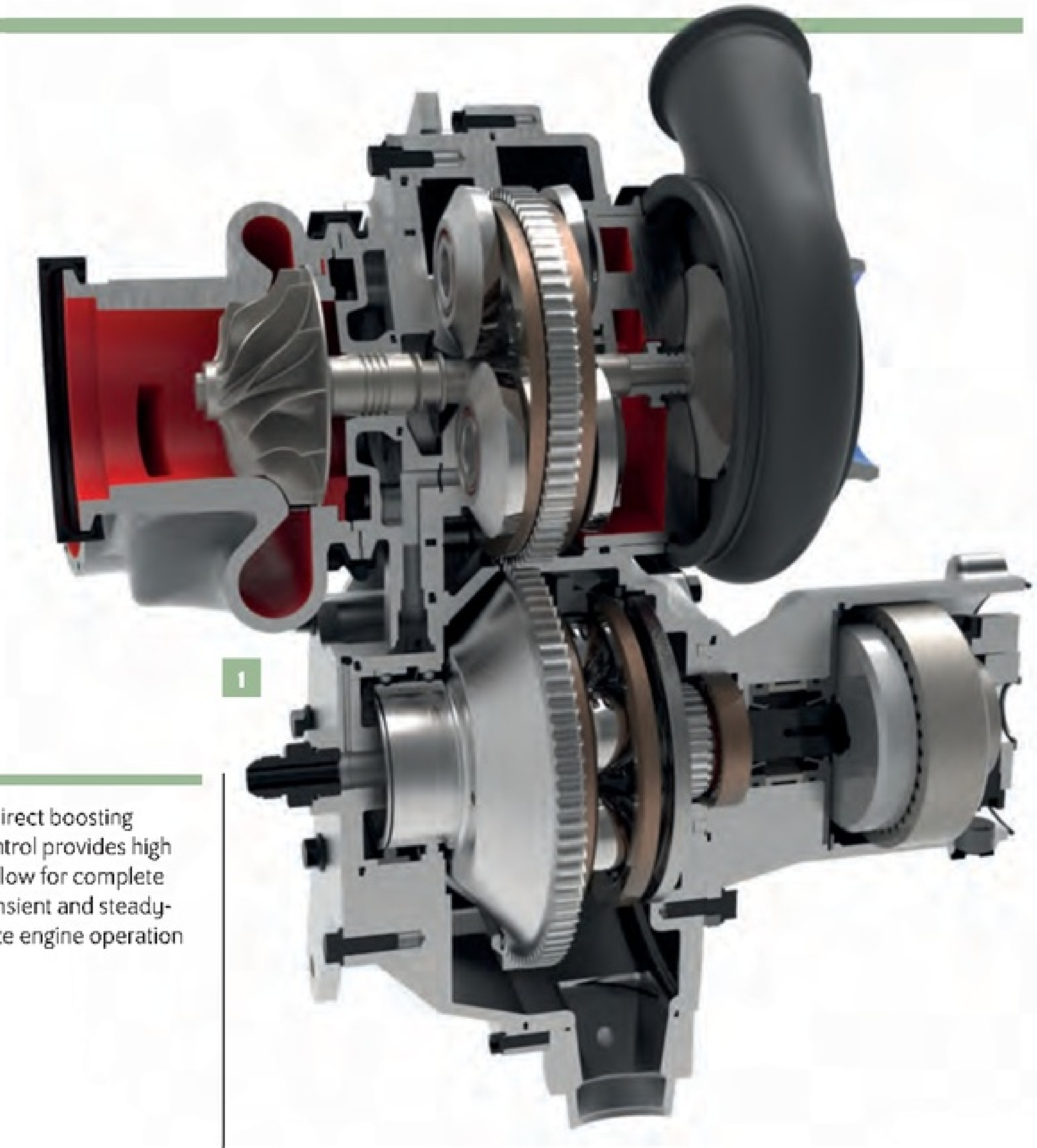
Boosting hydrogen

A mechanically driven turbocharger system offering bidirectional power transfer and speed ratio control can improve air management in H_2 engines



1. Direct boosting control provides high airflow for complete transient and steady-state engine operation

The push to decarbonize transportation is more urgent than ever. This is felt particularly in the hard-to-electrify commercial vehicle industry. Decarbonization, in combination with ultra-low pollutant regulations, requires a fundamental shift in powertrain architecture for both on-highway and off-highway applications. One of the most cost-effective and up-and-coming solutions being developed worldwide is the hydrogen internal combustion engine. However, this emerging powertrain faces a unique set of challenges.

There are fundamental issues that must be addressed before hydrogen engines can form a major part of the future automotive landscape. This includes achieving acceptable transient cycle torque response, maintaining low NO_x through transient cycles and along the lug curve, improving H_2 ICE brake thermal efficiency (BTE), avoiding hydrogen slip conditions and improving H_2 ICE power density and brake mean effective pressure (BMEP).

The SuperTurbo system addresses these issues. The SuperTurbo is a mechanically driven turbocharger that enables bidirectional power transfer and speed ratio control between the turbocharger and the engine. It is an on-demand boost system that responds to the engine's command for airflow. The exhaust-powered turbine delivers energy to the compressor and also mechanically to the crankshaft. The crankshaft can also deliver additive power to the compressor or receive excess exhaust power from the turbine. It combines and improves upon the capabilities of a supercharger, turbocharger and turbocompounder.

EFFICIENT POWER

The majority of hydrogen engines use injection/combustion architectures that rely on lean burn strategies to control NO_X formation. These systems need to continuously hold high air/fuel ratios at $\lambda>2$, which creates unique challenges for engine boosting. NO_X formation increases exponentially when λ decreases, to a point where aftertreatment systems will struggle to keep tailpipe NO_X compliant with new standards. This effect is most obvious during transient engine operation. There simply is not enough exhaust/turbine power available for what is desired from the compressor. This can force a difficult decision when engine tuning. The engine can either run the desired (or cycle-prescribed) torque response and have large NO_X spikes, or the torque response must be slowed to maintain high λ and low NO_X. The SuperTurbo overcomes this by efficiently adding supercharging power from the crankshaft to assist the turbine and provide rapid airflow response. The result is a full cycle, low NO_X hydrogen engine with torque response similar to a diesel.

Hydrogen engines also need an increase in efficiency to improve both vehicle range and long-term total cost of ownership, especially when compared to a fuel cell powertrain. Unlike during transient engine operation, hydrogen engines do offer sufficient steady-state exhaust/turbine power for energy recovery. The SuperTurbo uses any available excess exhaust power and returns it to the engine via mechanical compounding. Precise air control in combination with compounded power improves BTE. The control of airflow also supports a variety of engine architectures. The SuperTurbo enables EGR control independent from fresh airflow, and EGR can reduce the need to solely control NO_X with lean burn, often resulting in more optimal lug curve compressor limits and efficiency. This can enable a simultaneous increase in engine power and engine efficiency as well as lower NO_X.

In partnership with AVL, the SuperTurbo has been evaluated on a 13-liter hydrogen commercial engine. When compared to a variable geometry turbocharger (VGT) the transient torque response was improved by over 50%, the steady-state lug curve engine-out NO_X was reduced by 50% and the steady-state BTE was improved by up to 2%. The SuperTurbo is currently undergoing diesel-based design verification testing in preparation for start of production (SOP). Parallel hydrogen combustion engine evaluation and testing will be accelerated to address unique customer requirements for hydrogen powertrain architectures. ⦿