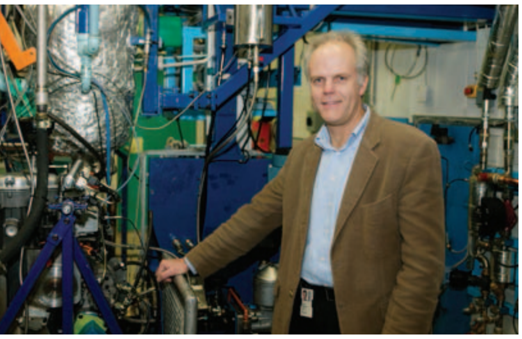
Focusing on the

Truck engine manufacturers are embarking on arguably one of the greatest challenges in 20 years – redesigning Euro 5 engines for Euro 6. Brian Tinham looks at the implications

Above: Andrew Nicol, Ricardo's technical specialist Below: Scania's engine development team leader Björn Westman



"To my mind, European legislators are now pushing particulate limits for truck engines too hard at Euro 6. Effectively, they are making expensive filter solutions mandatory by choosing an artificially low particle number [PN] limit, cutting it by 95% from Euro 5. That will reduce the particulate mass [PM] far beyond the half originally intended by the legislation."

So says Scania's engine development team leader Björn Westman (left). And he adds that what the transport industry needs is a technically feasible particulate limit that doesn't involve excessive costs for operators or manufacturers and, just as important, doesn't result in fuel consumption and CO_2 emissions being inadvertently hiked, as a result of exhaust back-pressure caused by beefed-up DPFs (diesel particulate filters) and/or energy-hungry engine modifications. "I just wonder whether we are focusing on the right thing," he says.

Be that as it may, by December 2013, if the European Commission wheels turn as expected, we will all be forced to purchase Euro 6 type approved engines. So what can we expect? The vast majority of engine designers agree that whereas, hitherto, clean engine technology has been about either EGR (exhaust gas recirculation) in-cylinder treatment or SCR (selective catalytic reduction) post-engine-out treatment, the future is almost certain to need both.

Received wisdom has it that Euro 5 was the limit for the either/or approach. Certainly, no-one is suggesting SCR alone as a solution and only one serious engine manufacturer, US-based Navistar, is still managing the Environment Protection Agency's 2010 limits (EPA 10, now in force in North America as of 1 January 2010 and close to the pre-PN version of Euro 6) using only EGR. As Westman explains: "The problem is not just how to provide

enough heat rejection to cool the increased quantity of re-entrant exhaust gases needed to suppress NO_x. We can tackle that. It's how do you manage transient behaviour of the engine when it's so close to the oxygen limit?"

One answer may be something similar to MAN's approach to ramping its EGR-only Euro 4 engines up for Euro 5, mostly by using twin turbochargers and beefed-up intercoolers to deliver the required ambient air pressure differential and temperature at the inlet manifold. On its higher-end D08 four- and six-cylinder engines, MAN went for BorgWarner high and low pressure turbos in compound sequence; while, on its 10.5-litre D20 and 12.4-litre D26 engines up to 440bhp, it selected Garrett turbos from Honeywell Turbo Technologies. Scania did something similar with variable geometry turbochargers, bumping up the EGR ratio on its EGR-only 9.3-litre and 12.7-litre Euro 5 engines (230hp to 480hp) to remove more NO_x, without having to retard the engine timing.

However, neither MAN nor Scania seems to be pursuing EGR alone on their routes to Euro 6, which should be no surprise, given the considerable cost implications of maintaining engine performance by chasing ever more sophisticated turbo compounding solutions. Similarly, although fuel injection pressures will no doubt rise further to reduce particulates by improving the burn through better atomisation of the fuel, there are always trade-offs. In the end, there are parasitic energy losses to consider, in the form of pumping up those pressures.

So, yes, we're back to a combination of EGR and SCR, probably with sophisticated emissions filtering technology on top. Hence the scale of innovation required of engine developers and manufacturers when they: a) have never done the combination before and b) in the current economic climate, can least afford to. All this raises the obvious question, how much EGR vs SCR? And then another: what are the likely cost (purchase and operational), robustness and maintenance implications?

EGR vs SCR debate

Taking EGR all the way at Euro 6?

Engineering solutions for Euro 6 that use only exhaust gas recirculation (EGR) may not be as unlikely as some believe. Ricardo's technical specialist for performance and calibration Andrew Nicol reveals that his organisation is working on at least one project aimed at achieving precisely that.

"EGR means reduced air induction, so then you have to push harder to get the oxygen for transient response," he explains. "Hence the multistage boosting systems in the market at Euro 5. EGR-only is feasible at Euro 6, but it becomes a bigger project to deal with the clean exhaust and back-pressure problems that arise under certain conditions. In the US, Caterpillar has been using recycled exhaust gas on the long route – the low pressure side, downstream of their DPF, but upstream of the compressor – since 2007. So that's cleaned exhaust gas, which gets round the problem of the compressor seeing too much debris.

"One way to get an EGR-only engine to work at Euro 6 might be to combine the short route with the long route. That could get around the problems with multiple stage boosting systems on the preferred short route, which hinge on the fact that a bypassed turbine sees less gas mass flow, so is unable to deliver as much work to the compressor – which then can't deliver so much boost to the engine. That's the reason for the care needed in matching the turbochargers for anticipated air rates.

"On the long route, the compressor sees much the same mass flow all the time and, as a result, so does the compressor. So it's less affected by changes to the EGR rate. So maybe life could become a little easier by using both to enable higher EGR rates, without the usual transient problems – although that would add even more cost."

To Westman, these are the 60 million dollar questions and understandably he's playing his cards close to his chest. He's not alone: Mats Franzen, Volvo Trucks' product manager for engines, says merely: "The amount of gas recirculated and how much AdBlue needs to be injected [into the exhaust gases] is not going to be a static relationship." He hints vaguely at optimum combinations to suit different operating conditions and even different duty cycles, no doubt managed by the ECU.

For Volvo, one of the options is bound to be building SCR onto the output side of its established variable gate turbo technology for EGR boosting at EPA 10 – also with heavier duty inter-cooling. Meanwhile, for MAN it could be similar, using a combination of its existing SCR technology (widely sold throughout mainland Europe), twin turbocharged EGR, even higher injection pressures and its Oxi-Kat oxidation catalyst (which replaced the PM-Kat combined particulate catalyst and filter used at Euro 4) to supplement NO_x reduction.

We could carry on speculating across the various truck and engine manufacturers. But let's instead examine the facts. Andrew Nicol, technical specialist for performance and calibration at world-renowned

Front cover photography Charlie Milligan

Workshop implications

So what are the implications for workshop technicians already working on Euro 5 engines (since the reduced pollution certificate incentive, now expired) and eventually also on Euro 6? Not many is the easy answer, given that today's engineers have had to be trained on engine and vehicle electronics, as well as automotive engineering since well before Euro 4. Most would agree that vehicle diagnostics and maintenance have been part of an ongoing revolution for the last 20 years.

That aside, Dave Tempest of diagnostics specialist Texa UK warns technicians to watch out for AdBlue problems on SCR vehicles, especially during the remaining winter months. "There have been a lot of problems surrounding crystallisation within the system's components. One truck we saw was pouring AdBlue out of the exhaust brake butterfly every time it stopped. The problem there was AdBlue crystallising in the air supply, meaning that it couldn't atomise the AdBlue, so just spewed it out as liquid."

Tempest also talks of crystallisation in the exhaust, due to faults allowing the system to inject AdBlue when the exhaust is not up to temperature. "Rather than hydrolysing, the AdBlue just crystallises. We recommend that operators scan their truck SCR systems for faults as part of the service regime. Go into ECUs to look for early signs."

He also refers to the old chestnut of contamination, with diesel filled into the AdBlue tank. "The problem is that the vehicle keeps on running, and technicians only see it when the diesel has made a mess of the seals, which creates problems that typically cost a few hundred pounds."

automotive engineering heavyweight Ricardo, is an excellent guide. He first provides a developer's insight on the PN versus PM debate, noting simply that, if the objective today is to cut sub-40 micron particles (since these are the most damaging to human health), the focus must now be on PN. Why? "Because we have already done the job on heavy soot particles – for example, by atomising the fuel better, using higher pressures and electronic fuel injection technology. But improving combustion in this way hasn't necessarily reduced the numbers of small particles, so PN is the way to go now."

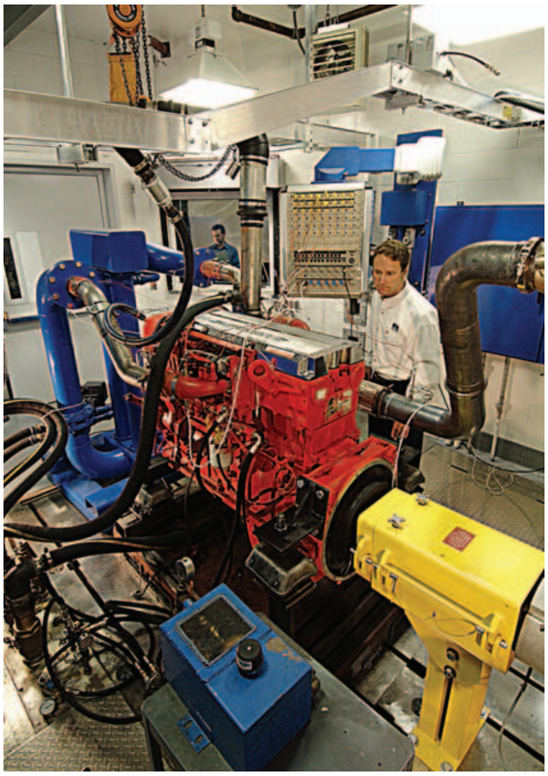
Particulate number analysis

What about PN testing – the source of so much doubt recently? Nicol agrees that, whereas PM was easy, instruments for measuring PN have taken some time to come. However, he points to Ricardo's participation in the EC PMP project, which provided a methodology to accurately assess PN. The result: "European regulation 595 2009 indicates that a specification for PN will be available no later than 1 April 2010 and we can also expect the methodology for testing to be announced then – notwithstanding pending agreement on the WHTC [world harmonised transient cycle]. That may result in manufacturers having to use advanced DPFs, because it's going to be very difficult to develop combustion technology to circumvent them and still get the PN down."

Accepting that point, what about NO_X and the difficulty that the processes harnessed to reduce it tend to have an adverse effect on fuel consumption, and thus emissions of CO_2? Nicol asks us to step back a few years, for a moment, alluding to the established truth that fuel consumption has remained more or less flat since Euro 3, back in 2000, despite more challenging limits on NO_X and particulates.

"Euro 3 limits were achieved with electronics for fuel injection. Then, for Euro 4, vehicle manufacturers used EGR or SCR, so that they didn't have to do nasty things to the engine timing," Nicol reminds us. Moving up to Euro 5 levels has similarly been accomplished, again without fuel penalty, by increasing the AdBlue quantities in SCR or going for the turbo boost approaches in EGR.

His points: first, very successful improvements have come in various forms, but at a cost; and secondly, the fact that engine manufacturers are where they are implies further considerable add-on development and equipment costs, especially for those hitherto wedded to SCR after-treatment, now they find themselves faced with bolting on EGR. Nicol cites the experience in the US with EPA 10, where manufacturers employing EGR and SCR saw increased costs of around $9,000 (£5,500). As DAF marketing director Tony Pain puts it: "Both EGR and SCR are expensive technologies, compared with those on a Euro 3 engine, so carrying the cost of



Left: Ricardo's engine development facilities at Shoreham-by-Sea, West Sussex, are world renowned

The drive to slash truck emissions

Nobody disputes that the average 44 tonne HGV truck at Euro 5 is seven times more damaging to the environment than a family car. But let's unpack that for a moment. MAN's head of UK service and support John Davies points to the classic estimate: "It takes just one truck to deliver groceries to a Tesco store, but some 500 family cars to take the equivalent shopping the few miles home – meaning cars do far more damage." And much the same applies to the tens of thousands of partially or unladen vans on the UK's roads every day.

Now let's look at it another way – comparing truck emissions and fuel efficiencies from the 1990s, pre Euro 1, to today. Do the sums and you'll find that it would take 35 Euro 4 vehicles to do the same amount of emissions damage as just one Euro 0 truck. "Euro 4 vehicles are 35 times more environmentally friendly than their predecessors and Euro 5 takes that even further on NO_x, reducing rates from 3.5 to 2g/kWh."

And all of that has happened despite – or some argue, because of – toughening emissions legislation, driving manufacturers to do better with electronic injection systems, continuously regulated turbo compounding technologies, active filters, etc.

Mats Franzen, Volvo Trucks' product manager for engines, says the rate of technology development, in terms of emissions and driveability, power density and fuel efficiency improvements on the truck side, as well as the fuel itself, never fails to amaze him.

"Go back to Euro 0 and no one dreamt that we could reach the levels we have now with Euro 5. Think about when we introduced a 16 litre 465hp engine in 1987. At the time, that was fantastic, but now it's just average for a 13 litre unit. And it's the same with fuel consumption, which has improved by more than 40% for 44 tonners on European long haul applications."

Top: John Davies says MAN used twin turbochargers and beefed-up intercoolers to deliver EGR-only Euro 5 engines
Above: Mats Franzen, Volvo: "The amount of gas recirculated and how much AdBlue gets injected will not be a static relationship"

both items and an active particulate trap is going to add to the price of a Euro 6 tractor."

For that and for technology limit reasons, Nicol suggests Euro 6 engine designers are most likely to minimise EGR, in favour of SCR. "More EGR requires a more sophisticated boosting system and, for engine manufacturers currently not using EGR, that means additional costs, including the pipework, EGR cooler and electronically-controlled EGR valve as a minimum. For moderate EGR rates [less than 20%], a waste gated turbocharger could be enough, but if they go to 25% EGR, they're into two-stage or variable geometry turbos and increasing the costs."

It also increases the work being done by the engine to rack up the pressure differential between the exhaust and the inlet manifold, needed to handle transients – and that directly affects fuel efficiency. "High EGR rates require high back pressure, which can increase fuel consumption. So, even though you could argue that high EGR [25—35% to cut engine-out NO_x to, say, 1.5g/kWh], followed by relatively low SCR after-treatment [cutting NO_x by another 80% to get below the 0.4g/kWh limit], is an almost ready-made solution, it's not the best."

Increasing the SCR balance to 88% and reducing the EGR to 15—20%, he says, is a more elegant and practical solution. "We know that we can achieve close to 90% SCR in normal exhaust temperature ranges, without thermal management around the catalyst boxes, as long as they're in the right place. And we know that EGR at 15% for intermediate speed [peak torque] and 20% rated speed is also very feasible for the rest of the work to get below the Euro 6 NO_x limit. This is doable and doesn't require any extra energy, so is likely to minimise fuel usage."

Meaning what? "Meaning that this combination should be as good as, if not better than, a current EGR-only Euro 5 engine, in terms of fuel economy, although there will be some offset for the AdBlue. That's a lot better than just whacking a load of EGR onto current engines. Fuel economy [and CO_2 emissions] could then be 8% worse."

What about adopting a SCR-only? Nicol is unequivocal: "That would require a very high SCR rate at 93% conversion efficiency. To do that, you have to manage the exhaust temperature in a very precise window, which means heating or cooling the catalyst somehow – and you're back to energy penalties and hence more fuel consumption."

And there's another issue. Nicol refers to the 'Swedish granny cycle' – a truck in the Swedish winter that stops and starts and doesn't exceed 10mph, meaning exhaust temperatures stay low. "There is the very valid concern that SCR needs temperatures of 200°C to operate and there are several issues around that. The catalyst is capable of converting some NO_x above 160°C, but aqueous urea injected below 200°C can crystallise around the injector and other cold parts of the exhaust, which hampers its operation. AdBlue is also acidic, so you don't want this to happen. MAN does have a point here, with its 'EGR-only' campaign. There will always be cases where it's difficult to get SCR to operate – such as UK refuse trucks operating in deep winter."

What about the fact that NO_x outputs are lower under these conditions? "There are generally lower NO_x engine-out levels at lower temperatures. But, while the grams are less, so are the kW, which means g/kWh is not negligible," explains Nicol.

That may not matter from a legislative standpoint, particularly if the regulators move to the WHTC – with its increased light load content – from today's European standard. The issue for conscientious fleet engineers is then one of corporate environmental responsibility, as spelt out in last year's campaign by the Engineering Council. TE

TE For further information on technology and suppliers, visit www.transportengineer.org.uk