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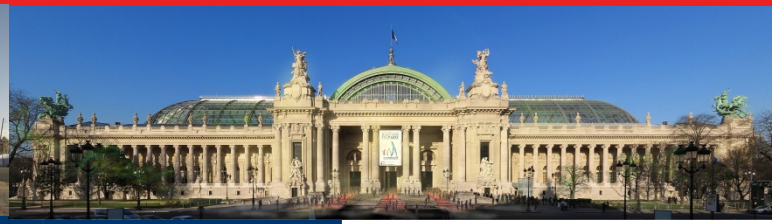

THE PROSPECTS OF THE FUTURE DIESEL-LIKE GAS ENGINE AND THE GAS QUALITY CHALLENGE

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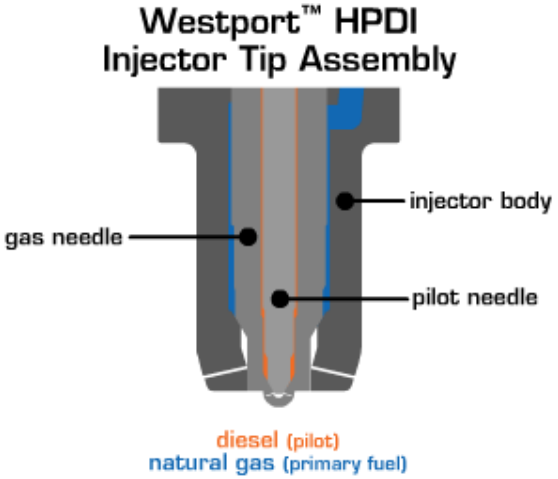
Gas quality challenge when considering NGV potential

- **A growing but still emerging market situation where peripheral market segments of two major business actors (grid owners and OEM's) interact**
  - Challenge: Reach low emissions and high fuel efficiency in heavy duty gas engines without risking the gas core business
  - Cost optimisation across two businesses: trust and cooperation needed, despite complexity
  - New conditions: Euro VI Certification on real market fuels with durability testing included (after 700,000 km or 7 years on the road)

The future gas engine with diesel-like performance

- **Current commercial trends:**
  - Scania Euro VI dedicated otto gas engine 340 hp: Sweet spot 40% efficiency, only 7% fuel penalty mixed driving. Rumours about >400hp version!
  - Westport HPDI 2.0: dual-fuel direct injection with diesel-like performance, launch 2014/15 e.g Volvo



The future gas engine with diesel-like performance

- **Ongoing research:**
  - Improved low load performance and increased max. power close to the dilution limit through high turbulence pistons, EGR, turbocharging, higher compression and model based control
  - Increasing dilution limit further: Fuelled prechamber tech delivered 47.5% efficiency at 10 bar IMEPg at first go (no optimization)
- **But: It all hinges upon the gas quality delivered!**

Most difficult parameters in CNG standardization

- **Methane number:**
  - Measure of knocking property – higher tendency for knocking as levels of higher hydrocarbons and hydrogen in the gas increase
  - Min. MN 70 demand from OEM's, gas business set on 65*
- **Sulfur:**
  - Normal levels in conventional automotive fuels: 10 ppmM
  - Current standardization is triple that* – source is sulfur based odorization
  - Increased levels of SO2 in exhaust rapidly ages the exhaust aftertreatment system, leading to higher CH4 slip

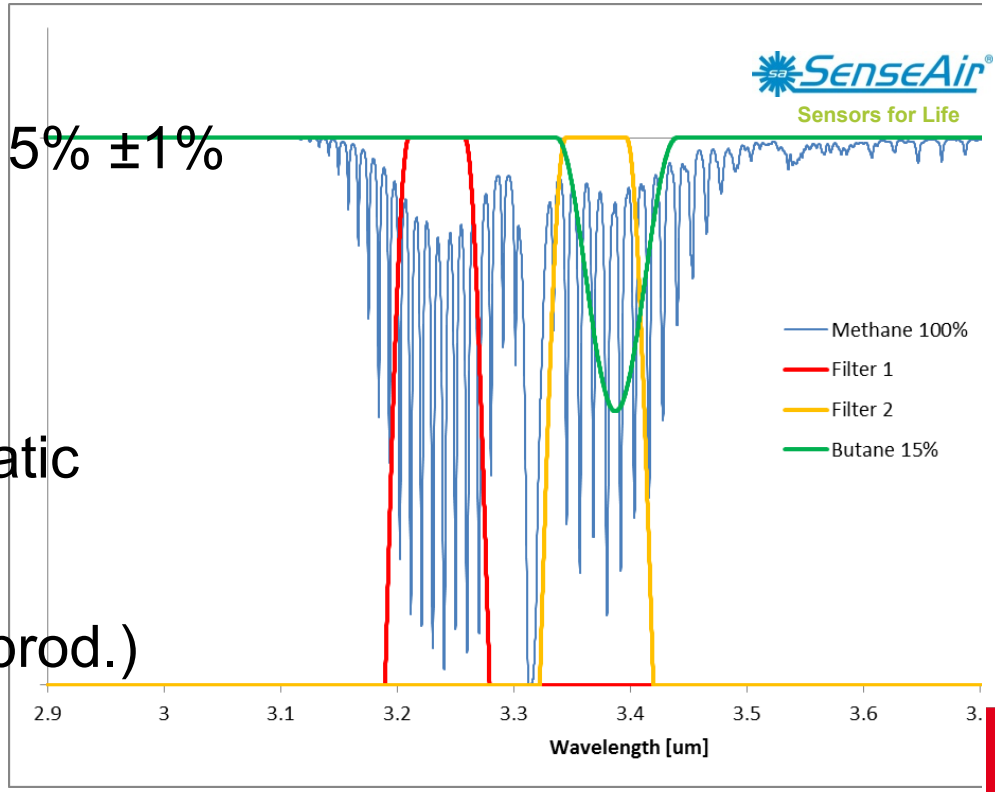
*With reference to ongoing standardization work in CEN/TC408

Why not cooperate to secure future NGV market growth?

- Joint market ventures, e.g. non-grid based distribution of MN 70+ gas for heavy-duty sector
- Joint research a way ahead? (Horizon 2020)
  - Sulfur free odorization (technical, market)
  - Fit for purpose gas quality sensor development (e.g. onboard) to change engine ignition timing
  - Gas engine research
  - (R&D cheap online biogas analysis equipment)

Gas quality sensors: near IR modular technology

- Methane 70% to 100% ±2%
- "Butane equivalents"* 0% to 15% ±1%
- Inert gas content ±3%
- Response time ~10 s
- Pressure up to 10 bar
- Calibration free due to automatic baseline compensation
- 1 EUR per unit (high volume prod.)



* Ethane= 0.6 Butane equivalents
Propane = 0.8 Butane equivalents

Ion current sensing + advanced signal processing

- Combustion → ion current
- Ion current sensed through the spark plugs (inexpensive!)
- Compute ion current information carriers
- Analyze the data *from all cylinders concurrently*
- Detect *deviation from desired state*
- Send information for correction to the ECU **if** the combustion process deviates and in **which way** (fuel quality)
- Corrections possible for each cylinder on a cycle basis