Heavy Duty Dual-Fuel Engines

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The technology delivers 20% fuel cost saving and carbon reductions.
- Originating in 1980’s California, CAP has pioneered Dual-Fuel technology to enable Heavy Duty Trucks to operate on natural gas & diesel.
- 70 patents (granted & pending) and over 30 years of Dual-Fuel experience.
- Only developer of Dual-Fuel technology to supply OEM on-line assembly.

Over 2500 vehicles in operation in Europe, N America, Asia & Australia.
Dual-Fuel Target Market Segment

**OPERATOR FLEET COSTS**

- Fuel: 38%
- Salaries: 14%
- Vehicle: 8%
- Maintenance: 13%
- Other: 27%

- Operator costs are dominated by fuel cost
- Other costs cannot be reduced
- Cost of diesel is not reducing
- Very limited scope to reduce fuel cost

- Dual-Fuel is ideally suited to heavy-duty transport
- Other efficiency-improving / low C technologies are not effective in the HGV sector
NGV Market Developments

- The global market for NG Trucks is expected to grow at a compound annual growth rate of 14% between 2012 and 2019*
- Growth is fuelled by NG availability, cost & environmental benefits, energy security and vehicle technology availability

*Source: Pike Research 2012
Dual-Fuel™ Engine System

**Air System**
- Boost control system, VGT or CAP’s boost bypass valve

**Gas Injection System**
- CAP Electronic gas injectors
- Single or Multi point injection
- Compatible with LNG or CNG

**Hawk™ Control System**
- Woodward ECU
- Sensors
- Harnesses
- CAN interface
Developments in Dual-Fuel Technology

- VCA-Approved Euro 5 compliance on Euro 5 base-engine
- No base-engine changes
- Similar efficiency
- Lower greenhouse gas
- 100% diesel fall-back
- On-line OEM production
Developments in Dual-Fuel Technology

- Focus on US market since 2010
- Concept project delivered 13 litre US 2010 Dual-Fuel engine without SCR
- Complex base engine:
  - Advanced boosting system
  - Cooled, modulated EGR
  - HP common-rail FIE
  - Base engine requires SCR to meet US2010 (0.2 g/bhph NOx)
- Complex Development
  - Multi-variable development
  - DoE
    - New combustion system concepts
- Dual-Fuel engine achieved less than 50% of the baseline NOx with same engine systems and no SCR
Low NOx Combustion Development

- Performance matched with 50% lower NOx
- Maximum load is limited by knock; influenced by
  - Rich limit
  - Comp. ratio
  - ACT
  - EGR / NOx
- Torque and power matched to:
  - 160 Nm/litre
  - 25 kW/litre

Full-Load Performance Comparison

- Dual-Fuel
- Diesel

Engine Speed [rev/min]

% Max Load

800 1000 1200 1400 1600 1800 2000
Low NOx Combustion Development

- Less than 50% baseline NOx achieved over the 13-Mode cycle
- Compliant with US2010 without SCR
- Similar levels of EGR used to base diesel engine
- Improved tolerance to EGR exhibited by Dual-Fuel system
- Improved combustion rates
- Efficiency maintained

EPA 13-Mode Comparison

BSNOx

% Max. BSNOx Emission

Scope: Diesel, Dual-Fuel

Mode: 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
Low NOx Combustion Development

- Efficiency improved with 50% lower NOx
- Similar cycle:
  - Same comp. ratio
  - Lean operation
  - No throttled operation
- Dual-Fuel exhibits similar $\eta_{\text{therm}}$ with lower NOx
- Similar exhaust temperatures
- Similar heat rejection to coolant
Low NOx Combustion Development

**In-cylinder analysis**
- Improved burn-rate observed
- Dual-Fuel exhibiting higher tolerance to EGR
- Combustion rates improved leading to more favourable NOx-Efficiency trade-off
- Limited analysis undertaken
- Now the subject for further research at Brunel University
Low NOx Combustion Development

- Engine test results demonstrated significant reductions in engine-out CH$_4$ emission.
- Pilot injection strategy included multiple pilot injections early in cycle to allow homogeneous pre-mixed combustion of diesel & gas.
- Significant improvements in CH$_4$ engine-out emissions can be made from engines equipped with EGR & multiple pilot capability.
**Low NOx Combustion Development**

**Greenhouse Gas (GHG)**
- Overall THC increases due to methane emissions
- Methane emission is off-set by lower CO2 and NOx emission
- Total GHG is reduced by c.5%
- Application of oxidation catalyst will bring further improvements
- New combustion system concepts exhibit potential to dramatically reduce methane emission

![EPA 13-Mode Comparison](image-url)
Well-To-Wheels Analysis

WTW analysis of Dual-Fuel using bio-methane shows GHG reductions of 40.1 to 64.2%

Source: CENEX UK. WTW Field trial studies conducted in 2009
Conclusions

- Natural Gas is the next major road-fuel
  - Availability (new extraction technologies & abundance)
  - Major oil & gas companies’ infrastructure, supply & extraction
  - Cost (lower than diesel)
  - National energy security
  - Environmental benefits (route to bio-methane too)

- Dual-Fuel will form part of the matrix, providing a secure and reliable NG option for HGV operators who require the attributes and fall-back of a durable heavy-duty diesel engine

- Dual-Fuel has demonstrated reliability and robustness as on OEM factory-fitted option at Euro III and Euro V and has shown the potential to meet challenging US and future EU emissions regulations.