

Features

HIGH-CAPACITY, HIGH-SPEED ENGINES

Wayne Ward



Rage against the machine

APTI DIVES INTO THE EXCLUSIVE WORLD OF HIGH-POWER, HIGH-RPM COMBUSTION ENGINES FOR THE HYPERCAR MARKET

In his poem on the end of his father's life, Dylan Thomas wrote:

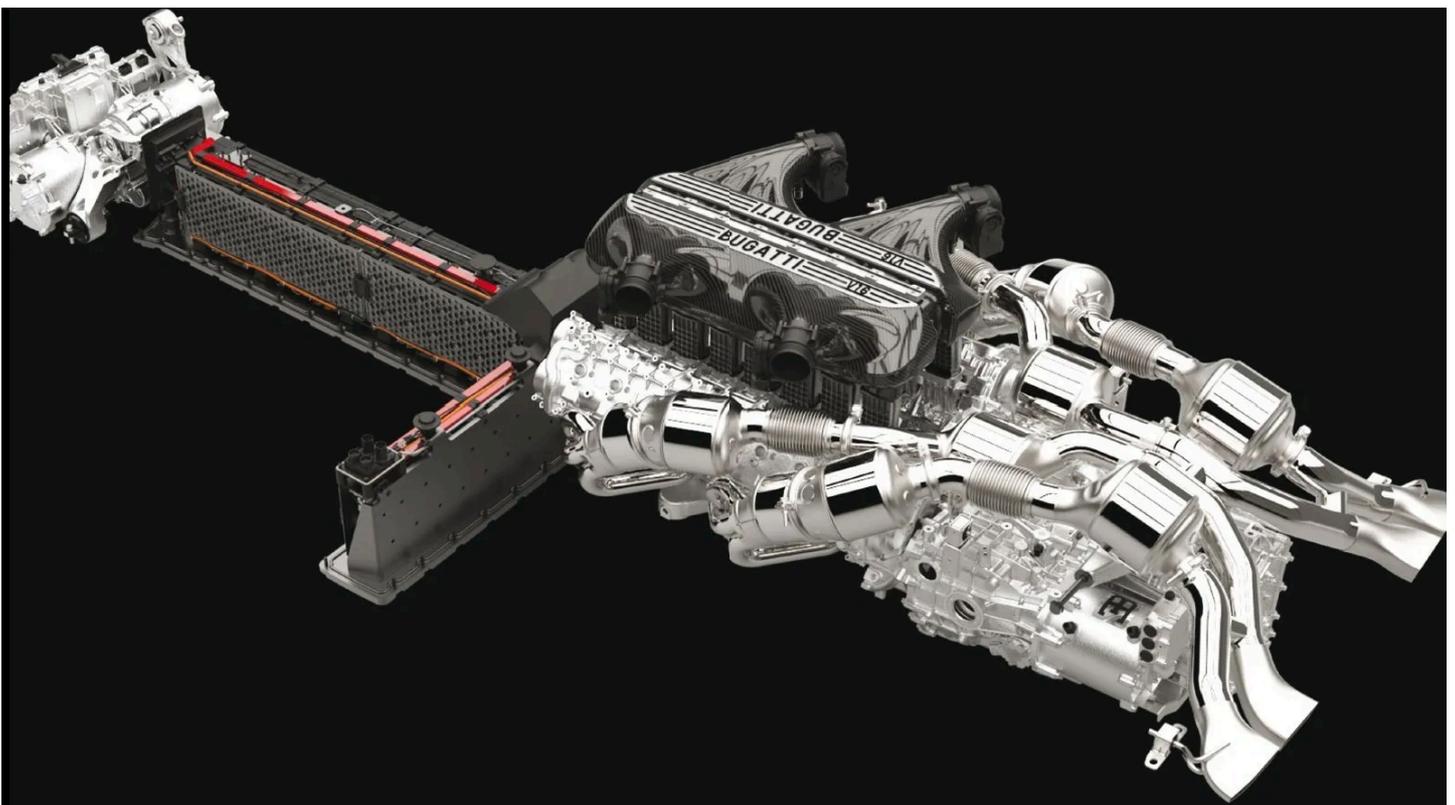
Do not go gentle into that good night, Old age should burn and rave at close of day; Rage, rage against the dying of the light.

As internal combustion engines come to what is arguably the end of their life as the default propulsion method for personal transportation in large parts of the world, many companies have stopped developing new engines and are simply doing what is required with their existing engines to satisfy regulatory requirements and keep their products viable while they transition to an increasingly or totally electrified future.

However, some notable companies seem to have reflected on Thomas's poem and taken its sentiment to heart. The likes of Aston Martin, Red Bull, Zenvo and Bugatti are not about to 'go gentle into that good night', but are burning, raving and raging instead. In what are possibly their last significant new engine-powered 'halo' models, they have not chosen to opt for something meek and downsized.

These companies are not in the business of making ordinary cars. They need only announce the smallest details of a new, more extreme, model to be manufactured in limited numbers, for their order books to be instantly full. It is a privileged position to be in – unless the car is an utter shambles, they cannot possibly fail. Even so, they are producing their most stupendous power units ever. Although the power outputs from these engines could be produced with efficient, boosted V6s, some of these manufacturers are continuing to produce engines with 10, 12 or even 16 cylinders. In a few of these cars, the engine alone produces more than 1,000hp (approximately 750kW).

But with truly impressive battery EV hypercars and brilliant hybrids, why are some manufacturers going for such performance from engines and, in several cases, rejecting common ways of producing performance – such as turbocharging? Even with these most impressive engines, they cannot hope to surpass the initial acceleration of EV hypercars. Very often, these incredible hybrid vehicles fail even to beat the acceleration of the best four-seater EV saloons, which cost a fraction of the price. These new engines power cars whose performance will only begin to exceed that of the EV saloon beyond the first quarter mile of a drag race. In normal driving, ICE and EV hypercars operate in a tiny and relatively inefficient corner of their operating envelopes, projecting potential rather than using it.



The Bugatti Tourbillon features a 16-cylinder engine developed by Cosworth »

With the engine alone, these ICE cars cannot really hope to fulfill their performance brief, despite the multimillion-dollar price tag. Therefore, they require the assistance of hybridization. I am not in the market for any of these cars, but there is clearly a disconnect between performance and perceived value, as there always has been in automotive and the wider world. Why are people willing to pay US\$4m for a car that is, from a practical standpoint, less capable than one costing US\$150,000? Why would someone pay US\$300,000 for an analog watch when a US\$30 digital will perform the same practical function better? The perception of value is the key.

"With the engine alone, ICE cars cannot hope to fulfill their performance brief, despite the multimillion-dollar price tag. Therefore, they require the assistance of hybridization"

In a digital world of electric powertrains that require ever less involvement from the driver, the analog experience of a car with an extremely powerful IC engine – with its characterful output curve and individual noise (of which there is too much in some of these vehicles) – is visceral. However, at the most expensive and exclusive end of the hypercar market, there is room for both pure EV (think Rimac) and ICE-hybrid (think Bugatti/Koenigsegg/Zenro et al).



Cosworth has produced a host of high-revving V12s for premium hypercar applications »

Another important consideration is reliability: how do OEMs equip a passenger vehicle with a power unit that would not disgrace a serious race car? Some of these vehicles boast much more power than anything competing in NASCAR, Le Mans or Formula 1, yet they will provide propulsion not for focused racing drivers in their fireproofs and helmets, but for a handful of very rich customers who will use them rarely.

WHAT ARE THESE ENGINES?

Electric vehicles – from four-seat saloons to hypercars – demonstrate that we need not one single cc to produce stupefying levels of performance. They offer unrivaled initial acceleration, a very easy driving experience and levels of refinement that many luxury car makers have been dreaming of for decades. That quiet, latent performance and the lack of driver engagement are what provide an opportunity for these potentially final great internal combustion engines to be brought into existence.

In some cases, the ICE vehicles are really loud. These engines are not built for quiet refinement; they are built for power and to loudly announce that power. They are designed to run to speeds that are more typical of motorcycles than cars. The track-only RB17 from Red Bull, for example, is powered by a Cosworth 1,000+ hp 4.5-liter V10 spinning to 15,000rpm. The Bugatti Tourbillon will be propelled by an 8.3-liter V16 (also designed by Cosworth), the rev counter of which will touch 9,000rpm and output almost 1,000hp. The Aston Martin Valkyrie is thrust forward by a wonderful-sounding V12 displacing 6.5 liters, revving to over 11,000rpm and again producing 1,000hp. The

Aston engine is also produced by Cosworth. Although the hybridized outputs of the cars built around these engines vary significantly, it seems that 1,000hp is the minimum stake to sit at the table.

What of Zenvo? Did it choose a naturally aspirated engine produced by Cosworth? No, it went next door (almost literally) to Mahle Powertrain to get its 6.6-liter turbocharged V12 producing 1,250hp.



Koenigsegg produces amazing powertrains with incredible power. The twin-turbo V8 in the Koenigsegg Jesko Absolut produces 1,600hp. That car is incredible: 0-400km/h in just over 25 seconds – without electric assistance or 4WD. It is hard to argue that this isn't the most impressive performance car with an IC engine. Koenigsegg has made great strides in engine and transmission control, and this plays a huge part in its ability to transmit such huge performance to the road. However, that power unit has been developed with a different ethos from that of the engines previously described. It is a sledgehammer of a car.

Likewise, Czinger, with its wonderful 21C, is producing almost 1,000hp, but from a boosted 2.88-liter V8. It is designed to be light and nimble. At Goodwood, I spent longer looking at the 21C than I spent looking at all the other road cars combined. Meanwhile, the new Ferrari F80 extracts around 900hp from a turbo V6. Again, these are very impressive engines and it might reasonably be argued that their smaller dimensions (particularly length) and potentially lower overall weight help make a better car. However, from an engineering showcase perspective, it is somewhat less impressive when the power is produced from a small boosted engine rather than a huge, noisy, naturally aspirated one.

Let's discount the Red Bull engine because it might never go into a road car. But be in no doubt that in Cosworth, Red Bull has a partner that can almost certainly push that engine, or something very similar, through the emissions legislation. Companies based in St James Mill Road in Northampton, UK, seem to have a particular set of skills.

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When we look at basic metrics such as performance per unit displacement or mean piston speed, the numbers are not untypical of racing engines from just a few years ago. The fact that these powerplants can be produced, albeit in limited quantities, with the required performance, sufficient reliability, compliance with emissions standards and within strict noise limits is extremely impressive.

I spoke to Mahle about its approach to designing this sort of power unit. The company has a wide range of automotive customers and has designed engines ranging from low-powered range-extendors for series hybrids through passenger car engines ranging from the mundane to the extraordinary to the

superlative engine for the Zenvo Aurora.



"The integrity of the main castings is obviously vital for reliability, especially the

cylinder heads around the combustion chambers”

Reliability is obviously a key concern. When a racing engine company takes a passenger car engine and adapts it for racing, it is looking to provide durability for a very much more severe duty cycle than the system was originally designed for, but over a much shortened lifetime. The challenge for a passenger car engine, even where collectors' cars are concerned, is to produce prodigious performance (should the customer choose to use it that way) but allied to durability that allows the driver to undertake long journeys without worry. Discussing the company's focus on reliability, Mahle Powertrain's director of sales, John Hollingworth, who has been heavily involved in the project, says, "The durability of hypercar engines is paramount, and we take the same approach to their mechanical development as we would with a high-volume engine. Hypercars will likely not do the same mileage as massmarket cars but their owners (and the niche manufacturers) expect the same levels of reliability throughout their lives, especially when the full performance envelope is being explored." He also alludes to what we might deem an abuse case: "Such cars will often be used as demonstrators by dealers and also driven very hard by motoring journalists, and the last thing anybody wants in these situations is a reliability issue."

Hollingworth notes that almost every component in the engine – from castings to more dynamic components – is highly stressed. "The integrity of the main castings is obviously vital for reliability, especially the cylinder heads around the combustion chambers," he says. "Pistons, piston rings, valves, spark plugs, cylinder head gaskets and turbos are also critical in these types of engines. Cooling and lubrication systems are also under very high stress when the engine is running at max output, so the associated pumps and hoses must be robust.

The engine management system and its related hardware (sensors, transducers, etc) also require a lot of focus. Essentially, every component must be diligently engineered as the engine will only be as strong as the weakest part. The Zenvo V12 engine uses more than 650 individual components and we have examined every single one in great detail."



The Zenvo Aurora is equipped with a turbocharged V12 developed by Mahle Powertrain
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EMISSIONS AND COMBUSTION

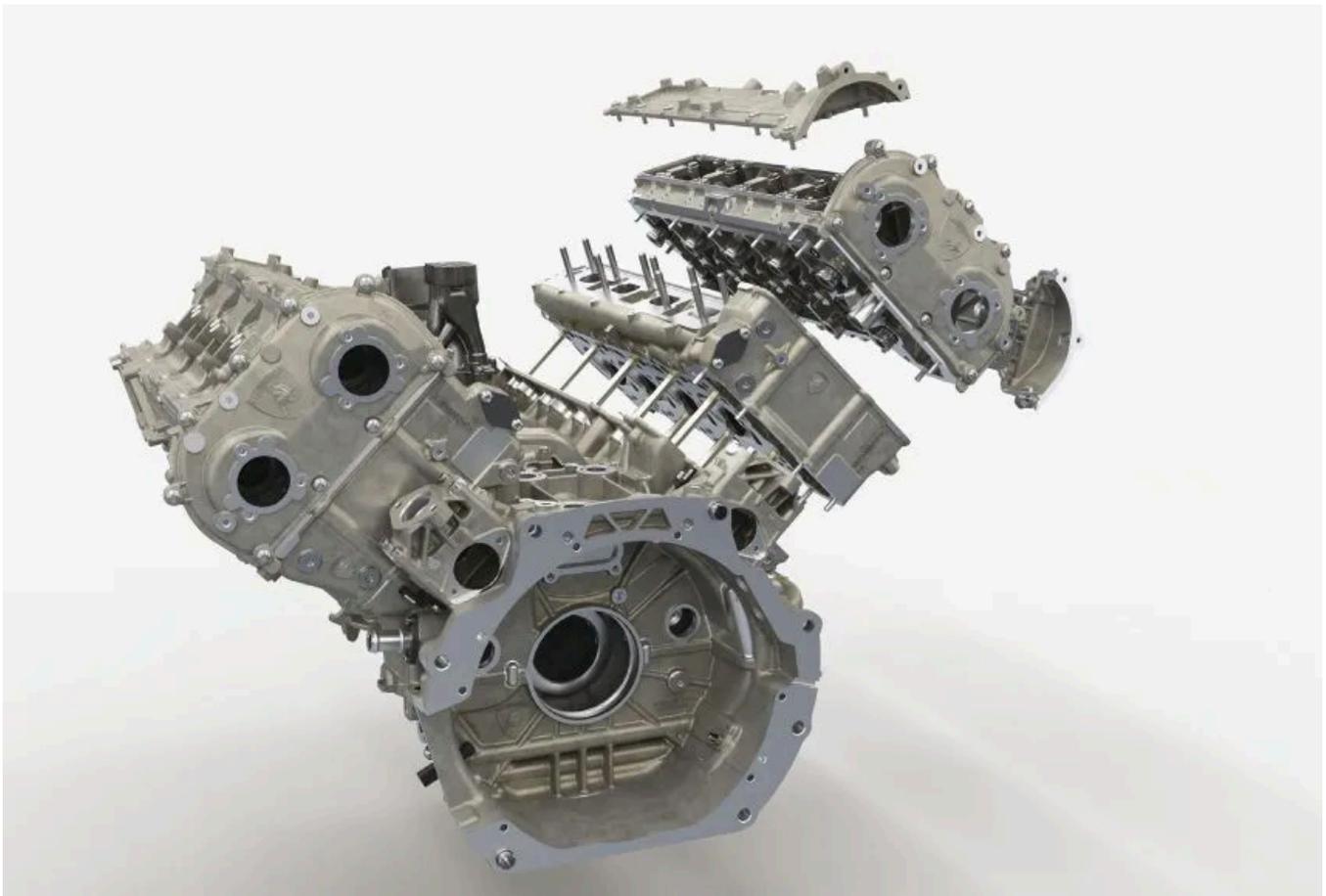
Another challenge with such levels of performance is emissions compliance. Mahle has produced many passenger car engines and is an expert in simulation and modeling of the gas exchange, combustion and emissions. "We are confident, based on our years of experience coupled with highly detailed modeling and simulation, that the Zenvo Aurora will meet all the necessary emissions regulations, including CARB/EPA and EU6b," says Hollingworth.

The company is also using combustion technology that has previously only seen very limited use in passenger car engines, namely passive pre-chamber ignition, which Mahle has been instrumental in developing for several years. One has only to research the work done on passive and active systems to know that the company is probably the leading expert on the design and practical implementation of this technology.

Of the Zenvo engine, Hollingworth says, "The combustion system employs Mahle Jet Ignition, our in-house-developed pre-chamber ignition system, which we know works very well in achieving good combustion efficiency with low emissions, especially NOX. We have developed a cold-start calibration with 48V electric catalyst heating to address this critical area for emissions compliance. The car will use a high-spec hybrid system where the battery and motors provide fill-in torque at low speed to significantly reduce exhaust emissions during catalyst heating and urban driving scenarios."

Like the other notable roadgoing implementation of passive pre-chamber ignition on the Maserati Nettuno engine, the Zenvo V12 has two spark plugs per cylinder: one in the conventional position with electrodes exposed to the chamber and one in the prechamber. Again like the Nettuno engine, the Mahle-developed Zenvo V12 uses both direct and port fuel injection to cover all the performance and emissions requirements.

Also of interest are the four 48V electrically heated catalysts that help improve emissions performance from startup. Zenvo was already producing prodigious performance from a well-understood V8 engine, so what led it to swap to a quad-turbo V12? Surprisingly, it was a project to address the emissions of the V8 that prompted the conversations about a V12. For Zenvo founder Jens Sverdrup, the new engine was a dream powerplant for a halo car. Once the performance brief had been set, displacement and speed were decided. Then came the decision about the number of turbochargers. There are good reasons for both two and four; four were chosen based on a combination of advantageous phasing (three strong pulses per turbo), faster transient response from smaller turbo units and the availability of turbos to handle the mass flow rates. There are many more turbochargers sized for ~300hp than for ~600hp. Quad-turbo is also a selling point for wealthy collectors of exclusive cars; such customers can certainly afford the additional outlay.



Lamborghini's L411 V8 revs to 10,000rpm and uses a P1 hybrid motor arrangement to provide boost infilling to support exceptionally large turbos »

Mahle completed the Zenvo project remarkably quickly. Thanks to the relationship between the companies, preparatory work was done before the purchase order was

signed. The time from the first serious engineering discussions to the first fired test of the engine was around two years. For a clean-sheet production engine of this performance and complexity, this is astonishing.

These engines are never going to be the parsimonious, gasoline-sipping power units that we are increasingly becoming accustomed to in what might be the twilight of the ICE-powered passenger car. They are as unnecessary as they are brash. But they show what is possible.

Why companies like Mahle Powertrain and Cosworth

The specifics of the Zenvo project worked well for Mahle because the company is used to doing clean-sheet powertrain development. Plus, the very limited number of engines being produced over a period of a couple of years means that around one engine per week is required, which perfectly suits Mahle's build capacity on such a project. It has a parent group to call on for some components, but also has an established network of suppliers of low-volume, high-quality components.

Although Cosworth has a long-established relationship with Aston Martin for engine design (think of the Aston Martin One-77, for example), it is primarily known for its motorsport reputation, having produced F1 engines as recently as 2013. Cosworth, like close neighbor Mahle Powertrain, is one of very few companies with the expertise and facilities to undertake such ambitious and prestigious projects successfully.

We all know that many automotive OEMs look outside of their powertrain departments for expertise in powertrain development. If projects like this are to be completed quickly, finding expert companies such as Cosworth and Mahle Powertrain is necessary and desirable.

THE 6.6-LITER TURBOCHARGED V12 ZENVO ENGINE USES MORE THAN 650 INDIVIDUAL COMPONENTS AND PRODUCES **1,250hp**



About the author

Wayne Ward is a powertrain engineer with more than two decades of experience across a diverse range of disciplines. He has had considerable involvement in top-level motorsport with the likes of Cosworth, Honda Racing Development and Mercedes AMG Performance Powertrains, working on ICE and hybrid/electric powertrains. He has also been active in the mainstream automotive sphere as a consultant engineer on electrification and combustion projects and across other industries including nuclear power