FACULTY OF ENGINEERING AND ARCHITECTURE

INCAT
Industrial Catalysis and Adsorption Technology

LCA LABORATORY CHEMICAL ANALYSES

LCT DRIVING CHEMICAL TECHNOLOGY

DEPARTMENT OF MATERIALS, TEXTILES AND CHEMICAL ENGINEERING

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NANOTECHNOLOGY IN CATALYSIS THE FORCE AWAKENS

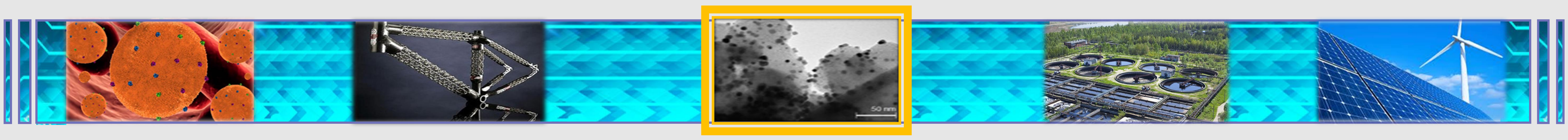
1+1=3

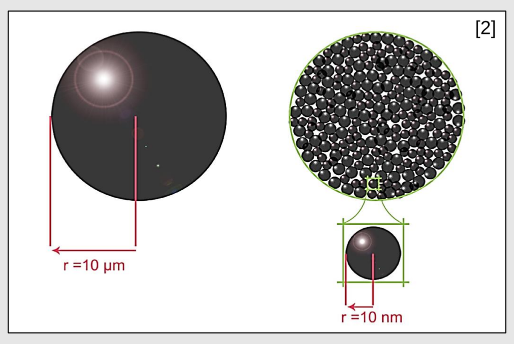
INTRODUCTION

Nanotechnology - defined as **Key Enabling Technology** in Europe - plays an important role in our society, e.g., in medicine, in sports, in water treatment applications, in energy devices and is now also emerging in the field of **catalysis**. It strongly encompasses research and development to synthesize, control, and manipulate catalytic systems of enhanced or even novel properties. These properties can be attributed to the size of the nanomaterial which is ranged in one or more external dimensions from approximately 1 to 100 nm. [1]

Focusing on the catalysis of organic reactions, **metal nanoparticles** (MNPs, preferably below 10 nm) are frequently used to enhance the catalytic performance. However, their use as catalyst requires their **stabilization** against self-aggregation and leaching. This is particularly critical for heterogeneous catalysis applications where a robust linkage between the MNPs and the support would afford better performances in terms of catalyst recovery and re-use as well as avoiding product contamination.

MEDICINE — **MANUFACTURING & MATERIALS** — **CATALYSIS** — **ENVIRONMENTAL** — **ENERGY & ELECTRONICS**

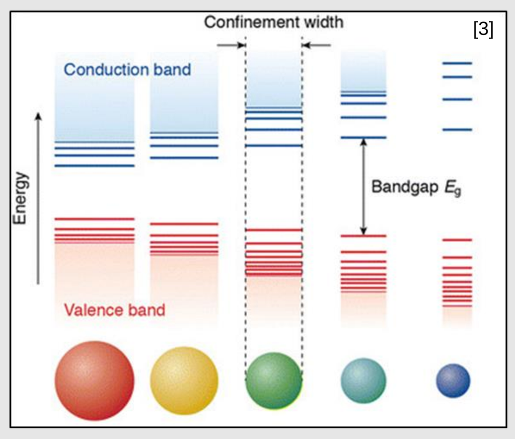




Why shifting towards 'nano' in catalyst design?

- The use of MNPs in catalytic reactions has brought **superior efficiency** in terms of **activity** and **selectivity** due to their high surface-to-volume ratio [2] and quantum confinement [3].
- The introduction of 'nano' enables the replacement of precious noble metals by catalysts tailored at the nanoscale and even by the use of non-noble metals, while preserving or outstanding the catalytic performance. As a result, the **process costs** could be **reduced** significantly.

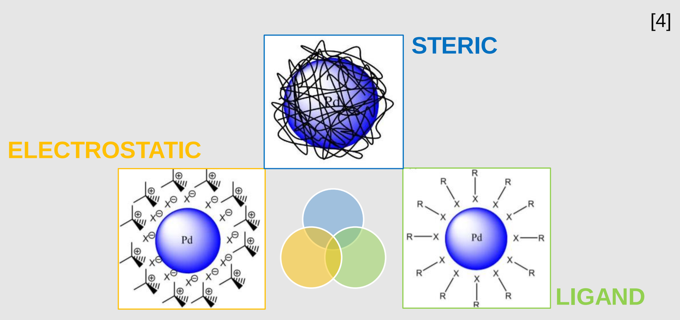
Most advances in industrial heterogeneous catalysis are based on merely enhancing the catalytic activity of supported MNP catalysts (i.e., 1+1=2). Only little is known concerning their ideal characteristics due to a lack of fundamental knowledge about the **mechanism of the interactions**. Understanding metal-support and NP size effects are necessary to enable new and useful insights in order to further tune heterogeneous catalysts, and hence, will bring incremental advances (i.e., **1+1=3**) in terms of catalytic performance to catalyzed chemical reactions in industry.



RESEARCH FOCUS

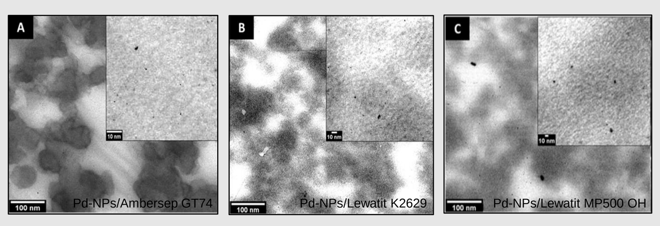
A missing link in current heterogeneous catalytic grafting designs is the lack of knowledge about the role of the support, and thus, the stabilization [4], on the catalytic performance. Therefore, this research focusses on these **metal-support interactions** as well as on **NP size effects** induced by e.g., varying the reduction temperature, the metal composition and NP structure [5].

STABILIZATION TYPES

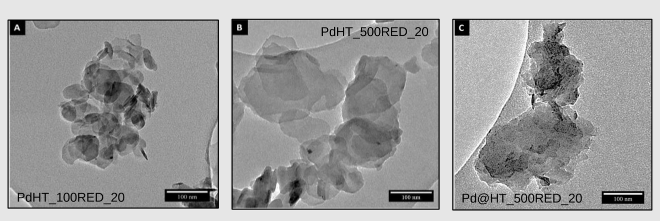


METAL-SUPPORT EFFECTS

- Effect of the resin functionality

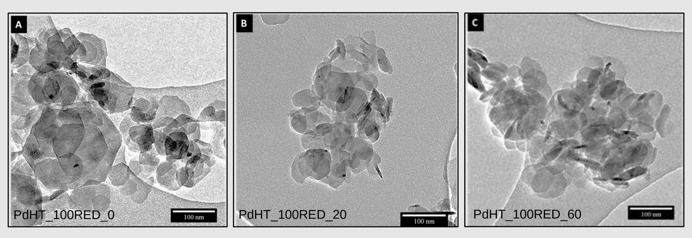


- Effect of the hydrotalcite structure

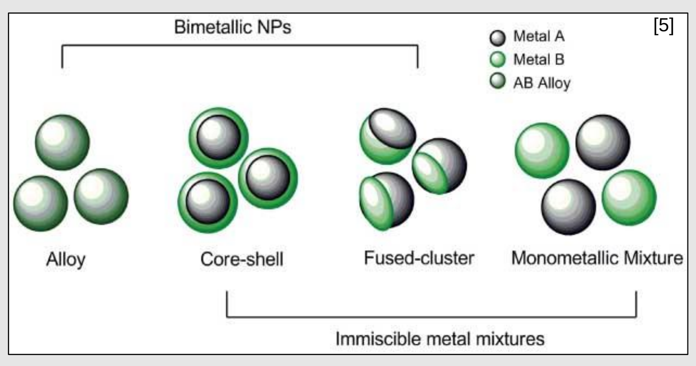


NP SIZE EFFECTS

- Effect of the reduction temperature



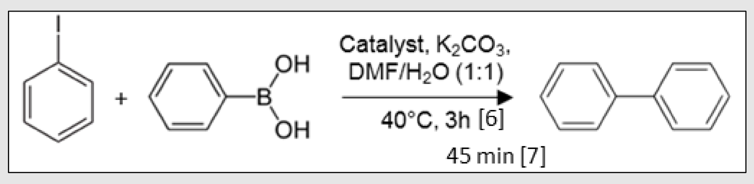
- Effect of the metal composition & the NP structure



APPLICATIONS

PHARMACEUTICAL AND FINE CHEMICAL INDUSTRIES

SUZUKI-MIYAURA CROSS-COUPLING



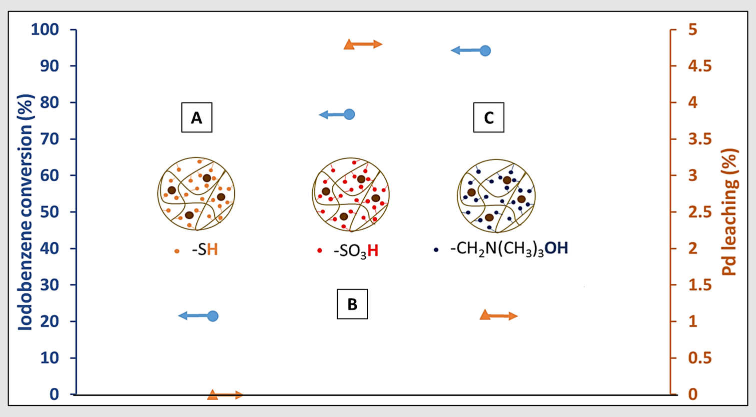


Figure 1: Catalytic activity and leaching with the proposed schematic representation of three different Pd-NPs (0.11 wt%) @resin catalysts. [6]

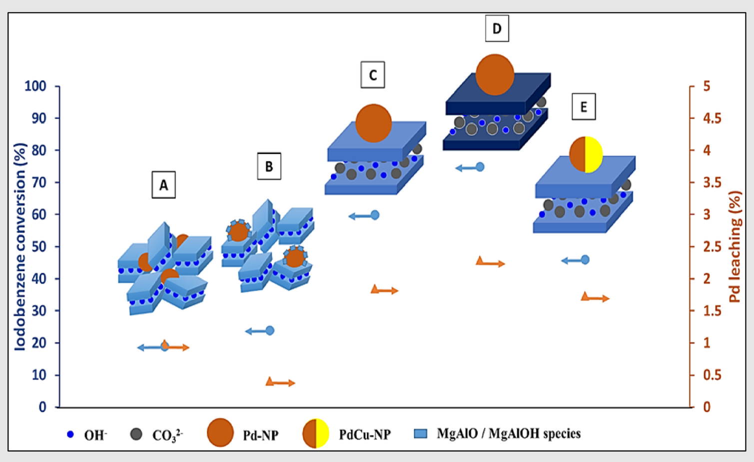


Figure 2: Catalytic activity and leaching with the proposed schematic representation of five different Pd-NPs (1.0 wt%) @hydrotalcite catalysts. [7]

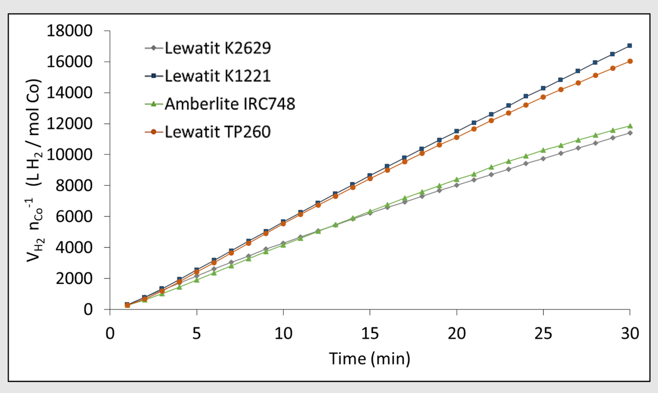
ENERGY INDUSTRY

HYDROGEN GENERATION

Catalyst, 5 wt% NaOH

$$NaBH_4 + (2+x)\,H_2O \rightarrow NaBO_2.xH_2O + 4\,H_2$$

50°C, 30 min



Resin	Functionality	Hydrogen Generation Rate ($L\ H_2\ g^{-1}\ Co\ min^{-1}$)	Co leaching (%)
Lewatit K2629	$-SO_3H$	6.6	1.48
Lewatit K1221	$-SO_3H$	9.9	1.60
Amberlite IRC748	$-CH_2N(CH_2COOH)_2$	7.0	0.96
Lewatit TP260	$-CH_2NHCH_2PO(OH)_2$	9.4	1.52

Figure 3: The volume hydrogen gas produced per mol Cobalt as function of time, the Hydrogen Generation Rates and leaching values for four different Co-NPs (6.5 wt%) @resin catalysts.

CONCLUSIONS

Based on metal-support and NP size effects, an optimized catalyst design was proposed which allows us to tune and further enhance the catalytic performance at mild reaction conditions, resulting in lower process costs.

SUZUKI-MIYAURA CROSS-COUPLING

- A strong basic functionality, positively participating in the reaction mechanism.
- An uncalcined, co-precipitated structure, causing a high accessibility of the active centers.
- More active NPs are achieved at lower reduction temperatures.

HYDROGEN GENERATION

- A strong acid functionality, co-catalyzing the hydrolysis reaction.

Contact

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[1] Kung, H.H., *et al.*, Nanotechnology and Heterogeneous Catalysis. In: Nanotechnology in Catalysis - Nanostructure Science and Technology. Springer, New York (2007) 1-11.
[2] Domènech, B., *et al.*, (2012) Bifunctional Polymer-Metal Nanocomposite Ion Exchange Materials, In: Ion Exchange Technologies. InTech, Rijeka (2012) 1-39.
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[6] Van Vaerenbergh, B., *et al.*, ChemCatChem (2017) 9, 451-457.
[7] Van Vaerenbergh, B., *et al.*, Applied Catalysis A – General (2018) 550, 236-244.

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