Dual-fuel Technology

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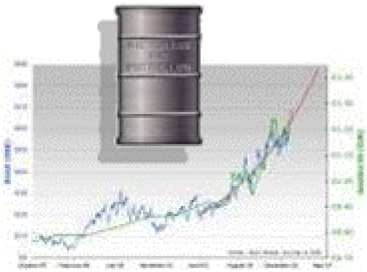
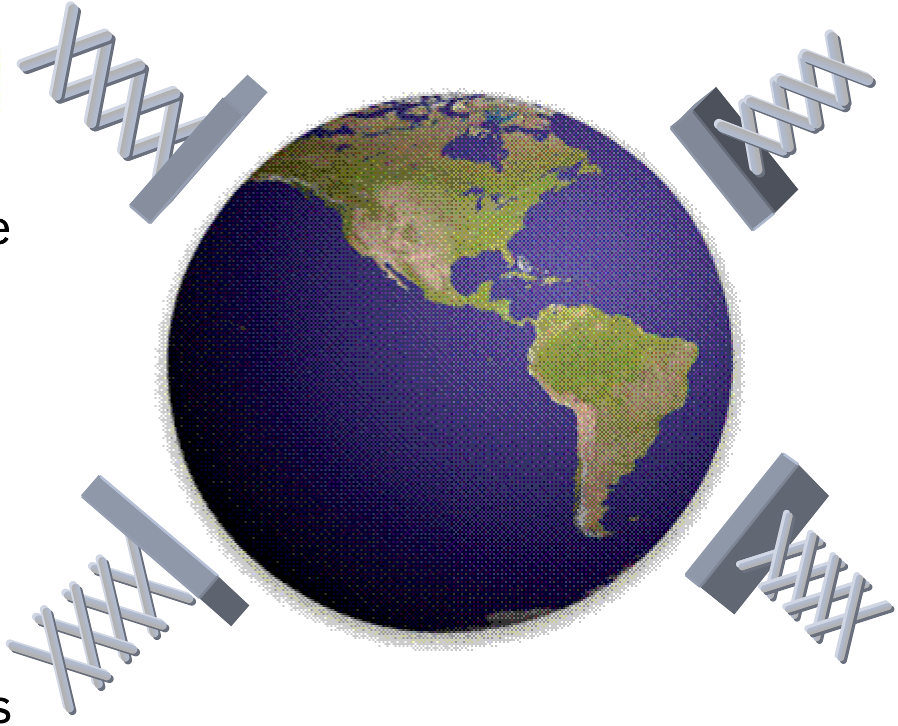
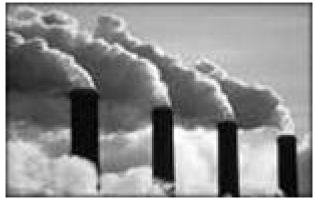
Dual-fuel Technology

World under Fuel Alternative Pressure!



Unstable Oil Price





Pollution

Natural Resources
Renewable Fuels

Global Warming

Motivation & Market Trends

Market	Drivers & Enablers	Alternatives
Developed Countries (USA, EU, Japan)	CO_2 reduction Emissions	→ Hybrid → Electric → Hydrogen → Natural Gas
Emerging markets	Costs (operational costs reduction and low taxation)	→ Bio-diesel → Ethanol → Natural Gas

→ Biofuels and Natural Gas are economically feasible and available solutions for several markets.

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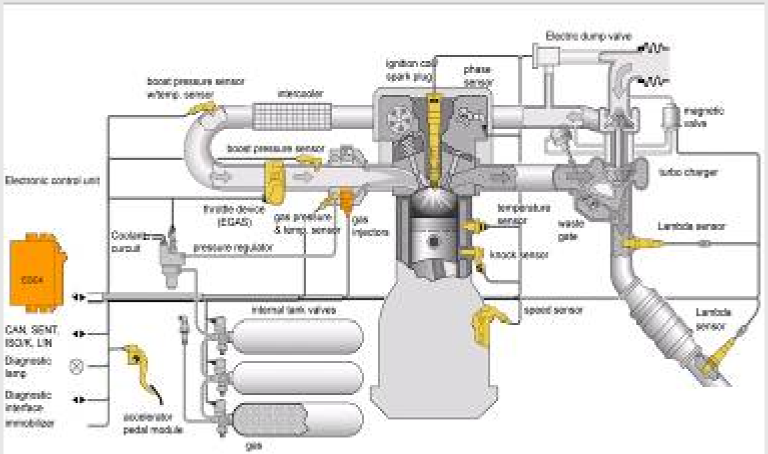
Bosch history with Natural Gas



1998	**1st Spark ignited CNG engine with Bosch system launched in the EU market**
2010	**4 new applications to be launched in the EU, India and China markets**
2011	**4 new applications to be launched in the Indian and Japanese markets**

➔ The development of the CNG spark ignited engine injection & ignition systems allowed Bosch to improve its product portfolio providing reliable components with state of the art technology to the market

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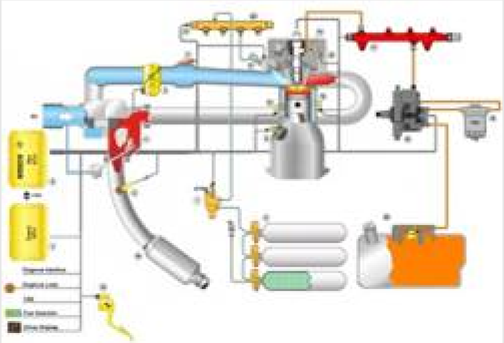
Bosch history with Diesel Dual-Fuel



2006 — **Start researching the Dual-Fuel technology with mechanical Diesel injection systems using CNG**

2008 — **First emissions homologation in Brazil of a Dual-Fuel Diesel / CNG powered engine**

2008 — **Start of research with electronically controlled Diesel injection systems**

2009 — **Dual-Fuel system development for applications with Natural Gas, Biomethane and Ethanol for original vehicles**

➔ Robert Bosch, worldwide leader in development and application of the Diesel technology, is dedicating its knowledge and experience to the development of a Dual-Fuel system, using the state of the art technology in components and software.

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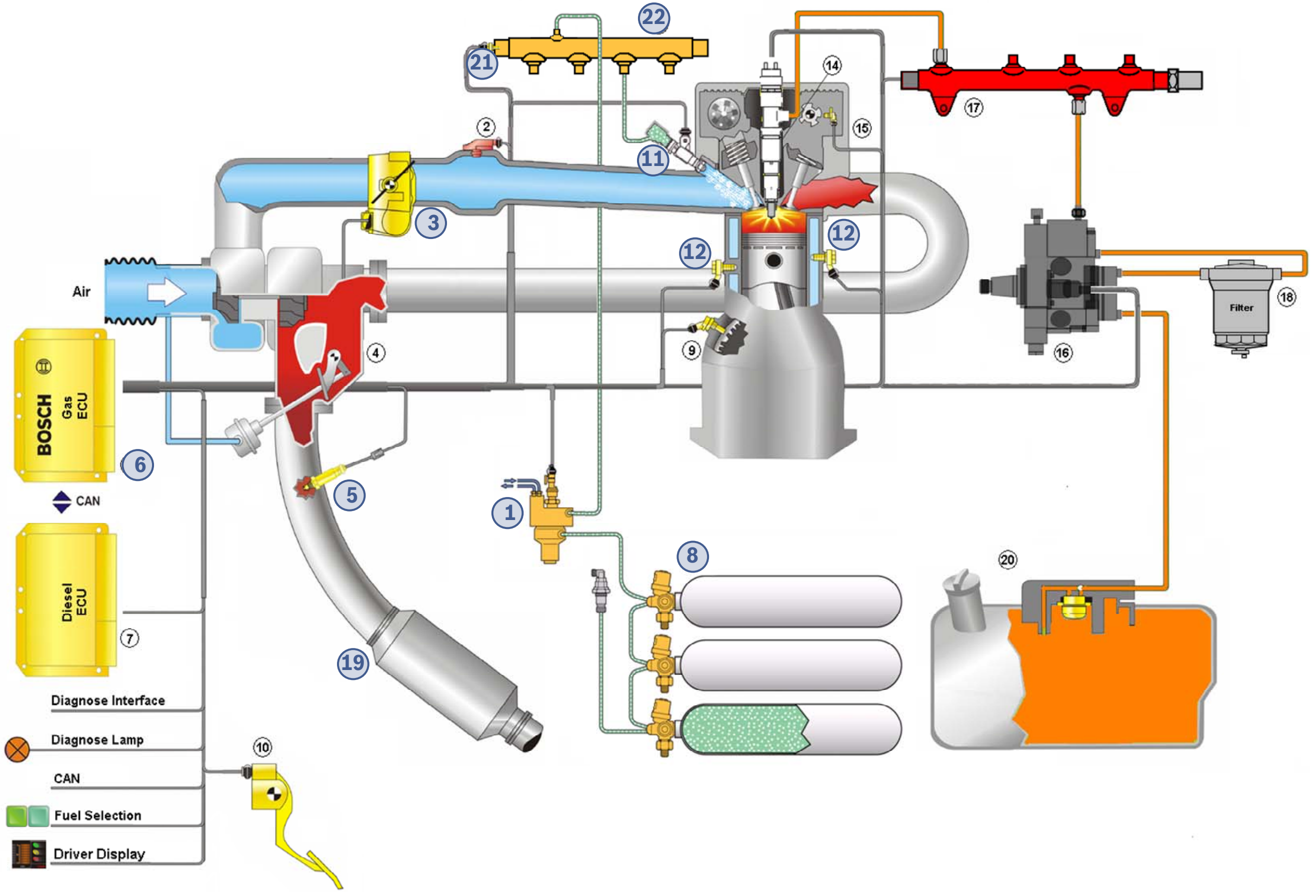
Diesel-Gas System Concept

Dual-Fuel	**Existent Diesel engines**, adapted with a **second injection system** to manage the NG fuel injection and the air control. The basic configuration of the original Diesel engine remains unchanged. **Ignition by Diesel injection**.
Operational Modes	Possible to operate either in original Diesel Mode or in Diesel-NG Mode, with significant substitution of Diesel by the Natural Gas.
Alternative fuels	System components and software compatible with: Natural Gas (**CNG** & **LNG**) and **Biomethane**.
Other features	Knock control strategy, diagnosis and monitoring function in Diesel-NG mode, closed loop strategy.

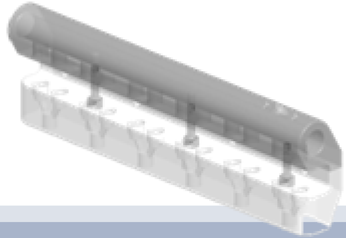
➔ Diesel-Gas integrates the high performance of diesel engines with the fuel flexibility.

Diesel-Gas System Layout



01 – CNG pressure regulator
02 – Boost pressure & temperature sensor
03 – Throttle valve
04 – Boost actuator
05 – Lambda sensor
06 – CNG ECU
07 – Diesel ECU
08 – CNG storage tank
09 – Engine speed sensor
10 – Accelerator pedal
11 – CNG injector
12 – Knock sensor
13 – Coolant temperature sensor
14 – Diesel injector
15 – Phase sensor
16 – High pressure pump
17 – Diesel common rail
18 – Fuel filter
19 – Oxidation catalyst
20 – Diesel tank
21 – CNG pressure & temperature sensor
22 – CNG rail

Diesel-Gas components supplied by Bosch



CNG Rail
FCA with DS-M1-TF

Dual-Fuel ECU
EGC10

Throttle Valve
RKL-E1

0_2 Sensor
LSU4.9

Knock Sensor
KS-4-S

CNG Injector
NGI2-CP

Diesel-Gas benefits to the customer

Fuel cost reduction	Maximize substitution rate of diesel by Natural Gas or Biomethane
Emissions compliance	Keeps same emissions level of engine on Diesel-only mode with enhanced particulate material, NOx and CO_2 emissions
Fuel flexibility	Allows driver to switch between Diesel-NG and Diesel-only modes with the same performance
Maintenance and lifetime	Reliability and tradition of Diesel engines
Affordable cost	Estimated ~10% of increase in the vehicle acquisition costs

→ Diesel-Gas keeps original integrity of the Diesel engines providing the same performance and fuel consumption efficiency still benefiting of high scale production

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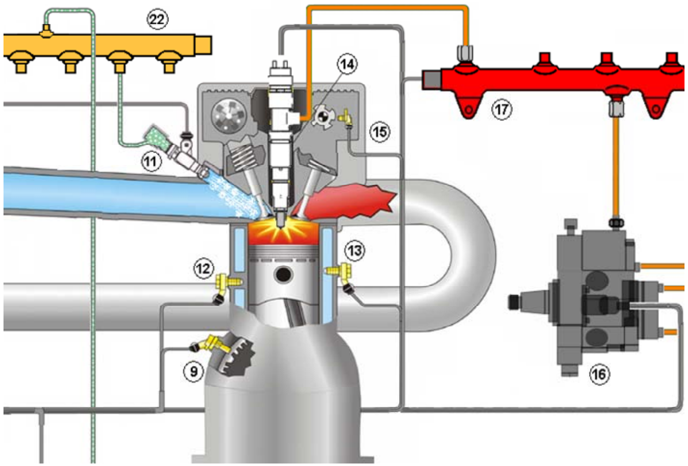
Diesel-Gas prototype engine research

Research with a Diesel prototype engine with EGR

Calibration parameters:

- Natural gas feed pressure ~ 9bar
- Multipoint injection (2 injectors / cylinder)
- Steady-state calibration on test cell
- Brazilian field Diesel



Engine data:

- Diesel engine with CRSN
- Power: 160 kW @ 2200 rpm
- 6 cylinder, 7.2 L
- EGR and electronic turbo control

Diesel-Gas prototype engine research

Research with a Diesel prototype engine with EGR

- **Calibration targets:** maximize the substitution ratio and substitution efficiency of dual-fuel Diesel-Gas combustion comparing to original Diesel as reference.

- **Success factors:** stable combustion; same engine performance; >85% average diesel substitution rate in steady-state condition; no undesirable side-effects.

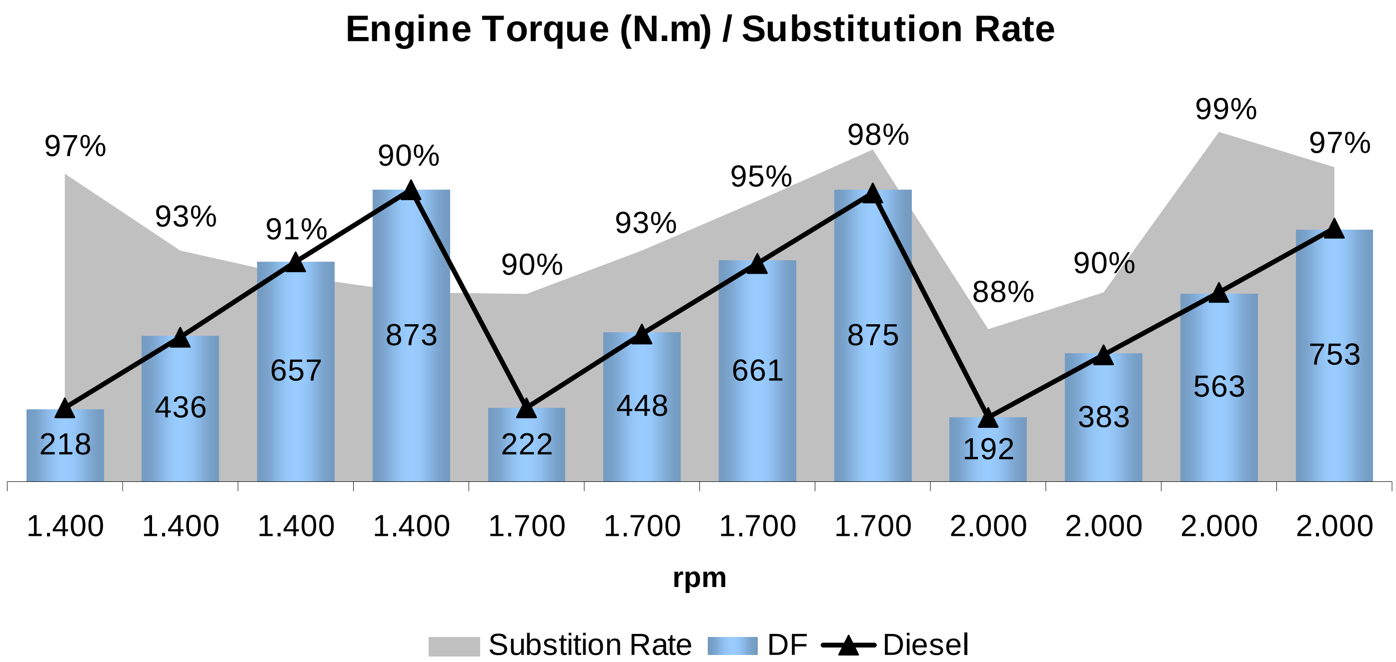
- **Controlled parameters:**
  - Diesel injection timing
  - Diesel injection quantity and pressure
  - Natural gas injection timing
  - Natural gas injection quantity
  - Air flow

- **Restrictions:**
  - Knock occurrence – measurement through combustion pressure behavior and knock sensor signal

Out of scope: dynamic calibration

Diesel-Gas research results - Torque

Research with a Diesel prototype engine with EGR – 13 Mode Test

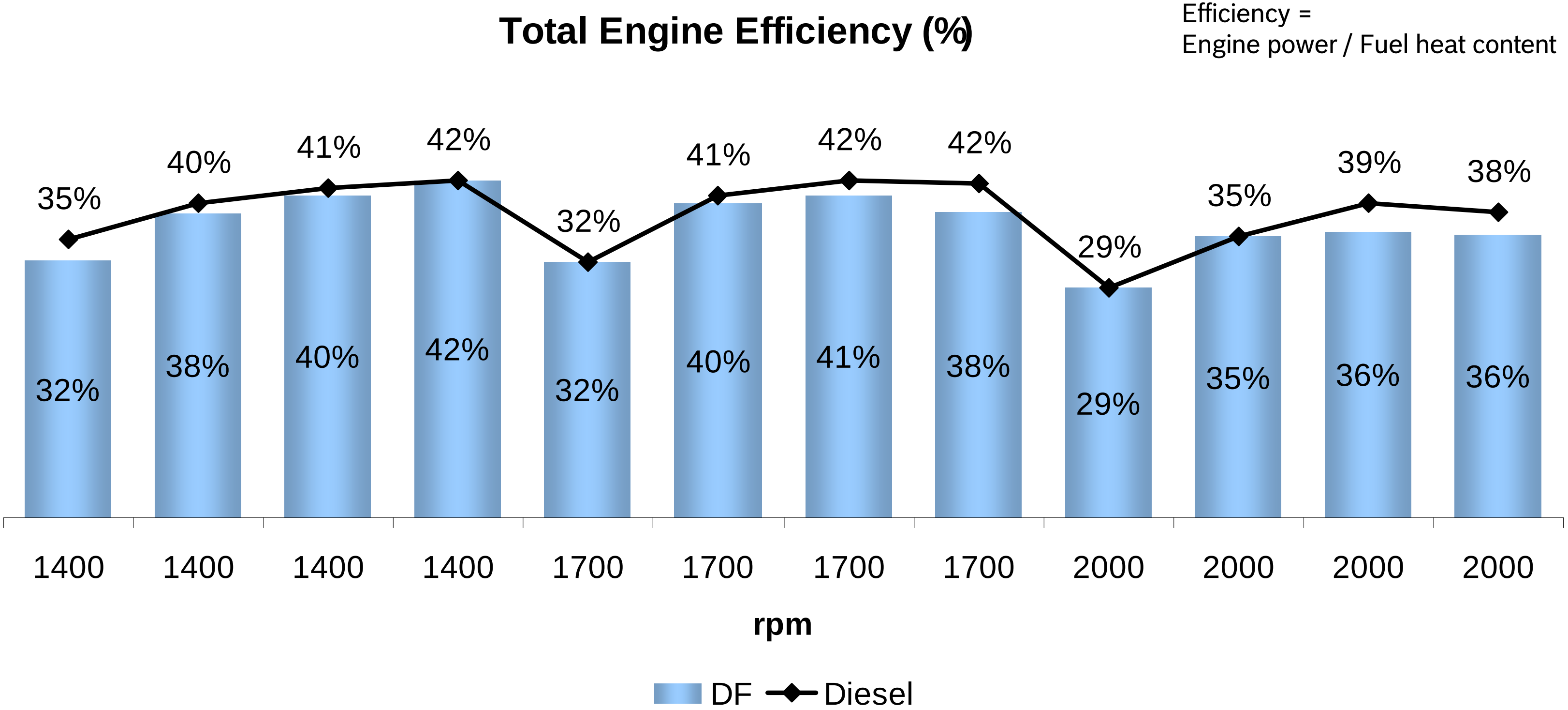


➔ Same original Diesel engine performance achieved on dual-fuel mode

Diesel-Gas research results - Efficiency

Research with a Diesel prototype engine with EGR – 13 Mode Test

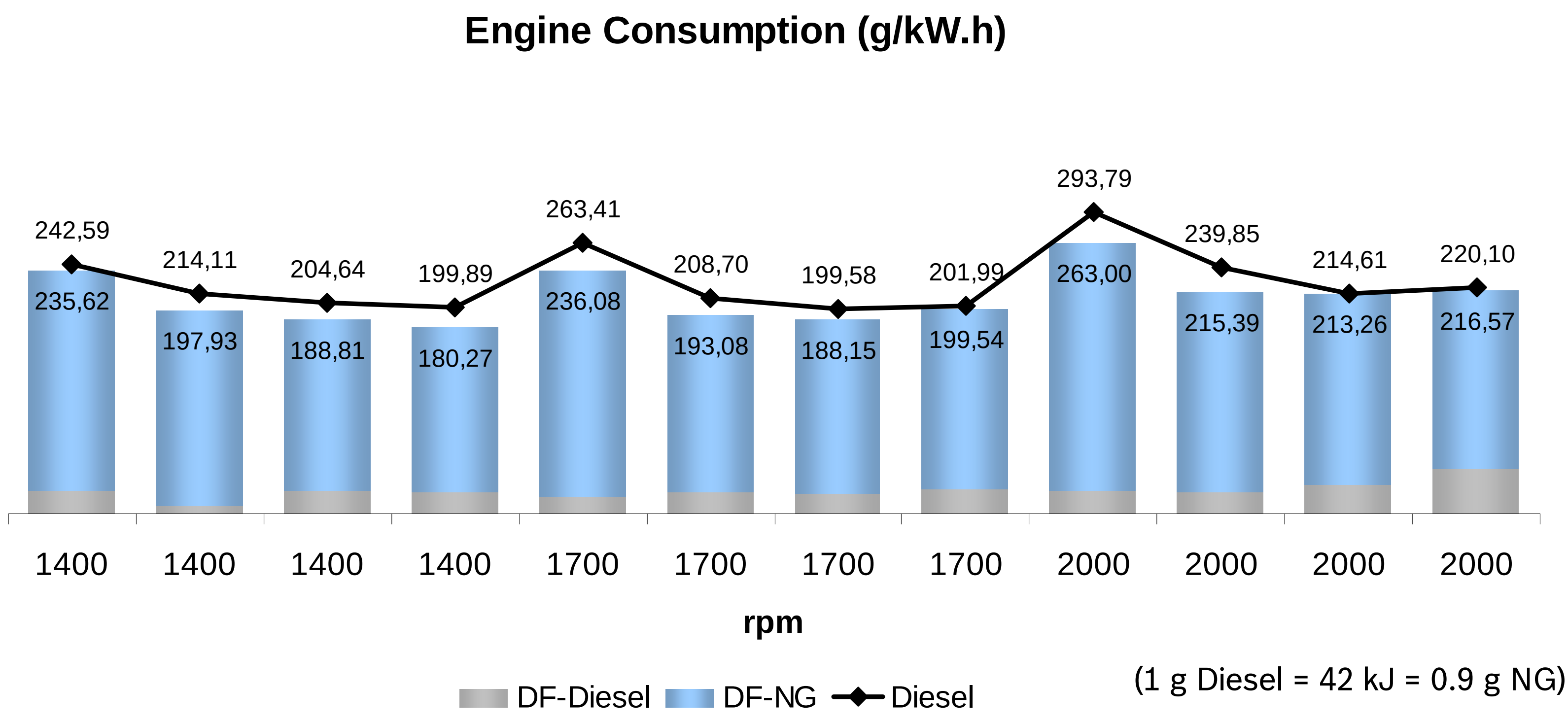
Efficiency =
Engine power / Fuel heat content



➔ Engine thermal efficiency ➔ similar to original Diesel mode

Diesel-Gas research results - Efficiency

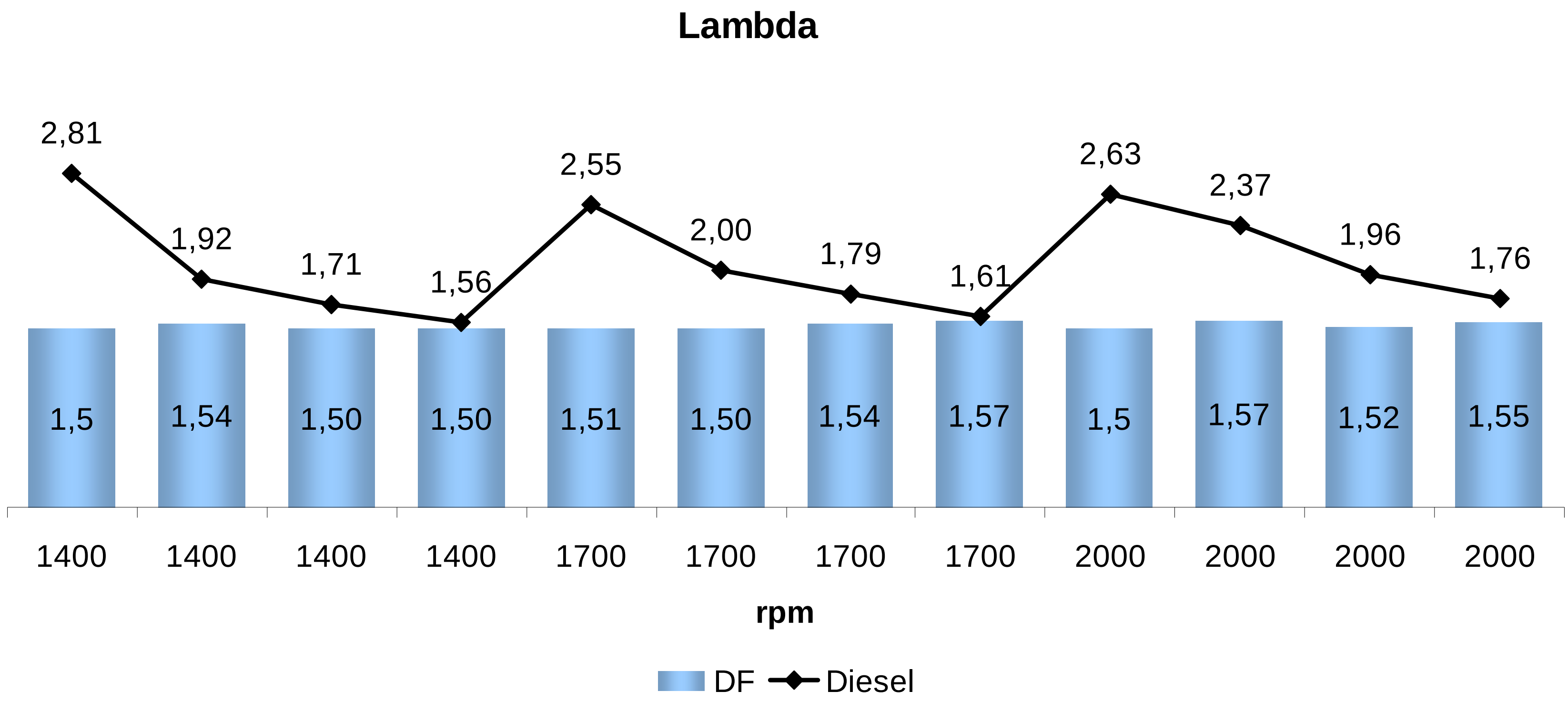
Research with a Diesel prototype engine with EGR – 13 Mode Test



➔ Engine specific consumption ➔ slightly lower in dual-fuel mode

Diesel-Gas research results - Efficiency

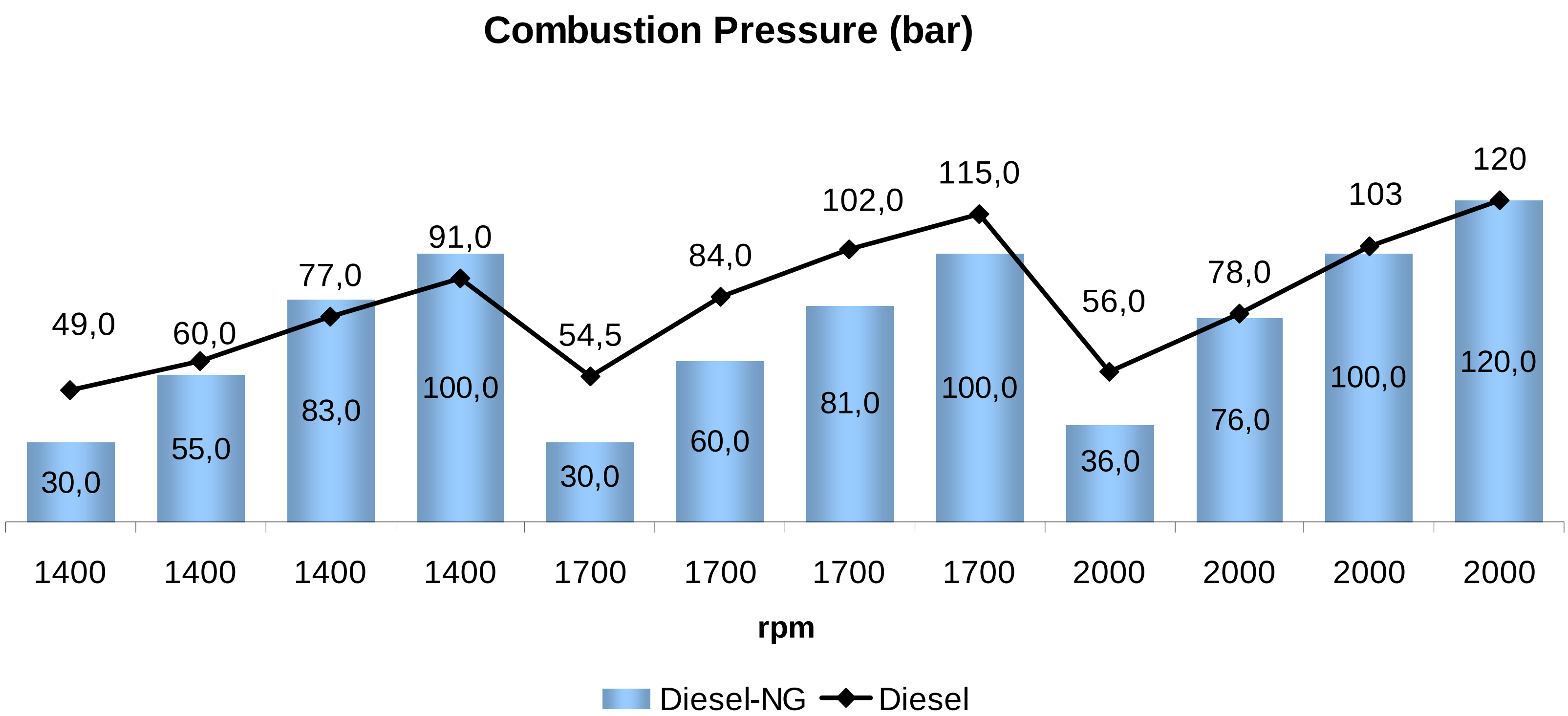
Research with a Diesel prototype engine with EGR – 13 Mode Test



➔ Lambda ➔ experiments show lambda close of 1,55 for best combustion efficiency

Diesel-Gas research results - Efficiency

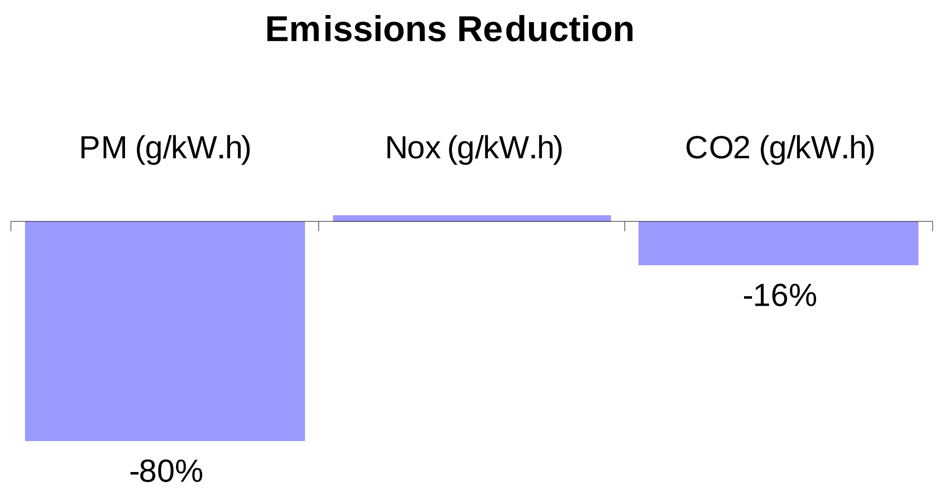
Research with a Diesel prototype engine with EGR – 13 Mode Test



➔ Combustion Pressure ➔ in average is lower than original Diesel mode

Diesel-Gas research results – Emissions

Research with a Diesel prototype engine with EGR – 13 Mode Test



EGR enabled in Diesel original mode
EGR disabled in Diesel-NG mode

- NOx → Potential for strong reduction considering EGR or SCR aftertreatment
- Calibration strategy would allow NOx and PM emissions enhancement in dual-fuel mode with possible original Diesel EGT customization

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Diesel-Gas project main targets

Average substitution rate

- Environmental conditions
- Gas quality
- Vehicle configuration
- Duty-cycle

Target 85%

Performance & drivability

Diesel original performance

Emissions enhancement

- Performance requirement
- Environmental conditions
- Aftertreatment configuration

NOx	PM	HC	CO	CO_2
↓	↓ 80%	-	-	↓ 20%

- NOx reduction depends on Diesel EGT strategy

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Economical Feasibility Study

Information of typical urban bus application[1]

Substitution rate	75%
Diesel/NG price relationship	55% (Diesel at 1,72BRL[2])
Vehicle acquisition cost	10% add-on to original Diesel vehicle
Vehicle maintenance costs	~original Diesel vehicle
Specific consumption	Worst case = original Diesel vehicle
Mileage/day	~350km/day
Vehicle resale	~70% depreciation during 7 years

Based on the following bibliografy:

1 Conceição, Guilherme Wilson. "A Viabilidade Técnica e Ambiental da Inserção do Gás Natural Veicular em Frotas de Transporte Coletivo Urbano de Passageiros", MA Thesis, Universidade Federal do Rio de Janeiro, 2006.
2 Reference to ANP fuel prices dated from Aug. 27th, 2010 - http://www.anp.gov.br/preco/prc/Resumo_Semanal_Index.asp

- ➔ Dual-Fuel eDG Flex allows transp. companies to end up a period of 7 years with very positive cash-flow considering possibility to resell the vehicle
- ➔ ROI expected to not exceed 1,5 years
- ➔ **Dual-fuel eDG Flex fits market economic requirements**

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Conclusions

- Alternative fuels for Diesel engines are demanded in several markets due to political, economical and environmental aspects.
- In most markets transportation companies need confidence to acquire alternative fuels powered vehicles where:
  - Flexibility is important
  - Shall keep original Diesel engine operation characteristics unchanged
  - Shall have feasible vehicles acquisition and operational costs
  - Vehicle resale market is mandatory for companies operational cash-flow
- Alternative fuels may represent the most prominent emissions reduction factor worldwide.
- Significant CO_2 reduction is also mandatory worldwide.
- If flexibility is **not necessary** (Diesel mode only for "limp-home" function) less complex after-treatment systems would be possible due to engine emissions trade-off curves improvement by substituting Diesel per alternative fuels (i.e. DPF not necessary and SCR calibration to reduce lower level of NOx than the Diesel original engines).

Thank you!