NEXT generation engines

Just when you thought it might be safe to forget heavy-duty engine emissions regulations, Brussels starts getting serious about 'Euro 7' – and not just for CO_2 reduction. Brian Tinham reports

Euro 6 heavy-duty diesel engine regulations have been done and dusted for more than two years now. You can't buy new trucks for operation in the EU with anything less. So why worry? Well, yes, but Euro 6 is still not quite over and a move to 'Euro 7' (strictly speaking Euro VII) also looks increasing likely. What's more, although pundits expect Euro 7 to focus on CO_2 instead of pollutants (good news, given its correlation with fuel consumption), the truth may well be different.

The point: trucks we acquire, drive, inspect and maintain today may soon be subject to yet more change. And some of that is almost bound to impact our decision making, in terms of engine and drivetrain specification and vehicle R&M, but also probably supplier and possibly even vehicle configuration.

First things first, and the Euro 6 emissions saga is now in its final stage of implementation under regulations 595/2009 and 133.2014, plus technical document 582.2011. How so? Because early limitations with onboard sensors (urea quality and particulates) led legislators and OEMs to agree on a phased introduction. That started with Euro 6 'a', which then moved to 'b'. Euro 6 'c' lands on 1 January 2017.

It's not that Euro 6's already stringent limits for NOx, particulates, etc, are being revisited. Those were set ahead of the 1 January 2014 deadline for new vehicles above 3.5 tonnes. The phasing does not impact type approval testing either – which, incidentally, moved from the European transient cycle (ETC) to the more realistic world harmonised test cycle (WHTC) as Euro 6 came in. And the annual witnessed emissions compliance checks that truck OEMs are required to perform on random in-service vehicles are also not affected.

What changes under Euro 6 'c' concerns the engines' OBD (onboard diagnostics – often referred to as the onboard policeman), which monitor all trucks' emissions for seven years or 700,000km (six years, 300,000km for N2 and N3 vehicles up to 16 tonnes and M3 Class I, II, A and B up to 7.5 tonnes). First, OBD NOx and particulates tolerances – before the system triggers torque de-rating – are tightened. Second, additional sensors, including urea quality devices, will be mandated to improve system efficiency and OBD sensitivity. And third, anti-tampering systems must be beefed up.

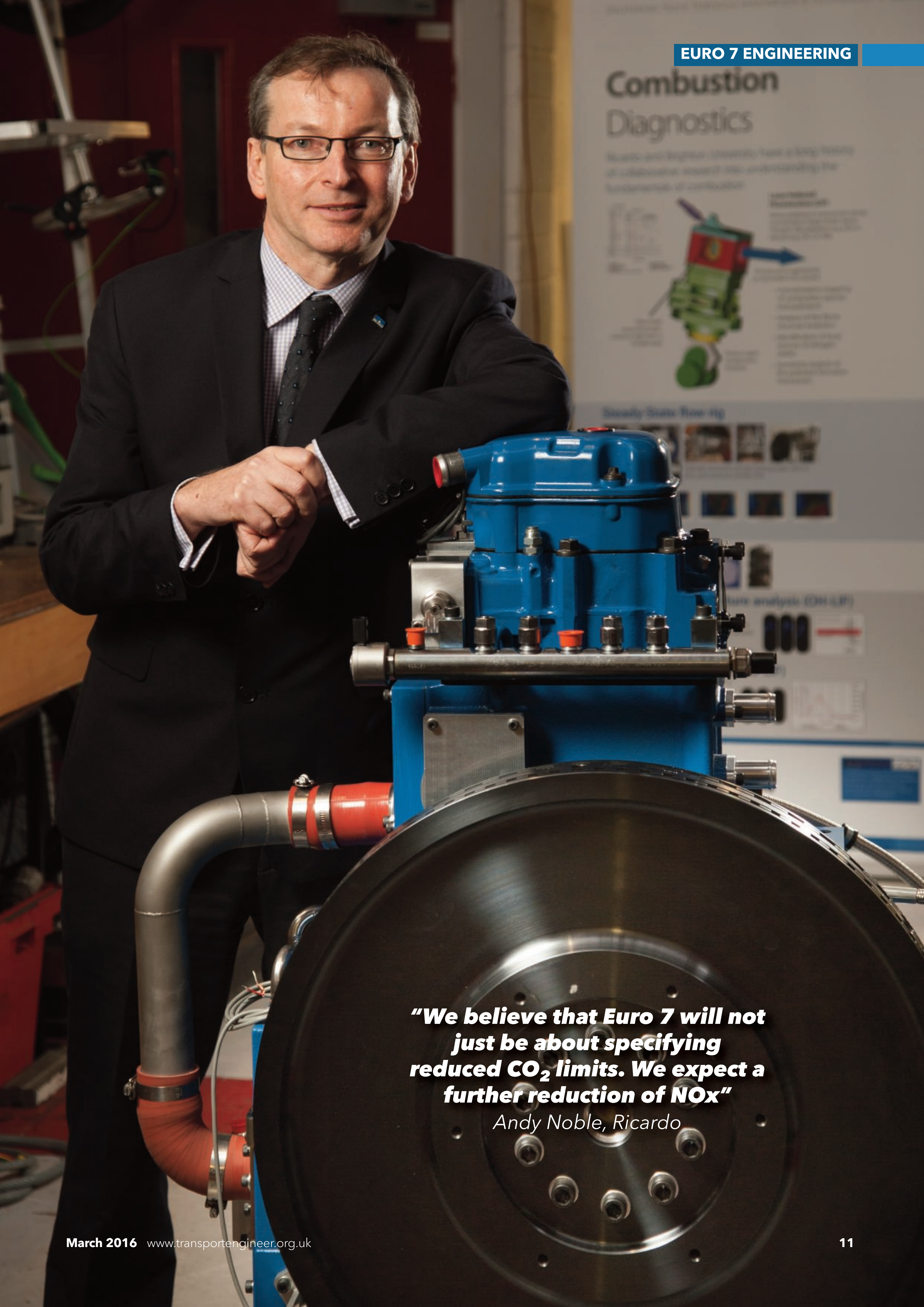
Reassuringly, given that this phasing was enshrined in law, you're looking at a progression of which the truck and engine manufacturers should be fully aware. But what about Euro 7? Well, no one knows, so we move into what Andy Noble, head of heavy-duty engines at internationally renowned Ricardo, refers to as "informed speculation" territory.

And the first shock: "We believe that Euro 7 will not just be about specifying reduced CO_2 limits," he asserts. "We expect to see a further reduction of total oxides of nitrogen [NOx] – probably to half that of Euro 6, so 23mg/kWhr on the WHTC. We also believe there will be a specific limit on NO_2, maybe 110mg/kWhr, because of its particular implications for human health."

POLLUTANT FOCUS

Perhaps we shouldn't be surprised, given that Euro 6 is not as stringent on NOx as the latest US EPA emissions limits. It's even further behind California's voluntary standard (7% of Euro 6, 0.02gm/bhphr). And note: this latter may well become mandatory for trucks anywhere in that US state after 2020. However, OEMs anticipating an era of engineering free from further mandated pollutant reductions may be dismayed.

But there's more. Noble believes that soot particle size (for Particle Number regulation) may also be impacted, possibly moving the current 23nm minimum recognised diameter down to 10nm, "which is only just about



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>
> *Andy Noble, Ricardo*

measurable". And that will be for all engine types and all fuels, not just heavy-duty diesel.

If he's right, the implications for aftertreatment design would include finer DPF (diesel particulate filter) materials. However, these could impact engine back-pressure, in turn causing CO_2 emissions and fuel consumption to rise – the polar opposite of our supposed primary Euro 7 goal. Noble points to gas engine trucks that could meet the requirements, but suggests that for diesel you're into new research. Not surprising given the general trade-off between NOx and CO_2. "We think it's achievable, but at what cost?"

Now the main event: CO_2. And although Noble concedes that no standards have yet emerged from Brussels, he believes we won't have to wait long. "We were expecting figures by the close of last year," he states.

GREAT EXPECTATIONS

What might we expect? Well, if Europe follows the US, which last year published CO_2 reduction targets all the way out to 2028, here's the deal. "The US is going for a 24% reduction in CO_2 emissions from large trucks, of which about 4% must come from the engine," reports Noble. Aerodynamics, telematics, lightweighting, driver training, intelligent AMTs (automated manual transmissions), etc, would be expected to deliver the rest.

The skewed focus away from engine development makes sense, given the huge impact that each of the latter interventions – particularly driver training and monitoring – can make. Indeed, many argue that Driver CPC should include a mandatory fuel-efficient driving module. However, assuming Europe follows suit, non-engine OEMs might be forgiven for wondering why tougher demands weren't on the table. But as Noble explains: "That corresponds to about 48% thermal efficiency for the engine itself, compared to today's best Euro 6 heavy-duty diesels at 45–46%." That isn't trivial.

So, how might such improvements be achieved? Noble points to the multi-consortia, part EC-funded, four-year CORE (CO2 Reduction) project, due to report as we go to press. This has been examining down-speeding, friction reduction, and exhaust aftertreatment and boosting strategies, the latter with approaches such as VVA (variable valve actuation), as per the Miller cycle.

CORE DEVELOPMENTS

Importantly, CORE's goal was ambitious – a 15% overall fuel/CO2 reduction against 2009 Euro 5 diesels. And Noble reports that its combination of technologies is up to that challenge.

Looking at the detail, he first says that down-speeding has proved effective, although at the expense of some drivetrain and engine redesign. The former (obviously) entails moving to a longer axle ratio, while for the latter it's about delivering a higher torque for any given engine power.

Noble says a Daimler OM936 medium-duty 350bhp 7.7-litre engine was subject to 18% down-speeding (by 400 rpm to 1,800 rpm). Peak torque had to be increased from 1,400 to 1,700Nm, but the net result was a 2% fuel improvement for a simulated mix of regional and long-distance driving.

Hard work for that gain? Not so, insists Noble, explaining that it was achieved mostly through engine recalibration and rematched turbo boosting – although he concedes this was just for the demo engine. "For a production engine, manufacturers would also have to redesign the cylinder head and crank train to withstand the higher cylinder pressures and vibration. They would also have to work on driveability, given the narrower peak torque window, by, for example, reviewing the auto transmission shift strategy and/or considering hybridisation – adding an electric machine to give the powertrain more torque."

Hybridisation wouldn't be cheap, he admits, but it would minimise other, more costly and fundamental engine modifications. Additionally, short-medium haul [not long-haul] 40-tonne trucks might no longer need 12–13 litre engines. More modest 7–8 litre alternatives would suffice, continuing the OEMs' trend towards downsizing, and offering users the dual benefits of capital and operational cost savings.

What about reducing engine friction? Beyond using low viscosity engine and transmission oils, CORE focused on the ring pack and piston skirt (as have several manufacturers), using low-friction coatings – not the liner, although a refined honing profile could also be considered. “Ricardo carried out this project and we recorded a fuel performance improvement of about 1%,” says Noble. And he adds that not only is this relatively easy to achieve, but it works across all duty cycles and operating conditions. In short, it’s a gift that keeps on giving.

UBER SCR

Moving on to aftertreatment, the approach is to increase NOx conversion from the SCR (selective catalytic reduction) pack, leaving the engine free to be recalibrated for higher NOx-out. That, in turn, leads to better fuel economy, largely by reducing or even eliminating EGR (exhaust gas recirculation), which also eases off back-pressure. Noble reports fuel/CO2 improvements in the range 1–2%.

Think of this as an evolution of Fiat Powertrain’s (FPT–Iveco) industry-leading high-efficiency SCR. Likely approaches would include reviewing the precious metal substrate formulation and the distribution of exhaust gas flowing through the catalyst. However, improving on real-time ammonia slip sensing systems might also allow driving of the aftertreatment pack closer to optimum efficiency.

Either way, reducing EGR in favour of SCR is in line with current design trends, driven by the desire to cut weight and complexity, as well as some recorded issues with DPF regeneration on suburban cycles. One caveat, though: cooled EGR can be a useful tool when used in concert with advanced injection timing, so expect some debate.

As for boosting, CORE has demonstrated that a revisited two-stage turbocharging strategy, as per MAN’s early work, in combination with sophisticated VVA to give Miller cycle operation, offers another way forward. Volvo and Honeywell have been driving this project, and Noble reports “worthwhile improvements” – although weight, packaging and cost are obvious challenges. However, adding in hybridisation, he says, could deliver an impressive 15% improvement.

Other potential CO_2-busting techniques beyond CORE’s remit include decoupling of the engine auxiliaries, and KERS (kinetic energy recovery systems), as per Torotrak’s widely reported ultra high-speed flywheel system. And there are also: higher fuel injection and cylinder pressures; redesigned combustion chamber profiles; and ultimately waste heat recovery.

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Touching on the former, Noble agrees that variable speed control of – for example, oil and water pumps to match actual operating conditions – makes a clear contribution through reduced parasitic losses. Longer term, that’s best achieved through electrification but, for now, electronic clutch control of belt pulleys is already being offered by some manufacturers, and there are sub 1% CO_2/fuel returns.

On injection pressures, some manufacturers already offer up to 2,700bar and that is expected to rise further – although there must be a limit, given the energy losses from pumping pressure. But atomising fuel and offering multiple injections for a better burn is one thing: engine power itself increases as peak cylinder pressures rise. “That’s why future heavy-duty 12–13 litre engines are now being designed for 250bar peak,” says Noble. “Ricardo’s research is based on fuel injectors running up to 3,400bar and cylinder pressures to 300bar.”

What about combustion chamber design? Noble points to Ricardo’s earlier work on its patented TVCS (twin vortex combustion system). “That offered very clean and efficient combustion, but we’re now running a research programme on a single-cylinder engine at the University of Brighton looking for even greater efficiencies. Whether that will lead to an evolution of TVCS or something more revolutionary is still under discussion.” Either way, the industry believes that any fuel efficiency gains will be incremental.

Finally, there’s the holy grail of waste heat recovery. And, here, Noble accepts that effective and reliable technologies are still a few years away. “Turbo compounding, particularly electrically controlled, could be adopted for recovery of more thermal exhaust energy probably into electrical, but possibly mechanical, power,” he agrees.

EXHAUSTING EFFORT

In a sense, that’s little more than an extension of what’s been done for years with turbines. And all manufacturers would argue that they’ve worked hard to harness exhaust energy to maintain heat in their Euro 6 aftertreatment systems. But both are a far cry from the Rankine cycle, which could eventually be worth some 4–5% fuel saving, assuming the truck’s duty cycle delivers a consistent and adequate waste heat energy source.

Noble sees the possibility of early adopters but emphasises that you’re looking at complex technology involving an expander – reciprocating or turbine – at the front end capable of reliably recovering enough thermodynamic energy. “There are bound to be challenges, at least in terms of system control and cost, so this is one of the last technologies mainstream engine designers are likely to adopt.”