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Powertrain Strategies Are Driven By Global Trends

Megatrends

1. Energy security (frontrunner US)
2. Oil price increase / volatility (all regions)
3. Urban air pollution (frontrunner Asian Mega-cities)
4. Climate change (frontrunner Europe)

Drivers

Push from governments

Supply-side regulation to OEMs (CAFE, ZEV, etc.)

Pull from consumers

Higher TCO for consumer
- Demand-side regulation (e.g. taxes, incentives)
- Cost of fuel consumption

Impact on future propulsion systems

Necessity for low CO₂ emitting / high efficiency powertrains

Fuel Consumption or CO₂

System Cost ($)
Primary Emissions
Vehicle Packaging
Vehicle Performance
Regional Transportation Energy Drivers – Current Issues

- CO₂/FE Regulations
- Fuel Prices
- Incentives
- Petroleum Reduction
- Gov’t mandates
- Leapfrog strategy
- CO₂/FE Regulations
- Oil dependency

Global trend for increased levels of fuel economy and/or Lower CO₂ will continue

Varying regional requirements for renewable fuels
Euro CO₂ Emission Reduction

2007 average NEDC CO₂ Emission in g/km

Source: European Federation for Transport and Environment

- Porsche
- Daimler
- BMW
- Mazda
- Nissan
- Hyundai
- VW
- Ford
- GM
- Honda
- Toyota
- Renault
- Fiat
- PSA

proposed legislation 2015
proposed legislation 2020
United States Fleet Average Outlook
CO₂ and CAFE

Compliance with EPA GHG means Higher MPG than CAFE
Customer Requirements and Trends – 5 to 10 Year View

- Full and plug-in hybrids incl. range extender concepts
- Efficient powertrain systems – downsizing and mild hybridization (incl. Diesel)
- Powertrains based on alternative fuels (incl. E-drive)
- Powertrains suitable for bio-mass based fuels
- High reliability, best availability
- Fuel efficiency and low cost powertrains
- Full hybrids based on efficient SI engines (niche fleets with FC)

Regional diversification of requirements leads to diversification of powertrain technologies
Current Options

Vehicle Weight [kg]

CO2 Emission in NEDC [g/km]

- Gasoline NA
- Gasoline TC
- Diesel
- Diesel - best in class
- GDI, GDI-tc (BMW, VW)
- Hybrid
- CNG Turbo (OPEL, VW)

EU-Proposal for CO2 Limit

Source: AR, KBA 2008

Best in-class Diesel similar to Hybrid concepts
What Happens Next?

“All Predictions are Wrong
Some Predictions Are Worthwhile”

Collaboration: OEMs, Suppliers, & Researchers

Flexibility To Adapt – Agile Solutions

Electrification?
Predictable Trend Towards Integration Of New Elements In Powertrain Systems
Selection Of Most Suitable “FLEXIBLE” Powertrain Structure

After three centuries of development, combined-cycle efficiency just exceeds 50%, simple-cycle remains below.

Chris Edwards - Stanford University

CO₂ [g/km]

Fuel Consumption or CO₂

System Cost ($)
Primary Emissions
Vehicle Packaging
Vehicle Performance
Selection Of Most Suitable “FLEXIBLE” Powertrain Structure

Highly Flexible IC Engine:
- Variable multi-stage turbocharging
- Variable multi-mode combustion
- Multiple Fuel
- Adaptive control
Selection Of Most Suitable “FLEXIBLE” Powertrain Structure

DI-Gas Key Features:

- High combustion stability and efficiency
- 25-30% CO\textsubscript{2} emission reduction compared to standard gasoline

PC Application:

- Standard vehicle 1600-1800 kg
- Application of DI-Gas combustion technology
- Combination with advanced full hybrid powertrain
- Consideration of 20% CO\textsubscript{2}-neutral Bio-Gas
Selection Of Most Suitable “FLEXIBLE” Powertrain Structure

Highly Flexible IC Engine:
- Variable multi-stage turbocharging
- Variable multi-mode combustion incl. biogas
- Multiple Fuel
- Adaptive control

Highly Flexible Transmission:
- Higher gear numbers & automation
- CVT and infinite variable transmission
- Electric transmission

Control Engine Operation Near Peak Efficiency
Selection Of Most Suitable “FLEXIBLE” Powertrain Structure

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Highly Flexible Transmission:
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Flexibility by Hybridization:
- From micro to full hybrid
- More degrees of freedom due to additional elements
Hybrids Come In Many Forms:

**Micro Hybrid**
Low voltage (12V)
Shuts down engine at idle to save fuel

**Mild Hybrid**
Low to medium voltage (12 to 120V)
Includes stop-start, regeneration braking and acceleration assist

**Full Hybrid**
High voltage (300V+)
Includes all mild HEV features PLUS EV-mode

**Plug-In Hybrid (PHEV)**
High voltage (300V+)
Ability to recharge battery through electrical wall outlet

**Pure EV**
High voltage (300V+)
Battery
Range extender with combustion engine
Fuel cell

Electrification

AVL Proprietary - Gary Hunter 14 July, 2010 UM-TRI
Hybrid – One Word For A Diversity Of Options

Additional E-Power Source in the Drivetrain for:

- Fuel Economy Improvements
- Emission Reductions
- Outstanding Driving Performance
- Superior Drivability
- Engine Simplifications
### Mild Diesel Hybrids

**Vehicle**
- Cycle power ~ 4 kW
- Testweight = 1470 kg
- 6 speed DCT

**Engine**
- HSDI 1.6 L
- WG-Turbocharger
- Low pressure - EGR

**Electrification**
- BSG ~ 4 kW
- ISG ~ 10 kW

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### CO₂ NEDC - g/km

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**Additional Features**
- + Start / Stop
- + Emission peak shaving + recuperat.
- + electric driving + recuperat.
Ideal Hybrid Powertrain – Long Term Benchmark

Key Features:
- High efficient battery >95%
- High efficient e-motors >95%
- High efficient inverter >95%
- Brake energy recuperation >85%
- High efficient engine >43%
SELECTION OF MOST SUITABLE “FLEXIBLE” POWERTRAIN ARCHITECTURE

Highly Flexible IC Engine:
• Variable multi-stage turbocharging
• Variable multi-mode combustion incl. biogas
• Adaptive control

Highly Flexible Transmission:
• Higher gear numbers & automation
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Flexibility by Hybridization:
• From micro to full hybrid
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Pure Electric Drive
• Highly efficient e-motor w/o idling losses
• Highly flexible system in view of energy supply – battery & range extender & fuel cell
Hybrids Require Different Types of Batteries Or Energy Provision Systems

Battery Size / Battery Cost

All Electric Range (AER)

Full Hybrid = Electric Driving!
Challenge: Battery Commercialization

Objectives “3 x 3”:
- 3 x lower cost than today
- 3 x energy density of today
- 3 x power density of today

Criteria and boundary conditions
- Safety and reliability
- LCA: Materials and resources
- New production processes
- High production volume
Range Extender Configurations

**Reciprocating** vs. **Rotary**

**Piston Engine Packaging**

- **2-Cyl. Range Extender**
  - 570ccm, 18kW@5000rpm
  - weight: 40kg

- **Wankel – Range Extender**
  - 250ccm, 18kW@5000rpm
  - weight: 29kg
Consistent Tools For Application During Configuration And Development Phase

Common Development Environment

- Software in the Loop
- Hardware in the Loop
- Component Bench
- Chassis Dyno
- Road

Consistency of tools and models throughout whole process

CONFIGURATION PHASE

DEVELOPMENT PHASE

Collaboration Between OEMs, Suppliers, and Researchers
SUMMARY

- Regional requirements and global agreements will continue to drive the future for the usage of alternative fuels and electrification.

- It is thought that in the next 10 years, some form of electrification will be required to meet CO\(_2\) emissions on all vehicles in regulated markets – this trend will continue.

- Significant extension of technology elements and variants by increasing electrification

- Extended modularity will support fast and flexible reaction to market requirements

- Cross functional and systems overlapping research, development and system integration is mandatory

- The long term fuel / CO\(_2\) saving potential in the range of 40 - 50% based on powertrain technology*

- The technology race is on…which technologies will “win” is yet to be seen.

* Baseline w/o hybridization and downsizing
Questions

Thank You!!