Euro 6
the inside story part 2

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CONTENTS

Euro 6 inside story part 2

4 The nitty-gritty of Euro VI rules, and why it matters
Few people are better placed than Pete Williams to cut through the dense legalese of European regulations to get at what they really mean for commercial vehicle engineers. The Cummins product environmental management director for Europe explains what makes this legislation a game-changer.

6 Hidden talents
Euro 6 versions of Cummins ISB engines are set to attract plenty of attention from truck and bus operators at this year’s Hannover show. The engineers behind the development programme explain why there is more to this range of four- and six-cylinder power units than meets the eye.

10 Forward thinking
Fuel efficiency, fuel efficiency and fuel efficiency. These are said to be the three top priorities of one leading engine development engineer as he plans for what follows Euro 6. So where does a manufacturer of turbochargers come into this? Tim Blakemore has been finding out.

12 Euro 6 powertrains take centrestage at Hannover
Where do leading European commercial vehicle manufacturers now stand in the run-up to the introduction of Euro 6 legislation? There is no better place to find out than at this year’s IAA show in Hannover. Tim Blakemore looks forward to it.

16 Any colour you like, so long as it’s green
Bus and coach operators tell Gavin Booth about Euro 6 effects on vehicle replacement policies, and about a powerful drive towards low-carbon public transport.

19 An A to Z of Euro 6
Part two of our plain English guide to some of the latest commercial vehicle engineering abbreviations, acronyms and jargon.

INTRODUCTION
Welcome to part two of the Commercial Vehicle Engineer/Cummins guide to what is generally reckoned to be the toughest technology challenge facing the commercial vehicle industry since emissions legislation began in the early 1990s. This time around we focus a little more on the bus and coach side of the road transport business and on the Euro 6 developments likely to attract most attention at this year’s huge Hannover show.

We’ve been hearing from vehicle operators, manufacturers and from development engineers behind the latest Euro 6-related innovations, not forgetting some aimed squarely at what comes next.

Many thanks to everyone who has responded so enthusiastically to the first part of this guide. We hope you find this second part equally informative. Please tell us what you think using the contact details below or on Twitter by following @CumminsEurope and @CVEngineer1.

For more information on Euro 6, visit www.cumminseuro6.com.

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The nitty-gritty of Euro VI rules, and why it matters

As product environmental management
director at Cummins, Pete Williams needs
to understand exactly what is meant by the
chapter and verse of the latest European
exhaust emissions legislation.
He’s been offering some expert
guidance to Tim Blakemore.

It is twenty years since the introduction of the first, Euro 1, European limits on exhaust emissions from trucks and buses. Since then, commercial vehicle operators have grown accustomed to reading about how engine and vehicle manufacturers are gearing up for the next stage of the process, from Euro 2 in 1996 to Euro 3 in 2000, Euro 4 in 2005 and Euro 5 in 2008. So sceptics may be forgiven for wondering whether all the unprecedented extra fuss about Euro 6 is really justified. Is this not just a natural progression including, as might be expected, the lowest limits yet on emissions of nasty pollutants such as oxides of nitrogen (NOx) and particulates (PM)? What exactly makes Euro 6 the commercial vehicle engineering game-changer it is sometimes rather glibly made out to be? Few people are better placed to answer such questions with authority than Pete Williams, product environmental management director for Cummins’ Europe, Middle East and Africa (EMEA) division, based at the company’s engine manufacturing plant and technical centre in Darlington, County Durham. A central part of Williams’ responsibilities is to stay bang up to date with global exhaust emission rules and regulations to ensure that the company’s engineering development teams continue to take aim at precisely the right targets. Small wonder he has a natural aversion to any hint of vagueness or ambiguity. He points out, for instance, that it can be misleading to use Arabic numerals (1, 2, 3, 4 and so on) in the familiar shorthand for Euro limits, including those soon to be introduced by European Union Regulation 595/2009 (published in July 2009) and commonly described as Euro 6. This is because there are parallel (but significantly different) Euro 6 regulations on light vehicles (generally below 3.5 tonnes gvw). To distinguish between these two sets of limits, the convention followed by Williams and other engineers is that Roman numerals (I, II, III, IV, V and so on) are used for the heavy vehicle limits, leaving Arabic numerals applying only to those for cars and vans. But he phlegmatically accepts that it can be more convenient to stick with “Euro 6” in circumstances where there can be no doubt that we’re referring to trucks and buses.

One other detail worth underlining is that Euro 6 limits are the first in this Euro series to be introduced by “regulation” rather than by “directive”. The key point here is that an EU directive has to be translated into domestic law separately by each and every member state whereas a regulation applies directly throughout the EU. So the legal process should be streamlined, in theory at least. But as Williams explains, the impact of Euro VI (let’s stick here with the preferred Roman numerals for the avoidance of any doubt, as they say in legal circles) goes way beyond the European Union and indeed beyond the whole of Europe. He points to a map of the world showing the regions where the three sets of exhaust emissions rules (from Europe, the US and Japan) are being applied at present or will be in future. The Euro limits area, encompassing the whole of Africa, Latin America and China, is many times bigger than the other two put together.

“Korea, Turkey and Hong Kong will be among the first to follow Europe with Euro VI limits,” says Williams. As for timing, it has already been widely reported that in the European Union the Euro VI regulation will come into force from 1 January 2013 for newly-type-approved vehicles and then from 1 January 2014 for all newly-registered vehicles. But Williams also points out that at least two elements of the legislation, related to on-board diagnostics (OBD) and in-service monitoring of NOx emissions, are being phased in later, up to 31 December 2016. “This phase-in may drive up to two revisions from the original certification and hence vehicle homologation,” he says.

Vehicle and engine manufacturers have long complained about crucial differences between

Pete Williams: “Euro VI impact goes way beyond Europe.”
the official engine test cycles used to measure exhaust emissions in Europe, North America and Japan, not least because this has meant that costly test-cells and other equipment used to homologate engines in the US cannot be used without even more costly modification for European engines, and vice versa. The Euro VI legislation is the first to begin to sweep away these disparities, employing “world harmonised” test cycles for the first time. These are the World Harmonised Transient Cycle (WHTC), World Harmonised Steady State Cycle (WHSC), and World Harmonised Not To Exceed Zone (WHNTE). But if this long-awaited global standardisation can be seen as the good news for engine manufacturers, the bad news is that the Euro VI test cycles are far more demanding than their Euro V predecessors.

“Both Euro V and Euro VI transient cycle points are defined by a full-load curve,” explains Williams. “But the Euro VI cycle has a lower average speed and load compared with Euro V, and it requires consecutive hot and cold cycles.” And there is far less leeway at Euro VI for “off-cycle emissions.” Much has been made already of the deep cuts in NOx and particulates emissions demanded by Euro VI, not to mention the challenge involved in achieving these cuts without severely compromising fuel economy. Williams does not disagree, pointing to the Euro V NOx and PM limits (measured in grams per kilowatt hour) under the European Transient Cycle (ETC) and the corresponding Euro VI limits under the more demanding World Harmonised Transient Cycle (WHTC). The NOx limit is going from 2.0 to 0.46g/kW hr and the PM limit from 0.03 to 0.010g/kW hr.

More than this, one late addition to the Euro VI legislation is a particle count limit in addition to the familiar particulate matter mass limit. So tiny are the particles in question, down to about 20 nanometres in diameter (about the same size as an atom of helium), that highly sophisticated measuring equipment is demanded, and questions have yet to be fully answered by anyone about the practicability of using such equipment out on the road in service vehicles, as the legislation would seem to require.

“Previous legislation has been focused on in-cell emissions which may not reflect actual real-world performance,” says Williams. “Euro VI brings stringent in-use requirements to better control emissions from the vehicle under normal operation. Products are required to meet 1.5 times the in-cell limits, both at type approval and for the full useful life of the vehicle.” For trucks and buses that “useful life” is defined in the legislation as seven years or 700,000km, whichever comes first.

For vehicle operators, drivers and maintenance staff some of the most noticeable changes with Euro VI engines will relate to repair and maintenance information, on-board diagnostic (OBD) systems and what is rather euphemistically described as “driver warning and inducement systems.” All these elements of the EU legislation seem to be driven by a determination at the European Commission not to get caught out by any efforts to circumvent exhaust emission legislation on in-service vehicles.

Euro VI rules require manufacturers to publish detailed repair and maintenance information so that it is accessible to anyone wanting to work on engines and their exhaust after-treatment systems. On monitoring of NOx emissions control, Williams explains that “the engine is required to detect issues with the NOx control system that could be construed as tampering.” Any sign that NOx control is not working as it should must activate a driver warning system within a set time. Then if no action is taken the “driver inducement system” must kick-in automatically.

At first the engine’s torque will be cut by 25 per cent, enough to have a noticeable impact on any truck’s driveability. The second stage of the process is even more severe, limiting the vehicle’s maximum speed to 20km/h (12.5mph) though Williams emphasises that “this won’t happen while you are driving along the motorway.” The second stage is activated only following the initial torque de-rate and then not until the vehicle has first come to rest.

The overriding aim of the Euro VI requirements on OBD is to ensure that emissions limits are satisfied by vehicles throughout their working lives. Exactly how this part of the regulation will be enforced is being left to individual member states to decide. It is clear that in the UK it will be the responsibility of the Vehicle and Operator Services Agency (VOSA) but precisely how the enforcement will be divided between roadside checks and planned annual inspections remains to be seen.

Global automotive emissions
What is the best way to satisfy Euro 6 exhaust emission legislation when your starting point is a successful Euro 5 four-cylinder, 4.5-litre diesel engine used extensively in lightweight European trucks and buses and becoming increasingly popular in hybrid (diesel/electric) bus drivelines? This, in a nutshell, the central question faced by Cummins engineers years ago as they set out on the ISB Euro 6 project. A cursory glance at the specification sheet of the Euro 6 ISB4.5 engine going on public display for the first time at this year’s IAA (Internationale Automobil-Ausstellung) show in Hannover, Germany (page 12) could leave a casual observer with the impression that the answer those engineers came up with was simply to take that Euro 5 engine, fine-tune it and add the latest exhaust after-treatment equipment, variable-geometry turbocharger and fuel injection equipment. Hey presto: job done. Just goes to show how wrong casual observations can be. In fact the Euro 6 ISB4.5 is all new, sharing virtually nothing apart from swept volume with its predecessor. The new ISB4.5 instead is based on the Cummins ISF3.8 engine, which first went into production in Beijing, China in 2008, at a manufacturing plant run by a joint venture between Cummins and Beiqi Foton, a big Chinese commercial vehicle manufacturer. The ISF3.8 and its 2.8-litre baby brother now power Foton light trucks in China as well as various other vans and light trucks between three and seven tonnes gvw from other manufacturers.

The decision to base the Euro 6 B-series on this ISF was taken way back in 2006, shortly after the Cummins/Foton joint venture was finalised, according to Neil Pattison, director of Cummins’ Europe, Middle East and Africa (EMEA) automotive engine division. But why this radical change of direction when the current four-cylinder B-series had apparently been doing such a good job, helped by regular updates, from Euro 1 to Euro 5? “Euro 6 is the most challenging piece of emissions legislation to date, with engine exhaust emissions moving to near-zero levels,” says Pattison. “This represents a reduction of 99 per cent since legislation began with Euro 1. For Euro 4 and 5 our ISBe engines have delivered class-leading performance, fuel economy and service intervals. We aim to maintain these levels with our new Euro 6 products, in spite of the challenge.”

So what exactly does the new 4.5-litre engine bring to the Euro 6 party that the current one could not? Ian Watson, product introduction chief engineer, picks up the story, pointing out that the new 4.5-litre power unit is a “global engine, designed in the UK, US and China and assembled at a state-of-the-art Beijing plant on which around RMB2.7 billion (£270 million) has been invested.” That’s all well and good, but what practical benefits will it bring to vehicle manufacturers and operators in Europe? Watson has a long list ready in response to such questions, starting with the low weight of the engine block and head, achieved without any compromise in durability, it is claimed. “The block is 10 per cent lighter and the head 20 per cent lighter than the previous ISB4.5,” says Watson. “Not only that but there is also improved coolant flow, improved
cylinder pressure capability, improved NVH (noise, vibration and harshness) and stiffness, and improved airflow for swirl balance.”

Further weight and noise reductions come from use of composite materials for components such as the valve cover and oil sump. This sump also boasts an integral dipstick and suction tube, cutting the number of parts.

Closed crankcase ventilation is demanded, in effect, by Euro 6 legislation, because blow-by gases will be counted in exhaust emission measurement. Cummins engineers have come up with a clever (and patented) design of crankcase ventilation system for the ISB4.5, involving blow-by gases being fed back through the hollow centre of the camshaft. No servicing is required.

More innovation is apparent in the “cooling module”, bringing together water-pump, oil-filter and oil-cooler in a single sub-assembly. Less risk of pressure drop and improved durability are said to be the main benefits.

Dry weight of a Euro 6 ISB4.5 is 316kg, compared with 366kg for a current (Euro 5) ISB4.5. This weight saving is crucial for truck and bus manufacturers because weight is added at Euro 6 by more complex exhaust aftertreatment combining SCR (selective catalytic reduction), DPF (diesel particulate filter) and DOC (diesel oxidation catalyst). As expected, this is the aftertreatment combination chosen by Cummins for all its Euro 6 engines in Europe as well as for engines in North America meeting the US EPA (Environmental Protection Agency) 2010 limit. The latest feather in the Cummins Emissions Solutions cap is a US order for this exhaust aftertreatment equipment from rival truck and bus engine maker Navistar. It is going to be used with Navistar MaxxForce engines (based on MAN’s D20 and D28 in-line sixes) from next year, under what Navistar describes as a “non-binding memorandum of understanding” with Cummins.

All elements of exhaust aftertreatment used on Euro 6 B-series engines are developed and manufactured in-house at Darlington by Cummins Emissions Solutions. The Euro 6 exhaust aftertreatment equipment is packaged in “a switchback configuration” to minimise the amount of chassis space occupied. The Cummins SCR system is patented and boasts exceptionally-high NOx (oxides of nitrogen) conversion rates, even at low temperature. No driver intervention is needed for regeneration of the diesel particulate filter, stresses Pattison. This “regeneration” (burning off of accumulated particles in the filter) is achieved under normal operating conditions.
conditions by sophisticated manipulation of fuelling, injection timing and air-handling (by the variable-geometry turbocharger). All the new Cummins B-series engines employ both cooled exhaust gas recirculation (EGR) and SCR to cut NOx emissions below the tough Euro 6 limits. “We closely balance the EGR and SCR systems to meet the regulated NOx levels,” says Pattison. “This allows us to optimise the fuel economy and AdBlue usage for the lowest possible running costs. We expect AdBlue usage will reduce at Euro 6 to around two to three per cent of fuel consumption (dependent on duty-cycle) from five to seven per cent at Euro 5.”

What of the six-cylinder, 6.7-litre B-series in the move from Euro 5 to Euro 6? This changes less radically, keeping the same cylinder block and cylinder head. But the Euro 6 ISB6.7 is not short of an innovation or two of its own. These include a closed crankcase ventilation system integrated with the valve cover; a bigger sump (to allow longer oil-drain intervals); and what is called a “nano-fibre” fuel filter. This is claimed to offer the most effective protection yet for an engine’s fuel system, removing particles as small as 4 microns in diameter. An interlock prevents the engine from being started if the filter is missing or not installed properly.

Cummins has listened carefully to customer feedback on the current 6.7-litre B-Series, stresses Ian Watson. Power ratings, fuel efficiency and oil drain intervals are unchanged, compared with a Euro 5 engine, but transient response is better and noise is lower, he points out. The target for diesel particulate filter cleaning interval at Euro 6 is 200,000km. “The better transient response and lower noise are usually the first things noticed by anyone driving a vehicle with this Euro 6 engine,” he says.

Like its smaller sibling, the ISB6.7 employs the latest sliding-vane variable-geometry turbocharger (VGT) from Huddersfield-based Cummins Turbo Technologies. This turbocharger complements the redesigned EGR system, explains Jonathan Atkinson, product development chief engineer in charge of the Euro 6 B-series project. “The EGR system is redesigned for better integration with cab-over (forward-control) truck applications and the Cummins VGT is optimised for high torque and low-speed capability, delivering significant performance
and driveability improvements,” he says. “The vgt also functions as an exhaust brake, allowing vehicle manufacturers to remove cost. There is a new electronic control module (ecm) for controlling the engine and aftertreatment as well as dealing with the challenging Euro 6 on-board diagnostics monitoring requirements.”

Until about four years ago Cummins engineers in the US seemed confident that EPA 2010 limits in North America could be met purely with egr and without scr. Sharp rises in the cost of fuel in the US was a crucial factor in making the engineers change their minds. Now there are many EPA 2010 Cummins engines of various sizes and power outputs running with both egr and scr in North America.

“To date we have over 330,000 EPA 2010 engines operating in the US,” says Pattison. “By the time Euro 6 comes in we will have over three years experience of using all the key technologies. We can use the combustion and aftertreatment architecture and tailor it for European market operations and duty cycles.”

He stresses that development of the six- and four-cylinder Euro 6 B-series engines has been a Darlington technical centre-led project involving a huge amount of lab testing in “state of the art” test cells and more than two million miles of road testing in trucks and buses to date. “Never before has the installation of the engine and its related technologies had the potential to impact the vehicle and its operation as much as it has at Euro 6,” he says. “Cummins air-handling-to-exhaust capability, with all leading technologies in-house, means that we can deliver the optimum recipe in terms of emissions, performance and operating costs.”

Maximum rated power outputs for the four-cylinder ISB4.5 at Euro 6 go from 150 to 210ps (148 to 207hp) for trucks and buses. Governed speed is down from 2,500rpm at Euro 5 to 2,300 at Euro 6.

Maximum rated power outputs for the six-cylinder ISB6.7 at Euro 6 go from 225 to 310ps for trucks and from 220 to 280ps for buses. Governed speed for these 6.7-litre engines is 2,300rpm in truck applications, 2,100rpm in buses.

Filed tests of the Euro 6 ISB engines already involve more than 40 vehicles.
Euro 6 engines are likely to remain a novelty for some time to come for most truck and bus operators. But already development engineers at engine manufacturers and their suppliers are looking further ahead, trying to figure out what comes next. Nobody is more acutely aware of this than Mark Firth, executive director for product line management and marketing at Cummins Turbo Technologies, the Huddersfield, West Yorkshire-based turbocharger manufacturer that is part of the Cummins Components Group. Firth is generally guarded, as might be expected, when answering any questions about his clients’ development plans (of the 2.4 million turbochargers made last year by Cummins Turbo Technologies more than half went to non-Cummins engines). But he has no qualms about revealing what he was told recently by one, anonymous, engine development chief at a big, unnamed, European engine manufacturer. “His priorities one, two and three are fuel efficiency,” says Firth.

Jonathan Wood, recently returned to Huddersfield from the Cummins Turbo Technologies operation in China to succeed Firth as executive director of engineering, underlines the point. “It’s still about emissions, but now people want the next level, and that means CO₂ emissions,” he says. “You’ve got to do the emissions, that’s a given. But the next step is all about fuel economy.”

So how exactly does a turbocharger developer and manufacturer respond to this? Answers will begin to become apparent at this year’s Hannover show, according to Firth. “Having successfully launched our vgt (variable geometry) product in various markets, Euro 6 has followed on for us from our US 2010 products,” he says. “For us the Euro 6 generation of vgt is the same as we launched in North America at US2010. But what you will start to see at the Hannover show this year from our European customers is a portfolio of technology. You’ll start to see the bespoke nature of our work.”

Jonathan Wood identifies three areas in which the design of familiar Holset variable-geometry turbocharger from Cummins is being tweaked to improve efficiency and thus squeeze a little more fuel economy from the engines on which they are used. Number one is “an inverse impeller design”. Based on research by University College London, this involves reshaping the blades of the compressor wheel on the cool side of the turbo, where air is driven into the engine’s inlet manifold. “Traditionally, blade geometry has been designed to give required flow conditions,” explains Wood. “Using the inverse method the designer specifies the desired flow conditions and the software develops the blade shape using an optimisation process.” The upshot is reckoned to be a one per cent improvement in compressor stage efficiency. What does this mean for truck operators? At today’s fuel prices he calculates that it would translate into a £100 per year saving on fuel bills for a 450hp truck covering around 150,000km annually. Given that the total annual fuel and oil running cost element for a truck of this kind at 44 tonnes gcw currently stands at around the £56,000 mark, according to the latest Commercial Vehicle Engineer truck operating cost tables, this £100 might seem trifling. In fact it is just the kind of incremental gain that truck operators and manufacturers are increasingly eager to exploit to the full. The first application of this new impeller design is a (non-Cummins) engine expected to go on show for the first
time at the Hannover show.

The second item on his improved efficiency list is what is called in turbo engineering jargon "super map width enhancement". The "map" in question here is in effect the operating range of the turbocharger, and the core of the "enhancement" is a sleeve insert in its intake throat. The real significance of this, according to Wood, is that the versatility of a variable-geometry turbo of a given size is extended, allowing higher torque at low speed from the engine on which it is fitted. "It's all about speed to market and doing more with a smaller unit," he says.

The third item on Wood's list of efficiency-improving measures is a switch from plain floating journal bearings to ball bearings on the shaft between the compressor and turbine wheels. Cummins Turbo Technologies engineers have always conceded that ball bearings offer marginally lower drag but hitherto have reckoned that this is more than outweighed by disbenefits in the form of durability, noise and cost. Now they are confident that a switch to "roller element" bearings could deliver a one per cent turbocharger efficiency gain. But Mark Firth goes out of his way to stress that durability and reliability are never going to be sacrificed, pointing to endurance testing of ball-bearings still going on at Huddersfield. "This is even before we have a launch date due," he says. "We want to be sure the product is reliable before we give it to customers. We're designing the turbochargers for 1.5 million kilometres on heavy-duty trucks in Europe. For a million miles in the US. For that we have to do a lot of testing to validate the product."

At a London IMechE conference on turbocharging two years ago it emerged that Cummins work on waste heat recovery was focusing on the Rankine cycle. Now it is clear that this work has been progressing apace at Huddersfield and gone well beyond the theoretical stage, to the point where a working prototype turbine expander is already being evaluated on a diesel engine. Jonathan Wood refuses to identify its manufacturer, naturally, but he is prepared to forecast that the engine could be in production, complete with waste heat recovery expander, between 2016 and 2018.

Meanwhile one of the fundamental questions that needs to be addressed by any engine manufacturer planning to employ such a waste-heat expander is whether its output should be mechanical or electrical power. Wood and his colleagues are happy to let their customers decide either way. The engine-making group already has considerable electrical power generation expertise at its disposal through the Cummins Power Generation division (incorporating Onan). Mechanical power output from the Cummins turbine expander, a prototype example of which will be on display at the Hannover show, is put at 25kW, electrical power at 5kW. In both cases this is enough, according to Wood, to deliver a fuel economy gain of five per cent on a typical heavy-duty truck. Nobody is yet ready to put any likely cost figures on the turbine expander but Wood is confident that it will be capable of paying for itself in fuel savings within two years, assuming an annual fuel bill saving (at current prices) of around £3,250.

Durability and performance testing are naturally crucial elements in Cummins plans to bring the waste heat turbine expander to market. But this is easier said than done. Despite the obvious mechanical parallels between this product and conventional turbochargers, using established turbocharger test cells is not feasible. Ed Halliwell, the engineer in charge of a newly-built turbine expander test rig at Huddersfield (built at a cost of around £1.4 million, including a £650,000 regional growth grant from the government) explains why. "The turbine expander's organic working fluids have thermophysical properties that are substantially different from those of our normal test fluids (air and exhaust gas)," he says. "These differences make it virtually impossible to operate the turbine expander anywhere close to its intended thermodynamic design point if tested on a conventional turbocharger test stand."

The new test rig at Huddersfield, in operation since early this year, is believed to be the first of its kind anywhere. Its main function, according to Halliwell, is to "extract performance data from the turbine expander by controlling the turbine expansion ratio, turbine inlet temperature and shaft speed to predetermined points while logging data, just like a conventional turbine mapping cell for a turbocharger."

But the key difference here is that the organic fluid cannot be vented to atmosphere. So "all the energy transferred to the working fluid to power the expander must be rejected from the working fluid before the end of the cycle."

You can expect to be hearing a lot more about waste heat recovery from truck and bus diesel engines in future. And expect Cummins Turbo Technologies engineers to be in the thick of it.
Mercedes promises better fuel efficiency

Fears that engines inevitably will be less fuel efficient at Euro 6 than at Euro 5 are beginning to subside. Mercedes, first off the Euro 6 blocks, is promising better fuel efficiency with its all-new OM 471, OM 470 and OM 934/936 engines. Road tests of the sleek new Mercedes Actros tractive unit seem to substantiate this, but exactly how much improved fuel economy is attributable to better aerodynamic efficiency remains open to question.

The three latest Mercedes Euro 6 power units were unveiled in March. The OM 470 is a smaller (10.7-litre), lighter version of the 12.8-litre OM471. As lighter, lower-power versions of the new Actros truck range are introduced, replacing the current Axor range, so the OM 470 will be phased in to replace the Axor’s Brazilian-built 11.97-litre OM457 straight-six engine. Maximum power outputs of the OM 470 go from 240kW to 315kW (322hp to 422hp).

The OM 934 and OM 936 are four- and six-cylinder replacements respectively for the long-serving OM 924 and OM 926, as used in the Mercedes Atego medium- and lightweight truck ranges and sold to other vehicle manufacturers such as Optare for use in Tempo and Solo midibuses. The four-cylinder OM 934 has a swept volume of 5.1 litres (compared with 4.25 litres for the current 900-series four-cylinder). This translates into a swept volume of 7.7 litres for the six-cylinder OM 936 (compared with 6.37 litres for the current six-cylinder 900-series).

Speculation that the 934/936 engines would turn out to be extensively revised versions of the current 900-series has proved to be ill-founded. Daimler Trucks’ head of truck product engineering Georg Weiberg stresses that both the latest 900-series range (abbreviated to OM 9x in Daimler-speak) and the OM 470 share virtually nothing with the engines they are set gradually to replace, initially in Europe, though he describes the OM 470 as “having the same dna as the OM 471.”

The OM 470 is the second example, after the OM 471, of Daimler’s all-new hdep (heavy duty engine platform) design going into production globally, points out Stefan Buchner, head of global powertrain, procurement and manufacturing engineering at Daimler Trucks. Like the OM 471, the OM 470 will be assembled at plants in Detroit (US), Kawasaki (Japan), Sao Bernardo (Brazil), and Cape Town (South Africa) as well as at the main Mercedes engine plant at Mannheim, Germany. Low weight, compact dimensions and excellent fuel economy are expected to be key selling points of this 10.7-litre unit. A dry weight (to Germany’s DIN 70020-A standard) of 990kg is claimed to make it “the lightest Euro-6 engine in its class.”

Euro-5 versions are also planned, though it is unclear when they will go into production and exactly where they will be available. Like-for-like, the OM 470 is reckoned to weigh about 60kg less than the current Axor truck engine.

Mercedes promises better fuel efficiency

For any truck or bus operator wanting to compare and contrast the latest in Euro 6 driveline technology, this year’s IAA show is the place to be.

Tim Blakemore explains why. 
For truck operators in particular, fuel economy is a crucial factor at Euro 6. The main fear is that cutting exhaust emissions, especially oxides of nitrogen (NOx), to meet the tough new limits will inevitably bring a fuel economy penalty. Weiberg is adamant that the OM 470 and OM 93x alike have “the ideal combination” in the form of high-pressure common-rail fuel injection systems, cooled exhaust gas recirculation (cEGR) and selective catalytic reduction (cSCR) exhaust after-treatment. The specific full-load fuel consumption of these engines (measured in grams per kilowatt hour) is 3-4 per cent lower than that of the Euro 5 engines they will replace, insists Weiberg, pointing to lower frictional losses and highly-sophisticated management of the combustion process by the on-board electronic control unit (cECU).

Like its big brother, the 12.8-litre OM 471, the OM 470 is equipped with a common-rail injection system dubbed X-Pulse. This is Daimler’s version of the Bosch “amplified common-rail system” (cACRS) which depends on hydraulic “amplifiers” in the injectors to lift injection pressure from the 900bar generated originally in the common rail. Maximum fuel injection pressure injection on the OM 470 is 2,100 bar. It is rather higher, 2,400 bar, on OM 93x engines. They use a more straightforward, single-stage common-rail system.

One technical novelty of the OM 934 and OM 936, claimed to be world-first in diesel engines, is a variable valve timing system capable of advancing exhaust valve opening by up to 65 degrees. All these new Mercedes engines have twin overhead camshafts, like the OM 471. The exhaust valve timing on OM93x engines is varied hydraulically, by means of a vane piston on the gear-driven end of the camshaft. Engine oil is directed into this piston under the control of signals from the engine’s electronic control unit. The purpose of this system (called “variable camshaft phaser” by Daimler) is not to modify engine performance in any way but simply to provide a means of delivering the hot exhaust gases needed for regeneration of the diesel particulate filter (cDPF). Recognising that these engines are frequently likely to be used on urban work in trucks and buses where exhaust temperature is never high enough for cDPF regeneration, Mercedes engineers decided that variable valve timing offered the solution they sought. Exhaust valves are made to open and close early to provide the blast of hot gases needed to burn off accumulated particulate matter in the downstream filter.

There is already a horizontal version (for coaches and buses) of the OM 936 but no horizontal version of the OM 470 is planned. One manufacturing innovation on all new Euro 6 Mercedes engines is what is described as aircraft industry style “matrix coding” of around 70 per cent of all parts, allowing each part to be traced individually throughout its life.

Flat out: horizontal version of the 7.7-litre OM 936.
**MAN makes its mark**

Despite seeming far less keen thus far than arch-rival Mercedes to shout about Euro 6 technology, MAN is promising to have plenty on show at Hannover. MAN engineers seem to have settled, as expected, for a combination of SCR, EGR and DPF, but usually favouring two-stage turbocharging over the variable-geometry variety. Bus operators will be keen to hear how MAN has managed to fit in all the extra exhaust after-treatment without sacrificing any city-bus seats. Truck operators visiting the MAN stand at Hannover may be more interested to learn more about an all-new 15.2-litre in-line six set to be unveiled there, with maximum power ratings said to start around the 500hp mark.

**Daf’s elegant Euro 6 MX**

Daf Trucks continues to play Euro 6 cards close to its chest, at least so far as the Leyland-built lightweight and middleweight (LF and CF) ranges are concerned. It is widely assumed that Daf will stick with Cummins power units for these truck ranges, gradually switching to the latest Euro 6 versions of the four-cylinder ISB4.5 and six-cylinder ISB6.7 (page 6) but this has not yet been confirmed. Cummins always politely and tactfully declines to answer any question on the future product development plans of any client, including Daf’s parent group Paccar.

But Paccar itself is less coy about the latest development of the 12.9-litre MX engine powering Daf XF and CF trucks in Europe as well as Kenworth and Peterbilt trucks in North America. In April it was confirmed that a Euro 6 version of this engine has been developed and will go into production early next year, with maximum power ratings initially at 410, 460 and 510hp.

“Achieving the ultra-low Euro 6 emission values requires additional technology, and our aim is of course to keep fuel consumption and CO2 emissions at the low levels of our current Euro 5 ATe vehicles”, says Ron Borsboom, Daf Trucks product development director. “We have done everything to get the very best out of the technology. Daf never aimed to be the first to introduce Euro 6. It was more important for us to use the time available to come up with the best solutions. Obviously, the introduction of new and additional Euro 6 technologies will have consequences for our vehicles. We will be revealing these at the IAA in Hannover. You can be sure that Daf will come up with something beautiful.”

It may not exactly qualify as beautiful, but one innovation on the Euro 6 MX Daf engine is certainly elegant and possibly unique. The Delphi electronic unit pump (eup) fuel injection system used on both Euro 5 and EPA 2010 variants of the MX engine has been converted to a common-rail system, using two high-pressure pumps integrated into the engine block and driven by the same camshaft that actuates the inlet and exhaust valves. Some fuel injection pipework is cast into the cylinder block and head. What is described as a “smart dosing” control of the common-rail fuel pressure minimises hydraulic losses and squeezes some extra efficiency out of the engine by pressurising only the volume of fuel needed at any given point on the engine’s load/speed operating map. The common-rail system’s fuel injection pressure can be up to 2,500 bar and can employ pre- and post-injection “events” in its search for the best possible trade-off between exhaust emissions and fuel economy.

“The highly advanced engine software and new sensors and actuators also play an important role in this respect, functioning even faster and more accurately to ensure that the best possible mixture of air, exhaust gases and fuel is injected at all times,” says Borsboom.

There have been reports that the Euro 6 Paccar MX engine is based on a US design, modified for European use. Those reports are fundamentally wrong. In fact the 12.9-litre MX started life as a Daf engine, based on an 11.6-litre in-line six which had served Daf well for long before the Paccar takeover of 1996 and the origins of which can be traced back to a Leyland engine. What Paccar has shrewdly done with the Euro 6 MX is make good use of experience gained in the US since the introduction of the EPA (Environmental Protection Agency) 2010 limits, which broadly parallel Euro 6 limits.

“This engine complies with current North American legislation, with emission values close to those set out in Euro 6,” says Borsboom. “We have therefore been able to build up vast experience of technologies we will now be applying in Europe for Euro 6, such as exhaust gas recirculation (EGR), a turbocharger with variable geometry, and an active soot filter. We have further developed these technologies, focusing in particular on how we can best integrate them into European vehicle concepts. A good example is the higher position of the EGR cooler, which allowed us to place the turbo closer to the block, further reducing the overall size of the engine. This is an important factor when it comes to fitting the engine in our European cab-over-engine vehicle designs; it allows for a low cab floor to ensure ease of entry and maximum cab space. In addition, we will of course also be applying technologies to the Euro 6 Paccar MX 13 engine that have recently been introduced as part of our ATe programme for Euro 5. An encapsulated exhaust manifold for even better turbo efficiency and optimised piston rings and cooling are just a few examples of these technologies.”

Volvo changes tune

“We want to be sure that customers have a reason to buy them before we launch Euro 6 engines,” So said a Volvo Trucks spokesperson about six months ago when asked about his company’s Euro 6 plans. Now those plans are becoming clearer, following the unveiling in July of the first Euro 6 Volvo truck engine. It is a 460hp version of the familiar inline six cylinder D13, making the move from Euro 5 to Euro 6 courtesy of the addition of exhaust gas recirculation (egr) and a diesel particulate filter (dpf) to the selective catalytic reduction (scr) exhaust after-treatment system which has been used on Volvo truck and bus engines for some time.

“The Volvo FH gets a new 460hp Euro-6 engine optimised for fast, fuel-efficient transportation on good roads, and the first trucks with the new engine will be delivered in spring 2013,” says Mats Franzén, Volvo Trucks’ engine strategy and planning manager. “It is currently difficult to determine how much demand there will be, but by offering our most popular engine in a Euro 6 configuration we meet the needs of a large proportion of our customers. The rest of the Euro 6 engine range will be launched well before the requirements become obligatory on 1 January 2014.”

It is an open secret that a replacement for the FH truck range is waiting in the wings, ready to go on show for the first time at Hanover. This new truck design, including Euro 6 engines, is sure to find its way into the Volvo group’s other truck-making division, Renault Trucks, as well. The ageing Renault Magnum’s days are now well and truly numbered, it seems.

One eye-catching innovation on the FH replacement has been revealed already, by a media-savvy Volvo marketing department keen to make the truck stand out from the Hannover crowd. An independent front suspension system, believed to be the first of its kind for a longhaul tractive unit like this, will “revolutionise handling in the truck world,” according to Volvo Trucks product manager Martin Palming. More details of the suspension, including exactly how much it owes to similar systems long used on Volvo buses and coaches, will be revealed at the Hannover show. Meanwhile it is already clear that it will be confined initially to left-hand-drive trucks.

“The Volvo FH without ifs will be number one on the market, but ifs is all set to revolutionise handling in the truck world,” boasts Palming.

Volvo’s 460hp D13 at Euro 6: ready for delivery next spring.

Four per cent cut in operating costs?

Iveco, the Fiat group’s commercial vehicles arm and part of its recently spun-off Fiat Industrial division, is promising that the latest updates to its Stralis heavy truck range, including the option of Euro 6 engines, will cut total operating costs by “up to four per cent for the ten most common vehicle missions.” The latest Stralis range, called Hi-Way, goes on show for the first time in Hannover.

“The current economic situation is among the most critical our vehicle” Tector engines at present is 2,700rpm, this is 2,500rpm at the lower end of the power spectrum. Increased bore and stroke means that the current 10.3-litre Cursor 8 are increased, giving the new Cursor 9 engine a swept volume of 8.7 litres. Three nominal power ratings (310, 330 and 360hp) are carried over from Cursor 8 to Cursor 9 but are joined by a 400hp,1,700Nm version. Rated speed has been cut from 2,400 to 2,200rpm. Strangely, only the 360hp engine gets more torque, up from 1,500Nm to 1,650Nm.

Increased bore and stroke means that the current 10.3-litre Cursor 10 becomes the 11.1-litre Cursor 11 at Euro-6. Two current power ratings, 420 and 450hp, are replaced by three: 420, 460 and 480hp. Rated speed is cut from 2,100 to 1,900rpm.

The Cursor 13’s swept volume, 12.9 litres, is unchanged at Euro 6, as are its two top power ratings: 500 and 560hp. But two new ratings, 410 and 450hp, are introduced as the 480hp version is dropped. So the Euro 6 Cursor 13 range overlaps the Cursor 11 at the lower end of the power spectrum.

The Bosch unit injectors used hitherto on all Cursor engines are replaced at Euro 6 by the latest Bosch common-rail fuel injection system, boasting nozzle injection pressures up to 2,200 bar. High injection pressures aid fuel atomisation, cleaner combustion and hence lower particulate emissions.

Iveco Stralis Hi-Way: on show for the first time in Hannover.
Caution and trepidation. These would seem to be the watchwords of many UK bus operating engineers in their approach to Euro 6 exhaust emissions legislation. Tales of price rises around £10,000 per chassis, of increased vehicle weight and poorer fuel economy are prompting some operators to stock up on Euro 5 vehicles while they can, with a view to taking a purchasing holiday until the inevitable can be put off no longer. Some engineers remain concerned that still too little is known about the detail of chassis manufacturer Euro 6 plans. They cite this as a reason for looking to Euro 5 buses and coaches, and for delaying vehicle investment plans.

Others worry about the durability of Euro 6 technology, about rumoured requirements for more frequent servicing, and about the risk of precious passenger space being pinched by the latest exhaust after-treatment equipment.

The consensus among engineers in Britain’s biggest bus operating groups would seem to amount to pragmatic recognition.
of the inevitability of Euro 6 legislation and the need therefore to learn as much as possible about its implications.

The lion’s share of Britain’s “big bus” market (above 8.5 tonnes gvw, broadly) is taken by three chassis manufacturers: Alexander Dennis (ADL), Scania and Volvo, though MAN, Mercedes-Benz, Optare and VDL Bus are also in the picture. MAN, Mercedes-Benz, Scania and Volvo use their own engines, whereas ADL and VDL fit Cummins engines. Optare customers can choose from Cummins, MAN and Mercedes-Benz power units.

Britain’s three biggest bus-operating groups, Arriva, First and Stagecoach, collectively run around 22,000 buses. This trio routinely accounts for more than two-thirds of all new bus registrations annually.

Around 8,000 buses and coaches are operated in Britain by Stagecoach, where the expertise of group technical engineer Adrian Havlin is by no means confined to passenger-carrying vehicles. He worked at Leyland Trucks, the Paccar group’s Lancashire-based truck-making subsidiary, before joining Stagecoach.

Compared with trucks, the age range of vehicles in a bus and coach fleet is extremely wide, stresses Havlin. Stagecoach is not unusual in still having pre-Euro-1 engines as well as examples of all Euro-standard engines from 1 to 5 in its UK fleet.

The introduction on some Euro 4 bus engines of selective catalytic reduction (scr) exhaust after-treatment and the AdBlue on which 4 depends presented particular challenges for Stagecoach, recalls Havlin, not least because AdBlue tanks were at first installed at only a small number of depots. This limited the potential for vehicles to be transferred easily from one depot to another. “That is not an issue now,” says Havlin. “We know how many new buses we’ll need over the next few years, and while we might take a late batch of Euro 5 buses we know we are only delaying the inevitable. At the moment we buy from a limited number of chassis-builders so we can adopt a structured approach to Euro 6. We have been talking to our suppliers and recognise that we need to work closely with them to overcome the perceived negative aspects of Euro 6.

“It seems likely that a chassis could cost £7,000-£10,000 more than its Euro 5 equivalent, and that there will be weight and fuel consumption penalties. But it’s early days. Mercedes-Benz, we'll need over the next few years, and while we might take a late batch of Euro 5 buses we know we are only delaying the inevitable.

The first phase of the Euro 6 legislation, applying to newly-type-approved vehicles, comes into force on 1 January 2013. All new trucks and buses will have to meet Euro 6 limits from 1 January 2014. Stagecoach surely must be planning its 2013/14 fleet investment already? “We have done as much as we can at this stage,” says Havlin. “We have talked to all the manufacturers, and had presentations from suppliers, because we want everyone to know what’s coming. So there should be no surprises and everybody should understand the challenges. And the trial double-decker will not only help the manufacturers understand how Euro 6 buses work in daily service, but will also allow us to know that all processes and protocols are right for Stagecoach.”

Havlin expects refinements to onboard diagnostic systems to follow on from the Euro 6 limits, and he is taking a keen interest in particular in development of sensors for measuring AdBlue quality.

Electric motors in place of diesel engines would seem to be the next logical step towards zero-emission buses, suggests Havlin, pointing out that Stagecoach is already among the UK operators pioneering both hybrid (diesel/electric) buses and bio-fuels in the quest to cut carbon dioxide emissions.

Stagecoach of course is not alone in its determined pursuit of low-carbon goals.
Several London-based operators have been leading the way in the UK with diesel/electric hybrid drivelines. Now the number of hybrids nationally is growing year-on-year, encouraged by the government’s Green Bus Fund.

Lothian Buses of Edinburgh put 15 ADL Enviro400H hybrid double-deckers into service in 2011. They are expected to cut this company’s carbon dioxide emissions by over 600 tonnes a year. Initially it was claimed that the buses should use at least 30 per cent less fuel than the diesel-only vehicles they replaced. Lothian now reports that this figure is easily being bettered day after day. There is growing interest too in battery-only electric buses. Three Optare Versa EV (electric vehicles) delivered in June to Travel De Courcey, a Coventry, West Midlands-based operator, are claimed to be the biggest battery-powered buses on Britain’s roads to date. They are working on a Coventry park-and-ride service. Each of these 11.1-metre Versas can carry 50 passengers, including 34 seated. They also boast fast-charging technology in the shape of an ABB Terra 51 fast-charging station, allowing a battery pack to be charged in less than two hours rather than the usual six or eight.

This means that batteries can be charged during the day as well as overnight, opening up the potential for the daily range of each bus to be doubled. Range on a single charge is said to be between 75 and 95 miles. “This is a really exciting breakthrough in the development of electric buses in the UK bus industry, which we have been pioneering at Optare for the past three years,” says Optare chief operating officer Glenn Saint. “A limiting factor in the introduction of electric buses in Britain has been the time it takes to recharge an electric battery. With the fast-charger a bus can be easily charged during a lunchtime layover or at other quiet periods in its schedule. In the Coventry park-and-ride operation, charge stations have been installed at both ends of the route to allow opportunity charging throughout the working day without the buses having to return to base.”

Sent to Coventry: these Optare Versas, operated by Travel De Courcey, are the biggest battery-powered buses on Britain’s roads.

Stagecoach: one of Britain’s three biggest public transport operators with around 8,000 buses and coaches.

The substantial cost of this ev project has been shared between Travel De Courcey (£400,000), the government’s Green Bus Fund (£300,000), and Centro, better known as West Midlands Integrated Transport Authority (£100,000). The bill (unspecified) for the fast-charging equipment has been picked up by Coventry City Council.

Arriva is one of several big bus operators in the UK showing increasing interest in gas engines. An order for 21 MAN EcoCity buses capable of running on compressed natural gas (cng) or biogas has been placed by Arriva. These buses will be operating in north-west and north-eastern England. The 12-metre, 40-seat EcoCity is powered by MAN’s 272hp E2876 gas engine.

Bus operator concern about rising kerb weights is nothing new. The trend seems to have been unstoppable as bus bodies have become more and more sophisticated and exhaust emission limits have become ever more stringent.

Now the impending introduction of Euro 6 engines and their hefty exhaust after-treatment kit appears to be encouraging fresh weight-saving innovation from bodymakers. One notable recent development is the introduction of several lightweight single-deckers offering an attractive alternative to the heavyweights still favoured for the most demanding routes. ADL has the Enviro300, VDL and Wrightbus the Pulsar, Optare the Tempo SR, and now Wrightbus has unveiled the StreetLite Max, powered by a four-cylinder Cummins engine driving through a Voith four-speed automatic gearbox.

Like their bus-operating counterparts, Britain’s coach operators are concerned about the cost, weight, fuel economy and maintenance implications of Euro 6. But the average age of coach fleets generally is much lower than that of buses. Operators tend to replace coaches more often, if only to keep up with competitors. Now there are signs of fleets beginning to hold back on normal vehicle-replacement plans until more information on Euro 6 engines and vehicles is available.

Mick Forbes is engineering director at the Shearings group, one of Britain’s biggest coach tour operators. The Shearings fleet of 265 coaches, mainly Mercedes-Benz Setras, operates year-round, throughout the UK and continental Europe.

“Shearings welcomes any initiatives that aim to improve sustainability and lower fuel emissions,” says Forbes. “We pride ourselves on having one of the greenest fleets on the road. Over the past three years, the Shearings group has made significant investment in its fleet, upgrading to newer, more fuel-efficient vehicles. We have purchased 135 Euro 5 Setra vehicles which have replaced our Euro 2 and many Euro 3 coaches.”

So will Shearings be looking at Euro 6 coaches soon? “We have a seven-year replacement policy, and we are unlikely to be purchasing any new vehicles until 2014 at the earliest, when we will replace our oldest vehicles with Euro 6 models,” says Forbes.

Punching above its weight: a growing number of operators are favouring lightweight single-deckers like this VDL/Wrightbus Cadet, operated by Arriva in Liverpool.
aftercooling - sometimes called intercooling or charge-cooling. A process for cooling an engine's inlet air between turbocharger and combustion chambers, mainly to make the air more dense and to lower thermal load.

articulated piston - two-piece piston with separate skirt and crown. Crown is often iron while the skirt is aluminium.


BMEP - brake mean effective pressure. “Brake” in this context means actual, as measured at the flywheel on a dynamometer. An engine’s BMEP is the work done in one cycle divided by swept volume.

BSFC - brake specific fuel consumption. Fuel consumption measured by mass relative to power output over a given time: grams per kilowatt hour (g/kWh).

CARB - California Air Resources Board. Body set up in California in 1967 to regulate the state’s air quality. Often at the cutting edge of vehicle exhaust emission legislation.

carcinogen - cancer-causing substance.

catalyst - something that affects chemical reaction speed though not one of the original reactants or end-products. Catalysts in exhausts promote chemical reactions to change exhaust emissions.

cloud point (CP) - a measure of diesel fuel performance at low temperature. The temperature at which wax first becomes visible in a standard test.

cold filter plugging point (CFPP) - another measure of diesel fuel performance in the cold. This is the lowest temperature at which a set volume of fuel will pass through a fine wire-mesh filter.

cordierite - a ceramic material used for catalyst substrates and in diesel particulate filters (DPF).

DfT - British government’s Department for Transport.

ECM - electronic control module. Small on-board computer for controlling fuel injection equipment.

ESC - European steady-state emissions test cycle (page 4).

EV - electric vehicle.

flash point - the temperature at which a fuel’s vapour will ignite.

genset - a power-generating set comprising an internal combustion engine driving an electrical generator.

HEUI - hydraulic/electronic unit injector. Introduced first by Caterpillar in 1993. Engine oil pressure instead of the camshaft is used to actuate unit injectors.

IDI - indirect injection. Diesel engine design employing a pre-chamber into which fuel is injected to be mixed with air before passing through a narrow passage into the combustion chamber. Largely now superseded by more efficient direct injection (DI).

LEV - low-emission vehicle. Originally one certified as meeting California Air Resources Board (CARB) emission limits.

LEZ - low-emission zone. Areas or roads where vehicles failing to meet set emission limits are restricted and/or penalised. London’s LEZ is well known but there are now many more throughout Europe and the number continues to grow. Sometimes called environment zones, umweltzonen, or milieuzones.

petroleum - more than just the fuel called petrol in the UK (gasoline in the US). A mixture of hydrocarbons and liquid organic compounds. From the Latin petra (rock) and oleum (oil).

unit injector - diesel injector incorporating both an injection nozzle and a plunger-type pump, usually actuated mechanically by means of a rocker and pushrod driven by an additional cam on the engine’s camshaft.

VCA - British Department for Transport’s Vehicle Certification Agency. Responsibilities include European type approval in the UK.

VDA - Verband der Automobilindustrie, German motor industry association.

VOC - volatile organic compound. Organic chemicals with high vapour pressure. Some are dangerous and some harm the environment. One carcinogenic VOC is benzene.

VOSA - Vehicle and Operator Services Agency. An “executive agency” of the UK Department for Transport. Responsibilities include vehicle testing and enforcement of roadworthiness standards, including compliance with Euro 6 requirements on vehicle emissions.

WHTC - world harmonised transient emissions test cycle (page 4).
We’ll fit in with your plans

Greener engines, perfectly adapted to meet your needs.

Over 90 years of engineering expertise is invested in our Euro 6 engine program. We are committed to designing class leading engines that will deliver benefits for you and your customers. We believe that strong customer partnerships drive mutual success, with our engineers working as part of your team to provide the best possible bus and coach installations. Backed by the widest experience in engine technologies such as SCR and DPF, Cummins is the natural choice for Euro 6. Contact us on enquiries.engines@cummins.com for more information.