Light Trucks

HIGHLIGHTS

■ **TECHNOLOGY STATUS –** This brief covers powertrain technologies for trucks with a gross vehicle weight of less than 3.5 tonnes, in the light of reducing greenhouse gas emissions in the transport sector. The efficiency of light trucks has been steadily increasing. Global average energy intensity fell from around 13.8MJ/tkm in 1995 to around 12.2 MJ/tkm in 2005. However there are still significant improvements available today that could produce a reduction in operating costs of up to 75%. Almost 100% of the worldwide fleet of light trucks are propelled by internal combustion engines (ICEs) running on fossil fuels. Alternative powertrains are currently in the prototype stages or deployed only in niche applications and unlikely to become mainstream before 2020 - 2030. Examples include hybrid electric, hydraulic hybrid, battery electric, plug-in hybrid and hydrogen fuel cell vehicles. Alternative hydrocarbon-based fuels can also be used, such as compressed natural gas or liquefied petroleum gas.

■ **PERFORMANCE AND COSTS –** ICE technology is expected to remain competitive for the foreseeable future. Alternative energy carriers can offer substantial efficiency savings, although the actual improvements achieved depend on whether the technology is suited to the drive cycle. Hybrid technologies are particularly well-suited to the typical driving patterns of light trucks, where they can recover energy from braking. CO_2 reductions of 18% - 22% are achievable for full hybrid models. Electric vehicles currently have limited range so suitable only for shorter range/local delivery applications, but are particularly beneficial where air quality issues are a concern due to the fact that they have zero tailpipe emissions. The additional capital cost for hybrid electric, plug-in hybrid and battery electric vehicles is around €5k, €13k and €60k respectively.

■ **POTENTIAL AND BARRIERS –** There is significant overlap with technologies for passenger cars and light trucks, which is expected to yield beneficial crossover effects. Drivers for increased uptake of alternative energy carriers include rising fuel prices and concerns about energy security and climate change. CNG and LPG are currently used in niche applications, but are expected to become less important over time. Hybrid and electric vehicles are expected to be mainstream in the medium term (2020 - 2030). Hydrogen fuel cell vehicles are currently not expected to become mainstream until the longer term (2030 - 2050), primarily due to the need for hydrogen supply infrastructure.

TECHNOLOGY STATUS – Light trucks are defined in this brief as goods or service vehicles with a typical gross vehicle weight of less than 3.5 tonnes. They are also known as light goods vehicles (LGVs), light commercial vehicles (LCVs) or vans. Heavy goods vehicles are discussed in ETSAP brief T09 (Heavy Trucks). Surface freight transport[1] accounts for over a quarter of global transport energy use and road freight transport makes up about 90% of this [1]. The majority of countries are heavily reliant on trucks for freight movement. Although rail or inland waterways are more efficient options - at least for longer distance transport cases - a significant modal shift is unlikely without significant infrastructure investment and government intervention [1]. In spite of steady improvements in efficiency, light trucks remain the most energy-intensive mode of surface freight [2]. Global average energy intensity fell from around 13.8MJ/tkm in 1995 to around 12.2 MJ/tkm in 2005 [1]. The following sections discuss technology options that could further improve the efficiency of light trucks. While significant overlaps and beneficial synergies exist with passenger cars, key differences such as drive cycle and buyer preferences will shape the uptake of new technologies for light trucks. For example, light trucks are predominantly used in urban conditions, for short low-speed journeys, with frequent restarts, periods of idling [3] and high number of miles per year. The effects of the technology on vehicle reliability, running costs and pricing, can influence purchasing decisions for light trucks to a much greater extent than for passenger cars [4].

■ **Internal combustion engines** (ICEs) running on fossil fuels are by far the dominant technology (close to 100% of the global fleet). There is some geographical variation as to whether diesel or gasoline is preferred (e.g. diesel is the main technology in Europe, whilst gasoline is predominant in the US). Some advanced gasoline and diesel engine technologies are applicable both to passenger cars and light trucks (covered in ESTAP technology briefs T01 and T02, respectively). In general these relate to improving the combustion process and reducing losses, for example though reduced engine friction losses, engine downsizing and variable valve actuation. However, some novel concepts regarding passenger cars will not necessarily enter the light truck segment as this is more demanding in terms of robustness and durability; examples of technologies which are likely to be less important in the light truck segment include piezo-injectors, continuous variable transmission, and strong weight reduction [2].

■ **Hybrid vehicles** can use energy from multiple sources, of which at least one allows storage of surplus energy. **Hybrid electric vehicles** (HEVs) operate a combination of an ICE and an electric motor with

[1] Light trucks, heavy trucks, and rail

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battery storage. The battery is charged by regenerative braking, thus hybridisation is particularly beneficial for urban driving where there is frequent braking and accelerating. There is little or no gain in efficiency relative to a conventional ICE when travelling at higher and steady speeds [5]. The battery type referred to here is lithium-ion, which are the most advanced type in use for light trucks; for a discussion of other battery types see ESTAP brief T04 (Hybrid electric vehicles). **Hydraulic hybrid vehicles** (HHVs) utilize kinetic energy from braking to power a pump, which moves fluid from a low pressure reservoir into a high pressure accumulator. The hydraulic system may be coupled with the conventional drivetrain in series or in parallel, much like a series or parallel electric hybrid. The engine can be shut off during deceleration or when stationary. Although not yet in widespread use, the system is being installed for further testing in demonstration vehicles by several industry players, such as those involved in the hydraulic hybrid working group [6]. This technology will be better suited to larger light trucks (and to heavy trucks), because the weight of the hydraulic fluid needed is substantial and therefore reduces the overall efficiency in smaller vehicles [7]. It is particularly attractive for vehicles that engage in a lot of stop-start driving. The US EPA predicts that the first commercial application with be for urban delivery trucks [8].

■ **Electric vehicles - Battery electric vehicles** (BEVs) are powered entirely by on-board batteries, which have historically had the drawbacks of limited range, high capital cost, and high battery weight. Despite these disadvantages, battery electric vans are available from specialist manufacturers such as Modec, Azure Dynamics and Smith Electric Vehicles. Since there is no ICE, there are no direct emissions during operation and energy consumption over urban/local distribution cycles is typically around 70% lower than conventional diesel alternatives [9]. The market for these types of van is where air quality concerns are important and trip distances are short, such as within Local Authorities, airports, and businesses based in urban areas [10]. The batteries are usually recharged by plugging into the grid. Other potential schemes, including battery exchanges or leases are discussed in ESTAP brief T05 (Electric and plug-in hybrid vehicles). **Plug-in hybrids** (PHEVs) incorporate an ICE and a battery which can be recharged from the grid. This gives them an extended range compared to pure battery vehicles, making them suitable for longer journeys. The vehicles may be operated in electric-only mode for short journeys in sensitive areas such as cities or warehouses. Many fleet vehicles return to a base at night, which is useful for recharging. Several manufacturers are developing PHEVs, and others - such as General Motors - have recently announced their intent to do so. Some models, for instance the Mercedes Sprinter, are produced as HEVs or plug-in versions.

■ **Hydrogen Fuel Cell vehicles** (FCVs) utilise an electrochemical process to power an electric motor from hydrogen and oxygen (in air) with a higher efficiency than a combustion engine. They have a range, performance, and refuelling time similar to ICE vehicles, which makes them more suitable than BEVs for higher loads and highway driving. ESTAP brief T07 (Automotive Hydrogen Technology) provides a more detailed overview how the fuel cell itself works. Major auto manufacturers, fuel cell companies and many governments are investing in research and development of FCVs. Delivery services have frequent stops and high annual mileage, which exploits the energy-saving potential of fuel cells and allows a more rapid recovery of the investment costs [11]. FCVs do however present two major challenges: on-board storage of hydrogen and the lack of hydrogen production and distribution infrastructure. Global investment to supply hydrogen to the world's transport sector could cost several hundred billion dollars over several decades (see [11] for more details).

■ **CNG & LPG** are usually used in bi-fuel vehicles that can also use petrol (but not at the same time), and are available as retrofit conversions. Liquefied petroleum gas (LPG) and compressed natural gas (CNG) are both well established in automotive markets worldwide; for instance, Ford Transit and Citroen Berlingo vans are available in both CNG- and LPG-fuelled versions. Further details can be found in ESTAP technology brief T03 (Automotive LPG and Natural Gas Engines). Both of these fuels require a larger, heavier storage tank which can detract from the loading capacity and fuel economy compared to ICEs. This concern may be outweighed by the benefits in terms of reduced emissions and running costs. In addition, blending or switching with biogas offers a route to reducing life cycle emissions from natural gas engines. Biogas could be sourced from anaerobic digestors or landfill.

PERFORMANCE AND COSTS – The global average energy intensity for light trucks has been gradually improving, although it remains the least efficient mode of surface freight transport per tonne-km activity [1]. Road freight cannot, however, be completely replaced by other modes as there is still a need for its flexibility in terms of infrastructure, capacity and tonnage.

It is cheaper to run a small van fully loaded than a half-empty larger van [12]. Heavier vehicles tend to consume more fuel per km, but on average, even though a fully laden van weighs 50% more than an empty one, the CO_2 emissions only increase by around 8% [4].

The ICE is taken as the benchmark against which any alternative system must compete in terms of cost, reliability and efficiency. It is expected that ICE technology will remain competitive for the foreseeable future [13]. Advanced ICE technologies have the

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potential to reduce GHG emissions. For 2020, ICE technology could reach a target of 125 g CO_2/km using extra strong downsizing, which would incur additional costs of around 20% (€4,000) compared to 2007 retail prices [21]. For this target, reduced engine friction losses could decrease CO_2 emissions by 3-6% at an additional cost of €40-120; extra strong downsizing could reduce CO_2 by 10% at an additional cost of €400-500.

The most significant cost component for **BEVs** is the battery. According to [14] the incremental investment cost is upwards of €55,500, although the running costs may be reduced by up to 75% [9]. Smaller models mean the batteries will be smaller and cheaper.

HEVs have been tested for several years now in North America, Asia and Europe [15]. A 12-month trial of diesel hybrid delivery vans reported that on-road fuel economy improved by around 29% while maintaining similar reliability and operational performance as conventional vehicles [16]. Retrofit stop-start hybrid systems are available at a retail price of around £27,000 (€32,360) [17]. For 2020, hybrid light commercial vehicles could reach a target of 125 g CO_2/km at a cost of around 30% (€6,000) higher compared to 2007 retail prices [**Errore. Il segnalibro non è definito.**].

According to the US EPA [18], a demonstration parallel **hydraulic hybrid delivery truck** has achieved 60-70% better fuel economy and 40% reduction in CO_2 emissions over a conventional vehicle. The same source suggests that added costs for the mass-produced hybrid components have the potential to be less than US $7,000 and the vehicle lifetime is typically 20 years.

Capital costs of **fuel cells** have been declining but still remain high compared to conventional ICE vehicles [19]. A delivery service is well suited to exploit the energy saving potential of fuel cells and recover the higher investment cost more quickly. The efficiency of hydrogen fuel cells is more than twice that of conventional ICEs [11]. The IEA estimates that fuel cells for use in the delivery van market segment would become cost effective at an incremental cost of US $15,000 per vehicle [11]. Maintenance costs are expected to be reduced due to the long life of the fuel cell drivetrain.

For car-derived vans running on **CNG or LPG**, the additional capital (conversion) costs are in the region of €4,500 [20]. CNG and LPG are already established, but in some cases they have not been found to be cost effective, particularly in areas where refuelling infrastructure is not already available [10].

The actual improvements in performance will depend on whether a suitable technology has been chosen for the drive cycle. For example, diesel hybrids are effective in the urban drive cycles typical for light trucks, but hybrid technology offers little benefit in long-distance freight applications (more typical for heavier trucks).

Potential and Barriers

■ **Major drivers for performance and costs -** The transport sector is predicted to account for 97% of the increase in world primary oil use between 2007 and 2030 [1]. Concerns about energy security and climate change will be significant drivers for a move towards alternative energy carriers and greater efficiency. For example, Corporate Average Fuel Economy (CAFE) regulations in the US, which are set separately for passenger cars and light trucks, aim to improve fuel economy. The IEA has recommended that mandatory fuel efficiency standards should be made more stringent, or be introduced if they are not already in place [1]. In the EU, mandatory CO_2 emission standards are in the process of being agreed for vans (i.e. light trucks) for 2015 and 2020. [21].

Surging oil prices or increasing fuel duties will also increase uptake of more fuel efficient technologies if the vehicles can be manufactured cheaply enough that a net saving is delivered over the period of ownership. Vehicle pricing and operating costs are ranked first in terms of importance for the purchase of company vans, contrasted with a ranking of around tenth for purchase of private passenger cars [4]. Environmental concerns and conforming to local schemes such as congestion charging are also cited as being among the most common drivers for low carbon van purchase [22].

The rapid development of e-commerce and just-in-time logistics has increased the need for fast delivery and small cargo volumes. Transport of goods by road is attractive due to its flexibility compared to rail. Other contributing factors towards smaller delivery packs include urban sprawl, decreasing size of households and increasing single-occupant households.

■ **Market potential and prospects -** One perspective for the potential for the various technologies is summarised in Figure 1.

Hybrids are especially appropriate for densely populated areas and stop-and-go use. In spite of the price disadvantage the market for hybrid vehicles has started to take off due to vehicle manufacturers with a long-term vision on energy efficiency and government incentives [**Errore. Il segnalibro non è definito.**]. According to market analysts [23], in the US (the single largest market) they could occupy almost a quarter of light-duty vehicle sales in 2030, driven by consumer preferences, high oil prices, and automaker's investments.

The market for **BEVs** is small compared to hybrids, as it appears that subsidies are not sufficient to drive greater

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uptake [6]. Even so, electric vehicles have the advantages of being clean and quiet, and could be a success in niche operations with a defined range such as local deliveries. Advances in Lithium-ion batteries have improved the near-term prospects for BEVs and PHEVs, although they are still limited by their range and storage capacity [19]. Greater penetration might be further supported if there is potential for them to act as energy storage when integrating renewable generation into the electricity grid. However, battery lifetimes (including number of charge/discharge cycles) would need to be substantially improved for this to become both a practical and economically attractive possibility.

	Near term ~2015	Medium term ~2030	Long term ~2050
HEVs	Niche	Mainstream	Mainstream
EVs	Niche	Mainstream	Mainstream
FCVs	Prototype	Niche-Mainstream	Mainstream
CNG / LPG	Niche	Niche	-

Figure 1 – projected market outlook for light truck powertrain technologies (adapted from [20])

The outlook for **FCVs** is less clear, although nine major manufacturers – Daimler, Ford, General Motors, Honda, Hyundai, Kia, Renault, Nissan and Toyota – signed a joint statement in 2009 suggesting that FCVs could be available in dealerships by 2015. European and US governments are favouring electric vehicles in the medium-term [20]. In general, the FCV is currently the favoured technology for longer range applications. Therefore it seems likely that in the absence of substantial improvements to battery technology this would be favoured in the medium-long term for larger vehicles / longer range duty cycles.

CNG and LPG are seen as short-medium term options to reduce emissions. Many countries already have appropriate infrastructure, although coverage varies [20].

In general, the emerging technologies for light trucks are immature, and will take time to influence the fleet. The significant overlap with technologies for passenger cars is expected to yield beneficial crossover effects. However, there are some characteristics of the light truck industry which may have an impact on its development: The large buyers of vans can be powerful enough to have vehicles built to their specifications. Such buyers could accelerate the maturity of a preferred technology. They include governments, delivery/collection services (e.g. groceries, mail), infrastructure service suppliers and hauliers [2]. For example, in the EU new technology development is expected to be stimulated by greater uptake by public sector procurement as a result of the Clean Vehicles Directive (2009/33/EC). Production volumes for light trucks are generally lower than those for cars, and product cycles are longer. The development of better technologies could be facilitated because the major manufacturers often collaborate in high-cost strategic technology development [2]. Uptake may vary by region, depending on the technology most appropriate for the dominant vehicle type. Areas with concentrated corporate structure in key sectors such as retail have greater demand for heavier vehicles, whereas those with a higher proportion of small businesses have demand skewed towards the car-derived van sector [2]. Some alternative energy carriers are better suited to smaller (or shorter range) vehicles – such as pure electric propulsion - while larger (or longer range) vehicles can benefit more from other technologies such as hydraulic hybrids and fuel cells.

■ **Barriers to development and deployment -** Currently, the high upfront costs and public perception are significant barriers for all alternative energy carriers. In the case of **BEVs**, the reduced range and extended charging times are barriers, particularly in cases where the fleet does not have predictable/local routes and usage patterns. The charging infrastructure is already in place if the batteries are refuelled from the electricity grid, but additional investment in fast charging stations would help the widespread adoption of BEVs [1]. Lithium-ion batteries are becoming the dominant battery chemistry for vehicle applications [1]. Significant increases of production volumes and improved battery characteristics are needed to bring costs down. Although most manufacturers are planning to bring new **hybrid** models to market in the coming years, it is expected that sales will be limited because of constrained supply [6]. Battery costs (per unit capacity) for hybrids are higher than for pure electric vehicles since they need to be designed with higher power density [1]. Penetration is expected to be lower in the absence of design innovations and cost reductions. The refuelling of **FCVs** is problematic in the absence of extensive hydrogen production and distribution infrastructure. There are some initiatives to set up and expand hydrogen networks, such as "H_2 Mobility" in Germany. Alternatively, fleet operators may invest in private refuelling infrastructure, for example where the vehicles return to a central base. However the wider diffusion of the technology is limited until a sufficiently large infrastructure is in place. For **CNG and LPG**, there are no significant drivers for uptake compared to other alternative fuels [20]. Again, infrastructure and availability are barriers in areas where they are not already in place.

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Table 1 – Summary Table: Key Data and Figures for Baseline and Alternative Light Truck Technologies [10, 15, 17]

BEV		
Energy Input	Electricity	
Base Energy Consumption, MJ/veh-km [15]	0.91	
Technical Lifetime, yrs [15]	12 (battery life)	
Additional cost , € [a, b] [15], [10]	55,500 - 65,000 (vehicle, incl. battery) 10,800 (battery)	
Maintenance cost (€/km) [b] [15]	0.0135	
CO_2 emissions, tailpipe g/veh-km [d] [15]	0	
LOW learning rate[c] [15]	0.90	
CENTRAL learning rate[c] [15]	0.85	
HIGH learning rate[c] [15]	0.80	
PHEV		
Energy Input	Diesel/Electricity	
Base Energy Consumption, MJ/veh-km [d] [15]	1.29	
Technical Lifetime, yrs	N/A	
Additional cost, € [b] [15]	11,000 – 14,500	
Maintenance cost (€/km) [b] [15]	0.0561	
CO_2 emissions, tailpipe g/veh-km [d] [15]	90	
LOW learning rate[c] [15]	0.90	
CENTRAL learning rate[c] [15]	0.85	
HIGH learning rate[c] [15]	0.80	
HEV		
Energy Input	Diesel	
Base Energy Consumption, MJ/veh-km [d] [15]	2.09	
Technical Lifetime, yrs [17]	7 (estimated battery life)	
Additional cost, € [b] [15]	5,000 (full hybrid)	
Maintenance cost, €/km [b] [15]	0.0561	
CO_2 emissions, tailpipe g/veh-km[d] [15]	200	
LOW learning rate[c] [15]	0.90	
CENTRAL learning rate[c] [15]	0.85	
HIGH learning rate[c] [15]	0.80	
Baseline Vehicle		
Energy Input	Diesel	Petrol [f]
Base Energy Consumption, MJ/veh-km [d] [15]	3.92	3.36
Technical Lifetime, yrs [15]	10	10
Basic cost, € [b] [15]	€20,295	€10,400
Maintenance cost, €/km [b] [15]	0.0561	0.0442
CO_2 emissions, tailpipe g/veh-km [15]	270	225

a) Battery price based on Smith manufacturer's data; b) operating/Maintenance cost excludes fuel costs. Data in GBP converted to Euros using an exchange rate of 1.2 (2010 average) and rounded; c) 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; d) Based on 2007 vehicle data; e) Actual energy consumption and CO_2 reduction will depend on the drive cycle; f) Petrol vehicles are typically smaller (e.g. car-derived vans) compared to diesel vehicles– in the UK petrol vehicle sales are around 40% /50% /10% for European N1 Class I /Class II /Class III respectively. In comparison the on average larger diesel vans registrations split in the UK is 14% /31% /55%.Class I vans are up to 1305 tonnes unladen weight, Class II are up to 1760 kg, and Class III all other vans over this weight.

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