

Nanomaterials for energy management and electronics

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Batteries & Supercaps are electrochemical devices that can be purchased already for decades. Still, our demand is to have **increased electricity storage capacity, increased power performance, improved safety at no cost**. These requirements are often the targets of the few projects supported by FP6 and FP7, and SusChem ETP has advocated more battery innovation since 2006. Both systems typically work with charge transfer of ions and electrons, which may be enhanced by increasing the surface area where the transfer takes place. It has been shown that by reducing their structural size, **earlier disregarded materials become suddenly electrochemically active, e.g. for lithium storage**. New crystal phases can be formed having an increased lithium storage capacity. Besides, the enhanced interface area of the nanostructure allows electrons and ions to be stored in separate phases so as to form a sort of double layer capacitor. A consequence of the use of nanomaterials is an increased rate of parasitic reactions of the electrode materials with the electrolyte, which are often responsible for **capacity fading**. In order to reduce fading, novel electrolytes are suggested such as **ionic liquids**. When using indifferent nanoparticles in these electrolytes, adequate ionic conductivities will be found. Also, stabilization of the electrode surface with coatings is a well-proven concept, particularly when this coating promotes the lithium insertion processes.

Printable Electronics are already under development by academia, start-up-companies and large industry, with impressive support in FP7. Applications include all consumer products where electronic functionality is desirable but where silicon chips are cost-prohibitive, e.g. RFID price tags and functional textiles. The topic of (organic) photovoltaics is of strategic relevance for Europe, but awaits the technical proof-of-concept and deserves further collaborative research. Special pitfalls include the need for indium tin oxide replacement with transparent conductive nano-composites, which should ideally be printable. **Charge transport across interfaces** is cross-sectional research between ICT and NMP that emerged from the SusChem community as pivotal topic in many instances: charge transport from nanocomposite to ICT-device, organic to inorganic, transport to nanoscale metal contacts in low dimensions (including the toxic-replacement issue of lead-free soldering), organic crystal boundaries (with high relevance for Organic LED efficiency), device interconnects and backplanes (e.g. by CNTs grown inside zeolites). The two ETPs SusChem and Photonics21 share more key research topics for the field of **efficient lighting**, recently boosted by the EU ban of light bulbs. OLEDs have architectural advantages and capitalize on synergies with the printable electronics, but also LEDs and lasers have growth potential.

Designing and safeguarding bio-nano-interactions

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The interaction of nanomaterials with biological matter is a Janus-headed topic with great potential and some concern: One research community seeks to exploit the designed properties of engineered nanomaterials for diagnostic and therapeutic purposes. On the other side we have to verify the safety of unintentional interactions by nanomaterials in human contact or released into the environment. Both aspects share the need to understand the bio-to-nano-interactions on a molecular level.

Controlled interactions on nano-structured surfaces open major innovation routes for billion-Euro markets. If we succeed to prevent the adhesion of micro-organism, we would prevent biofouling with zero or strongly reduced biocides. An FP6 project has targeted biofouling on vessels of ships, and further opportunities include membranes in water treatment, industrial process plants. Closely related are nanostructured surfaces for medical devices, where the formation of biofilms may be prevented at zero or lower doses of antibiotics. The **controlled biokinetics of nanoparticles** involves uptake and accumulation in the human body, and enables enhanced medical imaging and smart sensors, and in a further step drug delivery by triggered release of actives.

Water treatment may benefit from **nanomembranes**, especially when coated with an organophilic or selectively absorbing layer. Regions of water scarcity are growing also in Europe. Closely related technology may help to recover precious materials in recycling, keeping in mind that several core technologies will never reach market penetration unless key elements are recovered (photovoltaics: Indium, catalysts: Palladium, batteries: Lithium).

Related to the recycling issue, the full life cycle of nanocomposite materials needs to be analyzed in more detail than before. Since recent projects with national or EU funding have provided reasonably good guidance on the **worker's safety** in nanomaterials (esp. nanoparticle) production, the focus should shift towards **consumer** and **product safety of nanocomposite materials**. Exposition levels of release by degradation, combustion, recycling need to be established and compared to the concentrations of no observable adverse effect. The same comparison must be performed for leaching issues from nanocomposites used in medical and food packaging.

Nanomaterials for construction

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Nanomaterials bring promising novelties for many applications in different sectors. Construction industry is one of the sectors that would highly benefit from these nanomaterials with **new functionalities** (air purifying, self-healing, fire resistance, self-cleaning, etc) and **enhanced performances** (durability, higher strength, etc). Directly and indirectly construction industry is one of the biggest consumers of energy resources and accordingly, emitters of greenhouse gases. Also here, nanotechnology can help the sector to reduce its **carbon footprint**.

Construction is a traditional, highly cost oriented sector which makes adoption of new materials and techniques difficult. To speed up the uptake of innovative solutions that allow for a reduced carbon emission, governments take new measures and set new regulations for construction industries' performance regarding sustainability.

Also, industry is taking action; for example through the **Smart Energy Home initiative** which aims to speed up the uptake of available technologies (nano or not) which can reduce the CO₂ emission of new or existing residential buildings. Smart Energy Home is executing a concrete set of action lines that together complement the range of initiatives already being taken by governments: subsidies, regulations and guidelines. Members of SEH are BASF, Evonik, Acciona, Roca and Philips.

Clinker, which is the most air polluting material used for cement, can either be replaced or reduced by nanomaterials. **Self-healing features in concrete** could be gained through better control of cement hydration mechanism at nanoscales. Nano TiO₂ particles present on the surface of concrete help **decreasing the air pollution** due to road traffic by converting harmful nitrogen oxide to harmless nitrates through the photocatalytic reaction triggered by UV. Coatings (electrochromic / photochromic) which include nano sized particles on glass help controlling heat reflection / radiation and light transmittance / reflection leading to **higher energy efficiency** in the buildings. Coatings that comprise nanoparticles of Al₂O₃, TiO₂, ZnO and ZrO₂ bring **self-cleaning, anti-scratch, anti-skid** and other functionalities to ceramic tiles, sanitary ware, roofs, etc.

In the main European monitoring initiative ObservatoryNano, Bax & Willems Consulting Venturing monitors the market impact of nanotechnologies in construction, transport and in textiles. In addition, B&W is acting as project office of the Smart Energy Home initiative.

Lightweight materials

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Lightweight materials play a key role in reducing fuel consumption in the **transportation** sector as well as in **heating buildings**. For this reason they make a significant contribution to lowering emissions of greenhouse gases and other pollutants that result from burning fossil fuels.

The **transport** sector accounts for by far the largest share of global oil consumption. According to the International Energy Agency, transportation consumed 51.5% of the oil used worldwide in 2003. While transportation fuel consumption is not exclusively a function of weight, with other factors such as engine efficiency and air/rolling resistance playing their part as well, **minimizing weight** through the use of **advanced materials** is a key strategy for reducing fuel consumption. An estimated 75% of vehicle energy consumption is related to factors associated with weights. There is a great potential for new **nanostructured building blocks** and functional **nanocomposites** with **improved crash and damping properties**.

In western countries the energy used to **heat buildings** represents around 43 % of total energy consumption, generating the 2nd highest amount of greenhouse gases after transportation. Europe is already a world leader for new energy efficient construction materials, alternative energy systems in the home environment and insulation. European companies have started to integrate new technologies into demonstration homes and developments. The visionary project **Smart Energy Home** addresses many of these topics. This strength and the available knowledge need to be fostered by speeding up the market uptake. The technology breakthroughs required for this include superior building **materials for construction** with **nanoporous foams for improved insulation**, and technology approaches such as **nanocoatings** for decorations, **self-healing surfaces** and **photochromic coatings** for glass.

The cleanliness of hydrogen and the efficiency of fuel cells taken together offer an appealing alternative to fossil fuels. Implementing hydrogen-powered fuel cells on a significant scale, however, requires major advances in hydrogen production, storage, and use. **Hydrogen storage** for transportation presents a major materials research challenge. Nanotechnology opens new opportunities for addressing this challenge, with the potential for high surface areas and **hybrid structures** that enable multifunctional performance. **Nonporous hybrids (MOF, COF and ZIF)** have interesting properties regarding their storage capability. Due to their great potential in **gas-sorption related applications**, this class of materials has attracted much attention in recent years.

The **prediction of lifetime for materials in aggressive high temperature environments** (e.g. in jet engines, energy conversion, chemical or petrochemical plants) is of great interest. There is definitely a substantial lack in this respect for assessing the role of environmental attack in life-time prediction. Research should therefore target the development of a life-time prediction system based on the thermodynamics and kinetics of environmental attack at high temperatures for various technical applications.