



Surface engineering towards improving engine efficiency

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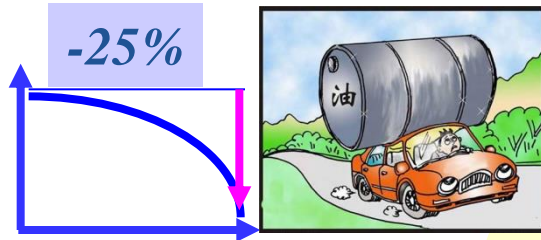


Outline

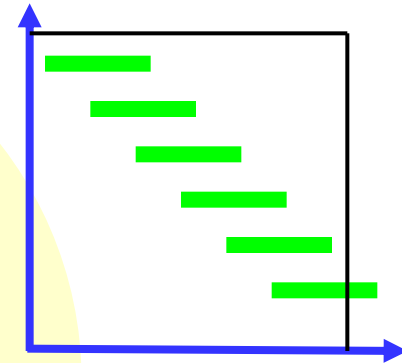
- ◆ **Background /objective/strategy**
- ◆ **Reliable Engineered coatings for Engine**
 - **High performance Hard Coating**
 - **Advanced Carbon-based Solid coating**
 - **Thermal resistant coatings**
- ◆ **Summary**

The requirements of Automotive Power System

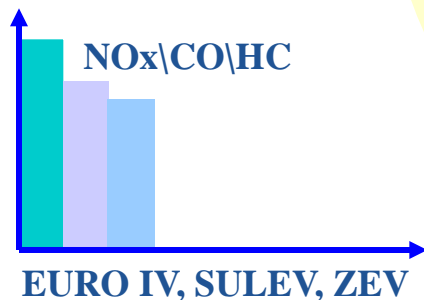
Fuel Economy



Development time & Costs



Emission Legislation



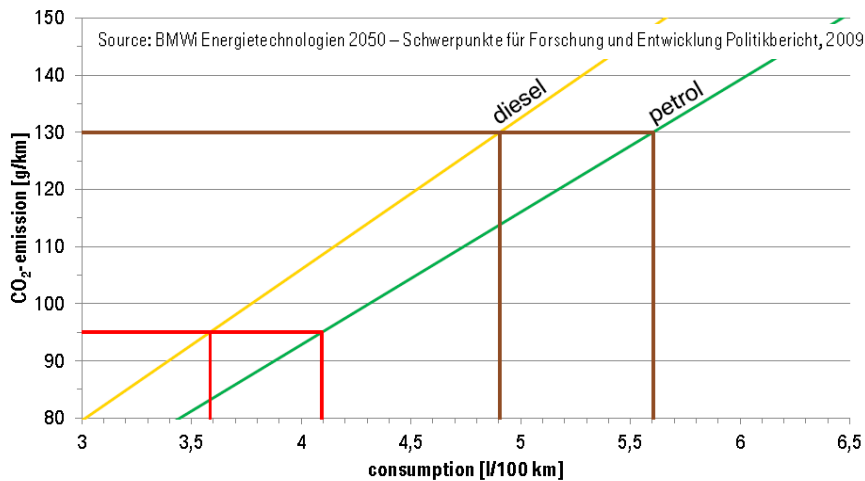
Customer & Market

*Power, Torque, Drivability
Comfort (Noise and Vibration)
Operating Cost, Durability
Maintenance, Service*

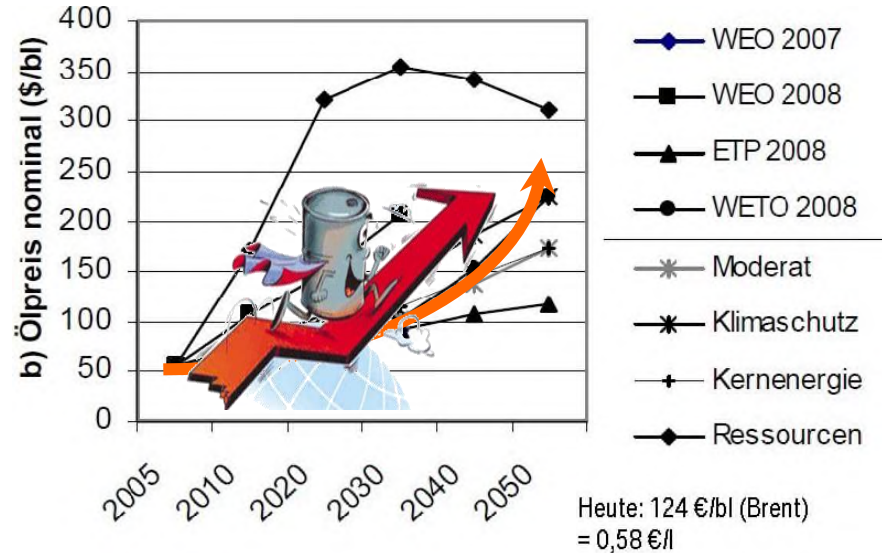


Key administration goals relevant to Vehicle Technologies: Reduce greenhouse gas emissions by 40% by 2030 and 80% by 2050 (compared to a 2002 baseline)

Fuel Economy



Relationship between consumption and CO₂ emission



A spike in fuel price

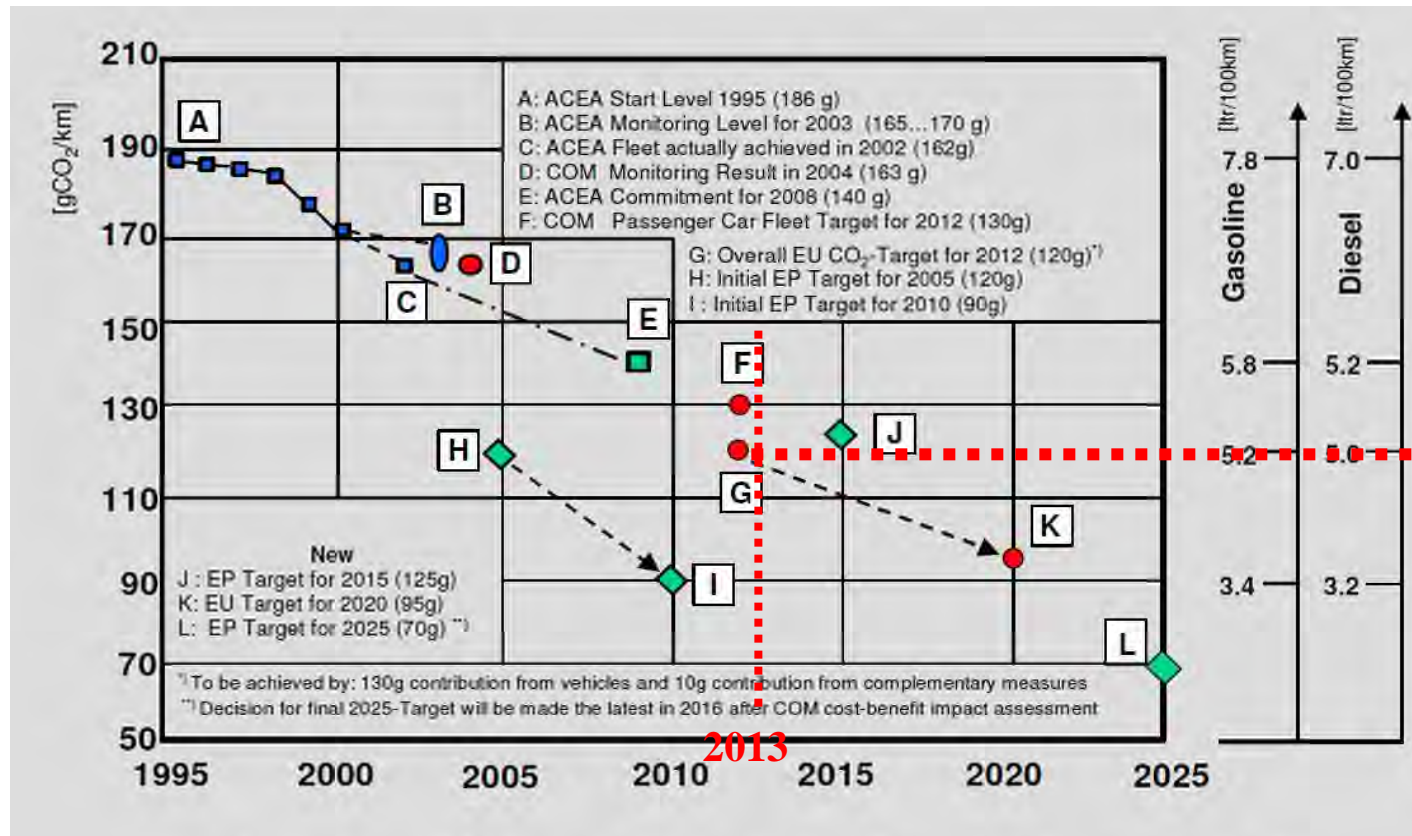
Audi A4 quattro
Fahrwerk und Antriebsstrang
Chassis and Drivetrain
2004



Power transmission system

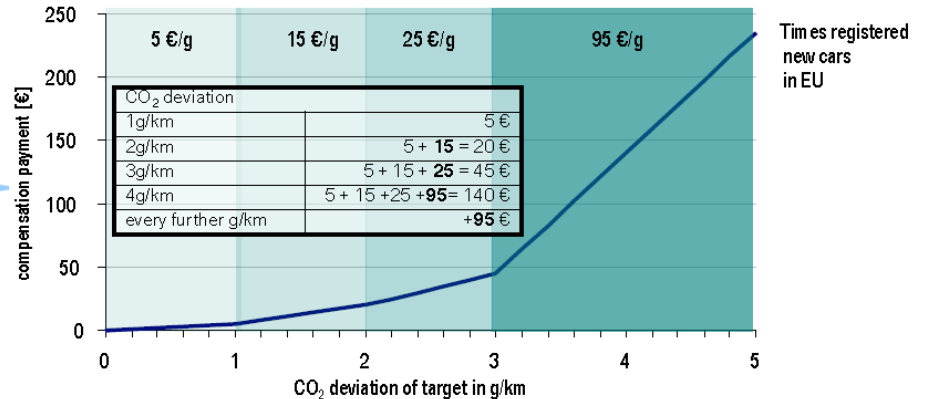
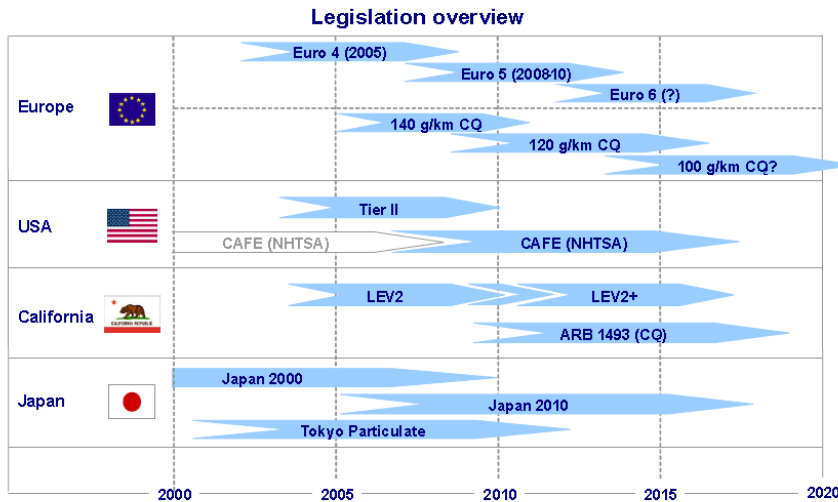
Friction leads to CO₂ emission about 0.52 million tons!

Emission Reduction



CO₂ emissions targets of the new passenger vehicle in Euro

Legislations Review



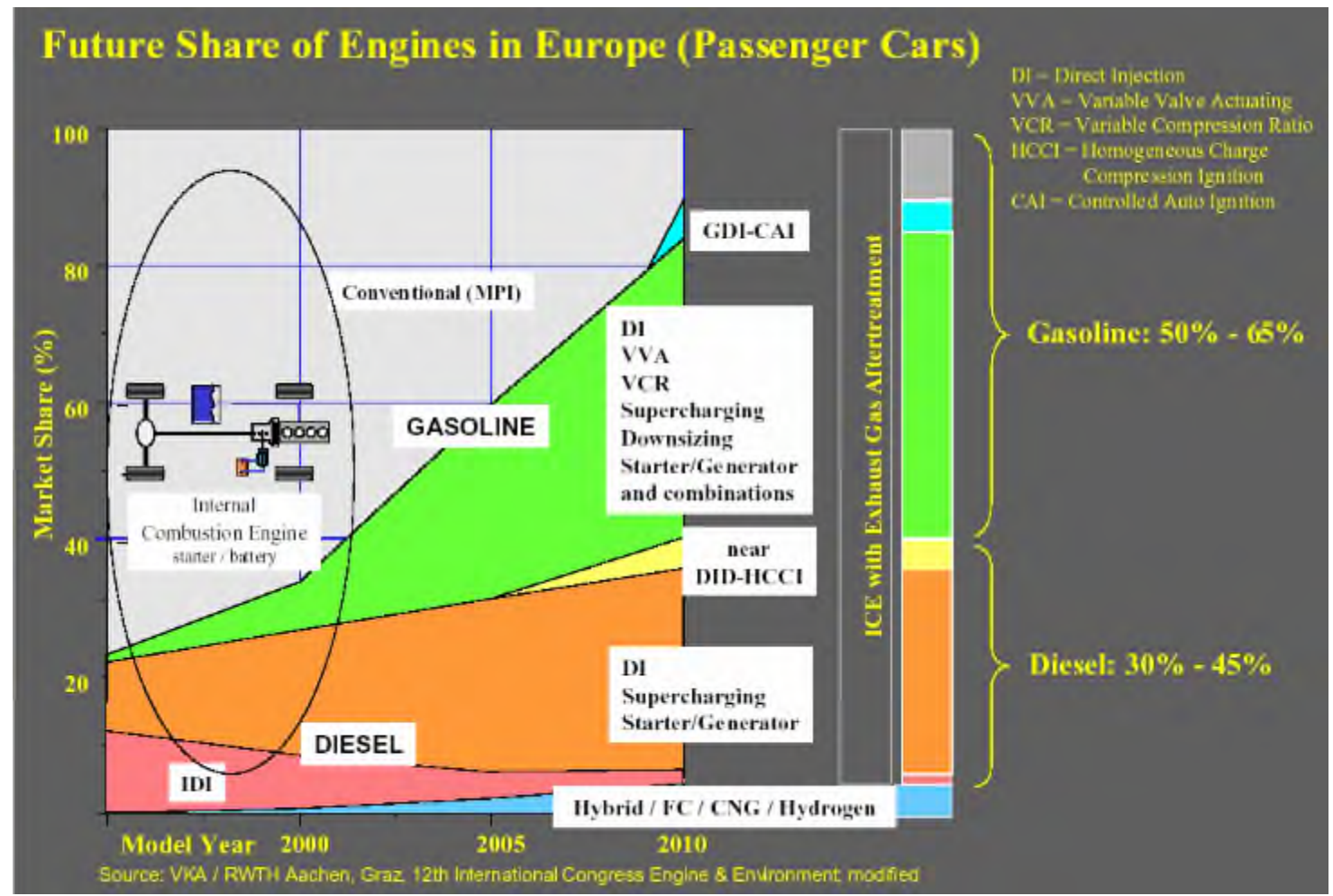
example: CO₂ deviation of the target for the vehicle fleet 1,8 g/km in 2014
 compensation payment = [(1 g x 5 €/g) + (0,8 g x 15 €/g)] x registered new cars in EU
 17 Mio.€ = (5 € + 12 €) x 1 Mio. cars

Compensation payment from 2019 on: 95 €/g/km

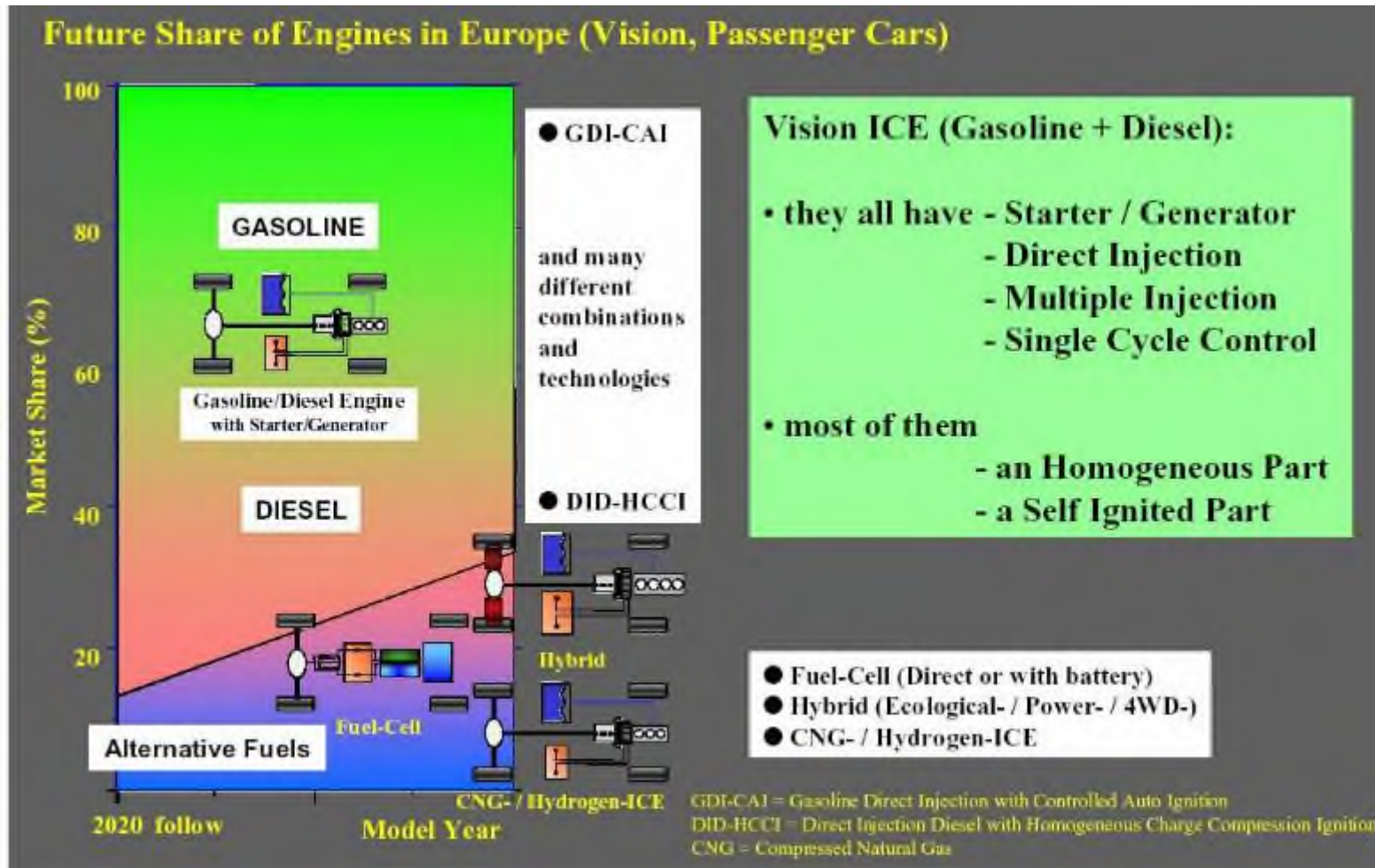


Growing penalties

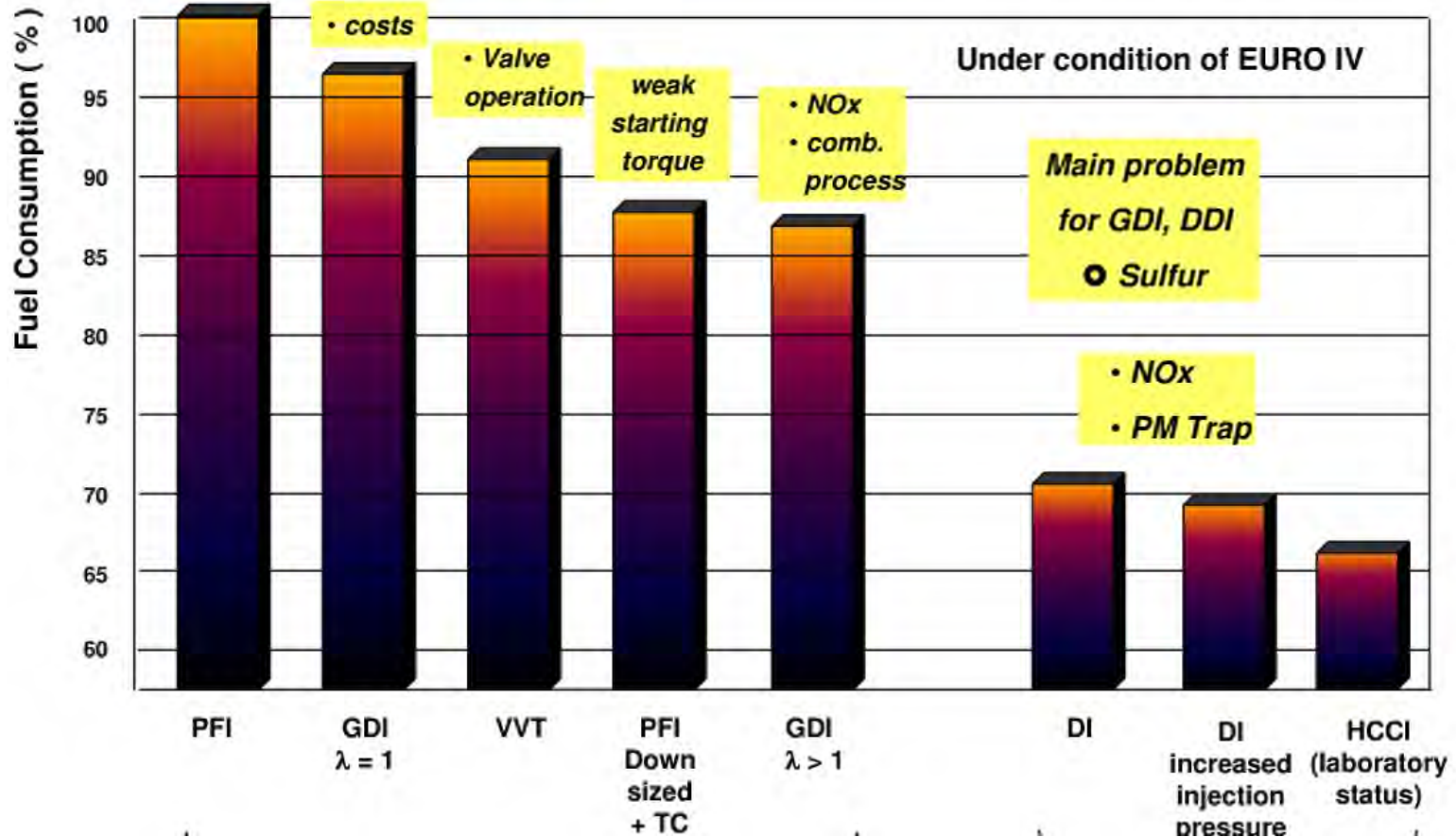
Future Market Share of Engines in Europe



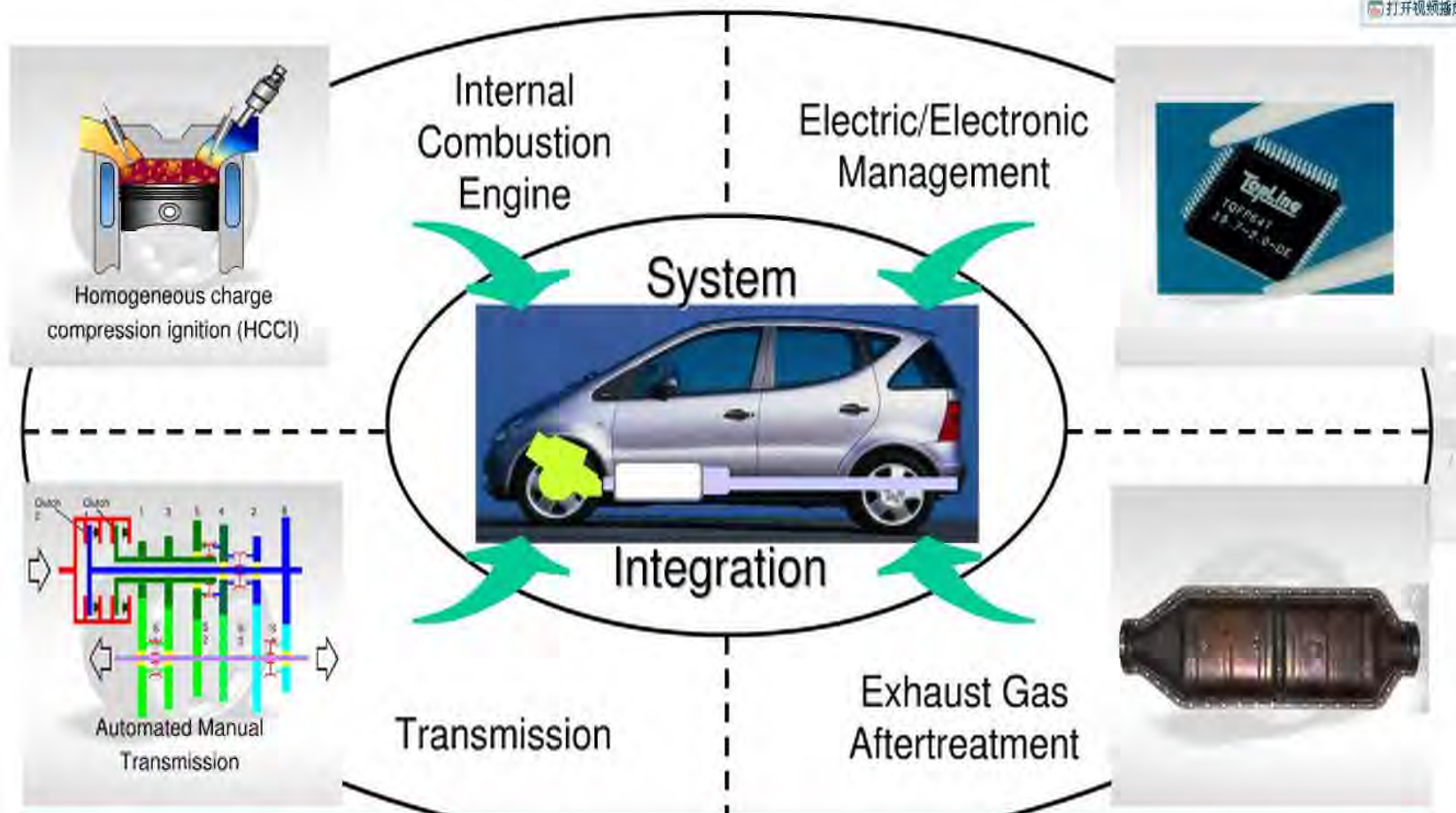
Future Market Share of Engines in Europe



The Potential of Internal Combustion Engine

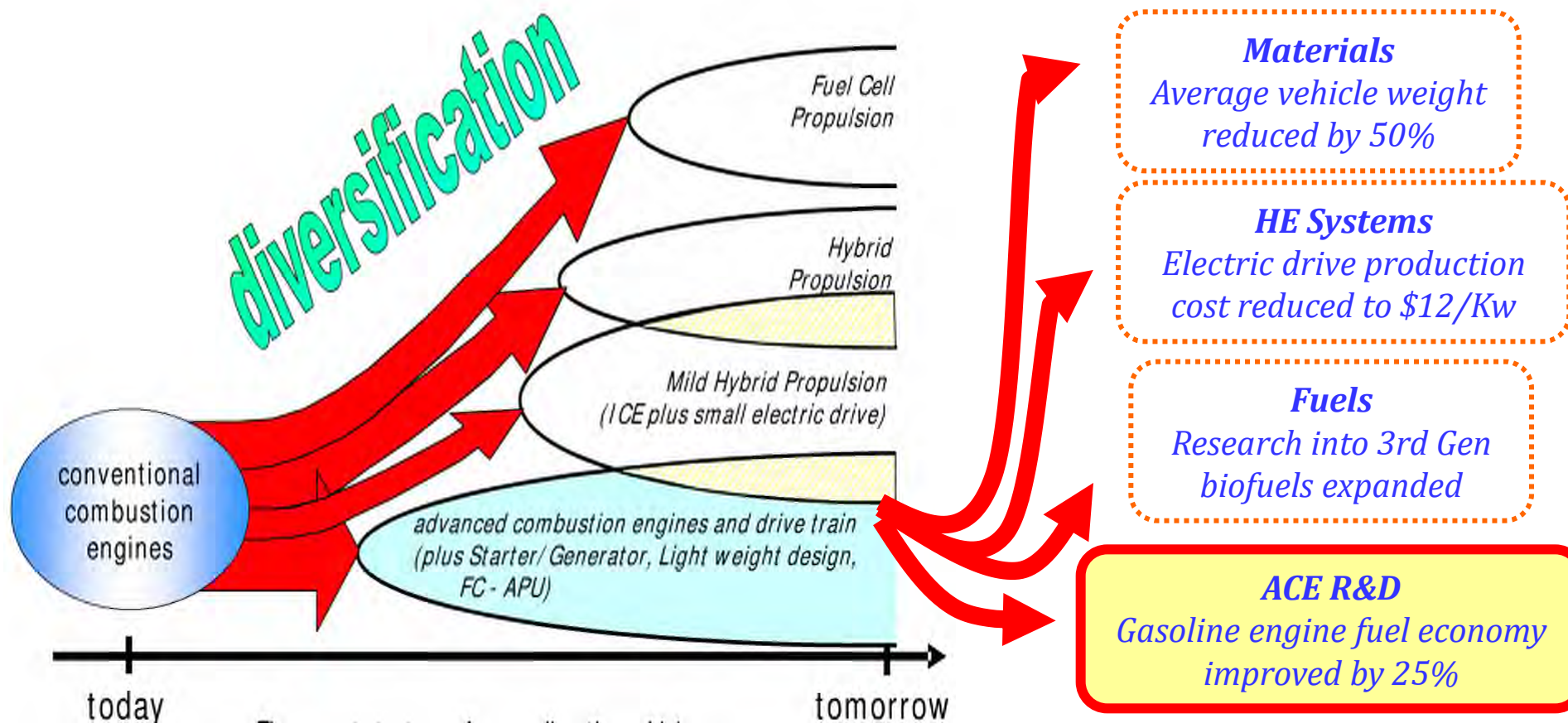


The System Integration



Integrated adaptive systems fulfill customer demands and further legislations

The important trends of auto power system and strategy

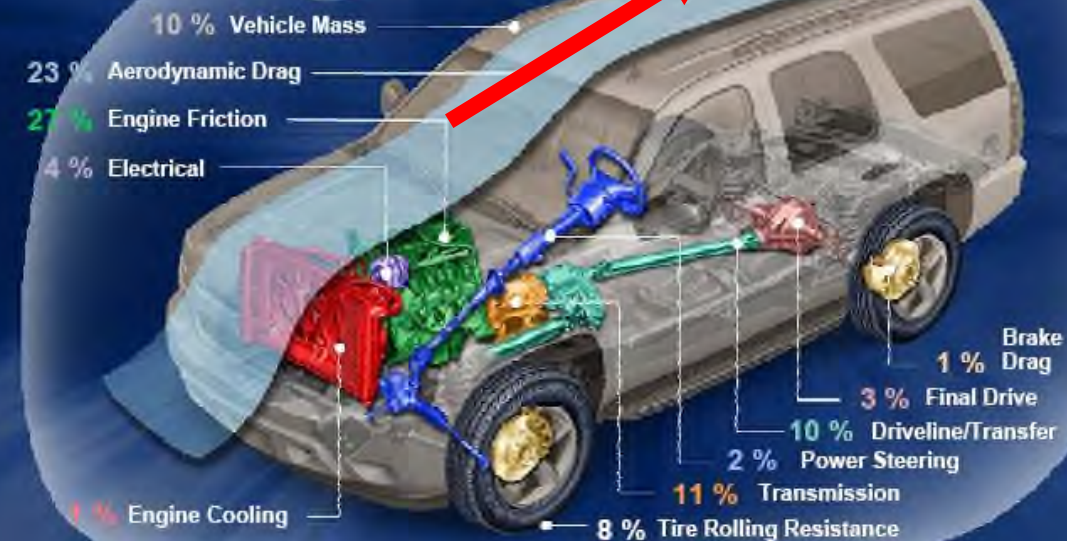


Reduce greenhouse gas emissions by 40% by 2030 and 80% by 2050 (compared to a 2002 baseline)

The Strategy of Engineering Fuel Economy

How We Engineer Fuel Economy

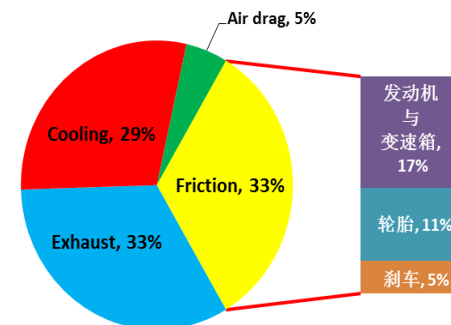
Gasoline Energy



Technology Development in Engine

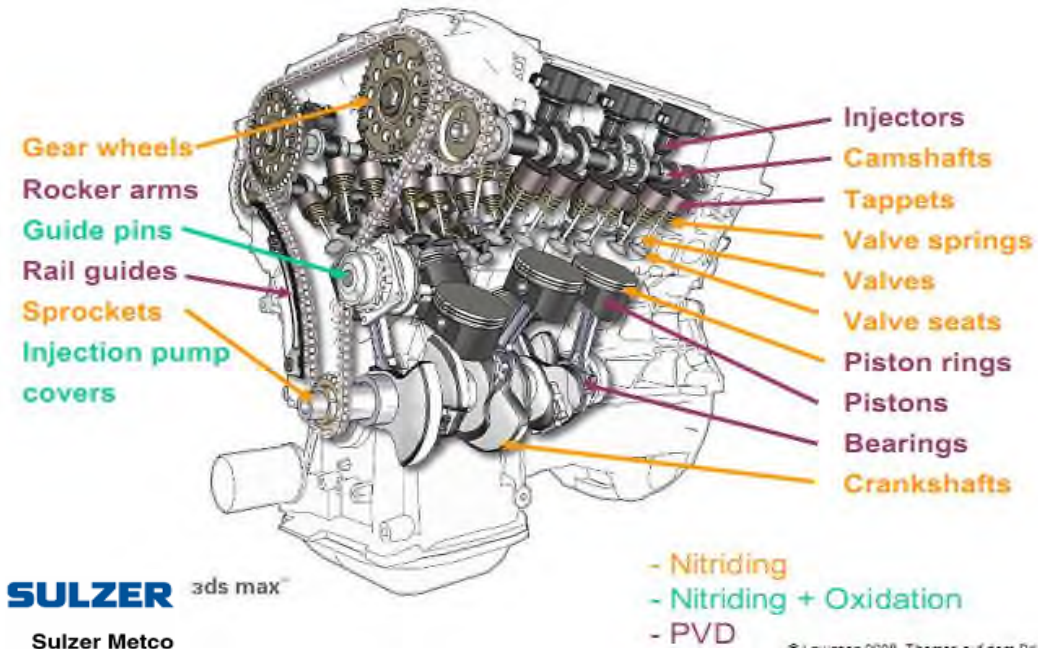
- ◆ Light Weight
- ◆ High output Power
- ◆ High Intensity
- ◆ Low oil consumption and low emission

汽车燃油消耗

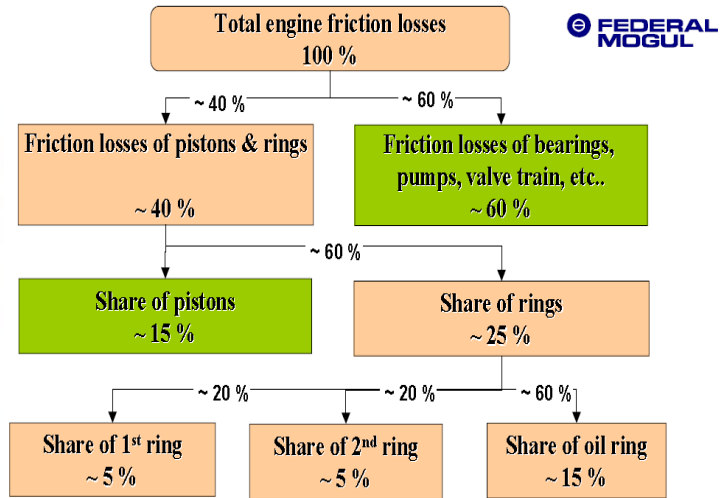


Reducing Automobile Engine Friction Through Tribology

Power Transmission System of Engine



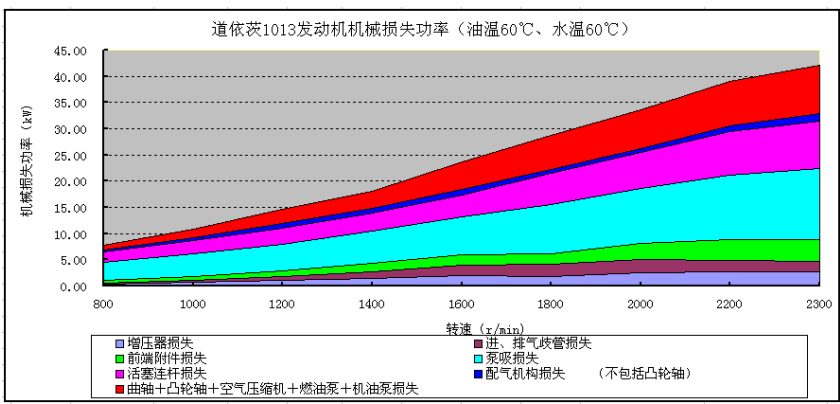
SULZER ads max[™]
Sulzer Metco



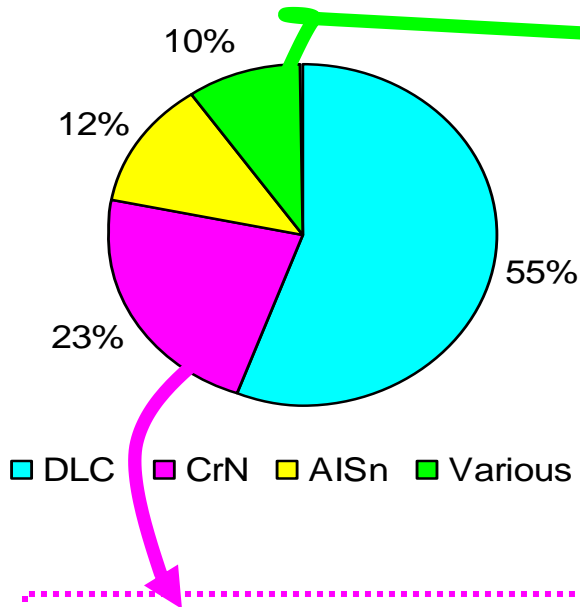
Total friction losses as well as the partition to single components is significantly influenced by overall engine concept and technology, speed, load, etc..

Performance Requirement of Key components in Engine:

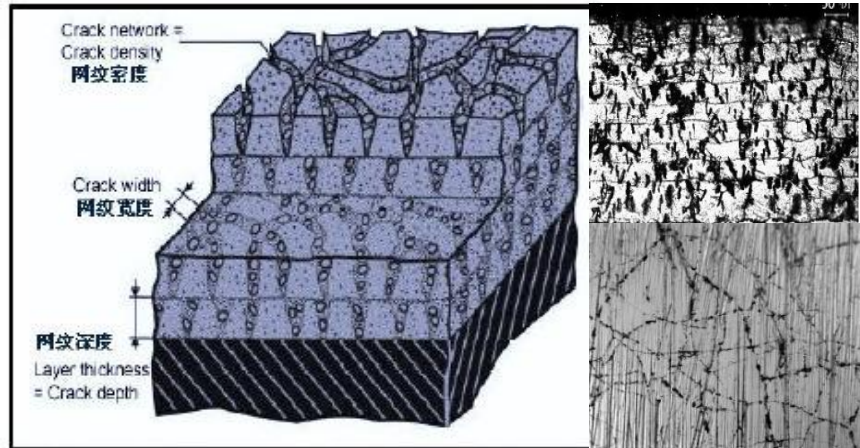
- ◆ High Wear Resistance
- ◆ High Fatigue Resistance
- ◆ Low Friction
- ◆ High Precision
- ◆ Long Service Period
- ◆ High Operation Reliability



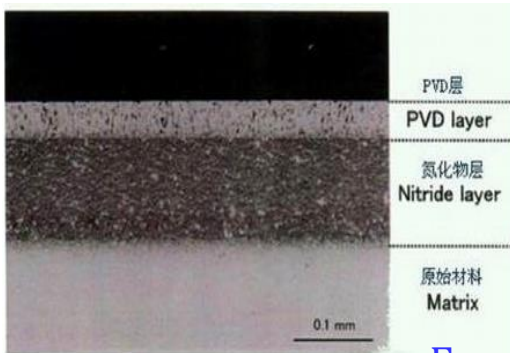
High performance Hard Coating



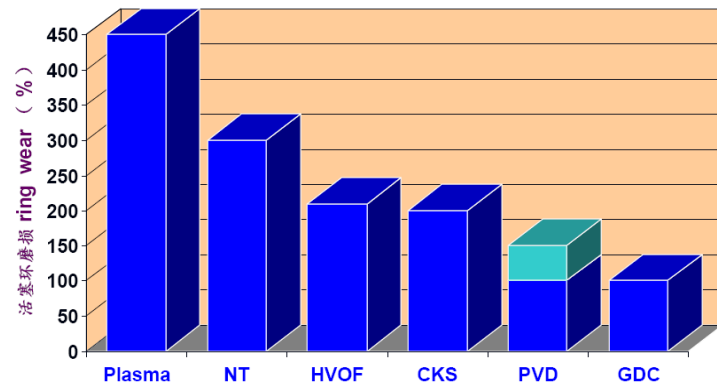
Cr-based Composite Plating Technology



PVD-CrN based coating technology



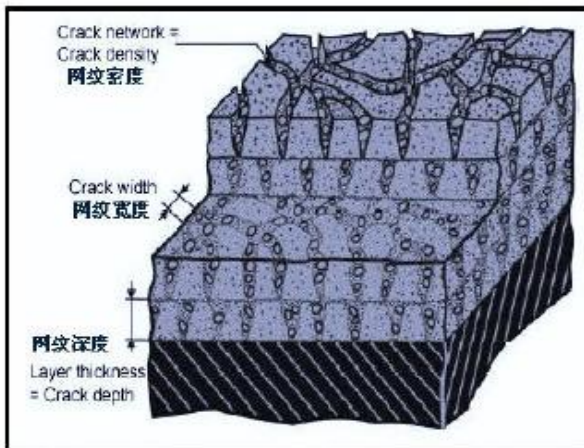
The Dominant Position in Diesel Engine Market



Excellently Wear-Resistance & Scuff-Resistance of Cr- & CrN- based coating

High performance Hard Coating

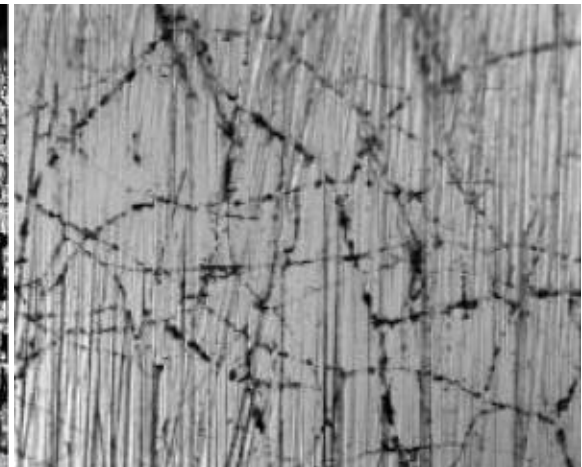
Cr-based Composite Plating Technology



Structural model



Section morphology



Surface topography

Advantages: a. low wear of piston ring/cylinder system

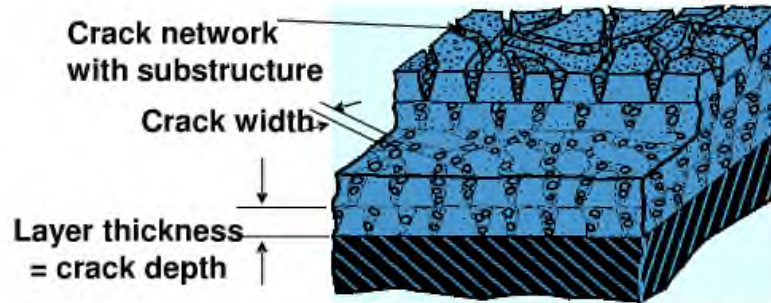
b. higher wear-resistance of piston ring than that of Cr and nitriding

c. longer service life for engine under sustainable low-emission state

d. the dominant position in diesel engine market

High performance Hard Coating

Cr-based Composite Plating Technology-----CKS



F-M is the inventor of the original CKS and GDC[®]

- 陶瓷颗粒 (Al_2O_3 , 2-5 μm) \Rightarrow CKS[®]
- 钻石颗粒 (0,25-0,5 μm) \Rightarrow GDC[®]

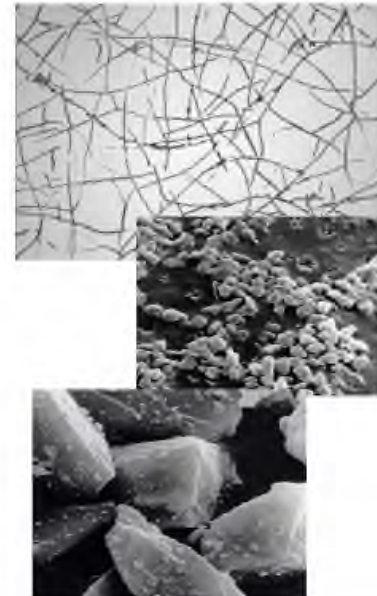
复合电镀技术在欧洲已广泛应用

LV Diesel (>80% share in Europe)

Turbo GDI

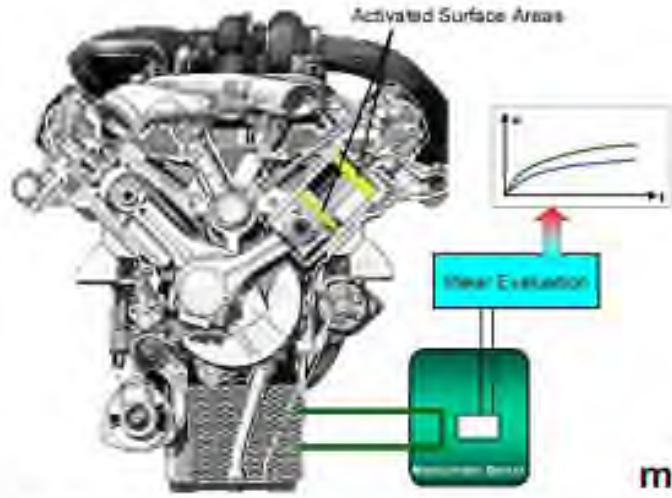
Truck Applications EU5 (>70% share in Europe)

Low wear Thick coatings Sharp bottom edge



The specific wear of CKS coating in 4-6L diesel engine of Europe was lower than 10 μm /100000km

High performance Hard Coating



test engine specifications

test engine specification	
displacement	10.5l
number of cylinders	6
engine type	inline
combustion system	Euro III, Common Rail, Cooled EGR
injection pump	fuel lubricated
rated power	320kW@1900rpm
max. torque	2100Nm @ 1100rpm
max peak firing pressure	185bar
lube oil	Shell Rimula Ultra Diesel Engine Oil 5W30

measured wear and oil consumption

liner surface and top ring	standard liner	optimised liner	plasma liner
	CKS 36 top ring	CKS 36 top ring	GDC 50 top ring
measured item @ rated power			
engine lube oil	Shell	Shell	Shell
oil consumption [g/h]	52	19.7	11.5
oil consumption [g/kWh]	0.16	0.06	0.04
oil consumption [% FC]	0.08	0.03	0.02
top ring wear rate [nm/h]	-	4	0.83
cylinder liner wear rate [nm/h]	-	0.26	0.67 *

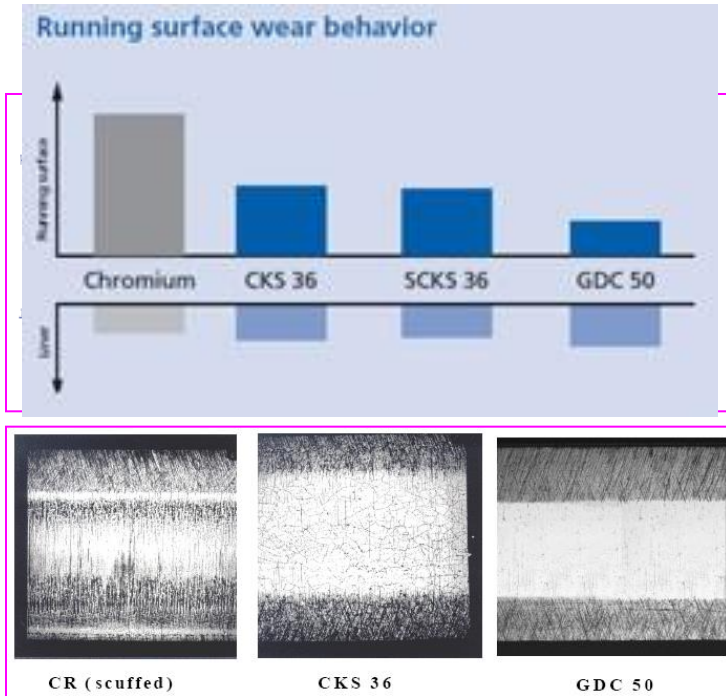
ca. 15 μ m over 1mio km

* higher wear rate caused by the GDC 50 top ring, which is more abrasive than CKS rings

High performance Hard Coating

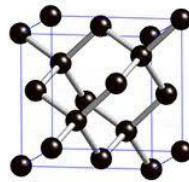
Good Adaptations of GDC coating to Following Conditions

- ◆ Higher operating requirement
- ◆ Higher load and thermal load in engine
- ◆ scarce oil lubrication even oil-free state



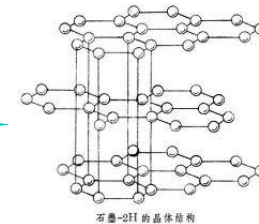
Wear-Resistance of CKS and GDC coating

High hardness
Highly adaptive capacity of
high load in engine



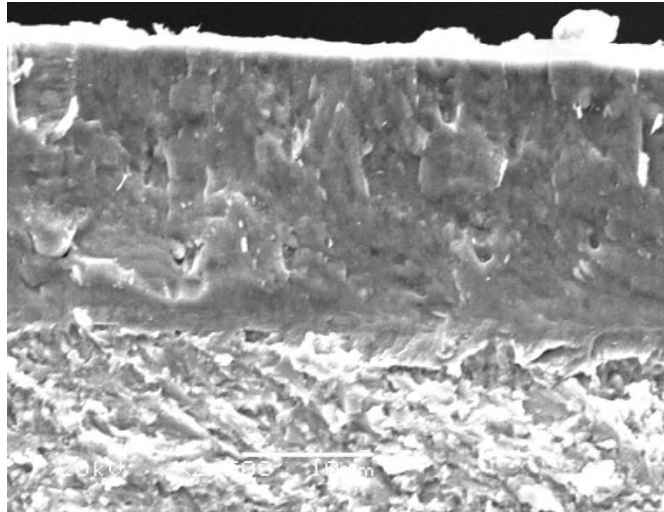
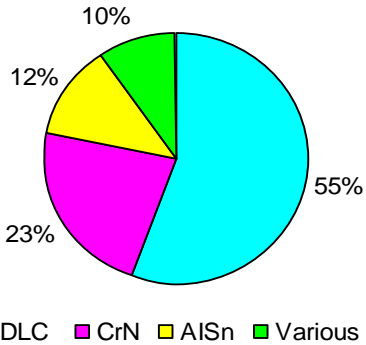
High temperature

High contact stress



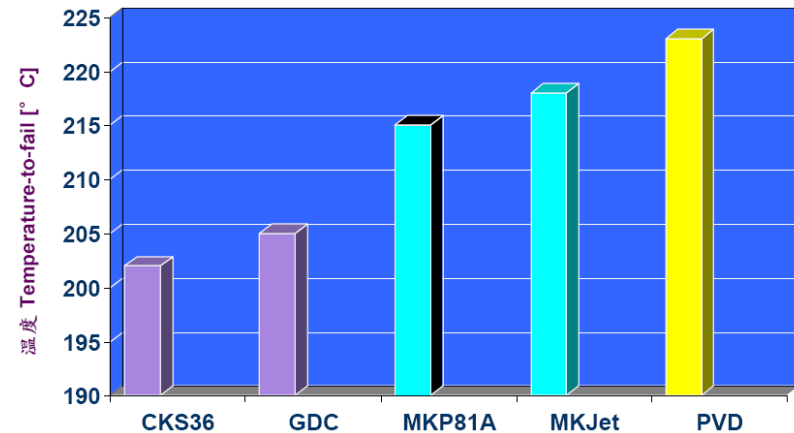
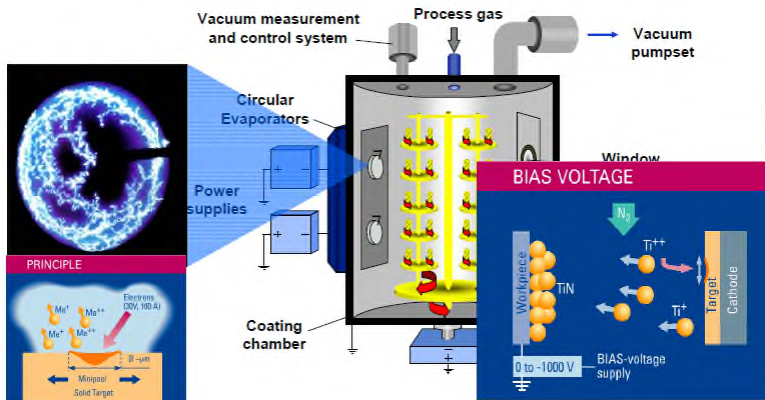
Self-lubricating characteristic

High performance Hard Coating



Performance of PVD-CrN Coating :

- High wear-resistance
- Low adhesive wear
- Low abrasive wear
- High corrosion-resistance



It was strongly dependent on the composition and structural variation

High performance Hard Coating

PVD240 - CrON

Coating Characteristic:

- Structure: CrN predominant [200] oriented
- Hardness: 1500 – 2200 HV 0.1
- Thickness: 30 / 50 μm

Technological Properties:

- good wear resistance
- good scuff resistance
- low friction coefficient comp. to steel

Application in HD –Diesel engine:

- Topping Steel nitrided



PVD242 – CrN

Coating Characteristic:

- Structure: CrN predominant [200] oriented
- Hardness: 800 – 1400 HV 0.1
- Thickness: 10 / 30 μm

Technological Properties:

- good wear resistance
- good scuff resistance
- low friction coefficient comp. to steel

Application

Diesel and Gasoline :

- TOP-Ring SGI and SAE-steel
- 2. Ring on SGI
- oil rings on SGI and steel

PVD243 - CrON

Coating Characteristic:

- Structure: CrN predominant [200] oriented
- Hardness: 1400 – 2200 HV 0.1
- Thickness : 10 / 30 μm

Technological Properties:

- good wear resistance
- good scuff resistance
- low friction coefficient comp. to steel

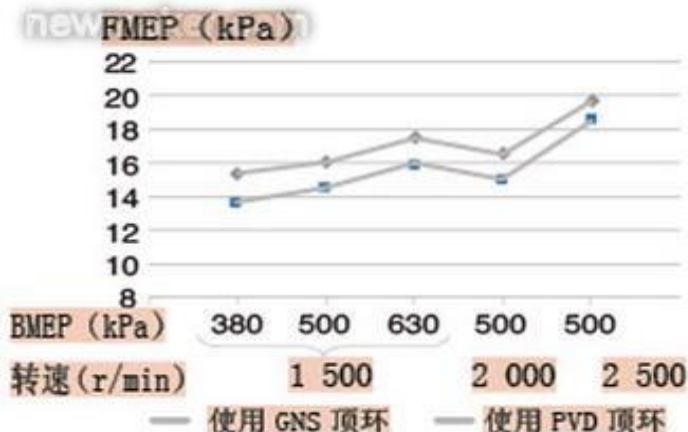
Application : Gasoline

- Topping Chromesteel-nitrided
- 3- pc. Oil ring nitrided

Wear Rate PVD-CrON In Turbo-GDI < 5 μm /1000h

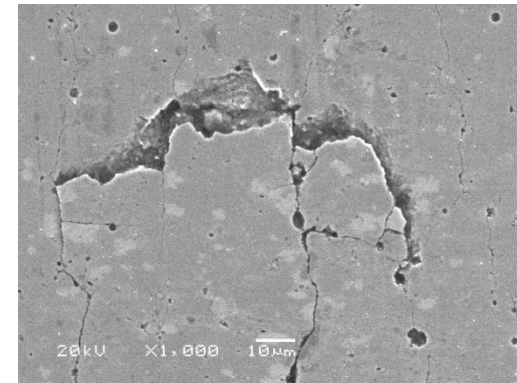
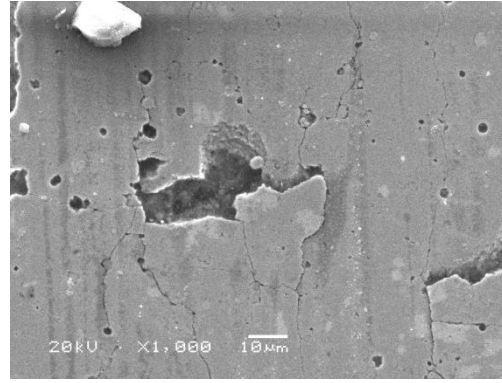
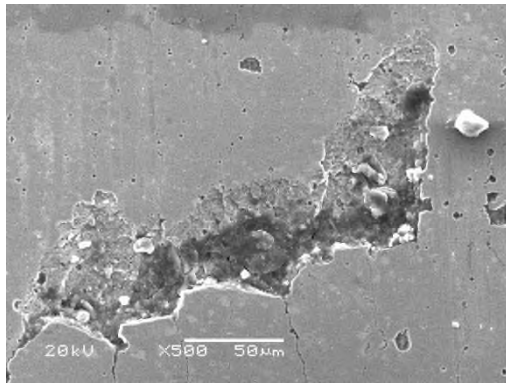
High performance Hard Coating

Properties	Coating-types				
	CrN	CrN-multilayer	CrN-modified	TiN	TiCN
Hardness HK	2100 - 2500	2100 - 2500	2200 - 2700	2300 - 2800	2800-3300
Max. operating temp./°C	650	650	700	500	400
Ductility	Very good	Very good	Good	Good	Satisfactory
Colour	Steel gray	Steel gray	Multicoloured	Gold	Gray, copper

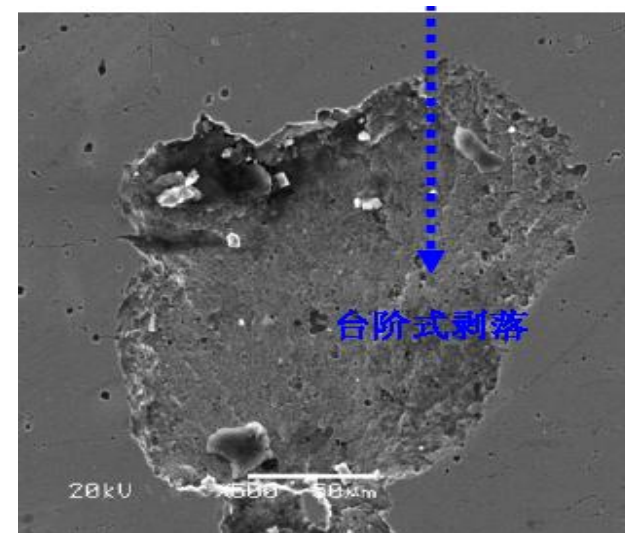
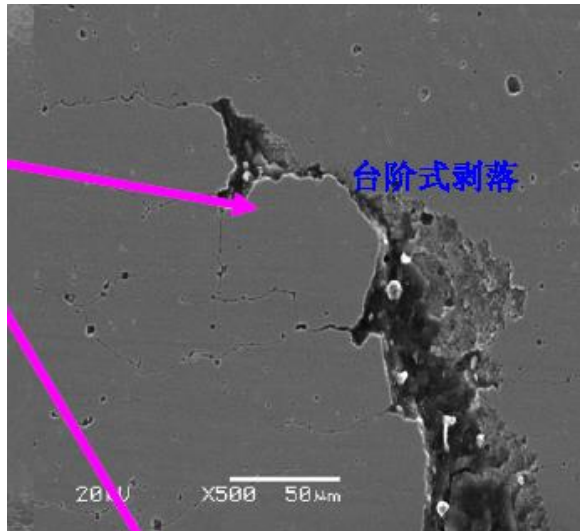


- ✓ Decreased Friction by 10% by PVD Coating (compared to GNS Baseline) for The Top Ring at 1500r/min.
- ✓ Decreased Friction by 5% by PVD Coating

High performance Hard Coating

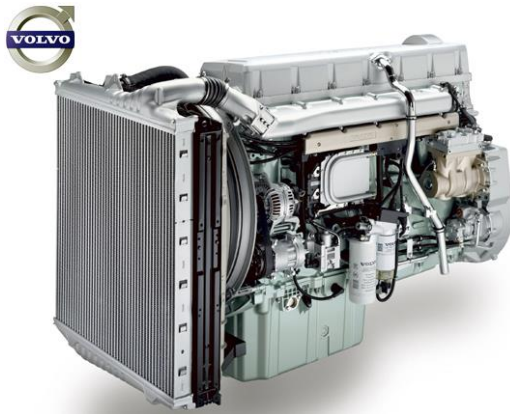


Fatigue Wear and Coating Exfoliation Caused by High Stress When Coating Thickness Beyond 50µm



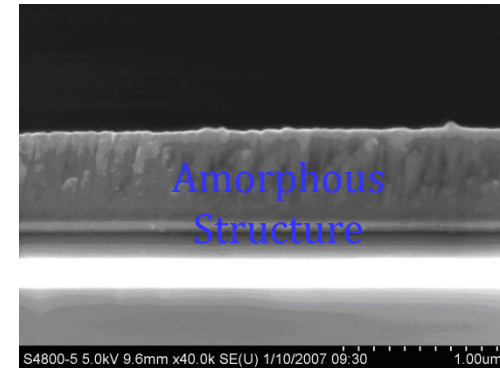
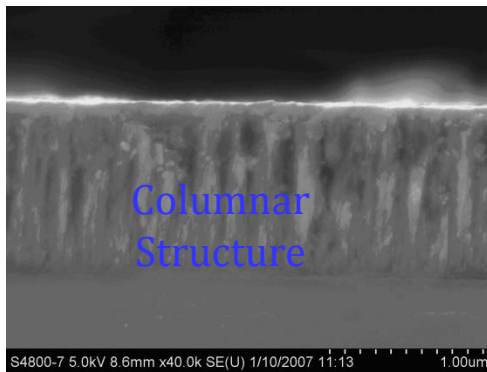
Bench Test Results

High performance Hard Coating



Higher operating requirement:

- ◆ Higher load
- ◆ Highly thermal load
- ◆ High Velocity
- ◆ Low Emission
- ◆ High Power

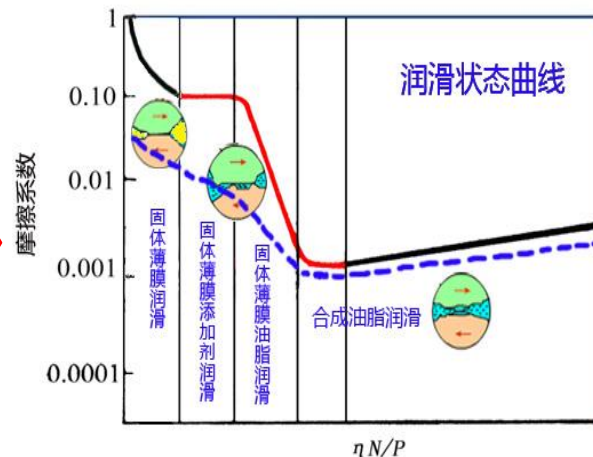
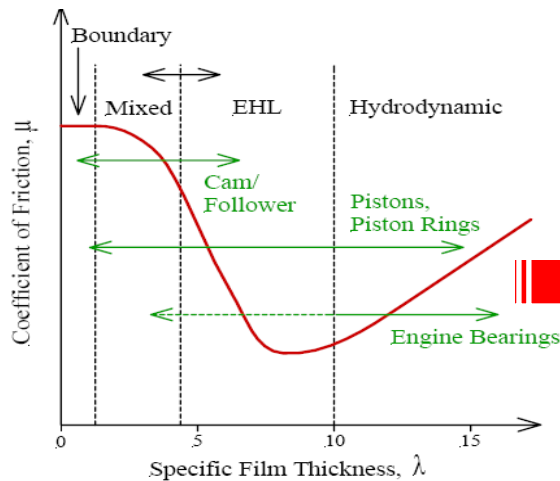


- ◆ Improved Hardness and Toughness, Enhanced Oxidation- and Wear – Resistance at High Temperature by Doping for The Next Generation of Piston Rings
- ◆ The development of Cr-X-N Coating to Satisfy Heavy-Load & High Velocity Automotive

Reducing Automobile Engine Friction Through Tribology

Problems in Engine Key components:

- ◆ Conventional Oil Not Solves lubrication for accuracy-control system
- ◆ Conventional Surface Treatment neglects Lubricating performance



Engine idling start-stop control technology

Approaches to Reduce Friction-induced Energy consumption:

- ◆ Wear-Resistance & Low Friction Coating with High Performance;
- ◆ Coating/Oil Composite lubricating Technology



Reliable Strengthening and lubricating Integration Technology

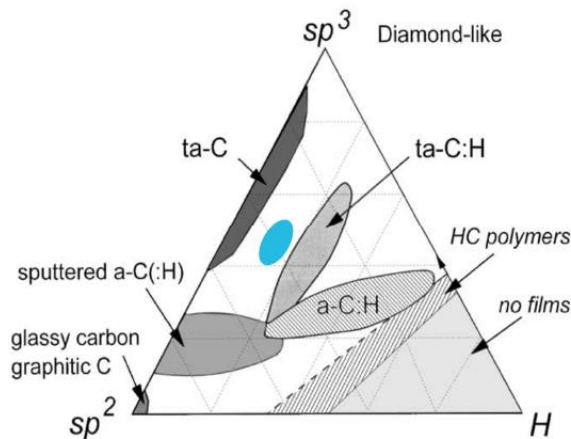
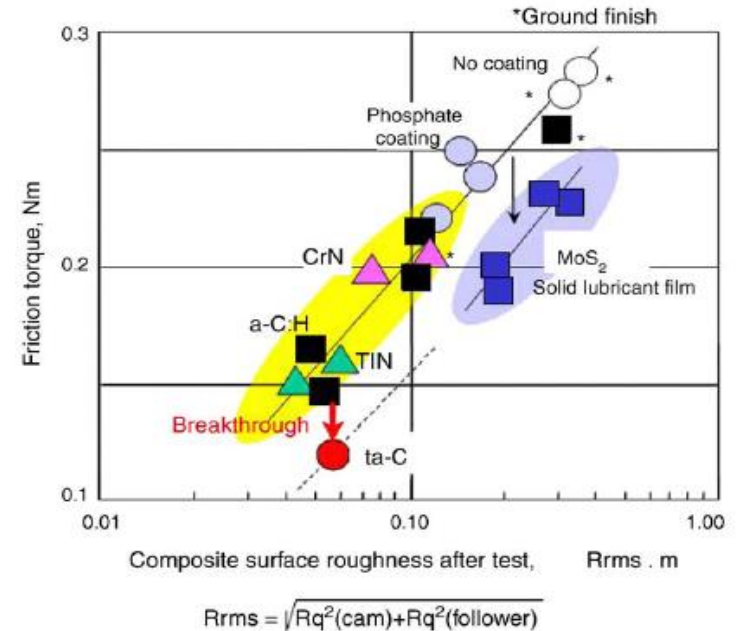
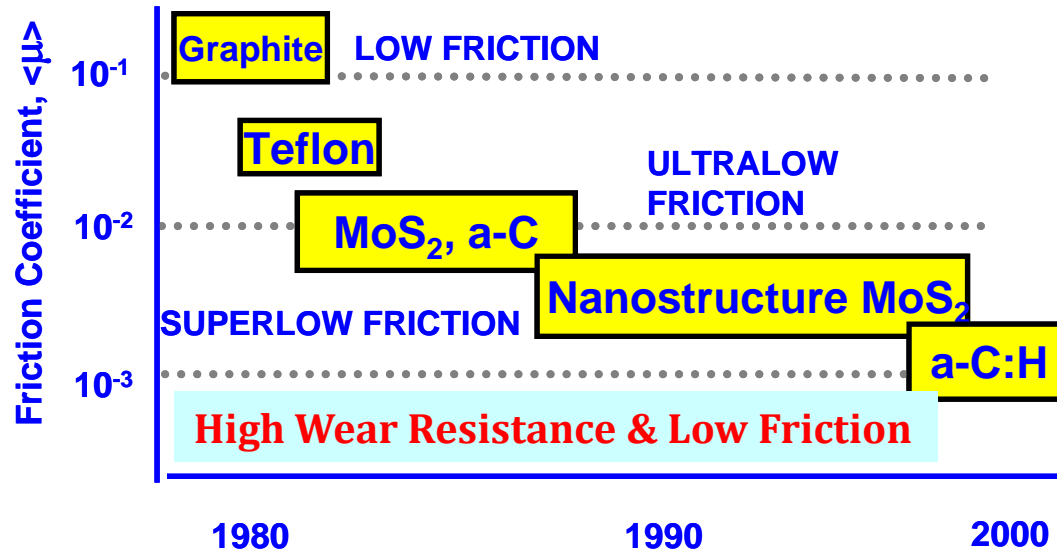
Tribological issues in Improvements in the tribological performance of engines can generate the following benefits:

- ☞ Reduced fuel consumption**
- ☞ Increased engine power output**
- ☞ A reduction in harmful exhaust emissions**
- ☞ Improved durability, reliability and engine life**
- ☞ Reduced maintenance requirements and longer service intervals.**

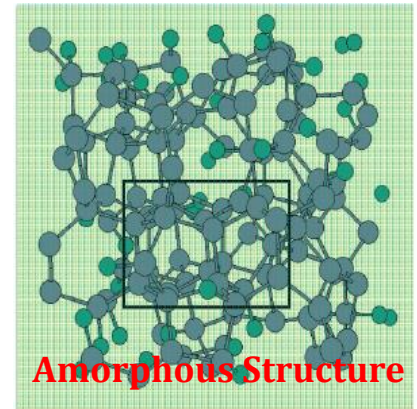
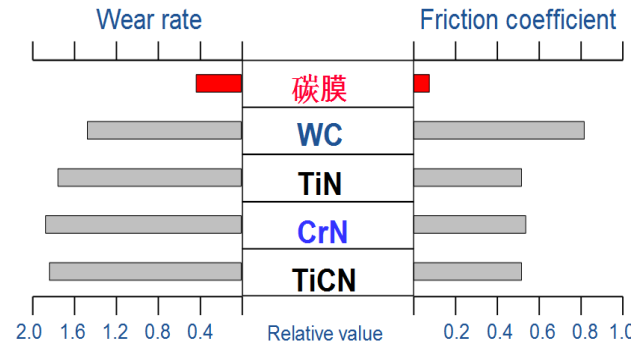
Advanced Carbon-based Solid coatings

Excellent Self-lubricating Performance and Wear-resistance

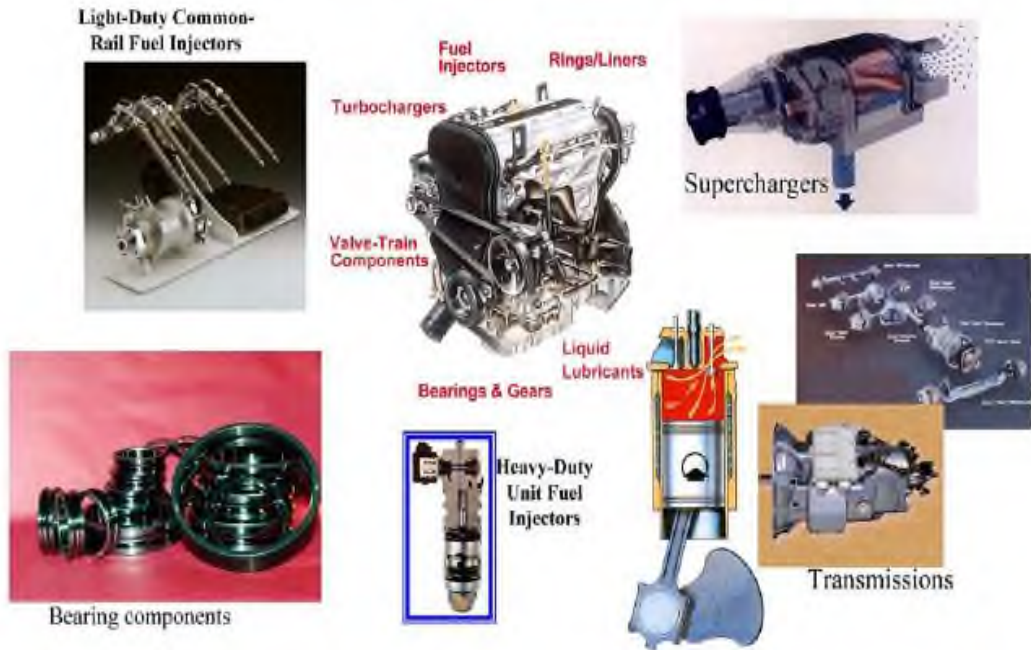
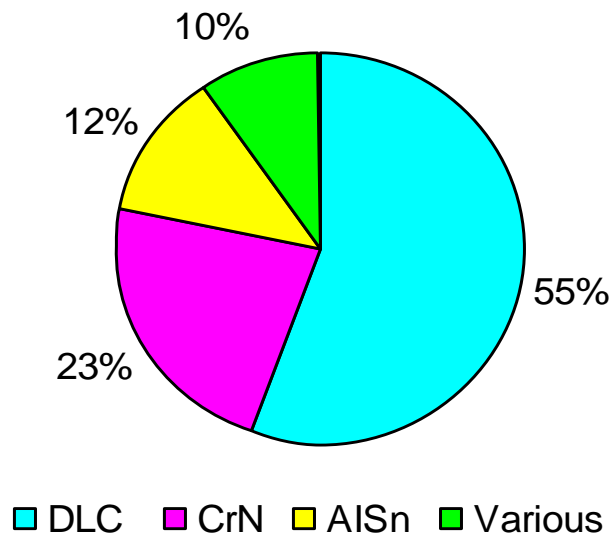
Advanced Carbon-based Solid coating



碳基复合薄膜低摩擦与高耐磨特性



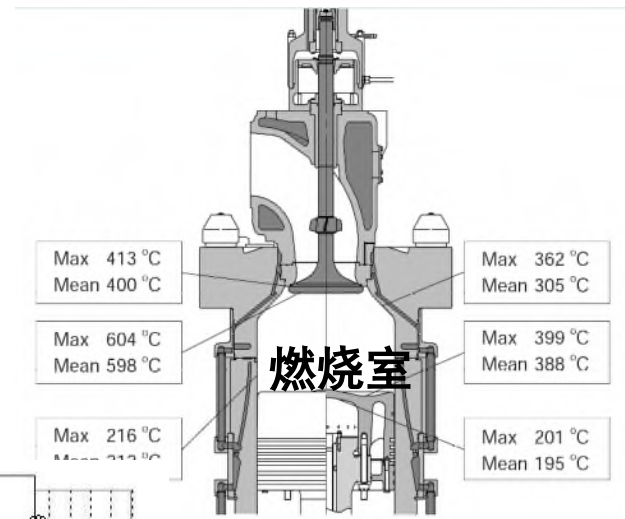
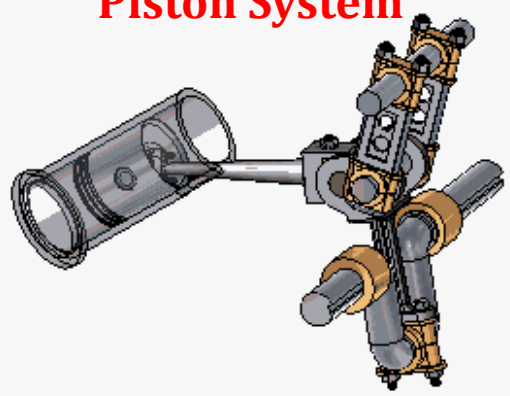
Advanced Carbon-based Solid coating



Energy-saving Applications for Low-friction Carbon Coatings in Engines

Advanced Carbon-based Solid coating

Piston System

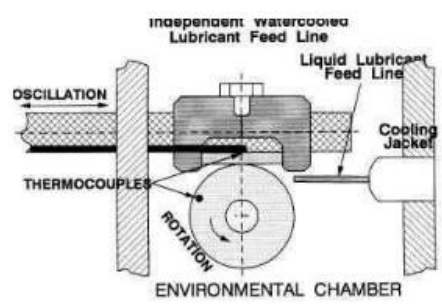
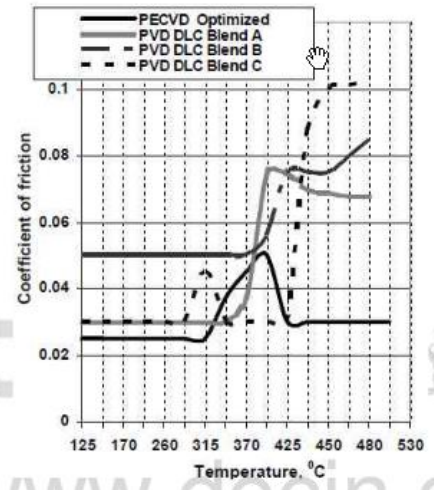
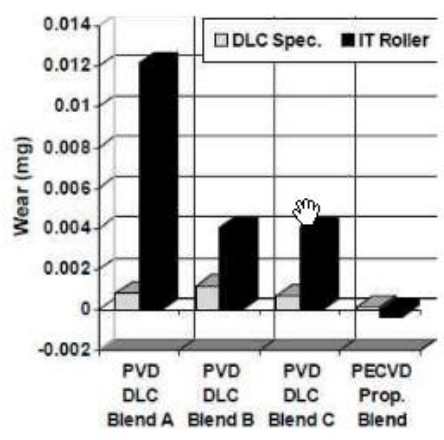


台架试验装置的照片



Piston Skirts

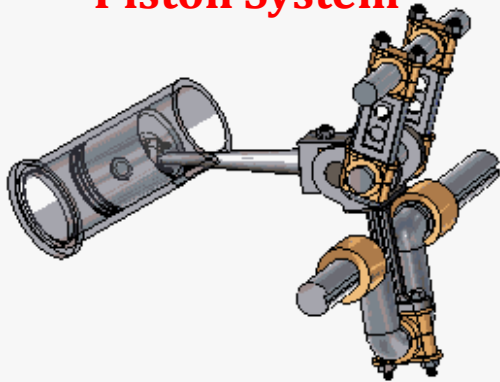
Anti-Thrust Side After Testing



Carbon-based Coating show the potential applications in Low heat high temperature diesel engine

Advanced Carbon-based Solid coating

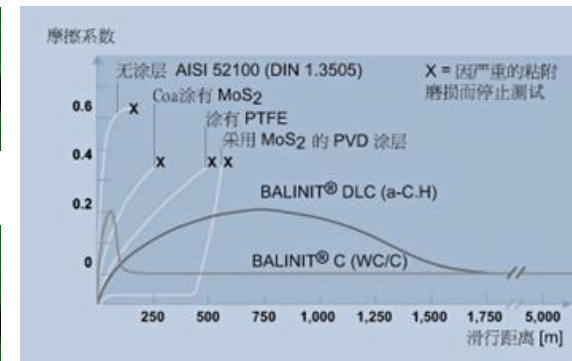
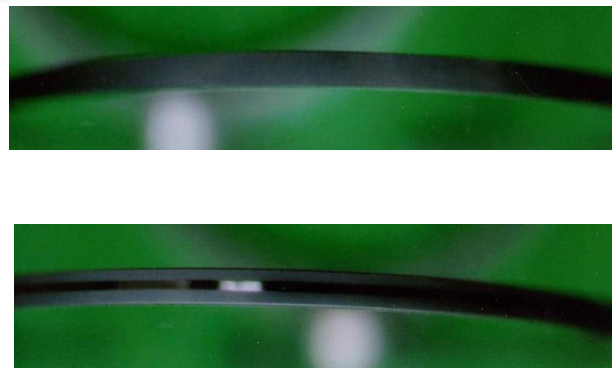
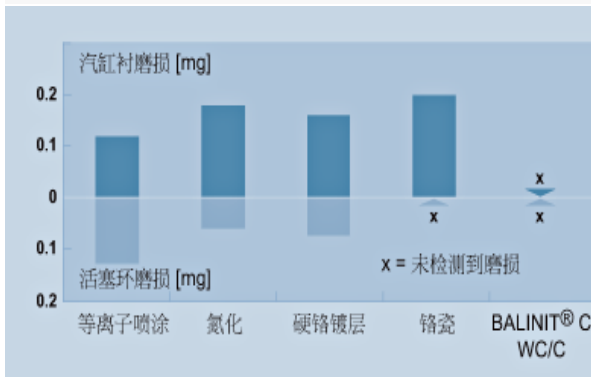
Piston System



Requirements:

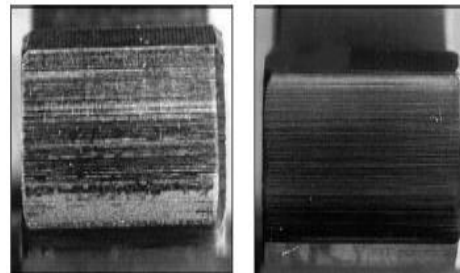
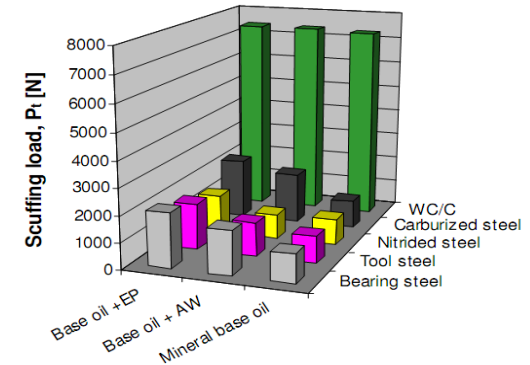
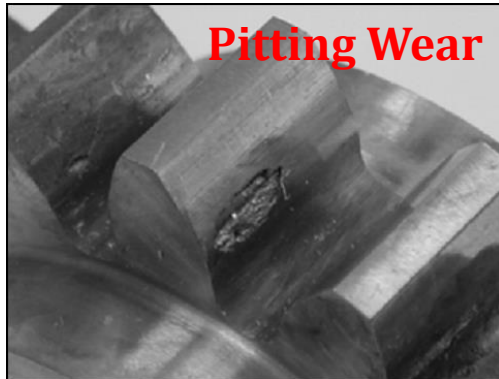
- Sliding contact
- Abrasive wear
- Temperature load

Coating: CrN+DLC; Cr+DLC; CKS+DLC; etc..



- ◆ Carbon-based Coating Made up by the upper DLC layer (2~10 μ m) and Hard Transition Layer (15~30 μ m)
- ◆ Improved the Stability of running-in period when encounter Oil-free or Less conditions;
- ◆ Reduced the Wear Volume of Cylinder by 15~20% (Experimental Results).

Advanced Carbon-based Solid coating



pinion	uncoated	MAXIT® W-C:H coated
gear	uncoated	uncoated
load	1500 N/mm ²	2000 N/mm ²
cycles	1,35*10 ⁶	5,4*10 ⁷
pittings	20% micro-pittings	micro-pitting free

- ◆ Carbon Coating Greatly Reduces Wear at Boundary Lubrication
 - stopping/starting,
 - severe load,
 - temporary loss of lubricant
- ◆ Maximum load carrying capacity of gears can be increased by 10-40%.

Gears coated by carbon-based coatings to Provide Pit and Scuff Resistance

Advanced Carbon-based Solid coating

Valve train:

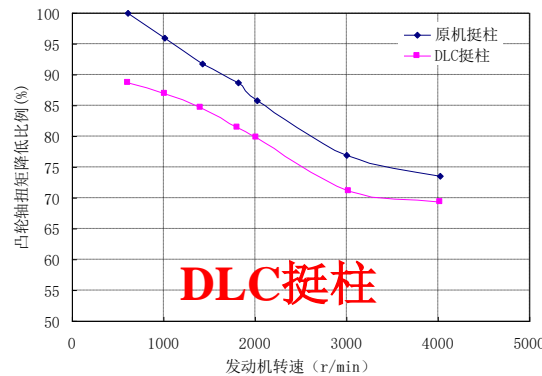
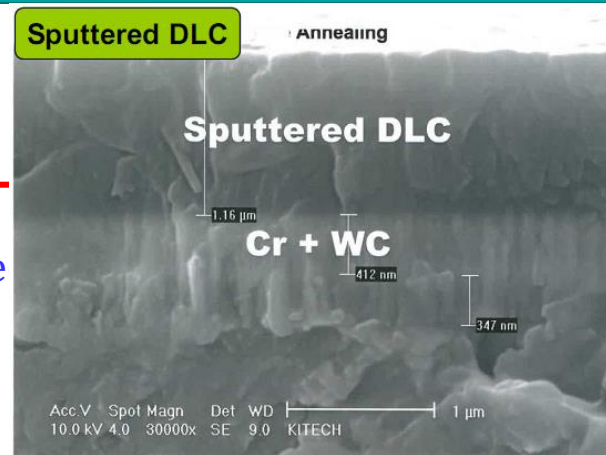
Part: Tappet

Coating: W-C:H + a-C:H, CrN

Process: PECVD and/or sputtering

Purpose: wear protection and friction re

Source: Volkswagen AG, Wolfsburg

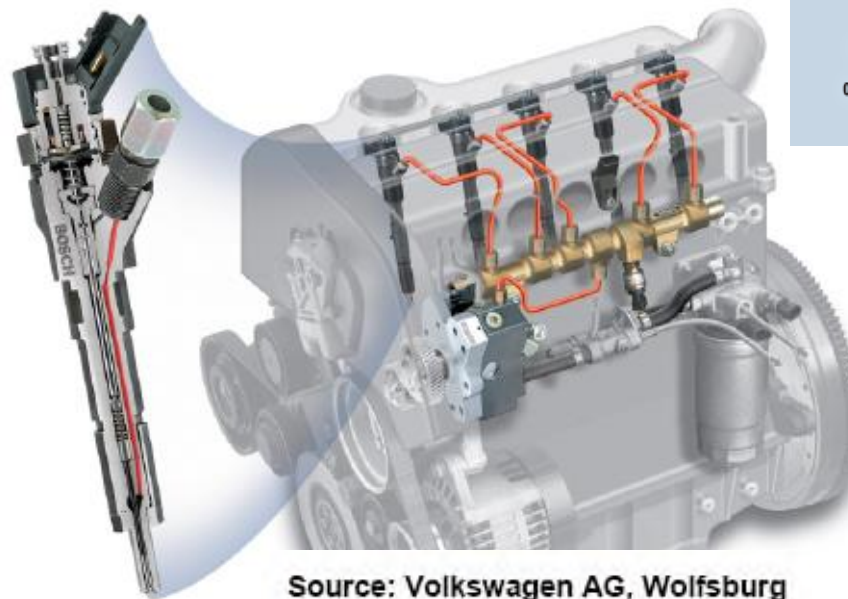


◆ Reduced Friction Loss by 11% for Tappet Coated Carbon-based Coating;

◆ Great Potentials for Energy-saving, Emission Reduction and lowering fuel consumption

Advanced Carbon-based Solid coating

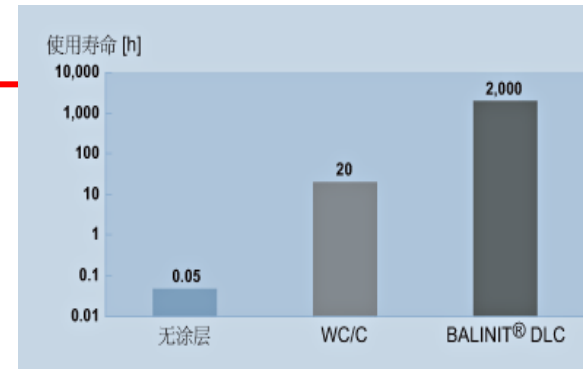
部件: 柴油喷嘴和曲轴
 涂层: a-C:H, W-C:H with metallic buffer
 涂层厚度: >1 μm
 优点: Wear resistance, preventing seizure



Source: Volkswagen AG, Wolfsburg

2000~3000bar

Figure from Robert Bosch GmbH



Carbon-based Coating Applied to Solve lubrication for accuracy-control system

Advanced Carbon-based Solid coating

Technical Data

Engine power: 96 KW (130 PS)

Injection pressure: 2050 bar

Pressure power: 14.000 N

Advantages

- Increased efficiency (lower friction)
- Increased engine torque
- Reduce energy consumption
- Reduction of the CO₂-emission

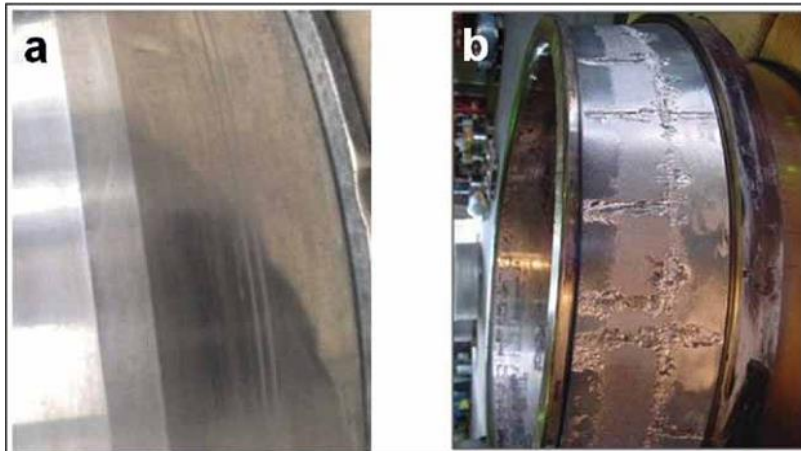


涡轮增压直接喷射单元



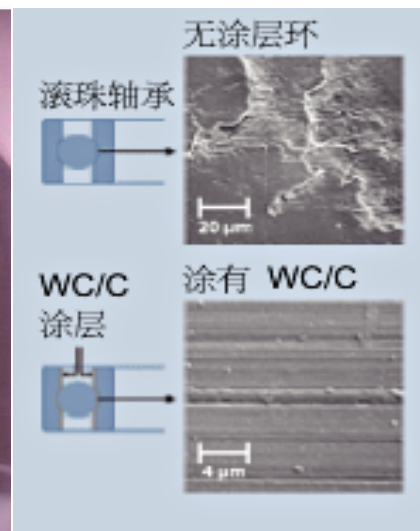
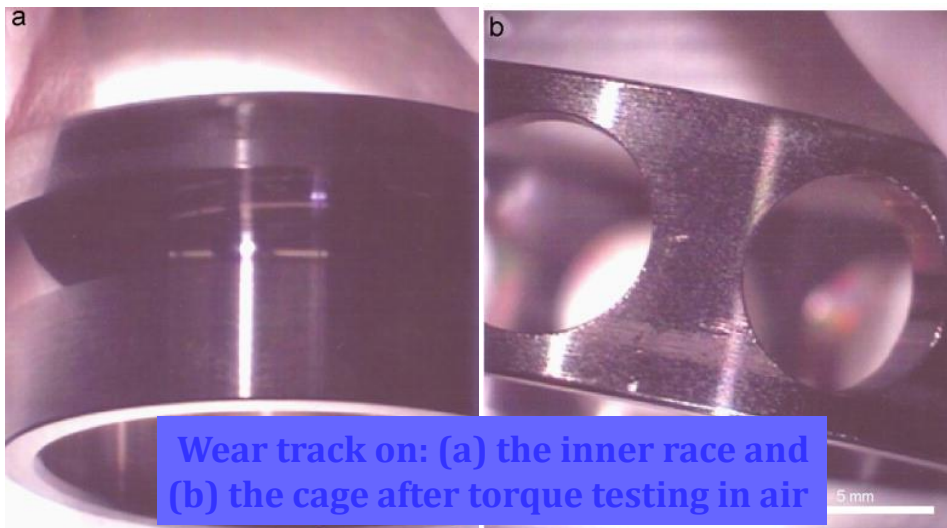
Source: Volkswagen AG, Wolfsburg

Advanced Carbon-based Solid coating

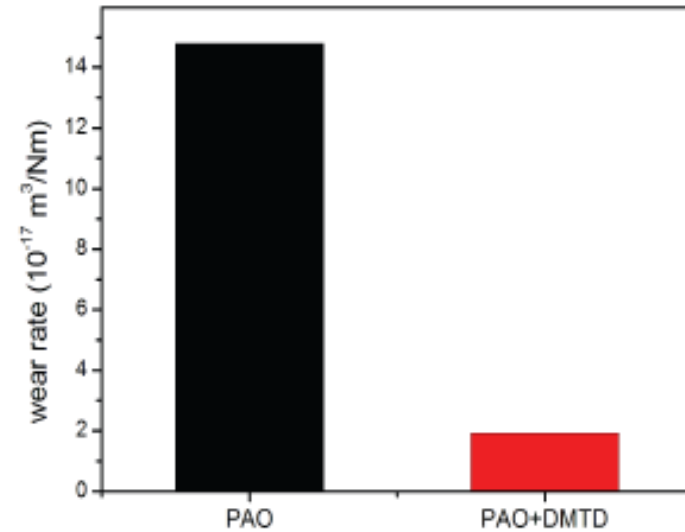
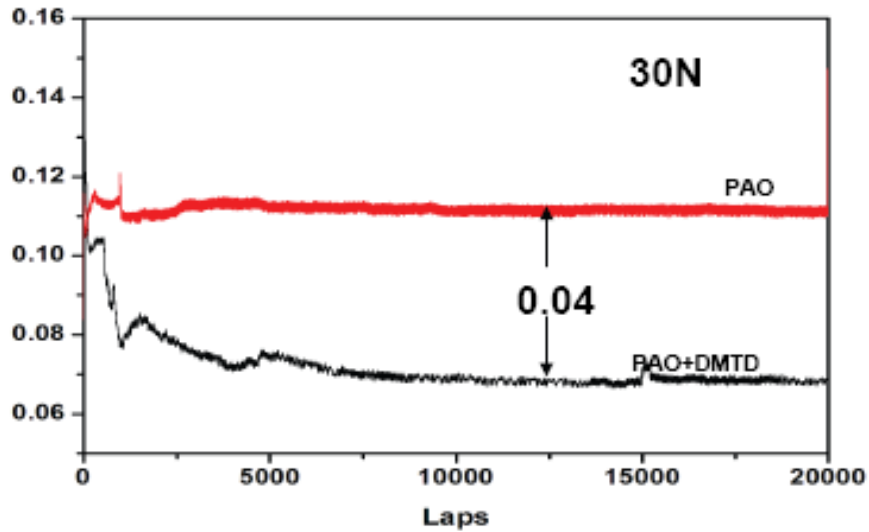


Performance of Coated Bearings

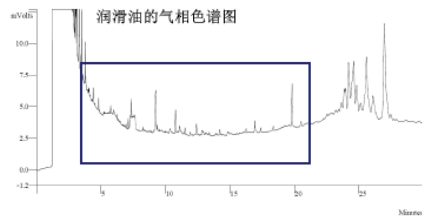
- ◆ Improved Bearing Capacity by 20%;
- ◆ Fatigue lifetime extended more than doubled;
- ◆ Increased Wear Resistance by 60%;
- ◆ Lowered Friction by 50%



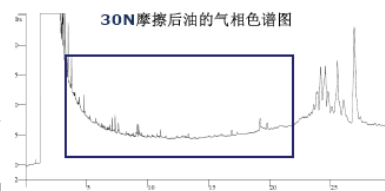
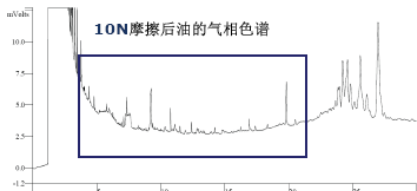
Advanced Carbon-based Solid coating



润滑油气相色谱分析结果

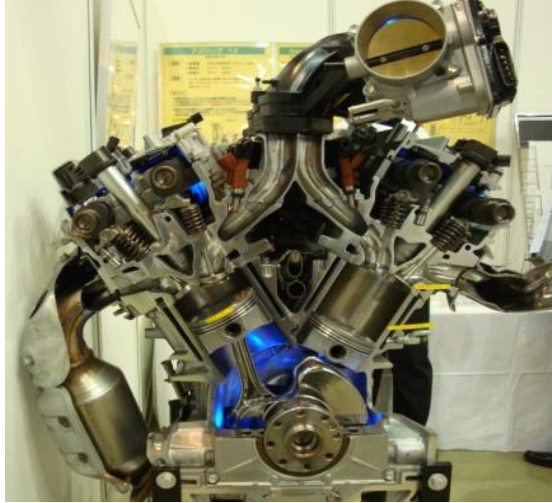


结论:
10N 添加剂分子
吸附减摩
30N 添加剂分子
反应减摩

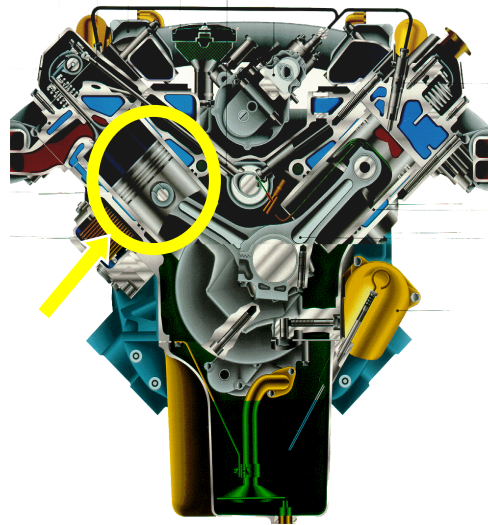


Based on Tribo-chemistry Intelligent Solid-Solid Composite Lubrication

Advanced Carbon-based Solid coating



Power system in Nissan



Power system in Hyundai



Fuel Injection System in Volkswagen

Super Low friction of DLC applied to engine key parts will result in:

- Friction decreased by 25~40%
- Fuel efficiency improved by 3~7%
- CO₂ emission decreased a lot
- 2.0~2.6 Kg CO₂ per L diesel or gasoline

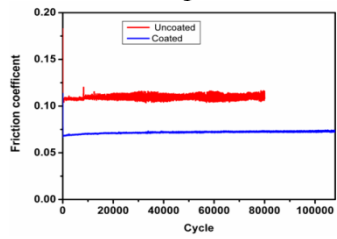
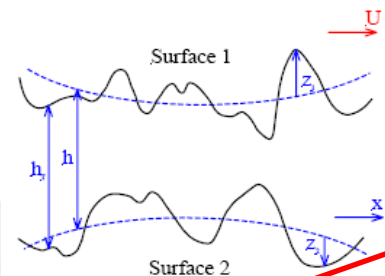
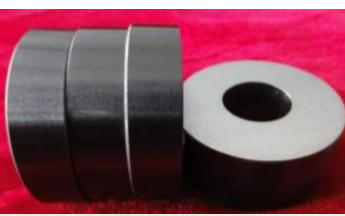
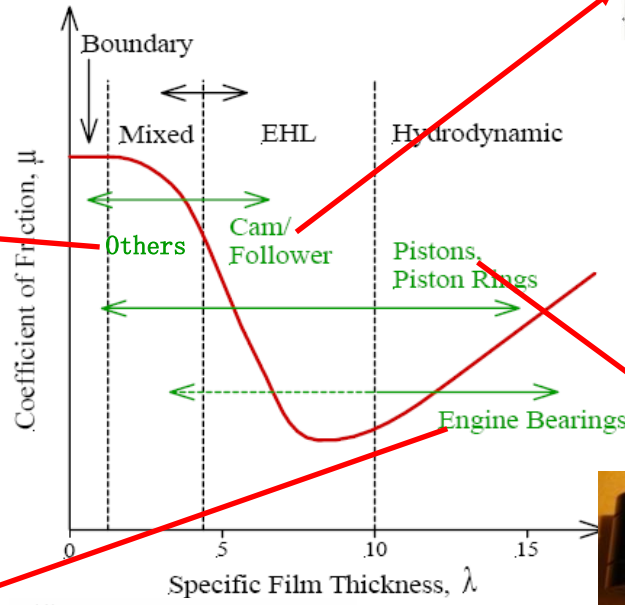
High Fuel-efficiency;
High Power performance & Reliability



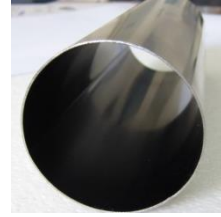
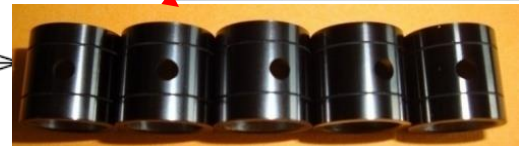
Mature Technology for Key Engine Parts

Over 16 low/super-low DLC-coated products

Modified Stribeck Diagram



Under oil-lubricated



LSL has successfully developed different low or super-low carbon coatings with improved friction-reduction and energy-saving performance aimed for automotive and compressor industry



欢迎莅临兰州化学物理研究所进行 技术交流!

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