres. This allows for air quality control technologies in tandem, such as DPFs, EGR and SCR which are becoming mandatory in the main trucking markets over the next few years, although they may be stymied in other markets because of associated fuel penalty and a lack of government steer.

The IEA scenario projections displayed in Figure 3 show energy use in freight transport by road, broken down by fuel. To reduce greenhouse gas emissions from the fuel mix displayed in the 2030 and 2050 baseline scenarios efficiency improvements on current technology will be vital. However, the BLUE Map scenario, which represents a 50% global CO₂ reduction by 2050 against 2005 levels, makes greater use of alternative fuels and technologies, particularly biofuels, advanced biofuels and hydrogen, to achieve its goal. GTL and CTL represent Gas-to-liquid and Coal-to-liquid respectively.

Further improvements could be made by switching to advanced biofuels and changes in behaviour [13], or more widespread uptake of electric or hydrogen trucks (albeit less likely in the shorter term). The duty cycles that account for the majority of activity (in tonne-km) by heavy trucks are regional distribution and long haul transport. Therefore electric and hydrogen advances

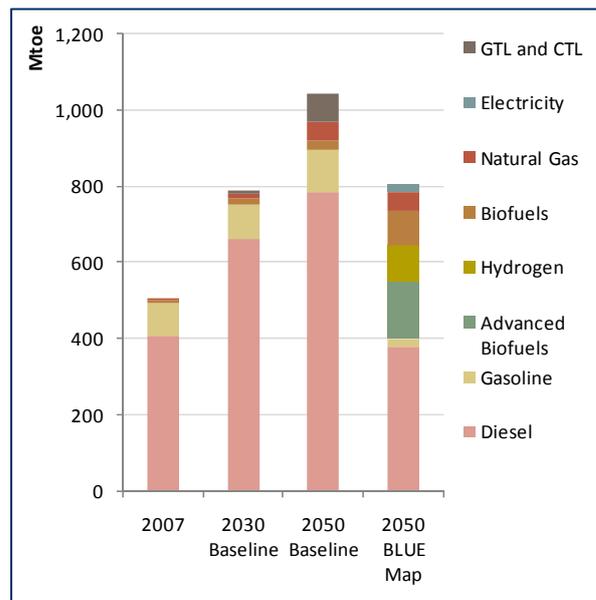


Figure 3 – Road freight energy use by fuel [3]

and deployment are expected to progress slowly (and contribute less to reduction in energy/emissions) compared to the car and van market while advanced biofuels are a more practical short-medium term option (though requiring government funding to take off) [1]. However in certain applications there are savings to be made in the short term from full electric trucks, such as inner city, multi-drop delivery driving. Dual fuel and CNG engines are likely to be a bridging option to the longer term, as biogas can easily be incorporated to enhance carbon savings [14]. In the medium term, hydrogen might be used where trucks return to a central point, bypassing the need for large-scale infrastructure. In the long term, depending on the decarbonisation of electricity and source of hydrogen, full electric and hydrogen technologies have the potential to develop and significantly reduce carbon emissions from heavy trucks.

■ **Barriers to Development and Deployment** – The intractable short-term problems are non-powertrain factors such as the feedstock sustainability for biofuels, infrastructure requirements or the carbon intensity of fuel production. The short-term deployment of biofuels will depend on the success of sustainable farming. Hydrogen and dual fuel market penetration will prevail initially where trucks have repetitive drive cycles and can return to a central point to refuel. Moreover, hydrogen, dual fuel and electric trucks require energy storage units which compete with payload. This further damages the economics of the technologies when considered over their lifetime (i.e. in addition to greater capital costs). It is also possible that incentives to improve fuel economy are lower or lost in the complicated arrangements between freight transport suppliers, their users and the split of ownership of vehicle components. For example, a transport company

which owns just tractor units may be employed by a supermarket to transport produce. The supermarket which owns its own trailers may pay the transport company per tonne of their produce transported, from which the transport company pay their fuel bill. This kind of arrangement dilutes price signals for improving the efficiency of the trailer. Furthermore, without

standard whole-body approval of fuel efficiency testing (and provisions for different duty cycles) it is difficult to compare new vehicles final performance (i.e. of completed vehicle with final bodywork and all auxiliary equipment) and do so independently of the individual manufacturer's claims.

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Table 1 – Summary Table - Key Data and Figures for Baseline and Alternative Heavy Truck Technologies
 [4], [9], [10], [14], [15], [16], [17], [18], [19], [20]

Dedicated Natural Gas		
	Rigid Trucks (7.5 - 33t)	Articulated Trucks (14 - 60t)
Energy Input	Natural Gas	
Typical drive range (km) [15]	500	
Base Energy Consumption (MJ/veh-km) [4]	8.58 ^a (4.7 – 13.3)	12.97 ^a (8.3 – 12.8)
Base Energy Consumption (l/100km) [4]	24.0 (13.2 – 37.2)	36.3 (26.0 – 35.8)
Technical Lifetime, yrs (average vehicle life) [14]	10	10
Additional Capital Cost, overnight, 2010 Euros [9]	€25,000	€27,000
Maintenance cost (€/km) [14]	€0.11 - €0.15	€0.109 - €0.114
O&M cost saving [16], [17]	10-50% lower fuel costs ^b	
Natural Gas Dual Fuel		
	Rigid Trucks (7.5 - 33t)	Articulated Trucks (14 - 60t)
Energy Input [4]	Natural Gas (up to 85% depending on duty cycle), Diesel	
Typical drive range (km)	500 - 1250	
Base Energy Consumption (MJ/veh-km) [4]	7.46 ^a (5.9 – 11.5)	11.28 ^a (7.1 – 14.5)
Base Energy Consumption (l/100km) [4]	20.9 (16.5 – 32.2)	31.6 (19.9 – 40.6)
Technical Lifetime, yrs (average vehicle life) [14]	10	10
Additional Capital Cost, overnight, 2010 Euros [9]	€25,000	€27,000
Maintenance cost (€/km) [14]	€0.11 - €0.15	€0.109 - €0.114
O&M cost saving [17], [10]	10-40% lower fuel costs ^b	
Battery Electric Vehicles		
	Rigid Trucks (7.5 - 33t)	Articulated Trucks (14 - 60t)
Energy Input	Electricity	
Typical drive range (km) [18]	150	N/A
Base Energy Consumption (MJ/veh-km) [4]	1.78 ^c (1.2 – 3.5)	N/A
Base Energy Consumption (kWh/veh-km) [4]	0.49 (0.33 - 0.97)	N/A
Technical Lifetime, yrs (average vehicle life) [14]	10	N/A
LOW Additional Capital Cost, overnight, 2007 Euro/unit [14]	€110,000 ^c	N/A
HIGH Additional Capital Cost, overnight, 2007 Euro/unit [14]	€150,000 ^c	N/A
LOW Learning Rate ^d [14]	0.90	N/A
CENTRAL Learning Rate ^d [14]	0.85	N/A
HIGH Learning Rate ^d [14]	0.80	N/A
Maintenance cost (€/km) [14]	€0.023	N/A
Fuel cost saving (€/km) [19]	€0.03	N/A
Baseline Diesel Vehicle		
	Rigid Trucks (7.5 - 33t)	Articulated Trucks (14 - 60t)
Typical drive range (km) [20]	580 - 1250	
Energy Input	Diesel	
Base Energy Consumption (MJ/veh-km) [4]	7.46 ^a (5.9 – 11.5)	11.28 ^a (7.1 – 14.5)
Base Energy Consumption (l/100km) [4]	20.9 (16.5 – 32.2)	31.6 (19.9 – 40.6)
Technical Lifetime, yrs (average vehicle life) [4]	10	10
Capital Cost, overnight, 2007 Euro/unit [14]	€25,000 – €40,000	€50,500 – €66,000
Maintenance cost (€/km) [14]	€0.11 - €0.15	€0.109 - €0.114

a) Based on European figures, the most common weight category for Rigid Vehicles is between 14 – 20 tonnes, 34 – 40 tonnes for Articulated Vehicles. These are the weight categories to which all energy consumption figures relate to, except for Battery Electric Vehicles – see note 'b'; b) Based on CNG retailing at discounts in the range of 20% to 60% against diesel fuel [17], with a 60% substitution of gas for diesel in the dual fuel case [10]; c) Costs and energy consumption data for Battery Electric Rigid Trucks represent vehicles less than 12t, as this is currently the largest commercially available weight class for an electric truck [1]; d) Learning rates represent the reduction in the costs of a technology with a doubling of total production volumes. Cost reductions typically result from improvements and advances in its manufacturing process.