WORDS | JACK ROPER

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Jonathan Brown, strategy director, Hypermotive

GREEN FUELS: PART TWO

Do hydrogen internal combustion engines and premium, clean diesel offer better alternatives than bio and renewable fuels for plugging the gaps in rail sector decarbonization?

Fuel for thought

Jonathan Brown believes the hydrogen internal combustion engine (ICE) may prove an apt bridge to decarbonize serving diesel locomotives and socialize hydrogen adoption. As strategy director at Hypermotive, his focus is fuel-cell ecosystems of the further future, but in a previous life at Ricardo Rail, Brown studied hydrogen ICE systems.

"Five years ago, the industrial engine OEMs bought into fuel cell technologies," he explains. "Now, there's been a shift. As fuel cell equipment takes time to decrease in price and prove its field-service robustness and reliability, almost all are redeveloping engines to run on 100% spark-ignited hydrogen."

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GREEN FUELS: PART TWO

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JCB, for example, unveiled a brand-new hydrogen engine at ConExpo 2023 in Las Vegas in March. "Our engineering team made enormous strides in a short time to develop a hydrogen internal combustion engine," explains JCB chairman Lord Bamford. "It already powers a JCB prototype backhoe loader and Loadall telescopic handler."

Hydrogen engines produce only trace CO_2 emissions from atmospheric carbon oxidized in combustion and with aftertreatment, air can come out cleaner than it goes in. Combustion in nitrogen-rich air still creates NOx emissions, but increasing the combustion mixture's air-fuel ratio can diminish these to zero.

"Hydrogen is a future fuel," comments Brown. "But converting to fuel cells is costly while the capacity and expertise to do so at industrial scale continues to develop. Hydrogen ICE is a transition technology which breaks down the challenge, allowing us to develop infrastructure, storage and socialization. Fundamentally, everyone understands engines."

Reutilizing diesel engines

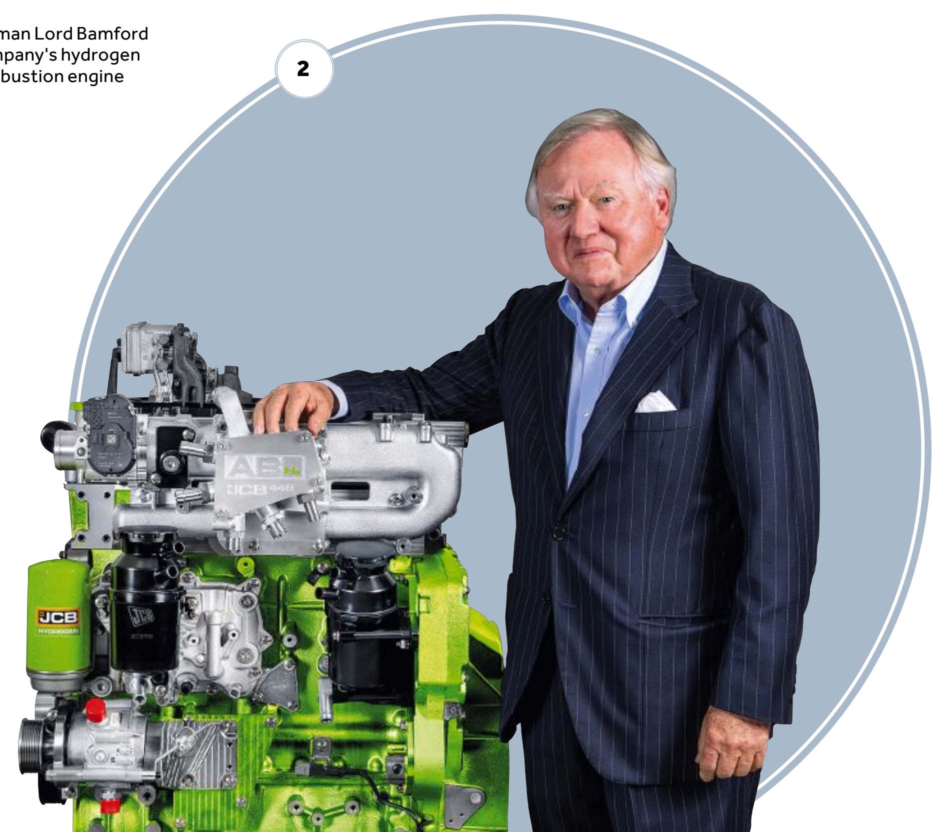
Typically, diesel engines have flat-roofed cylinders and pistons with machined bowls where fuel is swirled and compressed. Conversely, petrol engines have pent-roofed cylinders to provide the volume through which fuel tumbles vertically and correspondingly flat pistons. Locomotive diesel engines thus have flat-roofed cylinders, whereas newly-developed hydrogen ICE engines ideally follow the pent-roofed petrol template.

"We'd probably just replace smaller truck or bus engines," notes Brown. "But binning 12- or 16-cylinder locomotive engines with 30-year lifespans means writing off major capital expenditure. Repurposing cylinder-heads and reutilizing the engine makes far better commercial sense."

This involves a dual-fuel system where hydrogen squirted into the inlet port is ignited by diesel burned under compression. But having two fuel systems increases cost and dilutes emissions benefits by still burning some diesel. Hypermotive's Brown perceives a better way to run diesel engines run on 100% spark-ignited hydrogen.

"We could replace the fuel injector with a spark plug and re-machine cylinder-heads to prevent coolant escaping," he comments. "Ideally, hydrogen is injected into the cylinder, where swirling air draws it down, compresses it and makes it combust. Alternatively, putting hydrogen into the inlet manifold would require less cylinder-head modification, but be less efficient and create a risk of uncontrolled combustion," Brown adds.

The optimal air-to-fuel ratio for stoichiometric combustion is 14.5:1 for diesel, versus about 34:1 for hydrogen. Injecting less fuel would increase the air-fuel ratio but decrease 2MW engine output to 1.5MW or less. 2MW performance could only be maintained by larger or additional turbochargers (with associated cooling) forcing more air into the cylinder. Then comes hydrogen storage.



2. JCB chairman Lord Bamford with the company's hydrogen internal combustion engine

3 & 4. Heion Clean Diesel is combusted in a more eco-friendly manner than conventional B7 diesel. According to the firm, the method is versatile and can be used, for example, to improve biofuels, as well as conventional diesel used in rail traffic

Hydrogen storage challenges

"Liquid hydrocarbons allow energy to be packaged into small, complex shapes," explains Brown. "Even at 700-bar pressure, gaseous hydrogen requires eight times more space in fixed-shape pressure-vessels. The marine industry aims to combine hydrogen and nitrogen into ammonia, transport it at relatively low pressure, then crack it back into hydrogen. That's more feasible for freight than passenger trains because ammonia is whiffy, toxic stuff."

Liquid hydrogen offers better volumetric efficiency but must be stored below -253°C in cryogenic tanks and used almost immediately. Even with optimum insulation, liquid hydrogen would quickly dissipate into gas and need venting into the atmosphere.

"While not itself a greenhouse gas, hydrogen preferentially bonds with radicals which would otherwise convert greenhouse gases and make them inert," Brown explains. "Basically, venting hydrogen is not good."

Freight-train tender-cars could house cryogenic tanks. North American operators seem comparatively receptive, some having piloted tender-cars for liquefied natural gas (LNG) propulsion, but discussion of tender-cars in Europe remains beset by technical objections.

"War prevents us shipping food to Africa. Then we burn crops to make diesel? I think that's unethical"

Andreas Heine, founder and CEO, Heion Clean Diesel

"There's real vigor for hydrogen in the US," says Brown. "The Americans decide something, then throw money at it. The US Government just announced a US$7bn hydrogen hub scheme, whereas the UK has spent about £200m (US$240m) on hydrogen."

Are biofuels unethical?

Brown believes the benefits of biofuels are sometimes overstated. These include FAME (fatty acid methyl esters) and HVO (hydrotreated vegetable oil), known stateside as biodiesel and renewable diesel.

"Tailpipe emissions are similar to diesel, because you're burning similar stuff," he says. "While it may recycle carbon

A NEW APPROACH TO CLEANING, REFINING AND PRODUCING PREMIUM DIESEL FUEL

Heion Clean Diesel's patented process optimizes the emissions profile of conventional diesel by radicalizing then stabilizing diesel molecules in an acoustic reactor and incorporating oxygen atoms for improved combustion characteristics.

"We synthesize regular diesel with water and change its chemical structure to produce premium diesel with a higher cetane number," explains founder and CEO, Andreas Heine. "It results in 9% lower consumption, 16% less NOx, 75% less soot and up to 10% less CO_2 emissions. Consequently, it improves the longevity of filters and mechanical parts."

In Europe, Heine says Clean Diesel can be sold and used in any diesel engine without modification. "It meets Euro Norm (EN) 590 requirements," says Heine. "Those include cetane number, index, density, and sulfur content. There's no legal way to stop us selling it."

The system is novel in its application of industrially mature acoustic reactor technology (used in wastewater treatment) to diesel reformation. Heion's trailer-housed modular solution is readily deployable to fuel terminals and more energy-efficient than other replacement fuel production methods.

"It's a floating process," adds Heine. "Diesel and water are stirred together then pumped into a chemical reactor, which produces clean diesel and reusable water. Only the pumps need power, potentially from solar panels."

Shell subsidiary Schuster & Sohn successfully road-tested the fuel for two years and Heion recently sold its first industrial unit into a diesel terminal in Kaiserslautern, Germany. Captrain subsidiary Dortmunder Eisenbahn is also testing Clean Diesel on German railways.

"We've seen savings," Heine reports. "The locomotives run smoothly. One driver says it makes them more powerful. Once results are published, we will take orders from other railroads. The market is huge: Deutsche Bahn alone needs 400 million liters of diesel a year."

5. Wabtec concept image of a potential hydrogen locomotive

WABTEC'S WORK ON HYDROGEN DIRECT INJECTION

Beyond near-term use of biofuels in diesel locomotives, Wabtec is focused on a spectrum of future decarbonization technologies, including hydrogen direct injection.

"We're investing now for future enablement," says Wabtec vice president of project management, Robert Bremmer. "Several years ago, we invested in an LNG combustion engine. LNG was piped from an attached tender-car into the engine and burned.

"Hydrogen direct injection is a similar concept," he continues. "Liquid hydrogen would be stored at -253°C in a fuel-tank or tender-car, piped up to the engine and ultimately injected into the cylinders."

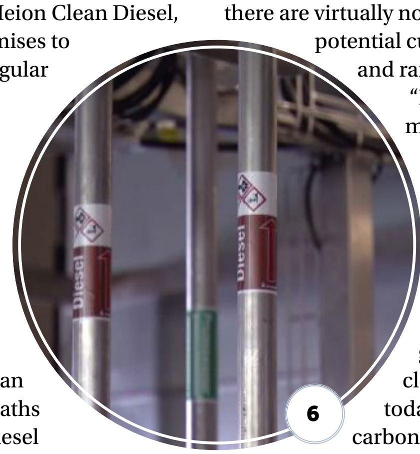
Burning hydrogen would entail more significant modifications to locomotive hardware than today's biofuel blends. "It requires slightly different pumps, nozzles and injectors," says Bremmer. "The main engine-block, power-assemblies, water-pumps, and turbochargers remain the same. It would just be an upgrade kit on specific components."

But unfortunately, the supply and supporting infrastructure needed to switch locomotives to hydrogen does not yet exist in North America. "By 2030, the projected supply of hydrogen would only satisfy 5% of fuel demand from North American railroads," adds Bremmer. "That's why we're pacing our investment. We're probably a decade away from this becoming a viable solution for North American railroads."

> "Liquid hydrogen would be stored at -253°C in a fuel-tank or tender-car, piped up to the engine and ultimately injected into the cylinders"
>
> ***Robert Bremmer,*** vice president of project management, Wabtec

absorbed by plants, its farming and processing can create significant carbon impacts, depending on the source. It's certainly no zero-emissions panacea. Replacing all the fuel used today with biodiesel would also leave insufficient space to farm food."

Andreas Heine founder and CEO of Heion Clean Diesel, whose acoustic reactor technology promises to improve the environmental profile of regular diesel [see *A new approach to cleaning, refining and producing premium diesel fuel*, page 25], echoes this sentiment. "Every year, thousands die from malnutrition," says Heine. "War prevents us shipping food to Africa. Then we burn crops to make diesel? I think that's unethical."



Heine sees little prospect of diesel becoming irrelevant, with steady or increasing global demand driven by Asian economies with over 500,000 annual deaths from respiratory illness. Heion Clean Diesel offers scalable mitigation seeking a route-to-market.

"We either find a global industrial partner to work with or sell the patent – that's the easiest way – or grow organically," adds Heine. "We're within EN 590 and patent-protected in all major markets. It's only a question of when and how we enter the market."

Diesel alternatives

Heion will target North American markets under the brand-name US Diesel, adapting its system to produce diesel whose chemical structure matches US specifications. Since there are virtually no diesel cars, US Diesel's potential customers are the truck and railroad sectors.

"For us, the US railroad market is 20 times bigger than Europe," comments Heine. "It has 40,000 diesel locomotives and 99% of the grid runs on diesel. Not everyone there believes in climate change, but that is beginning to shift," he adds.

Another diesel alternative is gas-to-liquid (GTL) fuel, a relatively clean-burning paraffinic diesel made today from natural gas with a 15% smaller carbon footprint than standard diesel.

"GTL becomes a positive option if we could make it from captive biomethane," adds Brown. "Fugitive methane from rotting agricultural biomass is 30 times more potent than CO_2 as a greenhouse gas. Converting that into diesel would actually have a positive net-impact. There aren't many people selling that now."

> **Gas-to-liquid (GTL) fuel is a relatively clean-burning paraffinic diesel made from natural gas with a 15% smaller carbon footprint than standard diesel**

6. Heion Clean Diesel reduces consumption and thus CO_2 emissions by up to 9.3% when compared to conventional diesel