TRENDS IN GASOLINE POWERTRAIN TECHNOLOGY FOR HIGH PERFORMANCE AND LOW EMISSION

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Dr. Hubert FRIEDL
AVL List GmbH
SOME HEADLINES

Automotive News Europe

German push to ban combustion-engine cars by 2030 wins support

The beginning of the end for the infernal combustion engine
By Greg Archer, clean vehicles director

PARIS IS CHOKING. TRAFFIC CONGESTION AND GRIDLOCK BLAMED.
Paris joins Athens, Madrid and Mexico City in banning diesel by 2025.

autoevolution

Germany Asks EU To Think About Banning Internal Combustion Engines By 2030
EXTENDED CONSEQUENCES OF “DIESELGATE”

- Extremely negative image of whole automotive industry
- “War” of Non Government Organizations against Diesel
- Aggressive scenarios (e.g. city access restrictions or even ban)
- Severe aggravation of RDE boundaries short termed
- Industry changes to proactive role regarding EV`s
- Over fulfillment of emission limits
- Broad introduction of Gasoline Particulate Filter in Europe
**CO₂ / EMISSION REDUCTION**

**Development Drivers**

### CO₂ Emissions
- Enhanced CO₂ limits additionally aggravated by boundaries (e.g. WLTP)
- Well to Wheel as next discussion point

### Pollutant Emissions
- Extended consequences of Diesel Gate
- ICE ban under discussion
- Minimum emissions under all operating conditions – over fulfillment of legislation ➔ “Zero Impact ICE”
- Shift towards electrification

### Connectivity /ADAS
- Intensively used for optimized powertrain control (e.g. energy management, emission, CO₂)
EXTENDED EMISSION COMPLIANCE
REAL DRIVING EMISSION

RDE REGULATIONS COME INTO FORCE
EXTENDED EMISSION COMPLIANCE
IMPACT TEST PROCEDURE

From EXACTLY REPRODUCIBLE TESTCYCLE towards
STATISTICAL PROPABILITY

→ Paradigm shift in technology, development and testing
RDE IMPLEMENTATION WORLDWIDE

RDE is a Global Topic

RDE is not restricted to Europe, it becomes a Global Topic

EU:
Monitoring: 04/2016
Conformity factors: 09/2017

South Korea:
09/2017 (diesel only)

Japan:
discussions

China:
Monitoring from 07/2020
CFs from 07/2023

India:
BS VI
04/2020: monitoring
04/2023: CFs

USA (CARB):
PEMS for detection of defeat devices
Real Driving Emissions (2016/427 1st package, 2016/646 2nd package, 3rd package)

Light duty vehicle on Real Driving Emission testing:
- Portable Emission Measurement System (PEMS) to measure CO2, CO, NOx, PN, Exhaust flow, Speed and GPS data.
- Implementation: EU 2016, Korea 2018, China 2020, India 2020, Japan 20xx

Limits:
- CF NOx: 2.1  CF PN: 1.5 to be fulfilled in each phase
- 2 calculation options, EMROAD (JRC) or CLEAR (TU-Graz)

RDE Test requirements:
- Cold- and hot-start test, 30min conditioning drive, 5-56h soak time,
- RDE Drive between 90 to 120min in normal traffic
- 34% Urban (<60km/h), 33% Rural (60 ... 90km/h), 33% Motorway (>90km/h)
- max. Speed 145km/h (can be extended to 160km/h)
- positive altitude gain < 1200m/100km
- PlugIn Hybrid test in Charge–Sustaining mode (will be revised in Package 4)
- Periodical Regeneration w/o Regeneration use ki-factors

Ambient conditions:
- Temperature 0°C to 30°C (extended range -7°C to 35°C)
- Altitude up to 700m (extended range 1300m) (China 2400m)
REAL DRIVING EMISSION
IMPACT OF NEW RDE BOUNDARIES (PACKAGE 3)

RDE Evaluation up to Dec. 2016

New RDE acc. Package 3

Significant aggravation of RDE compliance by RDE Package 3 (2016-12-20)
GPF APPLICATIONS FOR HIGHER EMISSION ROBUSTNESS EXHAUST GAS AFTERTREATMENT SYSTEMS

GPF Configuration Concepts

GPF expected to become mandatory at least for GDI – short termed!
Driving style has a huge influence in soot accumulation at cold temperatures, dominated by drive-off emissions.
REAL DRIVING EMISSION
PN EMISSIONS AT TEMPERATURES < 20°C

Engine Out PN Potential per Real World Driving Warmup Phase, EU6c calibration

- Driving style has a huge influence in soot accumulation at cold temperatures, dominated by drive-off emissions

Active Regeneration will be necessary for GPFs in winter city operation

Control Passive Regeneration to avoid thermal GPF damage
GASOLINE POWERTRAIN TECHNOLOGY

FEATURES FOR INCREASING EFFICIENCY

Combustion System
- Miller, Atkinson
- high BMEP TGDI
- Low PN
- CNG-DI
- Water Injection

Variable Crank Train
- Var. Compression Ratio
- Var. Expansion Ratio

Exhaust Gas Cooling
- External cooled EGR
- Cooled / integrated manifold

“Smart Hybridization”
- electric auxiliaries
- 48V systems

Boosting
- 2-stage
- electric boosting
- water cooled VGT

Variable Valvetrain
- 2-step / 3-step
- fully flexible

Cylinder Deactivation
- Mechanically
- Electronically

GASOLINE POWERTRAIN TECHNOLOGY FEATURES FOR INCREASING EFFICIENCY

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• Hybridization enables shift towards higher loads high load area and max. efficiency gaining importance.

Trade-off between maximum efficiency and spec. power becomes the key trade-off

• Miller / Atkinson Cycle confirmed as most cost effective CO₂ solutions (e.g. Toyota, Audi, VW, HMC, etc.)
ADVANCED CHARGING
SEQUENTIAL COMPRESSOR TC

2-stage compression + interstage cooling instead of single stage

- Lower turbine power demand
- Lower compression temperature
EVOLUTION OF GASOLINE TECHNOLOGIES
EXTENDING HIGH EFFICIENCY OPERATION

Telescopic Conrod for VCR Variable Compression Ratio
Variable Compression Ratio enables combination of high efficiency & high performance. Modular systems enable easy integration into std. engines.

- Compression ratio variation of 3-6 units
- Simple and cost-effective design
- Minimized friction impact compared to other VCR systems
- Applicable for Gasoline and Diesel engines

Full modularity with conventional ICE
• Formula 1 engines offer the by far most outstanding efficiency vs. spec. performance trade-off

• Emission compliance, esp. RDE compromises ultra high efficiency concepts, especially lean operation

• Water injection as enabler to extend the potential of advanced boosting

• Combined processes as long term concept for efficiencies > 50%

Different development directions: high performance + low efficiency, low performance + high efficiency, best compromise: adv. boosting + water injection or VCR
TECHNOLOGIES IN THE NEXT 10 YEARS

**2025**: 50% electrified, still 100 mio ICE’s, however, high scatter of predictions

**Fuel Cell**: limited to specific markets

**BEV**: Dependent on infrastructure, incentives and access restr.

**Plug In Hybrid**: CAFE and city access as major driver

**Full Hybrid**: Primarily with Japanese OEM’s

**Mild Hybrid**:  
- 48 V in various configurations P0 – P4  
- Power Increase 15 → 20 → 30 kW  
- ICE utilizes synergies

**ICE**:  
- Significantly higher effort for emission compliance (RDE, China6, SULEV xx, ...),  
- “Zero Impact Emission Concepts” starting  
- Increasing share turbocharging + Rightsizing,  
- Advanced boosting, exhaust energy recuperation, full map stoichiometric, EGR  
- E-fuels and E-gas increasing

**Global Engine Production**  
AVL Prediction 1/2017
FUTURE TECHNOLOGY IMPACT ON ENGINEERING DEMAND

- Dramatically enhanced engineering demand
- Connected & Autonomous
- New EV / Fuel Cell
- Huge variety of new complex XEV systems
- Significantly higher effort for emission compliance (RDE, China 6b, SULEV xx, ...)

AVL
(12/2016)
SUMMARY AND CONCLUSION

• The forthcoming Emission-Legislation together with RDE and CO2-limits will dramatically enhance technology requirements and optimization demand for powertrain and complete vehicle.

• For best Fuel Economy and RDE conformity, advanced powertrain technology features as well as Hybridization massively will be introduced to meet diversification requests from market globally.

• The “conventional” internal combustion engine proves to still have huge further improvement potential.

• Balancing the fuel economy and EAS measures on powertrain and vehicle side are essential to get optimum results at affordable product cost.
RIGHTSIZING THE FUTURE POWERTRAIN
## Abbreviations (1/3)

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AER</td>
<td>All Electrical range</td>
</tr>
<tr>
<td>AT</td>
<td>Automatic Transmission</td>
</tr>
<tr>
<td>BEV</td>
<td>Battery Electric Vehicle</td>
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<tr>
<td>BMEP</td>
<td>Brake Mean Effective Pressure (spec. value for engine torque)</td>
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<tr>
<td>BSFC</td>
<td>Brake Specific Fuel Consumption</td>
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<tr>
<td>BSG</td>
<td>Belt Starter Generator</td>
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<tr>
<td>CAI</td>
<td>Controlled Auto Ignition (general expression for HCCI)</td>
</tr>
<tr>
<td>CNG</td>
<td>Compressed natural Gas</td>
</tr>
<tr>
<td>CSI</td>
<td>Compression and Spark Ignition (AVL patented comb. system featuring HCCI)</td>
</tr>
<tr>
<td>CVT</td>
<td>Continuously Variable Transmission</td>
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<tr>
<td>DCT</td>
<td>Dual Clutch Transmission</td>
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<tr>
<td>DOC</td>
<td>Diesel Oxidation Catalyst</td>
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<tr>
<td>DeNOx</td>
<td>Nitrogen oxide reducing catalyst</td>
</tr>
<tr>
<td>DPF</td>
<td>Diesel Particulate Filter</td>
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<tr>
<td>EAS</td>
<td>Exhaust Aftertreatment System</td>
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<tr>
<td>EGR</td>
<td>Exhaust Gas Recirculation</td>
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<td>EU6</td>
<td>European Emission Limit Stage 6</td>
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<tr>
<td>EV</td>
<td>Electric Vehicle</td>
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<tr>
<td>FC</td>
<td>Fuel Cell</td>
</tr>
<tr>
<td>FE</td>
<td>Fuel Economy</td>
</tr>
<tr>
<td>FTP</td>
<td>Federal Test Procedure (USA)</td>
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<tr>
<td>GDI</td>
<td>Gasoline Direct Injection</td>
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<tr>
<td>GPF</td>
<td>Gasoline Particle Filter</td>
</tr>
<tr>
<td>HSDI</td>
<td>High Speed Direct Injected (Diesel)</td>
</tr>
<tr>
<td>ICE</td>
<td>Internal Combustion Engine</td>
</tr>
<tr>
<td>ITW</td>
<td>Vehicle Inertia Test Weight (curb weight)</td>
</tr>
<tr>
<td>LNT</td>
<td>Lean NOx Trap</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquified Petrol Gas</td>
</tr>
<tr>
<td>MPI</td>
<td>Multipoint Port Fuel Injection</td>
</tr>
<tr>
<td>MPV</td>
<td>Multi Purpose Vehicle</td>
</tr>
<tr>
<td>MT</td>
<td>Manual Transmission</td>
</tr>
<tr>
<td>MY</td>
<td>Model Year</td>
</tr>
<tr>
<td>NA</td>
<td>Naturally Aspirated</td>
</tr>
<tr>
<td>NEDC</td>
<td>New European Driving Cycle</td>
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## Abbreviations (3/3)

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<tr>
<td>OBD</td>
<td>On Board Diagnosis</td>
</tr>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer (=brand)</td>
</tr>
<tr>
<td>PEMS</td>
<td>Portable Emission Measurement System</td>
</tr>
<tr>
<td>PHEV</td>
<td>Plug-in Hybrid Electric Vehicle</td>
</tr>
<tr>
<td>PN</td>
<td>Particle Number (Emission)</td>
</tr>
<tr>
<td>RDE</td>
<td>Real Driving Emission</td>
</tr>
<tr>
<td>RPM</td>
<td>Revolutions per Minute (engine speed)</td>
</tr>
<tr>
<td>SCR</td>
<td>Selective Catalytic Reduction (for NOx)</td>
</tr>
<tr>
<td>SI</td>
<td>Spark Ignited</td>
</tr>
<tr>
<td>SULEV</td>
<td>Super Ultra Low Emission Vehicle (US, California Emission Standard)</td>
</tr>
<tr>
<td>SUV</td>
<td>Sport Utility Vehicle</td>
</tr>
<tr>
<td>TCI</td>
<td>Turbo Charged Intercooled</td>
</tr>
<tr>
<td>TGDI</td>
<td>Turbo Charged Gasoline Direct Injection</td>
</tr>
<tr>
<td>TWC</td>
<td>3-Way Catalyst</td>
</tr>
<tr>
<td>VVL</td>
<td>Variable Valve Lift</td>
</tr>
<tr>
<td>VVT</td>
<td>Variable Valve Timing</td>
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<tr>
<td>WLTP</td>
<td>World Harmonised Light Duty Vehicle Test Procedure</td>
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