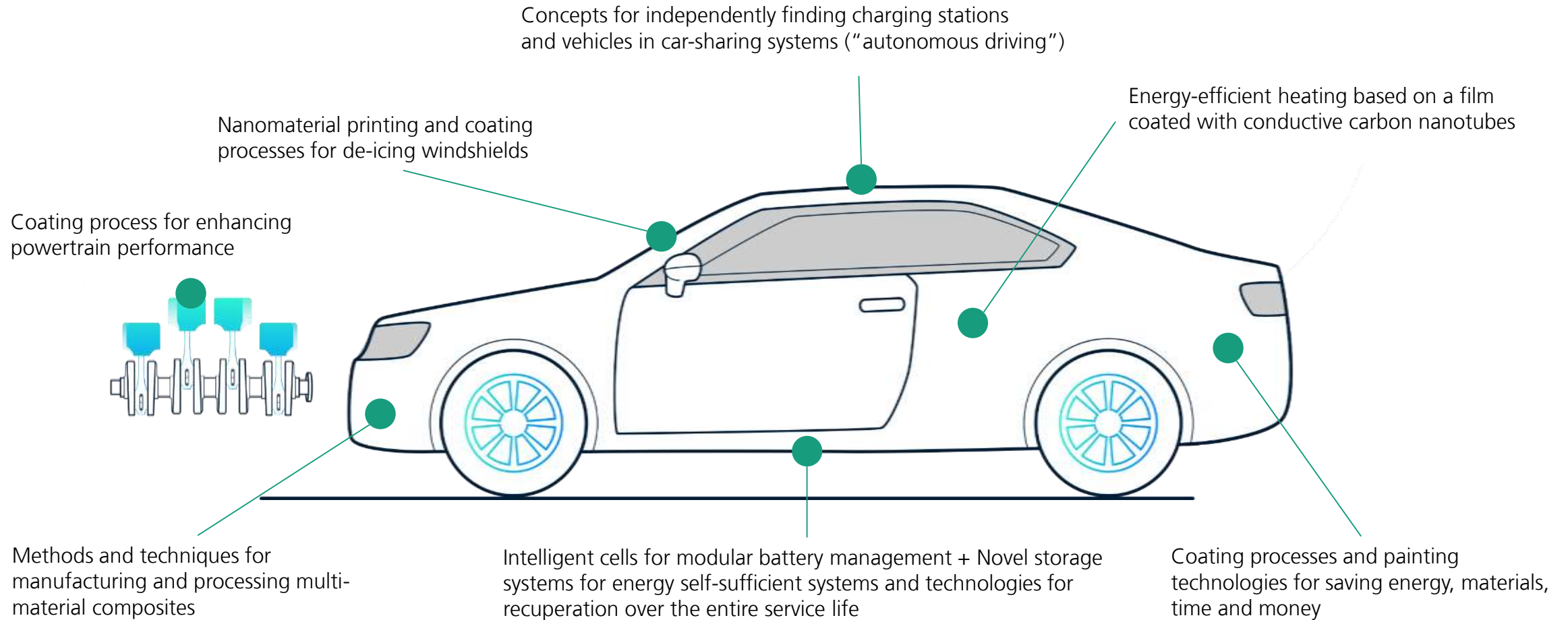




# Smart steel: Novell CNT graphene primer for active corrosion protection and predictive maintenance

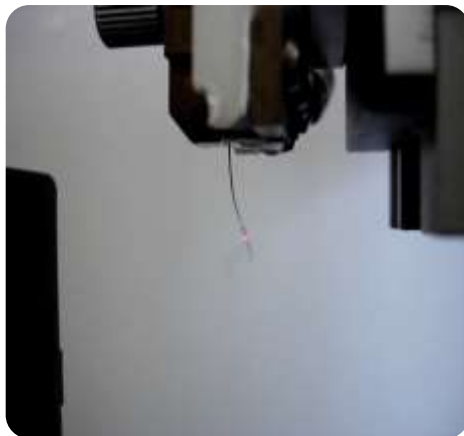
# Fraunhofer IPA

## Value creation based on project examples



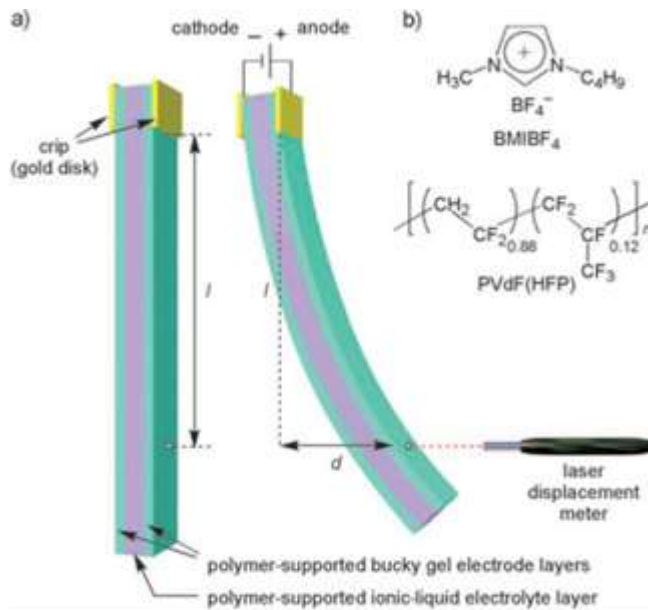
# Smart steel: CNT Graphene Primer

Abteilung Funktionale Materialien: EAP (CNT) Soft Actuators

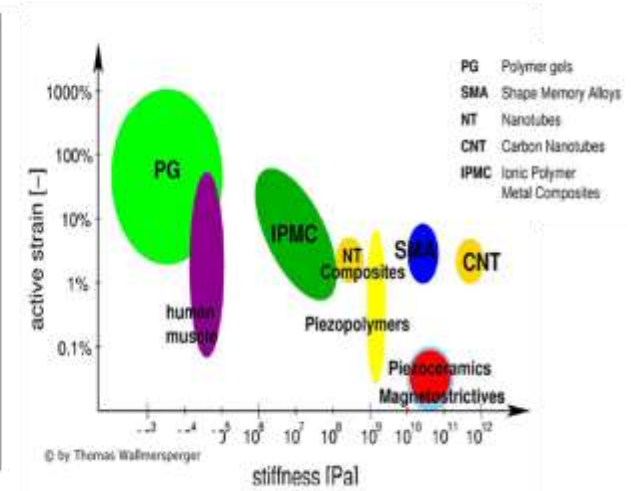
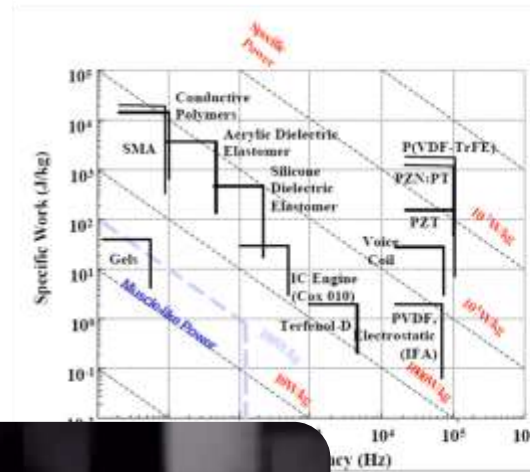
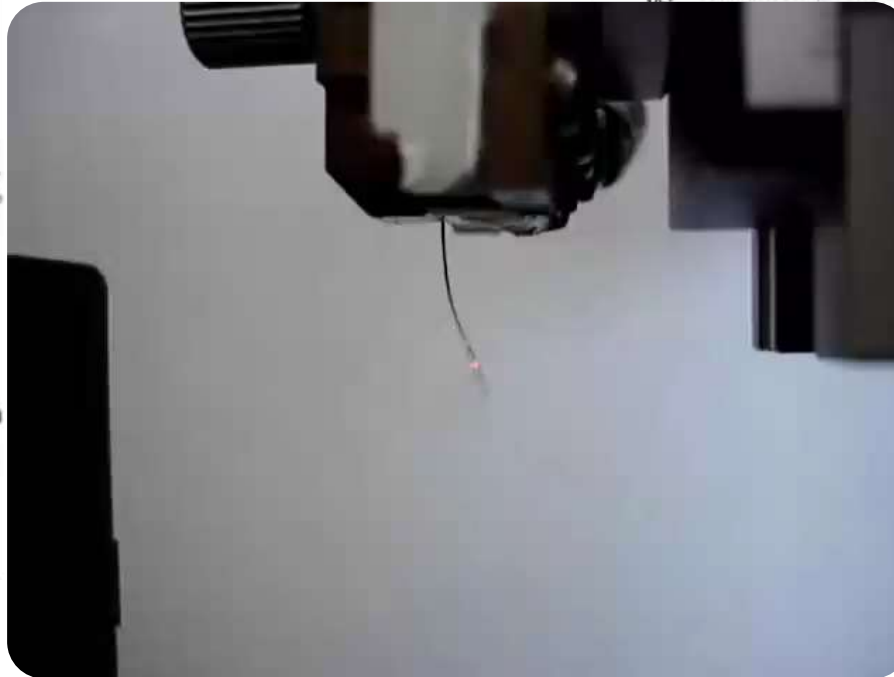


# Smart steel: CNT Graphene Primer

Abteilung Funktionale Materialien: Projektbeispiele



Source: Angew. Chem. Int. Ed. 2005, 44, 2410–2413



# Smart steel: CNT Graphene Primer

Abteilung Funktionale Materialien: Projektbeispiele

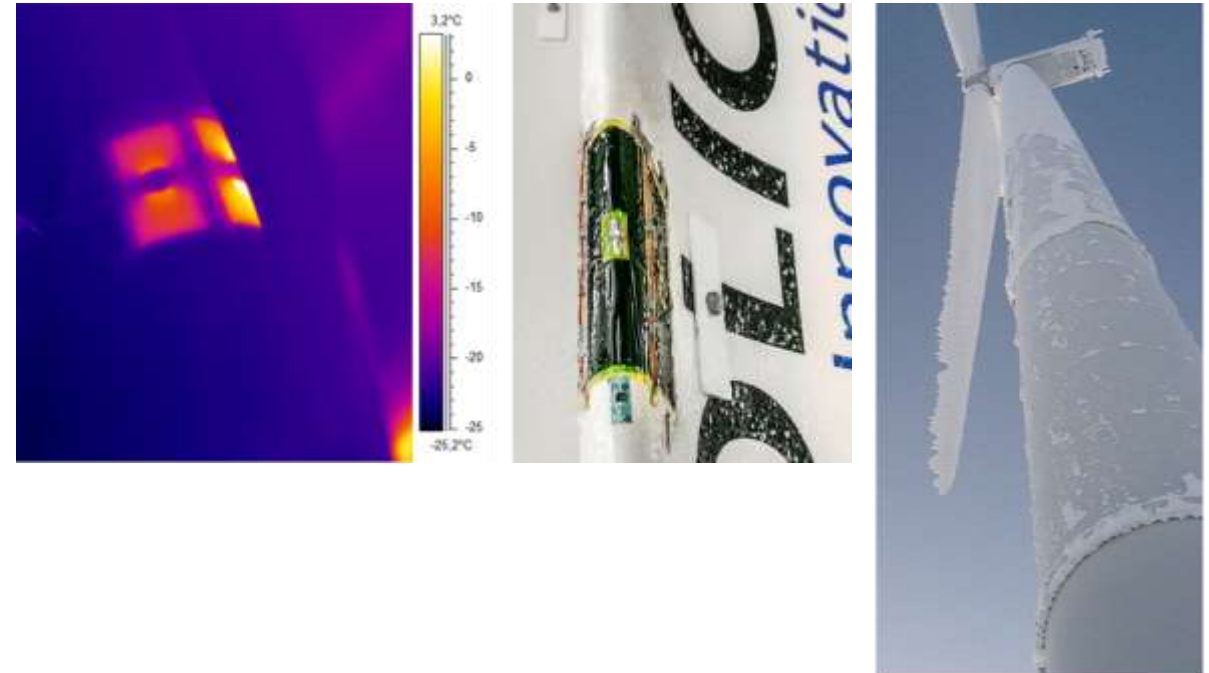
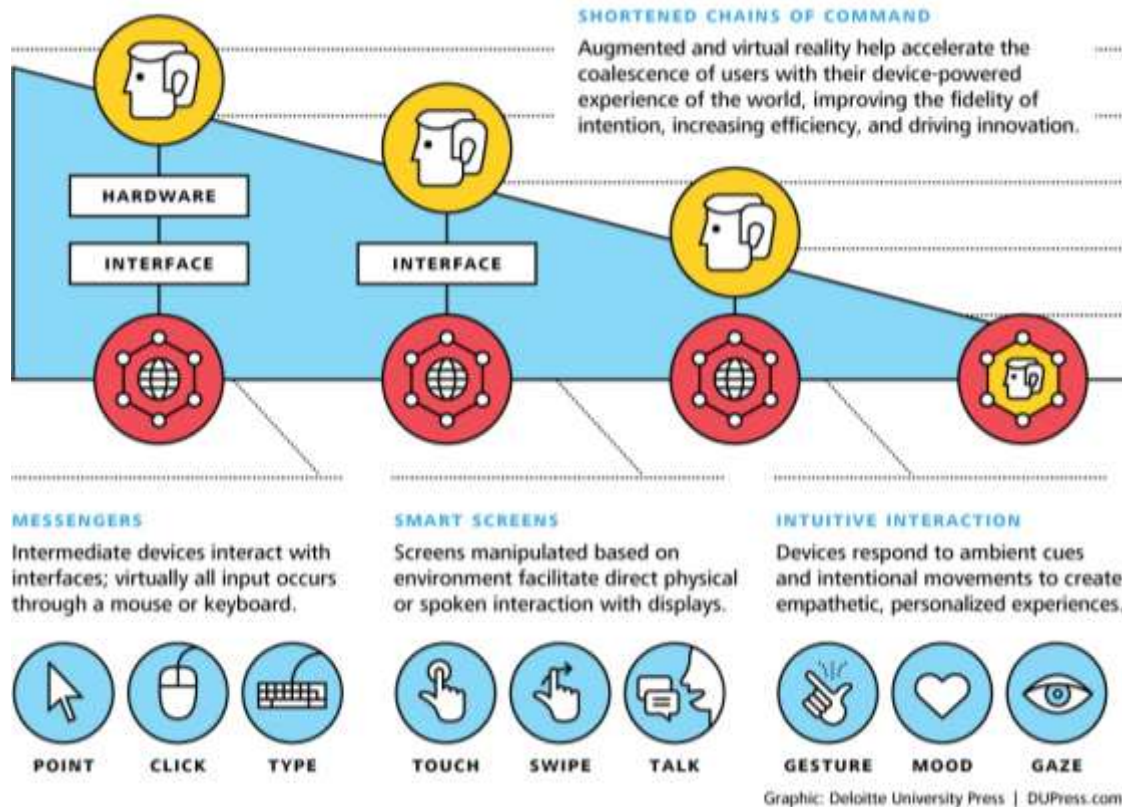


Photo: Kenersys



# Smart steel: CNT Graphene Primer

Abteilung Funktionale Materialien: Projektbeispiele



## Advantages:

- Integration of sensor/actuator applications in curved, complex 3D surfaces
- Personalized design & positioning of sensoric/actoric surfaces
- Saving of material by selective sensor integration (compared to off-the-shelf components and according to desired degree of variation)
- Better recyclability of printed HMI parts due to non-critical disposal of sensor-integrated polymeric parts (no rare metals etc...)
- Reduction of metallic material use due to nanocarbon-based conductive inks/polymers. -> Better recycling and resource efficiency
- Cost optimization due to simple & automated sensor integration/assembly.

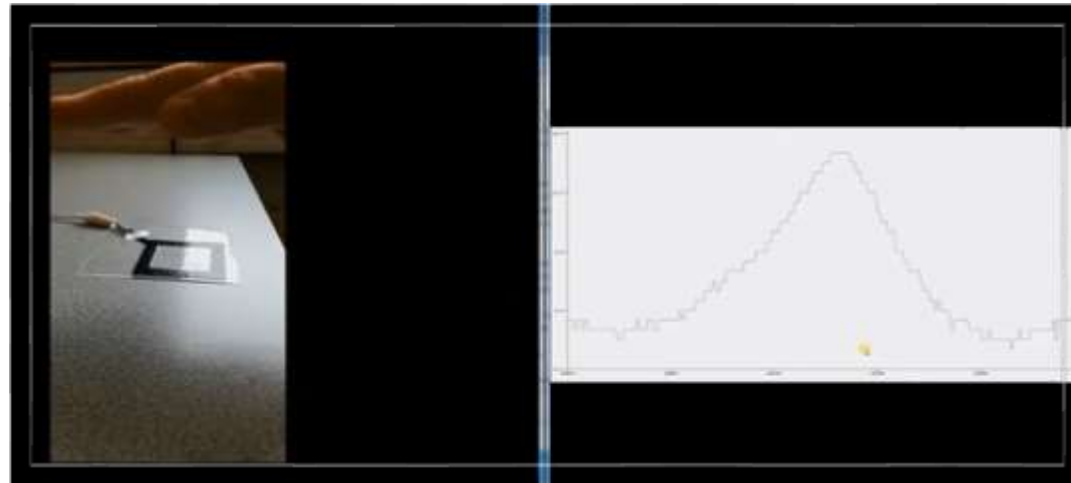
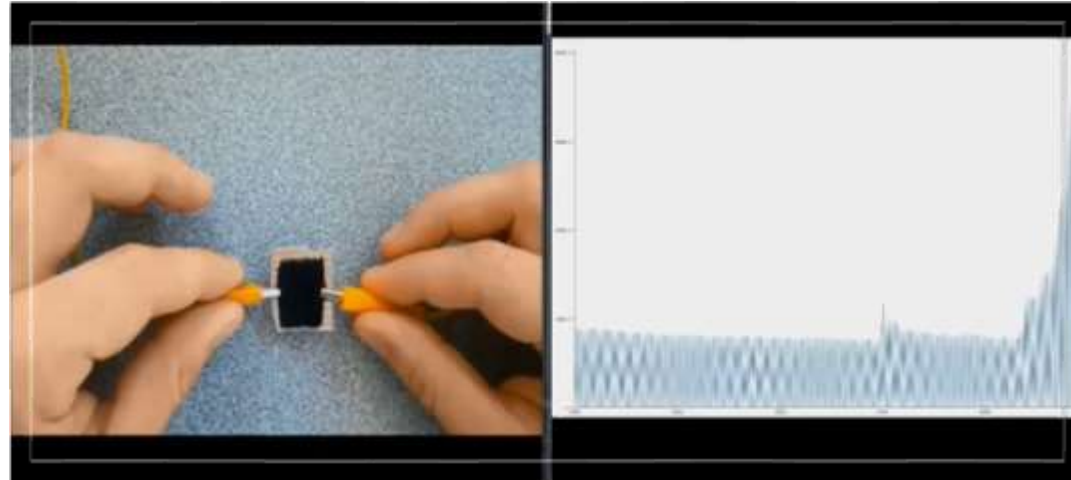
Seite 14

24.02.2023

© Fraunhofer IPA

# Smart steel: CNT Graphene Primer

Abteilung Funktionale Materialien: Projektbeispiele

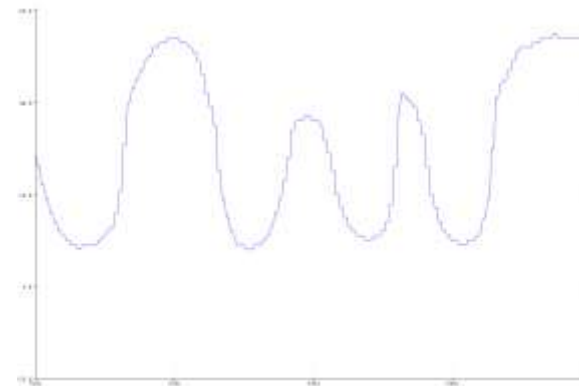
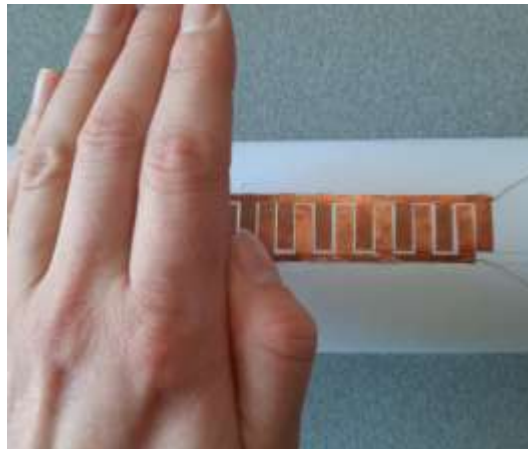
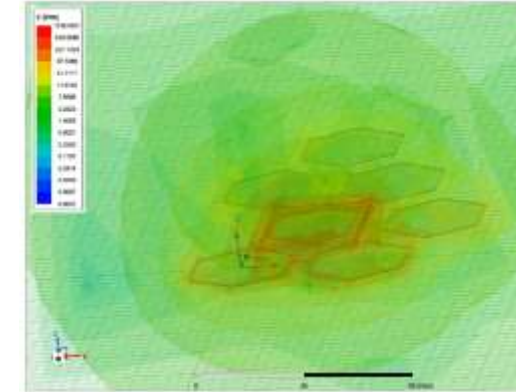
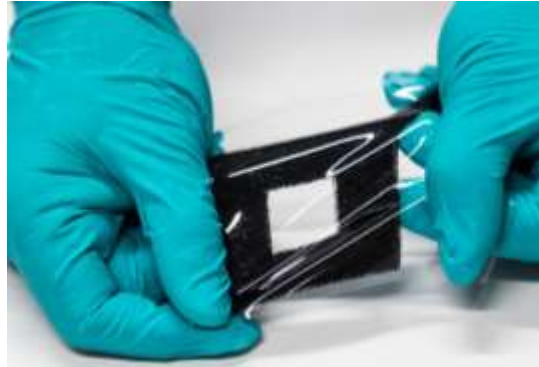


# Smart steel: CNT Graphene Primer

Projekte der Abteilung funktionale Materialien

## Flexible Näherungssensorik

- Dehnbare und flexible leitfähige Sensoren
- Detektion von Näherung  $>15$  cm durch kapazitives Messprinzip
- Räumliche Auflösung durch Sensormatrix und Auswertalgorithmus





# Smart steel: CNT Graphene Primer

Projektbeispiele: Bewegungserkennung im Industriellen Umfeld

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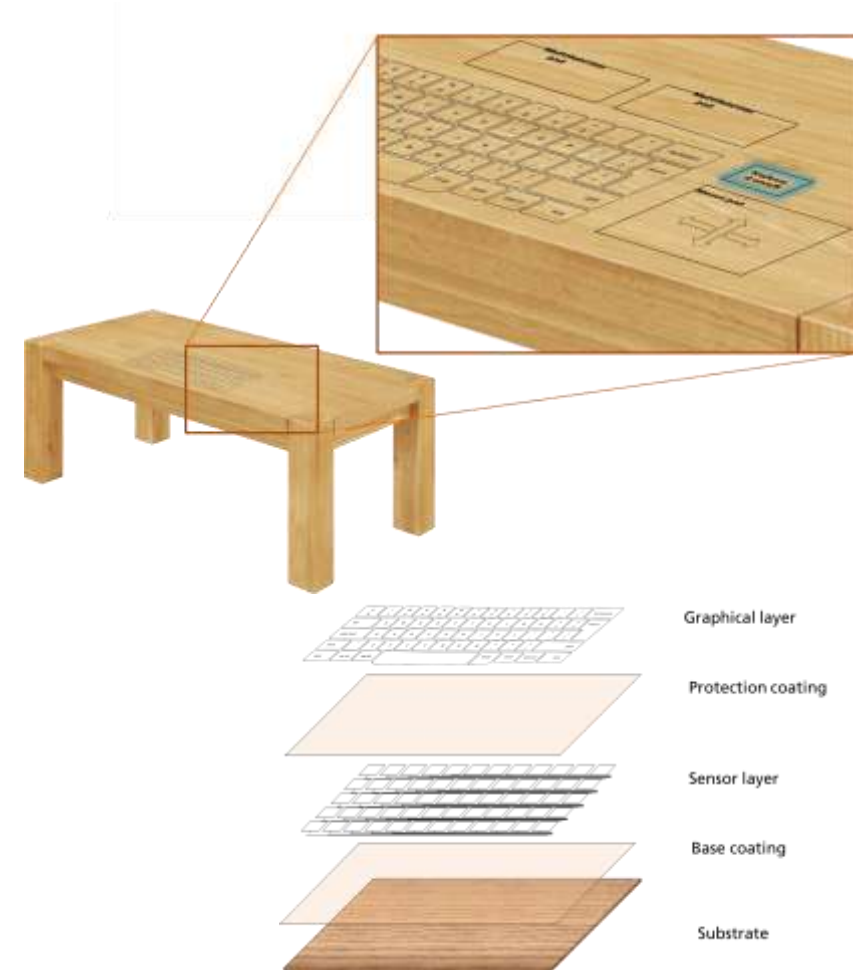


# Fraunhofer IPA

## Smart Furniture Personalized printed sensors in decorative coatings for smart surface applications

### State of the art

- Multilayer structures with adhesion and aging requirements
- Thermomechanical stress
- Required electrical contacts
- Connection layers or sensor films
- Protected from environmental influence by protective layers and mostly need primer layer(s) for adhesion

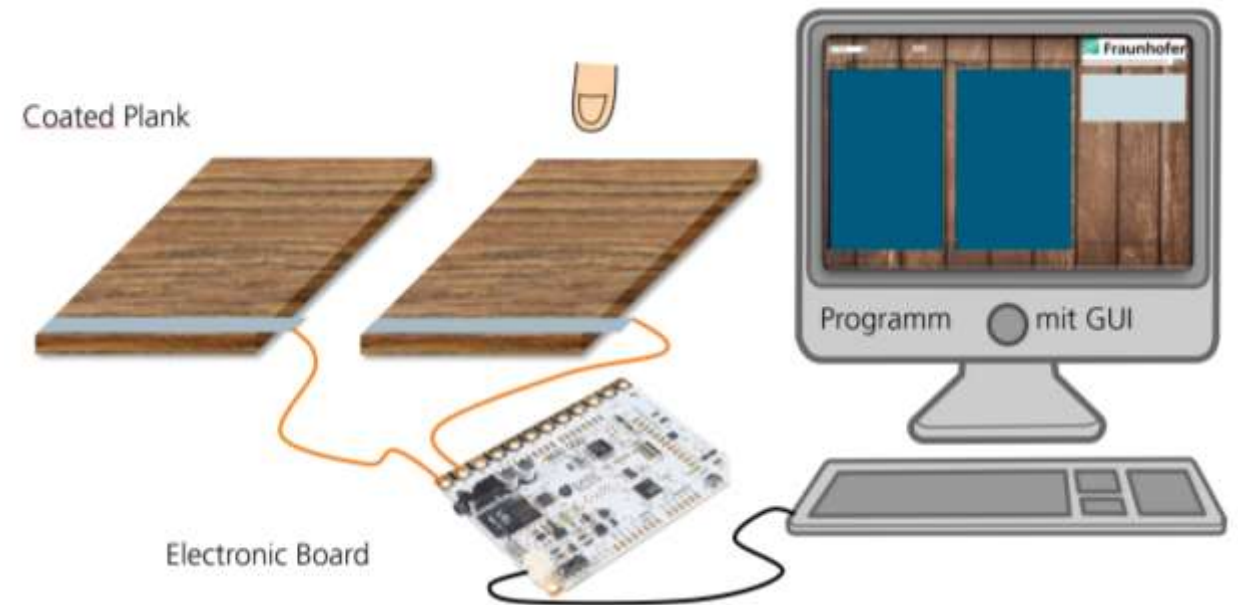


# Fraunhofer IPA

Smart Furniture Personalized printed sensors in decorative coatings for smart surface applications

The aim - personalized invisible printed sensors

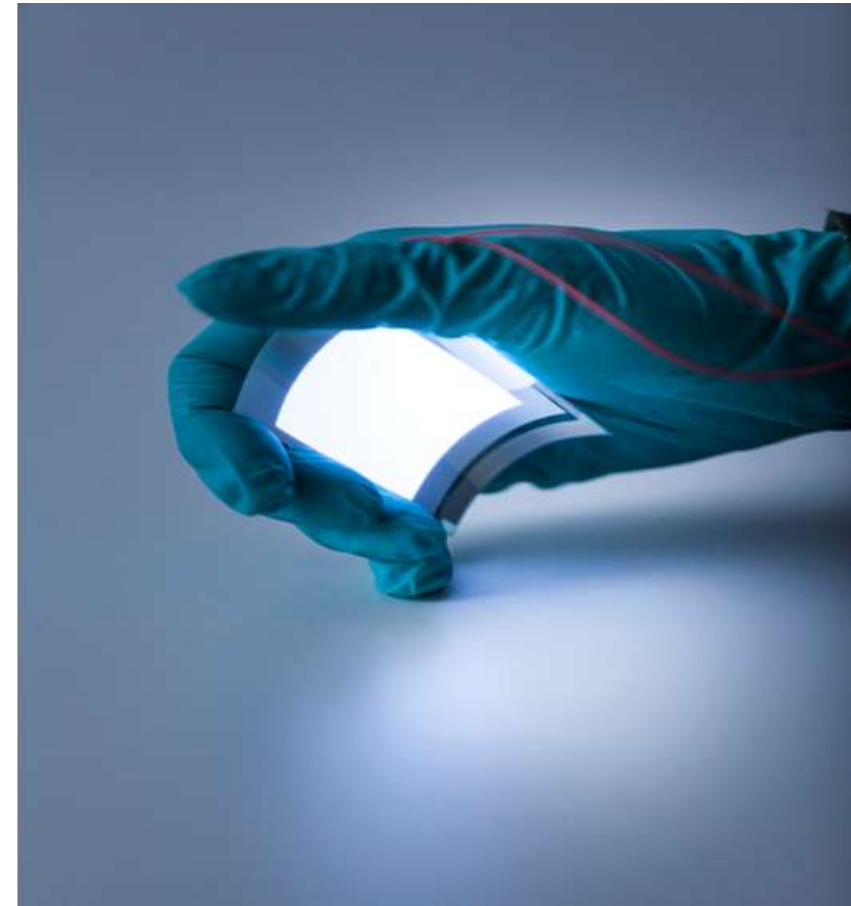
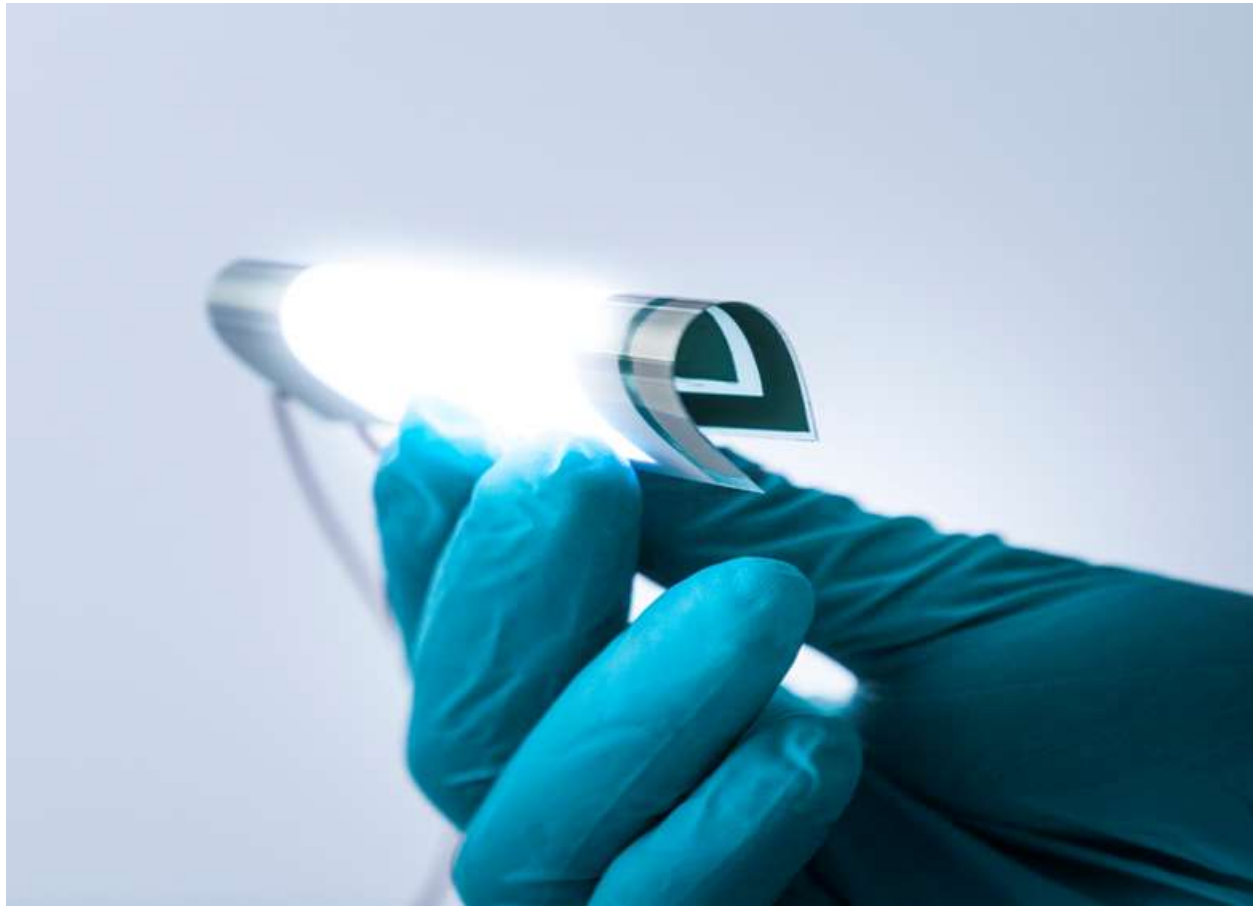
- Only one décor layer with different materials
- Less thermomechanical stress
- Connection layers or sensor films
- Cost effective solution



# Smart steel: CNT Graphene Primer

Projektbeispiele: Flexible Leuchten

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# Smart steel: CNT Graphene Primer

Projektbeispiele: Transparent Aktuators



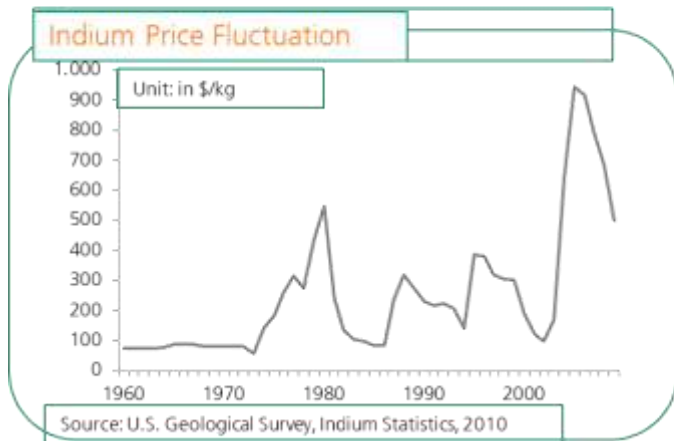
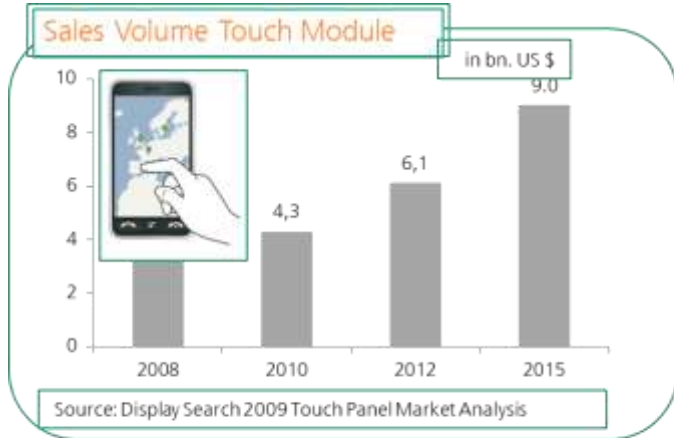
# Smart steel: CNT Graphene Primer

Abteilung Funktionale Materialien: ECO Touch CNT TCF



# Smart steel: CNT Graphene Primer

Abteilung Funktionale Materialien: ECO Touch CNT TCF



### ECO TOUCH concept

- *ECO TOUCH I*: conductive polymer + CNT 300Ω/□ at 84% transparency, improved in environmental stability
- *ECO TOUCH II*: pure single-walled CNT 300Ω/□ at 85% transparency, improved in UV-light resistance

**Merits:**

- Flexible
- Sustainable (no rare metal, recyclable material)
- Easy and energy-saving process

### Energy-saving process

#### Conventional process:

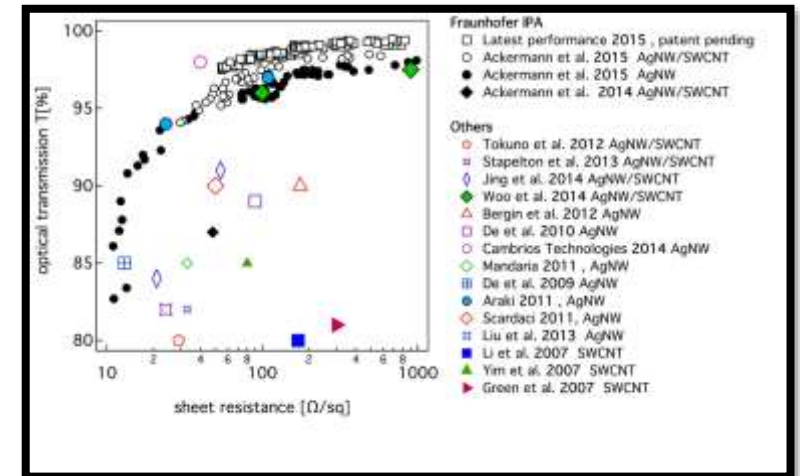
sputter = 890 Wh/qm

Source: Fraunhofer FEP

#### ECO TOUCH Process:

coating = 50 Wh/qm

Source: Fraunhofer IPA





# DIGITALIZATION



# Smart steel: CNT Graphene Primer

Abteilung Funktionale Materialien: Digitalisierung und Baden Württemberg



**IoT** describes a technical concept during which an object ("thing") with a unique identity is integrated into a digital network in such way that a connection between the physical world of things and the virtual world of data is crated.

**IoT user** is a simple consumer.

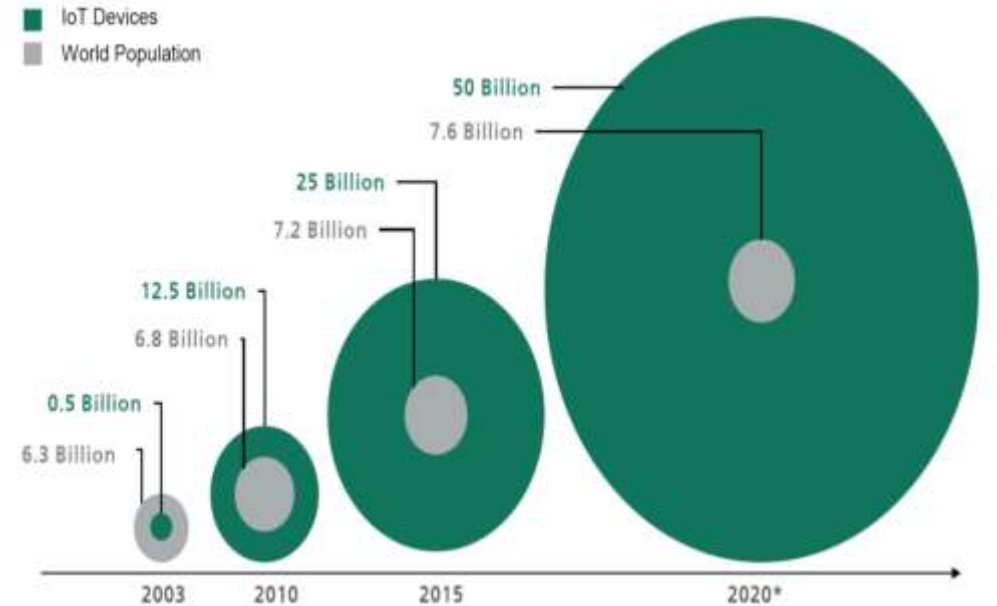


**IIoT** refers to IoT in the industrial environment and describes the interconnection of complex machines with integrated sensors in order to optimize production processes and generate new business models while establishing Machine-to-Machine (M2M) communication and utilizing big-data technologies.

**IIoT user** is a common company.



[Pictures: Fraunhofer IPA; intralogistik.tips; wearables.com; paksafe.de]

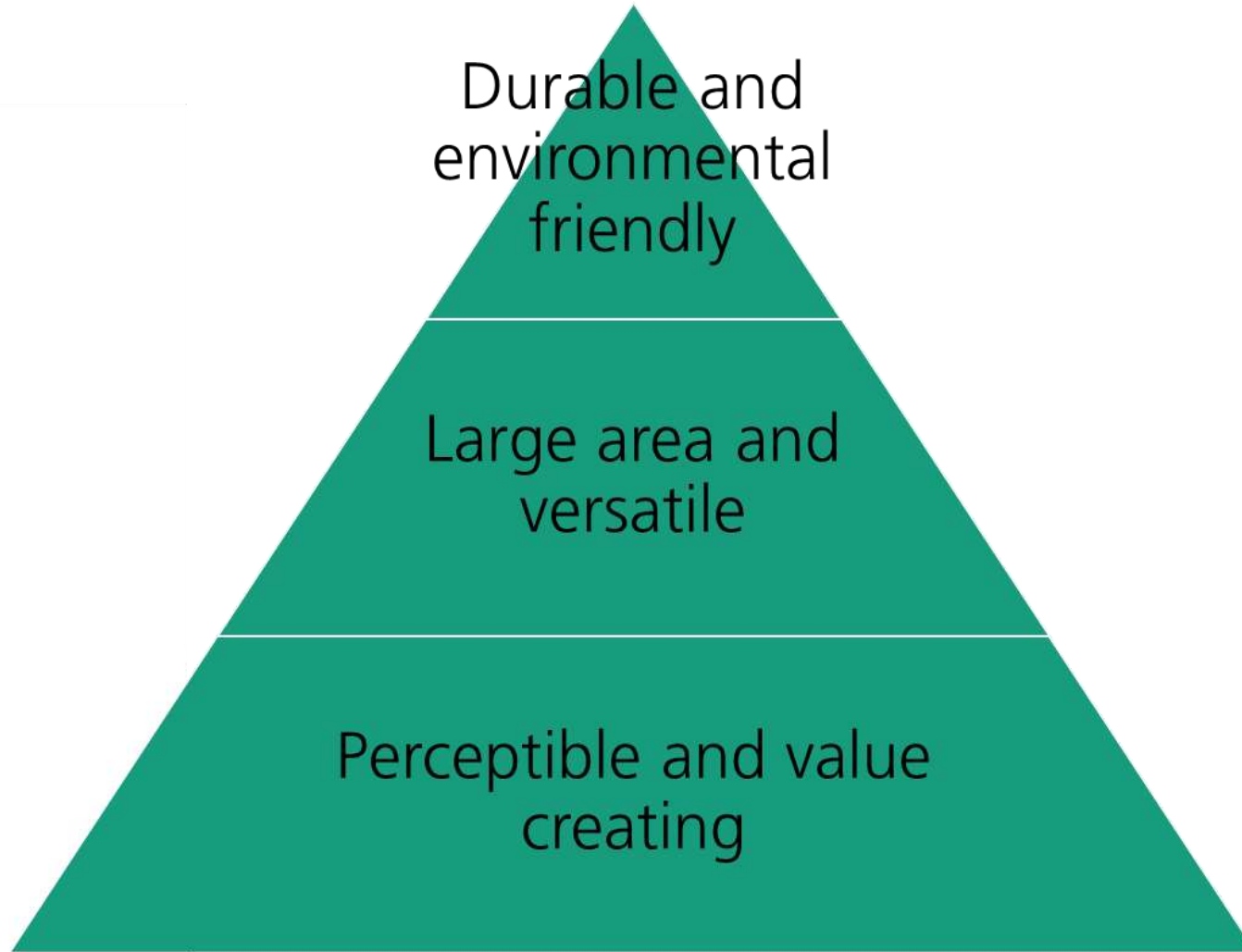


\*Expectations

[Based on Jason Parnis in «Internet of Things: A Threat or Blessing» (2014)]

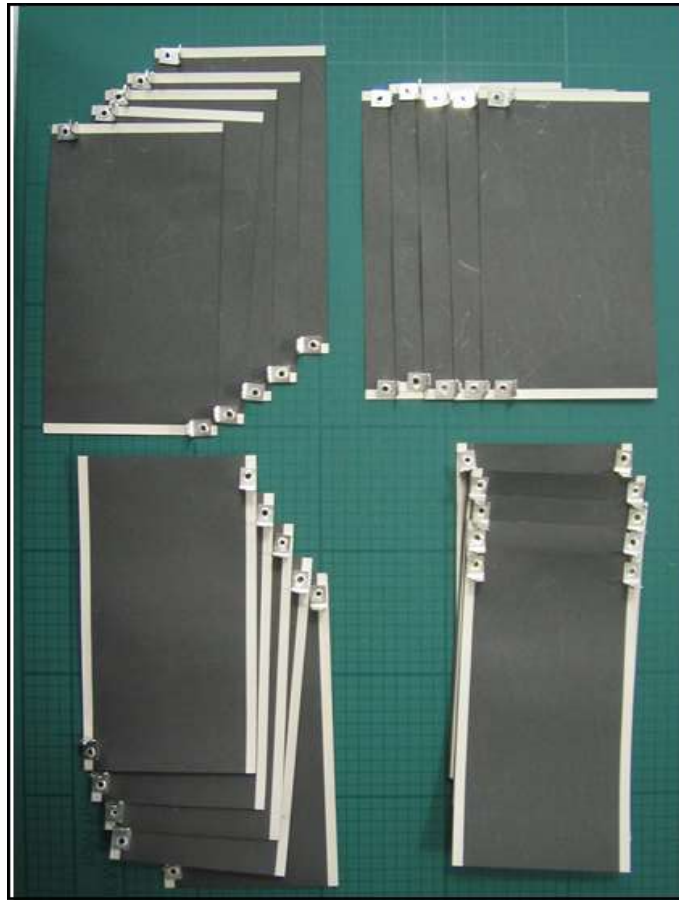
# Smart steel: CNT Graphene Primer

Motivation:



# Smart steel: CNT Graphene Primer

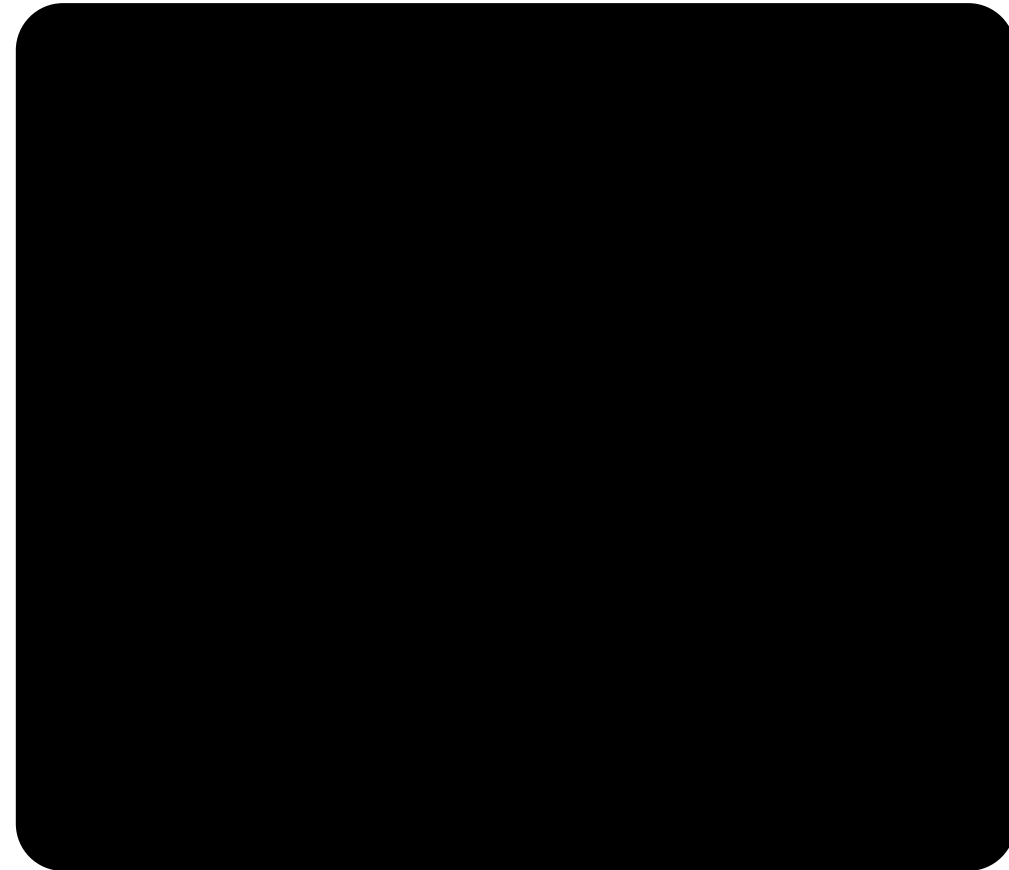
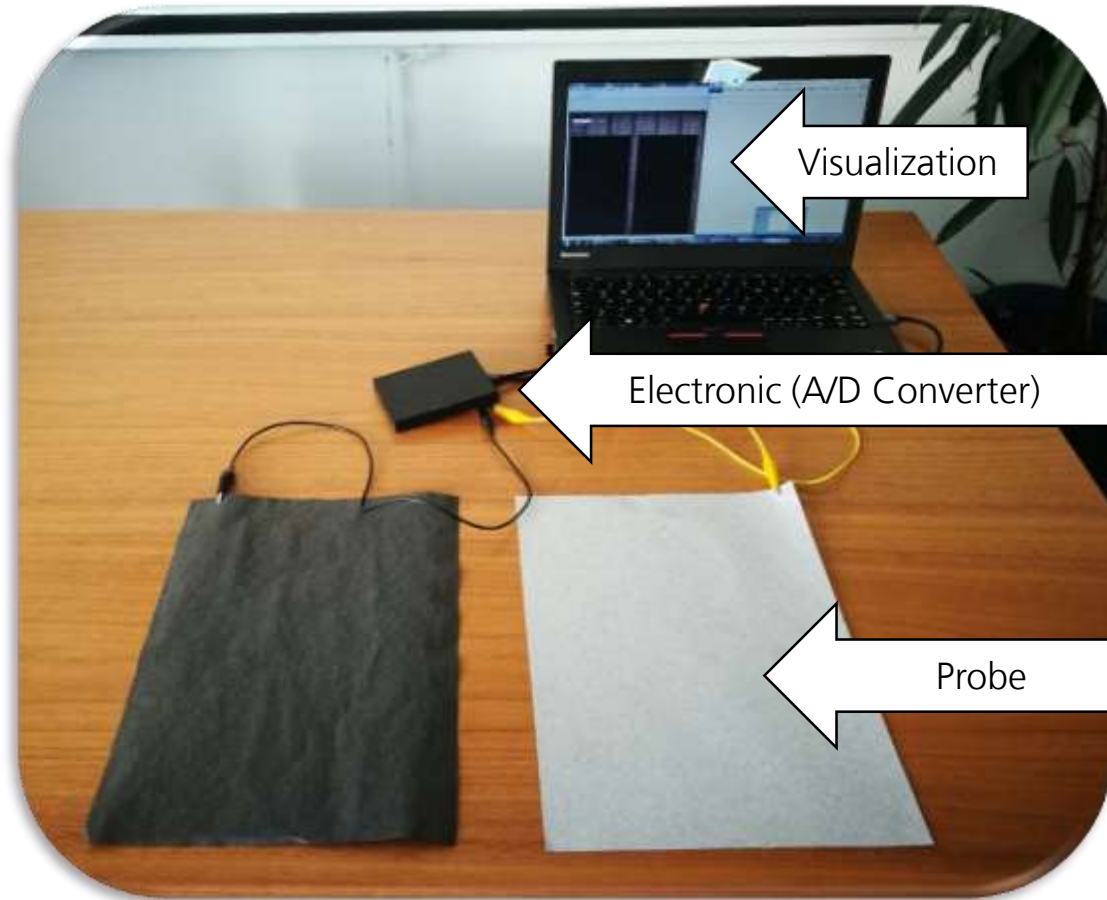
## CNT PAPER



Operating Voltage:	5-48V
Surface Temperature:	250°C
Power:	1,5 W/cm <sup>2</sup>

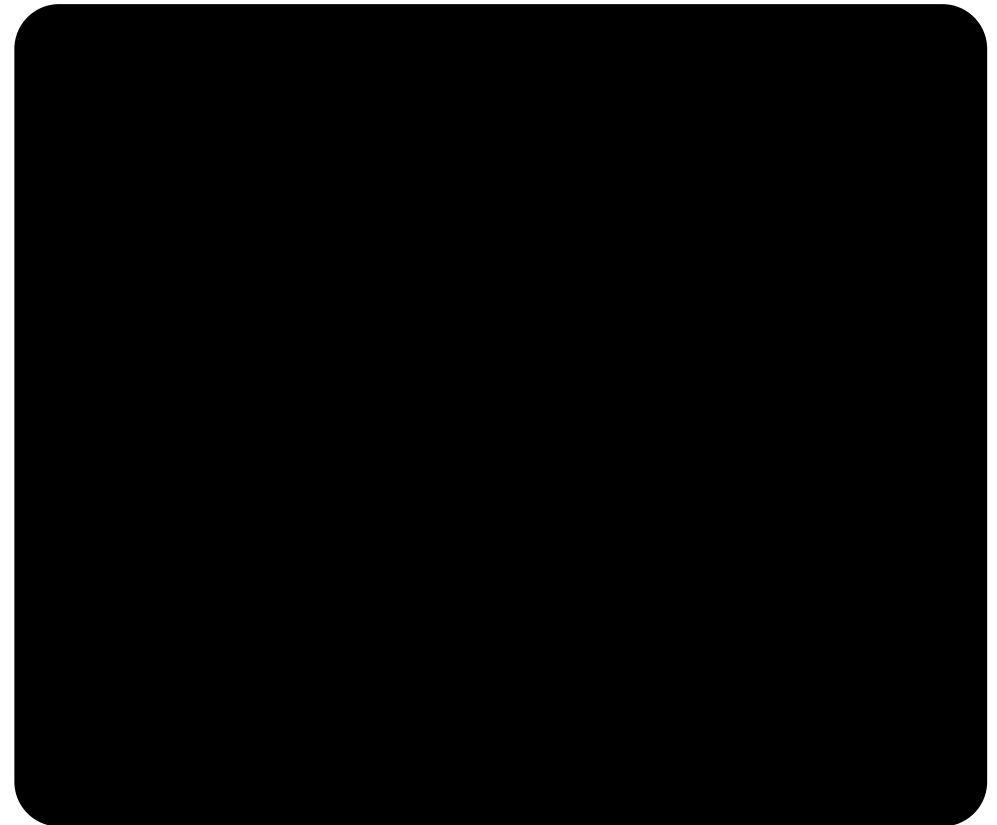
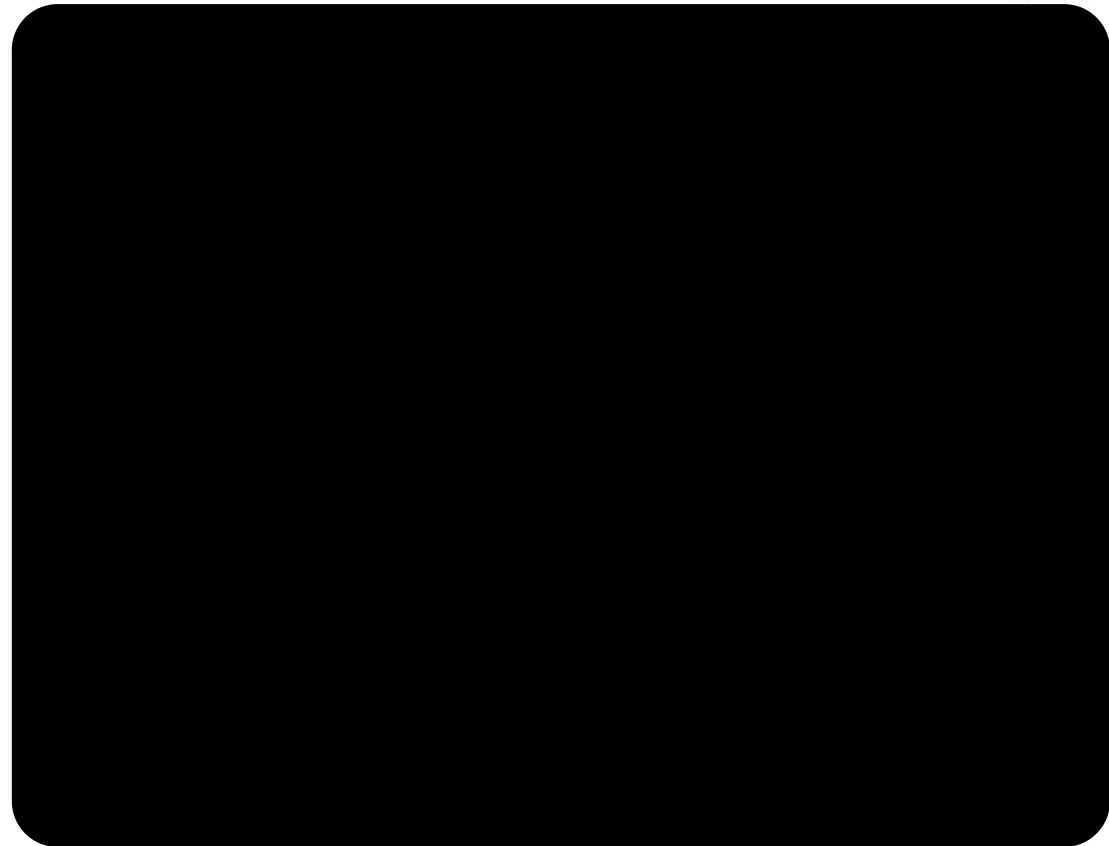
# Smart steel: CNT Graphene Primer

CNT PAPER



# Smart steel: CNT Graphene Primer

CNT PAPER



# Smart steel: CNT Graphene Primer

Smart Steel: Interdigitalstruktur



Interdigital structure



# Smart steel: CNT Graphene Primer

## Smart Steel: Interdigitalstruktur Architektur



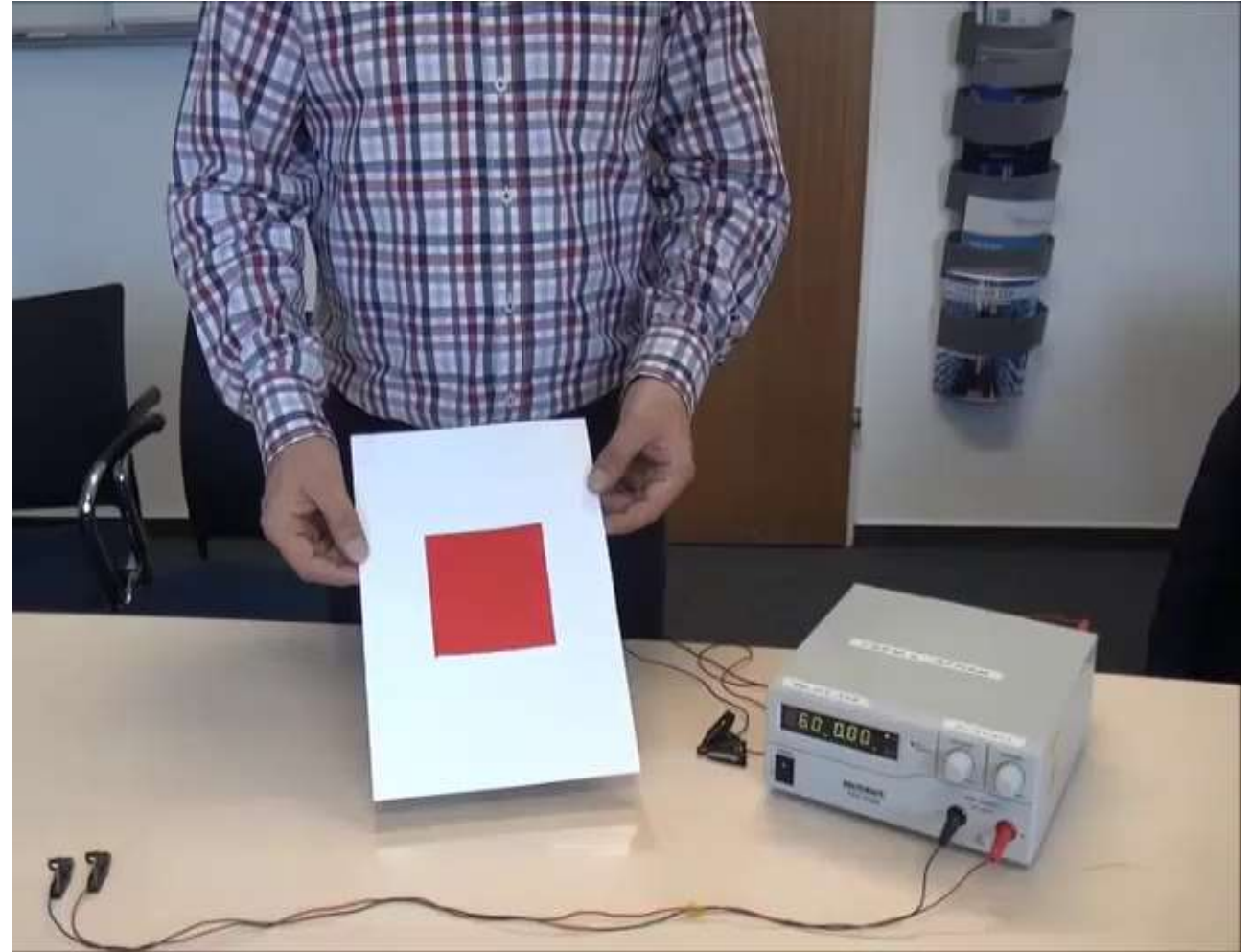
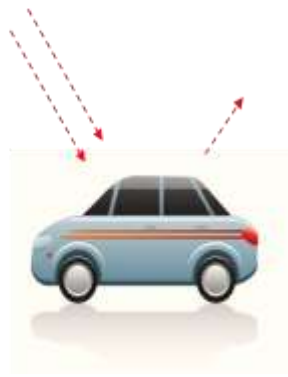
Sensor

clearcoat	(40 $\mu\text{m}$ )
basecoat	(10-20 $\mu\text{m}$ )
primer surfacer	(35 $\mu\text{m}$ )
e-coat	(20 $\mu\text{m}$ )
metal substrate	



# Smart steel: CNT Graphene Primer

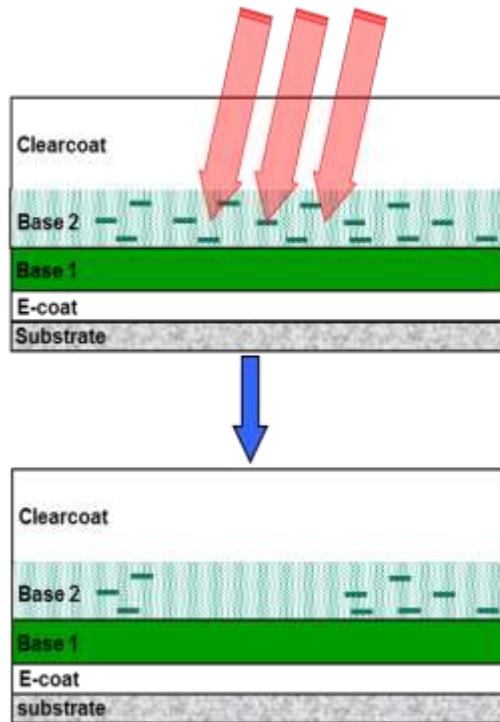
Smart Steel: Farbwechsel





# Smart steel: CNT Graphene Primer

Smart Steel: Interdigitalstruktur im Lackaufbau





Source: Pinterest

**2.200.000.000.000 US \$ / a**





Source: Morgufiles

Genoa, Italy Bridge Collapse



Sinking of the Erika



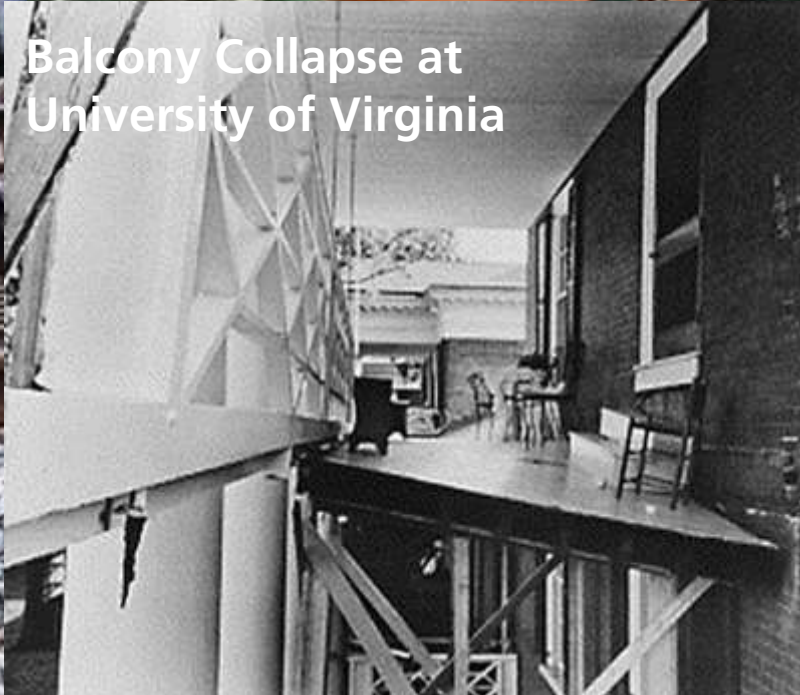
Bhopal, India Incident



Fall of Railway Traffic Lights



Balcony Collapse at University of Virginia



Source: Five Disasters Caused by Corrosion  
PCI

# Smart steel: CNT Graphene Primer



# Smart steel: CNT Graphene Primer

## Korrosionserscheinungen im Salzsprühstest

Stahl

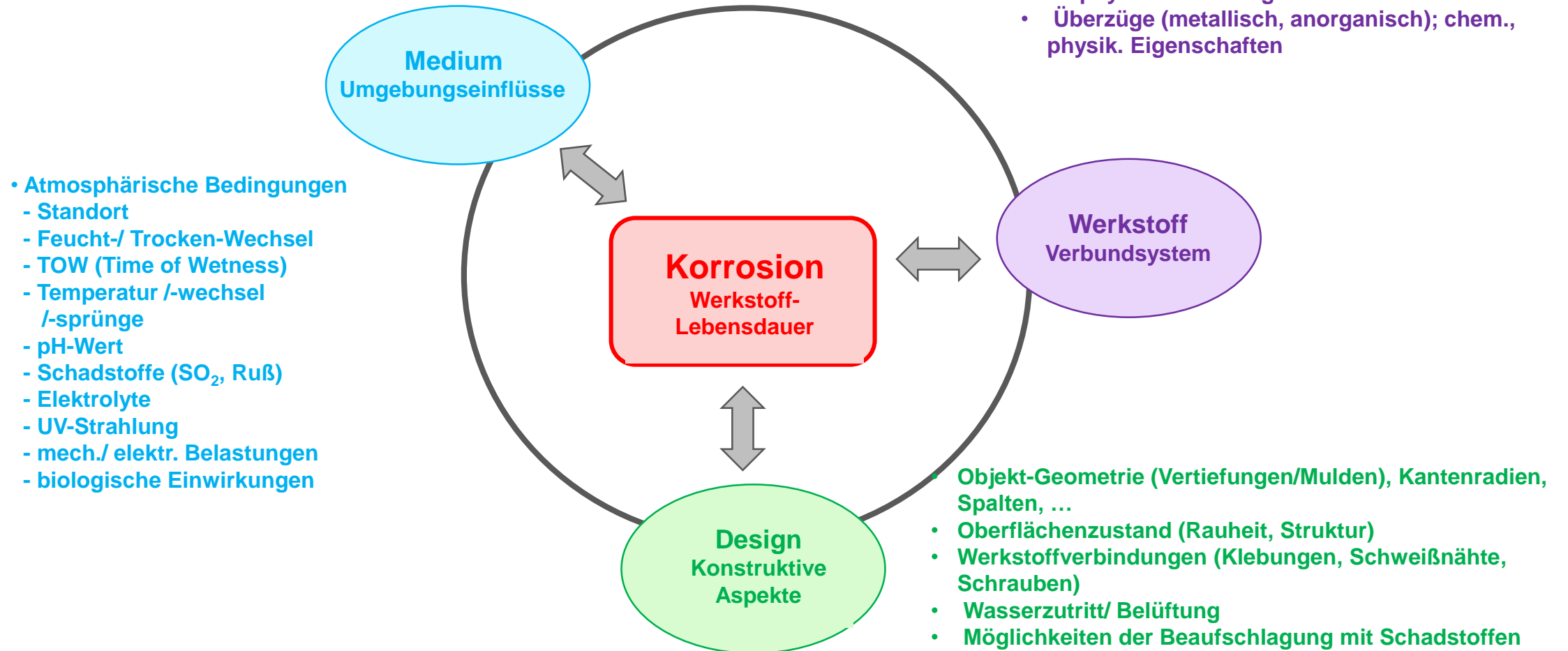
verzinkter Stahl

Aluminium



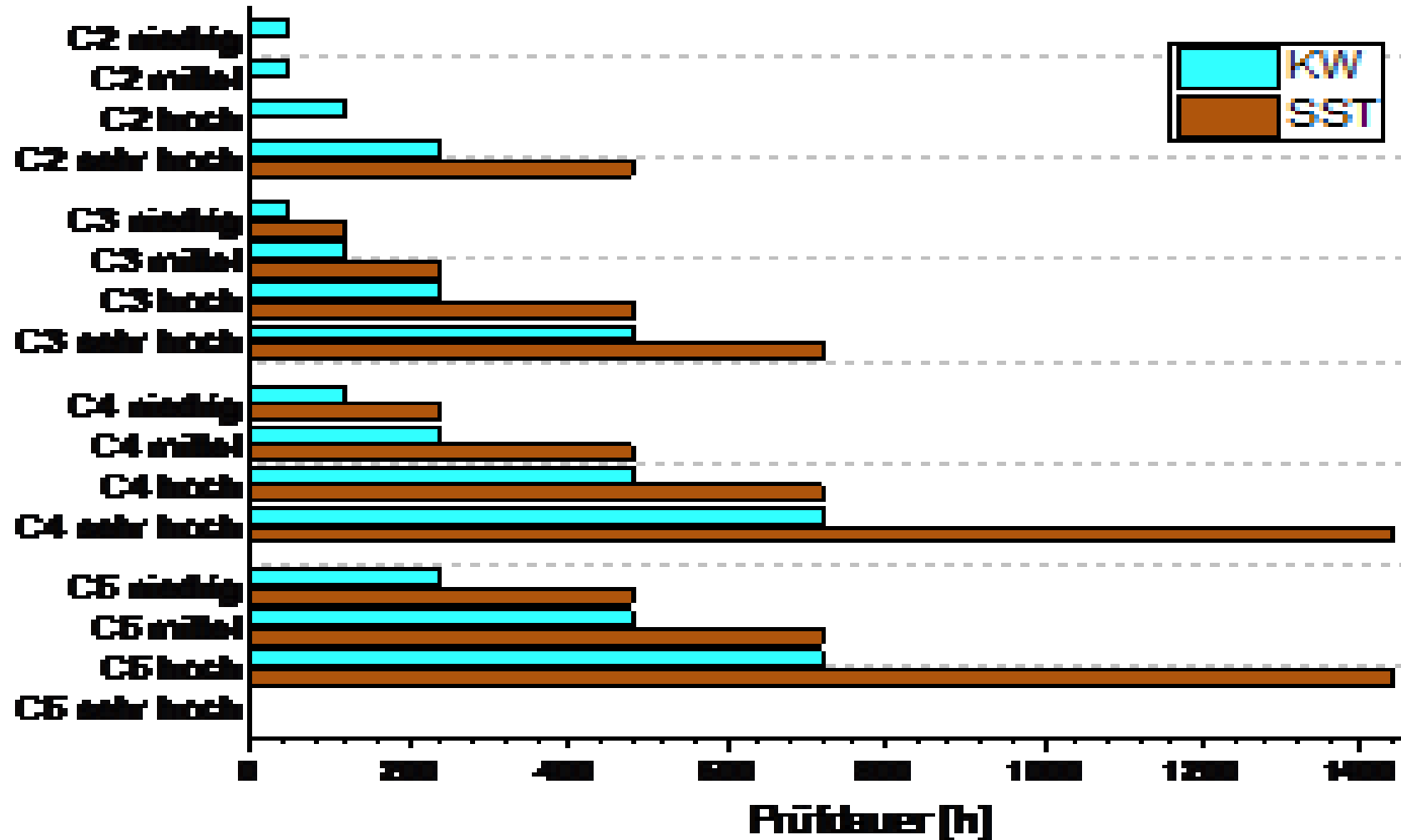
# Smart steel: CNT Graphene Primer

## Korrosion als Systemeigenschaft



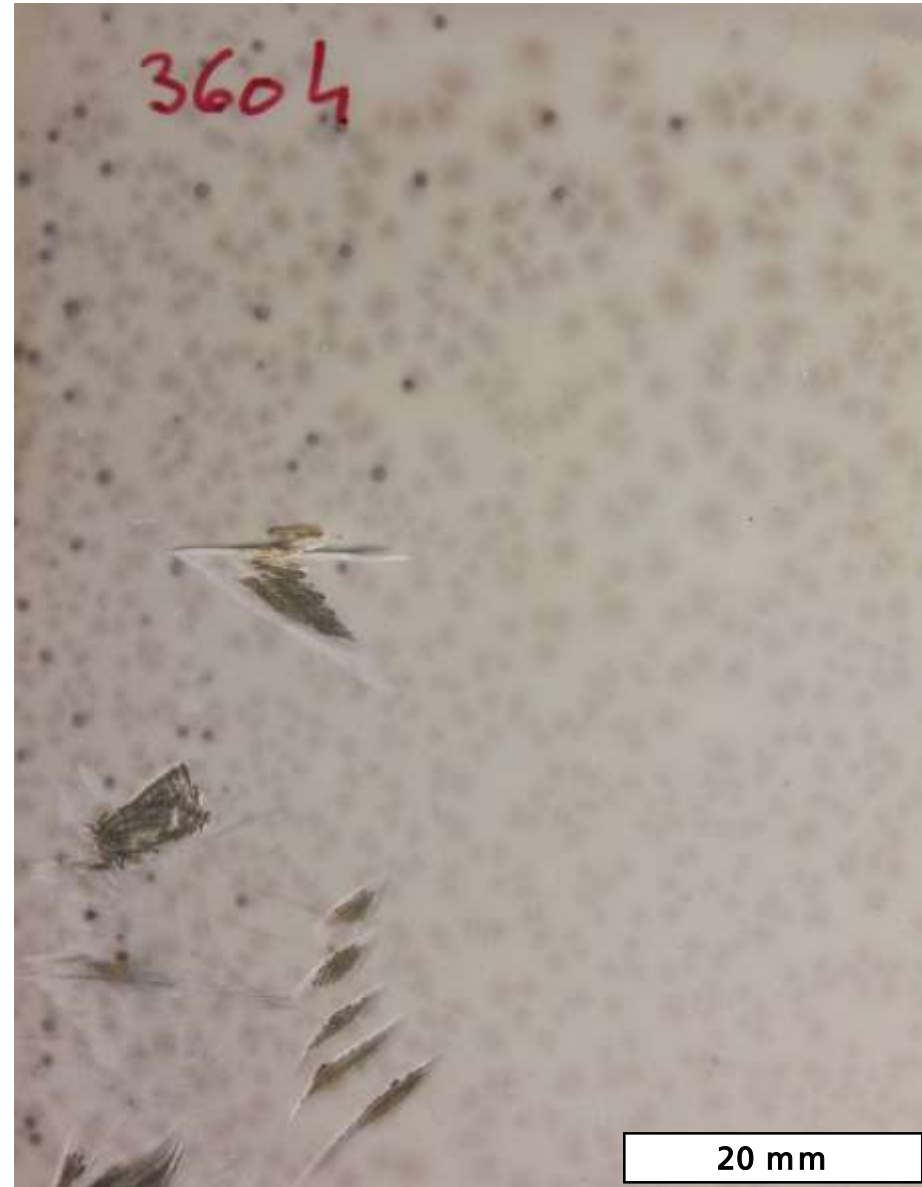


# Prüfdauer nach DIN EN ISO 12944-6

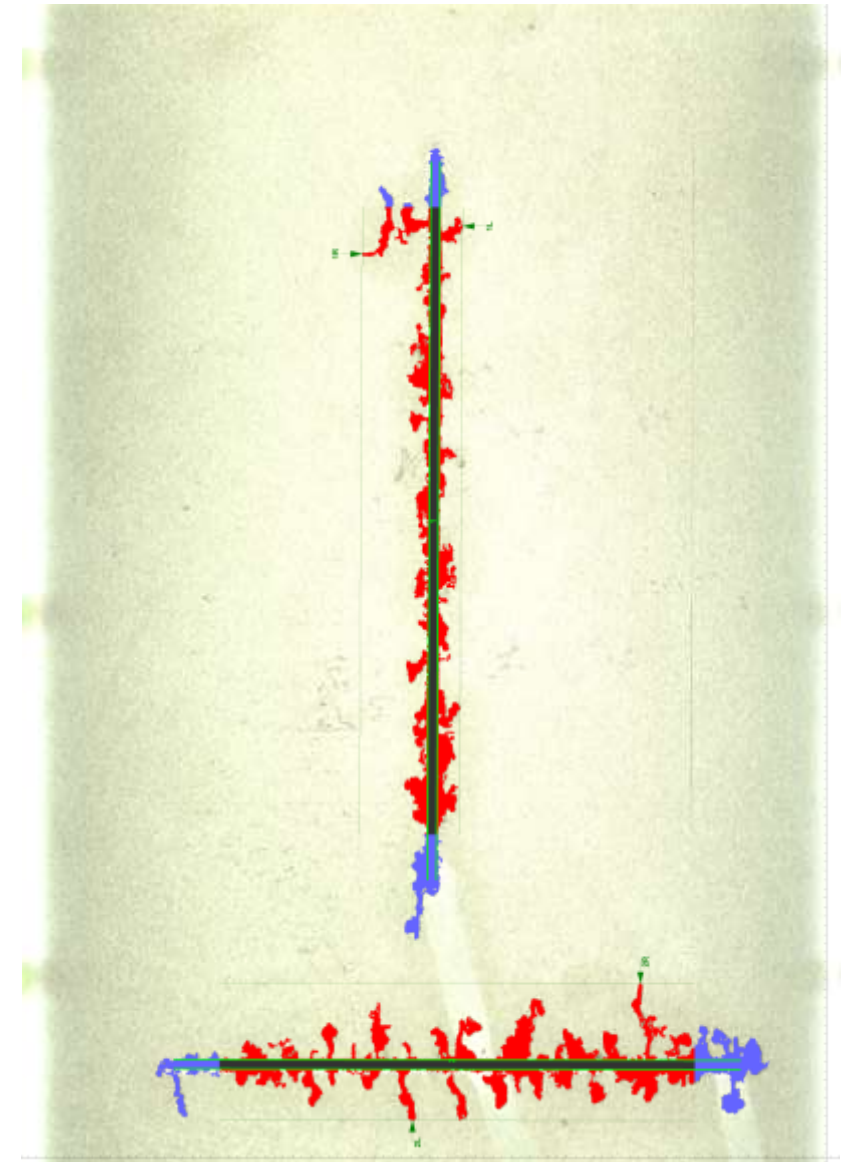
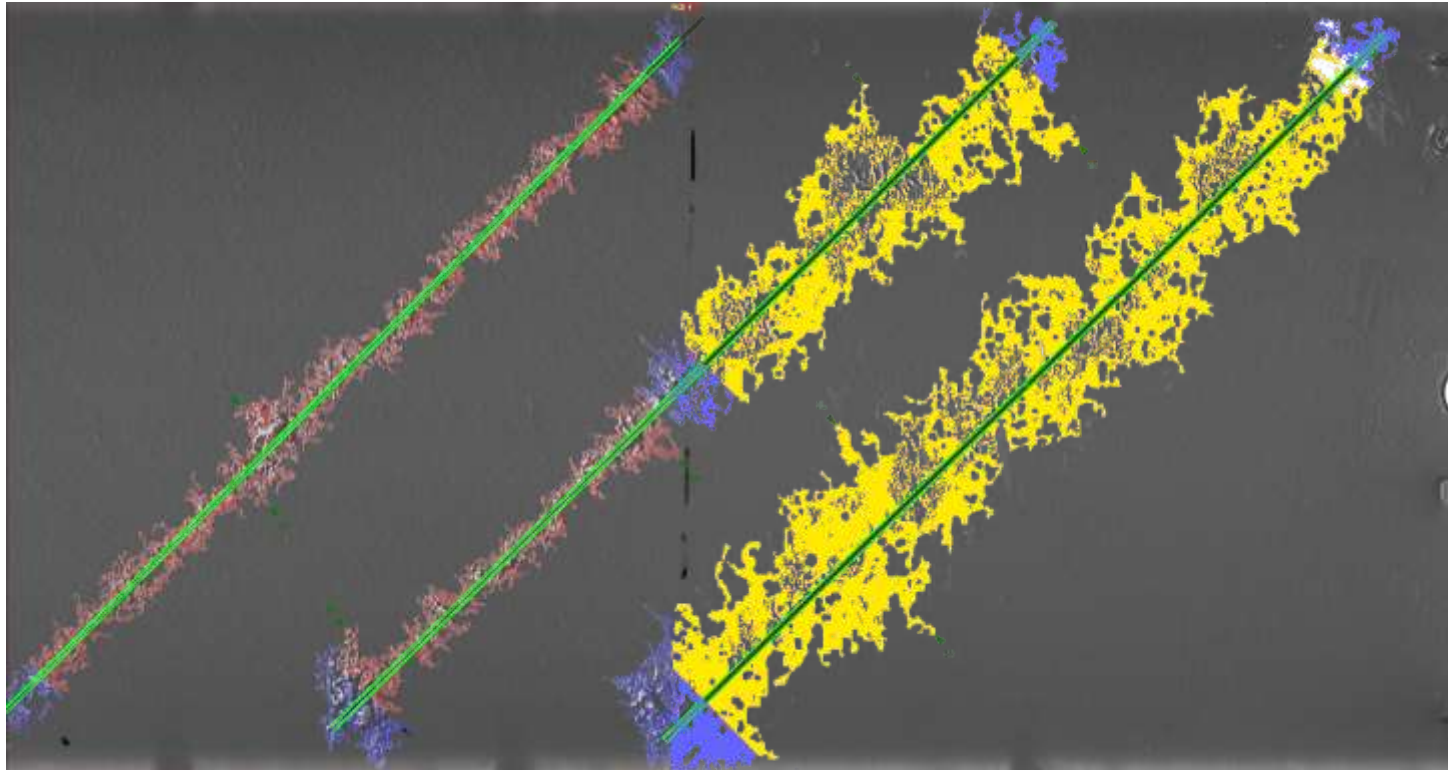


# Visuelle Bewertung

Blasen



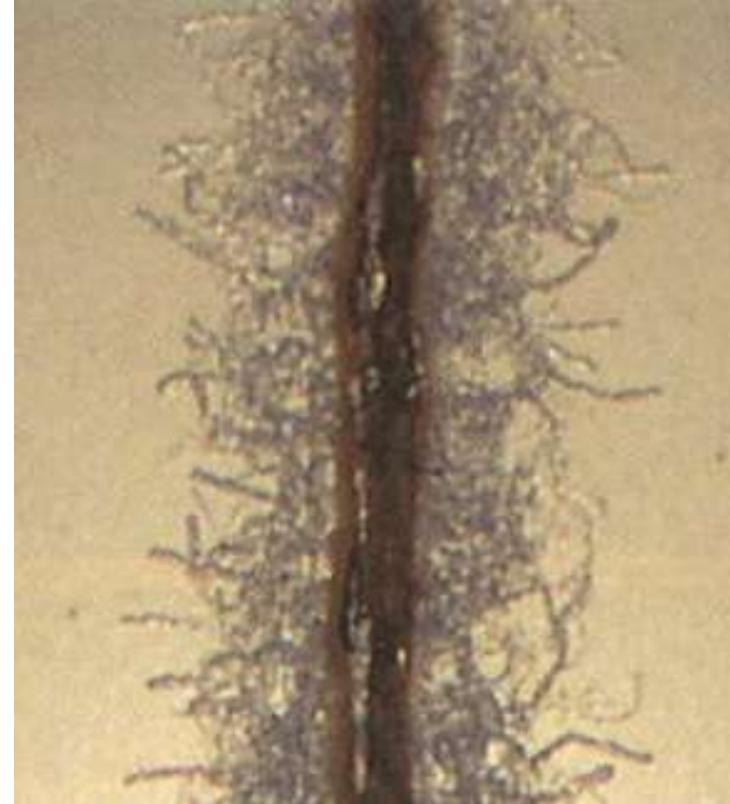
# Auswertung Filiformkorrosion



# Filiformkorrosion



Filiformkorrosion an Aluminiumrädern,  
ausgehend von Kanten bzw. Verletzungen



Filiformkorrosion auf Stahl

# Praxis

Fensterheber



LKW-Teil



Stalltor





New approaches to corrosion protection are called for. Legal requirements and regulations, as well as the demand for quality, efficiency and the ability to plan concepts, are forcing us to change our way of thinking.

What are the alternatives to zinc-based anti-corrosives?

How can corrosion protection be improved?

How can it be detected at an early stage or even avoided altogether?

# Smart steel: CNT Graphene Primer

## IPA Patent and Principle

### Fraunhofer IPA:

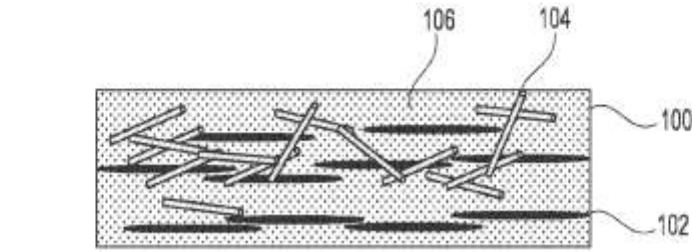


Fig. 1

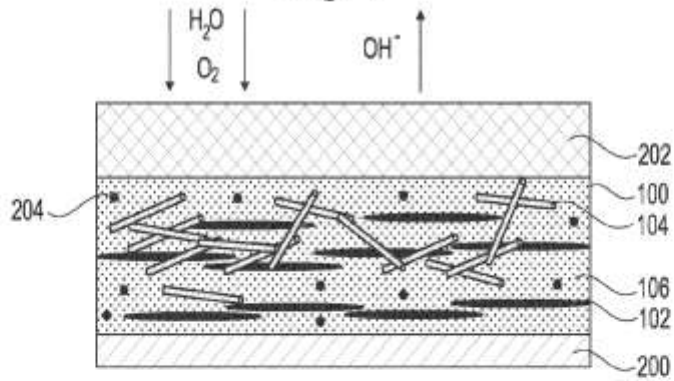


Fig. 2

### Others:

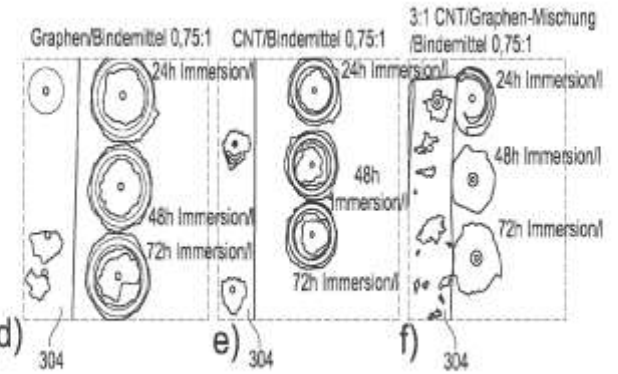
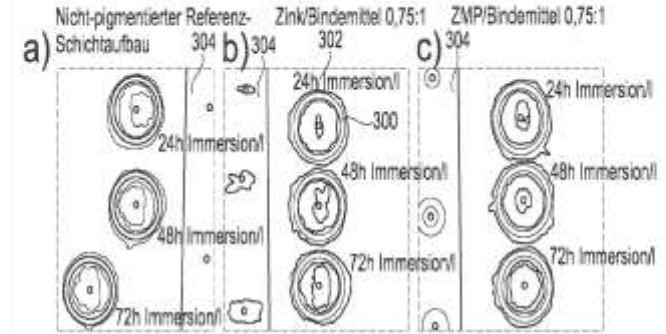
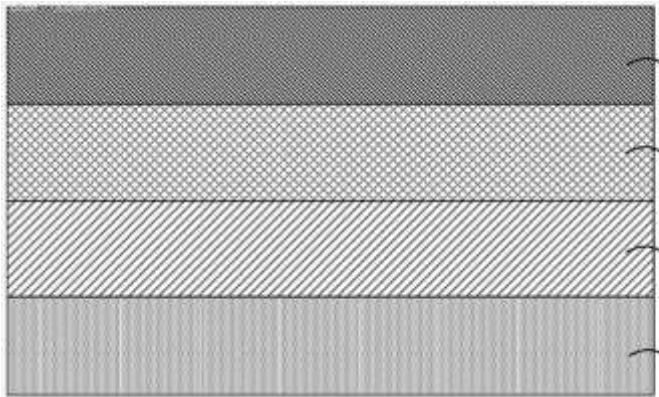


Fig. 3

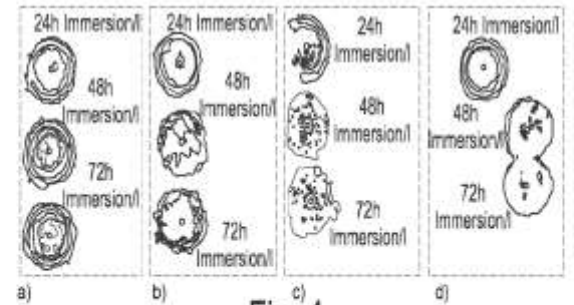
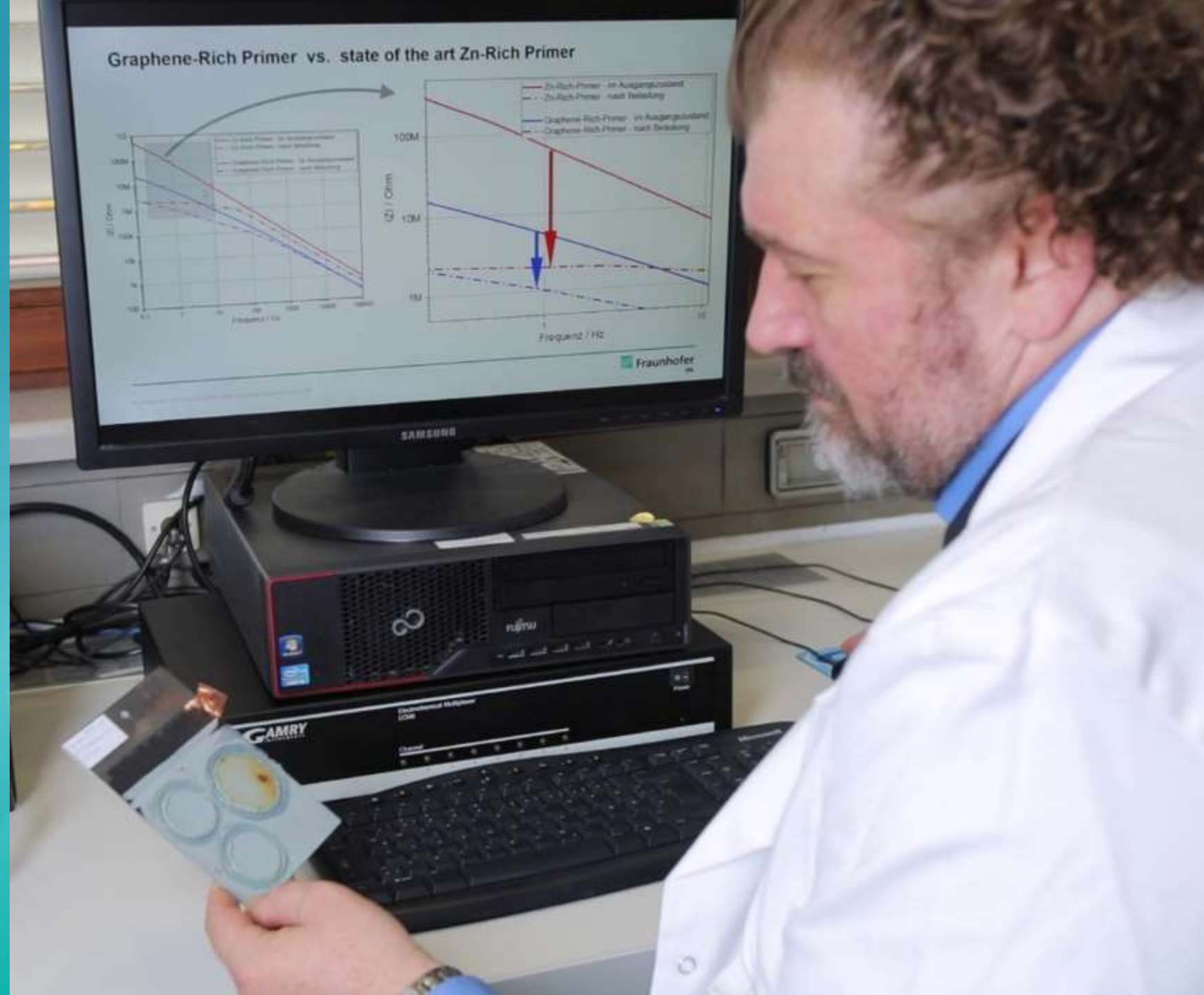


Fig. 4

The Smart Steel Technology developed by Fraunhofer IPA is an intelligent anti-corrosion technology for coating surfaces that combines corrosion monitoring with corrosion protection. The core of the technology is based on a graphene rich primer consisting of a combination of a first and a second functional filler component and the binder matrix polymer.

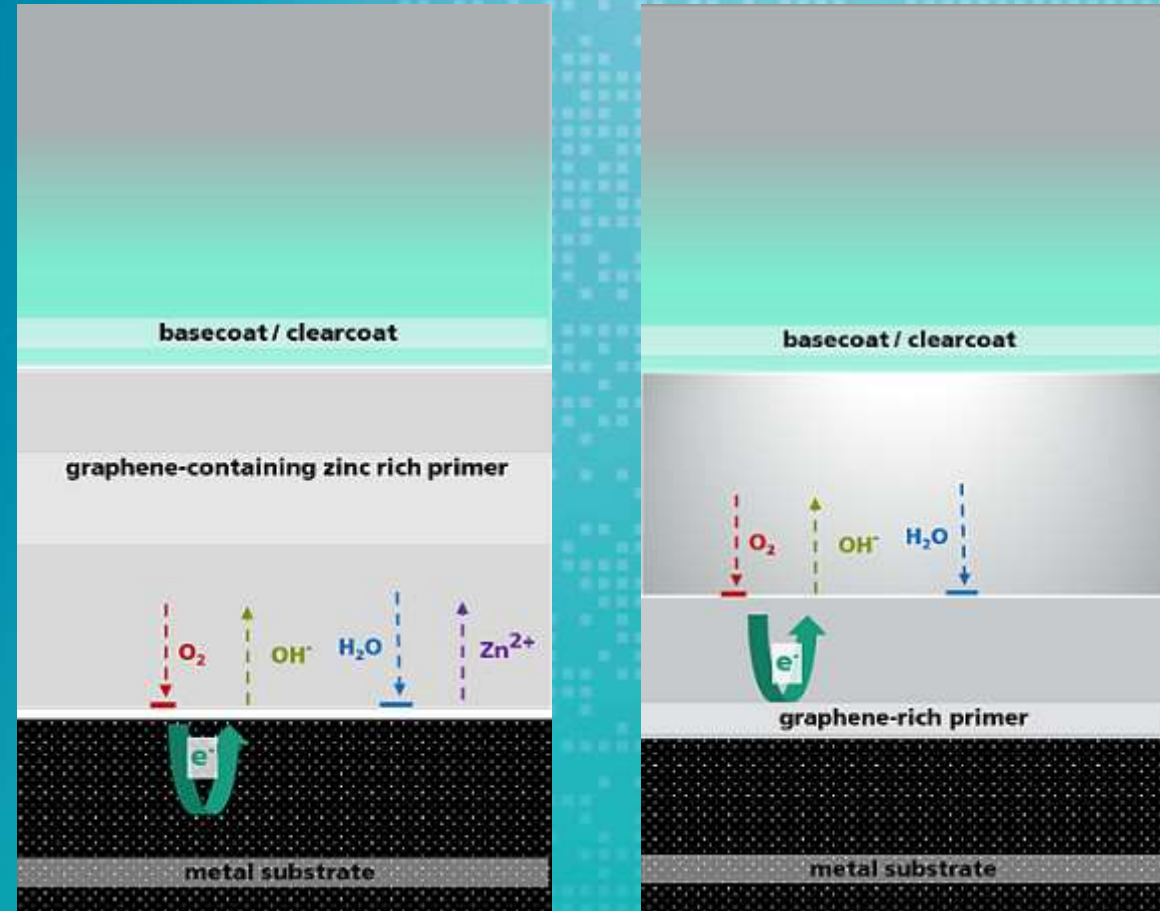




# Graphene Rich Primer / Smart Steel Technology

State-of-the-art / new innovative protection concept

The unique combination of two functional carbon-based fillers, the Smart Steel Technology allows the corrosion protection system to be adjusted in line with environmental conditions and customer demands as far as corrosion protection and monitoring are concerned, and can easily be extended by an active polarization concept if needed.



Salt Spray Testing:

Results obtained with 400h according to DIN EN ISO 9227



Graphene rich primer  
+ PUR topcoat

Conductive primer  
+ Graphene rich primer  
+ PUR topcoat

Reference:  
conventional  
zinc rich primer  
+ PUR topcoat

Smart Steel Technology based on Graphene Rich Epoxy primer and PUR topcoat. Substrate: sand blasted steel

# Automation and Monitoring by sensor integration

State-of-the-art / new innovative protection concept

## Sensor

Graphene rich Primer



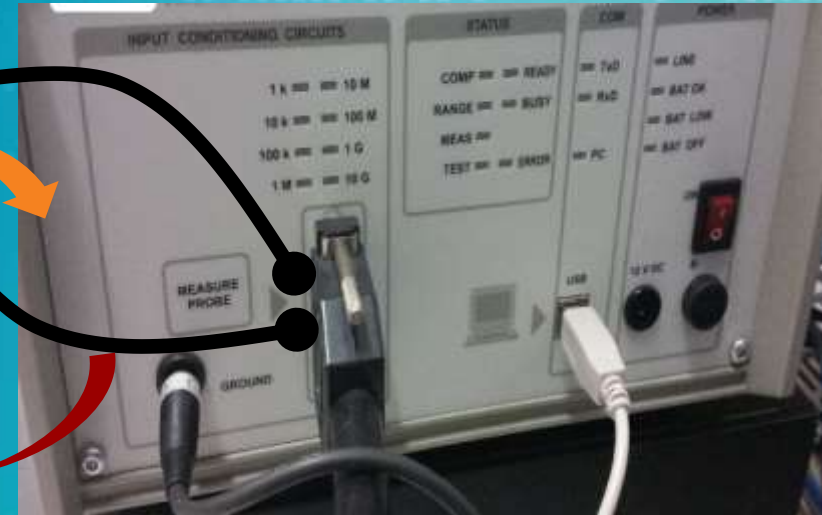
## Data transfer

Switch to control



## Data analysis

Control unit

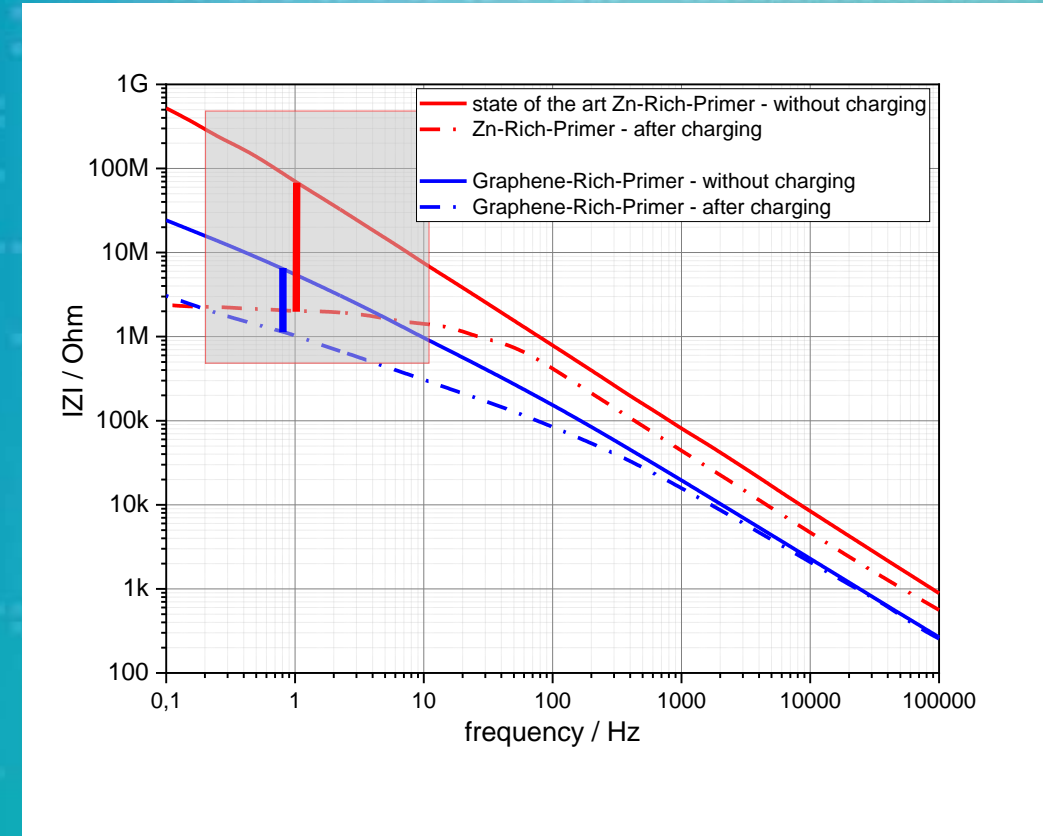
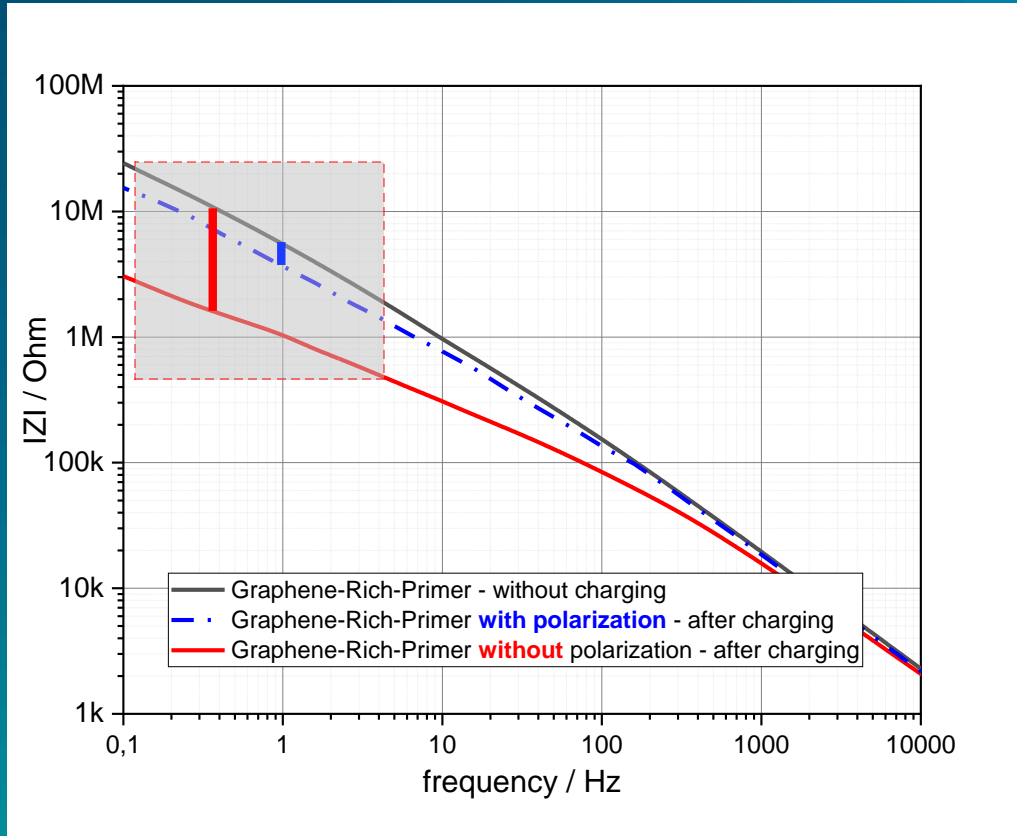


Polarization

Response

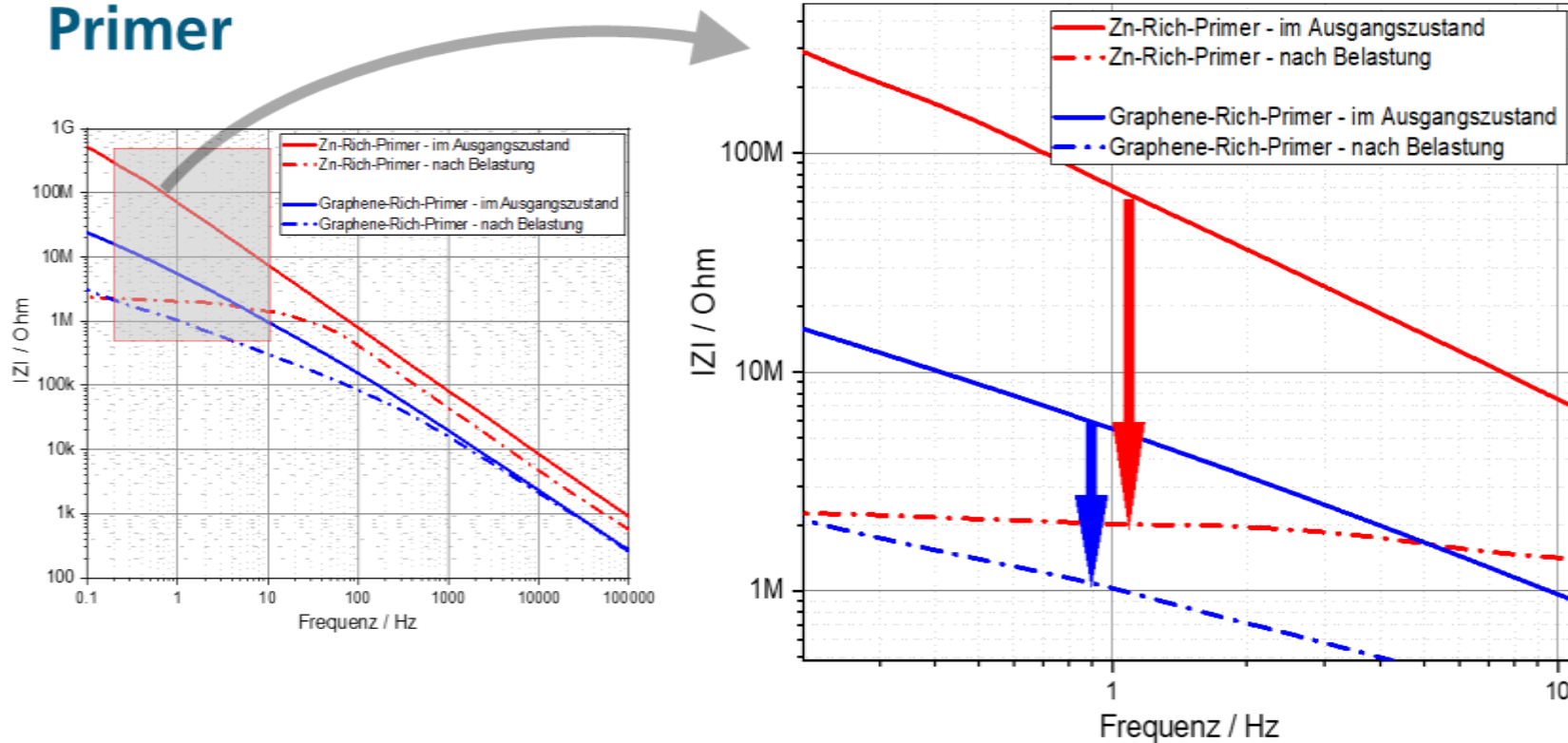
The Smart Steel Technology can be automated in that the polarization is directly regulated by the online monitoring unit. Its concept can be also used for a general sensor coating layer.

# Inhibition of corrosion by online impedance monitoring and polarization



# Smart steel: CNT Graphene Primer

## Graphene-Rich Primer vs. state of the art Zn-Rich Primer



# Track and Trace intra and extra logistics

Due to the Smart Steel technology, the steel is basically protected against corrosion.

The coating can also be used actively for track & trace purposes. The steel can be monitored from production to reprocessing and the quality can be controlled.

This is particularly advantageous for the increasing quality requirements, smart production and product liability.





# Predictive and remote maintenance

In this way, the surfaces can "communicate" The layer reports its condition and need for maintenance and servicing.

In this way, new, efficient services can be developed around predictive maintenance.



Fraunhofer Institute for Manufacturing  
Engineering and Automation IPA

# Contact

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