Landi Renzo experience with Dual Fuel systems

GFV Workshop

Bruxelles, 13/12/2012

Agenda

- **History of Diesel Dual Fuel in Landi Renzo**
- **Integrated Technical Approach**
  - **Components**
  - **Layouts**
  - **Targets & Optimization**
  - **Applications**
  - **Reliability & Safety**
  - **Homologations**
- **Conclusions & Perspectives**

History of Diesel Dual Fuel in Landi Renzo

- 80s: Dual Fuel experience on Buses:
  Mechanical Diesel pump systems and CNG mixer systems

- 2007: Engine test bench: 2800cc, Common Rail
- 2008: LCV vehicle for drivability experience

- 2009: Passenger Car: retrofit approach on 1900cc, Common rail
- 2010: Experience with HDs

- 2011: First Homologation Passenger Car (Italian regulations)
  Homologation Euro II HD
  First applications for urban mobility and trucks
  Focus on pollutant vehicles currently in use

- 2012: Homologation Euro III HD (2 engines)
  Homologation Euro 4 LD
  Further extension to different applications

LANDIRENZO INTELLIGENT MOVING
VEHICLE TRACKING TECNOLOGY

Dual Fuel in European Community

Technology	CO_2 Benefit (AEA/Ricardo)	NAS (2010) CO_2 Benefit
Dual Fuel Systems	10 – 20%	N/A
Variable flow / Electric Water pump	0.7% for variable flow 1 – 4% electric	N/A
Variable speed oil pump	1 – 3% possible	N/A
Hydrogen fuel cells	100% - tailpipe reduction only	N/A
Electric Vehicles	100% tailpipe reduction	N/A
Stop / Start Hybrid	HGV: 0 – 3%, average 1% Intercity / Coach: Up to 15%, average 3% City / Bus / Utility: Up to 30%, average of 6%	N/A
Mechanical Turbocompound	3 – 5% - best for long haul applications	2.5 – 5%
Electrical turbocompound	HGV: 2 – 8%, averaging at 3% Intercity / Coach: 1 – 5%, average 2.5% City / Utility / Bus: 0 – 2%, average 1%	3 – 10%, average benefit of 4 – 5% estimated including electric accessories
Bottoming Cycles	HGV: 1.5 – 6% with average values of 5% Intercity / Coach: 1 – 3%, average 2.5% City / Bus / Utility: 1 to 3%, average 1.5%	Up to 10%, Cummins demonstrated 7.2% using a Rankine cycle
Controllable Air Compressor	HGV: Average of 3.5% CO_2 reduction, range of 1 – 4% Intercity / Coach: Average of 1.5%, range of 1 – 2% City / Bus / Utility: Limited benefit due to frequent stop / start	N/A
Electric Engine Accessories	0 – 8%	2 – 4%
Automated Transmission	Up to 10% replacing manual with AMT	4 – 8%
Full Hybrid	HGV: Benefit ranges 4 – 10%, averaging 7% Intercity / Coach: Benefit ranges 5 – 20% with an average of 10% City / Utility: Benefit ranges from 15 – 30% with an average of 20% Bus: Benefit ranges from 20 – 40% with an average of 30%	Class 8: 5 – 10% Class 6: 20 – 45% Refuse: 20 – 35% Urban Bus: 12 – 50% Coach: 5 – 40% Van: 18 – 30%
Flywheel Hybrid	HGV / Intercity / Coach: Benefits range from 5 – 15% with an average of 5% for HGV and 7.5% for intercity and coach City / Utility: Benefit varies from 15 – 22% with an average of 15% Bus: Benefit ranges from 18 - 25% with an average of 20%	N/A
Hydraulic Hybrid	Estimated CO_2 benefit varies greatly with duty cycle but can be up to a maximum of 25% in frequent stop / start cycles with average "real world" usage seeing 15 - 18% in similar	City use: 20 – 25% Highway: 12% UPS demonstrated 60 - 70% reduction

Technology	CO_2 Benefit (AEA/Ricardo)	NAS (2010) CO_2 Benefit
	applications	
Low Rolling Resistance Tyres	Achievable CO_2 benefit depends on the number of tyres replace but trials suggest an average of 5% is possible for HGV, 3% for intercity and [illegible]	Between 4 and 11%: Class 8 – 4.5% average, Class 6: 1.4 – 1.8%, Refuse 1.5%, [illegible]
Single Wide tyres	[illegible]	[illegible]
Automatic Pressure Adjustment	[illegible]	[illegible]
Aerodynamic Trailers	[illegible]	[illegible]
Aerodynamic Fairings	[illegible]	[illegible]
Active Aero	Up to 8.7%	8%
Lightweight Materials	1-2% per tonne of weight saved, slightly better on freight efficiency basis 1.7% on volume limited applications and 4.2% on weight limited	1 – 2% per 1,000lb weight reduction Bus – 3.75 – 7.5% per 10% reduction
Alternative Fuel Bodies	10 – 20% depending on body power system replaced	N/A
Predictive Cruise Control	2 – 5% but will vary with route	Figures vary between 1 – 5% benefit
Vehicle Platooning	~20% for motorway speeds	N/A
Green Zone Indicator	5 – 10%	N/A
Smart Alternator, Battery Sensor & AGM Battery	Estimated at 1 – 2%	N/A
Acceleration Control	Up to 6% depending on driving style	N/A
Governing Speed Control – Progressive Shift	1 – 4% depending on driving style	N/A
Eco Roll – Freewheel Function	~1% - expected to be highly dependent on application	N/A

Source: Ricardo estimates, National Research Council, Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles

Dual Fuel technology has been recognized by European Community as an important technology for future CO2 reduction

Source: "Reduction and Testing of Greenhouse Gas (GHG) Emissions from Heavy Duty Vehicles – Lot 1: Strategy"
Final Report to the European Commission – DG Climate Action Ref: DG ENV. 070307/2009/548572/SER/C3

Integrated Approach:

Components

Homologations

Layouts

Reliability & Safety

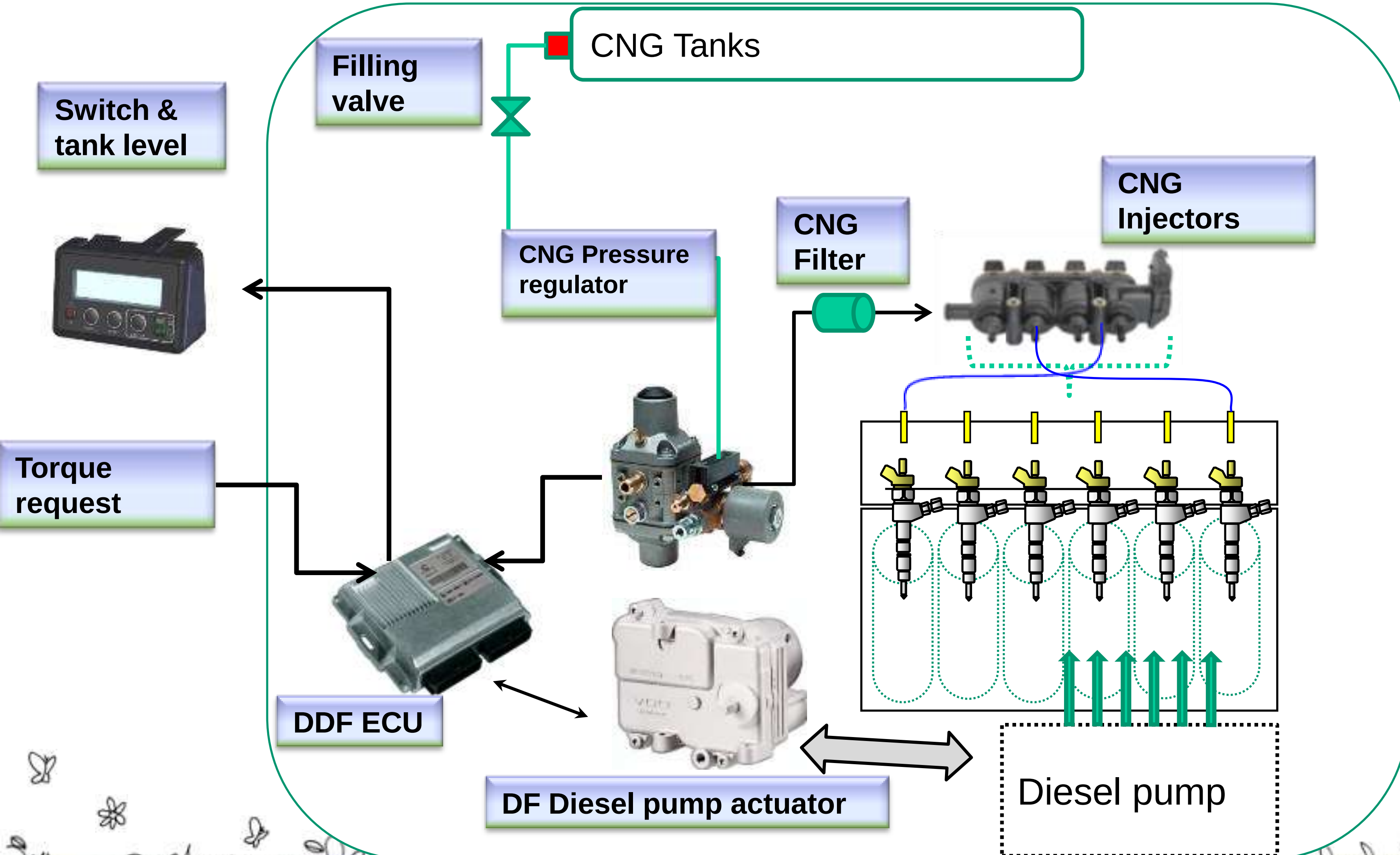
Targets & Optimizations

Applications

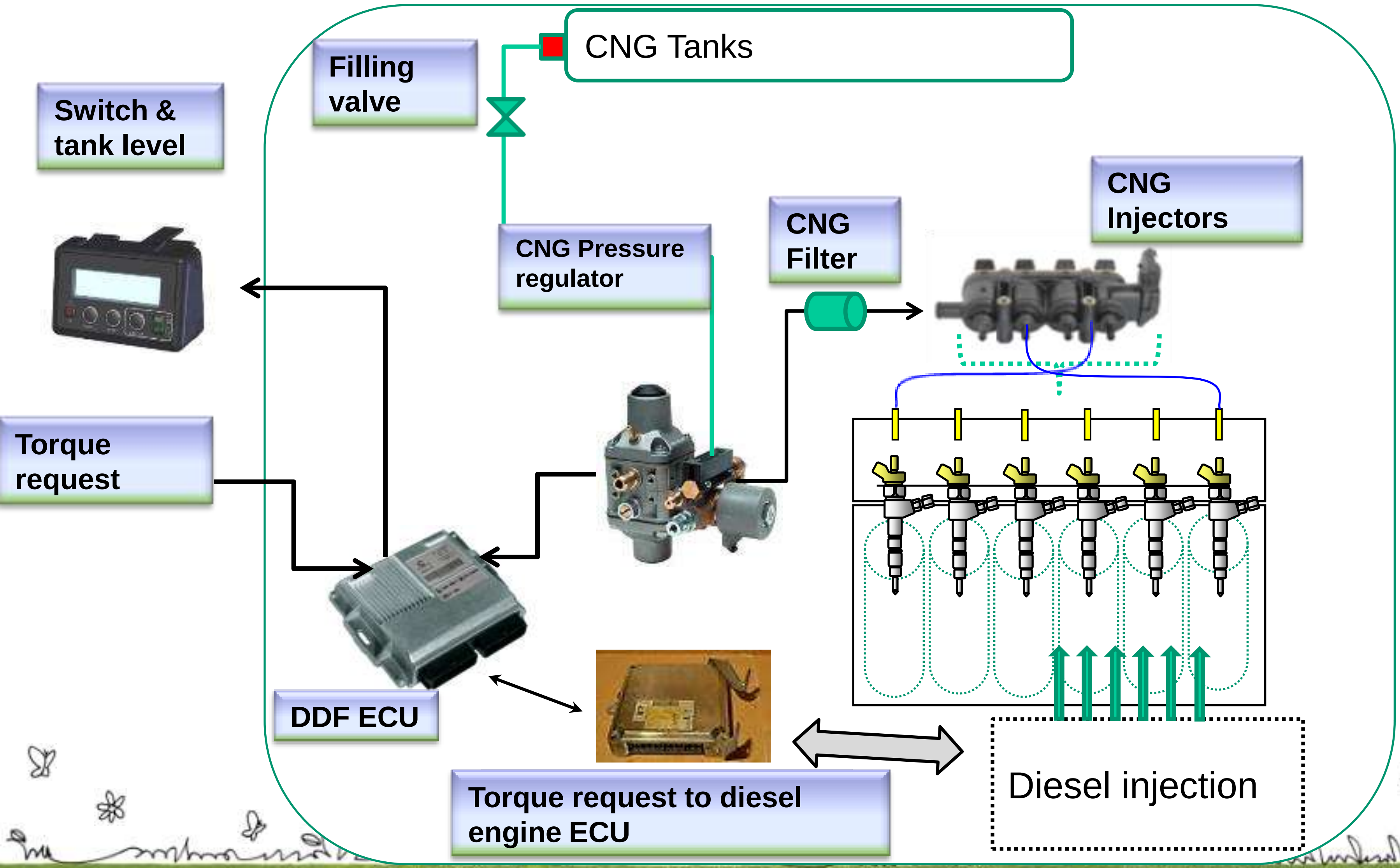
Components

- First applications shared components from CNG experience on petrol engines
- Due to specific characteristic of DDF engines, a constant evolution of components has been started and is planned for the future:
- Dedicated components (fuel pump actuators, accelerator pedal interfaces..)
- Dedicated Electronic Control Units (ECU) capable of interfacing with diesel electronics.
- Dedicated pressure regulators, including electronic pressure regulator and injectorless electronic regulators
- Dedicated Driver interfaces

Layout DDF – Mechanical pump systems



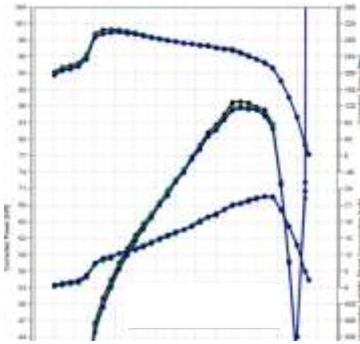
Layout DDF – Electronic injection systems

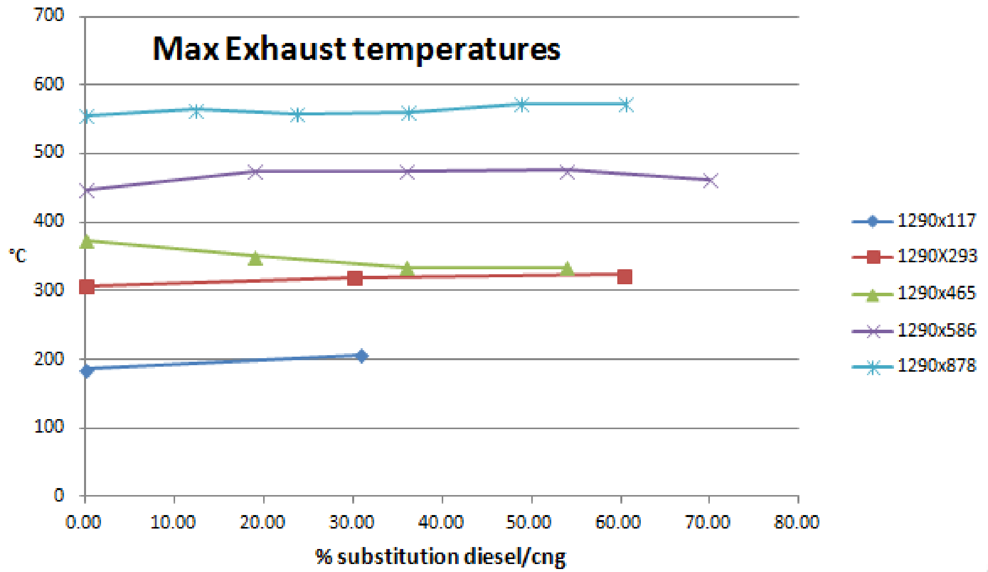


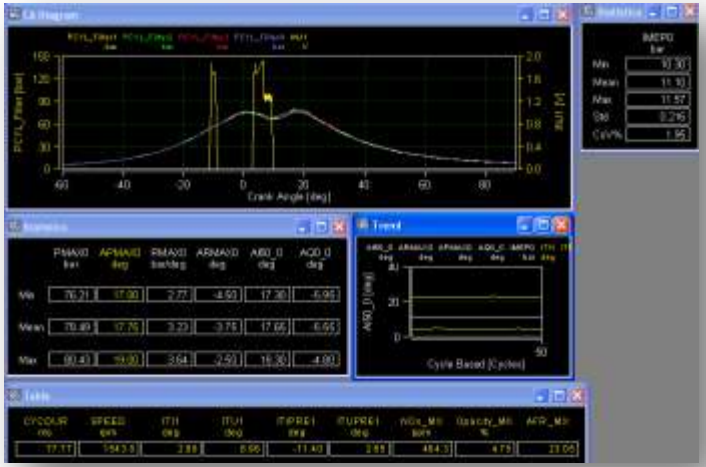
Targets & Optimization (1/2)

- Each application must preserve a number of characteristics of the original engine:

- Durability and Reliability:
  - Maximum output torque ≤ torque in Diesel mode
  - Combustion peak pressure ≤ pressure in Diesel mode
  - Combustion Stability
  - Exhaust temperatures ≤ temperatures in Diesel mode



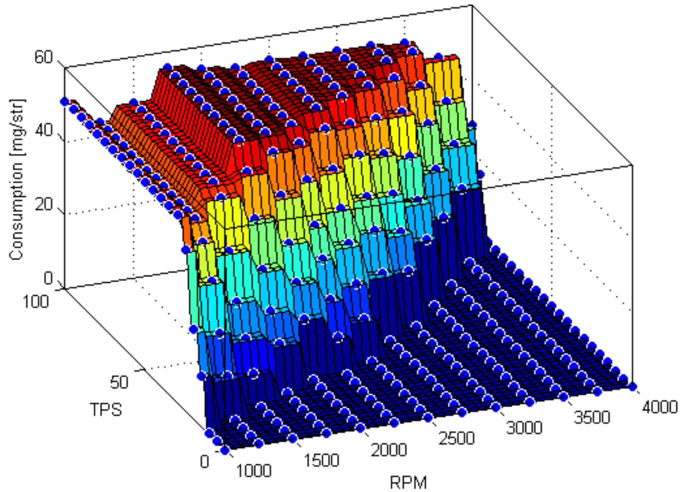




Targets & Optimization (2/2)

- The calibration targets for DDF applications are:
  - CO_2 saving
  - Fuel Cost saving
  - PM reduction
  - Noise reduction

- Such saving are enhanced by achieving a reasonably high diesel substitution rate, compatible with:
  - Knowledge of the base engine characteristics
  - Fine tuning of the diesel<=>CNG substitution in function of engine working point



Applications

- The basic requirements come from the market need of a DF conversion compatible with a large variety of different applications:
  - Original Fuel System (mechanical pump, electronic injection)
  - Vehicle subsystems (CAN, distributed electronics, no electronics)
  - Specific engine destination (Industrial, Truck, Bus, Marine, Genset)

  And with different technical means:
  - Availability of engine dyno
  - Availability of chassis dyno
  - Tests/measurements on the road

- This variety of systems leads to the definition of a comprehensive calibration procedure with large support from calculation tools:
  - Defined tests and acquisitions
  - Optimization tools (post processing)
  - Verification tests

Reliability – Engine Endurance test

- Endurance test has been performed on 2.8l engine for 1000 h (synthesis test) according to rpm/load profile of engine manufacturer test.

- First part of test (250h) was performed in Diesel and remaining (750h) in Dual in order to compare the behavior deviations between Diesel Vs Dual.

- Periodic measurements (250 h):
  - Full load curve with measure of torque, boost pressure, smoke, BSFC, blow-by
  - Oil consumption @ full power
  - Oil sample & analysis

- Summary of results:
  - Same performances on all test periods (torque, boost pressure, smoke, BSFC, blow-by)
  - Same oil consumption
  - Same oil properties with sensible decrease of Soot in Oil for Dual Fuel operations
  - On going components engine disassembling for component analysis; first visual inspection is positive.

Safety

- **CNG Fuel System safety**: no new issues, because the typical approach is to use same components and apply same rules of standard CNG fuel systems.

- **Torque safety issues**: being Dual Fuel Systems integrated into Diesel torque management system, potentially the engine could generate a higher torque respect to the driver request.
- This can happen in case of failure of components or unexpected operating conditions:
  - Excess of CNG (“rich” combustion)
  - Failure in gas pressure regulation system
  - ….
- Generally, in case of failure or relevant diagnostics, switch back to Diesel is applied.

- Complete FMEA of the system has been performed since the early development, leading to the highest level of safety through:
  - Redundancy of sensors
  - Specific diagnostic functions
  - Recovery functions


DFMEA FMEA DI PROGETTO - PRODOTTO
PROCESS FMEA
DESIGN FMEA
DFMEA N°:
System
Subsystem
Component
Item
Description
Product - System
Writer
FMEA Team Leader
New
Change
Different function
Item / Function
Potential Failure Mode(s)
Potential Effect(s) of Failure
Potential Cause(s)/ Mechanism(s) of Failure
Current Controls
Recommended Action(s)
Responsibility & Target Completion Date
Action Results
Actions Taken

Homologations

- At present in Europe a common regulation for Dual Fuel conversions (retrofit) approvals is not applicable.
- In Italy, a National rule is applicable for conversion kit as per “Circolare 220/M3/C2” defining engine/vehicle and conversion system families respectively identified by:

1) the engine type, displacement range (± 25%) and the emission class level derived from the tested parent engine (including earlier emission rules stages).
2) the R110 approved conversion kit used for parent engine homologation (including alternative components).

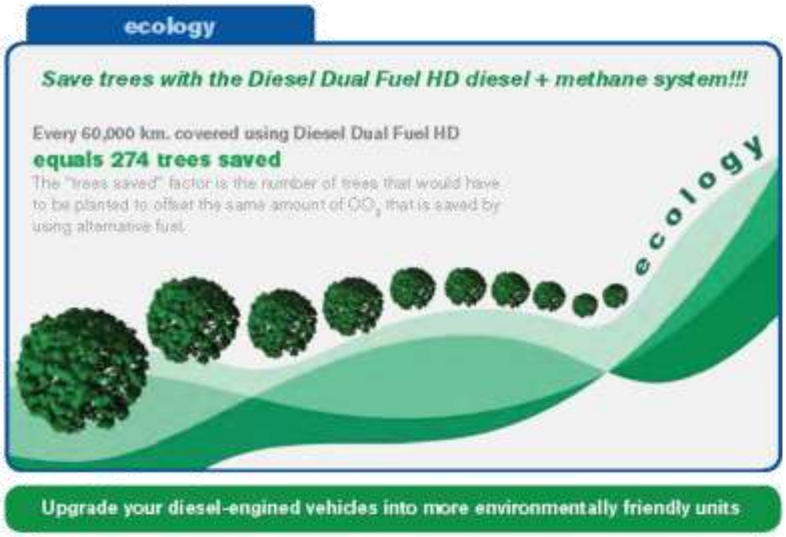
- List of parent engines fitted with Landi Renzo conversion kit, approved by Italian Government after testing according to the original approval (testing facilities):
    1) 1.9 lit. Euro 4 (chassis dyno)
    2) 3.0 lit. Euro 4 (chassis dyno)
    3) 2.8 lit. Euro II (engine dyno)
    4) 7.7 lit. Euro II (engine dyno)
    5) 10.3 lit. Euro III (engine dyno)
    6) 3.0 lit. Euro III (engine dyno)
    7) 5.9 lit. Euro III (engine dyno) → forecast Jan / 2013

- CNG DDF system components are installed according to ECE/ONU R110.

Conclusions and Perspectives

- Dual Fuel has proven to be a viable and reliable technology for using CNG on obsolete and current powertrains. It allows:
  - the recovery of dated fleets that should be discontinued otherwise, by reducing pollutant emissions and improving fuel economy.
  - A flexible use of Diesel and gaseous fuels, matching power and environment issues, depending on engine working point.

- Further developments include:
  - Additional functionalities, for intelligent moving and fuel consumption reduction
  - Increase the application field (including off-road machines and gen-sets)
  - Use of biofuels for even better sustainability, and of LNG for long-haul vehicles
  - Introduction of new components for fuel system, specialized for DDF technology
  - Cooperation with other manufacturers and the authorities to define an European framework for Dual Fuel regulations.



THANK YOU