Ceramic Applications in the Automotive Industry

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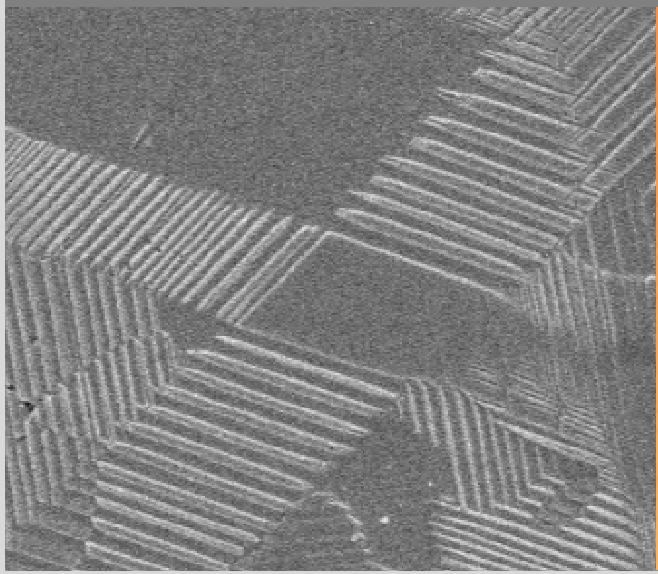
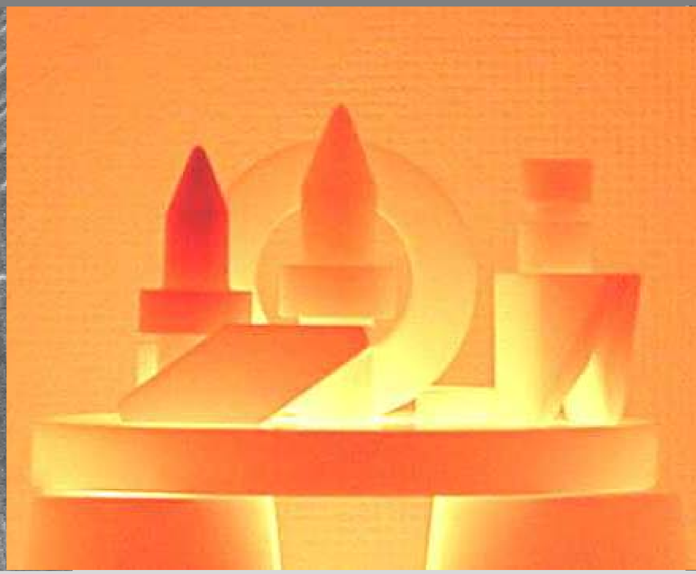
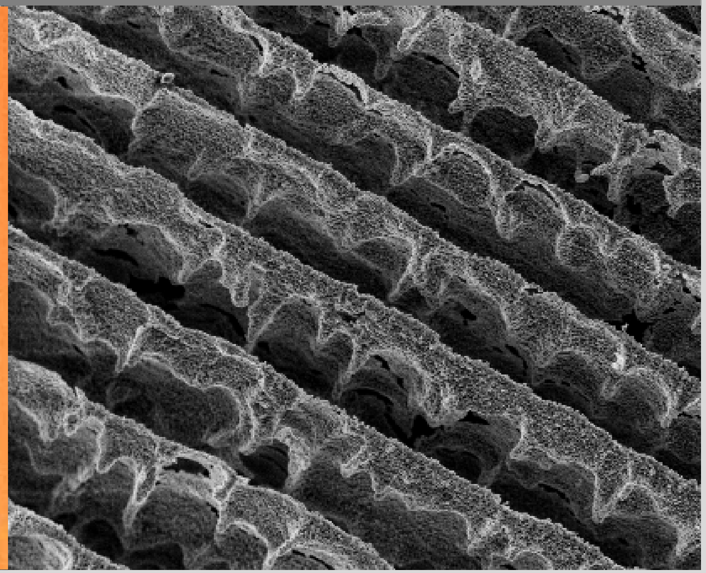
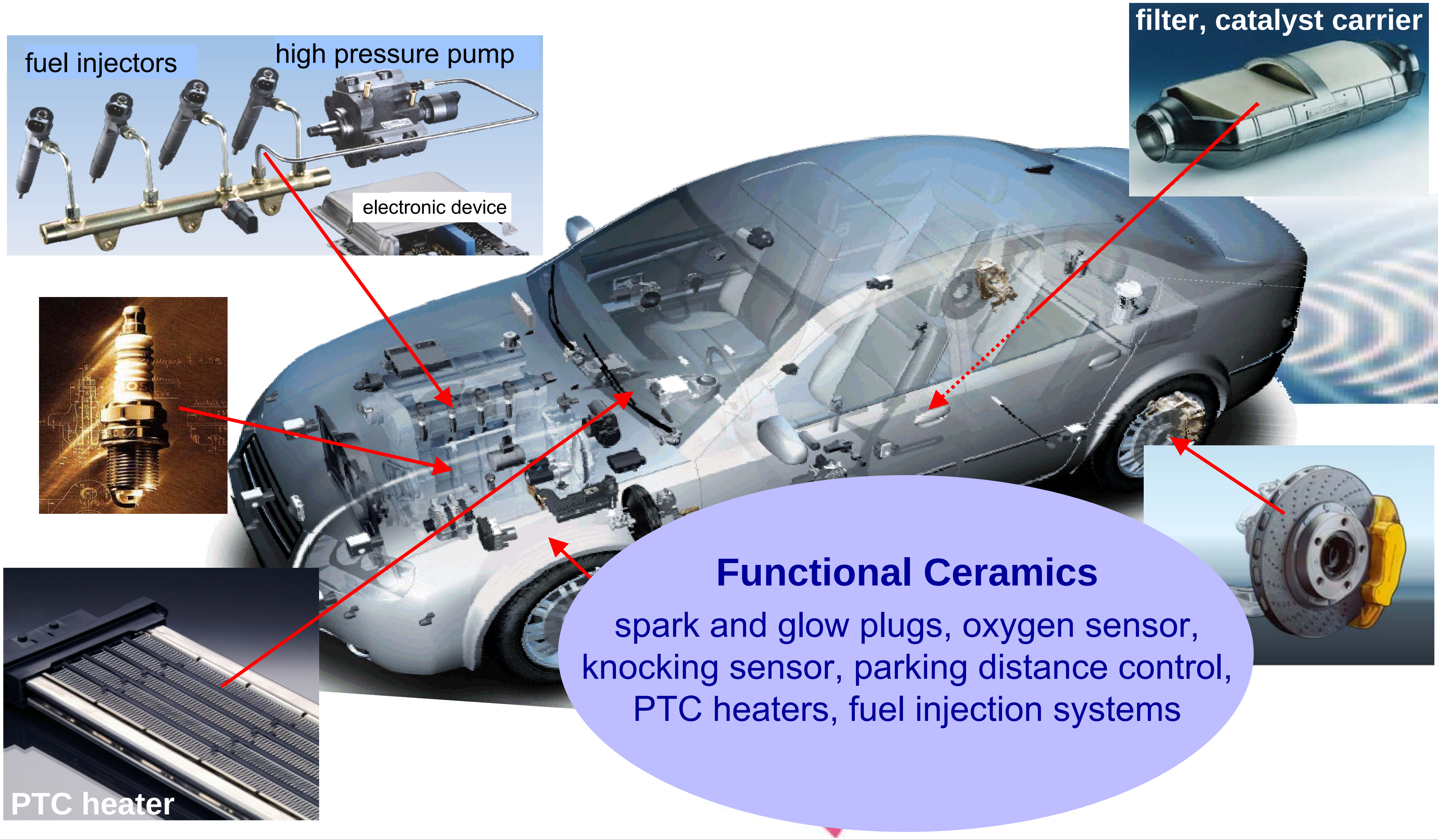


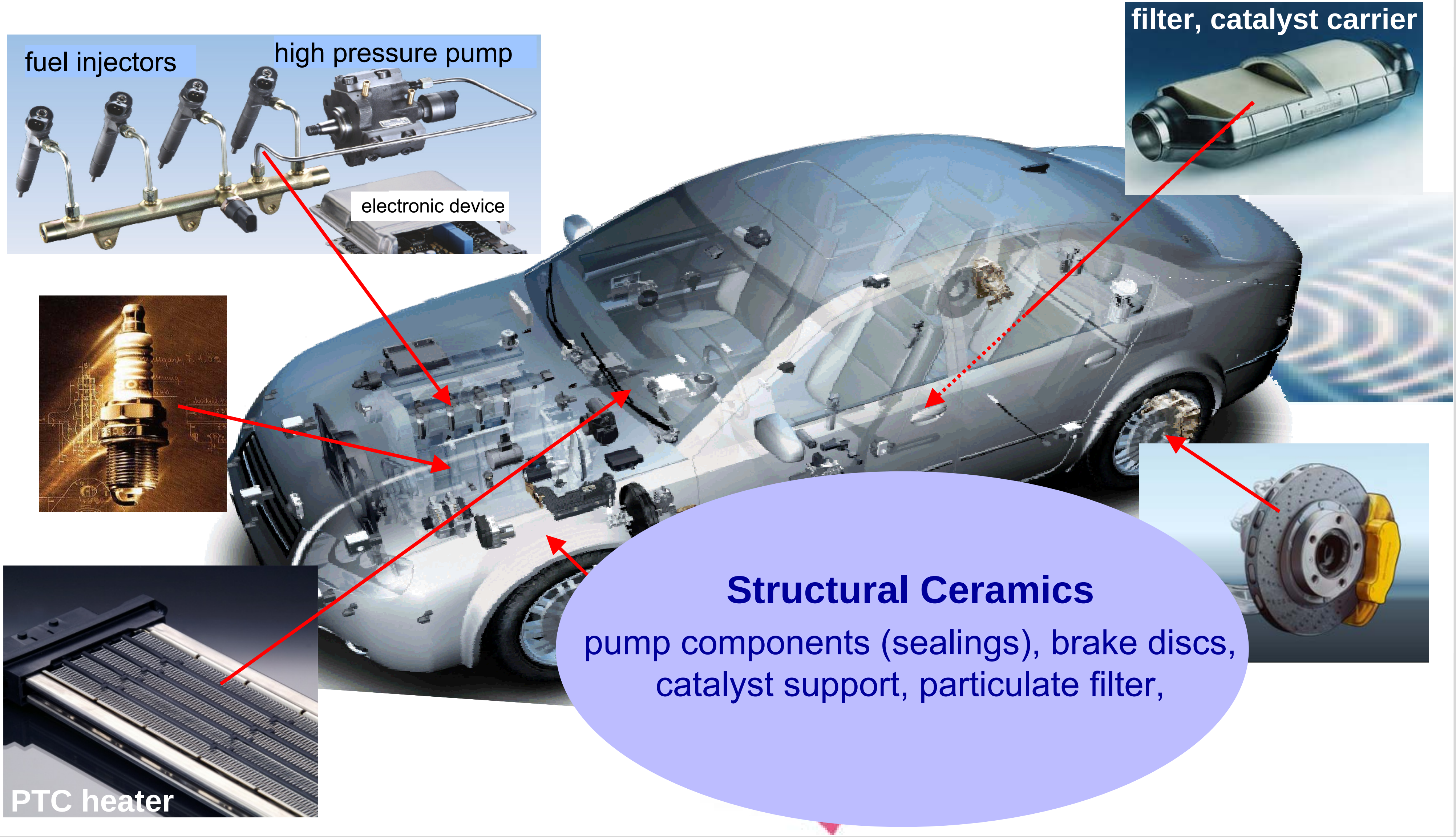




Ceramics components in automotive applications



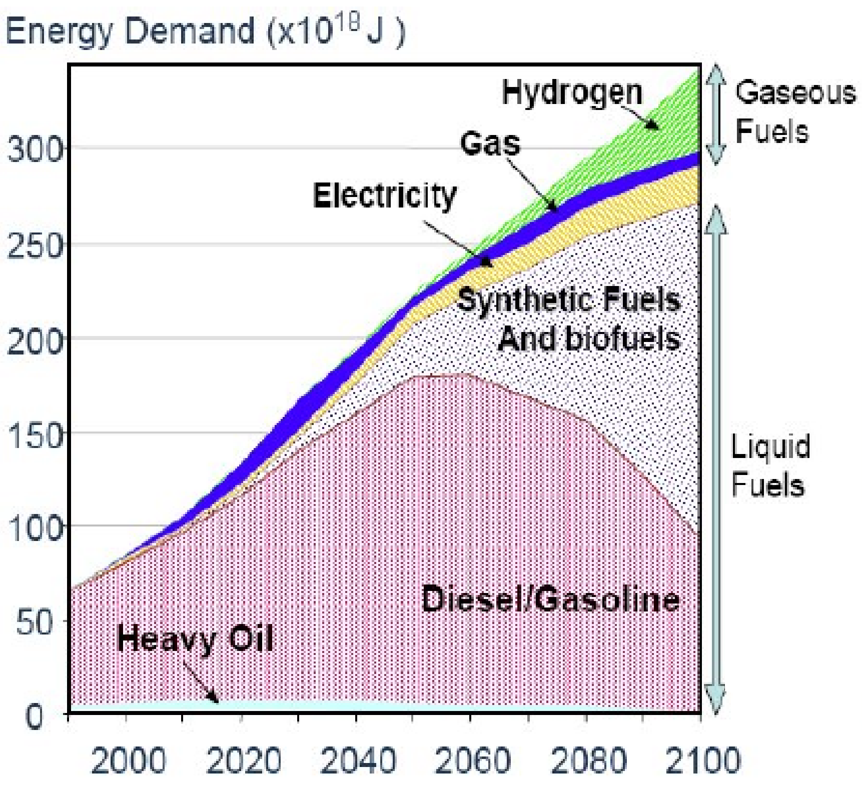
Ceramics components in automotive applications



Structural Ceramics

pump components (sealings), brake discs, catalyst support, particulate filter,

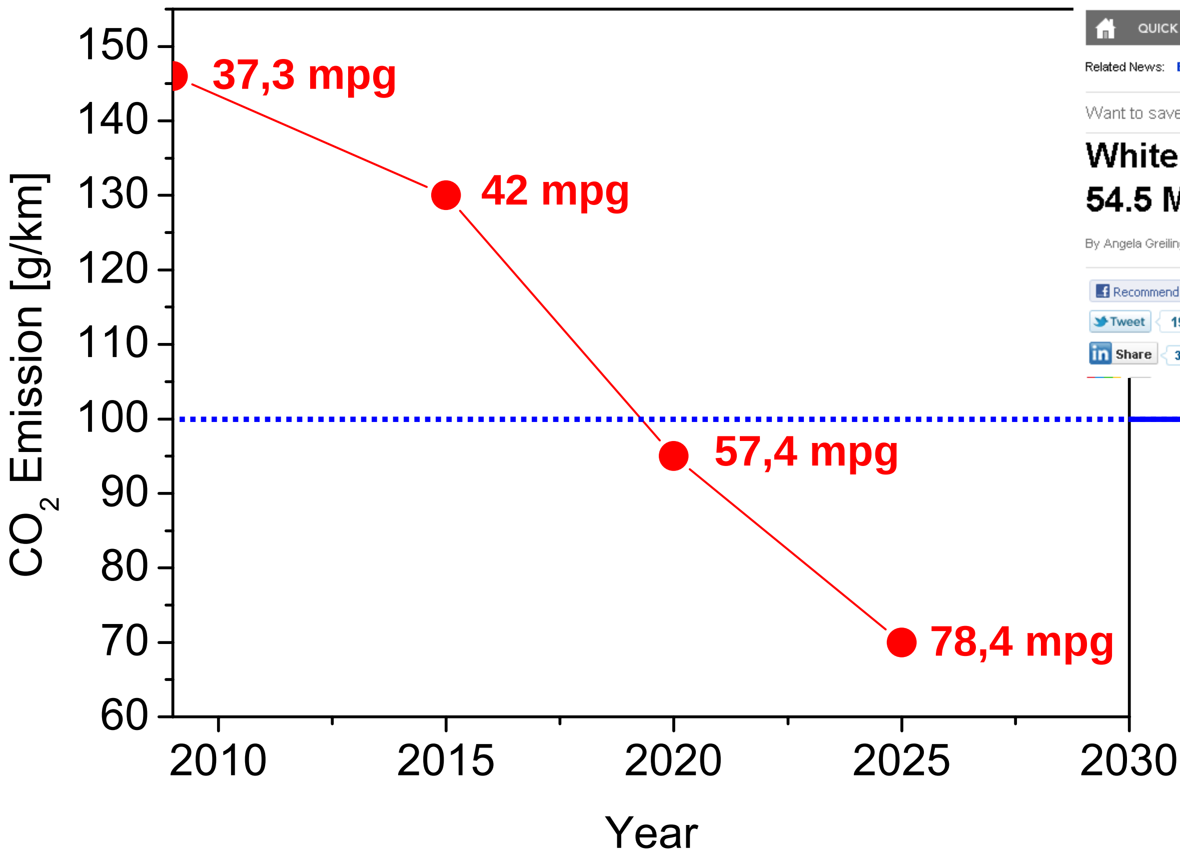
Projection of Total Energy Demand and Energy Mix



Quelle: World Energy Council WEC

- **Liquid fuels will still significantly contribute to up-coming energy demands**
- **Combustion engines are necessary in the next decades**
- **Individual transport: long range distance, trucks, hybrids**

European Fuel-Economy Goal up to 2025

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White House Is Said to Propose Relaxed 54.5 MPG Fuel-Economy Goal for 2025

By Angela Greiling Keane and David Welch - Jul 27, 2011 5:08 AM GMT+0200 ADD TO QUEUE

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President Barack Obama's administration altered its proposal for a 2025 U.S. fuel-economy average to 54.5 miles per gallon to make allowances for light trucks, people familiar with the negotiations said.

US Goal: 100 g/km

Goal can only be obtained by more efficient combustion engines
→ Downsizing concept (smaller, but more efficient engines)

Downsizing concept

Downsizing is based on the principle of a reduction in engine size in order to reduce consumption without affecting power.

Measures:

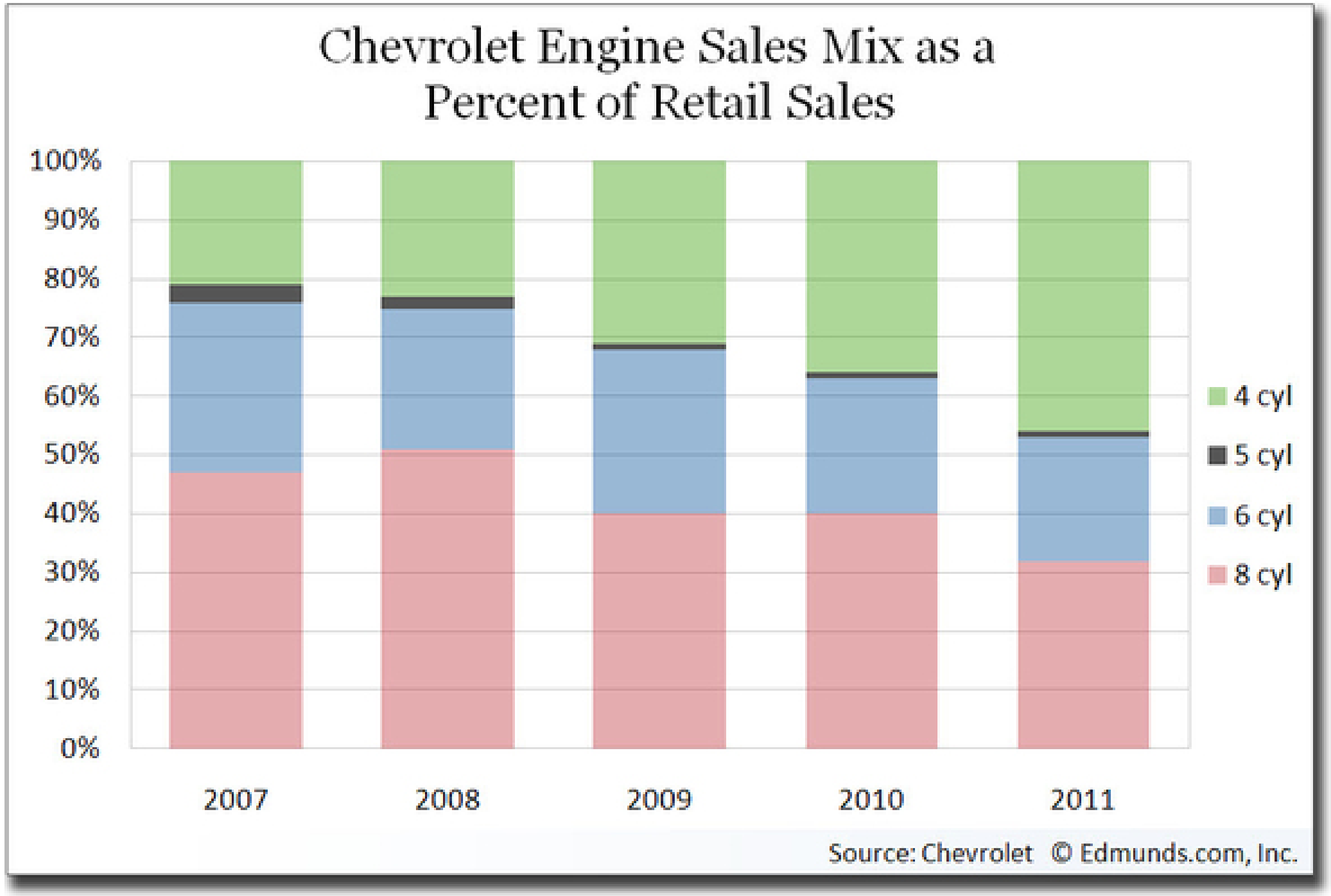
- **Reduction of number of cylinders**
- **Supercharging (use compressed air)**
- **Direct injection systems**

Challenges and Needs:

- **Injection control system**
- **High pressure fuel pump**
- **High thermal and mechanical loading**

Downsizing can reduce the CO_2 emissions between 5% for diesel models and 40% for gasoline models by 2020. These engines should be able to remain dominant for a long time in the car market.

Downsizing concept

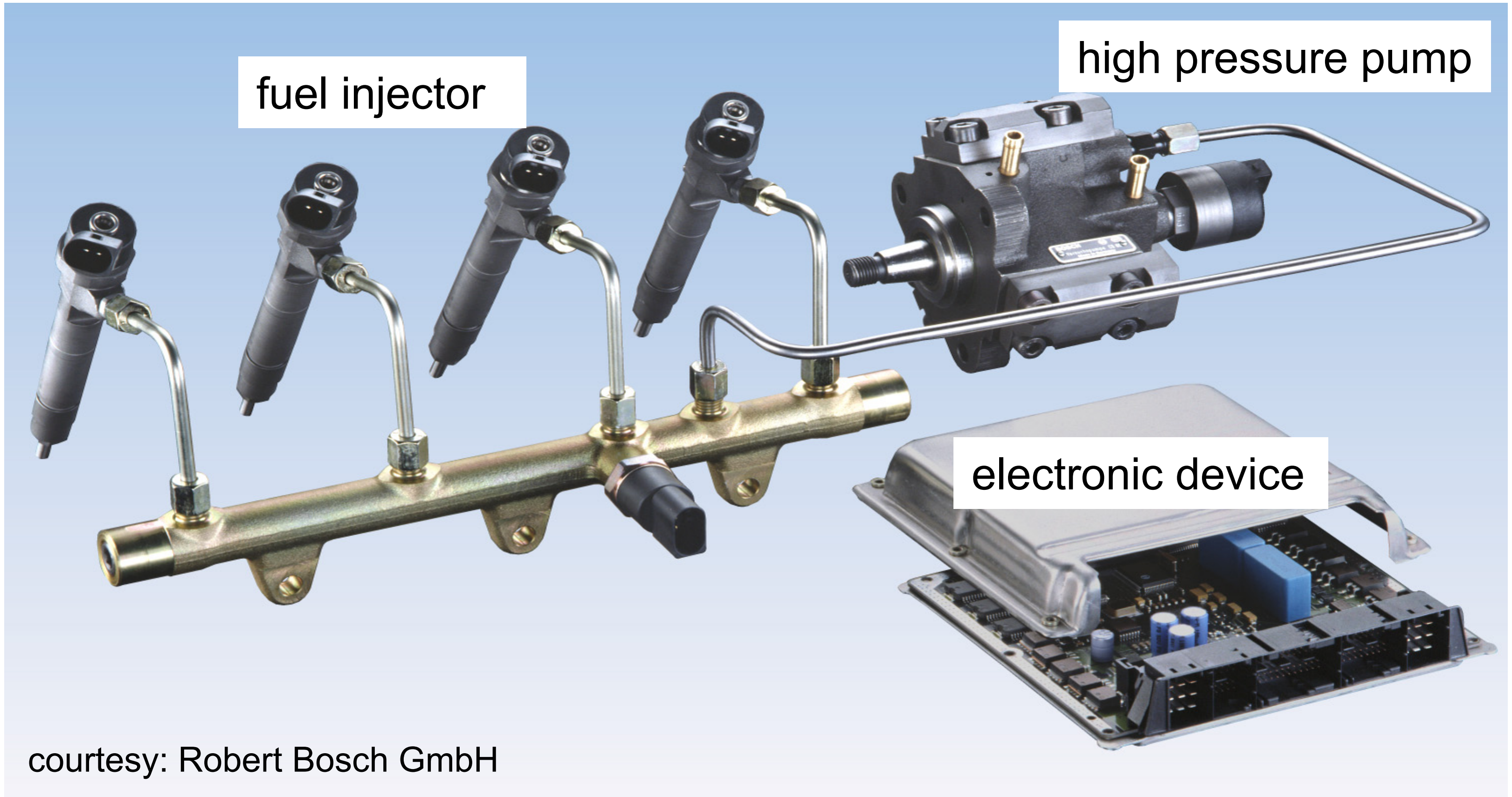


Downsizing is already reality in the present US market

Outline

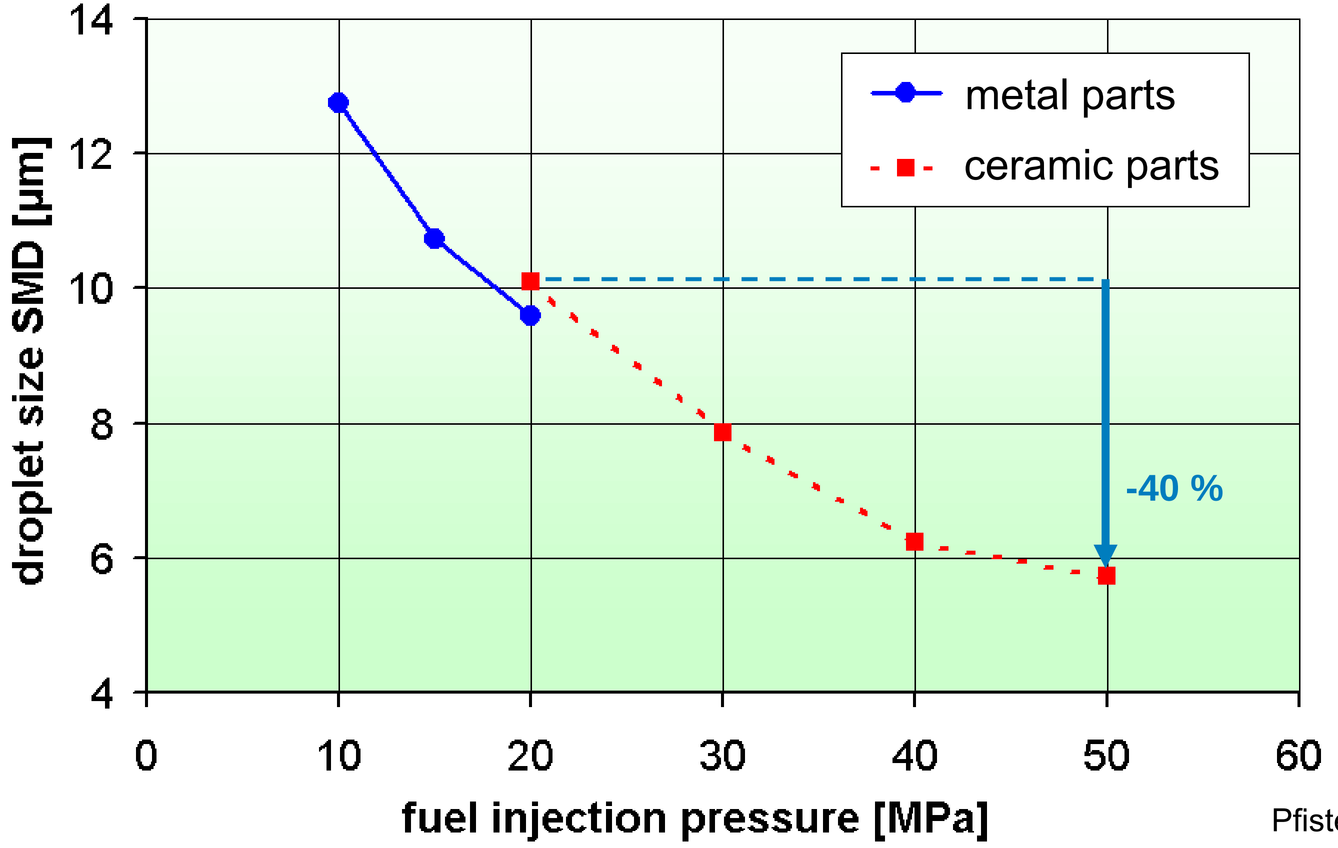
- High pressure pump systems for gasoline engines
- Spark plugs
- Porous ceramics for local reinforcement of metal matrix composites
- Piezoelectric injection systems
- PTC heating elements
- General conclusions

Piezoelectric Driven Common Rail Fuel Injection Technology



Piezo technology increases efficiency and reduces emission
→ already used in Diesel systems, but with a high potential for gasoline systems

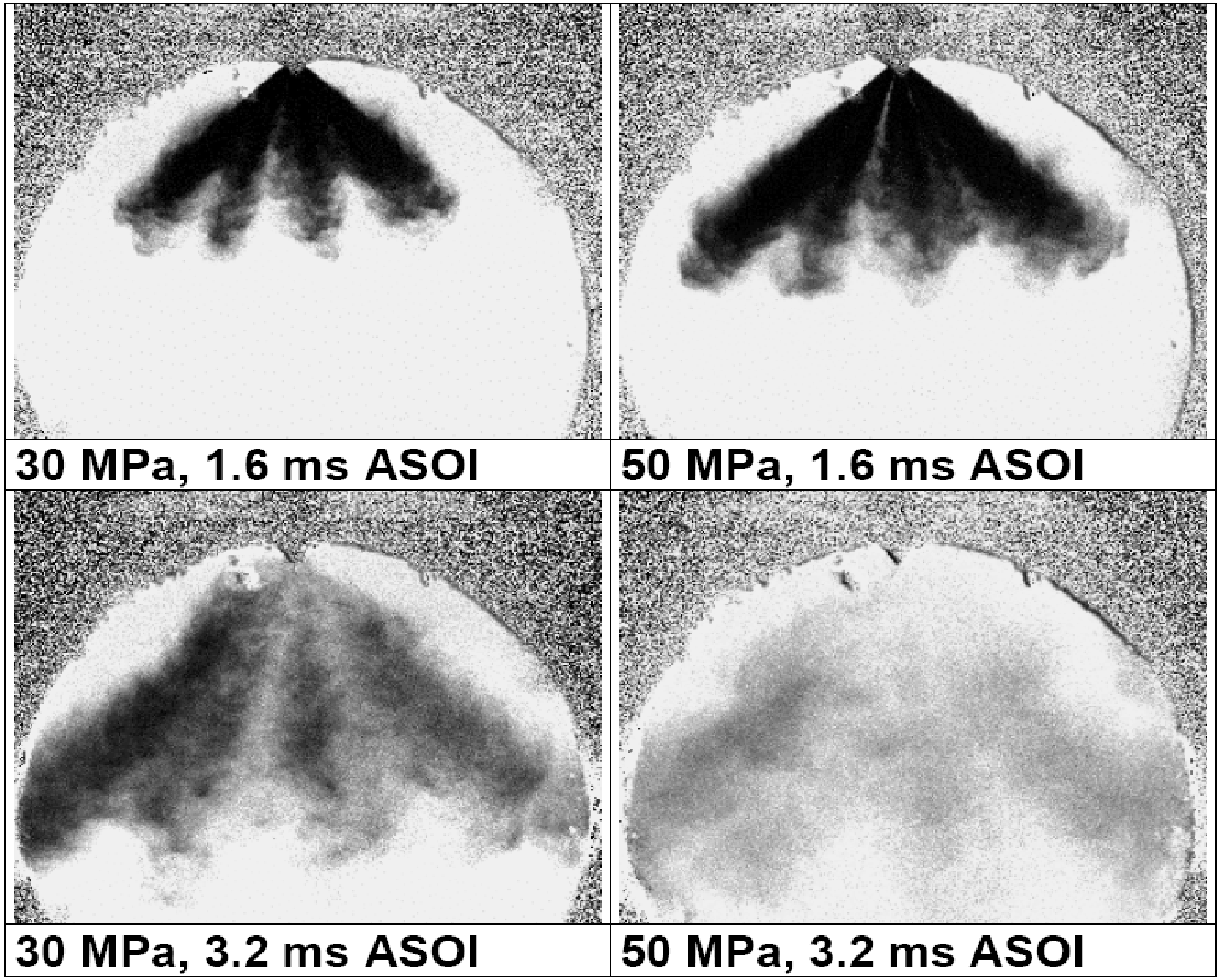
Piezoelectric Driven Common Rail Fuel Injection Technology



Pfister et al. Cer. Trans. (2011)

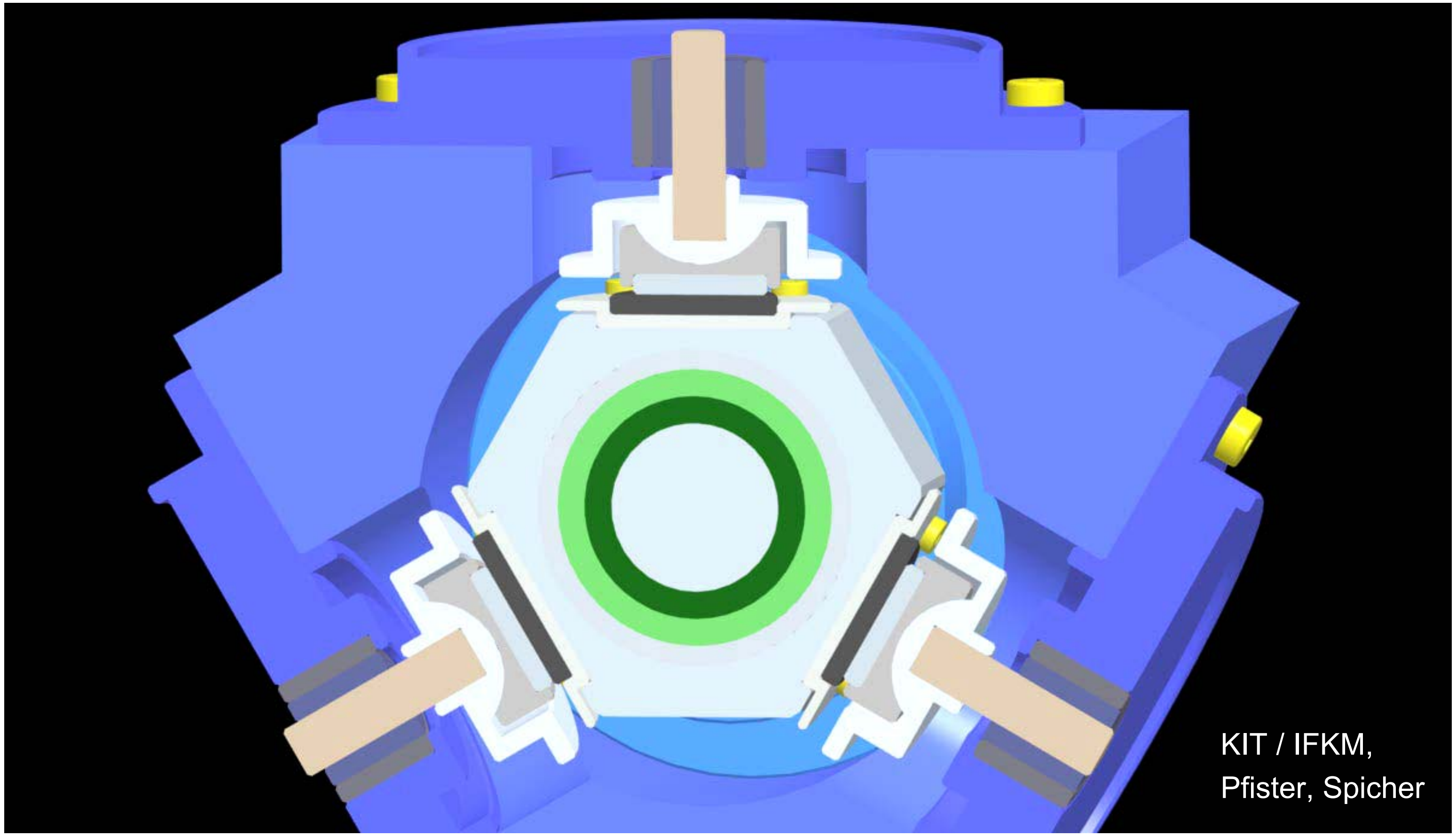
High fuel injection pressure is needed to reduce droplet size (-40%),
→ decrease of fuel consumption and pollutant emissions (-80%)

Fuel evaporation in combustion chamber



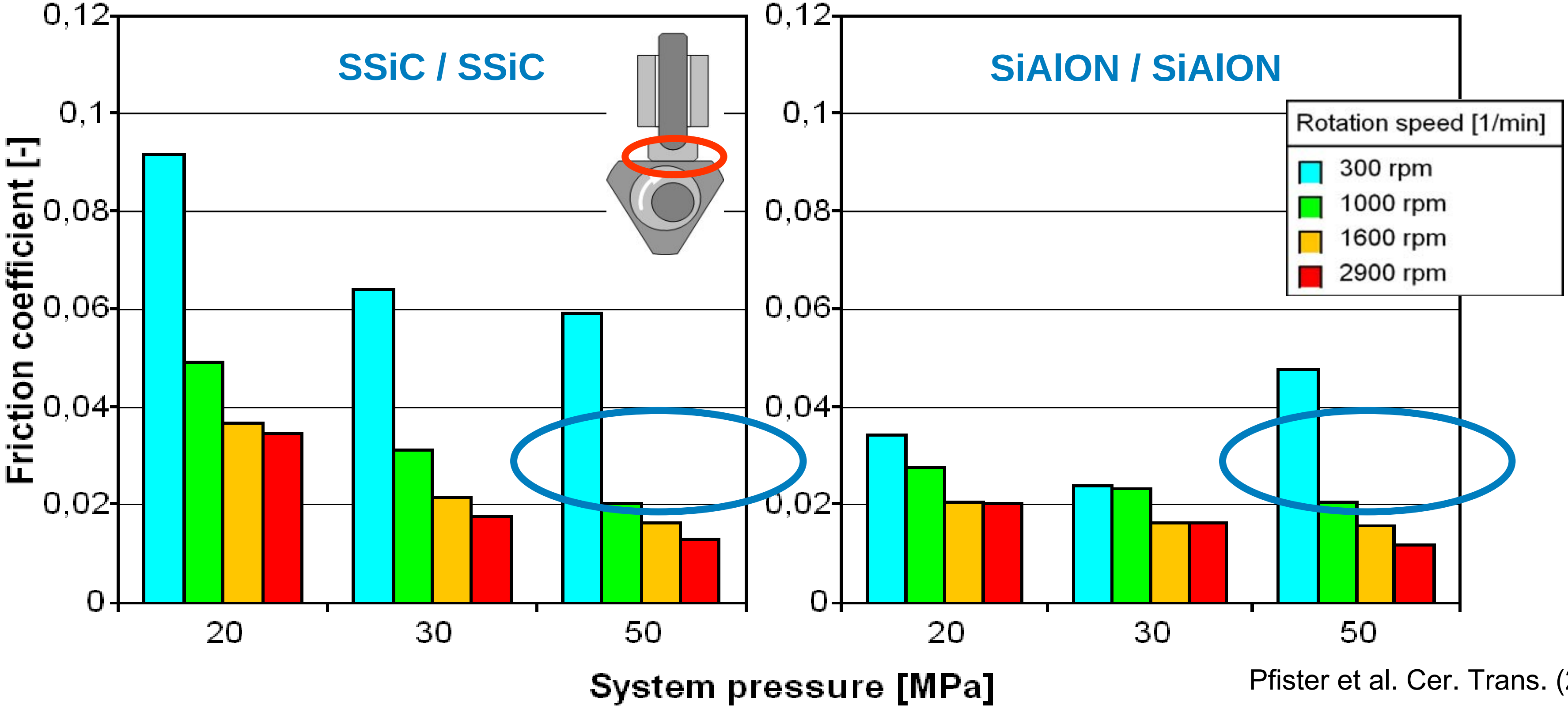
source: Spicher, KIT-IFKM

3-Piston High Pressure Pump for Gasoline Engines



Cam/sliding-shoe contact is tribological highly loaded due to an insufficient lubrication of petrol with increasing pressure → ceramic components can be a solution

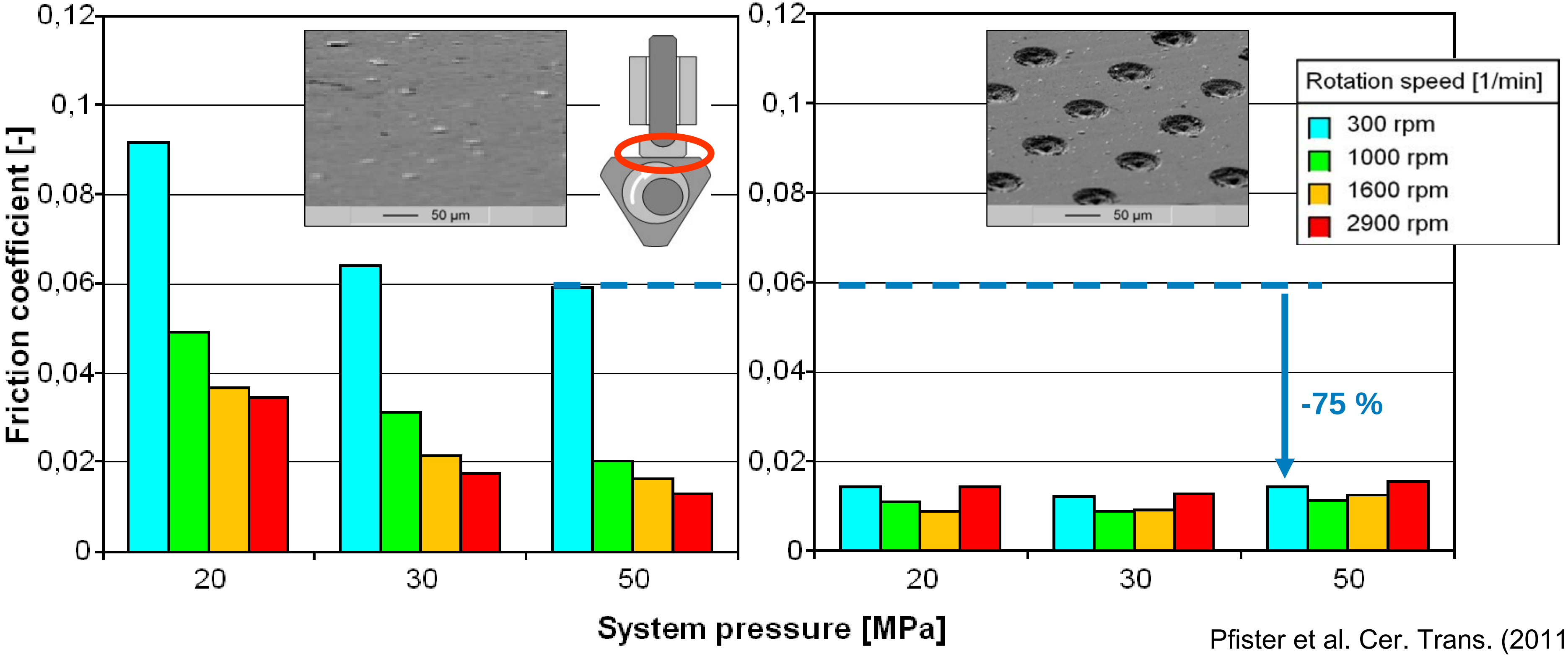
Friction coefficient in the cam/sliding-shoe contact



Pfister et al. Cer. Trans. (2011)

Silicon carbide and SiAlONs indicate a similar behaviour with a very low friction coefficients at a system pressure of 50 MPa

Effect of surface texturing of the cam/sliding-shoe contact



Pfister et al. Cer. Trans. (2011)

The texture significantly improves the performance of self-mated silicon carbide at low speed or low contact force

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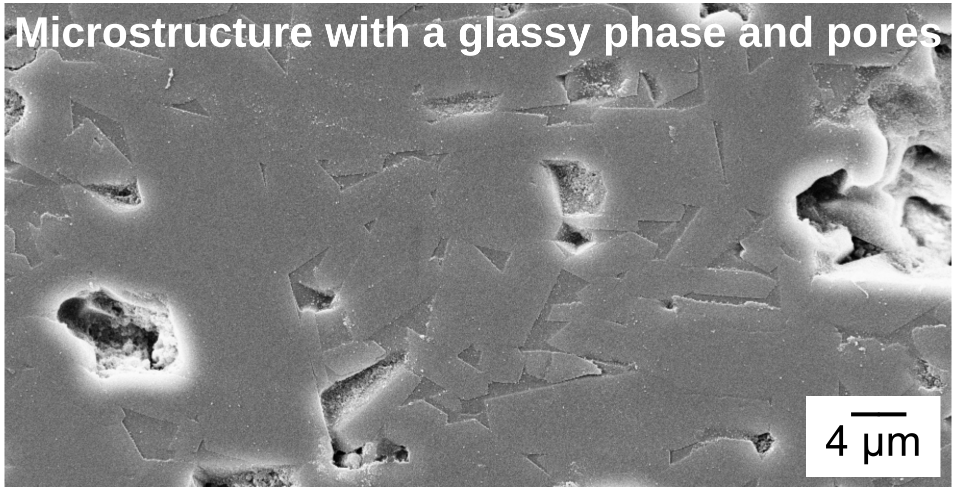
- General conclusions

Gasoline direct injection system

Source: KIT / IFKM, Spicher

An ignitable mixture for low and high loads is only formed in a very narrow spatial zone

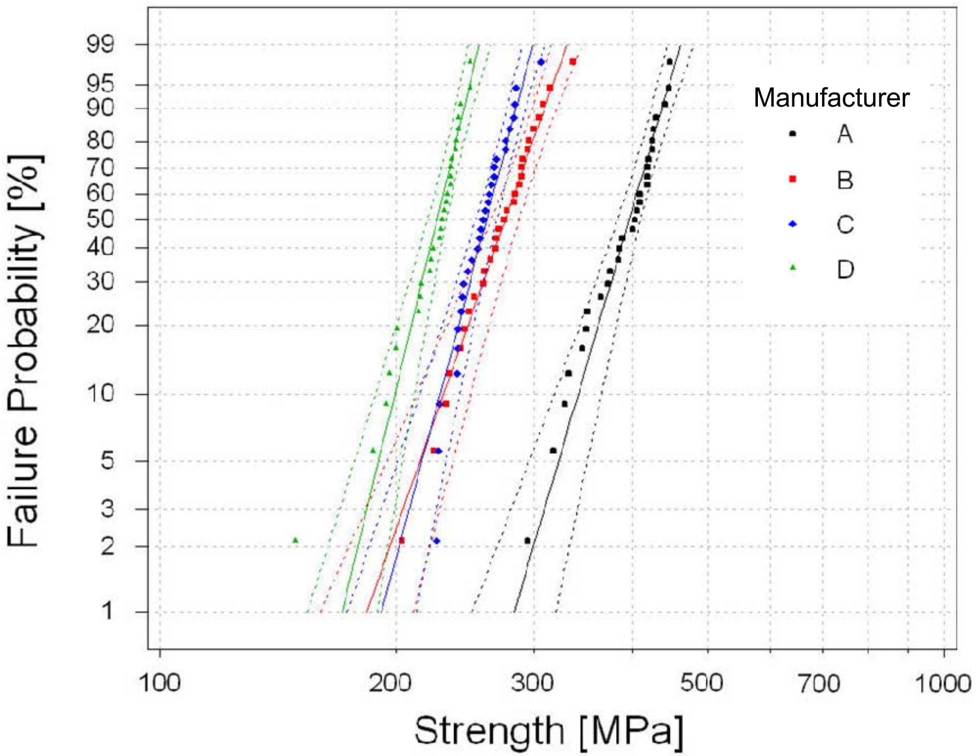
Future trends for spark plugs in fuel-efficient engines

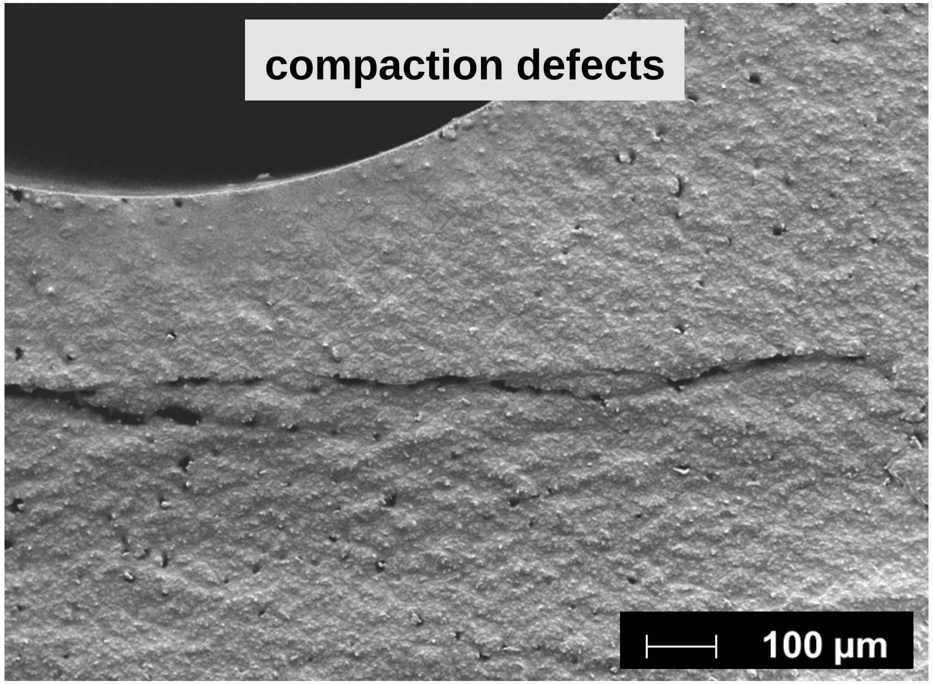


<u>Challenges</u>

- Distance between electrodes will increase
- Higher voltage will be applied
  → longer spark
- Pressure increase in combustion chamber
  → higher thermal and mechanical loading
- reduction in size

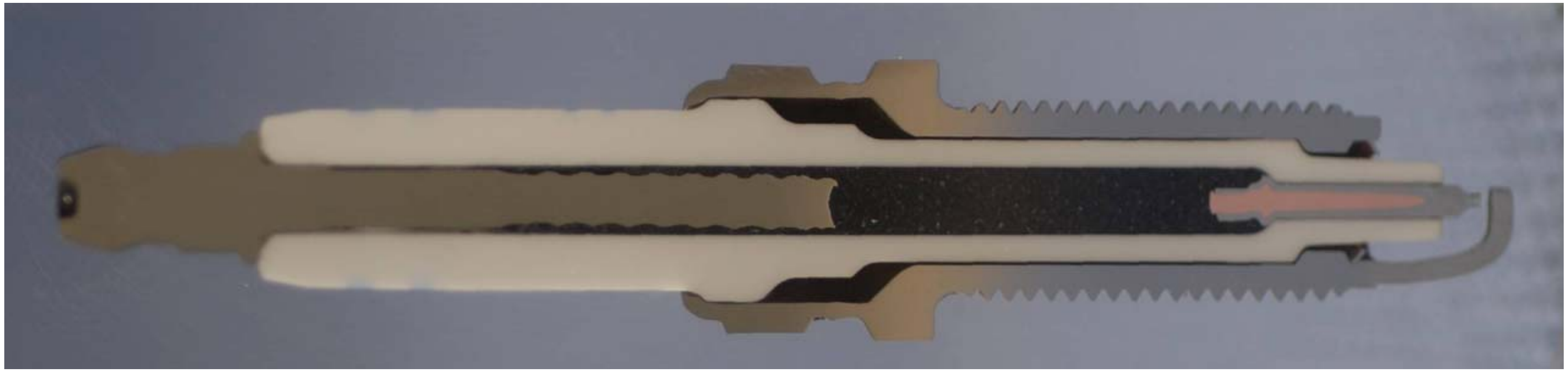
Strength distribution and typical failure mechanisms of commerical spark plugs





Strength distribution reflects also the electric breakthrough behaviour
→ Most current commercial materials do not match the requirements

Future trends for spark plugs in fuel-efficient engines



Challenges:

- smaller diameter → higher thermal and mechanical loading
  → strength must be increased by enhanced processing conditions
- adjustable resistance
- high voltage → increase in electrical breakthrough

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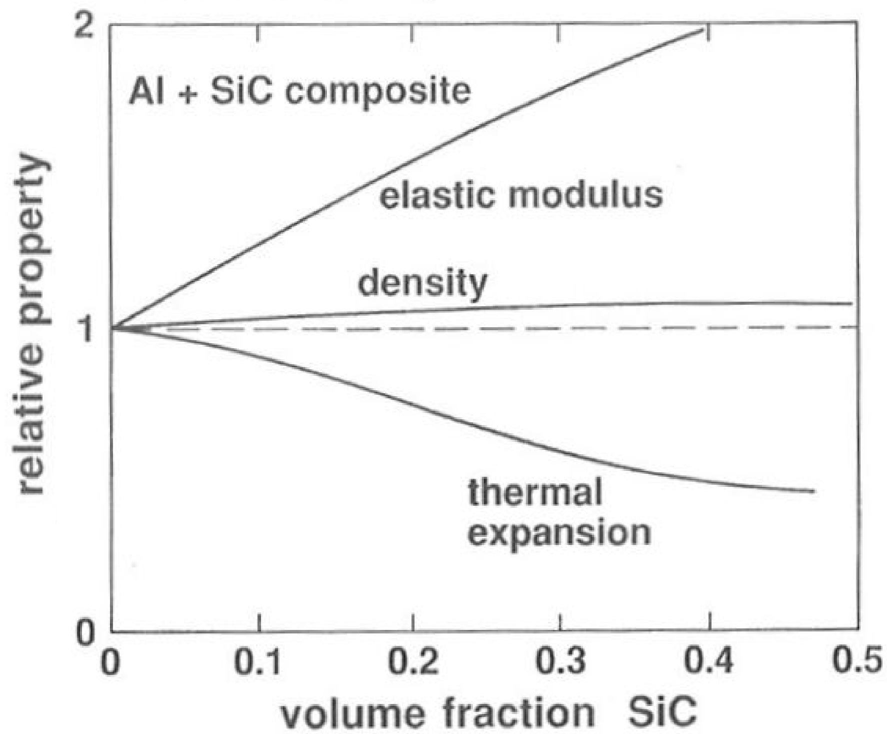
Metal Matrix Composites for Highly Loaded Engine Parts

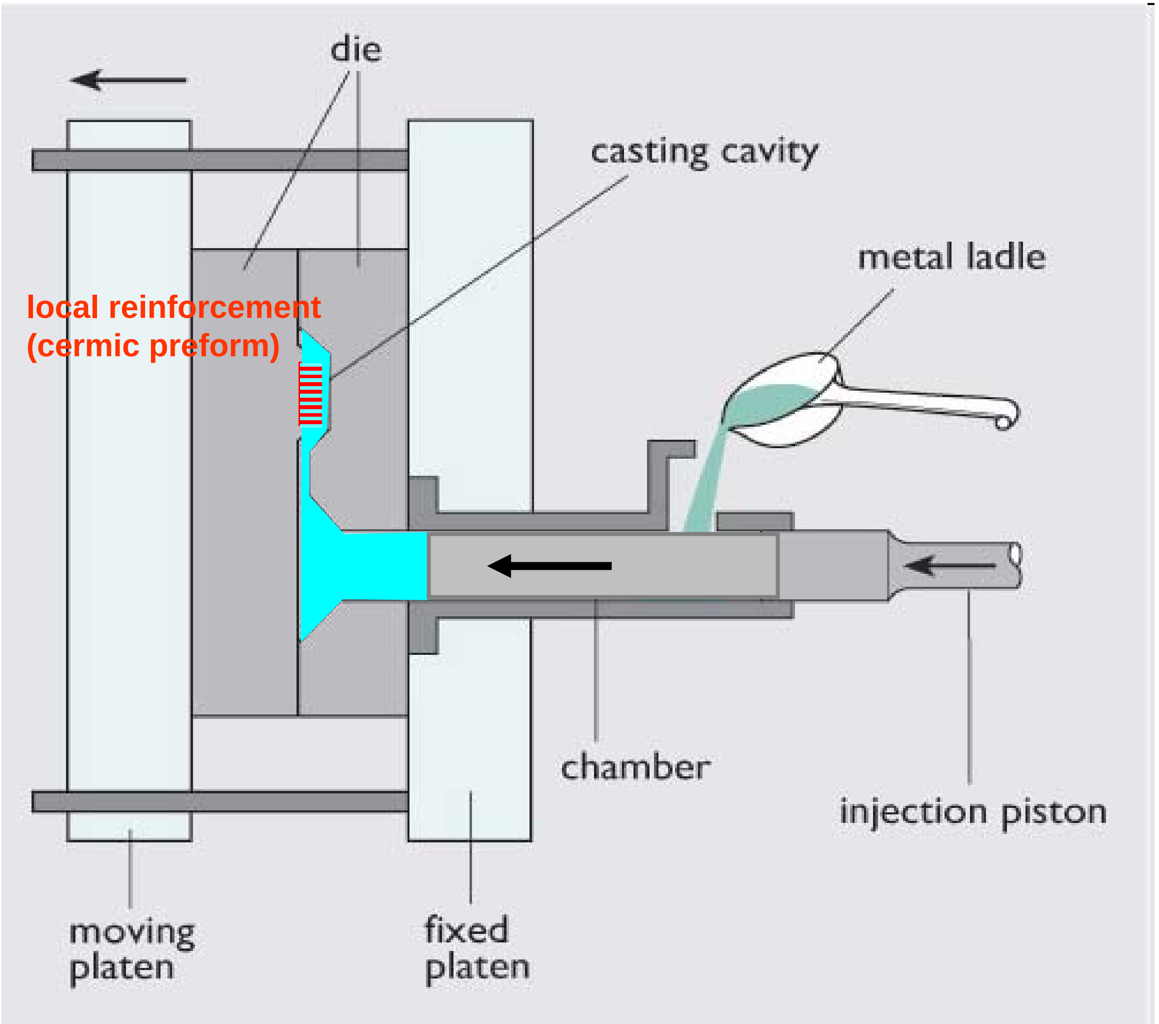
Engine part manufactured by pressure die casting of Al-based alloys



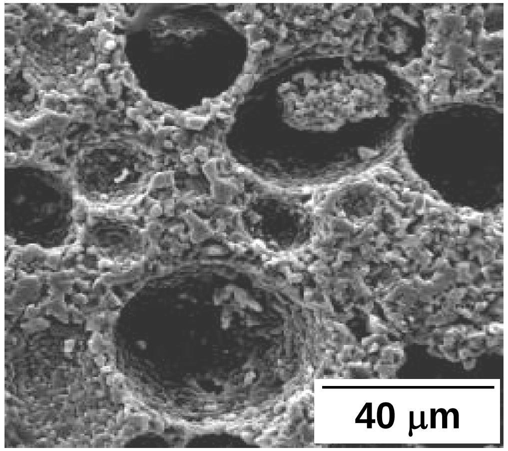
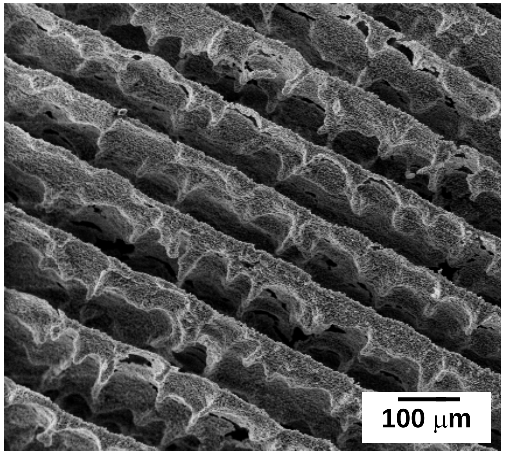
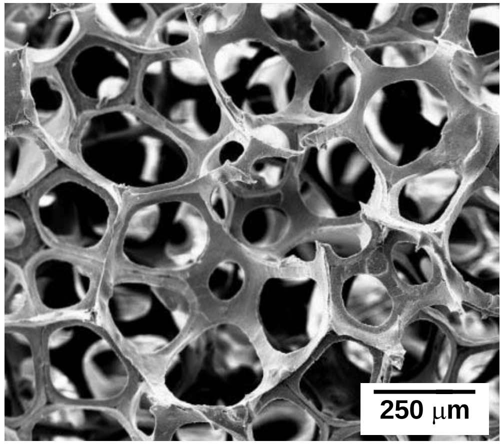
after German, 1994

Inhomogeneous cooling causes thermal stresses that can be minimized by a local reinforcement with ceramics (preform concept).

Local reinforcement of pressure die-casted Al-MMCs



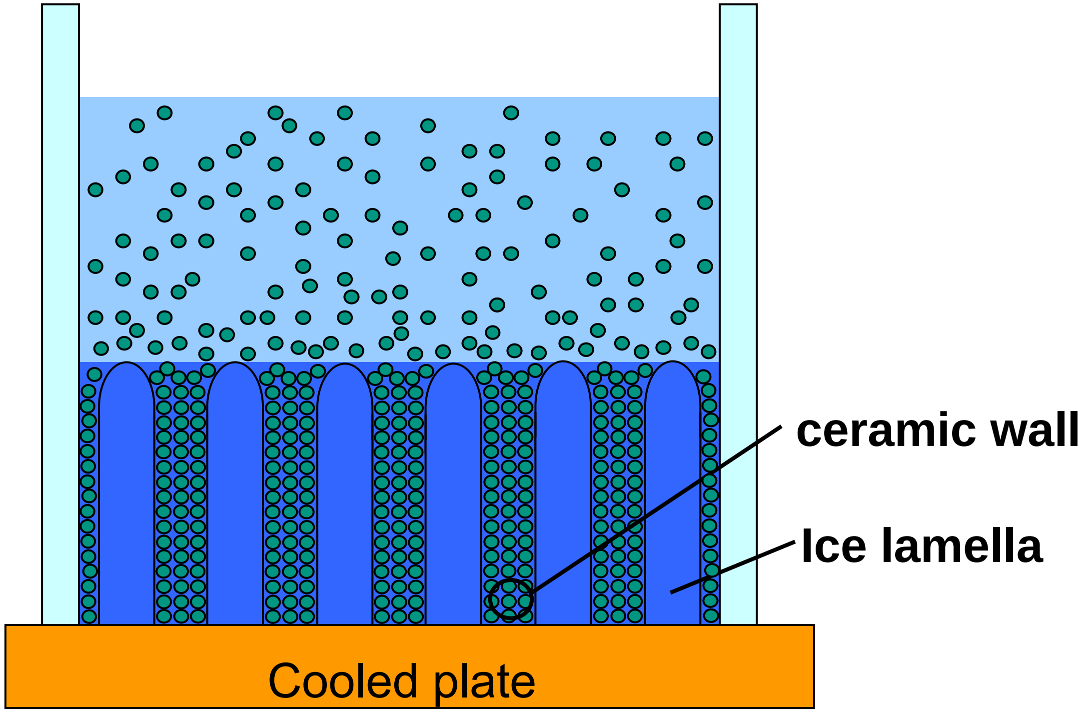
Preparation of Porous Ceramic Preforms

Pore filler concept	Freeze casting	Ceramic foams
		
Porosity: up to 75% Pore size and shape depend on filler	Porosity: 20-85% Ice crystals form final pores	Porosity: 85-95% cell size depends on polymer foam

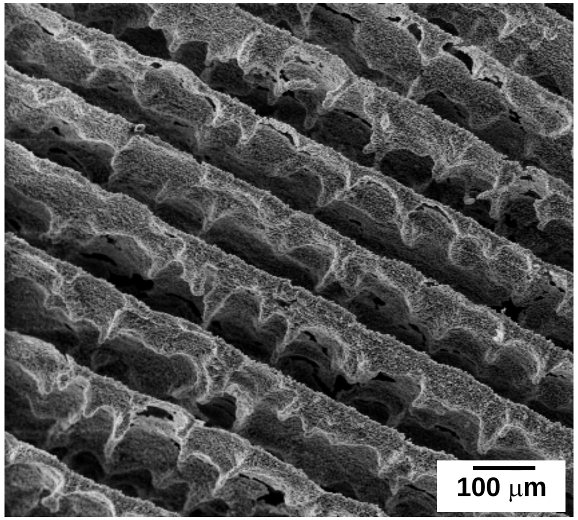
Mattern et al., JECS (2004).

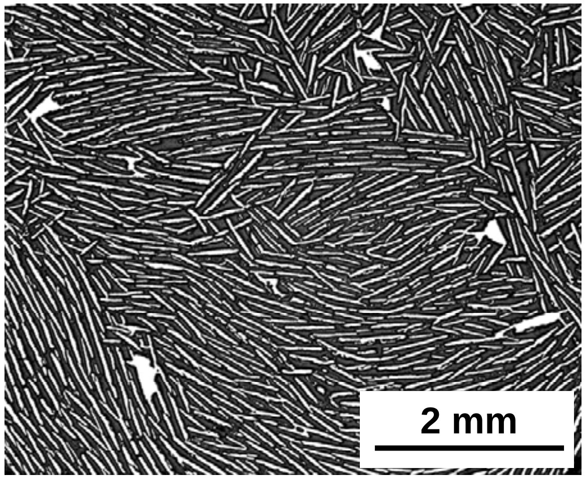
Different types of ceramic preforms can be manufactured by using powder technology processes.

Preparation of freeze-casted Al-MMCs



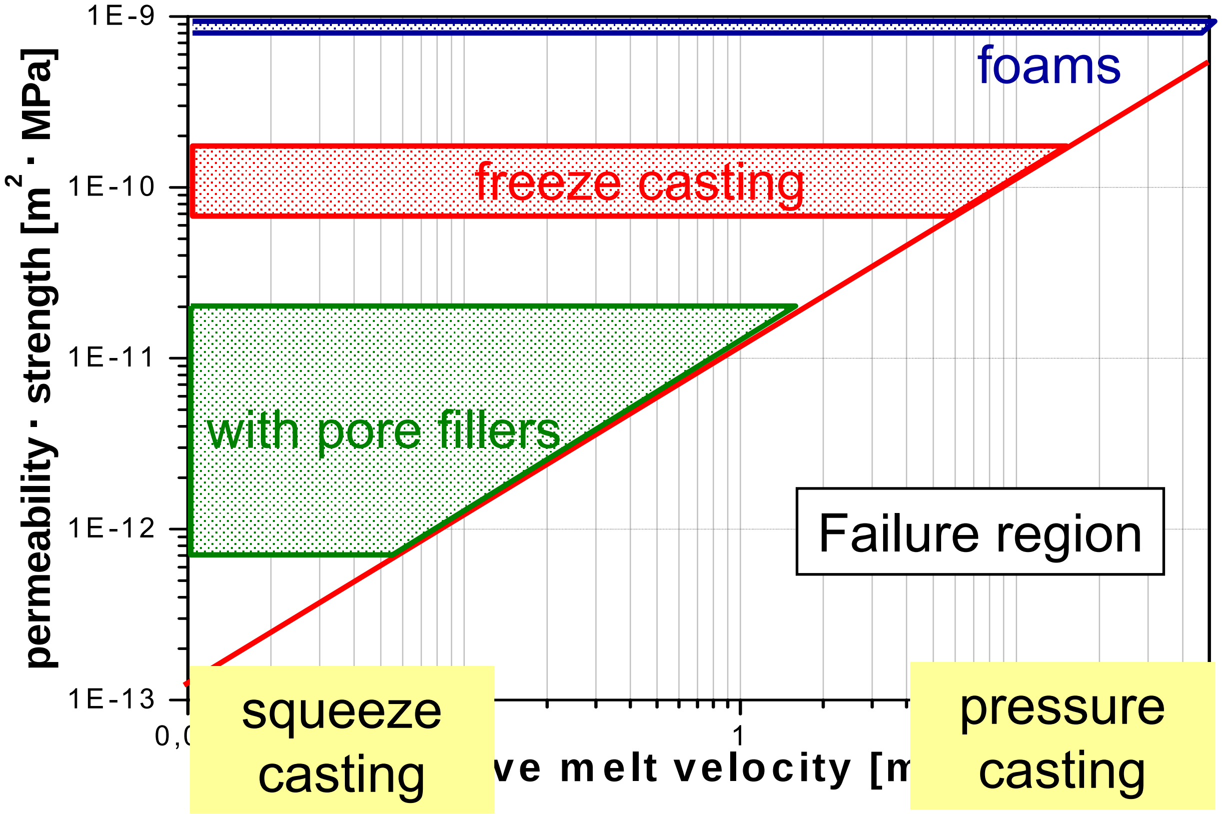
Waschkies et al., JACS (2009)





S. Roy & A. Wanner, Compos. Sci. Technol. (2008)

Estimation of failure probability for different perform types



Mattern et al., JECS (2004).

Freeze casted preforms can be used for pressure casting, while preforms with pore fillers and bottle neck pores will break

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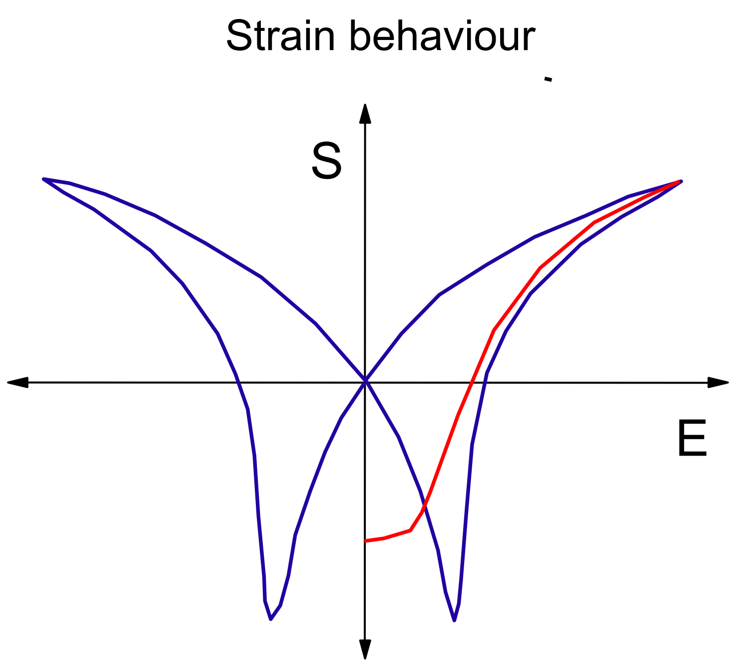
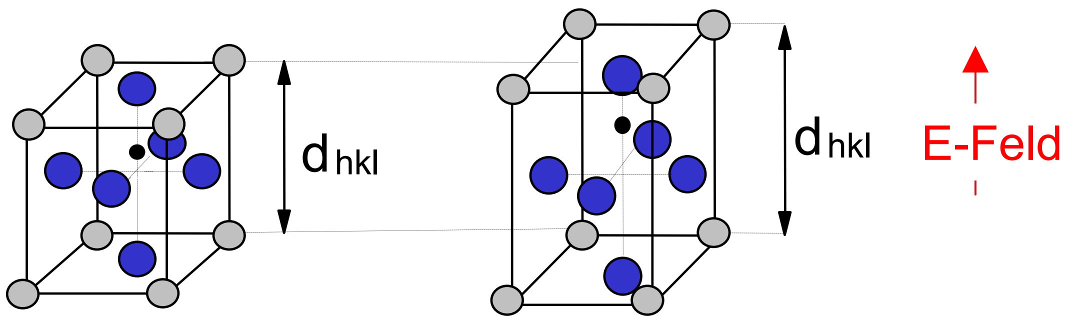
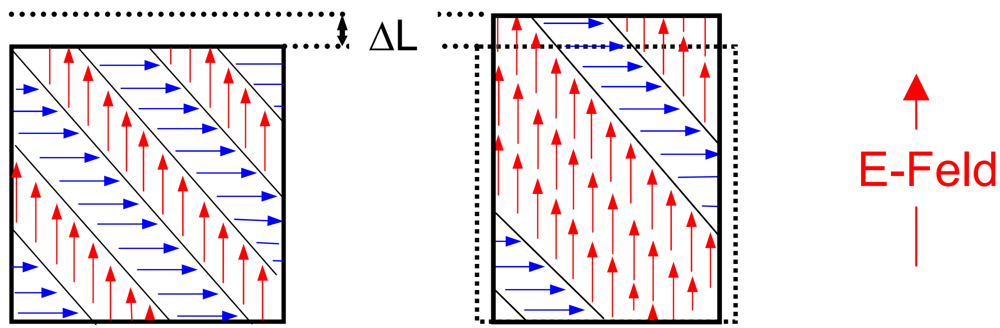
Mechanisms of high field strain in ferroelectric ceramics



Piezoelectric effect (intrinsic)

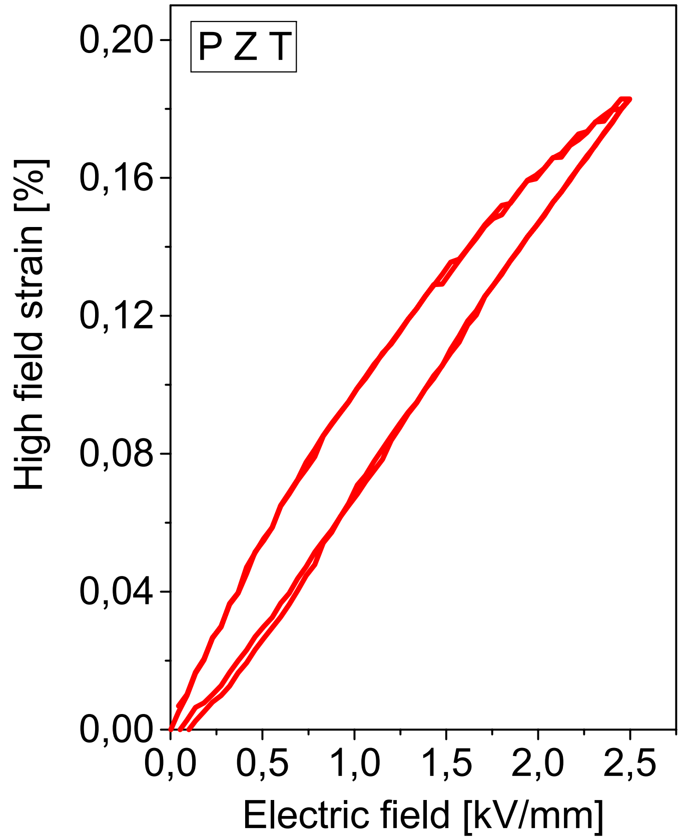


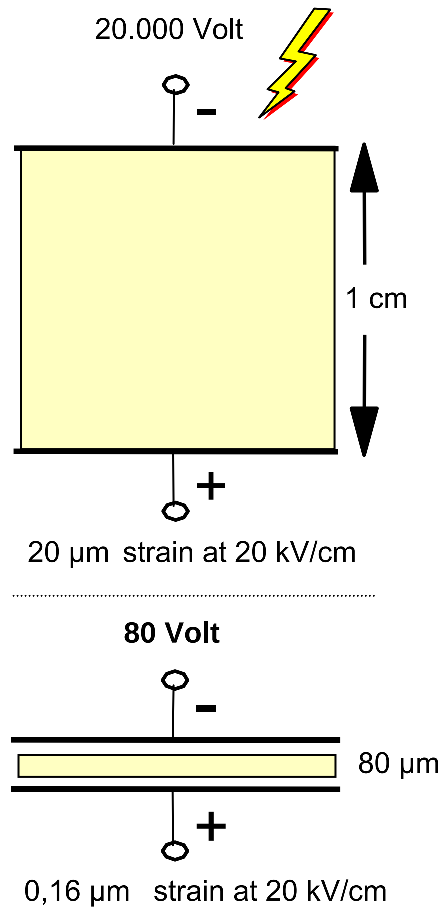
Domain switchung (extrinsic)



→ High strain materials rely on both intrinsic and extrinsic effect

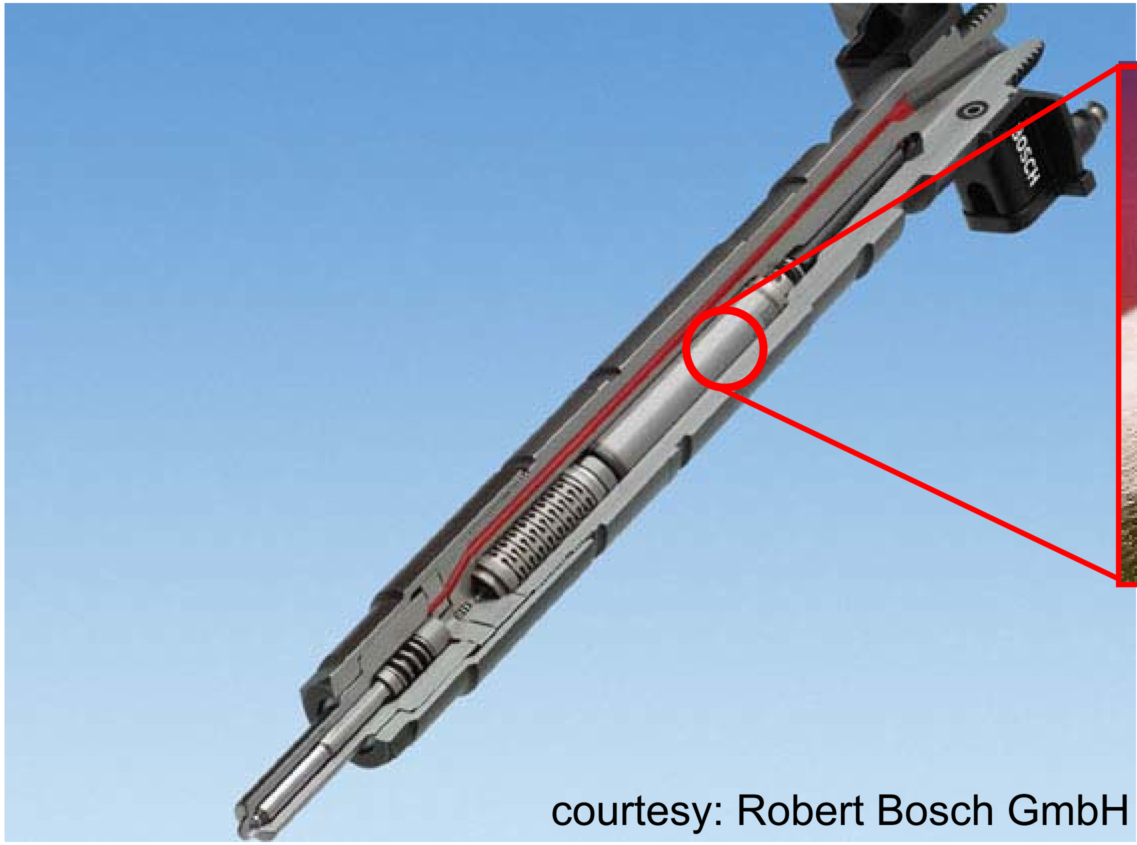
Strain behaviour of a ferroelectric ceramic at 20 kV/cm

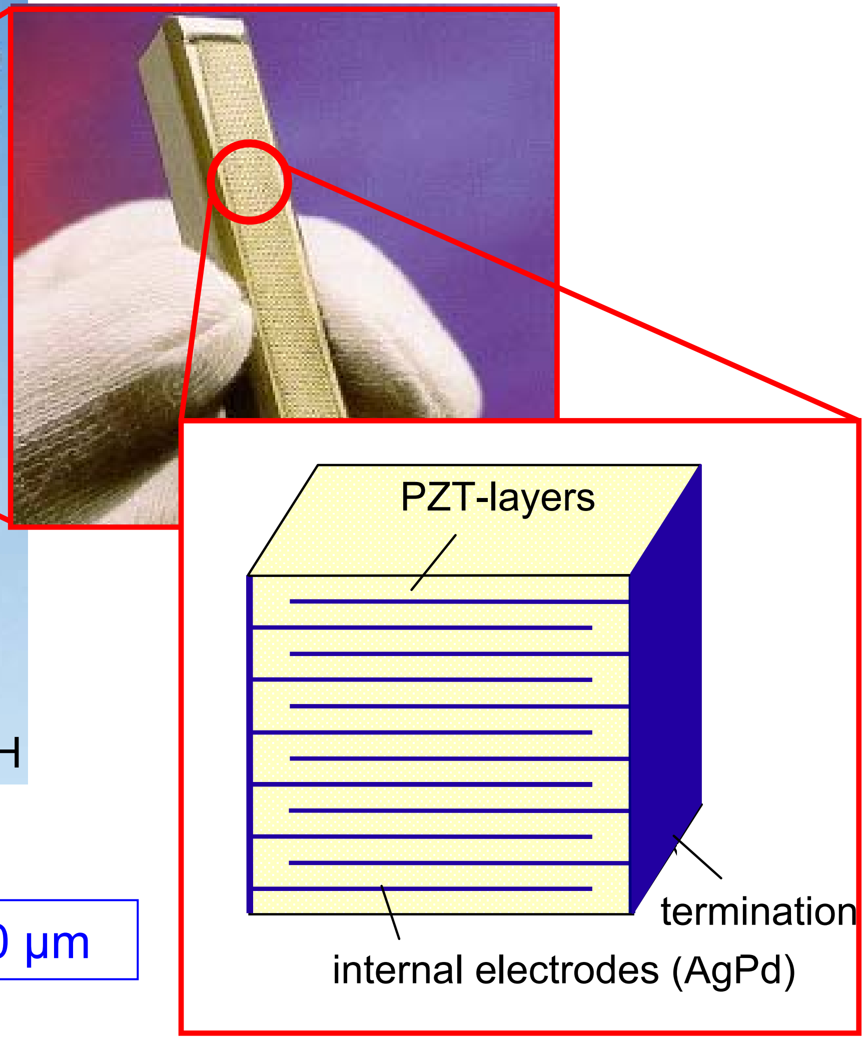




Typical strain of a donor-doped $Pb(Zr,Ti)O_3$ ceramic (PZT): 0.15 - 0.2 % at 20-30 kV/cm
→ Multilayer device

Piezoelectric Driven Common Rail Fuel Injection Technology



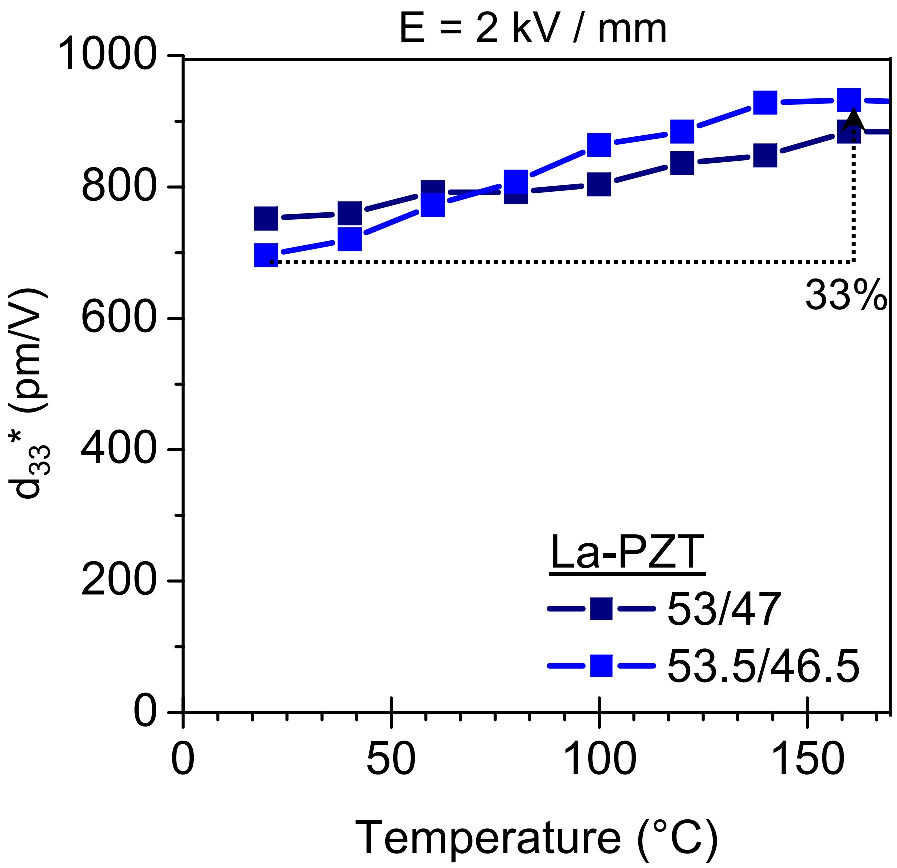


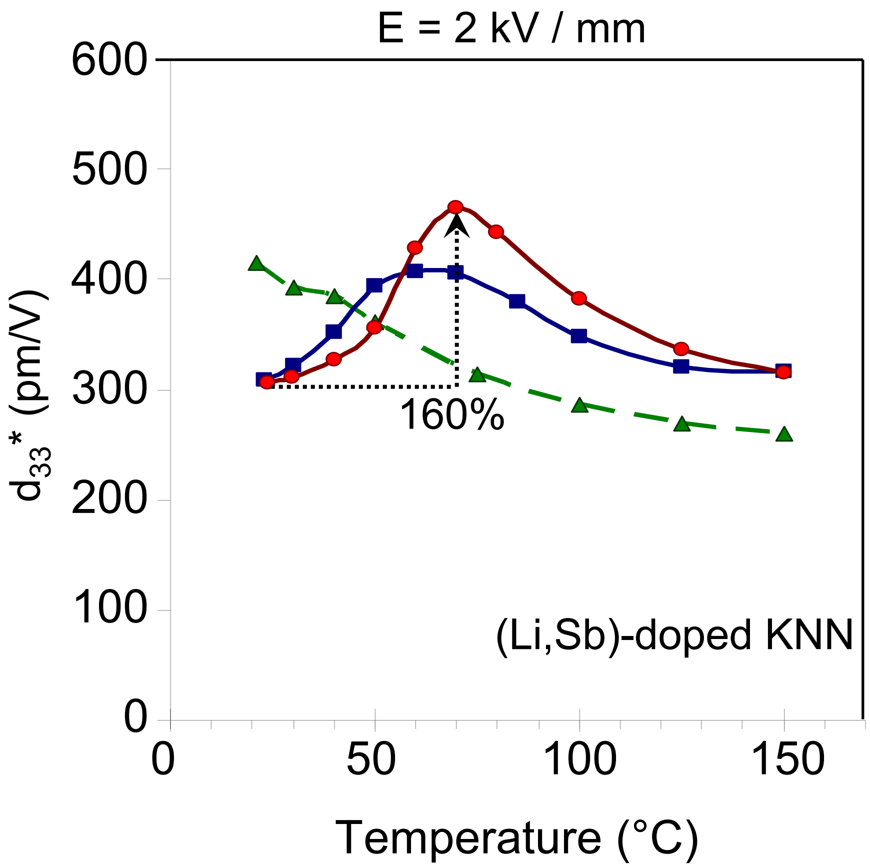
→ typical driving voltage: 100 V, total strain 20-30 µm

Requirements for piezoelectric actuators for fuel injection systems

- cofiring with internal electrodes (multilayer device)
- high strain
- operating temperatures from -40 to 150 °C
- small temperature dependence of strain
- high reproducibility (mass production)
- “low cost“
- challenge: replacement of PZT by lead free ferroelectrics

Comparison of $Pb(Zr,Ti)O_3$ and a lead-free ceramic





Lead-free ceramics show a lower strain for a similar electric field strength and exhibit a much stronger temperature dependence of strain

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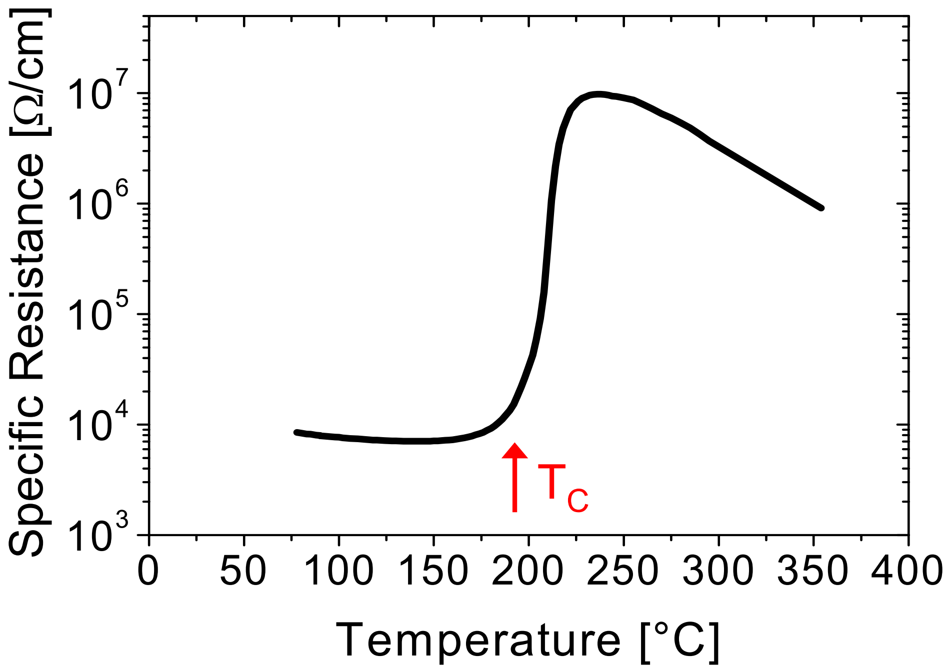
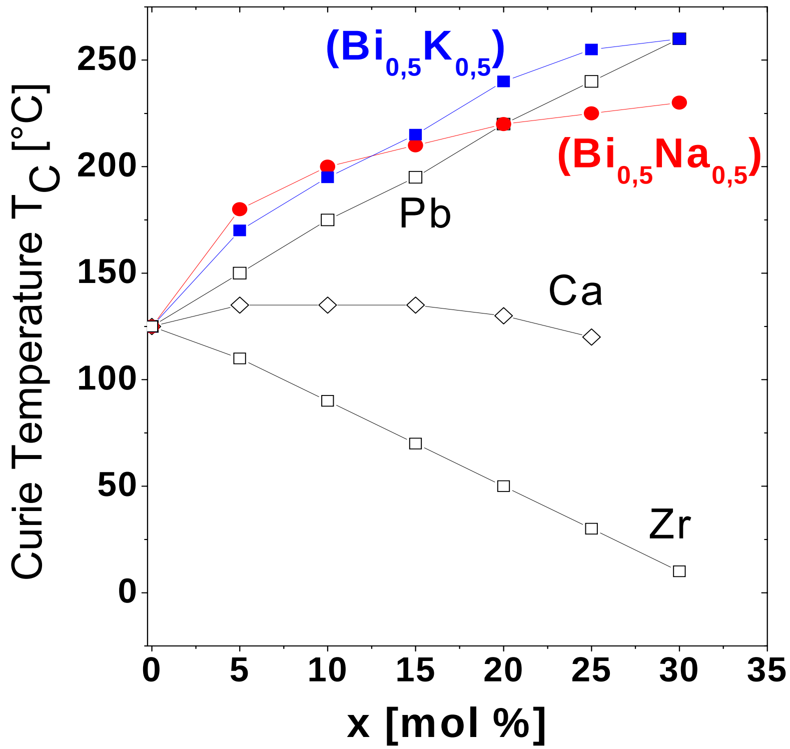
Heat deficiency for car heating systems with efficient engines

source: eberspächer catem, Germany

The increasing efficiency of fuel saving cars requires a supplementary heat system based on functional ceramics showing a positive temperature coefficient resistance (PTCR) effect.

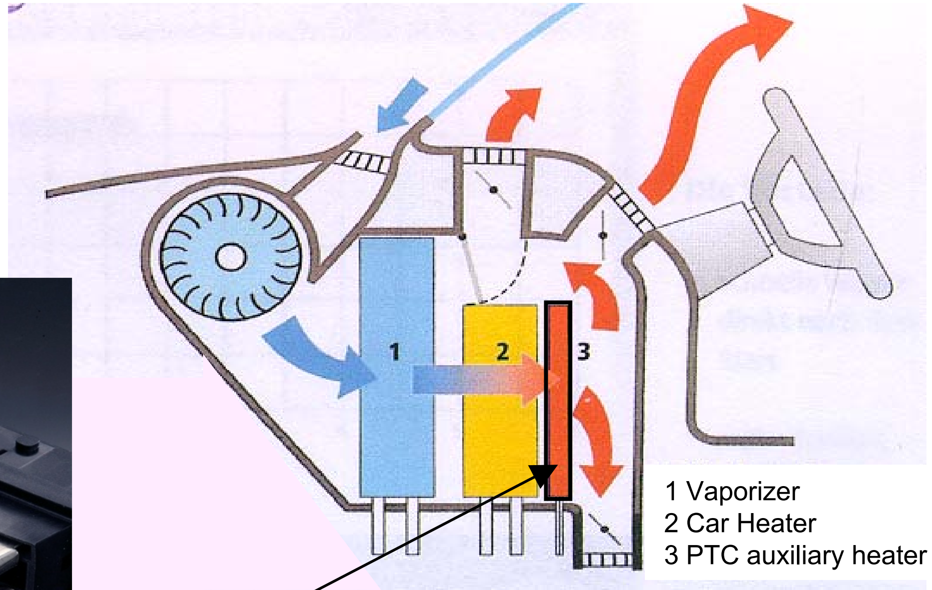
PTC effect in donor-doped $BaTiO_3$-based ceamics



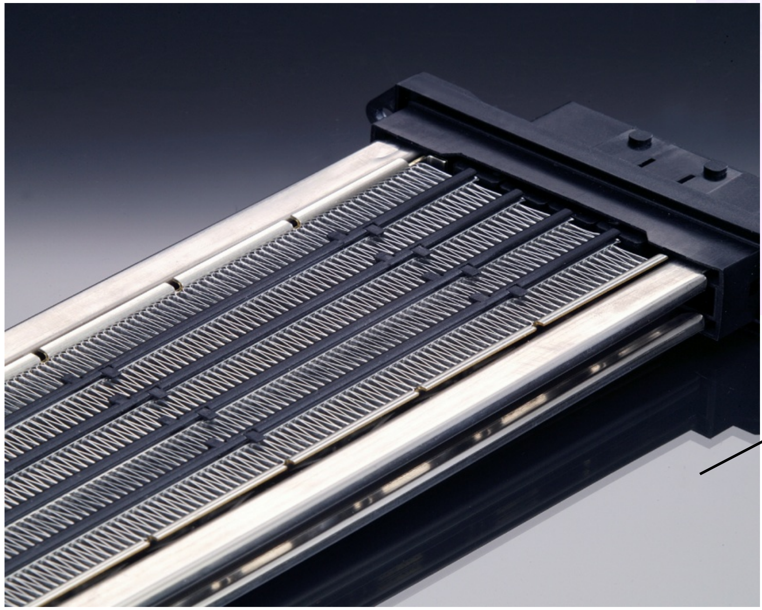


- **PTC-effect is based on the temperature depended potential barrier at the grain boundary → high electrical resistance above T_C**
- **The ferroelectric phase equals the charge of the potential barrier below T_C → low electrical resistance**

$BaTiO_3$-based PTC heating elements

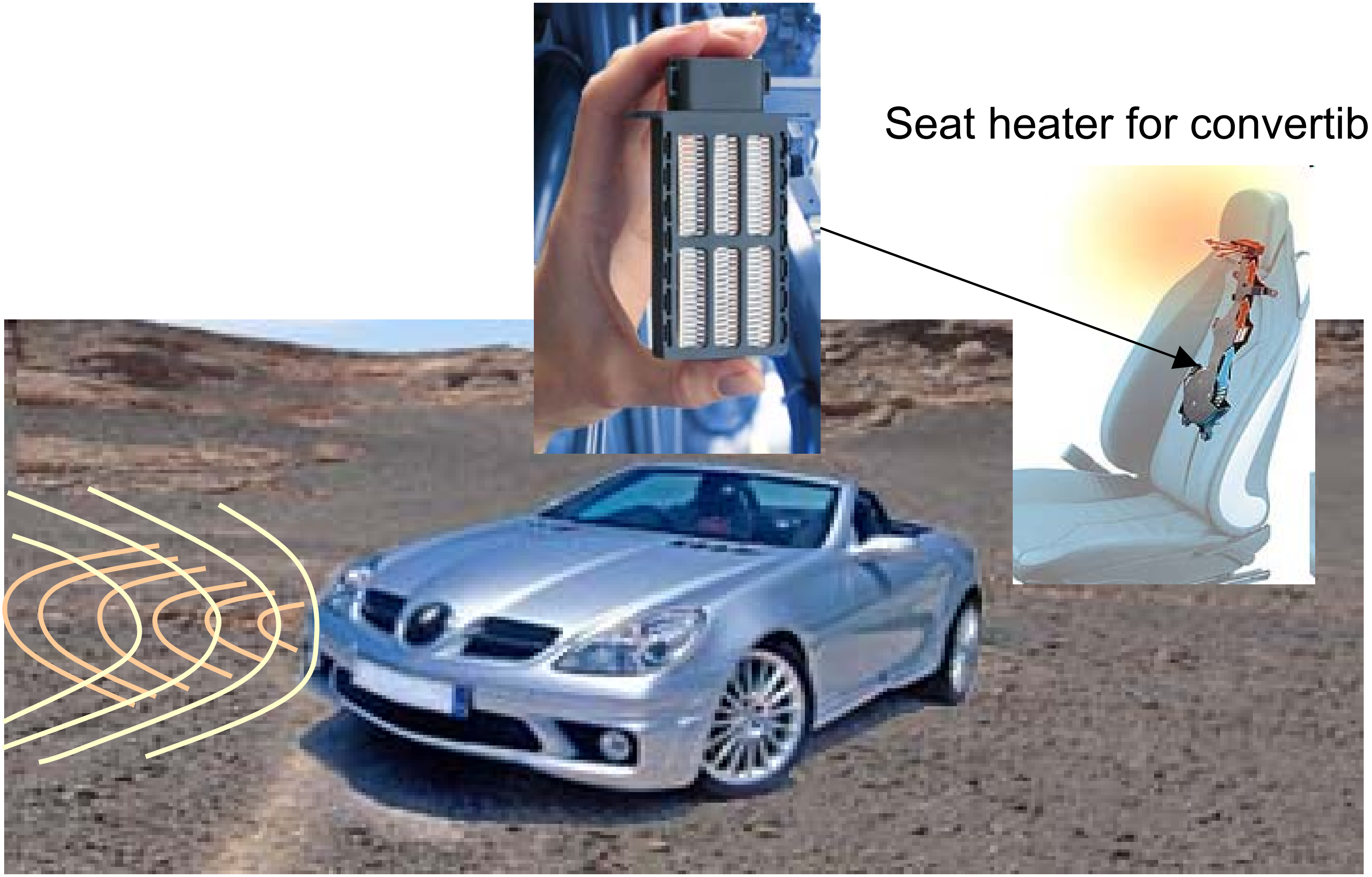


source: eberspächer catem, Germany



Highly efficient cars do not produce enough „waste energy“ for heating

PTC effect in donor-doped $BaTiO_3$-based ceamics



Seat heater for convertibles

OEMs favour different local heating elements to reduce total energy consumption

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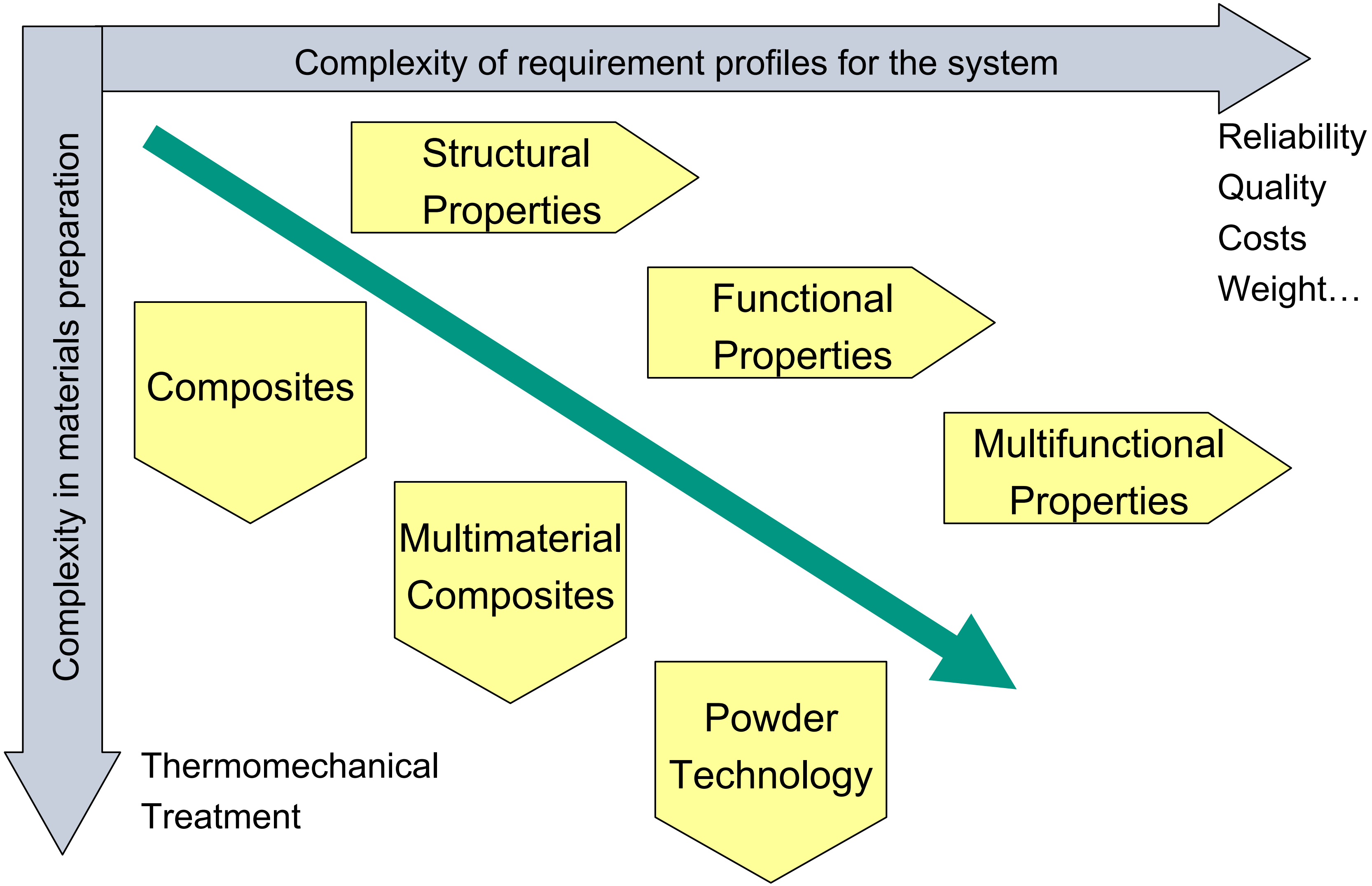
Requirements and Challenges for Materials Research



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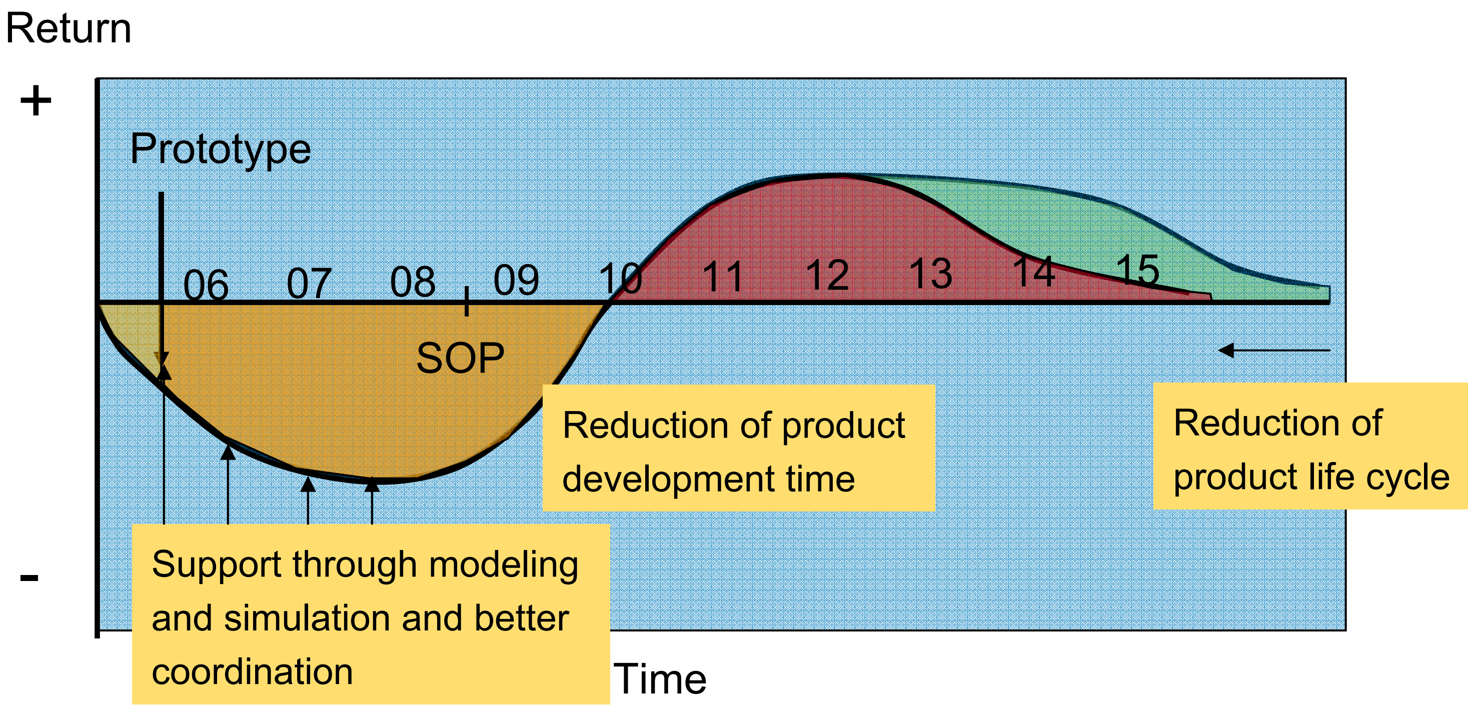
Requirements and Challenges for Product Development

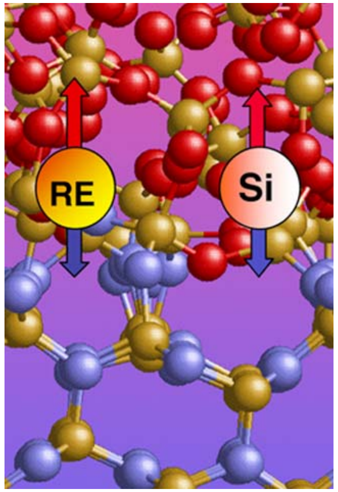


→ Reduction of product development time due to shorter product life cycles

Modeling and simulation across the whole length scale

length scale

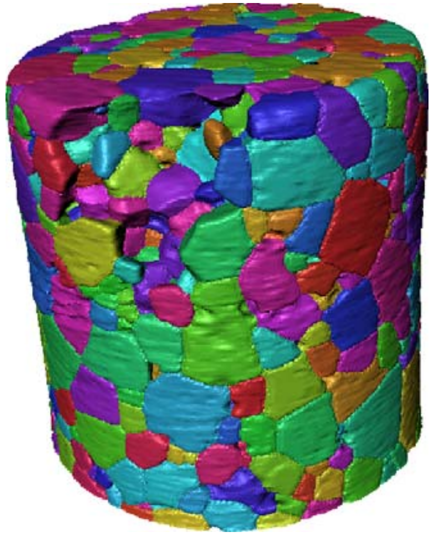
10^{-10} - 10^{-9} m



courtesy: P.F. Becher

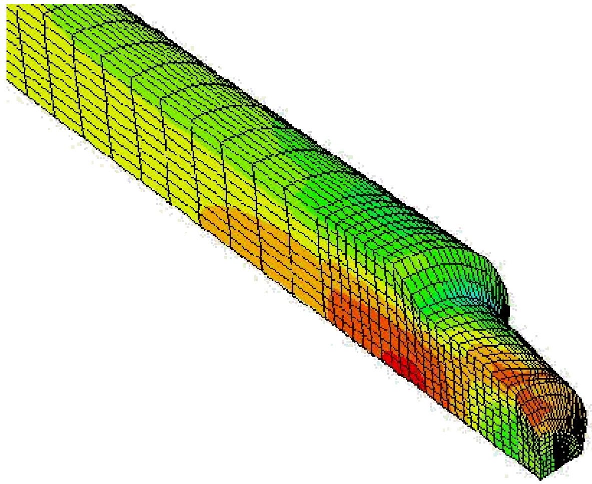
Ab-initio calculations
MD- simulation
→ New materals

10^{-7} - 10^{-5} m



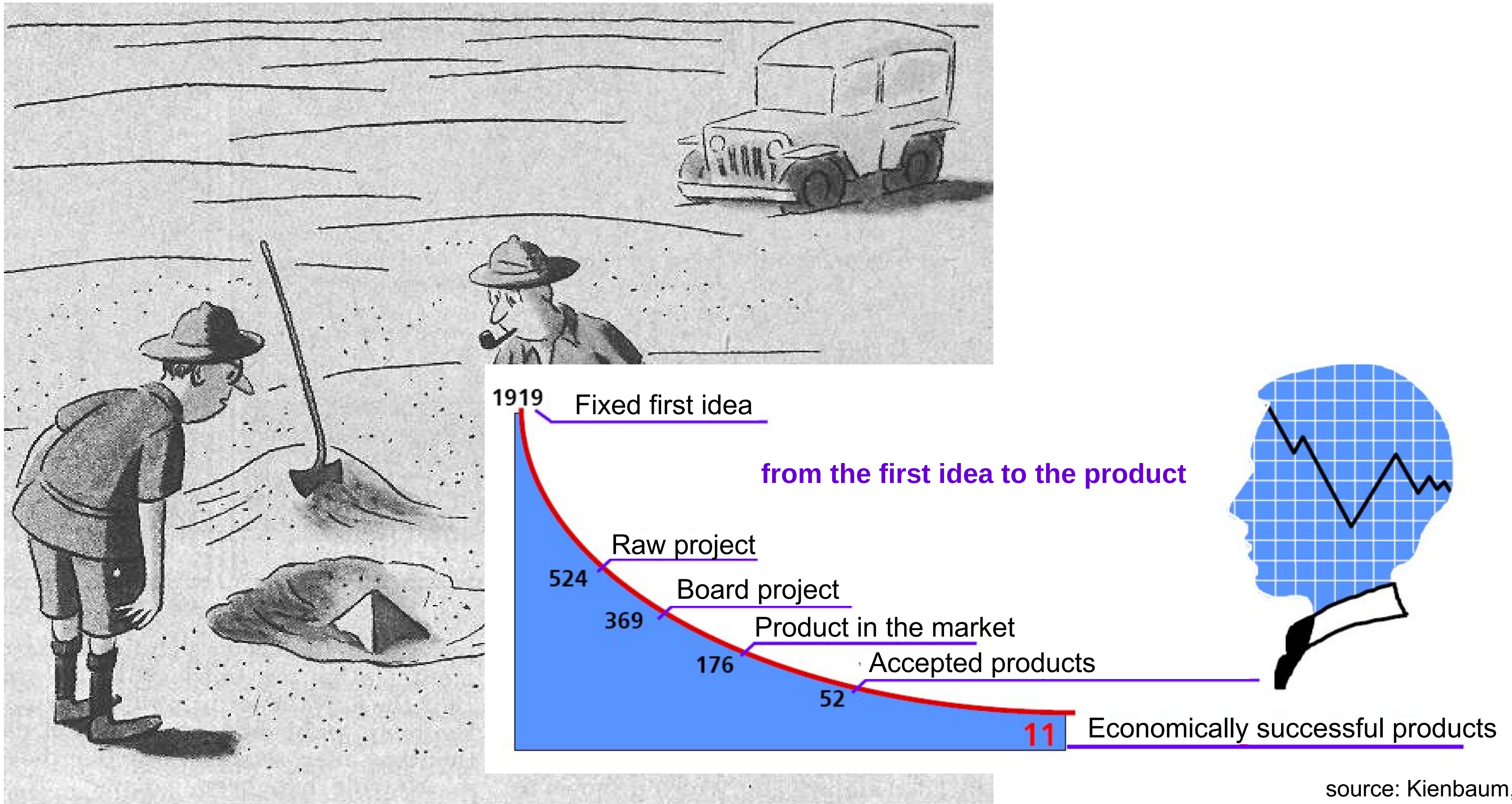
Phase field or vertex dynamic simulation
→ Microstrutural design

10^{-2} - 10^{-1} m



FE-methods for calculation of coupled loading conditions
→ Design optimization

Conclusion



"This could be the discovery of the century. Depending, of course, on how far down it goes."

source: Kienbaum, Bullinger