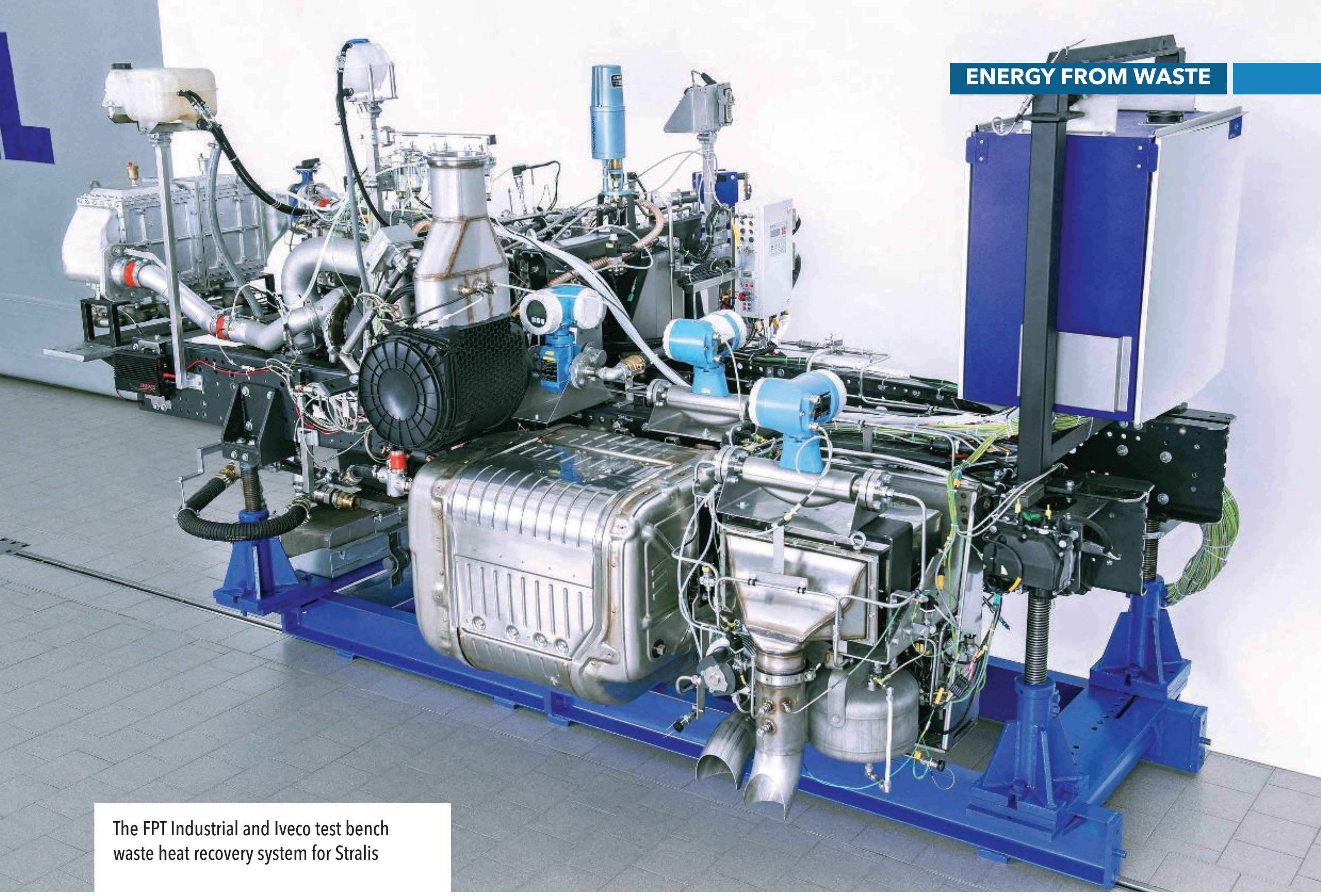

The FPT Industrial and Iveco test bench waste heat recovery system for Stralis

WASTE RECOVERY

As engine makers strive to boost diesel efficiency, is waste heat recovery the saving grace they're looking for? Brian Weatherley charts its progress and considers the pros and cons

Growing numbers of truck and engine makers have been citing waste heat recovery (WHR) as likely to play a key part in raising diesel engine brake thermal-efficiency (BTE). They also point to WHR's ability to improve fuel economy and hence also cut greenhouse gas emissions. Compared with many other future truck predictions, this re-engineering approach appears to have legs.

Why? Because, with WHR, Europe's engine makers can finally utilise fuel energy currently lost as heat through the exhaust pipe or EGR cooler (principal among engine waste heat sources), converting it either into mechanical power for feeding back to the crankshaft, or into electricity for powering ancillaries that are presently engine-driven. Whichever way WHR is applied, its potential to raise BTE on heavy-duty diesels beyond the current 43–46% is hard to ignore.

The attraction of putting previously wasted engine heat to work has long been recognised by Iveco and its diesel engine supplier FPT Industrial. Back in 2012, FPT's vice president for product engineering Massimo Siracusa revealed the firm's intention to raise the BTE of its engines to an unprecedented 55% by 2020, based on several fuel-saving interventions, including WHR. That came just two years after Iveco unveiled its futuristic Glider concept truck featuring, among other advances, WHR.

Fast forward to May 2015 and FPT, Iveco and AVL (the world's largest independent powertrain specialist) presented a joint paper entitled 'WHR for on-highway vehicles: from concept to industrialisation' at the eighth AVL commercial powertrain conference. Along with its partners, Iveco is now developing a WHR system for a Stralis truck using the Organic Rankine cycle – where waste heat runs through a heat exchanger that vaporises a liquid medium, in turn driving a turbine or expander before being re-condensed and returned to the heat exchanger.

The paper's authors report: "Simulations suggest that, by tapping

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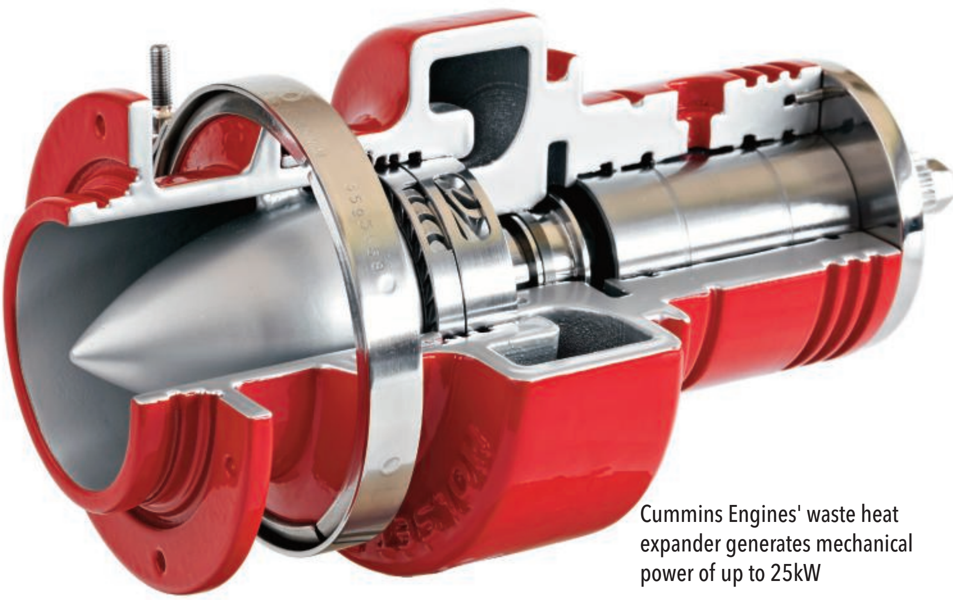


Cummins Engines' waste heat expander generates mechanical power of up to 25kW

multiple heat sources, up to 5% improvement in engine efficiency is possible, while a simplified system harvesting heat from only EGR and exhaust gas will allow up to a 2.5% increase in BTE." The prototype Stralis WHR system is based on an FPT Euro 6 Cursor 11 engine. It includes evaporators for both the exhaust and EGR, a high-pressure feed pump, a piston expander delivering power to the engine's PTO (via a belt drive and intermediate shaft), a condenser, and a reservoir for the heat transfer fluid – in this case ethanol, although water was also evaluated. Most of these components sit within a WHR box, which is chassis-mounted alongside the existing Stralis SCR/exhaust unit.

"First results from bench testing indicate a fuel economy gain around 3.5% for the Iveco Stralis Euro 6 truck during the real-world reference [engine test] cycle, using waste heat from both the EGR and exhaust evaporator," say the report authors. Further test bed trials will be performed by AVL, while on-road trials are expected this year.

But FPT isn't the only engine maker interested in recovering waste heat. In the US, Cummins has long had working WHR on a top-weight tractor as part of the recently concluded SuperTruck programme. Set up in 2010 under the auspices of the US Department for Energy, that project tasked American truck manufacturers and component suppliers with creating a heavy-duty artic capable of achieving a 50% improvement in overall freight efficiency measured in ton-miles per gallon.

ADVANCED ENGINEERING

Working with fellow SuperTruck participant Paccar, Cummins fitted a highly modified 15-litre ISX engine with a mechanical WHR system to a Peterbilt Model 587 6x4 tractor. That was coupled to an aerodynamic trailer and driven at a gross weight of 29.5 tonnes – typical for US artics.

Cummins ISX modifications included a revised piston bowl design, increased compression ratio, optimised fuelling, air handling and turbocharging plus improvements to its coolant, fuel and lubricant pumps. But the most interesting element was its parallel WHR, which takes waste heat from the engine's EGR cooler and exhaust pipe to heat a 'low global warming' pressurised refrigerant that runs through a turbine expander. Spinning at 35,000 rpm, the expander feeds power back to the crankshaft via a belt-drive.

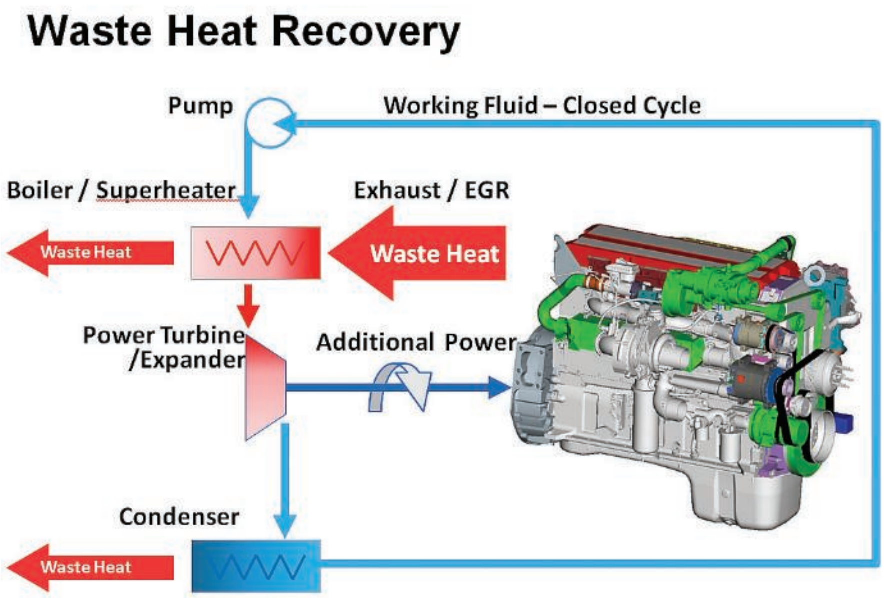
The SuperTruck went through several iterations during its four-year test period and, in February 2014, Peterbilt and Cummins announced it had greatly exceeded the DOE's target, delivering an 86% gain in freight efficiency, 75% fuel economy uptick and 43% cut in greenhouse gas (GHG) emissions over the 2009 vehicle. Indeed, the project reported a fuel figure of 10.7 mpg, with Cummins attributing 4–5% of the improvement to the WHR and claiming a BTE of 51% for the modified ISX.

Meanwhile, Cummins Turbo Technologies, in Huddersfield, helped by UK government funding, has been examining an expander-based WHR aimed at generating electrical power for ancillaries. Replacing existing belt drives to water and steering pumps, air compressor and alternator clearly reduces parasitic losses.

CTT says its electrical turbine expander is at the development stage. "There's not been the same amount of testing on the electrical system," says a spokesperson. "However, we continue to work with our customer base to develop the technology and we expect to see it in production, potentially around 2020." That's similar to the expected timeframe for Cummins' mechanical WHR.

But will WHR lead the charge for raising diesel engine efficiency over the next decade, or will other technologies prove less complex and more cost effective? One man with plenty of experience is professor Dan Wright, CEO of Scottish-based Heliex Power, which makes screw expander systems

> ***"If there are other factors meaning the industry has no choice, then the technologies are around and they do work. But there's a lot of work still to do to make WHR automotive compatible"***
> *Professor Dan Wright*



that take the energy from waste steam and turn it into electricity.

Prior to founding Heliex in 2010, Wright worked for Ford, before leading the buyout that created Albion Automotive Industries from the then failing Leyland DAF trucks. In 2000, he became managing director of Johnston Sweepers, transforming its performance.

Wright believes there are many challenges to putting a WHR system on a truck – not least in terms of complexity, cost and weight. It also needs to operate at consistently high loads to ensure maximum efficiency. "If you're looking at 'gradient loading', for every up there's a down. And unless the 'ups' [on the truck] are fully laden and the downs empty, you end up with a nil net sum," he says. "That's the big problem. Road vehicles spend the vast majority of their time running on light loads, so the cost and mass of WHR will not give a benefit that stands the test of normal economics."

European truck manufacturers will have to find space for WHR plant, too, within already crowded post-Euro 6 chassis, especially on tractors. No easy task, notes Wright. "Thinking of my time on Johnston, when we had to re-pack the chassis to include tipper or sweeper stuff, having to [add] a WHR system would make it even more complex."

ORGANIC RANKINE CYCLE

That said, Wright confirms that the Organic Rankine cycle is the best route for WHR, but says a screw expander is preferable to a turbine. Why? "Because it handles variable mass flow rates and variable pressure differences very easily, whereas a turbine does not. A turbine likes fixed conditions, unless you use variable geometry nozzles or guide vanes, in which case you're adding to the expense."

A screw expander also offers advantages for electrical WHR systems, he explains. "It runs at a speed that is compatible with a minor speed reduction on alternator technology. Turbines run at very high speed, so either you need a fancy geartrain or have to hook them directly to a high-speed alternator, along with a frequency convertor and all the stuff to get the voltage usable." With Heliex dealing with steam, unsurprisingly Wright sees this as an ideal heat transfer medium – particularly as it avoids adding another fluid to the automotive arena.

Steam's high energy density means it can also be stored and released back through the expander when required. "The advantage of steam in our screw expander is that the two rotors can touch one another and the steam acts as the lubricant," says Wright. "We do have oil going into the bearings: on a truck you'd run that with engine oil."

That said, Wright struggles to see the economic case for WHR right now. "I'm not saying, as some kind of Jonah, this isn't going to happen. Engineers are professional optimists and I've always been involved in the advanced technology end of the automotive industry. But from an engineering perspective it's not something you'd readily contemplate. If there are other factors meaning the industry has no choice, then the technologies are around and they do work. But there's a lot of work still to do to make WHR automotive compatible."

However, as regulators on both sides of the Atlantic seek major reductions in CO_2 from road transport, Wright's last comment is telling. "If the law changes, and you have to get fuel consumption or total thermodynamic efficiency higher than you do right now, then ... the cost goes out the window. You've got to find technology to meet the legislation."

Clearly, there's still a long way to go before we see a WHR system on production trucks. Yet, despite the engineering challenges and regardless of whether its wide-scale adoption is ultimately driven by legislation, there's no denying that WHR has, to quote a famous English landscape gardener, 'great capabilities'. TE