



What is Dual-Fuel™ ?

Steve Whelan

Technology Director

What is Dual-Fuel™ ?

- A Dual-Fuel™ engine is a diesel engine
- The Dual-Fuel™ engine runs on Diesel and Natural Gas, simultaneously
- Small pilot injection of diesel ignites gas mixture
- Average diesel-to-gas substitution rate from 60% to 85%
- Engine can still run on 100% diesel at any time



What is Natural Gas?

- Naturally occurring as Methane – CH₄
- Lowest carbon content of all fossil fuels (only hydrogen, H₂ is lower)
- Methane is a natural product of organic decomposition
- Natural gas burns cleaner than any other fossil fuels, which contain larger, more complex carbon-chain molecules (including toxins)
- Natural gas burns with virtually no particulate mass emission, low NO_x & almost zero toxic emission
- Methane is a greenhouse gas, but transport emissions of methane are insignificant compared to agricultural, industrial and naturally occurring sources
- Methane is an abundant, sustainable, and clean world-fuel

Dual-Fuel™ Delivers Two Product Streams

Dual-Fuel™ Technology

“Genesis” product

Simple & Effective

Retro-fit

Operator benefits



“Integrated” product

Integrated software

Production fit

Ultimate benefits

Dual-Fuel™: A Diesel Engine, Burning Gas

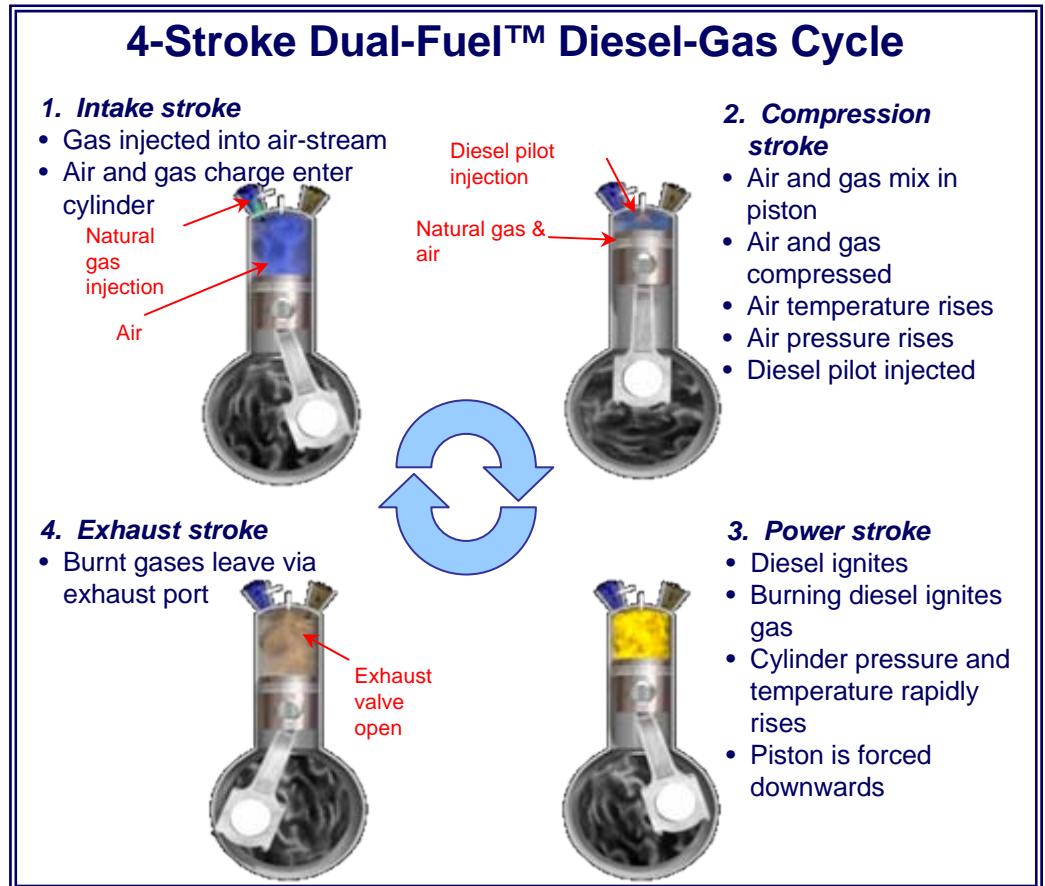
■ No change to the basic diesel engine

■ Operates just like a diesel engine, but it burns a cleaner fuel

■ Diesel efficiency

■ Diesel performance

■ Lower CO₂ & emissions



Engine System Hardware

a. Gas injection system

- Electronically controlled gas injectors installed in modified air inlet manifold

b. Turbocharger Air Bypass (TAB)

- Fast and accurate control of air-fuel-ratio

c. Dual-Fuel™ Electronic Control Unit (ECU)

- Controls/Integrated with engine OEM's ECU
- New generation Dual-Fuel™ ECU ready in 2007

Examples from Caterpillar engine installations

a.



b.



c.



Dual-Fuel™ Vehicle System Gas Storage

- Dual-Fuel™ can operate from CNG or LNG gas containment:
 - CNG Compressed Natural Gas – widest availability
 - LNG Liquefied Natural Gas – highest energy density



Dual-Fuel™: Safety Factors - Vehicle

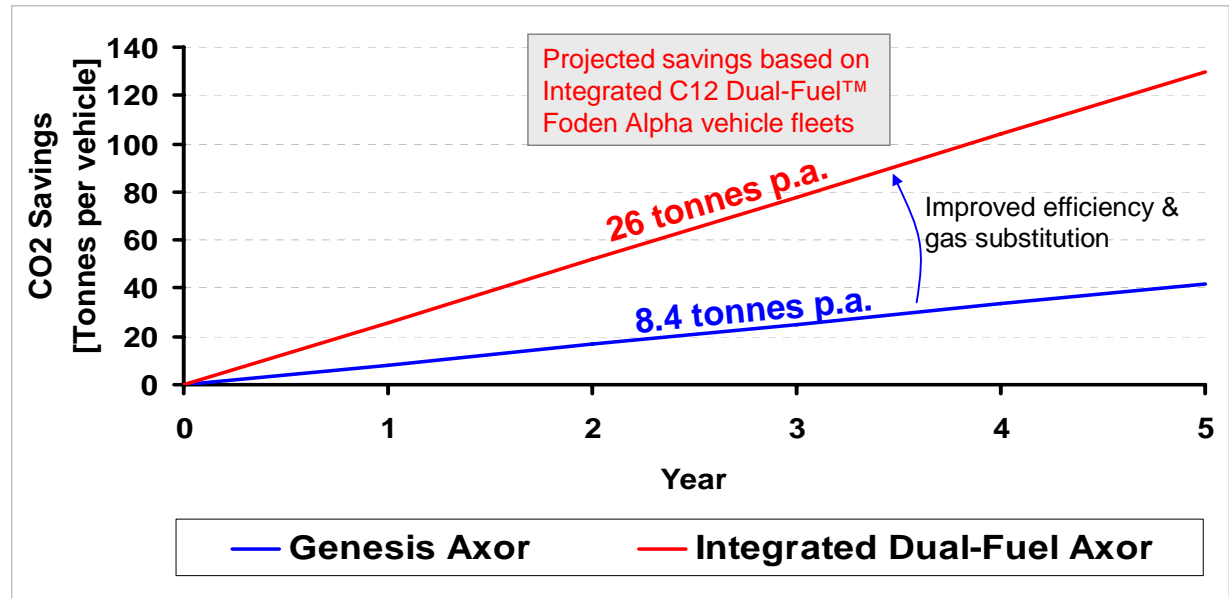
Dual-Fuel™ truck – safety controls:

- Stored in tanks stronger than diesel tanks (impact tested)
- Inbuilt features to prevent over-pressurisation (burst valves)
- Inbuilt features to prevent uncontrolled gas release (rapid shut-off valves)
- Individual tank isolation (stop valves)
- Inertia switch
- Anti drive-away system
- Anti tank movement system
- Automatic gas system isolation solenoid
- High pressure fully tested gas pipework

Performance & Emissions

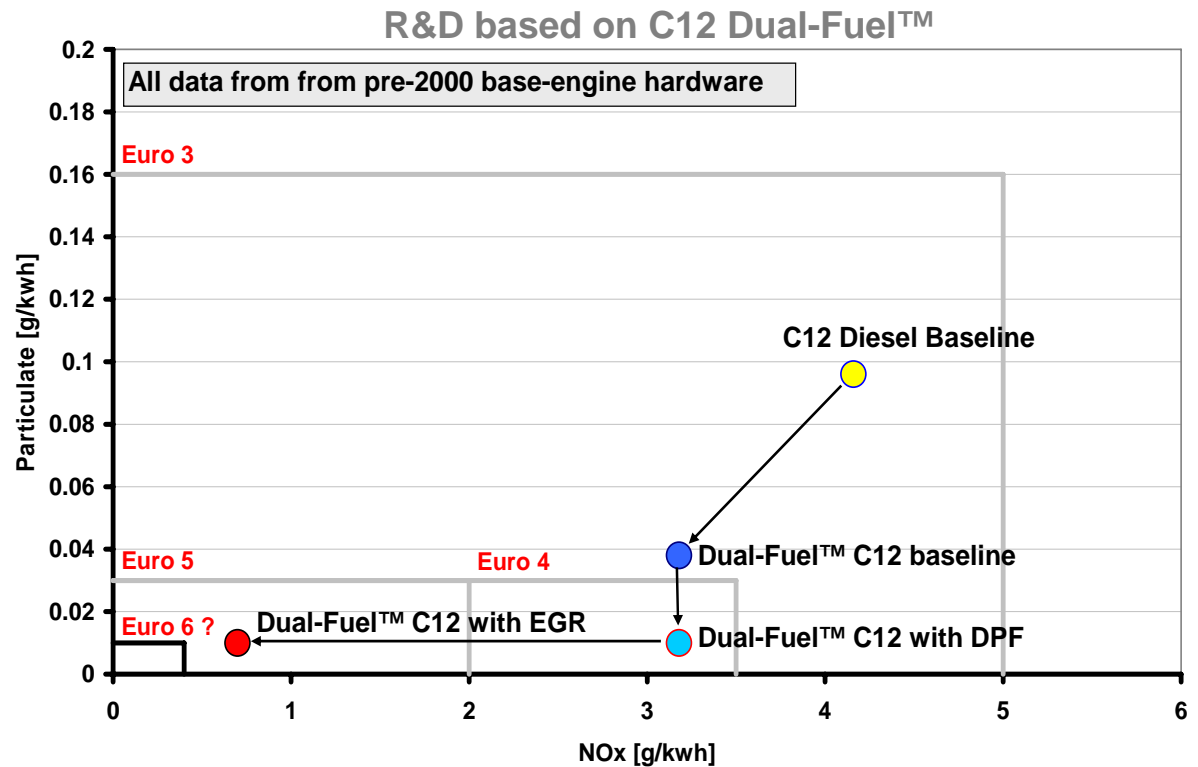
Integrated Dual-Fuel™ systems have demonstrated:

- Diesel-like performance – “drives like a diesel”
- C12 Euro 4 420HP
- C15 US2000 500HP
- Euro 4 from Euro 3 baseline engine
- c. 20% lower CO₂ than baseline diesel



Potential for Euro 6 and US 2010

- R&D has already shown a clear path to Euro 6 and US2010
- R&D conducted on pre-2000 base engine hardware
- Significant potential exists on Euro 4 and US07 base-engine hardware
- Dual-Fuel™ responds favourably to EGR and advanced diesel injection systems





Dual-Fuel™ and Bio-Fuels

- Dual-Fuel™ can operate on Bio-Diesel and Bio-Gas
 - Bio-Diesel pilot injection
 - Bio-Gas is methane – usually higher purity than natural gas
- Dual-Fuel™ enables the practical use of Bio-Fuels
 - Requires much less Bio-Diesel (60-85% less)
 - Efficient combustion of waste-produced Bio-Gas
- Bio-Diesel has low-yield and cannot satisfy supply demand
 - EU set-aside land could only provide 1.5% of EU road-fuel needs*
- Bio-Gas gives 3-4 times the range of Bio-Diesel (per hectare)**

* CONCAWE 2002 "energy and greenhouse gas balance of Bio-Fuels for Europe - an update" (5.6 MHa)

** Business Region Göteborg "Fuelling the future" 2006