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An Introduction to Dual-Fuel™ Technology

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Overview

The following document provides an introduction to Dual-Fuel™ Technology which is being pioneered by Clean Air Power and will be showcased at the European Road Transport Show taking place from 26th October 2007 until 3rd November 2007 in Amsterdam RAI, The Netherlands.

Dual-Fuel™ Technology

Dual-Fuel™ uses patented electronic control of diesel pilot injection to ignite a controlled pre-mixed charge of NG and air.

The system incurs no change to the base diesel engine, which runs according to Diesel's 4-stroke cycle, at high compression ratio with compression-ignition of a lean fuel-air mixture. The non-intrusive nature of the technology enables a Dual-Fuel™ engine to operate on 100% diesel in the absence of NG.

The high compression ratio of the diesel engine can be retained due to the high auto-ignition temperature of methane (352°C higher than diesel). Where spark-ignited NG engines have issues with the ignition of lean mixtures, the Dual-Fuel™ engine overcomes this with the diesel pilot injection. This pilot injection provides a multitude of ignition sites as the diesel spray droplets auto-ignite under compression. The result is that the Dual-Fuel™ engine can run with Lambda (excess air ratio) $\lambda \leq 2$.

Pilot injection is well understood and can be delivered by conventional diesel FIE. As with diesel combustion, the introduction of a pilot injection reduces the pre-mixed combustion phase. Similarly with Dual-Fuel™, the small diesel pilot results in minimized diesel pre-mixed combustion. This is the first mechanism for the reduction of both NOx emission and combustion noise.

Figure 1a and 1b show a comparison of fuel heat-release between diesel combustion and Dual-Fuel™ combustion. Clearly, the pilot injection in the case of Dual-Fuel™ is responsible for the elimination of the significant pre-mixed combustion phase.

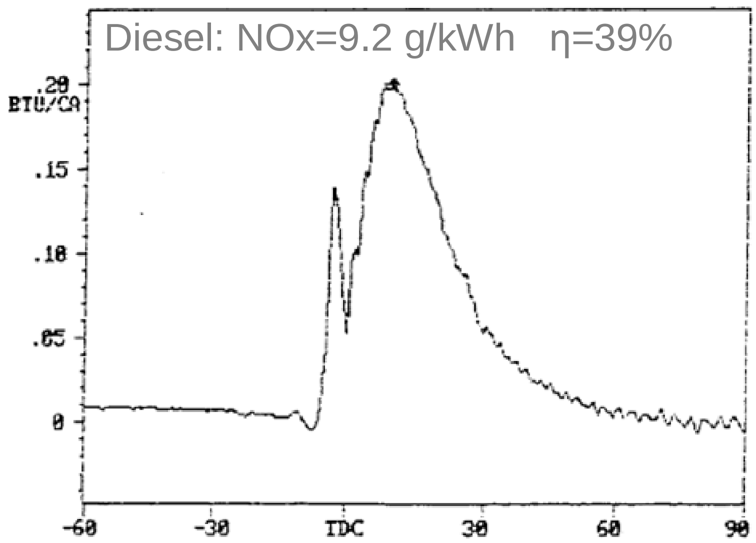

Figure 1a: Diesel Combustion Heat Release at 1800 rpm 70% load

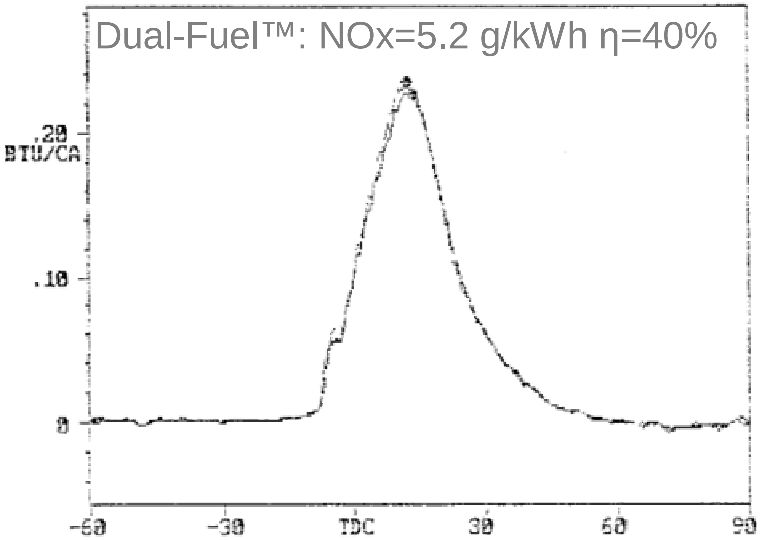

Figure 1b: Dual-Fuel Combustion Heat Release at 1800 rpm 70% Load

Also of note in Figure 1 is the similarity of the overall combustion event. Dual-Fuel™ is a hybrid combustion system, combining conventional diesel combustion with homogeneous gas combustion.

Both systems respond according to conventional understanding. Figure 2 shows how NOx is reduced with increasing λ, as expected from lean-burn NG engines.

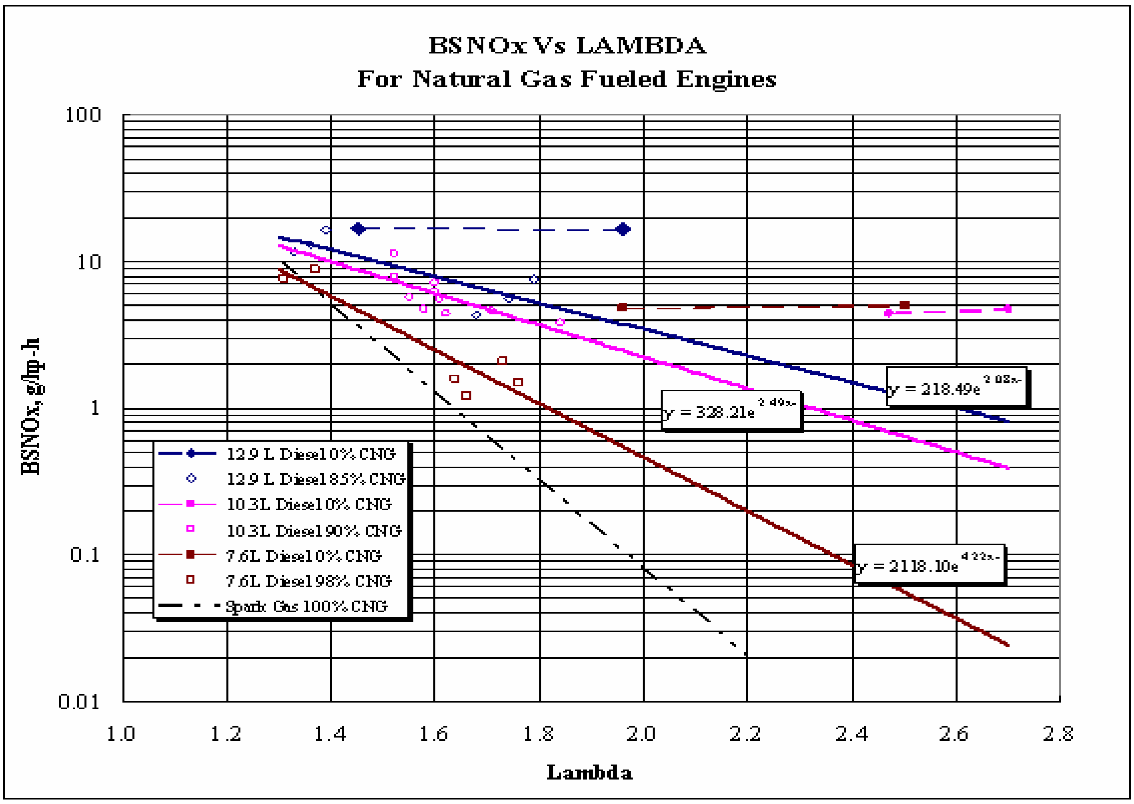

Figure 2: Reducing NOx with Lambda in NG Engines

Overall, the Dual-Fuel™ engine maintains the efficiency of the diesel engine, whilst delivering low NOx. Figure 3 illustrates how lower NOx is achieved from Dual-Fuel™ operation in a back-to-back engine test running at common conditions of similar efficiency.

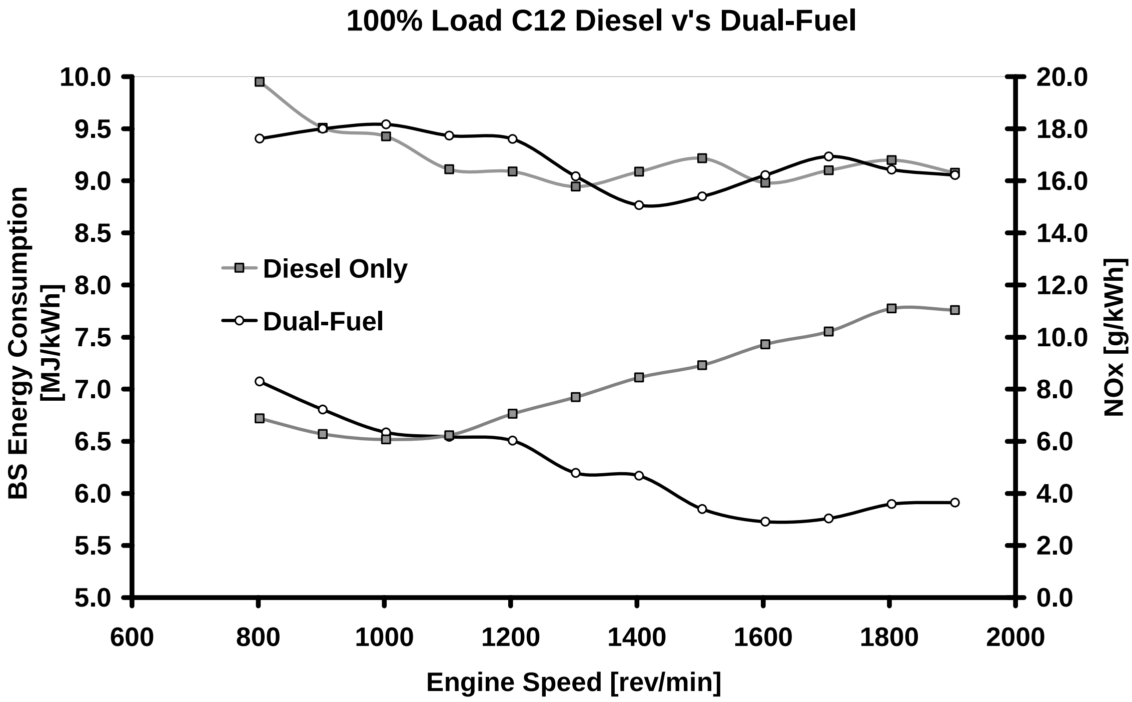

Figure 3: NOx and Efficiency at Full Load from Diesel and Dual-Fuel

By maintaining similar thermal efficiency and similar combustion rates, overall heat rejection to the coolant and the exhaust temperatures are similar to those of the base diesel engine operation. Figure 4 shows exhaust temperature comparisons between Dual-Fuel™ operation and conventional diesel operation of the same engine.

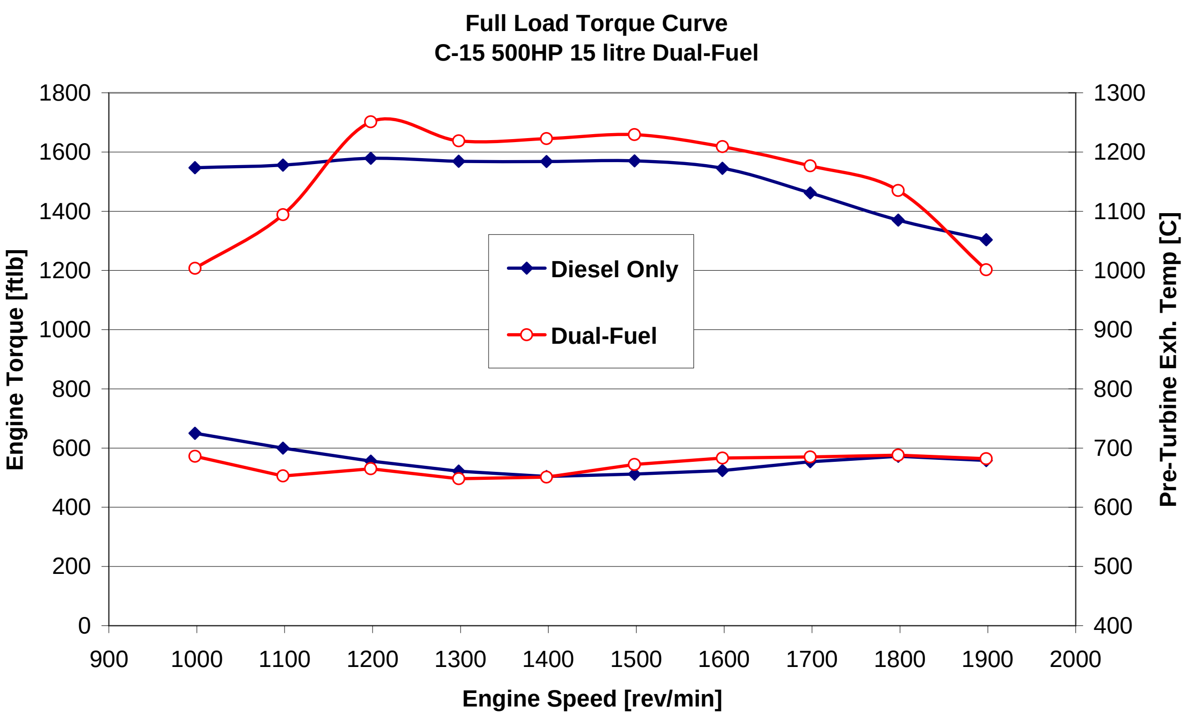

Figure 4: Diesel to Dual-Fuel Exhaust temperature at full load conditions

Dual-Fuel™ imposes no additional thermal or structural load to the diesel engine. Durability testing, investigating oil quality and wear concluded that Dual-Fuel™ operation will result in less wear and extended oil-change intervals (SAE972664). This conclusion was mainly attributed to the reduction of soot-in-oil from the inferred reduction in soot-based PM from the combustion of NG.

The emissions potential of Dual-Fuel™ has been demonstrated by independent, collaborative research. As the combustion system is based on diesel principals, the system responds to improvements in diesel technology. Previous work has demonstrated how emissions are reduced with reducing pilot quantities and increasing injection intensities. Such approaches have been patented. Today, advanced diesel FIE is capable of delivering such "Micropilot" and delivering the associated emissions reduction capability. Dual-Fuel™ has also been combined with EGR and demonstrated significant NOx reduction potential. From US DOE funded research, NOx levels of 0.5 g/bhph were achieved on US-heavy-duty cycle tests with a Dual-Fuel™ C-12 engine operating cooled EGR.

Figure 5 illustrates the demonstrated emissions and the obvious potential of the Dual-Fuel™ system when combined with contemporary Euro 4 or US2007 engine hardware.

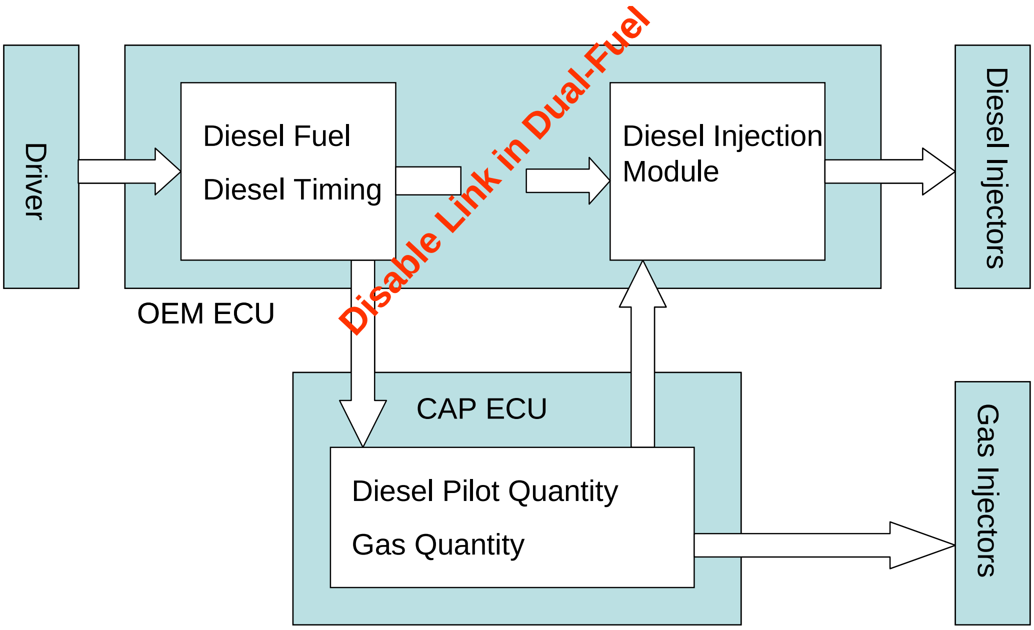

Figure 5: Potential of Dual-Fuel combined with contemporary "Euro 4" or "US07" diesel engine hardware

Dual-Fuel™ Control System

The engine operation is controlled by a patented Dual-Fuel™ engine management system (EMS) via a separate, integrated electronic control unit (ECU). The Dual-Fuel™ ECU communicates with the OEM engine ECU to regulate accurate delivery of diesel pilot injection. The Dual-Fuel™ ECU is electronically integrated into the software of the OEM EMS. It takes the diesel demand signal and calculates new pilot diesel quantity and timing and gas injection quantity based on accurate and predictive air flow calculations. Figure 6 illustrates simply how the two ECU's are integrated to deliver control of both diesel and gas.

Unlike normal diesel combustion, Dual-Fuel™ combustion is governed by accurate control of the air-fuel-ratio (AFR). Whilst Dual-Fuel™ combustion operates at similar AFR to diesel, boost air is accurately and rapidly controlled via a turbo by-pass valve. Accurate control over AFR is required to avoid combustion knock (detonation) or miss-fire.

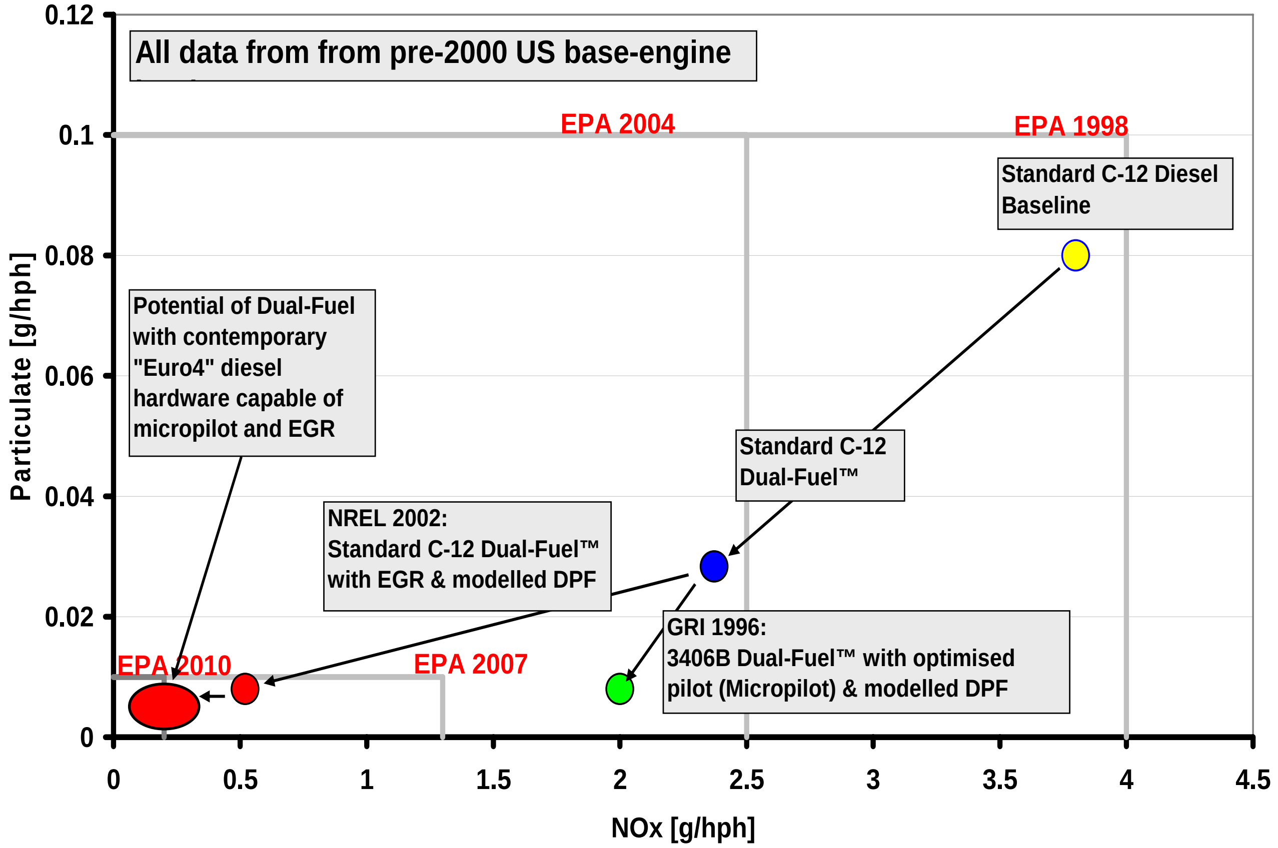

Figure 6: General ECU Integration Layout

Clean Air Power's new EMS, the "Hawk", is powered by the Mototron Motohawk 565-128, running a Motorola 565 microprocessor. This state-of-the-art EMS platform enables Clean Air Power to exploit it's patented use of the controller area network (CAN) to interface with the engine and vehicle systems. The new EMS features closed-loop control of air-fuel-ratio, dedicated dual-knock detection systems and adaptive strategies to cope with gas composition variation. This new platform was developed with software engineering support from Ricardo UK, ensuring the software is to the best automotive practice and standards.

The Dual-Fuel™ ECU is fitted with on-board-diagnostic features and can detect faults with the operating system as well as detecting instances of combustion knock. If a significant fault is detected, or loss of NG fuel pressure, the control system will revert back to 100% diesel vehicle operation at the next engine cycle with near undetectable transition.

For further information please visit http://www.cleanairpower.com

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