Unprecedented growth in Automotive Catalysts

SPEAKER

Pascal Reymondet
Executive Vice-President Catalysis
Agenda

Business profile

Light Duty Vehicles

Heavy Duty Diesel

Key takeaways
At Automotive Catalysts we develop technologies which allow our customers to meet automotive emission legislation at the lowest Total Cost of Ownership.

- Complete catalyst systems to reduce exhaust gas emissions
- People engagement
- Operational excellence
- Global manufacturing & technical footprint
- Customer focus
Global Production Footprint
Light duty vehicles

Burlington
Canada

Tulsa, OK
USA

Americana
Brazil

Rheinfelden/
Bad Säckingen
Germany

Karlskoga
Sweden

Nowa Ruda
Poland

Onsan
Korea

Himeji
Japan

Suzhou
China

Port Elizabeth
South Africa

Pune
India

Rayong
Thailand
Global Production Footprint

Heavy duty diesel

- Frederikssund, Denmark
- Florange, France
- Joinville, Brazil
- Tianjin, China
- Onsan, Korea
- Suzhou, China
- Pune, India (SOP 2019)
Global Footprint
R&D and Technical centers

Songdo
Korea

Tokoname
Japan

Suzhou
China

Hanau
Germany

Lyngby
Denmark

Auburn Hills, MI
USA

Tulsa, OK
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Americana
Brazil

Himeji
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Global Footprint
R&D and Technical centers
Recent additions through M&A

- Tianjin, China
- Houston, TX, USA
- Joinville, Brazil
- Frederikssund, Denmark
- Lyngby, Denmark
- Onsan/Songdo, Korea

Map showing locations around the world.
A clear trend towards clean mobility

"EU rolls out stricter car emission tests"

EU rolls out stricter car emission tests.

Reuters 31/08/2017

"Europe bolsters regulatory clout over carmakers."

Europe bolsters regulatory clout over carmakers.

Bloomberg 19/04/2018

"Bharat Stage VI: India revises standards specifications for petrol and diesel."

Bharat Stage VI: India revises standards specifications for petrol and diesel.

Reuters 18/01/2018

"China 6 emission standard to be implemented in 2020."

China 6 emission standard to be implemented in 2020.

Autonews 11/05/2018
Agenda

Business profile

Light Duty Vehicles

Heavy Duty Diesel

Key takeaways
More stringent emission norms across regions

No tolerance for pollution

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<td>India National</td>
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<td>BS IV (50-70 cities)</td>
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<td>Thailand</td>
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<td>Euro5?</td>
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<td>Brazil</td>
<td>PL 6</td>
<td>PL 6+ (GPF &amp; 160kkm durability) not officially decided</td>
<td>PL 7?</td>
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<td>Argentina</td>
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<td>Euro 6?</td>
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Legend:
- Tier: Emission standards for vehicles.
- LEV: Low Emission Vehicles.
- BS: Bharat Stage.
- CN: China National.
- EU: European Union.
- USCARB: United States CARB.
- Euro: European emission norms.
China, Europe and India on the verge of massive tightening of emission norms


EU
- Euro 6b
- Euro 6d temp
- Euro 6d

China National
- CN 4
- CN 5
- CN 6a
- CN 6b

India National
- BS III
- BS IV
- BS VI
- BS VII?
### Emission Standards
- **CN 4**
- **CN 5**
- **CN 6a**
- **CN 6b**

### Cycle
- **Emission**: New European Driving Cycle (NEDC)
- **Fuel Efficiency (F.E.)**: NEDC
- **World Harmonized Light Vehicle Test Cycle (WLTC)**
- **F.E.**: China Cycle

### Real Driving Emissions (RDE)
- **Development & Measurement Phase**
- **Only monitor**
- **Full operation**
  - CF$_{PN}$: 2.1, CF$_{NOx}$: 2.1

### Durability
- 100,000 km
- 160,000 km
- 200,000 km

### On board diagnostics
- CN 4
- CN 5
- CN 6

### Fuel
- IV
- V
- VI A
- VI B

### Fuel Efficiency (L/100km)
- 6.9
- 6.7
- 6.4
- 6
- 5.5
- 5
- 4

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*Fuel neutral; Particulate Number (PN) and Particulate Mass (PM) required for all engines.

China changes its role from follower to pace setter.
China’s huge gasoline fleet will become much cleaner

**China 5: current**
Gasoline PM limit of 4.5mg/km

**China 6a: July 2020**
More stringent CO, HC, NOx limits
Gasoline PN limit of $6 \times 10^{11}$

- 1.7x value vs. China 5

**China 6b RDE: July 2023**
- Gasoline PN limit of $6 \times 10^{11}$
- Conformity factor (CF) 2.1x under RDE
- HC and NOx further reduced

- 2.4x value vs. China 5

Source: IHS May 2018
Significant impact from new European testing regime

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<tbody>
<tr>
<td>CO\textsubscript{2} target</td>
<td>130 g/km</td>
<td>95 g/km</td>
<td>100% fleet</td>
<td>95% &gt; 100% fleet</td>
<td>-15%</td>
<td>-30%</td>
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<td>Emission standards</td>
<td>Euro 6b</td>
<td>Euro 6d TEMP</td>
<td>Euro 6d</td>
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<td>NEDC / WLTC</td>
<td>NEDC-based testing</td>
<td>WLTC-based testing</td>
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<tr>
<td>Real Driving Emissions</td>
<td>Development and monitoring phase</td>
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<td>CF\textsubscript{1PN}: 1.5</td>
<td>CF\textsubscript{2PN}: 1.0+margin (0.5)*</td>
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<td>CF\textsubscript{1NOx}: 2.1</td>
<td>CF\textsubscript{2NOx}: 1.0+margin (0.5)*</td>
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<td>On Board Diagnostics</td>
<td>Euro 6-1</td>
<td>Euro 6-2</td>
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All dates: New type approval Passenger Cars

*annual review and revision as a result of improved quality of PEMS procedure or technical progress
RDE calls for massive fitment with gasoline particulate filters

**EURO 6 REGION LDV MARKET BY 2025**

20 million

**Euro 6b: current**
Gasoline PN limit of $6 \times 10^{11}$/km

**Euro 6d temp: Sept. 2018**
Gasoline PN limit of $6 \times 10^{11}$/km with PN CF 1.5x under RDE

> 1.8 x value vs. Euro 6b

**Euro 6d final: Jan. 2021**
Gasoline PN limit $6 \times 10^{11}$ with PN CF 1.0-1.5x under RDE

> 2.2 x value vs. Euro 6b

Source: IHS
May 2018
* For all new vehicles sold

GPF/cGPF: for almost all GDI engines

cGPF: for ~80% of all GDI engines and 50% of MPI engines
RDE calls for more complex diesel catalysts

**Euro 6b: current**
NOx emission limit of 80 mg/km

**Euro 6d temp: Sept. 2019***
NOx emission limit of 80 mg/km with NOx CF 2.1x under RDE

> 1.3x value vs. Euro 6b

**Euro 6d final: Jan. 2021***
NOx emission limit of 80 mg/km with NOx CF 1.0-1.5x under RDE

> 1.5x value vs. Euro 6b

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Source: IHS May 2018
* For all new vehicles sold

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EURO 6 REGION
LDV MARKET
BY 2025

20 million

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20 million

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EURO 6 REGION
LDV MARKET
BY 2025

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India leapfrogs from Bharat Stage IV to VI

- **Legislation**
  - 2017: BS IV
  - 2018: BS VI
  - 2019: BS VI RDE (TBC)

- **Certification**
  - 2017: NEDC
  - 2018: (Modified)
  - 2019: WLTP (TBC)
  - 2020: RDE monitoring
  - 2021: RDE mandatory
Introducing similar norms to Euro 6b for gasoline...

**Bharat Stage IV: current**
No gasoline particulate limit

**Bharat Stage VI: 2020**
Gasoline particulate limit of $6 \times 10^{11}$/km

- $1.5x$ value vs. BS IV

**Bharat Stage VI RDE: 2023 (TBC)**
Gasoline particulate limit of $6 \times 10^{11}$/km

- $3x$ value vs. BS IV

Source: IHS
May 2018

*TWC* Single or double Three Way Catalyst obligatory but no stringent control

*With cGPF* Single or double Three Way Catalyst volume increase

*cGPF* for all GDI engines
As well as for diesel

**Bharat Stage IV: current**
- NOx emission limits of 250mg/km

**Bharat Stage VI: 2020**
- NOx emission limit of 80mg/km
- Particle emission limit $6 \times 10^{11}$/km

> 3 x value vs. BS IV

Oxidation catalyst required with particulate filter optional

Particulate filters (DPFs) and active NOx treatment (NSC or SDPF) required for all diesel engines

Source: IHS
May 2018

INDIA LDV MARKET BY 2025

8 million
Tightening emission norms drive massive value uplift

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<th></th>
<th>Average Value Gasoline Catalyst</th>
<th>Average Value Diesel Catalyst</th>
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<td>China 6</td>
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<td>2020: value x 1.7 vs. current</td>
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<td>2023: value x 2.4 vs. current</td>
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<td>Euro 6d</td>
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<td>2019: value x 1.8 vs. current</td>
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<td>2020: value x 2.2 vs. current</td>
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<td>Bharat VI</td>
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<td>2020: value x 1.5 vs. current</td>
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<td>2023: value x 3.0 vs. current</td>
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Euro 6d
- 2019: value x 1.3 vs. current
- 2020: value x 1.5 vs. current

Bharat VI
- 2020: value x 3.0 vs. current

x2 Upside value of up to 20% for pHEV catalysts x1.5
Leading to massive growth in the light duty vehicle market

**MARKET VALUE EVOLUTION BY REGION**

- Europe
- Greater China
- Japan / Korea
- Middle East / Africa
- North America
- South America
- South Asia (mainly India)

Source: IHS data and Umicore estimates

**Excluding the upside potential of hybrid cars**

<table>
<thead>
<tr>
<th>Region</th>
<th>2017</th>
<th>2020</th>
<th>2025</th>
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<tbody>
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<td>Japan / Korea</td>
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<td>South America</td>
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<tr>
<td>South Asia (mainly India)</td>
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Global LDV market nearly doubling in value by 2025

China representing the lion's share of the value increase
Umicore best positioned to capture this growth

- Gaining significant share in growing gasoline segment
- Disproportionate share of GPF platforms won in Europe and China
- Smaller player in light duty diesel
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Business profile

Light Duty Vehicles

Heavy Duty Diesel

Key takeaways
Global emission standards for HDD continue to tighten

**HDD**

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<th>Year</th>
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<th>Japan</th>
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<th>Russia</th>
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<td>EU VI a,b</td>
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<td>JP 16</td>
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**NRMM**

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<th>China (Nationwide)</th>
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**Notes**

- **NRMM** = non-road mobile machinery

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![Image](image_url)
China and India on the verge of massive tightening of emission norms

HDD

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<th>Japan</th>
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<th>Brazil</th>
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</table>
China VI to significantly toughen HDD emission standards
More advanced catalytic systems for HDD in the largest market globally

**China V: current**
- NOx limit of 2000 mg/kWh

**China VI: 2021**
- NOx limit of 460 mg/kWh
- Particulate number limit $6.0 \times 10^{11}$

Source: KGP & Umicore assumptions on-road and non-road engines produced May 2018
India leapfrogs from Bharat Stage IV to BS VI

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<th>2018</th>
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<td>PEMS monitoring</td>
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BS VI calls for significantly more complex catalysts on all on-road HDD

Bharat Stage IV: current
NOx limit 3500 mg/kWh

Bharat Stage VI: 2020
NOx limit 460 mg/kWh

> 4 x value vs. BS IV

Source: KGP & Umicore assumptions on-road and non-road engines produced May 2018
Tightening emission norms and market growth drive massive value uplift...

Legislation

<table>
<thead>
<tr>
<th>China 6</th>
<th>Bharat VI</th>
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<td>2021:</td>
<td>2020:</td>
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<tr>
<td>value x 2.8 vs. current</td>
<td>value x 4 vs. current</td>
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</table>

Market growth

Global HDD market expected to grow 1.6x between 2017 and 2025

Source: KGP and Umicore assumptions (expected on-road and non-road engines produced)
Leading to massive growth in the heavy duty diesel market

MARKET VALUE EVOLUTION BY REGION

Europe
Greater China
Japan / Korea
Middle East / Africa
North America
South America
South Asia (mainly India)

Global HDD market more than doubling in value by 2025

China quintupling by 2025

Source: KGP data and Umicore estimates
Umicore well positioned to capture this growth

- Competitive technology portfolio
- Strong position in China which is becoming the largest HDD market
- Development partner of most major HDD OEMs
Total LDV and HDD catalyst market set for unprecedented value growth

MARKET VALUE EVOLUTION BY REGION

Europe
Greater China
Japan / Korea
Middle East / Africa
North America
South America
South Asia (mainly India)

Value growth by far outpacing vehicle production
Technology and Innovation play

Source: IHS, KGP, Umicore estimates
Agenda

- Business profile
- Light Duty Vehicles
- Heavy Duty Diesel
- Key takeaways
Key takeaways

Unprecedented value growth driven by advanced catalyst systems for tighter legislation both in LDV and HDD

China becoming the pace setter

Umicore well positioned to outgrow the market through its technology leadership in key segments
materials for a better life