Bosch Powertrain Strategies

Agenda

Who is Bosch, and how do we develop powertrain for a complex global market?

What is the long term trajectory of powertrain development?

Is the US moving away from globally consistent powertrain development?

How do we analyze technology needs for the future?
WHO IS BOSCH?

AND HOW DO WE DEVELOP POWERTRAIN FOR A COMPLEX GLOBAL MARKET?
Bosch Powertrain Strategies

Ownership
- 7% Bosch family
- 1% Robert Bosch GmbH
- 92% Robert Bosch Stiftung (Charitable Foundation)

Business sectors and divisions
- Mobility Solutions
- Industrial Technology
- Energy and Building Technology
- Consumer Goods

Mobility Solutions
World's largest supplier of cutting-edge automotive technology

Energy and Building Technology
Leading manufacturer of thermo and building security technology; World's largest supplier of heat pumps

Industrial Technology
Leading in drive and control technology, packaging, and process technology

Consumer Goods
World's largest power tool manufacturer. Leading the field in household appliances

Who is Bosch?
- 92% Robert Bosch Stiftung (Charitable Foundation)
- 7% Bosch family
- 1% Robert Bosch GmbH

- 276 manufacturing sites
- approx. 390,000 associates
- 80.9 billion dollars in sales in 2016
Gasoline Systems
Diverse Product Portfolio to Support all Powertrain Variants
We have a global-local presence: we are present wherever our partners need us, and we understand our customers and markets.

In North America: we have...the entire value chain, local development expertise, full system support.
Powertrain Solutions: One business division. Three segments.

Electric vehicles, passenger cars, commercial vehicles & OH**

- Mobility will be electric in the long run
- Market will be growing strongly
- Technology is our differentiator

New emission regulations push today’s technology
Growing importance of hybrid technology

Diesel is the dominant technology
Demand for alternative technologies, e.g. Hybrids
Future Demand of FCEV expected

* incl. Hybrids
** Off-Highway

Gasoline Systems and Diesel Systems divisions become Powertrain Solutions
WHAT IS THE LONG TERM TRAJECTORY OF POWERTRAIN DEVELOPMENT?
## Bosch Powertrain Strategies
### Market Development by Powertrain Type (per Region)

<table>
<thead>
<tr>
<th>Region</th>
<th>2020</th>
<th>2025</th>
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<tbody>
<tr>
<td>EU28</td>
<td>18.4</td>
<td>19.2</td>
</tr>
<tr>
<td>US</td>
<td>16.4</td>
<td>25.2</td>
</tr>
<tr>
<td>CN</td>
<td>26.7</td>
<td>17.5</td>
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<tr>
<td>IN</td>
<td>0.9</td>
<td>0.6</td>
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<tr>
<td>JP</td>
<td>8.1</td>
<td>12.1</td>
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</table>

**Powertrain Types:**
- **EV**
- **PHEV**
- **HEV**
- **CNG**
- **GDI**
- **PFI**
- **Diesel**

**Pure ICE:**
- **EU28**
- **US**
- **CN**
- **IN**
- **JP**
Bosch Powertrain Strategies
NAFTA Light-Duty Vehicle Production

OEM

Energy & Fuel Injection Strategy

Engine Size

Transmission Strategy

- Mature Market with West Coast OEMs taking share
- Continued Growth in G-DI
- Continued Engine DZ, still 10% V8 in 2023
- Dominant 8+AT with Growing CVT & e-PT
IS THE US MOVING AWAY FROM GLOBALLY CONSISTENT POWERTRAIN DEVELOPMENT?
Global Regulations Summary

- Status 30.06.2016

### Data Conversion
1. Converted into g CO₂/km from Miles per gallon
2. Converted into g CO₂/km from l/100km

### Notes
- Data shown are measured in different test cycles with different procedures, therefore data are not directly comparable.
- Conversion to CO₂ g/km from mpg, km/l and l/100km using regional fuel conversion factors.

### Key Terms
- **EU**: CO₂ fleet targets, PC = Pass. Cars, LCV = Light Commercial Vehicles;
- **Japan** and **Korea**: PC fuel efficiency targets;
- **China**: CAFC = Corporate Average Fuel Consumption targets for PC;
- **US**: CAFE = Corporate Average Fuel Economy, PC = Pass. Cars, LT / LDT = Light Trucks (pick-ups, vans, SUVs), MD(P) V = Medium Duty (Pass.) Vehicles.

### Global Regulations Summary

#### EU
- **EU5**: NEDC, No PN limit
- **EU6b**: WLTC + RDE, PN: 6*10¹² 1/km
- **EU6d-temp**: WLTC + RDE, PN: 6*10¹¹ 1/km
- **EU6d**: WLTC + RDE, PN: TBD
- **EU7**: WLTC + RDE w CF

#### LEVII
- **LEVII FTP Testing**: NMOG 0.035 g/mi, NMOG+NOₓ 0.1 g/mi, fleet average 0.030 g/mi

#### LEVIII FTP Testing
- **US Fixed**: Proconve L5, PM CARB 10mg/mi
- **China – Beijing**: Phase 4
- **Phase 5 Step 1**: EU5, Phase 5 Step 2: EU5 / OBD
- **Phase 6 Stage 1**: WLTC, EU6c limits, PM, PN all SI
- **Phase 6 Stage 2**: WLTC, 0.5*EU6c limits, PM 3mg/km, PN all SI, RDE w CF

#### Brazil L7
- **Proconve L5**: FTP75, 160k km, NMOG+NOₓ = 0.08g/km
- **Proconve L6**: FTP75, 160k km, NMOG+NOₓ = 0.08g/km
- **Proconve L7**: FTP75, 160k km, NMOG+NOₓ = 0.08g/km

### Timeline
- **2010**: EU 229, CAFE LT/MDV
- **2015**: EU 217, CAFE LT/MDV
- **2020**: EU 189, CAFE LT/MDV
- **2025**: EU 137, CAFE LT

### Other
- **Status 30.06.2016**
- **GS/NE-NA | 14/07/2017 © 2017 Robert Bosch LLC and affiliates. All rights reserved.**

### Conversion Factors
- **2010**: 250 CO₂ g/km, 8.6 l/100 km, 6.4 g/km, 4.3 g/km, 2.1 g/km
- **2015**: 229 CO₂ g/km, 7.5 l/100 km, 5.7 g/km, 3.8 g/km, 1.9 g/km
- **2020**: 217 CO₂ g/km, 7.5 l/100 km, 5.7 g/km, 3.8 g/km, 1.9 g/km
- **2025**: 189 CO₂ g/km, 7.5 l/100 km, 5.7 g/km, 3.8 g/km, 1.9 g/km
## Bosch Powertrain Strategies
### Regional Implementation - US

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<tbody>
<tr>
<td>FE / CO2</td>
<td>CAFE: MY2012-2016 (34.1mpg)</td>
<td>CAFE: MY2017-2021 → 44.4mpg</td>
<td>MY2022-2025 → 54.5mpg</td>
<td>CO2: EPA</td>
<td>FE: NHTSA</td>
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<td>ZEV</td>
<td>ARB ZEV: large volume OEMs must sell BEV/PHEV/FCEV vehicles</td>
<td>Requirement grows to 10% of sales by 2025</td>
<td>California + 9 states</td>
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<tr>
<td>Emissions</td>
<td>ARB LEV III Phase-In (2025: 30mg NOx+HC, 1mg PM)</td>
<td>EPA Tier3 Phase-In (2025: 30mg NOx+HC, 3mg PM)</td>
<td>California-ARB</td>
<td>Federal-EPA</td>
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<tr>
<td>OBD</td>
<td>Additional requirements expected every 2 years</td>
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<td></td>
<td>Federal</td>
<td>Drives engineering services: • New data parameters • New monitoring strategies</td>
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**CAFE: MY2012-2016 (34.1mpg)**

**CAFE: MY2017-2021 → 44.4mpg**

**MY2022-2025 → 54.5mpg**

**California-ARB**

**Federal-EPA**

**ARB ZEV: large volume OEMs must sell BEV/PHEV/FCEV vehicles**

**Requirement grows to 10% of sales by 2025**

**ARB LEV III Phase-In (2025: 30mg NOx+HC, 1mg PM)**

**EPA Tier3 Phase-In (2025: 30mg NOx+HC, 3mg PM)**

**Additional requirements expected every 2 years**

**Drives engineering services:**
- New data parameters
- New monitoring strategies
Bosch Powertrain Strategies
Market Drivers - Beyond Regulation

Demographics

Regulations

Technology
- Autonomous driving
- Battery
- Electrification
- V2V connectivity

Business Models

- UBER
- zipcar
- MAVEN
- lyft
HOW DO WE ANALYSE TECHNOLOGY NEEDS FOR THE FUTURE?
Future Powertrain
Passenger Car Fleet MY 2016 - With MY 2015 Credits

% Improvement Required to Reach 2025 GHG Target
Based on MY2016 Portfolio

General Motors 41%
Ford 39%
FCA 44%
Honda 33%
Mercedes 42%
Nissan 31%
Mazda 31%
Toyota 31%
Hyundai 37%
VW 40%
BMW 39%

Source: Wards 2016
Future Powertrain

CO₂ Requirements US - Vehicle Footprint

- **240 g/mi Example**
  - 4cyl 2.0L
  - Port Fuel Inj.
  - 6-Speed AT
  - 1445 Kg

- 2016 Target
- 2021 Target
- 2025 Target

- Vehicles:
  - Compact Car
  - Large Car
  - Midsize Car
  - Subcompact Car
  - Compact Car (Hybrids)
  - Large Car (Hybrids)
  - Midsize Car (Hybrids)
  - Subcompact Car (Hybrids)
Future Powertrain
CO₂ Reduction Roadmap NA

Engine Measures

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<tr>
<th>Measure</th>
<th>2017</th>
<th>2021</th>
<th>Target</th>
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<tr>
<td>DI</td>
<td>6-8%</td>
<td>1-2%</td>
<td>1-2%</td>
</tr>
<tr>
<td>DZ</td>
<td>5-6%</td>
<td>3-6%</td>
<td>5-6%</td>
</tr>
<tr>
<td>SGDI</td>
<td>4-5%</td>
<td>4-5%</td>
<td>4-5%</td>
</tr>
<tr>
<td>Miller high ɛ</td>
<td>12-13%</td>
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<td></td>
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<tr>
<td>high ɛ cEGR</td>
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<tr>
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<td>Miller</td>
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<td>high ɛ cEGR</td>
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Powertrain Measures

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<thead>
<tr>
<th>Measure</th>
<th>2025</th>
<th>Target</th>
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<tbody>
<tr>
<td>BRS HEV</td>
<td>6%</td>
<td>5-8%</td>
</tr>
<tr>
<td>CVT or AT8+</td>
<td>11-14%</td>
<td>~16%</td>
</tr>
<tr>
<td>cEGR</td>
<td></td>
<td>+50%</td>
</tr>
<tr>
<td>Start Stop Coast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Friction Reduction</td>
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<tr>
<td>BRS HEV</td>
<td>6%</td>
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<tr>
<td>Start Stop Coast</td>
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<tr>
<td>Friction Reduction</td>
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Potential

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<tr>
<th>Mileage</th>
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<tbody>
<tr>
<td>240 g/mi</td>
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</tr>
<tr>
<td>2%</td>
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</tr>
<tr>
<td>1-2%</td>
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</tr>
<tr>
<td>6-8%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-6%</td>
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<td></td>
</tr>
<tr>
<td>4-5%</td>
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</tbody>
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Notes:
- ɛ = Compression Ratio
- FR = Friction Reduction
- DI = Direct Injection
- DZ = Downsizing w/ Turbo
- SGDI = Stratified Lean Burn
- CDA = Cylinder Deactivation
- high ɛ = High Compression
- BRS = Boost Rec. System
- CVT = Continuous Variable Tr.
- cEGR = Cooled Exhaust Gas
- AT8+ = 8/9/10 speed

Simulation for FTP75 test cycle
Bosch Powertrain Strategies

Bringing it together

Bosch portfolio covers all options for powertrain, with global products and local focus.

Electric (battery and fuel cell) is the future. But how to get there is the trick.

Macro trends and business models support regulatory push to reduce CO2 in US.

Future technology needs at macro level are developed by understanding individual OEM gaps and technology portfolio.