Key developments in Automotive Catalysts

Capital Markets Event
Seoul, 23 May 2012
What is an automotive catalyst?

Combustion engines produce toxic emissions due to incomplete combustion of fuel and the generation of by-products.

Automotive catalysts are needed for reducing these toxic emissions.

Legislation enforces this by setting emission limits for vehicles.

Toxic pollutants
- Carbon Monoxide (CO)
- Hydrocarbons (HC, NMOG)
- Nitrogen Oxides (NOx)
- Particulate Matter (PM)

Non-toxic by-products
- Carbon Dioxide (CO₂)
- Water (H₂O)
- Nitrogen gas (N₂)
Umicore Automotive Catalysts
business drivers

Growing global light duty vehicle production

- Light duty vehicles (LDV): passenger cars, SUVs and light trucks
- Heavy duty diesel (HDD): trucks and buses
- Non-road applications

Emission legislation and air quality standards are becoming more stringent in developed and emerging markets

CO₂ emission reduction

- Impacts engine complexity and fuel types used in different regions
- Determines choice of powertrain
Global light duty vehicle production outlook

Established Markets

[Graph showing production outlook for Established Markets from 2000 to 2019, with categories for Japan/Korea, North America, and Europe, and data points for each year.

Emerging Markets

[Graph showing production outlook for Emerging Markets from 2000 to 2019, with categories for Middle East/Africa, South America, South Asia, and China, and data points for each year.

Source: Umicore estimates based on external databases

Source: Umicore estimate based on external data sources
Global powertrain development
Internal Combustion Engine (ICE) remains dominant

Car production

Contains combustion engine
Requires catalyst system

Source: Umicore estimate based on external data sources
Global emission legislation present in most regions and becoming more stringent
Umicore’s global leadership position

Regional positions

- Market leader (#1 or #2 position)
- Smaller player (distant #3)

Circles indicative of 2011 light duty vehicle production volumes (≠ catalyst revenues)
Umicore’s global footprint in automotive catalysts
Impact of CO$_2$ regulation
Challenging CO₂ emission targets will push the use of advanced engine configurations

**Advanced engine configurations**
- Down-sized turbo-charged gasoline engines
- Gasoline direct injection
- Lean burning gasoline engines
- Diesel
- Hybrid electric vehicles

All these configurations require complex catalyst solutions

**CO₂ emission targets for light duty vehicles**

Source: Continental (2011)
Downsized turbo-charged direct injection gasoline engines are being implemented more widely

Turbo-charged Direct Injection (DI) engines enable reduced fuel consumption
- By reduced engine displacement and decreased engine speed
- By flexible combustion process
- By significant torque increase, esp. at low rpm

Profile of exhaust gases is different
- Hydrocarbons (HC) emissions increase
- NOx emissions decrease
- Exhaust gas temperature range increase due to heat sink - turbo charger effect

Catalyst requirements more complex
- Lower light-off temperature for the catalyst
- Catalyst bed temperatures above 1000°C require greater durability
- High dynamic lambda behaviour
Lean combustion provides the best fuel economy

Lean burning conditions offer better combustion properties
- Principle already used in diesel cars
- Introduced in lean burning gasoline engines
- Works in oxygen-rich environment

Direct NO\textsubscript{x} reduction with excess oxygen is not possible
- Engine optimisation offers limited possibilities

NO\textsubscript{x} aftertreatment solutions required in most cases
- Selective Catalytic Reduction (SCR)
- NO\textsubscript{x} Storage Catalyst (NSC)
**Electrification of the powertrain impacts catalyst size and catalyst complexity**

<table>
<thead>
<tr>
<th>ELECTRIFICATION</th>
<th>ICE</th>
<th>HEV</th>
<th>PHEV</th>
<th>EV</th>
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<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Start-stop</td>
<td>Mild</td>
<td>Full</td>
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<tr>
<td>Relative size</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>++</td>
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<tr>
<td>Relative complexity</td>
<td>+</td>
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</table>

No emission control catalyst
Hybrid powertrains require new operational conditions for the ICE and the catalyst

- Engine-stop phases cause significant cooling of the emission control system
  - Lower catalyst light-off temperature required
  - High temperature stability especially required for gasoline applications

- Engine restarts cause very high emissions peaks

- Emission control for hybrid applications needs dedicated solutions
Market status in Europe
Moderate growth of light duty vehicle production expected in Europe

Production in 2014 expected to reach record 2008 level

CO₂ targets drive fuel efficiency
  - 130g/km, phasing in 2012, full compliance by 2015
  - 95 g/km further reduction by 2020
  - Engine configurations changing
    - Diesel should keep market share of ~50%
    - Gradual introduction of electrified vehicles
    - Downsized turbo-charged gasoline direction injection should grow fast

EURO 6 legislation comes into force in 2014
  - Air quality requirements in cities drive NOₓ aftertreatment introduction for diesel
  - Particulate emissions regulation could drive Gasoline Particulate Filter (GPF) requirement

Car production

Source: Umicore estimate based on external data sources
Strengthening EURO 6 NO\textsubscript{x} limits for diesel cars require NO\textsubscript{x} aftertreatment systems

- EURO 3: 0.5 g/km (2000)
- EURO 4: 0.25 g/km (2005)
- EURO 5: 0.18 g/km (2010)
- EURO 6: 0.08 g/km (2015)

-84% decrease from EURO 3 to EURO 6
Diesel NO\textsubscript{x} aftertreatment system concepts

EURO 5

- Diesel oxidation catalyst (DOC) with catalysed Diesel Particulate Filter (cDPF)

EURO 6

- Replacement of DOC by NO\textsubscript{x} storage catalyst (NSC) and addition of Sulphur slip catalyst
- Addition of Urea-based Selective Catalytic Reduction (SCR)

2014
Strengthening EURO 6 PM limits may require gasoline particulate filters

EURO 6 legislations addresses the number of particulates, with a transition period of 3 years for gasoline engines.

Gasoline Direct Injection (DI) engines have higher Particulate Matter (PM) emissions (in number of particles) compared to diesel engines with Diesel Particulate Filter.

![Graph showing PM and PN limits for different Euro standards](image-url)
Potential Gasoline particulate reduction system concepts

EURO 5 / EURO 6
Three Way Catalyst (TWC)

EURO 6c
Combination of TWC and cGPF
All-in-one catalysed Gasoline Particulate Filter

2017
Umicore’s market position in Europe

European catalyst market should continue to outpace vehicle production due to the introduction of new legislation

Umicore has a strong leadership position in the European market

- Catalyst production in Europe started in 1974

Umicore has strong technology portfolio and system knowledge available to support the market requirements

- First to market with NO\textsubscript{x} storage catalysts and SCR systems
- Strong position in cGPFs established, critical IP generated and patents granted
- R&D centre supports development programmes with OEMs

New contract wins for EURO 6 diesel legislation (related to NO\textsubscript{x} aftertreatment systems) should allow Umicore to further strengthen market position
Market status in North America
Moderate growth of light duty vehicle production expected in North America

Production in 2016 expected to reach record 2000 level

Corporate Average Fuel Economy (CAFE) regulation
- 35.5mpg (miles per gallon) to be reached by 2016 (now 23.1 – 27.5)
- From 2017 to 2025 fuel economy will increase to an average of 54.5mpg
- CAFE regulation pushes towards more efficient engine types
  - Focus on turbocharged gasoline direct injection
  - Diesel market acceptance is increasing gradually

New Emission legislation
- EPA Tier 3 is currently under discussion
- LEV (Low Emissions Vehicle) III cuts emissions by 50% of current most stringent SULEV legislation
- Green House Gas Standards (GHG) includes standards for secondary emissions (N₂O, methane and particulates)
Gradual implementation of LEV III (SULEV20) emission standards to be reflected in vehicle fleet

Emission categories

Sales share to be reached to meet emission norms

-88%

NMOG: Non-Methane Organic Gases

Source: CARB 2010
Various emission categories require more and more advanced catalyst technologies

**System requirements**

**ULEV**
- Low light-off
- On-board diagnostics

**SULEV**
- Increased Hydro Carbon (NMOG) performance
- Robustness over lifetime

**SULEV20**
- Combined NMOG/NO\(_x\) performance
- Stricter particulate mass standards
- Durability increased to 150,000 miles
Umicore’s market position in North America

LEVIII and EPA Tier III pending legislation offers catalyst growth opportunities

Umicore has a leadership position in the North American market

- Catalyst production in North America started in 1983
- Acquisition of Delphi catalysts activities in 2007

Strong technology portfolio and system knowledge available to support the market requirements

- State of the art technology development centre in Auburn Hills to manage local development programs
- R&D centre in Tulsa to support local engine development
Market status in Japan / Korea
Moderate growth of domestic light duty vehicle market expected in Japan and Korea

Korean and Japanese OEMs strongly positioned worldwide
- Japanese OEMs have strong growth path globally and especially South East Asia
- Strong position of Hyundai/Kia in Korea with global growth path

Decision making power remains strongly in the home country
- Strong local automotive catalyst presence is therefore essential

OEM’s development focus for domestic and global markets
- Gasoline ICE mainly
- Strong focus on electrification

Emission legislation in Japan changing beyond 2015
Umicore’s market position in Japan and Korea

Korean and Japanese OEMs driven by growing export markets

Umicore has a leadership position in Korea
  • Catalyst production started in 1987

Distant follower in Japan
  • Catalyst production started in 1993
  • Core strategy to increase position with Japanese OEMs
  • First successes gained, mainly related to diesel for export markets

Umicore is established in Japan and Korea through
  • Local production facilities fully integrated into the global network
  • Technology development centres in Korea and in Japan and R&D centre in Japan

Umicore supplies catalysts for various hybrid vehicles including PHEV
Market status in China
Continued strong growth of light duty vehicle production expected in China

Continued strong growth of vehicle production expected

Powertrain development mainly focused on conventional gasoline engines

Diesel gaining momentum

Legislation follows European norms with a 3 to 5 year lag

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Source: Umicore estimate based on external data sources
Chinese emission legislation closely following European standards
Umicore’s market position in China

Umicore has a leadership position in China

Local production capacity since 2005

Platform exposure with both global and domestic OEMs

New production line for LDV and HDD being built in Suzhou (commissioning in Q3 2012)

Technology development centre under construction in Suzhou (commissioning in Q3 2012)
Market status in South America
South American market drivers

South American market for light-duty vehicles is growing

- Constant growth since early 2000
- Forecasts show local manufacturing of 6 million vehicles by 2017 (IHS)

Strongest market is Brazil

- Brazil emission legislation with upcoming PL6 regulations
- Flex Fuel systems are dominant for passenger vehicles and light duty power trains
- Driven by the Brazilian energy portfolio
- Specific flex fuel Technologies

Car production

Source: Umicore estimate based on external data sources
Umicore’s market position in South America

Umicore has a strong leadership position in the market
- Pioneer for Catalyst production in South America, started in 1991
- Launching of Vehicle Emission Tech Centre in 1992

Umicore has strong technology portfolio for bio-fuels and can provide system development capabilities locally

Investment in new vehicle test cell in Americana, Brazil was recently approved to help OEMs meet the upcoming PL6 and PL7 regulations
Market status in India, Russia and South-East Asia
Markets in Russia, India and South-East Asia

Car production growing with economic development of these countries

Legislation currently at low level
  • Following European legislation with 5-7 year delay
  • Very low durability requirements
  • No in-use control

Umicore ready to invest when markets develop further
On- and non-road HDD market
Expansion of scope of emission norms


materials for a better life
More stringent legislation enforces the use of emission control systems worldwide

<table>
<thead>
<tr>
<th>Country</th>
<th>Segment</th>
<th>Year</th>
<th>Standard</th>
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<tbody>
<tr>
<td>USA/Canada</td>
<td>On-road</td>
<td>2017</td>
<td>US HDD fuel economy</td>
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<td>2014-2015</td>
<td>Tier 4 final</td>
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<td>EURO V</td>
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HDD Global Technology Trends
Advanced legislation require PM and NO\textsubscript{x} aftertreatment

USA
- US 2007
- US 2010

Canada
Europe
- EURO IV/V
- EURO VI

Japan
- JP 2005
- Post JP 2009

India
Brazil
China
...

Euro IV/V

materials for a better life
Umicore’s market position in Heavy Duty Diesel

Umicore’s position in on- and non-road HDD
- Decided in 2005 to step in HDD market and started R&D efforts
- Technology gap with competitors closed by 2008-2009 followed by market positioning
- Contract wins in all regions with relatively more success in Europe and emerging markets
- Umicore continues to position itself for additional HDD business to be awarded in the near future

Technology, system design and customer intimacy are key for success
- Existing HDD test capability in Korea, Japan, Brazil, Europe and North America
- New technology development centre in China to be commissioned in Q3 2012

HDD production capability being established in North America, Europe and China
- Dedicated HDD facility in Florange, France will be commissioned mid 2012
- Expansion of flexible capacity in Suzhou, China will be commissioned in Q3 2012
Conclusion
Umicore Automotive Catalysts

Automotive catalysts market set to grow faster than vehicle production due to more stringent emission legislation in all the major markets

Umicore is a global leader for light duty applications
- Well positioned in Europe, North America and Korea
- Strongly positioned in fast growing Chinese and Brazilian markets
- Aiming to increase position with Japanese OEMs
- Ready to seize opportunities in India

Umicore is gradually gaining ground in HDD, supported by customer awards

Umicore is continuing to invest in manufacturing and testing capabilities
Forward-looking statements

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Wilfried Müller started at the Applied Technology Group Automotive Catalysts of Degussa AG in 1990. He became the Head of the Global DaimlerChrysler Businesssteam at Degussa/Umicore AG in 1996 and was appointed Director Research & Development NOx-Storage Catalysts Gasoline and Diesel at Umicore AG in 2003. Since 2006 he is the Director System Integration Automotive Catalysts, Light- and Heavy Duty Vehicles at Umicore AG. Wilfried holds a Mechanical Engineering diploma with the focus on internal combustion engines (University of Applied Sciences, Frankfurt).
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