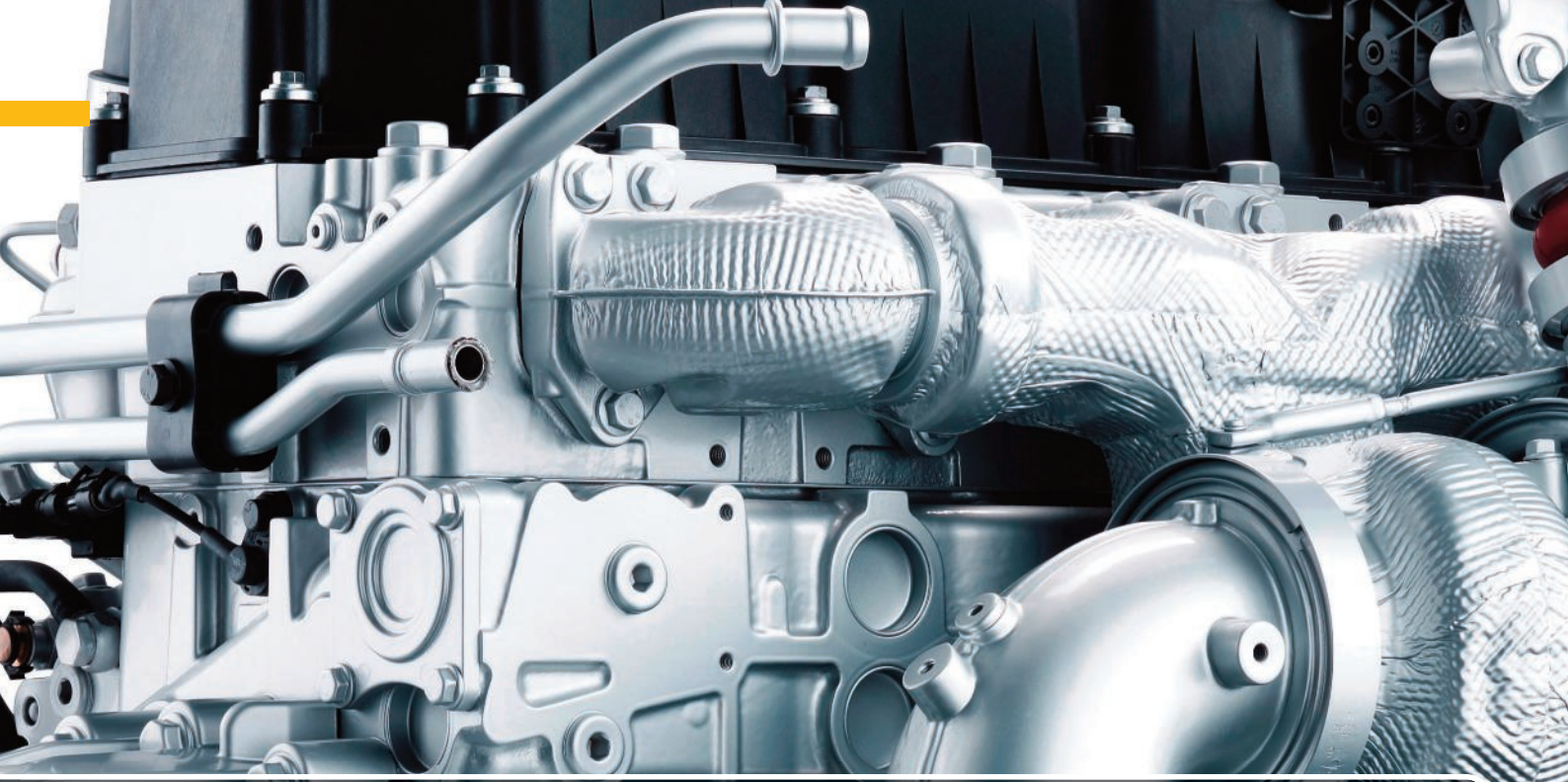


War on waste?

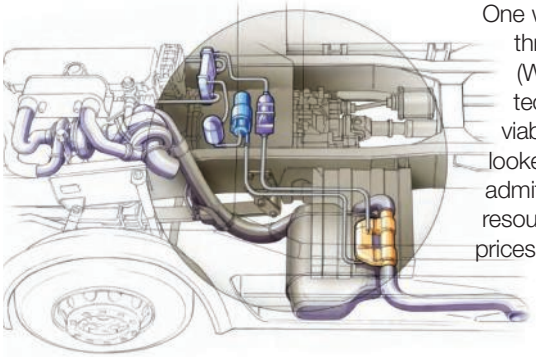
Despite the impressive levels of efficiency from today's diesel engines, far too much fuel energy is simply being wasted. Brian Weatherley looks at how it could soon be put back to work

Above: DAF has used thermal encapsulation on both its ATe Euro-5 MX engine (shown) and its Euro 6 MX-13 and MX-11 diesels

Below: exhaust gas heat recovery on Iveco's Glider concept truck produces electricity to power electrical auxiliaries, improving fuel efficiency by up to 10% (source: Iveco)

The experts agree, the diesel engine will continue to reign supreme for the foreseeable future. Yet, with a brake thermal efficiency (BTE) currently stalled at around 45%, it's sobering to think just how much of the energy in the fuel fed into today's advanced diesel engines is still being wasted.

Aside from frictional losses within the engine itself, and parasitic losses from various ancillaries, the biggest loss by far is in the form of heat. As Professor Doctor Franz Moser, diesel engine guru and executive delegate of the CEO for AVL, the world's largest independent company developing powertrain systems, explains: "We feed the fuel energy into the engine and the outcome is mechanical power. Unfortunately, there are huge losses – 48% of the fuel energy is lost. Engineers working on combustion systems want to make something out of this energy… We're now dealing with how to use [it]."



One way of clawing it back is through waste heat recovery (WHR) – only, until now, the technologies haven't been viable. "In the past, they've not looked economically attractive," admits Moser, "But with oil resources shrinking and fuel prices dramatically increasing, even expensive technologies will make sense and pay back within a rather short time."

Leading the WHR charge are systems based on the Rankine Cycle, whereby waste heat is used to create supplementary mechanical or electrical power. Ironically, though, while diesel engines generate masses of heat, Moser says: "Unfortunately, only the exhaust gases and the EGR (exhaust gas recirculation) cooling contain sufficiently high energy to be used in the Rankine Cycle. These two energy sources are used to heat up a medium, such as water or ethanol, which is then evaporated and expanded in a secondary process, in an expander or turbine. The power can be directly coupled to the crankshaft, adding to the mechanical power on the flywheel, or it can drive an electric generator. The electrical energy can be used to drive auxiliaries, like the fan, water pumps etc."

Rankine benefits

Adding a Rankine process like this to a conventional heavy-duty diesel would offer significant benefits, reckons Moser. "For example, according to our investigations, an engine with 250kW [335bhp] would get about 12kW [16bhp], just from the exhaust gases, and another 8kW [11bhp] from the EGR cooler. In total, that's a saving of 20kW [27bhp], which relates to 8% of the brake power of the engine."

Above: MAN exhaust stack – as fuel prices rise, WHR systems will assist even the most efficient truck engines

Below: Rankine Cycle systems could go a long way to recovering fuel energy wasted through the exhaust and the engine itself (source: AVL)

However, he stresses that those figures represent an ideal case. "We think the real saving potential will be somewhere in the range of 5%. Only when the technology is fully developed and mature will we see higher figures," he suggests. Nevertheless, while acknowledging that WHR technology is still in the early stages of development – closer to research than to series production – Moser insists that a 5% fuel-saving potential is already attractive. Moreover, he says: "I would expect the first appearances [of WHR] in series in trucks within the next five years."

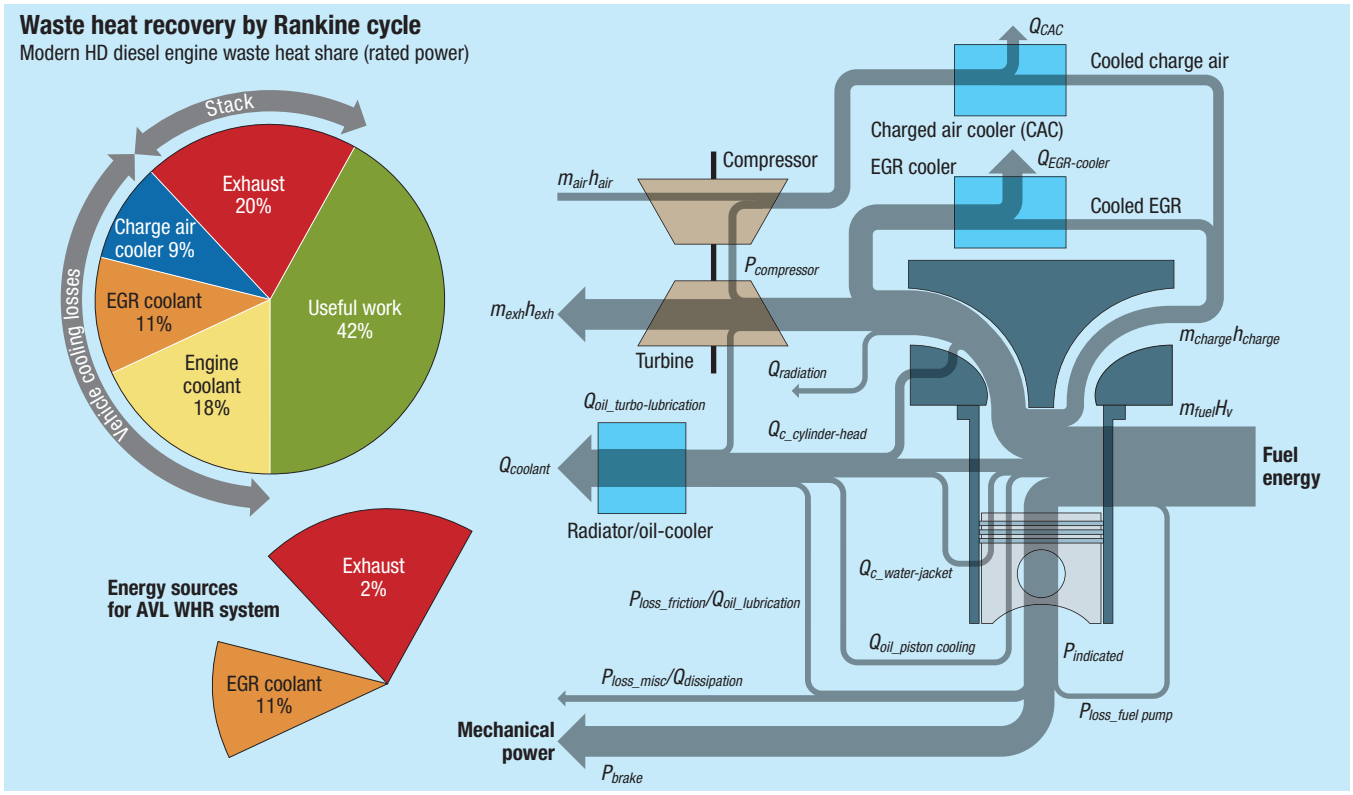
WHR could well feature in future Iveco engines, with the Italian truck maker's avowed aim to raise the BTE of its diesels to 55% by 2020. At the launch of Iveco's Hi-eSCR (high-efficiency selective catalytic reduction) Euro 6 engines last year, Massimo Siracusa, Fiat Powertrain Industrial's vice president for product engineering, declared: "To realise this ambitious target, we need to achieve the best results in more than just one area. We're analysing the possibilities of converting heat back into energy, with the low-energy Rankine Cycle, to generate mechanical power, and the Brayton Cycle [where compressed air is heated and expanded within a turbine, again either for direct mechanical or electrical power]. Both systems are being considered." Siracusa says a 4% improvement in efficiency derived from WHR could deliver an improvement in fuel consumption of up to 8%.

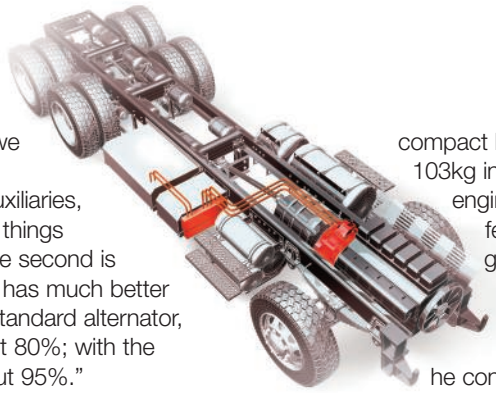
Iveco's interest in WHR extends back to the 2010 IAA exhibition and its Glider concept tractor unit, which featured several fuel-saving technologies, including an exhaust gas-based WHR system, said to offer CO_2 reductions up to 10%. Another benefit of WHR-generated electrical power is what Iveco calls the belt-less engine, where auxiliaries are driven by a high-efficiency electric motor with energy-saving controls.

But judging by the work being done by Cummins Generator Technologies, WHR isn't necessary to create electrical power. Having originally developed its CorePlus motor-generator for hybrid drivetrain applications in 2011, the firm is now looking to use it as a method of powering engine auxiliaries. And that begs the question: Why aren't they already electrically driven?

"The total power needed is around 15kW," responds David Moorhouse, Cummins Generator Technologies' new product marketing manager, "which is well beyond the capability of three standard alternators." Not surprisingly, OEMs view motor-generators with interest. Indeed, Moorhouse confirms: "Along with the [Cummins] engine business unit and others, we identified this whole concept of improving engine efficiency by driving auxiliaries electrically."

Moorhouse's colleague, power systems engineering manager Dr Krzysztof Wejrzanowski, explains that this interest is the result of two key drivers. "One is the rising cost of fuel. By using this





Above: Iveco's futuristic Glider concept tractor features several fuel-saving devices, such as 'smart cooling', waste heat recovery and a belt-less engine

Right: originally intended for hybrid-vehicle applications CGT's CorePlus motor generator (in red) is also being developed as an electrical power source for diesel-engine auxiliaries (courtesy of Cummins Generator Technologies)

motor-generator, we can decouple the engine from the auxiliaries, so we can control things more optimally. The second is that the generator has much better efficiency: with a standard alternator, we're talking about 80%; with the generator, it's about 95%."

Another point is that, since engine compartments are increasingly crowded with Euro 6 emissions equipment and their additional cooling airflow, packaging is becoming a major issue. "There's limited space within the truck [engine compartment]," confirms Wejrzanowski, "and you struggle to put these alternators in the surrounding area." And Moorhouse adds: "It's also not good, from a maintenance point of view, having multiple belt-driven alternators. This is what we've had back from the bus industry. When you have all these belt-driven auxiliaries, there are maintenance issues too."

Small, but powerful

So a relatively small, high efficiency, engine-driven generator opens up a whole new world for vehicle manufacturers beyond boosting efficiency. "With equipment like the air compressor being mechanically driven, you can't put it anywhere on the chassis," explains Wejrzanowski. "It has to be in the engine compartment. But you could put an electrically-driven compressor wherever you like: you've got more flexibility for packaging."

Moorhouse lists engine auxiliaries that could be electrically driven as: "Cooling fans, vacuum pumps, air compressors, power steering pumps [because they're a high-peak demand] and air conditioning – definitely." However, he adds: "Water pumps have been mentioned, but engine guys still prefer them to be mechanically driven."

His company is now in the process of re-engineering its original hybrid motor-generator for a generator-only application. While it already has a compact hollow rotor design – just 168mm long and 103kg in weight, allowing it to fit between an engine and gearbox – Moorhouse says OEM feedback on the desired maximum generator length is closer to 50–80mm.

"There's pressure on us to find a generator solution that is, to all intents and purposes, invisible to the drivetrain," he confirms.

Given that dimensional envelope, Wejrzanowski believes: "What we could do is mount [the generator rotor] directly on the crankshaft at the flywheel end." Sitting within the flywheel housing, from the operator's point of view it would be completely hidden. "It would be a fundamental part of the engine," insists Moorhouse. "Every engine would have one to drive those auxiliaries."

While the concept of using an integrated generator to power auxiliaries looks attractive – being lighter and less complicated than a WHR-based system – Wejrzanowski expects the first application of CGT's generator to be in controlled-temperature vehicles, or in refuse collection bodywork or concrete mixers, providing an electric power-take-off. "I think, for military applications, it will be around 2015–2016, and a similar timescale for regular truck bodywork too." However, Moorhouse believes that, when it comes to using electrification to drive engine auxiliaries and boost diesel engine efficiency, this is a technology that won't come in until Euro 7. "We're talking about something completely different," he says.

But with energy-draining auxiliaries removed from the engine, what sort of fuel savings is Moorhouse expecting? "I think it's a moving target and there's more work to be done, but it's somewhere between 5–10%," he asserts. "It doesn't deliver the same amount of fuel savings as a hybrid, but this would work on any engine, on any kind of duty cycle... And it's less frightening technology, too. It doesn't have a huge battery pack, with its weight and high cost. And, from the operators' point of view, this would just be 'the engine'. It will be completely hidden."

The family relationship between CGT and Cummins' diesel engine division clearly puts the former in a good position to understand the needs of OEMs, as well as truck and bus operators. Moreover, Moorhouse reports: "We've got something to demonstrate already. The engine and vehicle makers are looking at the next round of Euro legislation; they've done all they can, in terms of emissions, and the next big thing will be efficiency. There are lots of things in play, like waste-heat recovery, and electrifying auxiliaries is one of the big areas under investigation. We're evangelising this, because we can connect with the engine business. But even as recently as the last three months, there's been a lot more pull from outside than there is push from us."

Wrap it up

Thermally insulating key engine components is one way of reducing heat radiated from them. DAF's Euro 5 ATe MX engines featured not only thermal encapsulation for the turbocharger, but also for the exhaust manifold. The result was better air management by providing higher turbo efficiency and better combustion.

DAF's latest Euro 6 MX-11 and MX-13 diesels continue the trend, with encapsulation of the exhaust manifold, though not the turbine housing – which forms a single part with the exhaust manifold on its ATe engine, but is separate on its Euro 6 diesels.

DAF says: "The impact of encapsulation on the turbine housing is limited at Euro 6, as a variable geometry turbine is used, which can be optimally controlled for highest efficiency."