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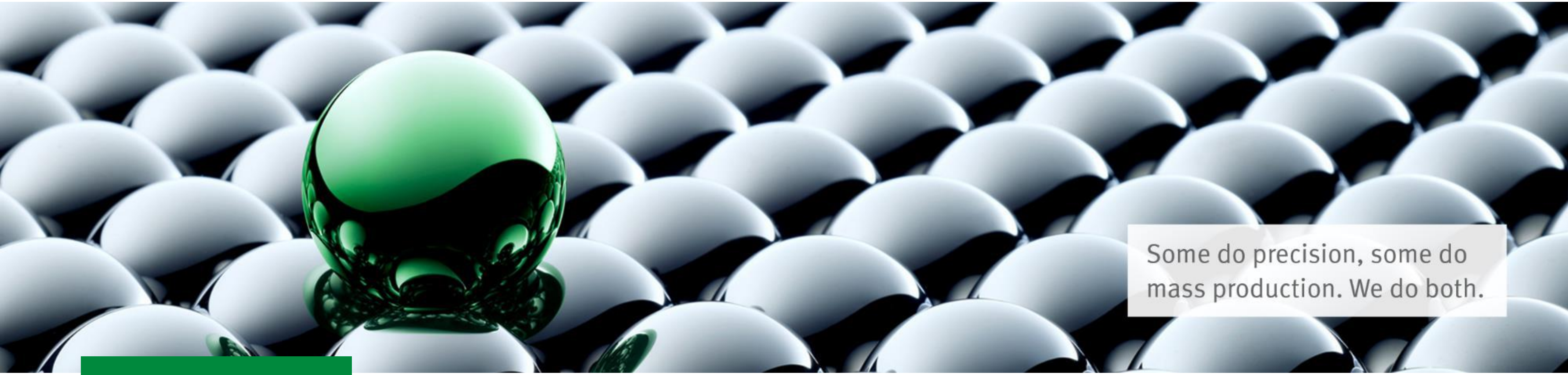

From R&D to series production – Role of characterization in large-scale production for the automotive industry

Dr.-Ing. Nazlim Bagcivan
Charakterisierung in der Dünnschichttechnik, 10. November 2025, Linz

We pioneer motion

AGENDA

1. General remarks
2. Development of Tribological Component Coatings
3. Development of Coatings for Electro-chemical Cells
4. Aspects of Serial Production

1 **General remarks**

2 Development of Tribological Component Coatings

3 Development of Coatings for Electro-chemical Cells

4 Aspects of Serial Production

AGENDA

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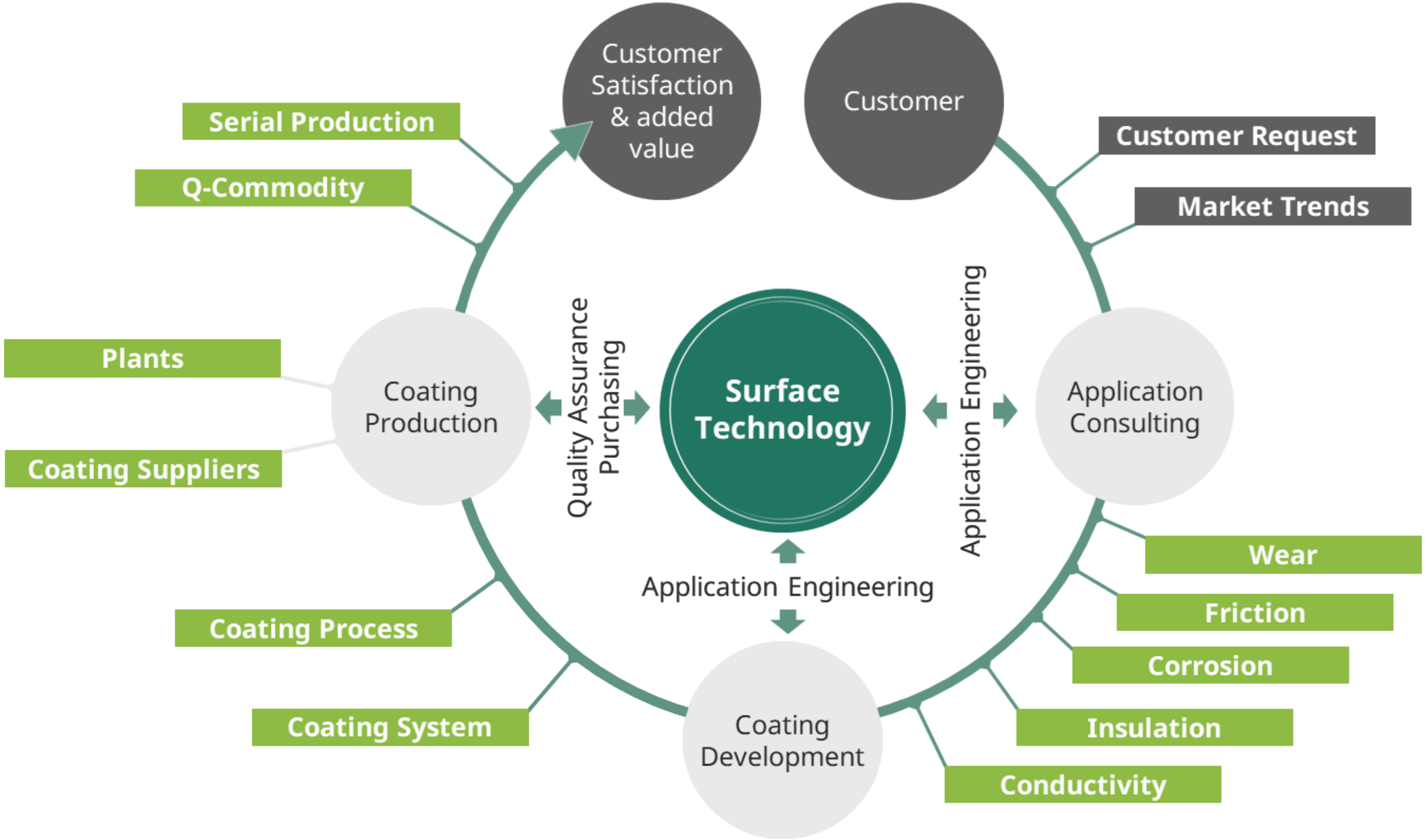

Customer Satisfaction & added value
Customer
Serial Production
Q-Commodity
Customer Request
Market Trends
Plants
Coating Production
Coating Suppliers
Quality Assurance
Purchasing
Surface Technology
Application Engineering
Application Consulting
Wear
Friction
Corrosion
Insulation
Conductivity
Application Engineering
Coating Process
Coating System
Coating Development

1 General remarks

2 **Development of Tribological Component Coatings**

3 Development of Coatings for Electro-chemical Cells

4 Aspects of Serial Production

AGENDA

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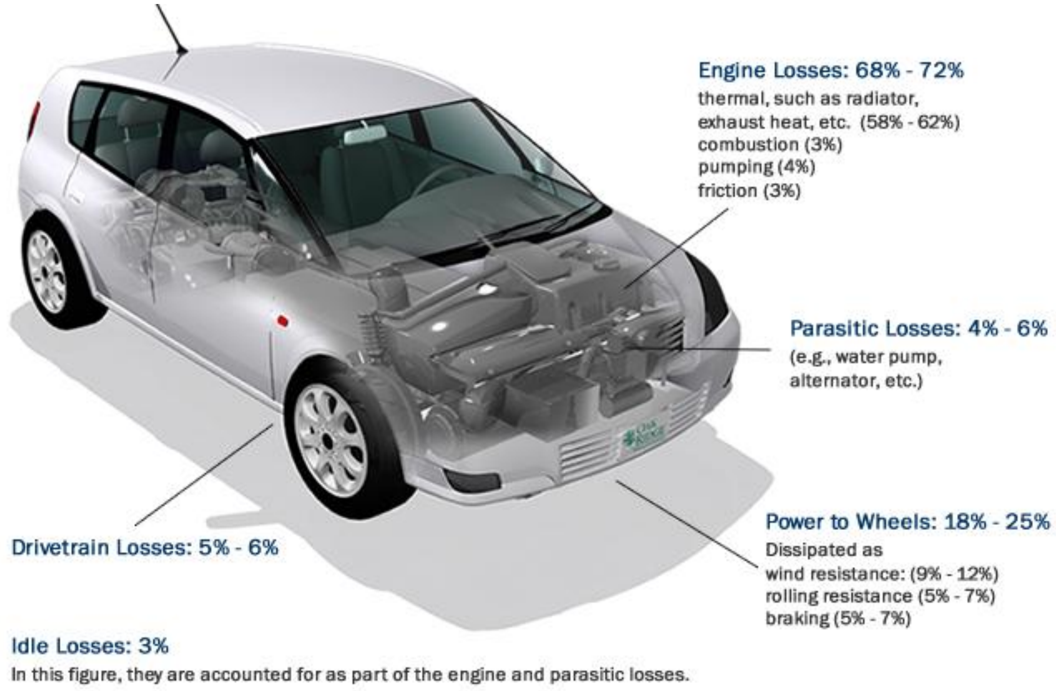
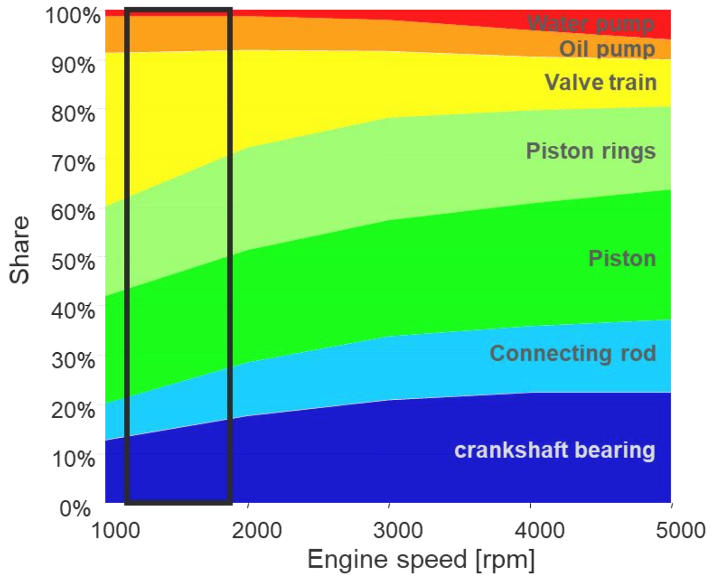
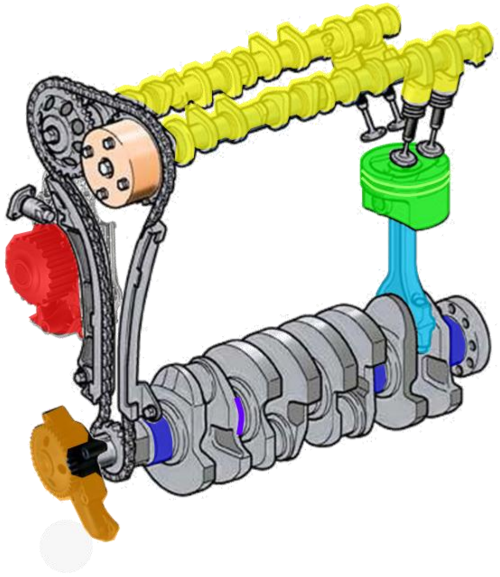
Application example: Valve Train (Tribo-System Cam/Tappet)







Source: http://fueleconomy.gov/feg/atv.shtml

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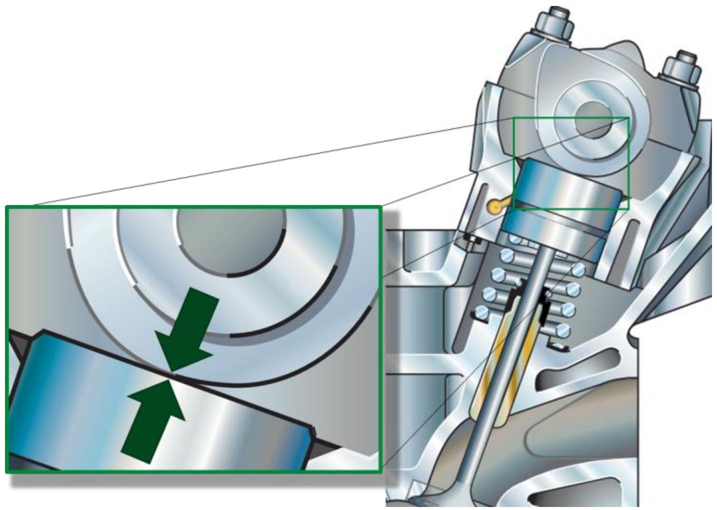
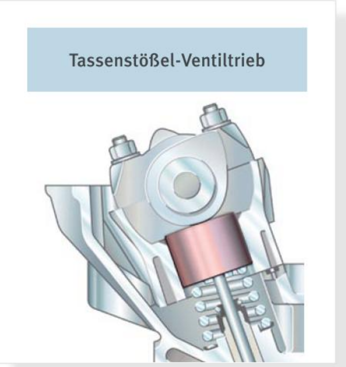
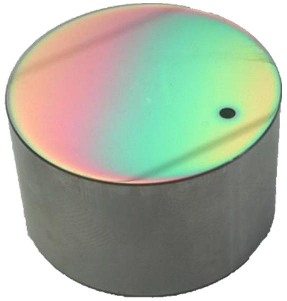
Application example: Valve Train (Tribo-System Cam/Tappet)

Tribo-System Cam/Tappet



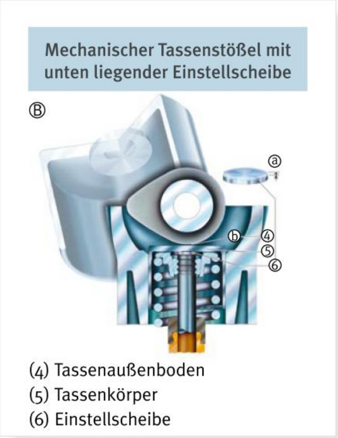




Merkmale

Die Einstellscheibe ist ...

- im Grundkörper lose eingelegt
- in verschiedenen Stärken erhältlich
- in Material und Wärmebehandlung frei wählbar
- durch ihre Stärke verantwortlich für das eingestellte Ventilspiel (a)



Merkmale

- definiertes Grundspiel (b) zwischen Nockengrundkreis und Tassenaußenboden durch die Stärke der Einstellscheibe
- sehr geringe Masse des Tassenstößels, damit werden die Ventilfederkräfte und die Reibleistung reduziert
- großer Kontaktbereich zum Nocken

Merkmale

- Das Ventilspiel wird über die Bodenstärke des Tassenstößels eingestellt (a).
- geringste Masse des Tassenstößels
- Die Ventilfederkräfte (und damit auch die Reibleistung) werden reduziert.
- großer Kontaktbereich zum Nocken
- kann sehr kostengünstig hergestellt werden

Tribo-System = f (Surface (Material + Coating + Topography), lubricant (base oil + additives, …), loads, contact geometry, environment, …)

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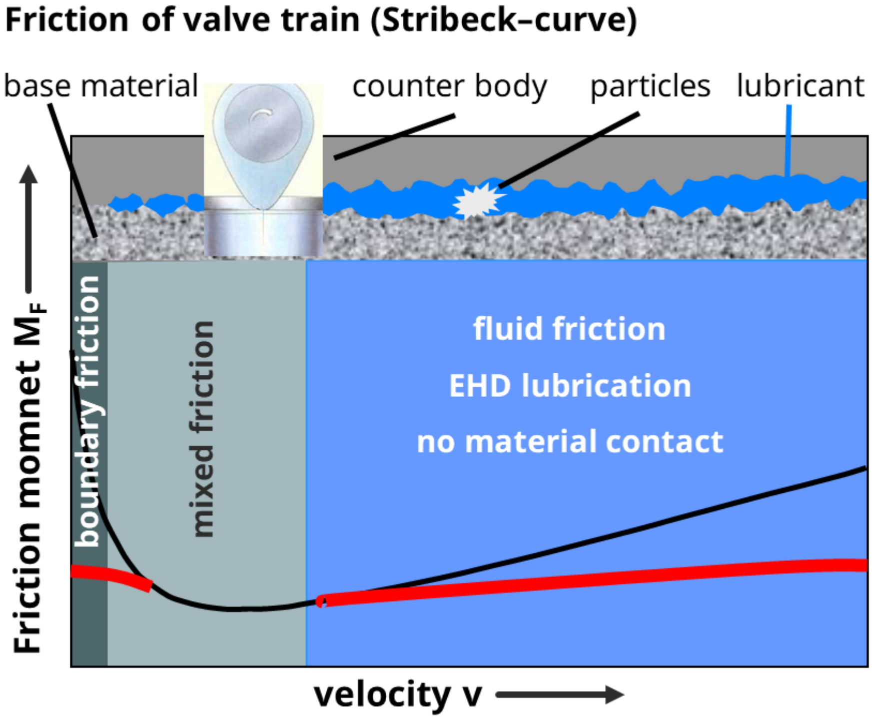
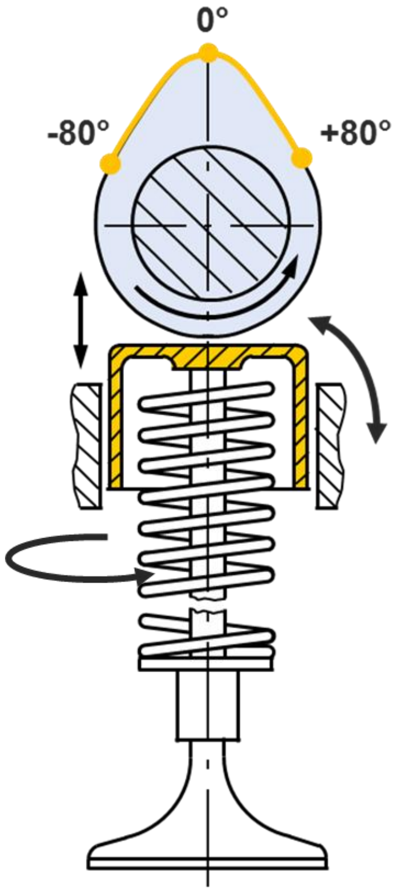
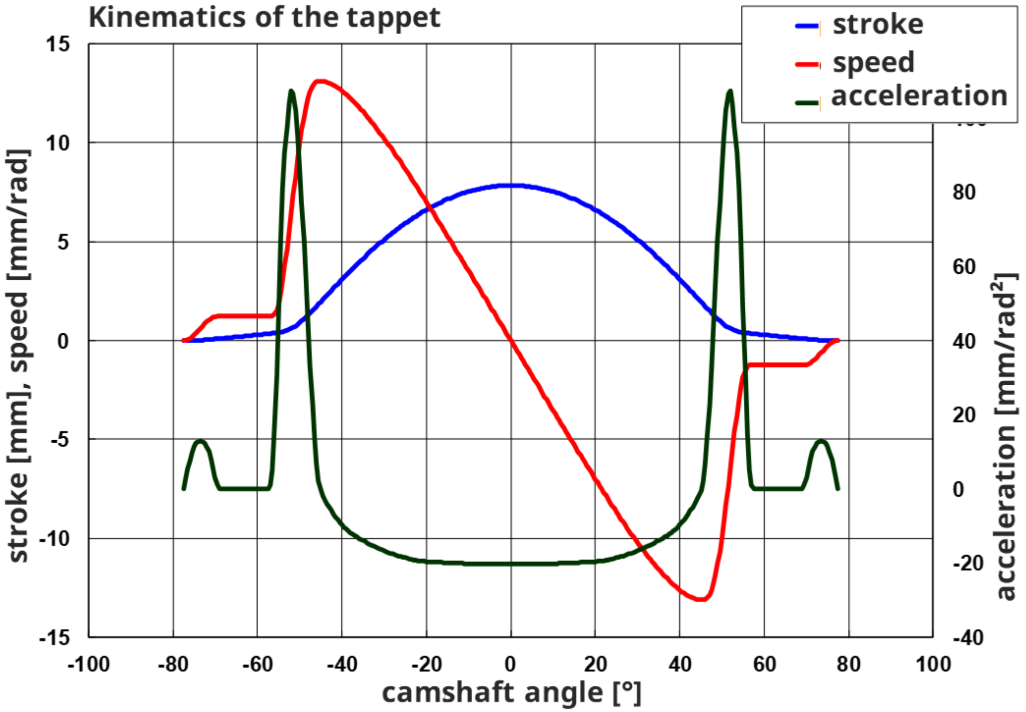
Application example: Valve Train (Tribo-System Cam/Tappet)







- High loads on components
- Complex kinematics
- High rotational speed of the tappet (70 Hz in a car, 140 Hz in a motorcycle)

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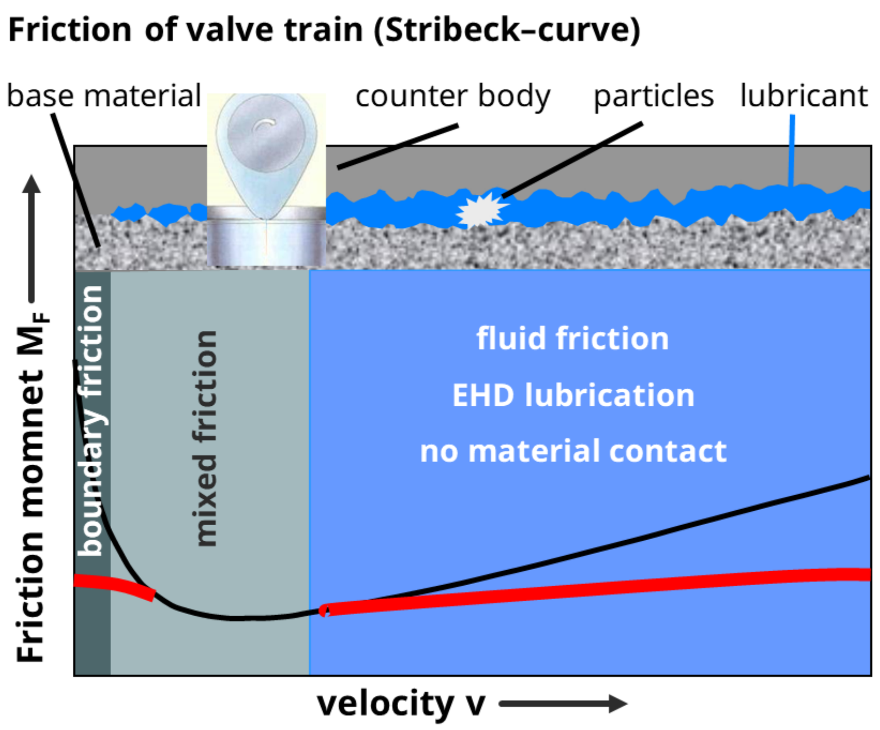
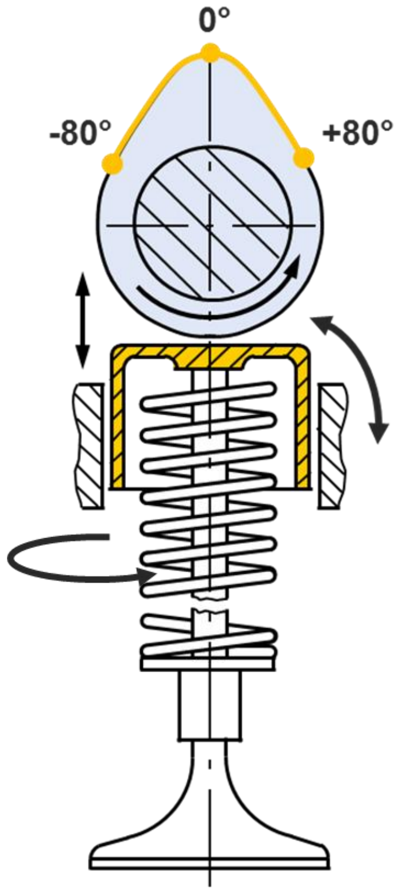
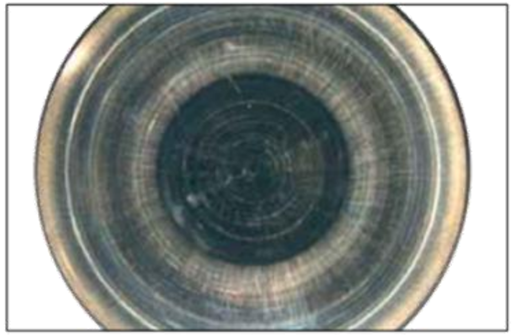
Application example: Valve Train (Tribo-System Cam/Tappet)







Regular wear

- Normal surface profile
- Circular markings are caused by tappet rotation

Heavy wear

- Heavily worn tappet surface
- Such surface profile is indication for heavy abrasion

- High loads on components
- Complex kinematics
- High rotational speed of the tappet (70 Hz in a car, 140 Hz in a motorcycle)

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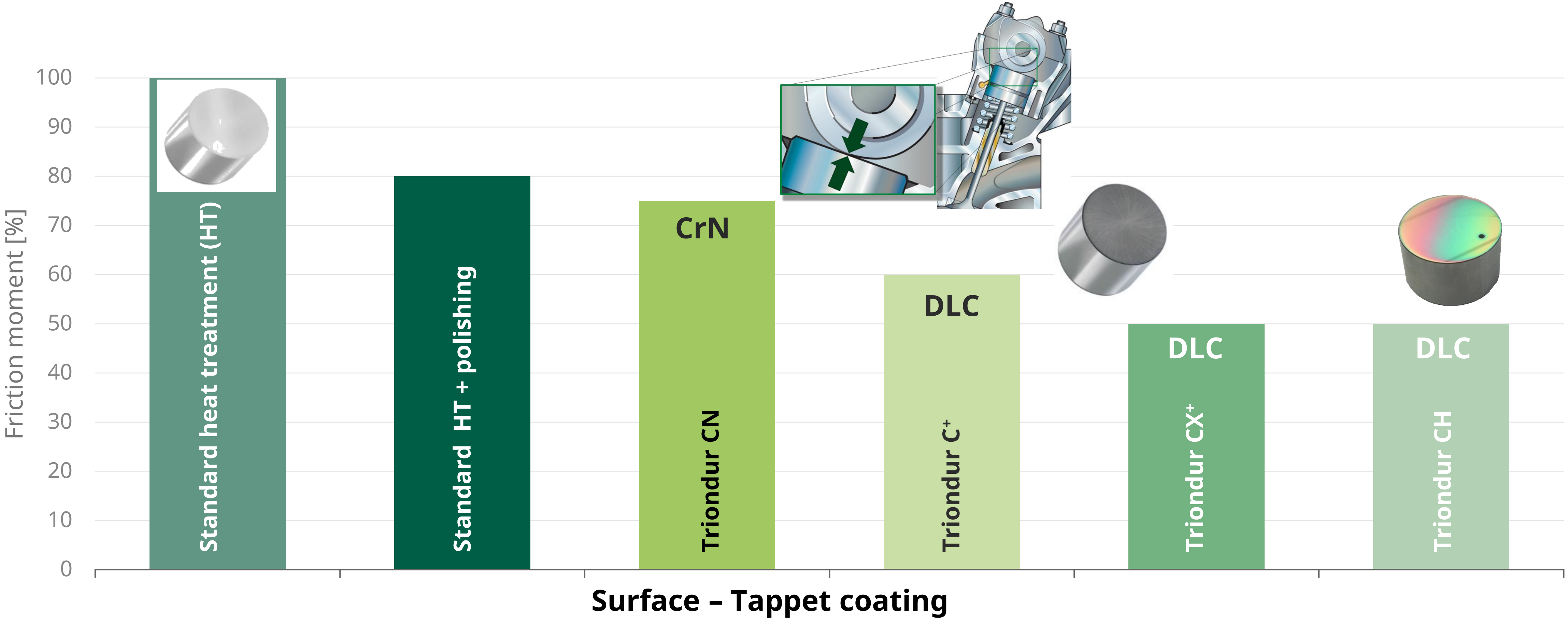
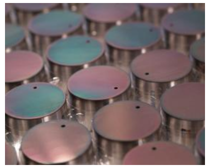
Application example: Valve Train (Tribo-System Cam/Tappet)





- Friction reduction in valve train (2000 rpm, 80° C). Optimized tribological system: surface, coating, lubricant
- Halving friction with Triondur DLC-coating in the valve train.
- In-house development and coating of more than 100 million components in 2024.

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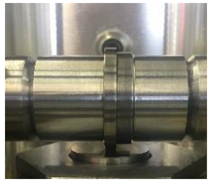
Systematic testing categories – essential for best cost/benefit in R&D and time to market

Laboratory

Roughness
Contact angle
Thickness
…

Adhesion

Hardness

Categories of tribological characterization according to DIN 50322					
Model test	Sample test	Component test	Aggregate test	Test stand	Operating test
					

Increase in time, efforts, and cost

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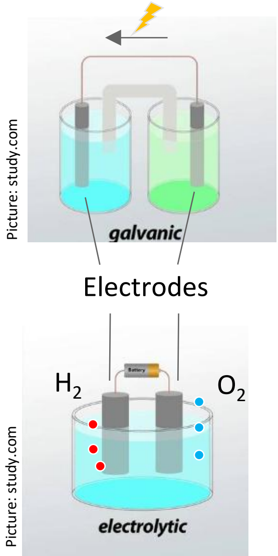
Fuel Cells & Electrolyzers Common Technology: Plates, Cells, Stacks

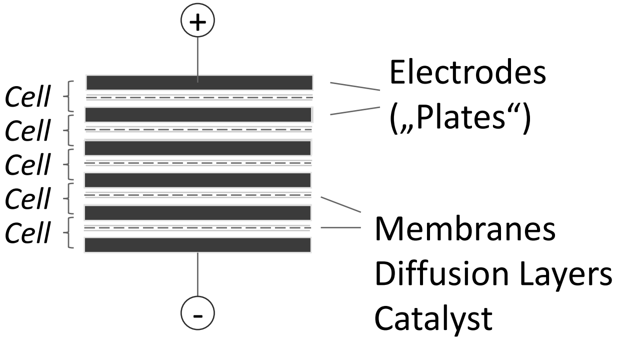
Cell Principle



Fuel Cells

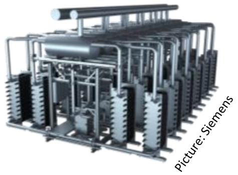
Water Electrolyzers

Scale-up: The *Stack* principle



*Cell „Sandwich“ = **Stack***

Typical Fuel Cell
- 10 - 150 kW Stack Power
- < 400 cm² Plates



Industrial Electrolyzer
- 500 - 2,000 kW Stack Power
- 1,500 - 5,000 cm² Plates

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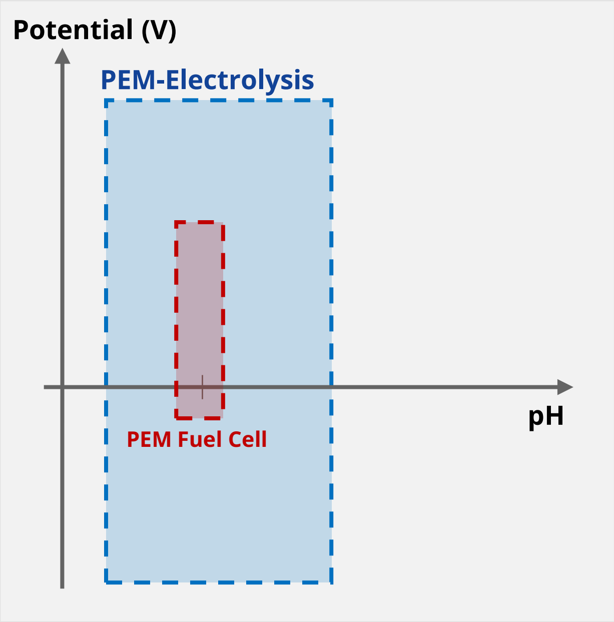
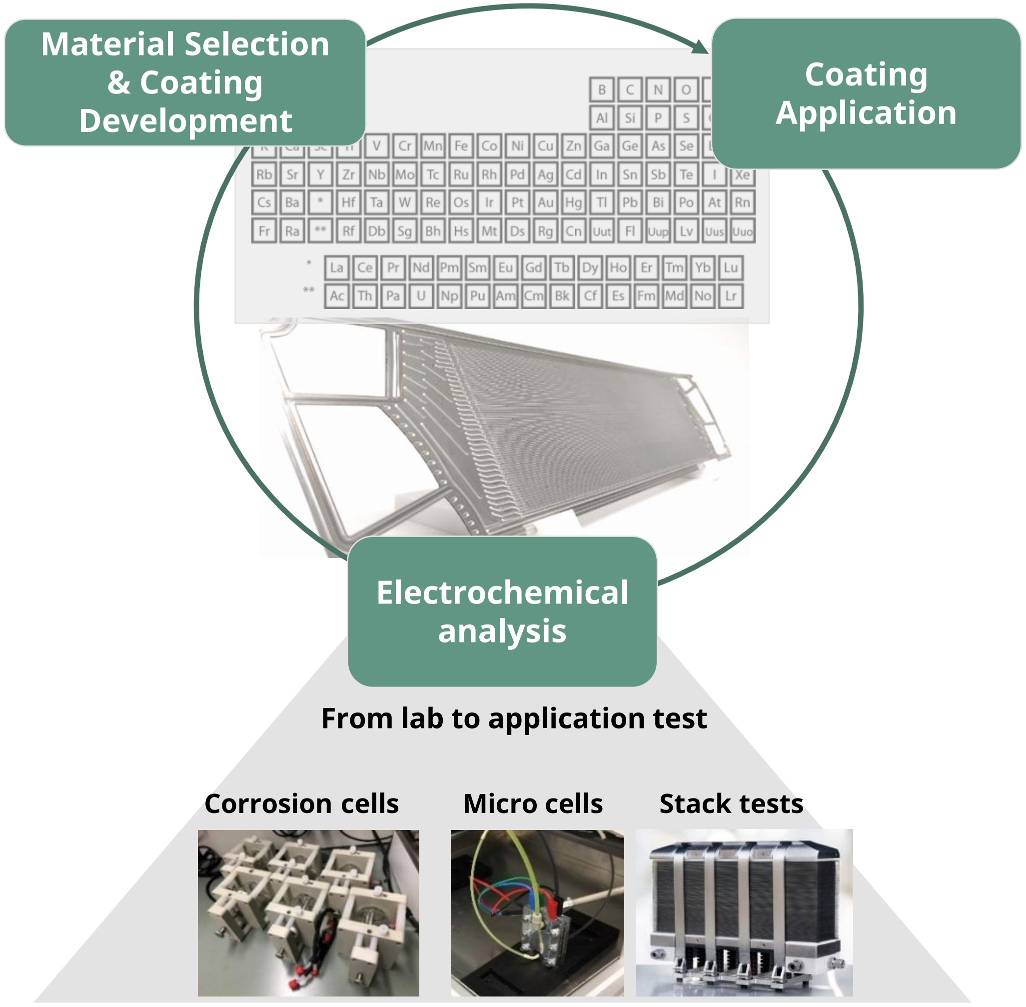
Integrated development approach enables tailored coatings

Requirements from pH regime and potential conditions

- Corrosion protection Fuel Cell/Electrolysis
- Electric Conductivity Fuel Cell/Electrolysis
- Mechanical stability Stack assembly





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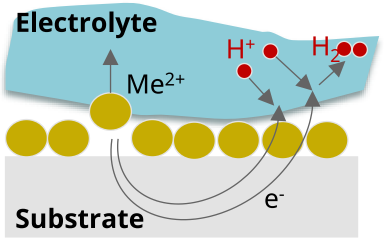
Integrated development approach enables tailored coatings

Determination factors of interfaces for corrosion phenomena of metallic surfaces

Types of corrosion

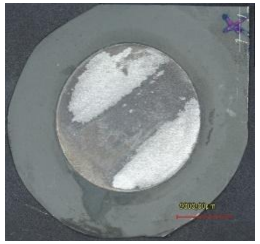
Appearance



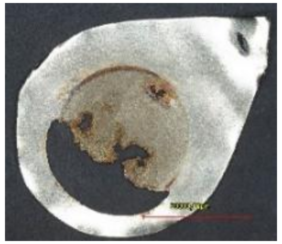
Uniform corrosion

Anodic/cathodic reaction

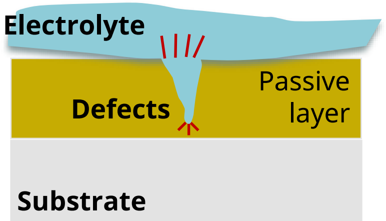
External drivers: Electrolyte (pH) and potential[1)]



Coating corrosion



Coating + substrate corrosion

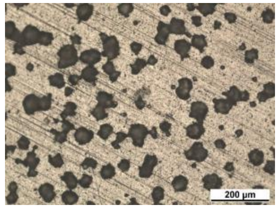


Localized corrosion

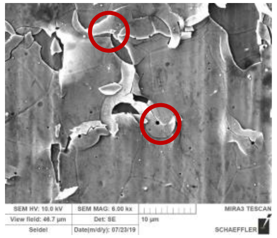
Pitting/crevice corrosion

Stress corrosion cracking

External drivers: Local change of electrolyte (pH) and potential



Pittings

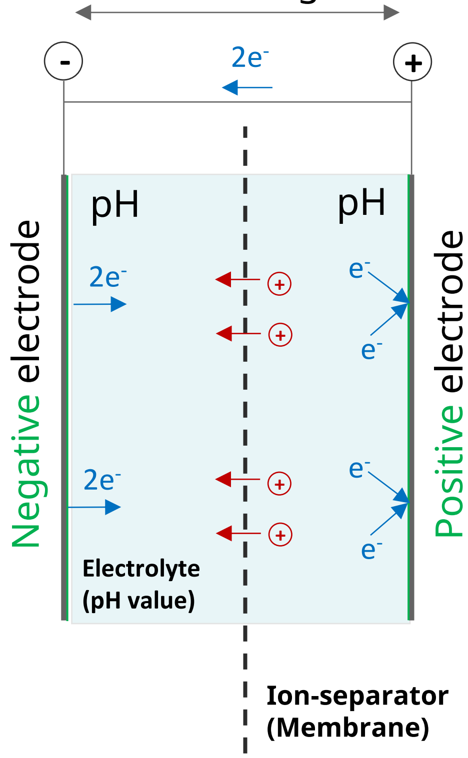


Surface delamination

Stable and functional interfaces require tailored materials and surface morphology.

[1)] Requirements from application

Schematic electrochemical cell



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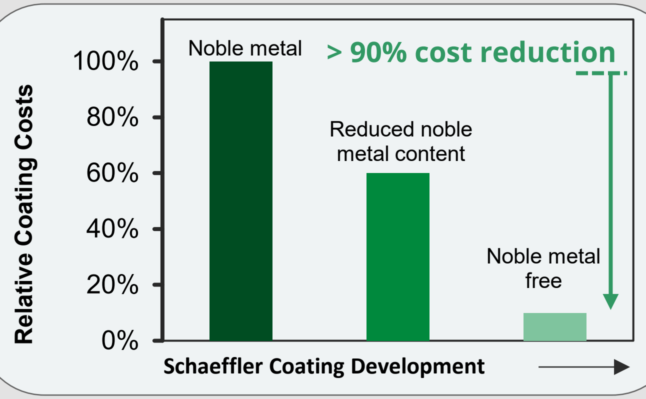
Integrated development approach enables tailored coatings

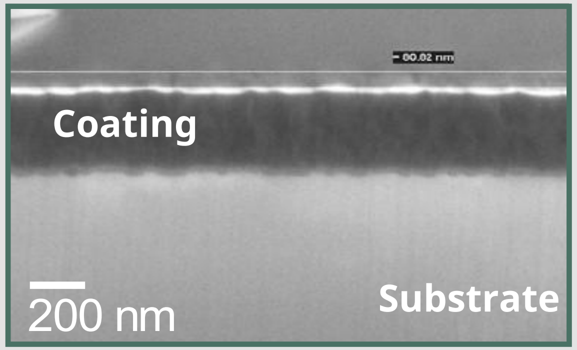
Requirements from pH regime and potential conditions

Corrosion protection Fuel Cell/Electrolysis
Electric Conductivity Fuel Cell/Electrolysis
Mechanical stability Stack assembly

Material Selection & Coating Development

Coating Application



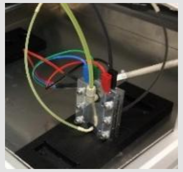


Electrochemical analysis

From lab to application test

Corrosion cells

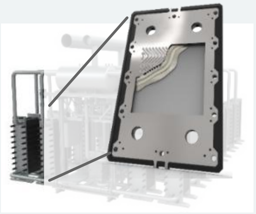
Micro cells



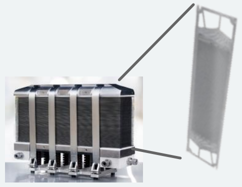
Stack tests

Transfer to product

Electrolysis (PEMEL)



Fuel Cell (PEMFC)



Enertect coatings → Enabler for H2 as energy carrier

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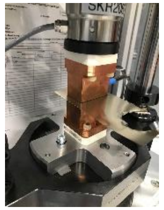
Systematic testing categories – essential for best cost/benefit in R&D and time to market

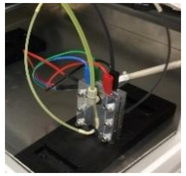
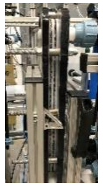
Laboratory



El. Resistance

Roughness
Contact angle
Thickness
...

Indention

Categories for electrochemical testing (not standardized)				
Model test	Sample test	Component / aggregate test	Test stand	Operating test
		 		

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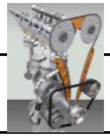
Systematic testing categories – essential for best cost/benefit in R&D and time to market

Laboratory

Adhesion

Roughness
Contact angle
Thickness
…

Hardness



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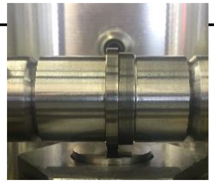
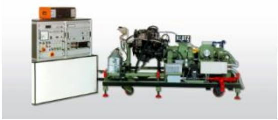
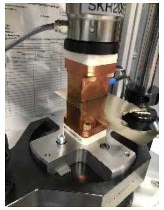
					

Increase in time, efforts, and cost →

Laboratory



El. Resistance

Roughness
Contact angle
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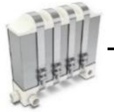

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	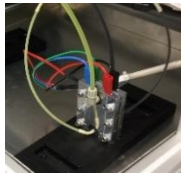	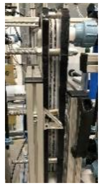 		

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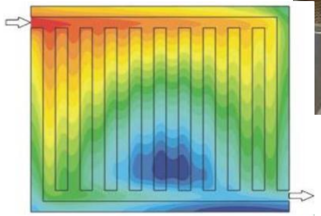
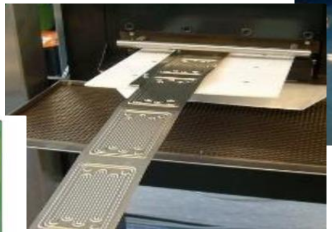
Industrialization Platform for Mass Production

Process development plate production

Simulation & Design



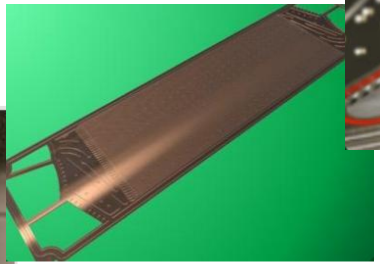
Forming



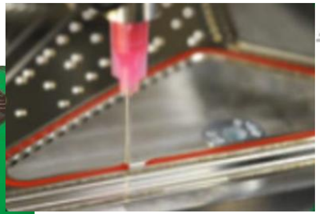
Welding

Cleaning

Coating



Sealing



Mass production Schaeffler Bipolar Plate Module

1. **What is the methodical frame for transfer from R&D to mass production?**
2. **What do we need to measure to assure quality in robust production processes?**

Advanced Product Quality Planning

1 General remarks

2 Development of Tribological Component Coatings

3 Development of Coatings for Electro-chemical Cells

4 **Aspects of Serial Production**

AGENDA

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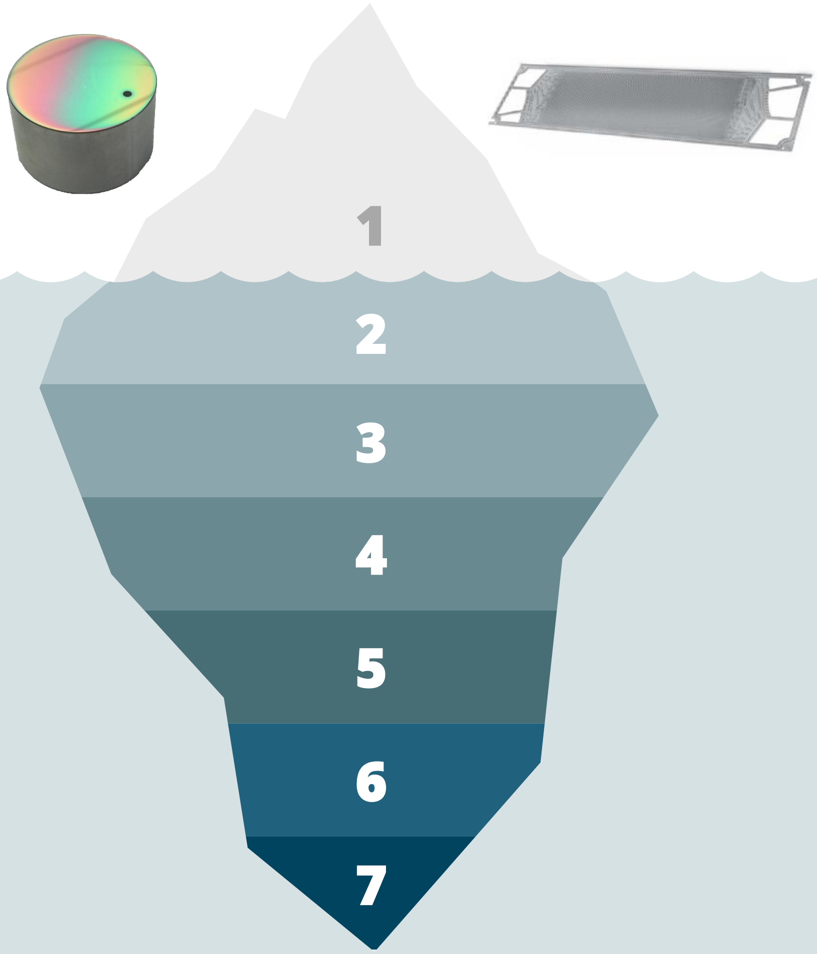
PPAP -
Production Part Approval Process



PPAP is a structured process that defines the requirements for approving production parts and production processes before, during, and after manufacturing.

PPAP covers all production parts, bulk materials, and processes that affect the final product quality in the automotive and manufacturing supply chain.

1. **Coated products** – Provide coated products with added value.
2. **Confidence** – Build customer-supplier confidence.
3. **Requirements** – Demonstrate understanding of requirements.
4. **Validation** – Validate the manufacturing process.
5. **Quality** – Provide objective evidence of quality.
6. **Defects & Risks** – Prevent defects and risks early.
7. **Product Quality** – Ensure consistent product quality.

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PPAP - Production Part Approval Process

PPAP necessary when:

- New part introduction
- Engineering design or specification change
- Change in manufacturing process, material, tooling, or location
- After using new or replacement tooling
- Supplier change
- Restart after long inactivity

1
Design Record: Drawing or CAD data approved by customer

2
Authorized Engineering Change Documents: Any customer-approved design changes not yet included in drawings

3
Engineering Approval: Customer-specific approval (if required, e.g., prototype or test trials)

4
Design FMEA (DFMEA): Analysis of potential failures in product design

5
Process Flow Diagram: Visual map of manufacturing steps

6
Process FMEA (PFMEA): Analysis of potential failures in the manufacturing process

7
Control Plan: Document outlining process controls to maintain quality

8
Measurement System Analysis (MSA) Studies: Gage R&R, bias, linearity, stability studies

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PPAP - Production Part Approval Process

9
Dimensional Results: Measured values of part features compared to design specs.

10
Records of Material / Performance Test Results: Lab test reports (material, mechanical, functional)

11
Initial Process Studies (SPC Studies): Statistical process control & capability studies (Cp, Cpk).

12
Qualified Laboratory Documentation: Accreditation proof of labs used for testing. Documentation

13
Appearance Approval Report: For parts affecting appearance (color, finish, texture).

14
Sample Production Parts: Physical samples submitted to customer

15
Master Sample: Retained at supplier/customer for future reference.

16
Checking Aids: Tools, fixtures, gages used to measure /inspect parts.

17
Customer-Specific Requirements: Any extra documents as defined by customer

18
Part Submission Warrant (PSW): Formal summary document confirming all requirements are met.

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Statistical process control & capability - Machine & Process Capability

Machine capability

Machine capability is a quality metric that evaluates a machine's ability to consistently produce parts within a specified tolerance.

- C_m (capability machine):

  Assesment of production variance

- C_{mk} (capability machine Katayori (offset)):

  Assesment of production variance and centering

Where:

USL = Upper Specification Limit
LSL = Lower Specification Limit
μ = Process Mean
σ = Process Standard Deviation

$$C_m = \frac{USL - LSL}{6\,\sigma} \qquad C_{mk} = min.\left\{\frac{USL - \mu}{3\,\sigma} \middle| \frac{\mu - LSL}{3\,\sigma}\right\} > 1{,}67$$

Process capability

Process capability is a statistical measure of how well a process can consistently meet defined specifications, comparing the process's natural variation to its acceptable limits.

- C_p (capability process):

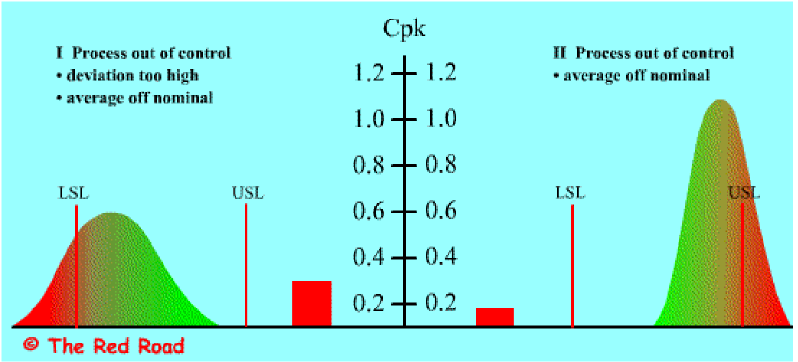
  Assesment of process variance

$$C_p = \frac{USL - LSL}{6\,\sigma}$$

- C_{pk} (capability process Katayori (offset)):

  Assesment of process scatter and centering

$$C_{pk} = min.\left\{\frac{USL - \mu}{3\,\sigma} \middle| \frac{\mu - LSL}{3\,\sigma}\right\} > 1{,}33$$

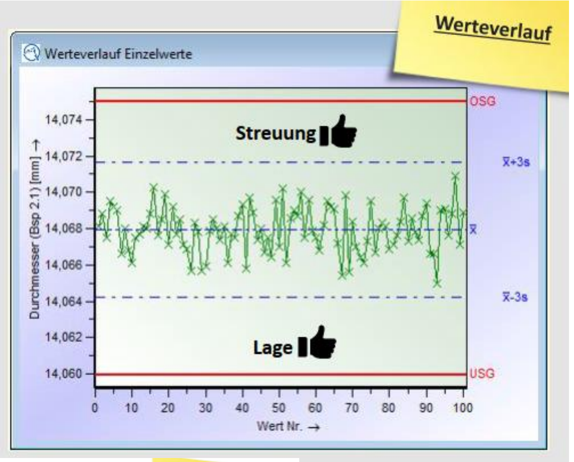


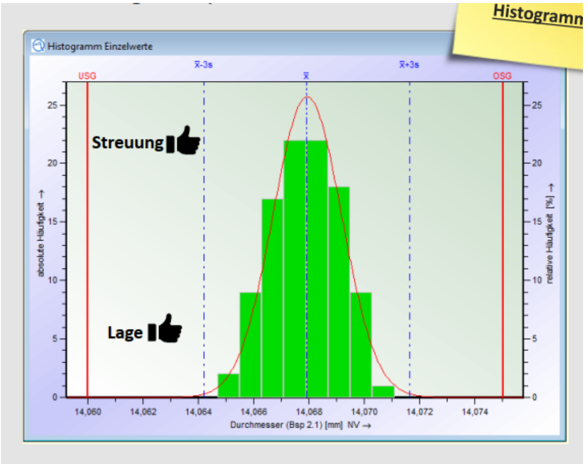
SCHAEFFLER

Statistical process control & capability - Machine & Process Capability

Task: Measurement of Diameter

- Nominal dimension: 14,07 mm
- Upper Specification Limit: 14,075 mm
- Lower Specification Limit: 14,060 mm
- Number of measurements: 100





Result:

- C_m = 2,01
- C_{mk} = 1,90

➔ machine is capable

Potential improvements:

Reduce scatter

Result:

- $C_m \geq 1,67$ ✓
- $C_{mk} \geq 1,67$ ✓

SCHAEFFLER

Statistical process control & capability - Machine & Process Capability

Before Start of Production (SOP)

SHORT-TERM CAPABILITY
MACHINE CAPABILITY

Machine
Production Facility

C_m, C_{mk}

PRELIMINARY
PROCESS CAPABILITY

P_p, P_{pk}

After Start of Production (SOP)

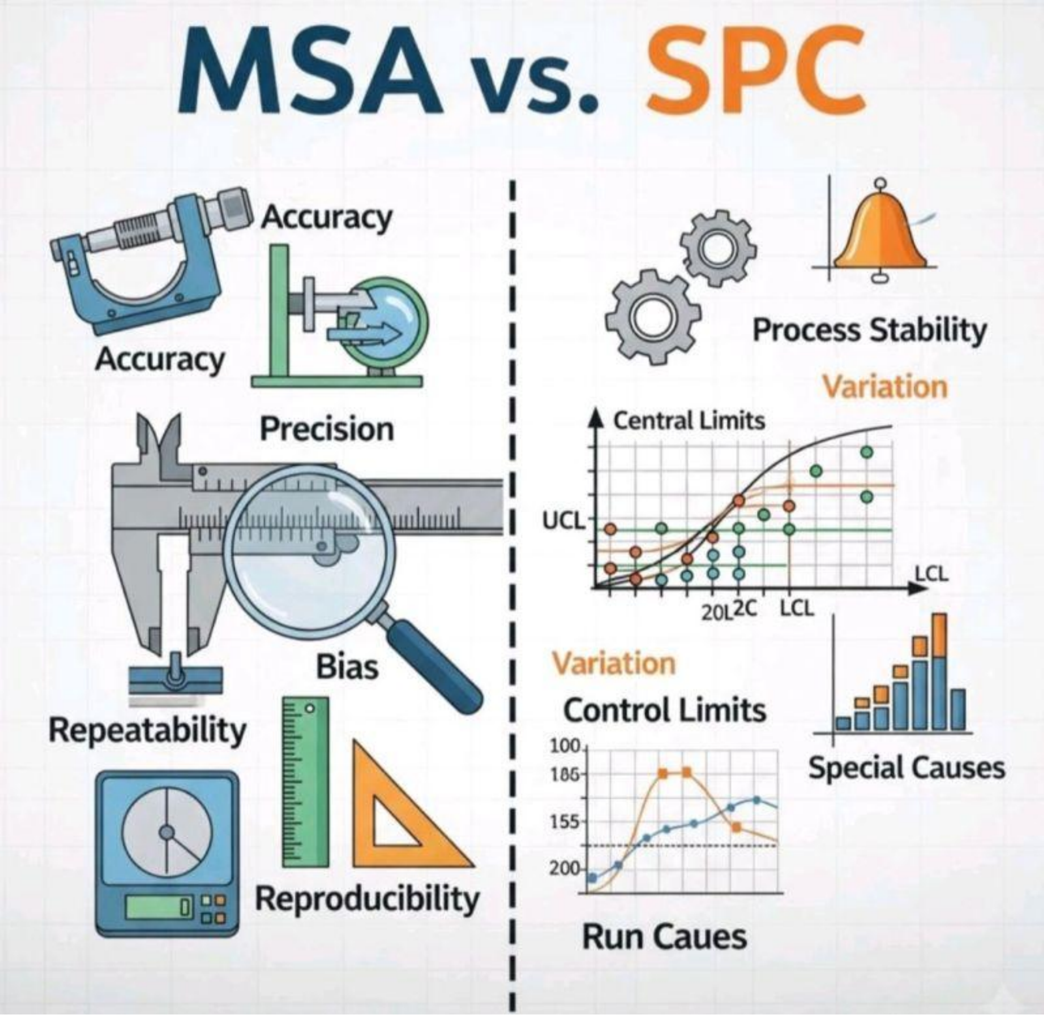
LONG-TERM CAPABILITY
PROCESS CAPABILITY

C_p, C_{pk}

Human, Machine, Material, Environment, Method, Measurement Process

Manufacturing Process

Measurement System Analysis vs. Statistical Process Control (& capability)



Source: Six Sigma Manufacturing