Programme Area: Heavy Duty Vehicles

Project: HDV OH Market Analysis

Title: Final Report

Abstract:

This report was prepared by Ricardo UK Ltd, in conjunction with Ricardo Energy & Environment and Automotive World. It has been established that demand for On Highway Heavy Duty Vehicles will grow from 3.34m vehicles in 2015 to 4.24m vehicles in 2030 (in the 6 large markets studied). The majority of this growth will be in the >7.5 ton vehicle sector, as the Chinese and Indian road transportation markets mature from an “owner operator” model towards a “fleet operator” model. The increase in vehicle weight will increase demand for larger displacement engines (>6 litres) and also encourage further uptake of Automatic Manual Transmissions (AMT) at the expense of manual transmissions. Diesel will remain as the dominant fuel type for HDVs with ~85% HDVs powered by Diesel Internal Combustion Engines in 2030. It is expected that City Buses will have greater levels of hybridisation and there will be a variety of technical solutions for City Buses, including fully electric, as inner city air quality concerns and legislation increases. Emissions legislation will continue to develop in the various regions, with increasing harmonisation between the standards. There is a trend towards increasing number of regulated pollutants, over a larger number of tests and an increased duration (life) that the vehicle must meet the targets. Some regions are beginning to use CO2 / fuel efficiency regulations and it is expected that this trend will spread to other regions over time.

Context:

The aim of this project is to provide an improved understanding of the current activities and trends occurring in the On-Highway Heavy Duty Vehicle arena. Future technologies and legislation are being assessed to further enhance the our knowledge of the existing market and anticipated future market state.

The project is being delivered by a consortium led by Ricardo UK with partners Automotive World and Ricardo-AEA.

AW Automotive World

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Heavy Duty Vehicle Efficiency Programme
On-Highway Market Analysis Project

FINAL REPORT

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4 March 2016	RD15-002476-2	JAP	Second issue Updated following feedback from ETI

EXECUTIVE SUMMARY

The Heavy Duty Vehicle On-Highway Market Analysis project, commissioned by the Energy Technologies Institute (ETI), has provided insight into the current market activities, legislative changes and future technologies impacting the on-highway heavy duty vehicle arena. The outputs from this project will help the ETI to understand the potential market attractiveness and value of the current and future ETI HDV projects; and to understand what technologies OEMs are currently developing for on-highway heavy duty applications.

The project has considered the **six largest markets** or regions for HDV demand – China, North America, Europe (EU + EFTA), South America, India and Japan – and a range of vehicle segments from 3.5-7.5t trucks to multi-axle articulated trucks, as well as buses and coaches. Aggregate HDV demand in these selected markets fell by 2.5% in **2014 to 3.38 million units**, with declines in four of the six markets. The forecast anticipates aggregate demand falling marginally further in 2015 to 3.34 million units before growing to **4.24 million units in 2030**.

The aggregate rate of growth is constrained by the weak growth expected in the 3.5-7.49t segment. This segment is dominated by China, which typically accounts for 75% of demand across the six markets studied. The expected under-performance of this segment over the forecast period reflects the anticipated switching of demand to higher and lower weight classes as the Chinese transport industry matures.

The Bus & Coach segment and Articulated Truck segment are expected to show the highest rates of growth from 2014 to 2030.

The global truck industry is dominated by producer groups with an output in excess of 100,000 upa. **The Top-10 producers accounted for nearly 70% of the 6t-plus industry volume in 2014 and 76% of the 16t-plus sector.** These percentages rise still further if output by non-consolidated affiliates is included.

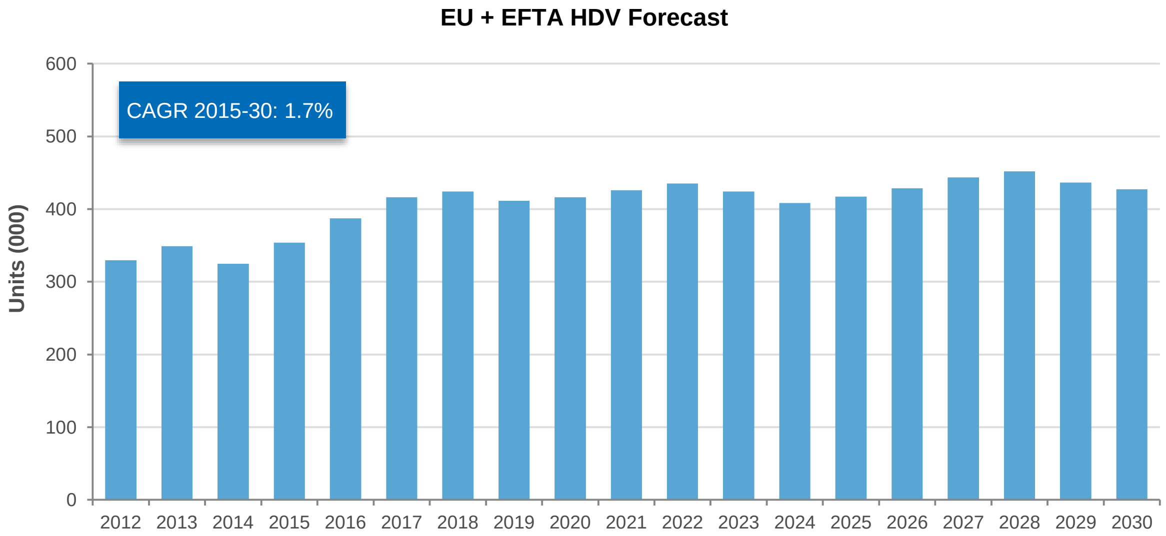

Figure 1: On-Highway Heavy Duty Vehicles Market Forecasts for Europe

Aggregate production in the selected markets is typically higher than the aggregate demand because the production data includes vehicles destined for export outside the selected markets. Aggregate HDV production in the six markets fell by 2% in 2014 to 4.49 million units, with an equal distribution of regions showing a decline and those showing an increase. The forecast anticipates **aggregate production rising to nearly 5.5 million units by 2030**, with a compound annual growth rate (CAGR) of 1.25% from 2012, though demand cycles will cause aggregate output to fall in some years.

Diesel-fuelled HDVs accounted for 93% of output in 2014. Significant growth is anticipated, both regionally and globally, in the proportion of HDVs powered by fuels other than diesel. However, at a global level diesel is still expected to account for 85-86% of output in 2030. Within individual sectors, such as urban buses, the growth in alternative fuels is expected to be greater, influenced particularly by China's development of all-electric and hybrid-electric buses.

Heavy duty vehicle emissions legislation around the world principally falls under three regimes: US, European or Japanese, with minor differences depending on the characteristics of the region. The main legislative trends across all regions are to tighten the emission requirements, increase the number of regulated pollutants, increase the number of tests for which a vehicle must demonstrate compliance, and extend the life over which a vehicle must continue to perform within tolerance.

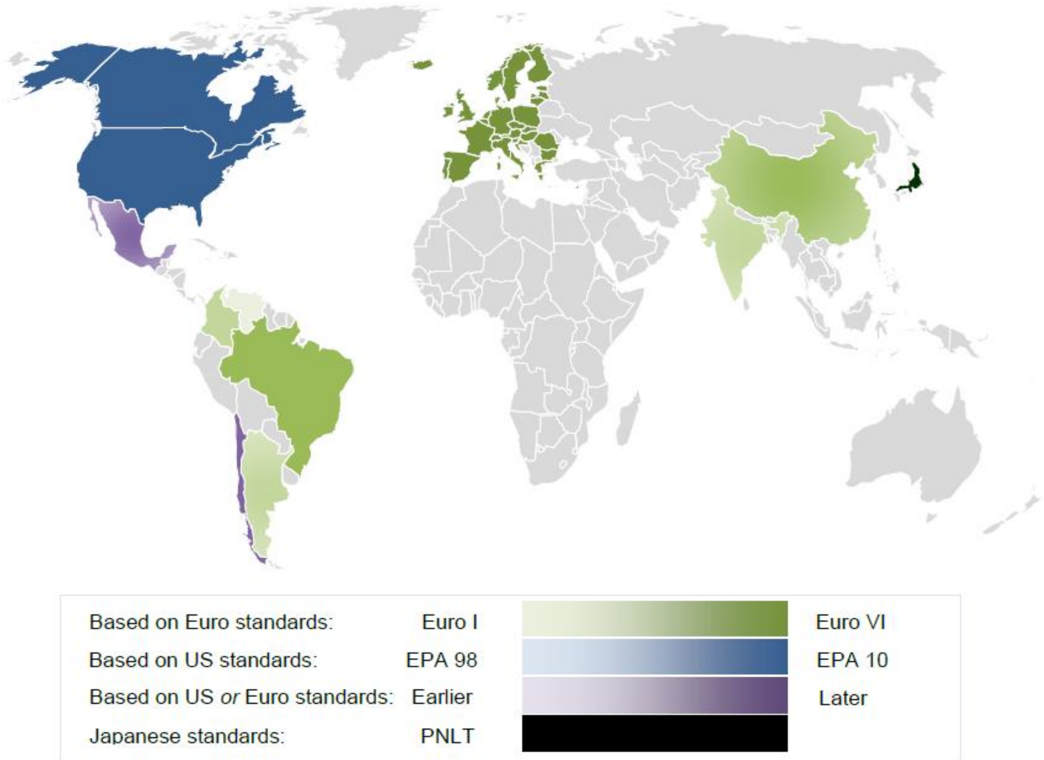

Figure 2: Current Emission Standards for the Six Regions

Several regions are also implementing CO_2 / fuel economy minimum standards, although the reasons for doing so vary. For example, the key driver for fuel economy regulation in the USA is the need for energy security, whilst in Europe reducing transport greenhouse gas emissions is more significant.

The importance of **total cost of ownership (TCO)** versus up-front costs to purchasing decisions varies significantly by region. Generally more mature markets place a greater emphasis on TCO, while developing markets are more concerned with upfront cost. The importance of other factors (such as reliability) in the decision-making process also varies between different regions.

The project profiled over 50 current and future technologies applicable to on-highway heavy duty vehicles. These technologies covered changes to engine design, thermal management improvements, gas exchange, fuel injection equipment, combustion systems, aftertreatment requirements, alternative fuels, hybridisation, transmission systems, vehicle technologies, and the introduction of waste heat recovery. Opinion was provided on the efficiency and emission benefits of each technology, additional cost, current technology maturity and future status.

To understand the expected future technology direction of the European on-highway HDV sector, the technologies were combined into likely Technology Packages. Market factors related to customer requirements and business (OEM) needs mean the preferred technology solutions may be not be the same for all vehicle segments. Therefore, the project considered likely technology combinations for future Heavy Duty Long Haul trucks, Medium Duty Distribution trucks and City Buses operating in Europe applied in two future timeframes, 2020 and 2025.

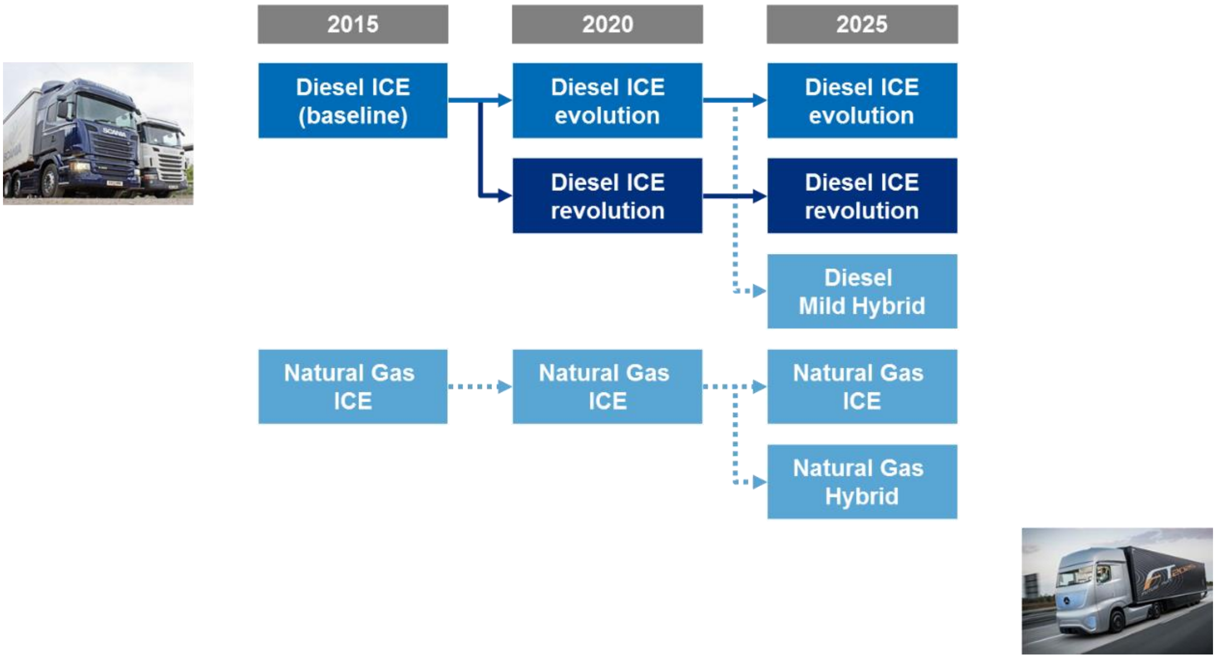

Figure 3: HD Long Haul Truck – Potential Technology Pathways to 2025

Mid-blue represents the likely mainstream Technology Pathway and Technology Packages in 2020 and 2025
Navy represents Ricardo's selected alternative Technology Pathway and Technology Packages for 2020 and 2025

For European **Heavy Duty Long Haul** trucks, the Technology Packages for 2020 and 2025 are likely to remain as diesel ICE. The mainstream options will feature evolutionary enhancements to existing technology to reduce tailpipe emissions and improve energy efficiency within a cost effective package. However, the alternative Technology Package could feature technology revolution through the addition of waste heat recovery and mild hybridisation enabled by 48V systems.

For **Medium Duty Distribution** trucks, the mainstream Technology Packages are expected to follow similar trends to the HD Long Haul mainstream Technology Packages. Evolutionary enhancements to the powertrain and vehicle will help to achieve emission limits while improving overall vehicle energy efficiency. The alternative is likely to feature hybridisation, although the higher capital investment is likely to limit the market uptake of this lower CO_2 option.

For **City Buses** the future Technology Packages are different than HD Long Haul and MD Distribution trucks. Hybrid technology is already a significant alternative technology in this sector, and is likely to be the mainstream option by 2025. A wider range of alternative technologies are already available. For this study, Ricardo selected electric vehicle technology as the alternative Technology Package for 2025. Other options include plug-in hybrid, natural gas and hydrogen fuel cell. Diversification of technology in the bus sector is expected to continue. Many of the alternative options require significant investment in infrastructure to enable the technology, such as building a natural gas refuelling station or installing on-street opportunity charging for EV buses at bus stops. Across Europe, each city and region will need to select the technology option which is most appropriate to their requirements and context.

Many of the technology trends predicted for Europe are likely to apply in North America, and to a limited extent, in Japan. South America and India lag behind Europe with regard to technology introduction, and this lag is expected to continue. China has demonstrated strong political will towards introducing ultra-low and zero emission technology for urban and city buses. The production share of electric and plug-in hybrid buses in China is expected to grow. Within the 10-15 year time horizon considered in this study, China could “leap frog” Europe in terms of market and technology maturity of alternative technologies for the HDV sector.

The Heavy Duty Vehicle On-Highway Market Analysis project has been delivered by a consortium led by Ricardo UK with partners Automotive World and Ricardo Energy & Environment.[1]

[1] Ricardo Energy & Environment is a trading name of Ricardo-AEA Ltd.

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1 INTRODUCTION

The Energy Technologies Institute is investing in developing technologies and measures that will improve the energy efficiency of medium and heavy duty commercial vehicles. To be able to evaluate the potential market attractiveness and value of current and future ETI HDV projects, the current and future operational environment needs to be understood. Therefore, the ETI commissioned the Heavy Duty Vehicle On-Highway Market Analysis project to provide information on:

- The current worldwide on-highway heavy duty vehicle market
- Expected future legislative changes
- State-of-the-art of HDV technologies, and the OEMs and Tier 1 suppliers active in developing these technologies
- Likely future Technology Packages for different HDVs
- Future HDV production levels

This document is the Final Report from the Heavy Duty Vehicle On-Highway Market Analysis project. It provides an overview of the current HDV market for the six geographical regions considered during the study – Europe, North America, South America, Japan, China and India – along with market and production projections to 2030. Trends regarding legislation and market drivers are discussed to provide insight into how this is shaping the HDV technology landscape. A series of future Technology Packages is presented to represent the likely mainstream and alternative options for heavy duty long haul trucks, medium duty distribution trucks and city buses in Europe.

The HDV OHMA project has been delivered by a consortium led by Ricardo UK with partners Automotive World and Ricardo Energy & Environment.[2]

[2] Ricardo Energy & Environment is a trading name of Ricardo-AEA Ltd.

2 NOMENCLATURE

2-Stage	Two-Stage Turobcharging
AMT	Automated Manual Transmission
ACC	Adaptive Cruise Control
AHSS	Advanced High Strength Steels
ASC	Ammonia Slip Catalyst
AT	Automatic Transmission
AW	Automotive World
BMEP	Brake Mean Effective Pressure
BSFC	Brake Specific Fuel Consumption
CAGR	Compound Annual Growth Rate
CGI	Compacted Graphite Iron
CFRP	Carbon Fibre Reinforced Plastic
CH_4	Methane
CHIC	Clean Hydrogen in European Cities
CI	Compression Ignition
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CR	Common Rail
CVT	Continuously Variable Transmission
cyl	Cylinder(s)
DCT	Dual Clutch Transmission
DI	Direct Injection
DOC	Diesel Oxidation Catalyst
DOE	Department of Energy (USA)
DOHC	Dual/Double Overhead Cam
DPF	Diesel Particulate Filter
EC	European Commission
ECU	Engine Control Unit
EFTA	European Free Trade Association
EGR	Exhaust Gas Recirculation
EHRS	Exhaust Heat Recovery System
ELR	European Load Response
ESP	Electronic Stability Program
ESC	European Stationary Cycle
ETI	Energy Technologies Institute
ETC	European Transient Cycle
EU	Europe / European Union
EV	Electric Vehicle
FAME	Fatty Acid Methyl Ester
FC	Fuel Cell
FC	Fuel Consumption
FCEV	Fuel Cell Electric Vehicle
FGT	Fixed Geometry Turbocharger
FIE	Fuel Injection Equipment
GHG	Greenhouse Gas
GPS	Global Positioning System
H_2	Hydrogen
HC	Hydrocarbons
HD	Heavy Duty
HDD	Heavy Duty Diesel
HDV	Heavy Duty Vehicle

HEV	Hybrid Electric Vehicle
HP	High Pressure
HP EGR	High Pressure EGR
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
LDW	Lane Departure Warning
LEV	Low Emission Vehicle
LEZ	Low Emission Zone
Li-ion	Lithium Ion
LNG	Liquefied Natural Gas
LP	Low Pressure
LP EGR	Low Pressure EGR
MD	Medium Duty
MT	Manual Transmission
NACFE	North American Council for Freight Efficiency
NG	Natural Gas
NH_3	Ammonia
NiMH	Nickel-Metal Hydride
NMHC	Non-Methane Hydrocarbons
NO	Nitrogen Monoxide
NO_2	Nitrogen Dioxide
NOx	Oxides of Nitrogen
NVH	Noise, Vibration and Harshness
OBD	On-Board Diagnostics
OEM	Original Equipment Manufacturer
OHMA	On-Highway Market Analysis
ORC	Organic Rankine Cycle

PEMS	Portable Emissions Measurement System
PHEV	Plug-in Hybrid Electric Vehicle
PI	Positive Ignition
PM	Particulate Matter
PN	Particle Number
R-EE	Ricardo Energy & Environment
R&D	Research and Development
SCR	Selective Catalytic Reduction
SCRF	Selective Catalytic Reduction on Filter
SME	Small Medium Enterprise
SOHC	Single Overhead Cam
TC	Turbocharger
TCO	Total Cost of Ownership
TP	Technology Package
TRL	Technology Readiness Level
ULEZ	Ultra Low Emission Zone
UK	United Kingdom
UN	United Nations
US(A)	United States (of America)
VECTO	Vehicle Energy consumption Calculation Tool
VGT	Variable Geometry Turbine
VVA	Variable Valve Actuation
VVT	Variable Valve Timing
WGT	Waste Gate Turbocharger
WHSC	World Harmonised Steady State Cycle
WHTC	World Harmonised Transient Cycle

3 THE CURRENT HDV MARKET

The on-highway heavy duty vehicle market consists of a range of medium and heavy duty vehicles generally used for the transportation of goods and people. Over 320 thousand HDVs were sold in Europe (EU and EFTA markets) in 2014, compared to 500 thousand in North America and nearly 1.8 million in China.

In Europe, the preference is for articulated trucks and >16t rigid trucks for transporting goods and materials. In contrast, in Japan and in China the preference is for smaller medium duty vehicles.

The on-highway heavy duty vehicle market is **competitive** and **cyclical**. New vehicle registrations and the use of the vehicles is strongly linked to national and regional economies. Changes in emissions legislation can also distort the market, as some truck operators bring forward their new vehicle purchases ahead of new emission limits, motivated partly by cost considerations and partly by a desire to stick to proven technology

The global truck industry is dominated by manufacturers producing more than 100,000 units per year. The top 10 OEMs account for nearly 76% of the industry volume for >16t vehicles (see Figure 5).

Extensive industry consolidation over the past two decades has seen several truck companies taken over by larger concerns. Daimler, Volvo and VW have all played a major buy-side role in this process. There have also been a number of alliances, particularly with partners in developing markets.

Table 1: Types of On-Highway Commercial Vehicles

HDV Segments			HDV Segments		
	1	3.5 - 7.4t		5	Articulated Truck 2-axle
	2	7.5 - 15.9t		6	Articulated Truck multi-axle
	3	≥16t 2-axle Rigid Truck		7/8	Bus and Coach
	4	≥16t multi-axle Rigid Truck			

Pictures: Iveco Daily Cab, www.iveco.com/uk ; Mercedes Atego, Antos, www.mercedes-benz.co.uk; Volvo FH series www.volvotrucks.com; Volvo 9500 bus www.volvobuses.com; www.trucksplanet.com

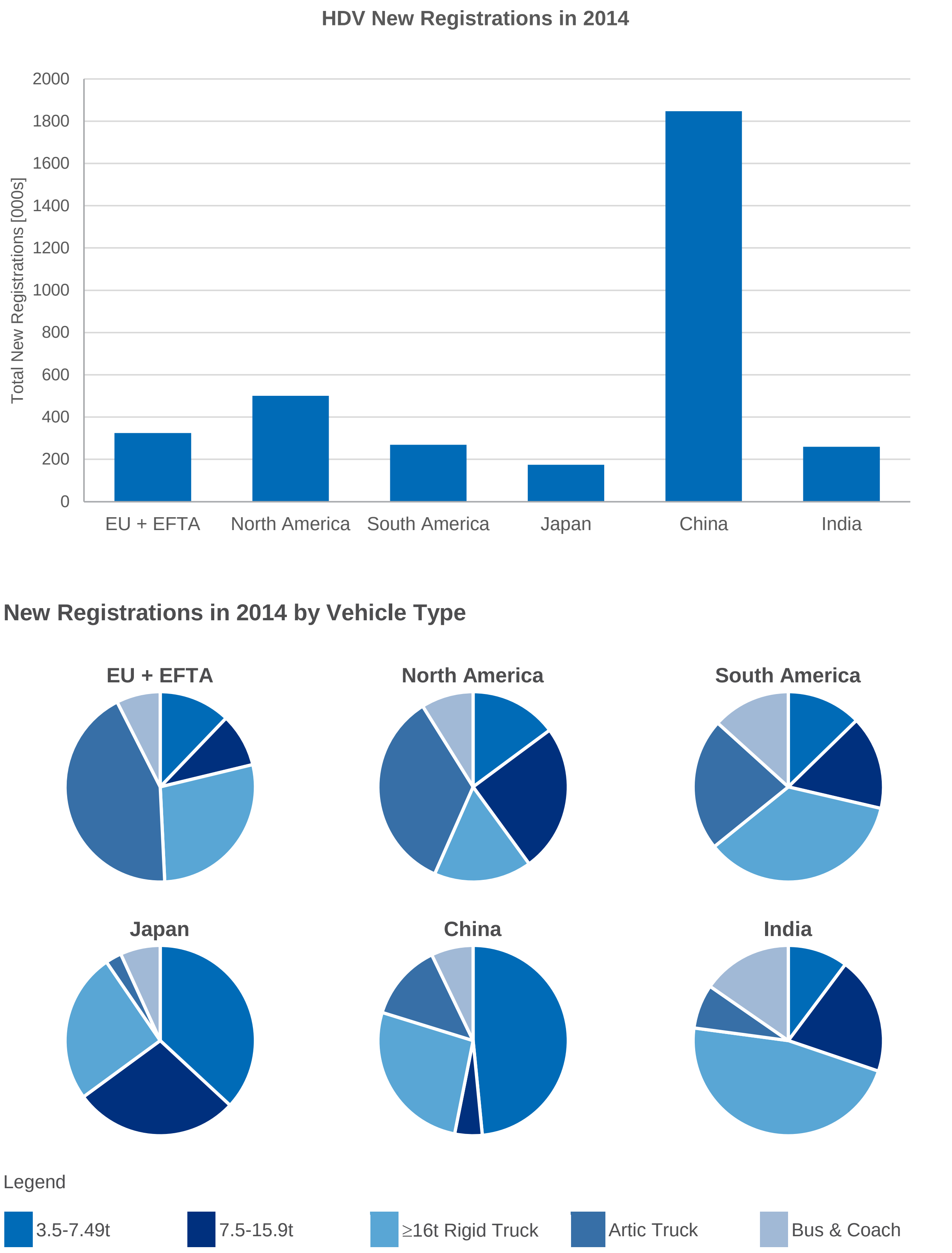


Figure 4: New HDV Registrations in 2014

Source: Automotive World

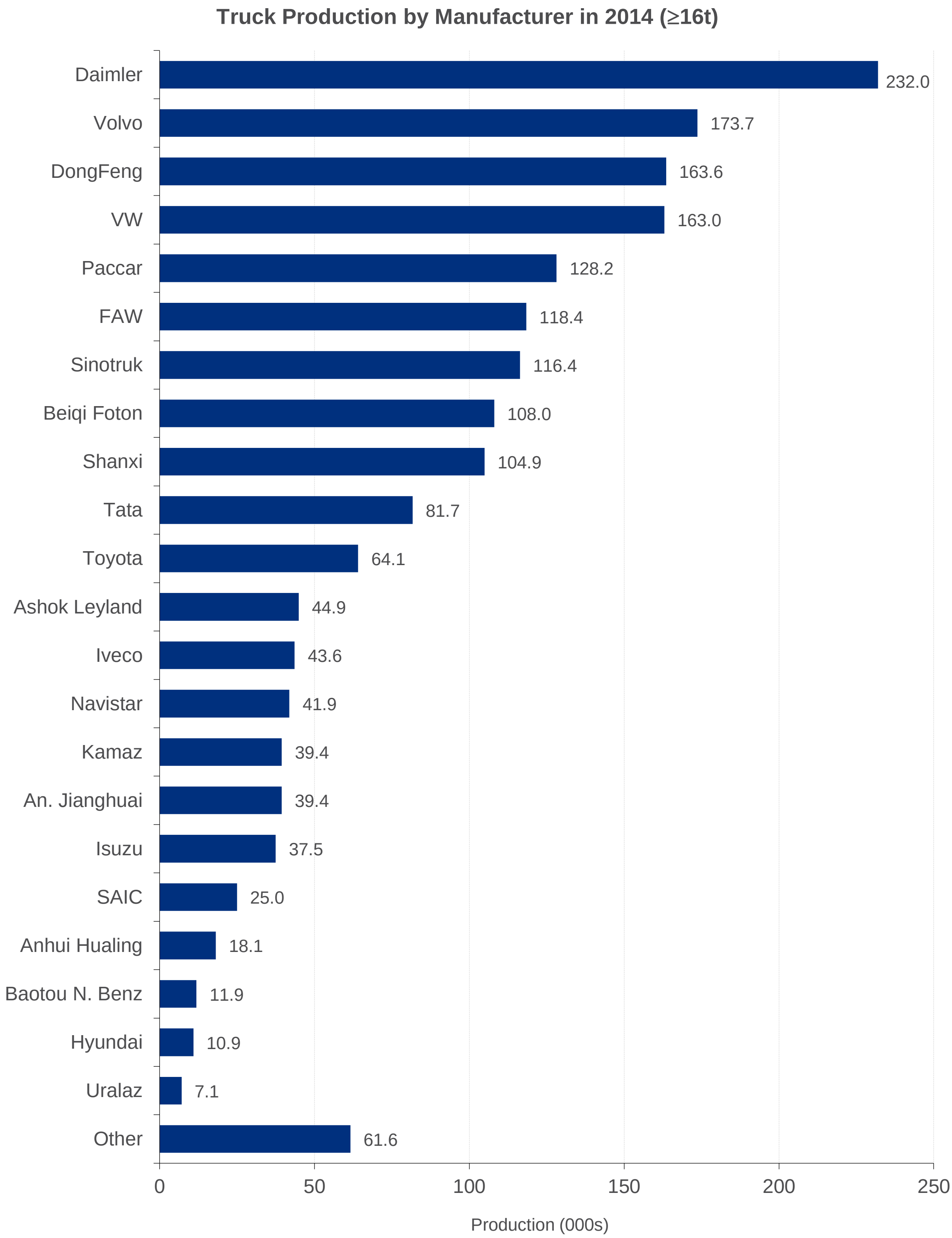


Figure 5: Truck Production (≥16t)

Source: Automotive World

Note: Chinese firms such as Beiqi Foton, Dongfeng and Sinotruk, are shown as separate entities in the figure above, though their joint ventures with Daimler, Volvo and MAN respectively, give (or will give) these three European firms even greater scale. If such joint venture output is included, the share of the top-10 producers increases by about 10pts.

Recent examples of HDV industry consolidation:

- MAN's acquisition of VW Truck & Bus, a 25% stake in China's Sinotruk and takeover of the joint venture with Force Motors in India
- Daimler's purchase of a further stake in Kamaz, buyout of Indian joint venture partner Hero and alliance with China's Foton
- Hyundai Motor's initial agreement with China's Baotou Bei Ben Heavy-Duty Truck
- Navistar's joint venture with Anhui Jianghuai Automobile
- VW's acquisition of MAN and Scania
- Volvo's joint venture with Dongfeng

Further consolidation of the industry looks imminent, particularly in China and among medium-sized players. In China there is excess capacity in the truck industry and the market looks unlikely to return to the rampant growth it experienced pre-2011. Medium-sized players will find it harder to compete with the truly global players as those players begin to exploit their economies of scale fully.

The pursuit of scale economies underlies a steady drift towards greater integration between North American and European operations. The Europeans are leading this trend, introducing in-house components to their North American model ranges. As well as the upstream scale economies in development, manufacturing, and purchasing, this also confers downstream benefits from aftermarket sales through the service network. For example Paccar's Parts Division has seen faster revenue growth than its other two divisions since 2011 when it began offering an in-house engine to North American customers.

In a business as markedly cyclical as the truck industry, it is a company's ability to remain profitable throughout the demand cycle which is the real sign of having got the fundamentals of the business right. Therefore **operating profit and margin,** measured over the market cycle, are important to the HDV OEMs.

In Automotive World's opinion, a margin of 5-7% is probably the lowest target range a HDV OEM is likely to set as a long term cyclical average. Remarkably, despite the severe post-credit crunch downturn, in the five years 2008-12 there were three western HDV OEMs which managed to exceed this suggested 5% threshold: Scania, Paccar and MAN. Volvo was close behind at 4.8%. In the last five years ending in 2014, there were at least seven OEMs close to or exceeding this operating margin target (see Figure 6).

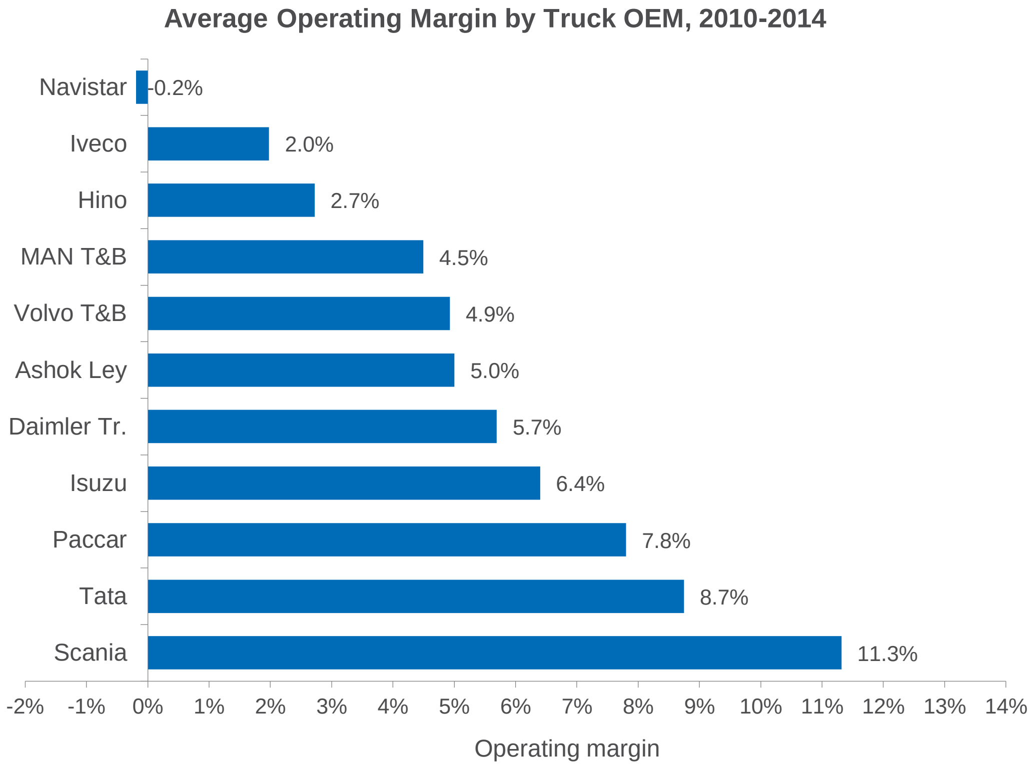


Figure 6: Average operating margins of the major truck makers, 2010-14

Source: Automotive World. Based on published company reports

There are various similarities between the developed HDV markets of Europe, North America and Japan. The vehicles are particularly fuel efficient and adhere to some of the world's most stringent emission standards (see Chapter 4). The buyers in these markets share a number of preferences such as improved fuel efficiency, reliability and reduced maintenance schedules and rank them similarly. **Total cost of ownership (TCO) is paramount.** Access to capital is now good in all three regions, having been a constraint on demand following the credit crunch. Furthermore, the vehicles are typically designed, produced and procured from the host region.

High fuel prices in Europe have led to some of the world's most fuel efficient HDVs in the absence of specific regulation. This continues to be one of the strongest drivers of innovation today. Current engine brake thermal efficiencies are around 45%, and will need to exceed 50% if the expected fuel economy legislation is introduced. By contrast, in the USA fuel efficiency improvements tend to be driven by the need for national energy security and resulting legislation.

The fleet characteristics for Europe and the US are loosely similar with a distinct preference for heavier, articulated HDVs used in long-distance freight transport. However Japan's shorter average journey and widespread urban geographies have led to a preference for smaller, rigid HDVs.

The maturing automotive markets of China, India and South America are at various stages between prioritising TCO and initial purchase price, generally leaning towards the latter because access to capital is often more difficult. Although each market is gradually shifting towards TCO considerations and is experiencing a growth in demand for mid-market vehicles, the typical vehicle remains cheap and prioritises reliability and functionality over comfort and safety.

Reliability, robustness and ease of maintenance are important criteria for buyers in these maturing markets, where vehicle maintenance comprises a larger proportion of HDV operating costs than in economically developed regions. The reasons for this include the additional wear caused by poor road conditions and the frequent loading of vehicles well beyond their design weight. Such operating conditions are a major factor in explaining the shorter vehicle lifespans in these regions.

Vehicle overloading compounds road quality problems and in combination with congested roads, this results in lower average speeds which increases the demand for idling technologies but reduces the effectiveness of resistance-improvement technologies.

The maturing markets are otherwise very distinct in their consumer demands, vehicle properties and fleet characteristics. Whilst the typical South American vehicle is large, Chinese and Indian vehicles are typically rigid and small, possibly due to the higher proportion of owner-operator vehicles in these countries who can only afford such vehicles. The South American market is increasingly using imported articulated trucks, whilst Chinese vehicles are largely vocational or specialised domestic products. The average fuel efficiency is improving in each of the regions as in all cases it makes up the largest operating cost, however the demand for fuel efficiency improvement varies. The degree to which operators in each region lean towards initial purchase price is also quite different: whereas Chinese and South American buyers will weigh up both, Indian buyers are comparatively less interested in TCO.

These differences reveal the importance of considering the intended geography in HDV technology and technology investment decisions.

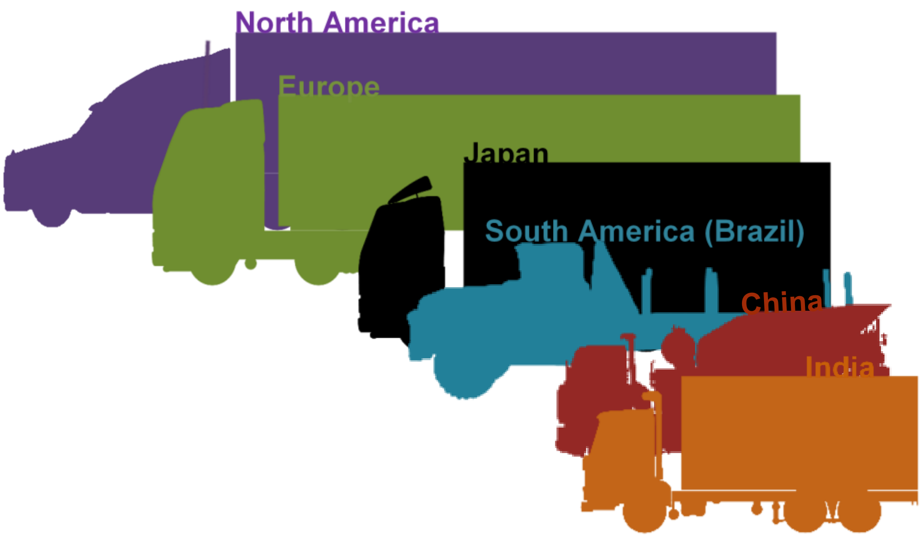


Figure 7: An illustrative comparison of average HDV size in each region

Picture: Ricardo Energy & Environment

The use of Alternative Fuelled Vehicles (AFVs) within the European HDV sector is very limited, except in Sweden, Poland, the Czech Republic and Austria, which have sizable natural gas truck fleets and, in places, electrically-powered trolley-bus systems (Ricardo and AEA, 2011). There are however, numerous incentives to purchase clean heavy duty vehicles and additionally restrictions in the movement of more polluting HDVs. In particular, the Clean Vehicles Directive (Directive 2009/33/EC) assists public authorities and fleet operators with the procurement of clean and energy efficient vehicles, including HDVs. In addition, low-emission zones have gained prevalence in Europe in recent years, and this trend is expected to continue.

4 TAILPIPE EMISSIONS AND CO_2 / FUEL ECONOMY LEGISLATION

Tailpipe Emissions Legislation

Tailpipe emissions legislation has been and will continue to be a significant driver for HDV technology development as vehicle and engine OEMs seek to identify solutions that will comply with emission limits while minimising adverse impacts on performance and fuel economy.

Legislative trends can be roughly categorised into two regimes: one for developed or 'advanced' regions and the second for less developed regions. In developed regions such as the **Europe**, **North America** and **Japan**, emission regulations on the 'traditional' pollutants of CO, HC, NOx and PM have become increasingly strict. Vehicles complying with the latest standards have exceedingly refined engines and aftertreatment systems. In cost terms, the 'low-hanging fruit' has been seized. Further reductions in these traditional pollutants are likely to yield diminishing returns, unless new technologies can be identified.

The emerging trend in developed regions is for legislation to expand the number of regulated pollutants. For example, particle number limits have been included in the most recent European limits (Euro VI), and the NO_2 component of NOx is being reviewed.

Another legislative trend in developed regions is the desire to more accurately reflect real-world emissions in the testing procedures. Some of the latest regulations include in-service conformity requirements, PEMS testing and off-cycle emissions (not-to-exceed) limits. On-board diagnostic (OBD) strategies have become more stringent, allowing the vehicle to self-identify when its tailpipe emissions are abnormally high and to warn the operator during real-world use, perhaps even going into a 'limp-mode' until rectified.

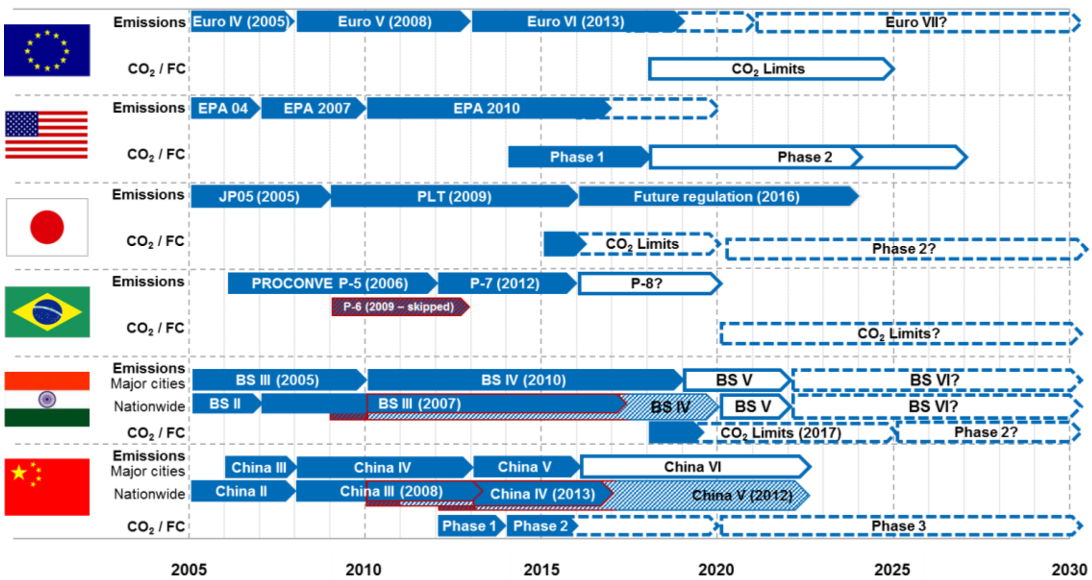


Figure 8: HDV Emissions and CO_2 / Fuel Consumption Legislation by Region

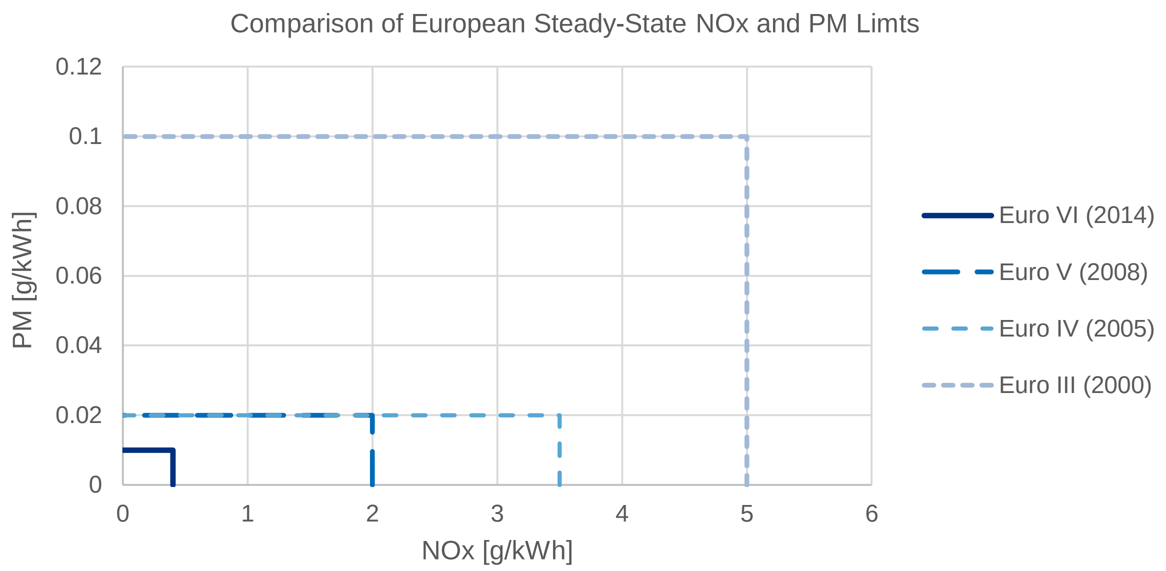


Figure 9: Comparison of European steady-state NOx and PM limits

Note: Euro VI standards use two new global heavy duty engine dynamometer test cycles developed by the United Nations working group on pollution and energy (GRPE). These cycles are the Worldwide Harmonised Steady state cycle (WHSC) and the Worldwide Harmonized Transient Cycle (WHTC). WHSC is a 13 mode ramped test cycle. WHTC is a 30 minute duration transient cycle based on real-world driving conditions for heavy duty vehicles. Previous European emission standards used the ESC 13 mode steady state cycle and the ETC transient test cycle.

Table 2: Euro VI Emission Limits by Test Cycle

Test Cycle	CO [mg/kWh]	THC [mg/kWh]	NMHC [mg/kWh]	CH_4 [mg/kWh]	NOx [mg/kWh]	NH_3 [ppm]	PM [mg/kWh]	PN [#/kWh]
WHSC (CI)	1,500	130	-	-	400	10	10	8.0×10^{11}
WHTC (CI)	4,000	160	-	-	460	10	10	6.0×10^{11}
WHTC (PI)	4,000	-	160	500	460	10	10	6.0×10^{11}

The trends shared by the developed regions suggest some harmonisation of regulations. Europe has already adopted the new World Harmonised Steady State Cycle (WHSC) and World Harmonised Transient Cycle (WHTC) in Euro VI (2014), and Japan will adopt WHTC from 2016. This is strongly desired by HDV manufacturers who must certify over many tests within many markets. Development costs are significantly reduced if OEMs can use the same technologies and calibrations across markets. Regulators cannot currently accurately compare performance of vehicles sold in their territories with those sold in other markets due to the differing test cycles. Thus harmonisation may also provide some beneficial insights for them too. However, the principal counter argument to any harmonisation is that the geographical markets have different ambient characteristics, road types, typical duty cycles and, most importantly, fuel prices. Indeed, the WHTC does not reflect typical HDV duty cycles in the US.

Less developed regions tend to follow in the wake of the more developed regions, typically applying duplicate or slightly tweaked versions of the European or US EPA standards. In multiple regions, however, such as the majority of **South America**, **India** and **China**, inadequate fuel quality has repeatedly stunted progression. The advanced aftertreatment systems required to meet more stringent emissions regulations are sensitive to sulphur content in the fuel. This is a recurrent issue at the implementation of each successive standard, particularly between Euro IV-VI and US EPA 04-10. The main issue in the affected countries is the lack of suitable refineries for low and ultra-low sulphur diesels.

CO_2 / Fuel Consumption Legislation

Unlike USA, Japan and China, there is currently no legislation to limit CO_2 emissions from heavy duty vehicles in Europe. However, this is expected to change in the time frame 2020-2025 and is likely to have implications regarding which technologies are selected for HDVs.

Japan established the world's first fuel efficiency standards for large diesel-powered trucks and buses. These fuel efficiency standards are set using the ‘top runner’ principle. The targets were set in April 2006 and required vehicle manufacturers to improve fuel economy by an average of 12.2% from 2002 levels by 2015. Penalties are levied against manufacturers failing to submit corporate average fuel efficiency data showing fuel economy improvements. The fuel efficiency standards (km/L) are split by vehicle type and weight band.

In **USA** GHG emissions and fuel economy standards for on-highway medium and heavy duty vehicles have been effective under Federal law since 2014. Legislation has been introduced in response to the high portion of GHG emissions from transport attributable to medium and heavy duty vehicles in USA. Phase 1 is intended to focus OEMs to “redesign and upgrade” their products. Phase 2 (from 2018) will cultivate a single national programme, aligning the standards of the EPA, NHTSA and CARB, to allow OEMs to build a single fleet of vehicles and engines for the US market. Collectively, Phase 1 and Phase 2 seek to reduce the fuel consumption of Class 7 and Class 8 trucks by 30-45% compared to 2010 level.

In **China**, the current ‘Stage 2’ fuel economy limits for HDVs have applied since 2014. The fuel consumption limits (L/100km) vary by vehicle type and gross vehicle weight.

In **Europe**, the cost of fuel is a significant proportion of the total operating costs for HDV fleet operators. Therefore, there is an existing financial incentive towards reducing fuel consumption. OEMs have been active for many years in researching and developing cost-effective technologies for Europe that will improve energy efficiency within a sensible payback period for their customers.

Since the introduction of Euro VI emission standards in 2014, it is necessary to measure CO_2 emissions from new engines over the World Harmonised Steady State Cycle (WHSC) and World Harmonised Transient Cycle (WHTC). This is enabling comparable data to be collected from MD and HD engines for monitoring and for establishing a suitable baseline.

The European Commission has reported its intention to propose legislation that would require CO_2 emissions from new HDVs to be certified, reported and monitored. This will contribute to a more transparent and competitive market and encourage the adoption of more energy efficient technologies. Initial reports suggest this could be implemented from 2018, at least for diesel trucks (European Commission, 2014). Following a period of CO_2 monitoring and declaration, it is possible that the European Commission will introduce CO_2 limits for HDVs in the timeframe 2020-2025.

The trend for HDV fuel economy regulations is to use a combination of component testing and vehicle simulation to predict fuel efficiency and CO_2 for a range of variants and duty cycles. This is a lower cost and more practical solution than requiring all HDV variants to be tested on heavy duty vehicle chassis dynamometers. For example, the US use the Greenhouse gas Emissions Model (GEM) to predict whole vehicle fuel consumption.

The European Commission is investing in developing VECTO (Vehicle Energy Consumption Calculation Tool) for estimating fuel efficiency and CO_2 for HDVs. It is postulated that this tool may be basis for future HDV CO_2 legislation.

5 OTHER MARKET DRIVERS AND MARKET BARRIERS

There are many factors that influence the adoption and uptake of new technology in the on-highway HDV sector. These drivers, summarised in Figure 10 below, can be broadly divided into legislation and government policy, customer requirements, and business (OEM) needs.

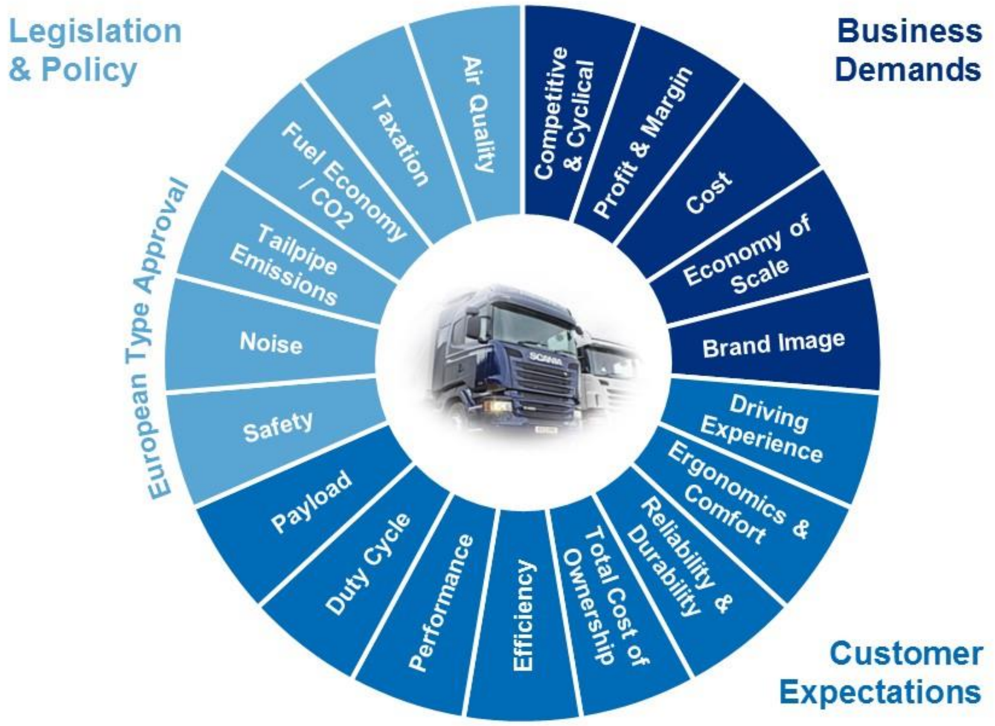


Figure 10: Market Drivers influencing HDV technology selection in Europe

Legislation Requirements and Government Policy

As discussed in the previous Chapter, tailpipe emissions legislation and emerging CO_2 regulations are strong drivers for developing HDV technologies. However, this is not the only legislation relevant to HDVs.

Vehicle Type Approval is required to be able to sell a new HDV in Europe. In addition to the tailpipe emissions legislation, there are over 50 other European Directives and UN Regulations that have to be met to receive vehicle type approval. Many of these directives relate to vehicle **safety** features, such as braking systems, passive and active occupant protection, visibility around the vehicle, pedestrian and cyclist safety.

Taxation and **incentives** can influence the type of vehicle purchased and used. For example, in the UK vehicle excise duty (VED) tax bands for goods vehicles depend on the type of vehicle and its total weight. As a consequence, many logistics operators transporting light goods will use 38t vehicles rather than 44t.

Air quality is an issue for many cities across Europe, which is leading many city authorities to introduce Low Emission Zones (LEZ) that limit vehicles' access according to their emission standards. For example, London plans to introduce an Ultra Low Emission Zone (ULEZ) from September 2020. All cars, motorcycles, vans, minibuses and trucks will need to meet the specified exhaust emissions standards or pay an additional daily charge to travel within the zone. Such local and regional policies will impact on the vehicle requirements specified by HD and MD fleet operators.

The **European Clean Vehicles Directive** (2009/33/EC) aims to promote and stimulate the market for clean and energy efficient vehicles in public transport. The directive requires public authorities and operators to consider the in-use impacts of the vehicle, such as energy consumption, CO_2 emissions and pollutant emissions, when purchasing new buses.

Customer Requirements

The basic **performance and functionality requirements**, defined by what the vehicle will be used for (e.g. transporting goods or passengers) and how it will be used (its typical duty cycle), will determine the type of vehicle to be purchased or leased. In Europe, truck operators, particularly fleets, tend to consider the **total cost of ownership** (TCO), rather than focusing only on the initial capital cost.

European buyers expect HDVs to be reliable, durable, and low maintenance, with readily available access to a servicing network.

Fleet operators are continually seeking to **optimise their fleet configuration**, which could impact on the future vehicle market for heavy and medium duty distribution vehicles. For example, operating two heavier trucks with larger trailers on a regular logistics route may be more fuel efficient than operating three conventional trucks. Considering a holistic view of vehicle fleet and transport requirements could help fleet operators significantly reduce the CO_2 footprint of their logistics operation. Altering national cabotage limits could help to boost freight efficiency further, although this links back to legislation and government policy.

Business (OEM) Requirements

For vehicle OEMs **profitability** and **operating margins** are obviously key concerns. Therefore the **costs** associated with adopting a new technology, or making changes to the existing technology, will be carefully considered during product planning.

Over the next decade, it is expected that larger global OEMs with multiple vehicle brands will seek to exploit more fully the potential of their **economies of scale**. This is strongly influencing the trend towards greater integration between European and North American operations.

Market Barriers

There are several market barriers that could block, limit or delay the transition to low carbon technologies in the HDV sector. Predominant barriers to the adoption of low carbon technologies include [Roeth et al, 2013; Ricardo analysis]:

- **Lack of credible information**
- **Uncertainty around the payback period**
- **Lack of access to capital** to invest in new technologies
- Questions regarding the **reliability** of the new technologies
- **Lack of availability** of fuel-saving technologies from preferred OEMs or component suppliers
- **Lack of refuelling or recharging infrastructure**
- Changes required to **existing legislation**
- **Lack of political will**
- Access to **insurance**, or concerns over **liability**
- **Inability to manufacture** the technology at appropriate volumes and
- **Hardware, development and installation costs**

6 HDV TECHNOLOGY EVOLUTION AND REVOLUTION

Technology development within the on-highway HDV sector is primarily focused on improving energy efficiency, while increasing performance and meeting stringent tailpipe emission limits. Any solutions need to be cost effective, delivering sufficient in-use benefits to ensure payback within a couple of years.

Current key research topics include:

- Improving powertrain efficiency
- Electrification and hybridisation of vehicle systems, especially ancillaries
- Weight reduction
- Improving safety
- Developing better telematics and remote fleet management tools for remote vehicle 'health checks' and to optimise logistical operations
- Investigating the potential of alternative fuel powertrains, such as natural gas

Ricardo profiled over 50 current and future technologies applicable to on-highway heavy duty vehicles. These technologies covered changes to engine design, improvements in thermal management, the introduction of waste heat recovery, developments in gas exchange, fuel injection equipment and combustion system, aftertreatment requirements, alternative fuels, hybridisation, transmission systems and vehicle-level technologies (see Figure 11). The technologies range from those already available in the market to those at an early stage of technology development.

These technologies are usually applied in combination together within a vehicle, to fulfil the requirements of legislation, customers' expectations and OEM business needs. The technology combinations are called Technology Packages (TPs).

The powertrain Technology Packages for heavy and medium duty trucks and buses have already begun to diversify. In 2005, Fuso launched its new Canter Eco Hybrid, a small medium duty delivery truck, and offered an updated version in 2012. European production of this model began in 2015. Hybrid buses have already achieved 10% of the market share for new city buses. BYD and Alexander Dennis' electric bus is on trial in London, with plans for 51 new electric buses by August 2016. Several other bus OEMs, such as Irizar and Volvo, have launched electric or plug-in hybrid buses. Fuel cell buses have been trialled in many cities and towns across the world over the past 20 years. One of the current demonstration projects, Clean Hydrogen in European Cities (CHIC) (2010-2016), is deploying 56 fuel cell buses across 8 European cities. The LNG Blue Corridors project is demonstrating HDVs running on liquefied natural gas, and creating a network of LNG refuelling stations along several key truck routes in Europe.

In order to provide an assessment of the expected future technology direction of the HDV market, Ricardo created three pairs of Technology Packages (TPs) for two timeframes, 2020 and 2025. These TPs represent the likely technology combinations for future Heavy Duty Long Haul trucks, Medium Duty Distribution trucks and City Buses operating in Europe. The first package in each pair represents the mainstream option. The second package represents an alternative, such as a 'best in class' for fuel economy, or a solution for inner city Low Emission Zone (LEZ).

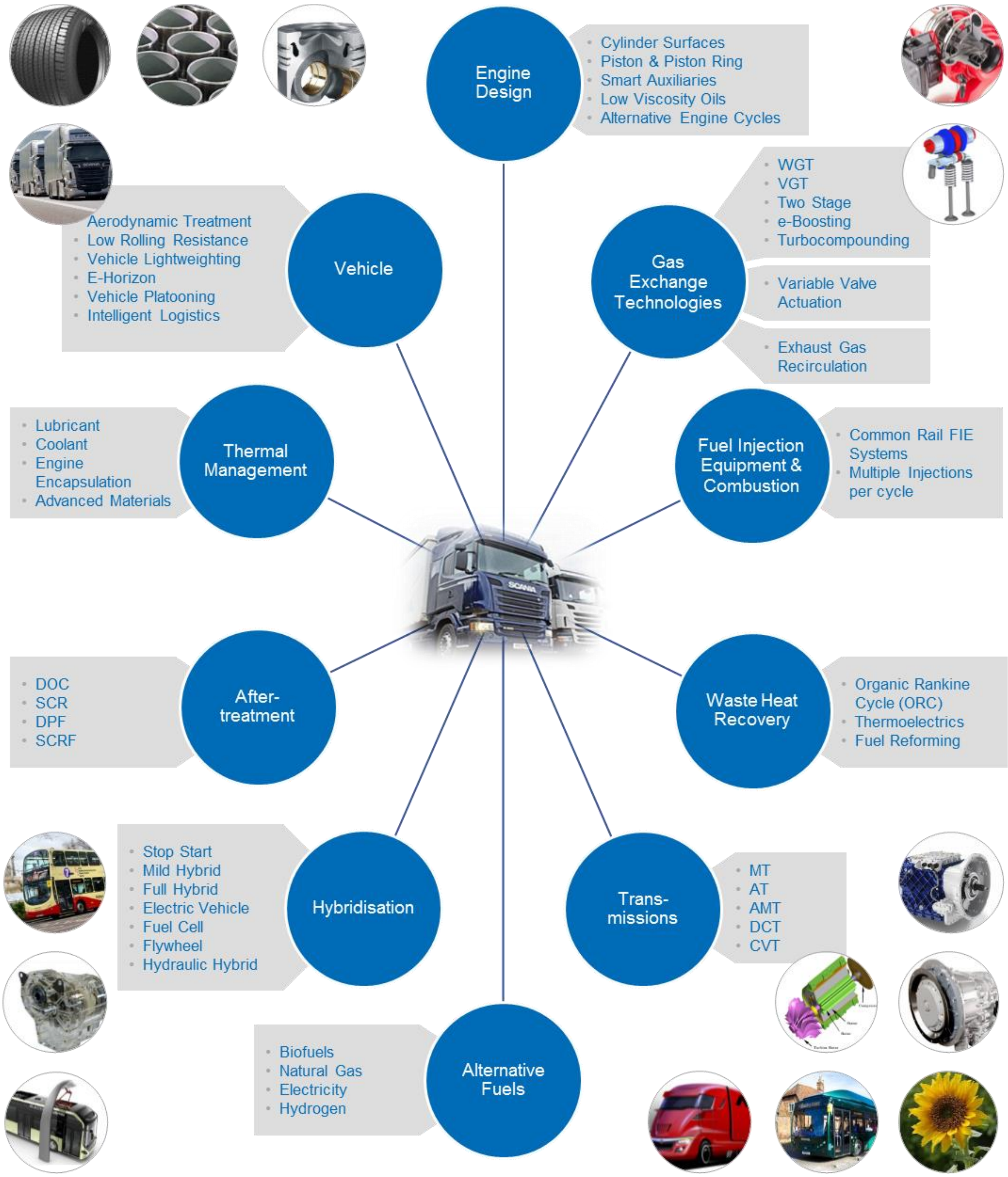


Figure 11: HDV Current and Future Technologies

Figure 12: Examples of current European HDVs

Pictures: Mercedes-Benz Actros, Volvo FH Series, DAF LF series, Iveco Eurocargo, MAN Lion's City, Volvo Electric Bus

To provide a baseline for comparison, current representations of these vehicles are illustrated in Figure 12. The baselines provide an anchor point for assessing the extent of technology change expected in the on-highway heavy duty vehicle sector over the next ten years.

HD Long Haul Truck

Heavy duty vehicles carrying payloads over long distances require space and mass efficient on-board energy storage. Therefore, the future Technology Package (TP) options are mostly limited to those that use liquid fuels with an internal combustion engine. A few natural gas HD Long Haul trucks may be available, but these will be limited to specific regions in Europe that have a suitable CNG or LNG infrastructure.

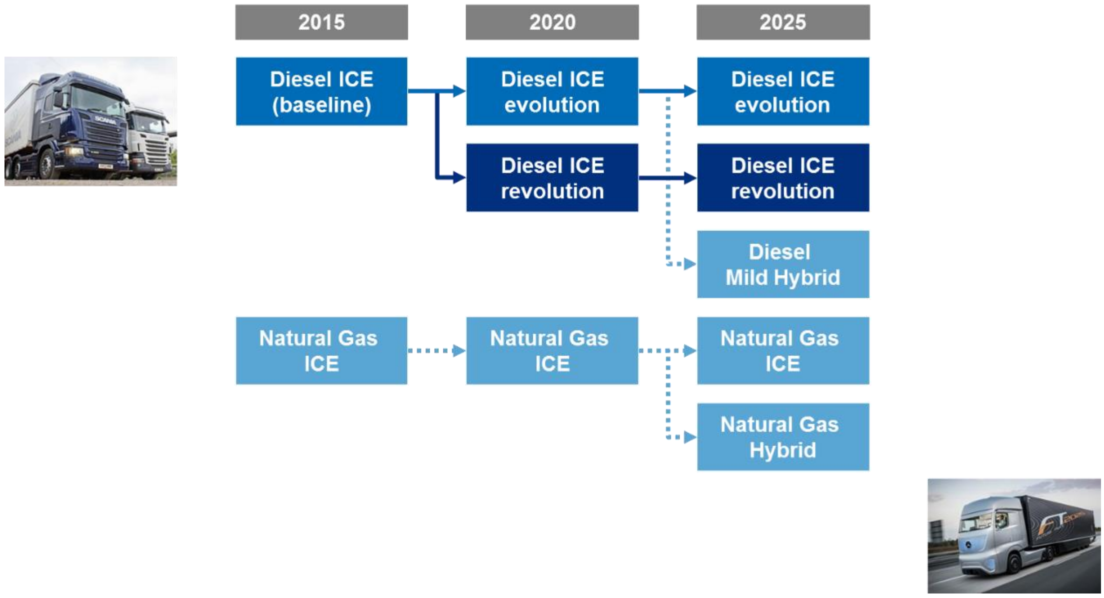


Figure 13: HD Long Haul Truck – Potential Technology Pathways to 2025

Mid-blue represents the likely mainstream Technology Pathway and Technology Packages in 2020 and 2025
Navy represents Ricardo's selected alternative Technology Pathway and Technology Packages for 2020 and 2025
Pale blue represents other potential niche Technology Pathways and Packages

For Heavy Duty Long Haul truck, mainstream future Technology Packages for 2020 and 2025 are likely to remain as diesel ICE, with evolutionary technology enhancements to meet future emissions legislation and to reduce tailpipe CO_2.

Alternative Technology Packages designed to achieve better fuel efficiency are likely to feature a few revolutionary technology steps, such as the addition of Organic Rankine Cycle for waste heat recovery and more radical vehicle design to reduce weight and improve aerodynamics. The alternative Technology Package for 2025 could also feature a mild hybrid system, enabled to 48V systems. Although the Alternative TPs will achieve better in-use CO_2 savings, the initial purchase cost could be €10k-€15k higher than the equivalent mainstream TPs.

MD Distribution Truck

Medium Duty Distribution trucks transport goods over short, medium and long distances. As for HD Long Haul, payload capacity is important, and may be volume or mass limited. Typical duty cycles feature more low speed and stop-start operation than HD Long Haul trucks, creating greater potential savings from energy recovery systems such as electric hybrid technologies. If breakthroughs in the cost of the hybrid system can be achieved, then it is likely that most MD Distribution trucks will feature some form of hybridisation by 2025.

An overview of the potential technology pathways to 2025 for MD Distribution trucks is presented in Figure 14 below. These pathways include evolutionary enhancements to the current conventional internal combustion engine technology, as well as alternative powertrain options, such as full hybrid and plug-in hybrid.

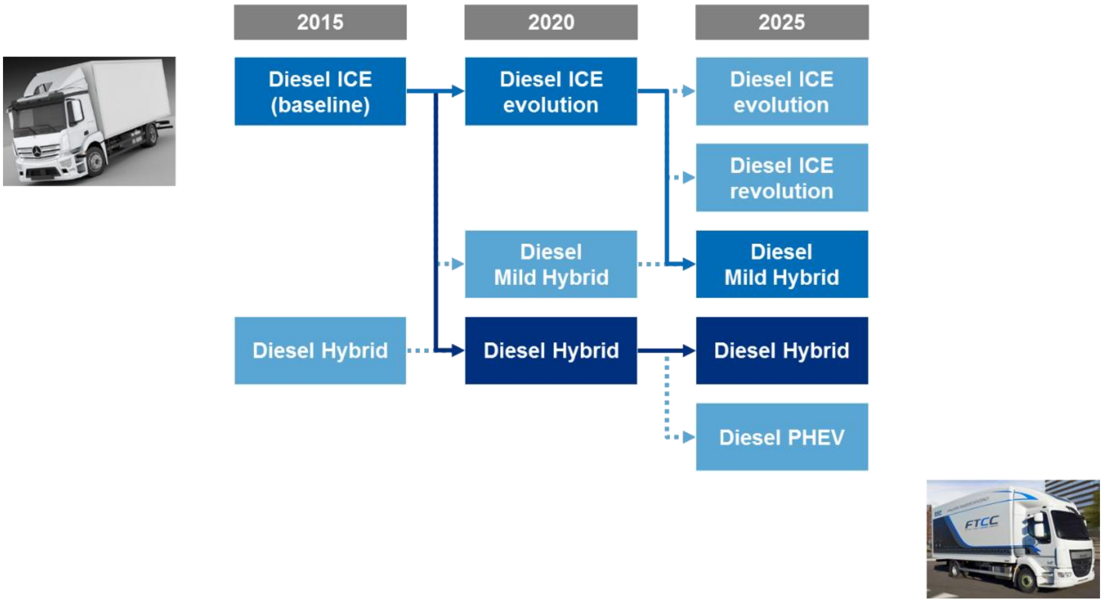


Figure 14: MD Distribution Truck – Potential Technology Pathways to 2025

Mid-blue represents the likely mainstream Technology Pathway and Technology Packages in 2020 and 2025
Navy represents Ricardo's selected alternative Technology Pathway and Technology Packages for 2020 and 2025
Pale blue represents other potential niche Technology Pathways and Packages

For Medium Duty Distribution trucks, the mainstream future Technology Packages in 2020 and 2025 are likely to be similar to the mainstream TPs for HD Long Haul trucks, as engine and transmission technology improvements are rolled out across the OEMs' powertrain portfolios. However, hybrid technology is a more likely alternative package for this type of vehicle, especially in smaller MD Distribution trucks (7.5t-12t), which are used in urban distribution. Again, greater in-use CO_2 savings will be achieved, but at a higher capital cost.

City Bus

The duty cycle of a City Bus is very different to a HD Long Haul truck. The City Bus typically operates in urban environments at low speeds (<30 km/h), with frequent stops to allow passengers to disembark or board. The bus routes are known, although occasionally a bus may be diverted from its route due to external factors. At the end of their work day, the buses return to the bus depot for cleaning and refuelling. At the depot the buses will be arranged and parked in order for the next day's operation.

The stop-start duty cycle, fleet operation and legislation such as the European Clean Vehicles Directive (2009/33/EC) means City Buses are an attractive commercial vehicle for trialling new and alternative technologies. This is reflected in the diverse range of potential technology pathways identified by Ricardo in Figure 15.

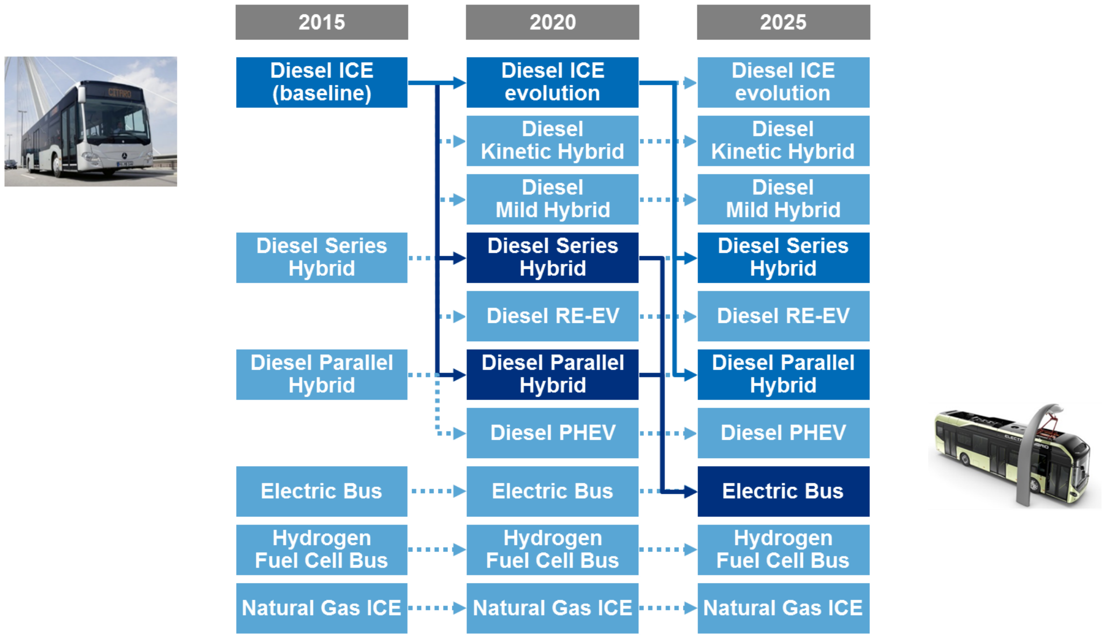


Figure 15: City Bus – Potential Technology Pathways to 2025

Mid-blue represents the likely mainstream Technology Pathway and Technology Packages in 2020 and 2025
Navy represents Ricardo's selected alternative Technology Pathway and Technology Packages for 2020 and 2025
Pale blue represents other potential niche Technology Pathways and Packages

It is difficult to foretell which technologies will dominate in the European City Bus sector, since it is likely that each city authority will select the technology options which are most effective for their public transport requirements. CNG or hydrogen will require appropriate refuelling infrastructure at or near bus depots. This may be an issue for some towns and cities depending on their built environment and the location of the bus depot. Electric or plug-in hybrid buses will require recharging facilities at the bus depot, which may need to be supported by new electrical networks. Top-up charging facilities at bus stops may also be attractive. Current options include inductive charging or overhead pylon.

For this study, Ricardo predict that the mainstream option for City Buses will still be diesel ICE in 2020. Like for MD Distribution, the 2020 Euro VI diesel engine will feature evolutionary enhancements compared to the Euro VI diesel engine of 2015.

Hybrid technology is already a significant alternative technology in this sector, and is likely to be the mainstream option by 2025. Real world CO_2 savings in 2020 are likely to be 10-30% compared to the 2015 baseline. This could increase to 20-40% by 2025, due to incremental improvements aimed at optimising the overall hybrid system. The cost of the diesel hybrid system will remain high. Although there is likely to be some cost reduction as production volumes increase, Ricardo predict the on-cost for diesel hybrid will be €25,000-€50,000 in 2020 and 2025 compared to the 2015 baseline.

For city buses, Ricardo selected the alternative Technology Package for lower tailpipe emissions, since these buses are likely to be used in Low Emission Zones across Europe. Ricardo selected electric vehicle technology as the alternative Technology Package for 2025. However, other options that could have been considered include plug-in hybrid, natural gas and hydrogen fuel cell. This diversification of technology options is expected to continue in the city bus sector. Many of the alternative options require significant investment in infrastructure to enable the technology, such as building a natural gas refuelling station or installing on-street opportunity charging for EV buses at bus stops. Across Europe, each city and region will need to select the technology option which is most appropriate to their requirements and context.

Regional Variations

Many of the technology trends predicted for Europe are likely to apply in the other regions considered in the HDV On-Highway Market study. Greater convergence in technology and vehicle design is expected between Europe and North America, especially as OEMs seek to gain from economies of scale. Since Japanese heavy duty vehicles tend to be smaller than in Europe and North America, the Technology Packages for MD Distributions are of greater interest.

Developing markets, such as India and South America, lag behind the developed markets, such as Europe, with regard to technology introduction, and this lag is expected to continue. Differences in infrastructure, such as fuel quality, will be a barrier to introducing technologies for controlling emissions.

China has demonstrated strong political will towards introducing ultra low and zero emission technology for urban and city buses. The production share of electric and plug-in hybrid buses in China is expected to grow. Within the 10-15 year time horizon considered in this study, China could ‘leap frog’ Europe in terms of market and technology maturity of alternative technologies for the HDV sector.

7 FUTURE MARKET PROJECTIONS

Analysis by Automotive World shows the aggregate HDV demand in the six largest markets[3] fell by 2.5% in 2014 to 3.38 million units, with declines in four of the six markets. Growth is expected during 2015 in Europe, North America, Japan and India, helped by a broadly supportive macro-economic background, as well as market-specific factors. However, the market declines in China and South America are predicted to continue, to bring the anticipated global demand in 2015 1.2% lower to 3.34 million units, the second successive year of decline. At a global level that decline is concentrated in the lightest segment, the 3.5-7.49t vehicles. If they are excluded, global demand for all the other truck segments as well as Buses & Coaches is expected to increase during 2015.

The HDV market forecasts for the six regions out to 2030 include Automotive World's view of the likely cyclical patterns of demand. Even in markets where the trend level of demand is expected to increase strongly, actual demand will fluctuate as the industry moves through its cycle.

The under-performance of the 3.5-7.49t vehicle segment is a continuing feature of the forecast to 2030. China exerts by far the biggest influence on this segment, typically accounting for 75% of demand across the six markets studied. The relative decline of this segment reflects the anticipated switching of demand to higher and lower weight classes as the Chinese transport industry matures.

In Europe, beyond 2015 the HDV market is expected to continue growing for a further three years before a mild slowdown. Subsequent growth is predicted to take the market to a new peak of 452,000 new registrations in 2028.

The North American truck market is strongly cyclical, typically taking 10 years to move from peak to peak or trough to trough, although this can vary by 2 or 3 years. The cycle is there as a trend but will always be influenced by prevailing circumstances. For example, pre-buying in advance of emissions changes or, in the most recent trough, extreme events such as the credit crunch.

The US truck market is more homogenous than the European market. This is partly because it is more dominated by big fleets, particularly in the heavy sector. When the fleets detect a downturn approaching, they stop new orders and cancel existing orders very quickly. Hence the typical period from market peak to trough is shorter than the typical trough to peak period.

The Japanese commercial vehicle market is completely dominated by the Japanese brands in the light, medium and heavy sectors. Volvo and Daimler now have a stake in the market through their stakes in UD Trucks (formerly Nissan Diesel) and Fuso respectively.

The Bus & Coach segment and Articulated Truck segments are expected to show the highest rates of growth from 2014 to 2030.

[3] The ETI HDV On-Highway Market Analysis project considered the six largest HDV markets – China, EU+EFTA, India, Japan, North America and South America

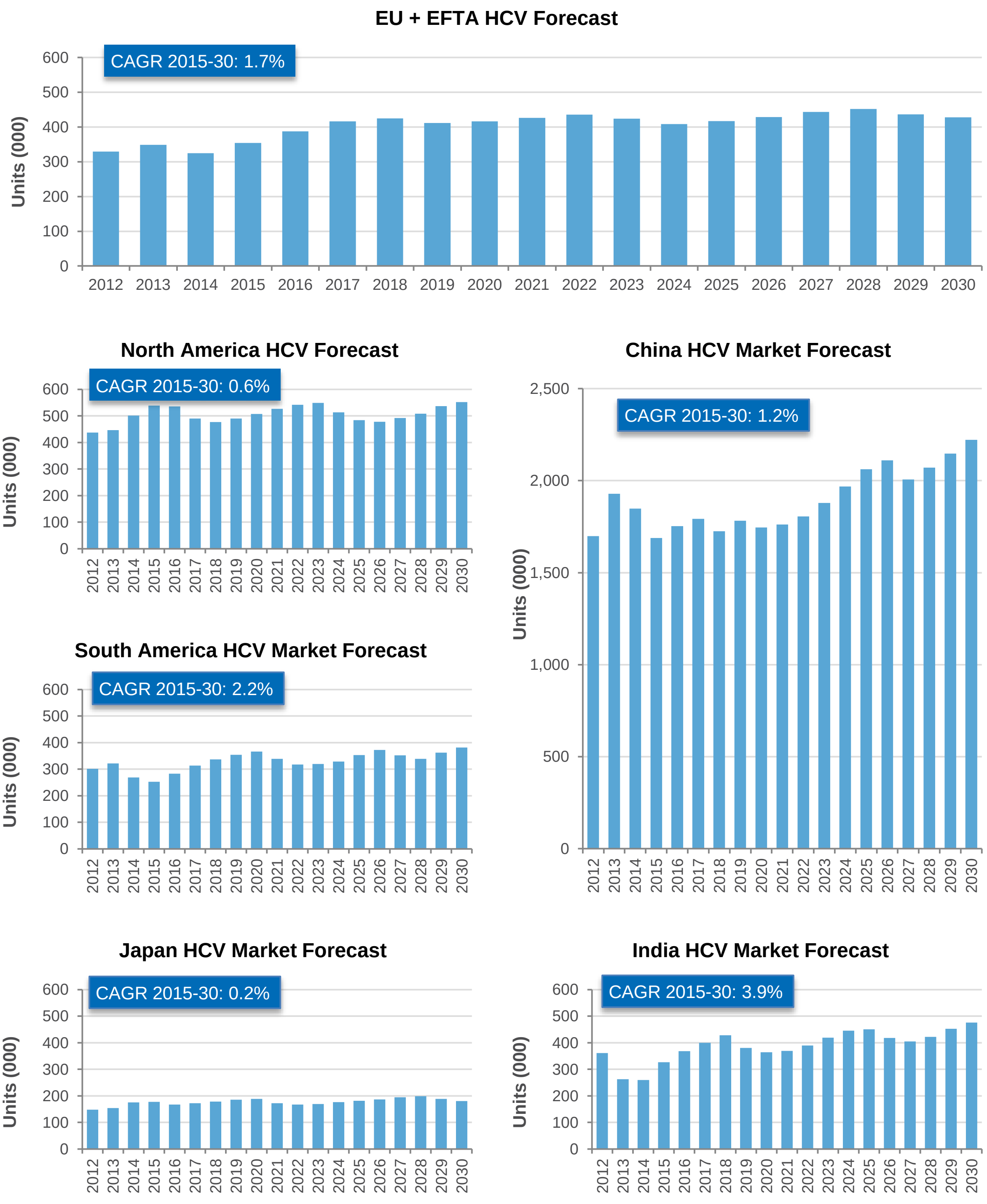
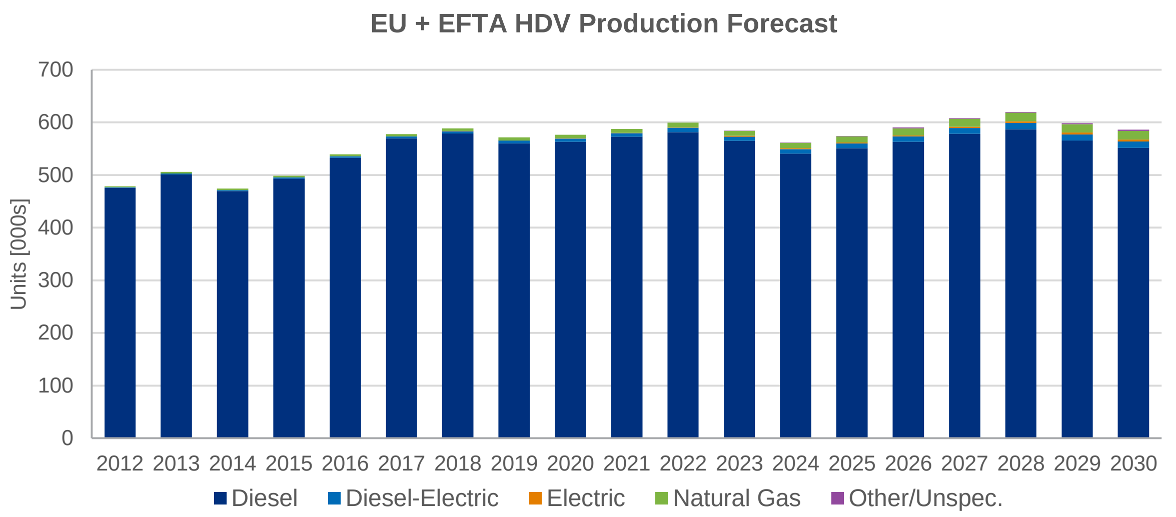
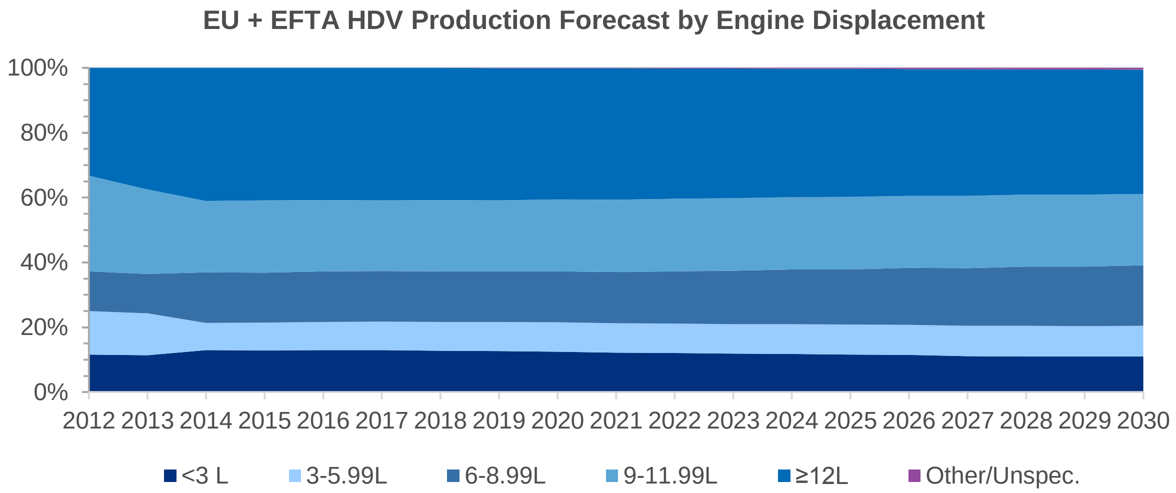


Figure 16: Heavy-Duty Commercial Vehicles Market Forecasts by Region

Source: Automotive World

The HDV Market Forecast Database, created by Automotive World for the ETI HDV On-Highway Market Analysis project, covers the six largest markets for HDV demand: China, EU + EFTA, India, Japan, North America and South America. It combines historical data on new vehicle registrations (2012-2014) with future predictions (2015-2030) from Automotive World's truck forecasting model. The forecasts feature Automotive World's view of the likely cyclical patterns of demand for seven HDV segments – 3.5-7.49t trucks, 7.5-15.9t trucks, 2-axle rigid trucks, multi-axle rigid trucks, 2-axle articulated trucks, multi-axle articulated trucks, and buses and coaches.





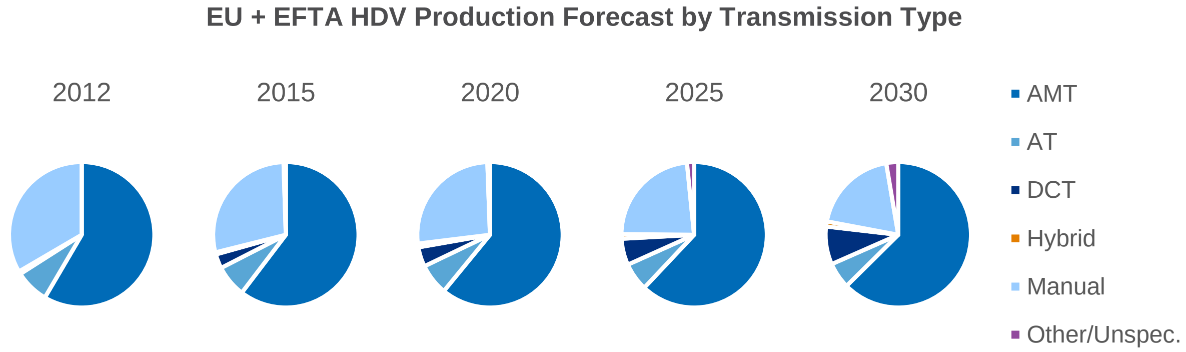


Figure 17: Heavy-Duty Commercial Vehicles Production Forecasts for EU + EFTA

Source: Automotive World

The HDV Production Forecast Database, created by Automotive World, considers the same six regions - China, EU + EFTA, India, Japan, North America and South America. Historical HDV production data for 2012-2014 has been combined with Automotive World's predictions from 2015 to 2030. The HDV production forecasts are broken down by region, fuel type, engine displacement and transmission type. Aggregate production in these six geographical markets is typically higher than "new registrations" since the production data include vehicles destined for export.

Automotive World also analysed HDV production in China, EU+EFTA, North America, South America, India and Japan. Aggregate HDV production in the selected markets fell by 2% in 2014 to 4.49 million units, with an equal distribution of regions showing a decline and those showing an increase. The forecast anticipates aggregate production rising to nearly 5.5 million units by 2030, a CAGR of 1.25% from 2012 though demand cycles will cause aggregate output to fall in some years.

The forecasts for aggregate HDV production for these six regions are typically higher than the aggregate market demand because the production data includes vehicles destined for export outside the selected markets.

Diesel-fuelled HDVs accounted for 93% of output in 2014. The forecast anticipates significant growth, both regionally and globally, in the proportion of HDVs powered by fuels other than diesel. However, at a global level diesel is still expected to account for 85-86% of output in 2030.

Within individual sectors, such as urban buses, the growth in alternative fuels is expected to be greater, influenced particularly by China's development of all-electric and hybrid-electric buses.

Although still dominant, the share of manual transmissions has declined at a fairly rapid pace since 2010, falling successively from 85% in that year to 75% in 2014. A further decline to below 60% is forecast by 2030. While much of the anticipated decline is due to increased fitment rates of other transmission types, market weighting factors also need to be considered as the segments in which MTs are most popular (e.g. small HDVs in China) are expected to under-perform over the forecast period.

The distribution of production by engine displacement is closely correlated with that of production by weight class. Hence the expected out-performance of heavy trucks and under-performance of light trucks over the forecast period explains most of the changes anticipated in engine displacement.

8 CONCLUSIONS

The Heavy Duty Vehicle On-Highway Market Analysis project provides insight into the market, legislative and technology trends that are shaping the future HDV technology landscape.

- The on-highway heavy duty vehicle market is **competitive** and **cyclical**.
- The industry is **dominated by <15 OEMs**. The top 10 OEMs account for nearly 76% of the industry volume for 16t+ vehicles.
- Over the past two decades **industry consolidation**, coupled with restructuring measures by individual OEMs, has **improved the resilience** of the industry to shocks and **improved the profitability** of the leading players – though the two largest OEMs have yet to achieve their targeted level of profitability. The relatively healthy state of the industry suggests that it will not be resource constrained when it comes to researching and developing new technologies.
- **Legislation will continue to play a dominant role** in defining the research agenda for on-highway medium and heavy duty vehicles. The introduction of vehicle-based fuel economy regulations has already had an impact on the research priorities in USA. Discussions in Europe concerning potential future HDV CO_2 regulations are influencing R&D decisions.
- **Cost effective solutions** are required to meet future tailpipe emissions and CO_2 targets. In developed markets, such as Europe and North America, fleet operators tend to consider the **total cost of ownership** (TCO), rather than focusing on the initial capital cost. Therefore, more expensive technologies will be considered, but only if the in-use savings repay the higher capital cost within a short duration.
- The market preference is likely to be **technology evolution** rather than revolution. Successive changes will be made to the powertrain system and vehicle to improve the overall vehicle efficiency. Although the number of Alternative Fuelled Vehicles is expected to grow between 2015 and 2030, the market share is likely to remain low.
- **The exception is city buses**. Hybrid powertrains are likely to be the mainstream option for European city buses by 2025. Plug-in hybrids or electric buses could be a significant niche, although will be restricted to cities that have invested in a suitable recharging infrastructure to support the bus services

The HDV OHMA project has focused on technologies that can be applied to individual medium and heavy duty vehicles to reduce CO_2 and tailpipe emissions. Although significant energy efficiency gains are predicted for future HDVs, it should be noted that bigger gains may be possible by taking a wider system view of freight and passenger transportation. Topics for future consideration include:

- Optimising fleet configuration
- Optimising logistics, through the use of IT-based tools
- Optimising traffic flow and introducing vehicle platooning

9 REFERENCES

European Commission. (2014). *Strategy for reducing Heavy-Duty Vehicles' fuel consumption and CO_2 emissions*. Brussels. Retrieved from http://ec.europa.eu/clima/policies/transport/vehicles/heavy/docs/com_285_2014_en.pdf [Last accessed 1 February 2016]

EuroTransport.de. (2015, May 22). *Hard times for the Used*. Retrieved from EuroTransport.de: http://www.eurotransport.de/news/nutzfahrzeug-markt-schwere-zeiten-fuer-gebrauchte-6637787.html [Last accessed 1 February 2016]

Oliver Wyman. (2011). *Management Summary: Trucks go Global, Trucks go Green*. Retrieved from Oliver Wyman: http://www.oliverwyman.de/content/dam/oliver-wyman/europe/germany/de/insights/publications/2011/ManSum_Charts_Commercial%20Vehicles%202020.pdf [Last accessed 1 February 2016]

Ricardo and AEA. (2011). *Reduction and Testing of Greenhouse Gas Emissions from Heavy Duty Vehicles - Lot 1: Strategy*. Retrieved from http://ec.europa.eu/clima/policies/transport/vehicles/docs/ec_hdv_ghg_strategy_en.pdf

Roeth, M., Kircher, D., Smith, J., and Swim, R. (2013). *Barriers to the Increased Adoption of Fuel Efficiency Technologies in the North American On-Road Freight Sector*. July 2013. Available at: http://www.theicct.org/sites/default/files/publications/ICCT-NACFE-CSS_Barriers_Report_Final_20130722.pdf [Last accessed 7 December 2015]

APPENDIX 1 FUTURE TECHNOLOGY PACKAGES

Appendix 1A Technology Packages for HD Long Haul Trucks

HD Long Haul	**"Business as Usual" – The Mainstream Option**		
	2015 (Baseline)	**2020**	**2025**
	38t 2-axle Artic Truck with Euro VI diesel engine used for national and international distribution.	38t 2-axle Artic Truck with upgraded Euro VI diesel engine. **Evolutionary enhancements** to the powertrain and vehicle, and increased use of algorithms and analytics to optimise vehicle operation will help to reduce CO_2 emissions compared to the 2015 baseline Higher power ratings have been increased. This Technology Package does not include waste heat recovery or hybridisation.	38t 2-axle Artic Truck with "Euro VII" diesel engine. The next step in **evolutionary enhancements** will target 50% engine brake thermal efficiency, while meeting tougher emission limits. Enhancements to vehicle design will support improving vehicle efficiency for lower CO_2. This Technology Package does not include waste heat recovery or hybridisation.
Energy Vector	**Diesel**	**Diesel**	**Diesel**
Emissions	Euro VI	Euro VI + CO_2 reporting	Euro VII + CO_2 regulation
Engine	10-13 L, inline 6 cylinder, 24v	10-13 L, inline 6 cylinder, 24v	10-13 L, inline 6 cylinder, 24v
Cylinder Pressure	Pmax 220—230 bar	Pmax 220-230 bar	Pmax 220-250 bar
Combustion & FIE	Common Rail, 1600-2500 bar	Common Rail 2000-2500 bar	Common Rail 2000-2700 bar
Boosting	FGT or VGT	More efficient VGT or Sequential two-stage (high torque at low speed)	Further efficiency improvements to VGT or Sequential two-stage (high torque at low speed)
EGR	External high pressure cooled EGR EGR rate 0-25%	External high pressure cooled EGR EGR rate 0-15%	External high pressure cooled EGR EGR rate 0% - 25%
Valvetrain	DOHC or SOHC	DOHC or SOHC	VVA – for aftertreatment thermal management and / or variable compression ratio
Aftetreatment	Single box, with single or dual flow, containing DOC + DPF + SCR + ASC (SCR conversion efficiency>92%, depending on EGR strategy; urea consumption >3% fuel consumption equivalent)	Single box, with single or dual flow, containing DOC + DPF + SCR + ASC (SCR conversion efficiency>95%, depending on EGR strategy; urea consumption >5% fuel consumption equivalent)	Single box, with single or dual flow, containing DOC + DPF + SCR + ASC (SCR conversion efficiency>98%, depending on EGR strategy; urea consumption >8% fuel consumption equivalent) (LNT may also be required, depending on NOx limits)
Engine Control	ECU	ECU	ECU, model based control OBD, in-use emissions monitoring

HD Long Haul	"Business as Usual" – The Mainstream Option		
	2015 (Baseline)	2020	2025
	OBD – basic functional + threshold based OBD + rated based monitoring	OBD – basic functional + threshold based OBD + rated based monitoring – with tighter thresholds More sensors (e.g. soot), exhaust temperature thermal management	
Materials & Coatings	Cast Iron or CGI cylinder block Steel pistons	CGI cylinder block Steel pistons	CGI cylinder block Steel pistons
Thermal Management	Belt-driven coolant pump Traditional thermostat	Belt-driven coolant pump Traditional thermostat	Multi-speed water pump and by-pass for charge cooler Variable displacement oil pump Smart thermostat Smart piston cooling jets
Low Friction Technologies	-	Low friction coatings for bearings, pistons, piston rings, etc. Lower friction lubricant	Low friction coatings for bearings, pistons, piston rings, etc. Smart ancillaries – alternator and compressor Lower friction lubricant
Waste Heat Recovery	-	Without waste heat recovery	Without waste heat recovery
Hybridisation & Electrification	Without hybridisation	Without hybridisation	Without hybridisation
Battery	-	-	-
Electric Motor	-	-	-
Charging System	-	-	-
Transmission	9-12 speed AMT	12-16 speed AMT	16 speed AMT
Vehicle Design	Standard design for tractor and trailer	Evolution in tractor and trailer design to reduce mass and drag, while maximising payload capacity	Further evolution in tractor and trailer design to reduce mass and drag, while maximising payload capacity Customisation of trailer for specific payload, such as matching deck width to pallet type, and "low belly" trailers for using redundant space
Vehicle Lightweighting	High strength steel tractor cab and trailer Minor vehicle lightweighting, compared to previous model	Vehicle lightweighting through increased uptake of Advanced High Strength Steels (AHSS) in tractor and trailer structures Lighter weight ancillaries, such as aluminium fuel tanks, 5th wheel, landing legs, axles and brakes	Some further reductions in vehicle weight compared to the 2020 design, achieved through the application of aluminium in chassis and trailer structures
Aerodynamic Treatment	Some aerodynamic treatments	Improved aerodynamic design of vehicle body Improved aerodynamic design of trailers "Fifth wheel" / trailer gap optimisation	Advanced aerodynamic treatments, especially with regard to integrating the tractor and trailer designs to match the aero profile Extensive application of side fairings

HD Long Haul	"Business as Usual" – The Mainstream Option 2015 (Baseline)	2020	2025
			Underbody aero treatments Addition of trailer tailboard aero-features
Low Rolling Resistance	Low rolling resistance tyres	Low rolling resistance tyres	Further improvements to low rolling resistance tyres
Vehicle Control	Driver assistance tools Adaptive Cruise Control Lane Departure Warning Electronic Stability Program Active and passive cab safety	Driver assistance tools Predictive and Adaptive Cruise Control LDW, ESP Active and passive cab safety Smart logistics	Driver assistance tools Vehicle Platooning Enabled / Super-Adaptive Cruise Control LDW, ESP Active and passive cab safety Smart logistics
Other Vehicle Technologies	Improved visibility Energy efficiency lighting Cameras	Improved visibility Energy efficiency lighting Cameras	Improved visibility Energy efficiency lighting Cameras
Performance		Slight downspeeding	Further downspeeding
Power	320 – 400 kW at 1800 – 1900 rpm	320 - 420 kW at 1600 – 1800 rpm	300 - 440 kW at 1600 rpm
Torque	2100 – 2500 Nm at 1000 – 1400 rpm	2200 – 2700 Nm at 1000 – 1400 rpm	2200 – 2800 Nm at 1000 – 1400 rpm
Energy Efficiency / CO_2	2015 Baseline	1-4% fuel consumption reduction compared to baseline Note: Urea consumption >5% of fuel consumption	5-10% fuel consumption reduction compared to 2015 baseline Note: Urea consumption >8% of fuel consumption
Cost	2015 Baseline	Minor cost difference compared to 2015 baseline	€3000 - €6000 more than 2015 baseline
Justification	This baseline has been developed from MY2015 specifications published by the vehicle OEMs, and from the Ricardo HDD engine benchmark database.	The evolution of current powertrain technology for meeting Euro VI tailpipe emissions captures the expected near-term trends in base engine design, air handling, FIE, thermal management and aftertreatment systems, such as: • Slight engine downspeeding, requiring higher speed AMT • Further use of improved turbochargers (VGT and/or 2-stage) in place of conventional waste-gated TCs, with emphasis on boost at low engine speed to enable engine downsizing • Trend to reduce EGR rates, as SCR efficiency is improves, depending on relative price of AdBlue compared to diesel	This Technology Package has been adapted from the European CO_2RE project (www.co2re.eu). The Technology Package represents the likely mass market strategy for meeting post-Euro VI tailpipe emissions, based on highly efficient SCR with moderate rates of EGR. The Technology Package is based on further evolution of the 2020 TP. VVA is employed with downspeeding to manage BMEP, and to modulate exhaust temperatures to improve effectiveness of aftertreatment systems Higher speed AMT is required due to engine downspeeding. Note: Increasing the payload volume on the trailer could help to reduce the number of journeys required to

HD Long Haul	"Business as Usual" – The Mainstream Option		
	2015 (Baseline)	2020	2025
		More significant changes are expected to vehicle design, as research on aerodynamics and lightweighting matures. Greater evolution in software tools expected for optimising logistics operation, linking to "internet of things" technology.	transport goods. This will help to reduce fleet CO_2 beyond what has been considered in this individual Technology Package

HD Long Haul	"Better for Energy Efficiency" – An Alternative Option		
	2015 (Baseline)	2020	2025
	38t 2-axle Artic Truck with Euro VI diesel engine used for national and international distribution.	38t 2-axle Artic Truck with upgraded Euro VI diesel engine. This Technology Package builds on the mainstream TP with additional **revolutionary technologies** and **more radical vehicle designs** to achieve lower CO_2 emissions. The tailpipe emissions control strategy is that same as the mainstream TP.	38t 2-axle Artic Truck with "Euro VII" diesel engine. Total vehicle efficiency is the objective. Builds on the alternative 2020 TP, featuring more **holistic evolutionary and revolutionary** steps to achieve greater overall vehicle efficiency and the tougher tailpipe emission limits. Target 55% engine brake thermal efficiency. Development has considered the whole vehicle system, enabling functional integration of vehicle, engine, transmission, axle and control systems has reduced the number of component and vehicle weight. **Radical vehicle design** has improved the aerodynamic performance and reduced vehicle mass (unladen).
Energy Vector	**Diesel**	**Diesel**	**Diesel**
Emission Standard	Euro VI	Euro VI + CO_2 reporting	Euro VII + CO_2 regulation
Engine	10-13 L, inline 6 cylinder, 24v	10-13 L, inline 6 cylinder, 24v	10-13 L, inline 6 cylinder, 24v
Cylinder Pressure	Pmax 220—230 bar	Pmax up to 220-230 bar	Pmax 220-250 bar
Combustion & FIE	Common Rail, 1600-2500 bar	Common Rail 2000-2500 bar	Combustion system improved via redesigned piston bowl and better fuel injection Common Rail 2000-2700 bar
Boosting	FGT or VGT	More efficient VGT or Sequential two-stage (high torque at low speed)	Further efficiency improvements to VGT or Sequential two-stage (high torque at low speed)
EGR	External high pressure cooled EGR EGR rate 0-25%	External high pressure cooled EGR EGR rate 0-15%	External high pressure cooled / hot EGR EGR rate 0% - 25%
Valvetrain	DOHC or SOHC	VVA for aftertreatment thermal management	VVA for aftertreatment thermal management
Aftetreatment	Single box, with single or dual flow, containing DOC + DPF + SCR + ASC (SCR conversion efficiency>92%, depending on EGR strategy; urea consumption >3% fuel consumption equivalent)	Single box, with single or dual flow, containing DOC + DPF + SCR + ASC (SCR conversion efficiency>95%, depending on EGR strategy; urea consumption >5% fuel consumption equivalent)	Low temperature, highly efficiency aftertreatment in a single box, with single or dual flow, containing DOC + DPF + SCR + ASC (SCR conversion efficiency>98%, depending on EGR strategy; urea consumption >8% fuel consumption equivalent)

HD Long Haul	"Better for Energy Efficiency" – An Alternative Option		
	2015 (Baseline)	2020	2025
Engine Control	ECU OBD – basic functional + threshold based OBD + rated based monitoring	ECU, closed loop combustion control OBD – basic functional + threshold based OBD + rated based monitoring – with tighter thresholds More sensors (e.g. soot), exhaust temperature thermal management	Cylinder deactivation ECU, model based control OBD, in-use emissions monitoring Engine optimised for vehicle duty cycle
Materials & Coatings	Cast Iron or CGI cylinder block Steel pistons	CGI cylinder block Steel pistons	CGI cylinder block Steel pistons
Thermal Management	Belt-driven coolant pump Traditional thermostat	Multi-speed water pump and by-pass for charge cooler Variable displacement oil pump Smart thermostat Smart piston cooling jets	Multi-speed water pump and by-pass for charge cooler Variable displacement oil pump Smart thermostat Smart piston cooling jets
Low Friction Technologies	-	Greater use of low friction coatings for bearings, pistons, piston rings, etc. Smart ancillaries – alternator and compressor Lower friction lubricant	Greater use of low friction coatings for bearings, pistons, piston rings, etc. Smart ancillaries – alternator and compressor Lower friction lubricant
Waste Heat Recovery	-	Organic Rankine Cycle	Organic Rankine Cycle
Hybridisation & Electrification	Without hybridisation	Without hybridisation	48V mild hybridisation, including stop-start
Battery	-	-	Li-ion start battery and APU
Electric Motor	-	-	-
Charging System	-	-	-
Transmission	9-12 speed AMT	DCT with GPS / topography enabled intelligent control	DCT with GPS / topography enabled intelligent control
Vehicle Technologies	Standard design for tractor and trailer	More radical design of tractor and trailer to reduce aerodynamic drag and maximise the payload capacity. Some fleet operators may use trailers with electronic steering functionality. This enables standard length trailers (13.7 m) to be used in locations with restricted delivery access.	Continued use of more radical designs for tractor and trailer to reduce drag Use of longer trailers, with same mass limit, to reduce tonne/km of light weight / volume restricted goods. Combined tractor and trailer length $\leq$ 18.55 m
Vehicle Lightweighting	High strength steel tractor cab and trailer Minor vehicle lightweighting, compared to previous model	Vehicle lightweighting through uptake of Advanced High Strength Steels (AHSS) and aluminium in tractor and trailer structures	Further vehicle lightweighting compared to 2020 design, through application of aluminium in chassis and trailer structures

HD Long Haul	"Better for Energy Efficiency" – An Alternative Option		
	2015 (Baseline)	2020	2025
		Lighter weight ancillaries, such as aluminium fuel tanks, 5th wheel, landing legs, axles and brakes	
Aerodynamic Treatment	Some aerodynamic treatments	Improved tractor aerodynamic design to match aerodynamic trailer Trailer redesigned to reduce drag without compromising payload capacity Design features likely to include streamlining shapes and reducing the gap between the tractor and trailer "Fifth wheel" / trailer gap optimisation	Next step in improved aerodynamic design, featuring heavily integrated tractor and trailer designs Extensive application of side fairings Underbody aero treatments Addition of trailer tailboard aero-features
Low Rolling Resistance	Low rolling resistance tyres	Super single steer tyres	Super single steer tyres Low friction axle
Vehicle Control	Driver assistance tools Adaptive Cruise Control Lane Departure Warning Electronic Stability Program Active and passive cab safety	Driver assistance tools Predictive and Adaptive Cruise Control Improved LDW and ESP technologies Active and passive cab safety Smart logistics	V2V and V2I enabled predictive cruise control Driver assistance tools Improved LDW and ESP technologies Vehicle Platooning enabled Active and passive cab safety Smart logistics
Other Vehicle Technologies	Improved visibility Energy efficiency lighting Cameras	Improved visibility Energy efficiency lighting Cameras	Improved visibility Energy efficiency lighting Cameras Better cab insulation
Performance		Downspeeding, especially at part load	
Power	320 – 400 kW at 1800 – 1900 rpm	320 - 420 kW at 1400 – 1600 rpm	300 - 440 kW at 1400 rpm
Torque	2100 – 2500 Nm at 1000 – 1400 rpm	2200 – 2700 Nm at 1000 – 1400 rpm	2300 – 3000 Nm at 1000 – 1400 rpm
Energy Efficiency / CO_2	2015 Baseline	10-15% fuel consumption reduction compared to 2015 baseline Note: Urea consumption >5% of fuel consumption	Target 18-25% fuel consumption reduction compared to 2015 baseline Note: Urea consumption >8% of fuel consumption
Cost	2015 Baseline	€10,000 - €15,000 more than 2015 baseline	€15,000 - €25,000 more than 2015 baseline
Justification	This baseline has been developed from MY2015 specifications published by the vehicle OEMs, and from the Ricardo HDD engine benchmark database.	This Technology Package represents a potential model option for fleet operators keen to use low CO_2 HDVs.	Further evolution and revolution in HDV technology to increase vehicle efficiency. This Technology Package assumes legislation has changed to allow longer trailers to be used in Europe

HD Long Haul	"Better for Energy Efficiency" – An Alternative Option		
	2015 (Baseline)	2020	2025
		The Technology Package features more evolutionary steps than the mainstream TP, such as the addition of VVA. It is assumed that the engine is not brand new, but an upgrade. Therefore powertrain improvements come from technologies that can be added or exchanged without changing the base engine. Features ORC for waste heat recovery More radical changes to the tractor and trail vehicle design are expected to achieve low CO_2 ratings.	For comparison, see Greszler (2014), Howden (2014) and Keski-Hynnila (2014)

Appendix 1B Technology Packages for MD Distribution Trucks

MD Distribution	"Business as Usual" – The Mainstream Option		
	2015 (Baseline)	2020	2025
	7.5-16t Rigid Truck with 4x2 or 6x2 axle configuration used for regional or local distribution. 4 or 6 cylinder Euro VI diesel engine with 6-9 speed AMT.	7.5-16t Rigid Truck with 4x2 or 6x2 axle configuration used for regional or local distribution. 4 or 6 cylinder upgraded Euro VI diesel engine with AMT. The Technology Package features various **evolutionary** steps in technology development designed to improve energy efficiency in a cost effective package.	7.5-16t Rigid Truck with 4x2 or 6x2 axle configuration used for regional or local distribution. 4 or 6 cylinder upgraded Euro VII diesel engine with AMT. Continuation of the technology **evolutionary** steps to achieve tougher emission limits, while improving energy efficiency in a cost effective package. Slight downsizing requires a higher speed AMT. Power density has been increased. **Mild hybridisation**, and better vehicle design, will help to improve overall energy efficiency.
Energy Vector	**Diesel**	**Diesel**	**Diesel**
Emission Standard	Euro VI	Euro VI + CO_2 reporting	Euro VII + CO_2 regulation
Engine	4.5-5.1L, inline 4-cylinder, 16v 6.5-8L, inline 6-cylinder, 24v	4.5-5.1L, inline 4-cylinder, 16v 6.5-8L, inline 6-cylinder, 24v	4-5L, inline 4-cylinder, 16v 6-8L, inline 6-cylinder, 24v
Cylinder Pressure	Pmax 200 – 230 bar	Pmax 200 – 230 bar	Pmax 210 – 240 bar
Combustion & FIE	Common Rail, 1600-2400 bar	Common Rail, 1600-2400 bar	Common Rail, 2000-2700 bar
Boosting	VGT	VGT	VGT
EGR	External high pressure cooled EGR EGR rate 0-25%	External high pressure cooled EGR EGR rate 0-15%	External high pressure cooled EGR EGR rate 0-25%
Valvetrain	DOHC or SOHC	DOHC or SOHC	DOHC or SOHC
Aftetreatment	DOC + DPF + SCR + ASC (SCR conversion efficiency>92%, depending on EGR strategy; urea consumption >3% fuel consumption equivalent)	DOC + DPF + SCR + ASC (SCR conversion efficiency>95%, depending on EGR strategy; urea consumption >5% fuel consumption equivalent)	DOC + DPF + SCR + ASC (SCR conversion efficiency>98%, depending on EGR strategy; urea consumption >8% fuel consumption equivalent) (LNT may also be required, for cold start operation in inner cities)

MD Distribution	"Business as Usual" – The Mainstream Option		
	2015 (Baseline)	2020	2025
Engine Control	ECU OBD – basic functional + threshold based OBD + rated based monitoring	ECU OBD – basic functional + threshold based OBD + rated based monitoring – with tighter thresholds More sensors (e.g. soot), exhaust temperature thermal management	ECU, model based control OBD, in-use emissions monitoring
Materials & Coatings	Cast Iron Aluminium pistons	Cast Iron Aluminium pistons	Cast Iron Aluminium pistons
Thermal Management	-	Belt-driven coolant pump Traditional thermostat	Multi-speed water pump and by-pass for charge cooler Variable displacement oil pump Smart thermostat Smart piston cooling jets
Low Friction Technologies	-	Low friction coatings for bearings, pistons, piston rings, etc. Lower friction lubricant	Low friction coatings for bearings, pistons, piston rings, etc. Smart ancillaries – alternator and compressor Lower friction lubricant
Waste Heat Recovery	-	Without waste heat recovery	Without waste heat recovery
Hybridisation & Electrification	-	Without hybridisation	48V mild hybridisation, with stop-start
Battery	-	-	-
Electric Motor	-	-	-
Charging System	-	-	-
Transmission	6-9 speed MT	6-9 speed MT	9 speed AMT
Vehicle Technologies			
Vehicle Lightweighting	High strength steel chassis and cab	Minor design changes to decrease vehicle weight Lighter weight GF composites used in upper boxes	Shift to higher grade steels to reduce vehicle weight Lighter weight ancillaries, such as aluminium fuel tanks, light weight wheels, etc.
Aerodynamic Treatment	-	Minor design changes to improve aerodynamics	Some design changes to improve aerodynamics
Low Rolling Resistance	Low Rolling Resistance Tyres	Low Rolling Resistance Tyres	Low Rolling Resistance Tyres

MD Distribution	"Business as Usual" – The Mainstream Option					
	2015 (Baseline)		2020		2025	
Vehicle Control	-		-		-	
Other Vehicle Technologies	-		-		-	
Performance					Slight downspeeding	
Power	150-220 kW at 2000-2500 rpm	230-260 kW at 2000-2300 rpm	150-240 kW at 2000-2500 rpm	230-280 kW at 2000-2300 rpm	160-260 kW at 1800-2400 rpm	240-300 kW at 1800-2200 rpm
Torque	750-1200 Nm at 1200-2000 rpm	1100-1400 Nm at 1000-2000 rpm	800-1300 Nm at 1200-2000 rpm	1100-1500 Nm at 1000-2000 rpm	800-1400 Nm at 1200-2000 rpm	1100-1600 Nm at 1000-2000 rpm
Energy Efficiency / CO_2	2015 Baseline		3-6% fuel consumption reduction compared ty 2015 baseline Note: Urea consumption >5% fuel consumption		8-12% fuel consumption reduction compared ty 2015 baseline Note: Urea consumption >8% fuel consumption	
Cost	2015 Baseline		Minor cost difference compared to 2015 baseline		€2000-€4000 additional cost compared to 2015 baseline	
Justification	This baseline has been developed from MY2015 specifications published by the vehicle OEMs, and from the Ricardo HDD engine benchmark database.		The Technology Package features several "quick hits" technologies, introduced to improve engine energy efficiency, such as lower friction bearings. It is expected that power and torque will increase for the higher performance engine variants. Minor changes to the vehicle design to reduce drag and rolling resistance will help to improve fuel economy, compared to the 2015 baseline.		The engine will be upgraded to achieve Euro VII emissions. Mild hybridisation and further changes to vehicle design will help to reduce CO_2.	

MD Distribution	“Better for Energy Efficiency” – An Alternative Option		
	2015 (Baseline)	**2020**	**2025**
	7.5-16t Rigid Truck with 4x2 or 6x2 axle configuration used for regional or local distribution. 4 or 6 cylinder Euro VI diesel engine with 6-9 speed AMT.	7.5-16t Rigid Truck with 4x2 or 6x2 axle configuration used for regional or local distribution. **Diesel hybrid** with 4 or 6 cylinder Euro VI diesel engine and DCT	7.5-16t Rigid Truck with 4x2 or 6x2 axle configuration used for regional or local distribution. **Diesel hybrid** with 4 or 6 cylinder Euro VII diesel engine and DCT
Energy Vector	**Diesel**	**Diesel**	**Diesel**
Emission Standard	Euro VI	Euro VI + CO_2 reporting	Euro VII + CO_2 regulation
Engine	4.5-5.1L, inline 4-cylinder, 16v 6.5-8L, inline 6-cylinder, 24v	3-5L, inline 4-cylinder, 16v 6-8L, inline 6-cylinder, 24v	3-5L, inline 4-cylinder, 16v 6-8L, inline 6-cylinder, 24v
Cylinder Pressure	Pmax 200 – 230 bar	Pmax 200 – 230 bar	Pmax 210 – 240 bar
Combustion & FIE	Common Rail, 1600-2400 bar	Common Rail, 1600-2400 bar	Common Rail, 2000-2700 bar
Boosting	VGT	VGT	VGT
EGR	External high pressure cooled EGR EGR rate 0-25%	External high pressure cooled EGR EGR rate 0-15%	External high pressure cooled EGR EGR rate 0-25%
Valvetrain	DOHC or SOHC	DOHC or SOHC	DOHC or SOHC
Aftetreatment	DOC + DPF + SCR + ASC (SCR conversion efficiency>92%, depending on EGR strategy; urea consumption >3% fuel consumption equivalent)	DOC + DPF + SCR + ASC (SCR conversion efficiency>95%, depending on EGR strategy; urea consumption >5% fuel consumption equivalent)	DOC + DPF + SCR + ASC (SCR conversion efficiency>98%, depending on EGR strategy; urea consumption >8% fuel consumption equivalent) (LNT may also be required, for cold start operation in inner cities)
Engine Control	ECU OBD – basic functional + threshold based OBD + rated based monitoring	ECU OBD – basic functional + threshold based OBD + rated based monitoring – with tighter thresholds More sensors (e.g. soot), exhaust temperature thermal management	ECU, model based control OBD, in-use emissions monitoring
Materials & Coatings	Cast Iron Aluminium pistons	Cast Iron Aluminium pistons	Cast Iron Aluminium pistons
Thermal Management	-	Belt-driven coolant pump Traditional thermostat	Multi-speed water pump and by-pass for charge cooler Variable displacement oil pump

MD Distribution	"Better for Energy Efficiency" – An Alternative Option		
	2015 (Baseline)	2020	2025
			Smart thermostat Smart piston cooling jets
Low Friction Technologies	-	Low friction coatings for bearings, pistons, piston rings, etc. Lower friction lubricant	Low friction coatings for bearings, pistons, piston rings, etc. Smart ancillaries – alternator and compressor Lower friction lubricant
Waste Heat Recovery	-	Without waste heat recovery	Without waste heat recovery
Hybridisation & Electrification	-	Diesel hybrid	Diesel hybrid
Battery	-	Lithium-ion 2-4 kW (depending on vehicle size)	Lithium-ion 2-4 kW (depending on vehicle size)
Electric Motor	-	40-80 kW continuous power	40-80 kW continuous power
Charging System	-	-	-
Transmission	6-9 speed MT	6-9 speed DCT	6-9 speed DCT
Vehicle Technologies	-	-	-
Vehicle Lightweighting	High strength steel chassis and cab	Lighter weight chassis through use of higher grade steels and aluminium GF composite upper boxes	Lighter weight chassis through use of higher grade steels and aluminium Aluminium cab GF composite upper boxes Lighter weight ancillaries
Aerodynamic Treatment	-	Minor design changes to improve aerodynamics	Some design changes to improve aerodynamics
Low Rolling Resistance	Low Rolling Resistance Tyres	Low Rolling Resistance Tyres	Low Rolling Resistance Tyres
Vehicle Control	-	-	-
Other Vehicle Technologies	-	Additional safety features, such as pedestrian or cyclist warning	Additional safety features, such as pedestrian or cyclist warning

MD Distribution	"Better for Energy Efficiency" – An Alternative Option					
	2015 (Baseline)		2020		2025	
Performance			Some engine downsizing Slight downspeeding (-200 rpm)		Further downspeeding (-200 rpm)	
Power	150-220 kW at 2000-2500 rpm	230-260 kW at 2000-2300 rpm	150-220 kW at 1800-2300 rpm	230-260 kW at 1800-2100 rpm	150-220 kW at 1600-2400 rpm	230-260 kW at 1600-2000 rpm
Torque	750-1200 Nm at 1200-2000 rpm	1100-1400 Nm at 1000-2000 rpm	750-1200 Nm at 1200-2000 rpm	1100-1400 Nm at 1000-2000 rpm	750-1200 Nm at 1200-2000 rpm	1100-1400 Nm at 1000-2000 rpm
Energy Efficiency / CO_2	2015 Baseline		10-15% fuel consumption reduction compared ty 2015 baseline		18-30% fuel consumption reduction compared ty 2015 baseline	
Cost	2015 Baseline		€20,000-€30,000 additional cost compared to 2015 baseline		€15,000-€25,000 additional cost compared to 2015 baseline	
Justification	This baseline has been developed from MY2015 specifications published by the vehicle OEMs, and from the Ricardo HDD engine benchmark database.		An alternative Technology Package for MD Distribution trucks, with a greater focus on improving energy efficiency. The higher initial cost of this package will limit market uptake. The full hybrid configuration is likely to achieve better fuel consumption results for MD trucks used for urban delivery. Therefore, this TP is likely to be more applicable to 7.5-12t MD trucks rather than 12-16t MD trucks. The hybrid system enables engine downsizing. Some vehicle lightweighting technologies are likely to be applied, especially to the vehicle structure, to help off-set the additional weight of the hybrid system.		A continuation of the alternative hybrid Technology Package for MD Distribution trucks. As the technology matures, it is expected that further fuel consumption savings will be achieved through better system integration and optimisation. The cost of the package is also likely to reduce as volumes increase.	

Appendix 1C Technology Packages for City Buses

City Bus	"Business as Usual" – The Mainstream Option			
	2015 (Baseline)	2020	2025	
	Single decker, 12m low-floor city bus with 1-3 doors. Capable of transporting 100 passengers (30 seated). Euro VI diesel 6-11 L engine, with 6 cylinders	Single decker, 12m low-floor city bus with 1-3 doors. Capable of transporting 100 passengers (30 seated). Upgraded Euro VI diesel engine. **Evolutionary enhancements** to the powertrain and vehicle help to reduce CO_2 emissions compared to the 2015 baseline This Technology Package does not include hybridisation.	Single decker, 12m low-floor city bus with 1-3 doors. Capable of transporting 100 passengers (30 seated). **Euro VII Diesel Hybrid**, either parallel or series configuration.	
Energy Vector	**Diesel**	**Diesel**	**Diesel**	
Emission Standard	Euro VI	Euro VI + CO_2 reporting	Euro VII + CO_2 regulation	
Engine	6-11 L, inline 6 cylinder, 24v	6-11 L, inline 6 cylinder, 24v	6-11 L, inline 6 cylinder, 24v for parallel hybrid	4-7 L, inline 4 or 6 cylinder, 16 or 24v for series hybrid
Cylinder Pressure	Pmax 190 – 220 bar	Pmax 190 – 220 bar	Pmax 210 – 250 bar	Pmax 210 – 240 bar
Combustion & FIE	Common Rail, 1600-2400 bar	Common Rail, 1600-2500 bar	Common Rail, 2000-2700 bar	
Boosting	FGT or VGT	FGT or VGT	FGT or VGT	
EGR	External high pressure cooled EGR EGR rate 0-25%	External high pressure cooled EGR EGR rate 0-15%	External high pressure cooled EGR EGR rate 0-25%	
Valvetrain	DOHC or SOHC	DOHC or SOHC	DOHC or SOHC	
Aftetreatment	DOC + DPF + SCR + ASC (SCR conversion efficiency>92%, depending on EGR strategy; urea consumption >3% fuel consumption equivalent)	DOC + DPF + SCR + ASC (SCR conversion efficiency>95%, depending on EGR strategy; urea consumption >5% fuel consumption equivalent)	DOC + DPF + SCR + ASC (SCR conversion efficiency>98%, depending on EGR strategy; urea consumption >10% fuel consumption equivalent)	
Engine Control	ECU OBD – basic functional + threshold based OBD + rated based monitoring	ECU OBD – basic functional + threshold based OBD + rated based monitoring – with tighter thresholds	ECU, model based control OBD, in-use emissions monitoring	

City Bus	"Business as Usual" – The Mainstream Option			
	2015 (Baseline)	2020	2025	
		More sensors (e.g. soot), exhaust temperature thermal management		
Materials & Coatings	Cast Iron or CGI cylinder block Steel or Aluminium pistons	Cast Iron or CGI cylinder block Steel or Aluminium pistons	Cast Iron or CGI cylinder block Steel or Aluminium pistons	
Thermal Management	Traditional thermostat	Traditional thermostat	Smart thermostat and cooling system, designed for hybrid operation	
Low Friction Technologies	-	Low friction coatings for bearings, pistons, piston rings, etc. Lower friction lubricant	Upgraded bearings, suitable for more stop-start operation	
Waste Heat Recovery	-	Without waste heat recovery	Without waste heat recovery	
Hybridisation & Electrification	-	Without hybridisation	**Diesel parallel hybrid**	**Diesel series hybrid**
Battery	-	-	Li-ion battery pack	Li-ion battery pack and/or ultra capacitors
Electric Motor	-	-	100-150 kW continuous power traction motor	100-150 kW continuous power traction motor
Charging System	-	-	Not required	
Transmission	4 to 6 speed AT	4 to 6 speed AT	9 speed AMT	
Vehicle Technologies	Energy efficient lighting and air conditioning Cantilever seats Segmented side walls	Energy efficient lighting and air conditioning Cantilever seats Segmented side walls	Energy efficient lighting and air conditioning Cantilever seats Segmented side walls Electric air conditioning	
Vehicle Lightweighting	Steel chassis Aluminium upper structure GF composite panels Wood / plywood flooring	Lighter weight structure and fixtures Aluminium wheels Aluminium fuel tank	100% aluminium structure Lightweight glazing CFRP panels and inter-decks	
Aerodynamic Treatment	-	Minor improvements to aerodynamic design	Minor improvements to aerodynamic design	
Low Rolling Resistance	Tyre pressure monitoring	Tyre pressure monitoring	Tyre pressure monitoring	

City Bus	"Business as Usual" – The Mainstream Option			
	2015 (Baseline)	2020	2025	
Vehicle Control	Electronic stability (ESP)	Electronic stability (ESP)	Electronic stability (ESP)	
Other Vehicle Technologies	-	Additional safety features, such as pedestrian or cyclist warning	Additional safety features, such as pedestrian or cyclist warning	
Performance			Slight downspeeding	Smaller engine for series hybrid
Power	180-270 kW at 1800-2200 rpm	180-270 kW at – 1800-2000 rpm	180-270 kW at 1600-2000 rpm	150-250 kW at 1800-2400 rpm
Torque	1100–2100 Nm at 1000-1600 rpm	1100–2100 Nm at 1000-1600 rpm	1100–2100 Nm at 1000-1600 rpm	800-1200 Nm at 1000-1600 rpm
Energy Efficiency / CO_2	2015 Baseline	<5% fuel efficiency improvement compared to 2015	20-40% fuel efficiency improvement compared to 2015	
Cost	2015 Baseline	Similar price compared to 2015 baseline	€25,000 - €50,000 on-cost compared to 2015 baseline	
Justification	This baseline has been developed from MY2015 specifications published by the vehicle OEMs, and from the Ricardo HDD engine benchmark database.	Similar technology to 2015 baseline, with some cost-effective evolutionary enhancements to the powertrain and vehicle to improve energy efficiency, such as lower friction bearings. Slightly reduced EGR rate, as SCR efficiency is improves, depending on relative price of AdBlue compared to diesel. Some changes expected to vehicle design, as research on aerodynamics and lightweighting matures.	Diesel hybrid is expected to become the dominant powertrain option for European city buses sometime between 2020 and 2025. Both parallel hybrid and series hybrid configurations are valid for city buses. Bus operators will select the option which will be most effective for their city and bus operations. Real-world fuel savings are very dependent on the bus routes. Series hybrid has the potential for greater fuel savings when operating in inner city routes. However, parallel hybrid is likely to offer better savings than series hybrid for suburban bus route. Further efficiency savings will be achieved through better integration and optimisation of the hybrid powertrain system. It is likely that the transmission system will be a carry-over component from the HD and MD truck sector	

City Bus	“Better for Air Quality” – An Alternative Option		
	2015 (Baseline)	2020	2025
	Single decker, 12m low-floor city bus with 1-3 doors. Capable of transporting 100 passengers (30 seated). Euro VI diesel 6-11L engine, with 6 cylinders	Single decker, 12m low-floor city bus with 1-3 doors. Capable of transporting 100 passengers (30 seated). **Euro VI Diesel Hybrid**, with either parallel or series hybrid configuration	Single decker, 12m low-floor city bus with 1-3 doors. Capable of transporting 100 passengers (30 seated). **Electric Bus**, used in cities and towns that have installed the required recharging infrastructure
Energy Vector	**Diesel**	**Diesel**	**Electricity**
Emission Standard	Euro VI	Euro VI + CO_2 reporting	Euro VII + CO_2 regulation
Engine	6-11 L, inline 6 cylinder, 24v	6-11 L, inline 6 cylinder, 24v for parallel hybrid 4-7L, inline 4 or 6 cylinder, 16v or 24v for series hybrid	Electric powertrain, therefore no internal combustion engine
Cylinder Pressure	Pmax 190 – 220 bar	Pmax 190 – 220 bar	-
Combustion & FIE	Common Rail, 1600-2400 bar	Common Rail, 2000-2500 bar	-
Boosting	FGT or VGT	FGT or VGT	-
EGR	External high pressure cooled EGR EGR rate 0-25%	External high pressure cooled EGR EGR rate 0-25%	-
Valvetrain	DOHC or SOHC	DOHC or SOHC	-
Aftetreatment	DOC + DPF + SCR + ASC (SCR conversion efficiency>92%, depending on EGR strategy; urea consumption >3% fuel consumption equivalent)	DOC + DPF + SCR + ASC (SCR conversion efficiency>92%, depending on EGR strategy; urea consumption >3% fuel consumption equivalent)	-
Engine Control	ECU OBD – basic functional + threshold based OBD + rated based monitoring	ECU OBD – basic functional + threshold based OBD + rated based monitoring – with tighter thresholds More sensors (e.g. soot), exhaust temperature thermal management	-
Materials & Coatings	Cast Iron or CGI cylinder block Steel or Aluminium pistons	Cast Iron or CGI cylinder block Steel or Aluminium pistons	-
Thermal Management	Traditional thermostat	Traditional thermostat	-

City Bus	"Better for Air Quality" – An Alternative Option			
	2015 (Baseline)	2020		2025
Low Friction Technologies	-	Upgraded bearings, suitable for more stop-start operation		-
Waste Heat Recovery	-	Without waste heat recovery		-
Hybridisation & Electrification	-	**Diesel parallel hybrid**	**Diesel series hybrid**	**Electric powertrain**
Battery	-	Li-ion battery pack	Li-ion battery pack and/or ultra capacitors	Li-ion battery pack
Electric Motor	-	100-150 kW continuous power traction motor	100-150 kW continuous power traction motor	100-150 kW continuous power traction motor
Charging System	-	Not required		Rapid inductive (wireless) or conductive (e.g. pantograph) top-up charging at bus stops Conductive or inductive charging at bus depot
Transmission	4 to 6 speed AT	9 speed AMT		1 to 3 speed AT for electric powertrain
Vehicle Technologies	Energy efficient lighting and air conditioning Cantilever seats Segmented side walls	Energy efficient lighting and air conditioning Cantilever seats Segmented side walls Electric air conditioning		Energy efficient lighting and air conditioning Cantilever seats Segmented side walls Electric air conditioning
Vehicle Lightweighting	Steel chassis Aluminium upper structure GF composite panels Wood / plywood flooring	Lighter weight structure and fixtures Aluminium wheels Aluminium fuel tank		More use of higher grade steels and aluminium in vehicle structure Lightweight glazing CFRP panels and inter-decks
Aerodynamic Treatment	-	Minor improvements to aerodynamic design		Minor improvements to aerodynamic design
Low Rolling Resistance	Tyre pressure monitoring	Tyre pressure monitoring		Tyre pressure monitoring
Vehicle Control	Electronic stability (ESP)	Electronic stability (ESP)		Electronic stability (ESP)
Other Vehicle Technologies	-	Additional safety features, such as pedestrian or cyclist warning		Additional safety features, such as pedestrian or cyclist warning

City Bus	"Better for Air Quality" – An Alternative Option			
	2015 (Baseline)	2020		2025
Performance			Smaller engine for series hybrid	
Power	180-270 kW at 1800-2200 rpm	180-270 kW at 1800-2200 rpm	130-250 kW at 1800-2400 rpm	-
Torque	1100–2100 Nm at 1000-1600 rpm	1100–2100 Nm at 1000-1600 rpm	800-1200 Nm at 1000-1600 rpm	-
Energy Efficiency / CO_2	2015 Baseline	10-30% fuel efficiency improvement compared to 2015 baseline		Zero emissions at point of use "Well-to-Wheel" emissions depend on the grid electricity mix
Cost	2015 Baseline	€25,000 - €50,000 on-cost compared to 2015 baseline		€20,000 - €60,000 on-cost for the vehicle compared to 2015 baseline Also requires significant investment in developing the recharging infrastructure
Justification	This baseline has been developed from MY2015 specifications published by the vehicle OEMs, and from the Ricardo HDD engine benchmark database.	Diesel hybrid will be a popular alternative powertrain option for urban buses. Both parallel hybrid and series hybrid configurations will be available. Real-world fuel savings will depend on the bus duty cycle. Bus operators will select which type of hybrid is most effective for their city. Better integration and optimisation of the hybrid powertrain system will help ensure the advertised fuel savings are achieved. Some carry-over in engine development expected from HD and MD truck sector. It is likely that the transmission system will be a carry-over component from the HD and MD truck sector Some changes expected to vehicle design, as research on aerodynamics and lightweighting matures.		Zero emissions technology option for inner cities, but likely to be limited to operating on routes with rapid or top-up charging infrastructure. Vehicle on-cost depends on the size of the battery pack, which in turn will dictate the driving range. Requires extensive investment in re-charging infrastructure for wider roll-out. So only suitable to towns and cities with the required political will and access to capital funds.