Environmental relief effects of nanotechnologies – factor 10 or only incremental increase of efficiency

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Sustainability and Innovation

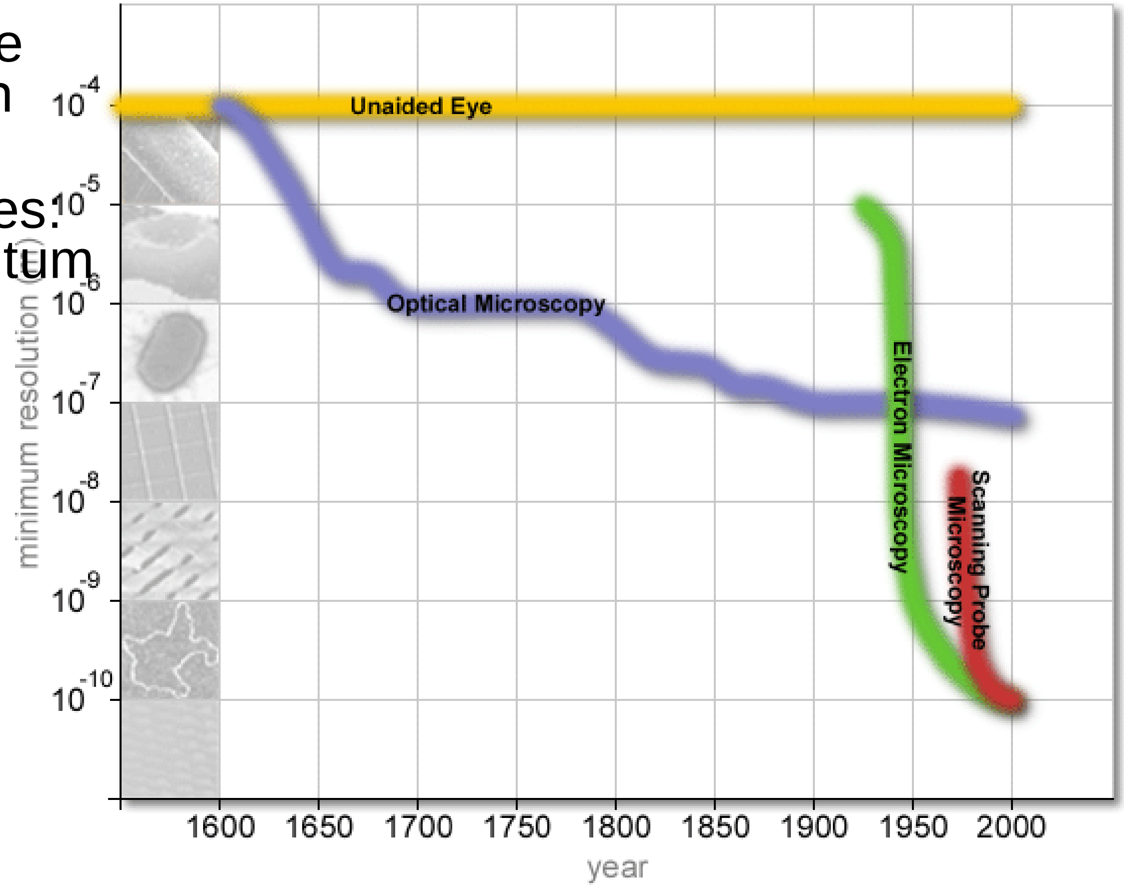
- Technological innovations will play an important role on the way towards sustainability
- But just as much institutional und organizational innovations
- Incremental innovations will not be enough
- Radical innovations (change of technological trajectories) and ‚systemic innovations' are necessary

There are reasonable expectations for environmental innovations based on nanotechnologies

Nanotechnologies

Not well defined 'umbrella term'

- Scale 10^{-9}m
- Design at molecular scale (‚atom by atom' Feynman 1959)
- New effects and properties: reactivity, catalysis, quantum effects, self organisation



Nanotechnologies and Environment

Reasonable Expectations for Environmental Innovations

Top down Nanotechnologies – Materials (increased control)

- Miniaturisation (dematerialisation)
- Designing materials (avoiding additives and alloys)
- Designing materials (wear resistant, anti-corrosive, lubrication free..)
- Designing surfaces (self-clean, thin film (organic) solar cells …)
- Catalysis (atom efficiency, specifity)
- Substitution of hazardous substances

Problems in a life-cycle view

- Material and energy input for materials purification (waste) and controlled sizes and structures (basic conditions)
- Use of ‘hazardous’ materials (cadmium selenide, lead telluride, gallium arsenide) and hazards from nanoparticles

Nanotechnologies and Environment

Reasonable Expectations for Environmental Innovations

Bottom up Nanotechnologies - Materials

(letting things grow)

- Self-organising molecules and materials (fullerenes, CNTs)
- Smart materials
- Biomimetic materials (synthetic bones, teeth, nacre; bionic adhesives and bonding)
- Self-healing materials

Problems in a life-cycle view

- Use of ‘hazardous’ materials (fullerenes, CNTs)
- Hazards from shift from self-organisation to self-replication

Environmental Nano-Innovations

Typology

End-of-pipe-technologies

- **Pollution control** (filters, membranes, catalysts)
- **Recovery and recycling** (filters, membranes, catalysts, particles)
- **Remediation** (particles)

Integrated solutions (processes, products)

- **Material choice and design for resource efficiency and recycling** (smart materials, coatings)
- **Substitution of hazardous substances** (flame retardant materials)
- **Energy conversion and efficiency** (photovoltaic, fuel cell, hydrogen storage, insulation, light weight construction, lighting and displays)

Nanotechnology-based products / applications on the market (I)

End-of-pipe Nano-Innovations

Measurement and monitoring	**nanosensors**			
End-of-pipe process, pollution control technologies	**catalysts, e.g. catalytic inverter**	**nanostructured filter systems**	**nanoporous membranes**	**photo catalysts**
Wastewater treatment	**nanostructured filter systems**	**nanoporous membranes**	**nanocoated ceramic filters**	**nanofibres**
Recovery and recycling				
Clean-up-technologies (remediation)	**catalytic active nanostructured particles and und metal oxides**		**magnetic nanoparticles**	

case-study exist

Nanotechnology-based products / applications on the market (II)

Integrated Nano-Innovations, process- / product-integrated

conductive polymers (organic metals)

UV-protection coating

anti-microbial technical facilities

process catalysts

abrasion resistance

non-stick coating

polymers with better rheology

special cements

nanoelektronics

wear protection coating

abrasion-resistant car tires

water storing granulates

easy-to-clean-coating

flame retardants

scratch-resistant coating

corrosion protection coating

wear protection lubricants

conductive foils

catalytic-clean-coating

anti-reflex coating

ferrite adhesives

fuel additives

Nano-Innovations, energy related solutions

Efficiency

OLEDs

lighting - LEDs

insulation, aerogels

Storage

ceramic separators, Li-ion batteries

Conversion

photovoltaics, thin film

case-studies exists

Anticipated nanotechnology-based applications

End-of-pipe Nano-Innovations

Measurement and monitoring

Water/ Wastewater

Air

Soil

Waste

nanosensor-networks

lower-cost nanoporous membranes

nanoscale biocatalysts, wasterwater treatment

CNT-membranes, desalination of seawater

nanoporous membranes, carbon capture

photocatalytic air- and water purification

nano-mesh

Material efficiency

lower-cost nanoporous membranes for raw materials production

smart materials

ultra rugged lightweight construction

production by self-organisation

nanocomposite, lightweight construction

bionic adhesives

nanobionics

Nano-Innovations, energy related solutions

Efficiency

OLEDs

quantum dot-LEDs

insulation nanofoams

FEDs

Storage

efficiently hydrogen storage

high-performance Li-ion batteries

supercapacitors

very high-performance batteries

fuell cells (mobile, heater)

thermoelectricity

Conversion

nanojets

photovoltaics, organic

thermophotovoltaics

photovoltaics, thin film

photovoltaics, quantum well / quantum dot

artificial photosynthesis

photovoltaics, dye

Market entry, rather at short notice | Market entry, rather in the long term | Conceptions

(yellow highlight:) case-studies exists

Comparative Life Cycle Ecoprofiles of Nano Innovations

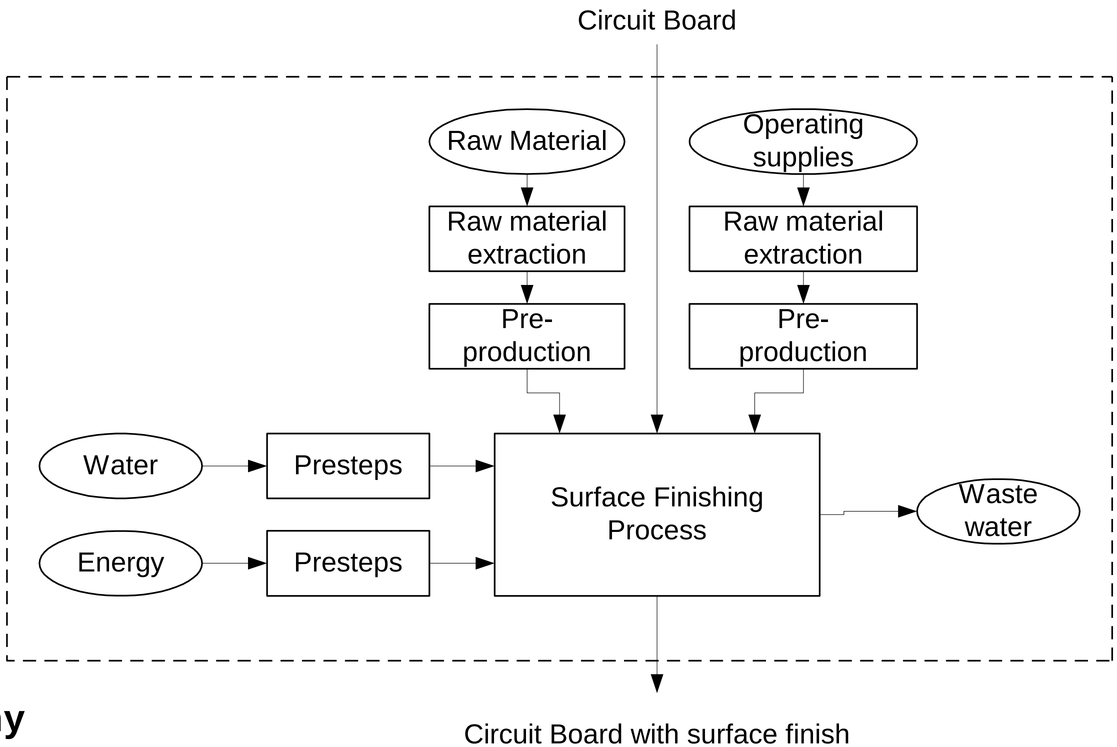
- based on the life cycle assessment (LCA) methodology
- only ecoprofiles (no real LCA) due to lack of data in early stages of innovation
- focus on the potential environmental relief provided by nanotechnology products and processes
- risk aspects, particularly in dealing with nanomaterials, are examined in form of a preliminary assessment

Case study: Surface Finishing of Circuit Boards
(prepared for soldering)

Variants (vertical/horizontal):
conventional
HASL: Hot Air Solder Leveling
ENIG: Electroless Nickel/ Immersion Gold
Im Ag: Immersion Silver
Im Sn: Immersion Tin
OSP: Organic Solderability Preservative

nanotechnology-based
OM Nanofinish: Organic Metal (nanoscale polyanilin) plus silver

System limits for the comparative life cycle assessment

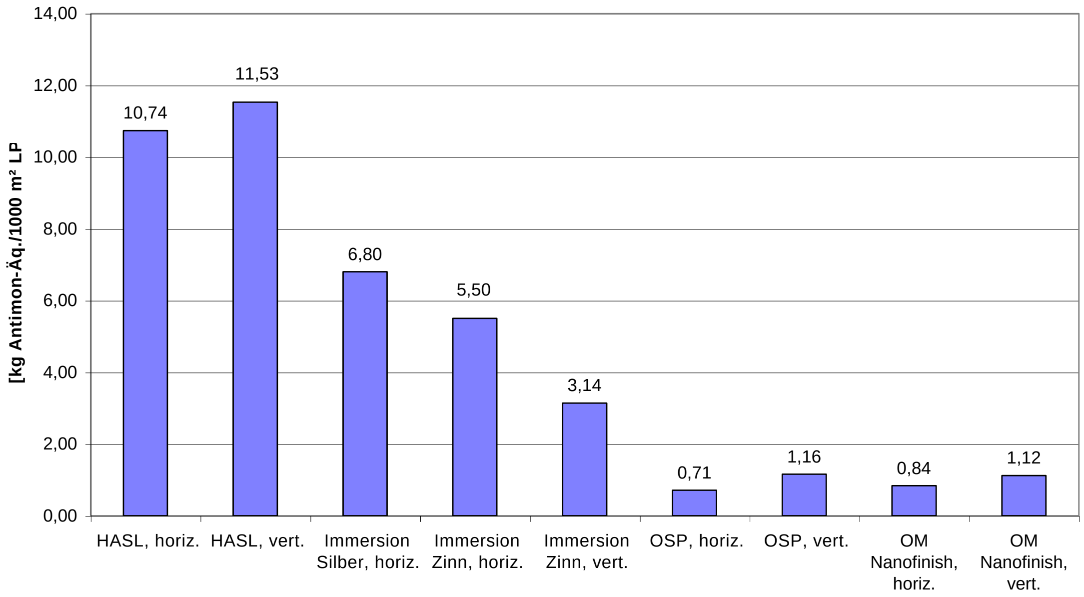


Basic data from a EPA study and data from Ormecon GmbH, Germany

Selected results: (see also poster session)

Abiotic resource consumption (ENIG: 411,91 kg Antimon-Eq./1000 m² CB!!!)

OSP and OM Nanofinish have significantly lowest abiotic resource consumtion



The fields of application of OSP are not in high-grade production, rather in the mass markets (**quality differences)**

- A reduction of > 90% in the metal demand compared to metallic surface finishes
- A reduction of 50 – 95% in the energy demand
- A reduction of around 70% in the water demand
- A reduction of > 80% in the greenhouse potential compared to metallic surface finishes ...

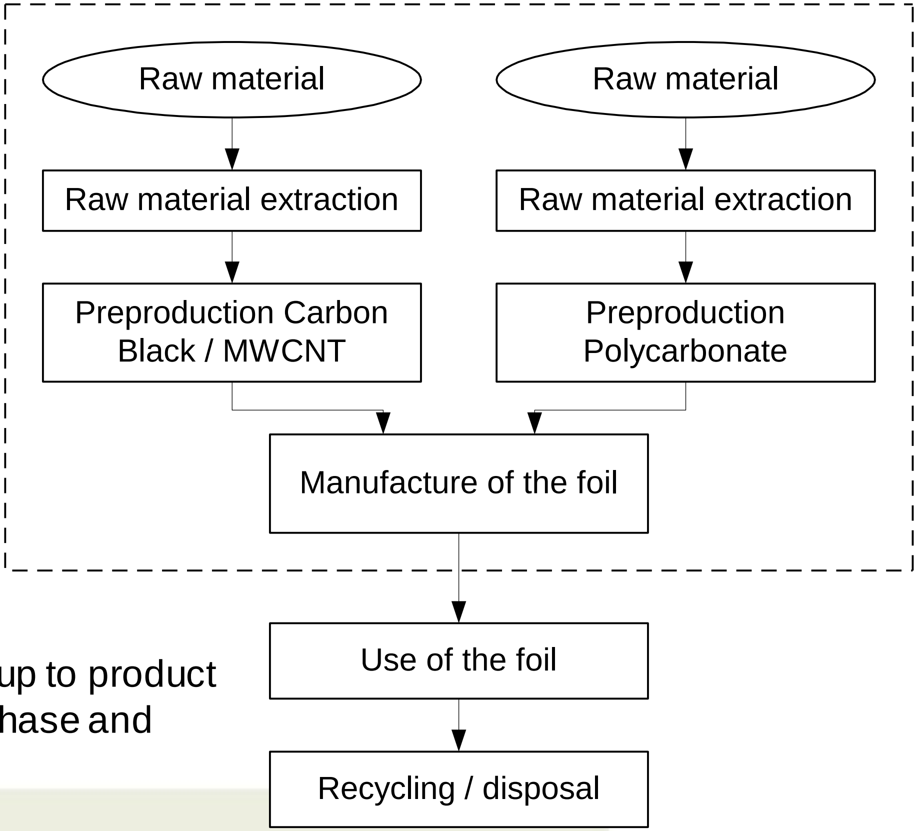
Source: Steinfeldt et al. 2010

Case study: Conductive Plastic Foil with MWCNT
(Baytubes) in semiconductor industry

Variants:

	Foil,old with Carbon Black	Foil, new with MWCNT
Main component	Polycarbonate, 85%	Polycarbonate, 97%
Additive	Carbon Black, 15%	MWCNT, 3%
Necessary foil thickness	100%	Reduced foil thickness, 80%
Manufacture of foil	Deep-drawing	Deep-drawing
Functional equivalence	1000kg	800kg

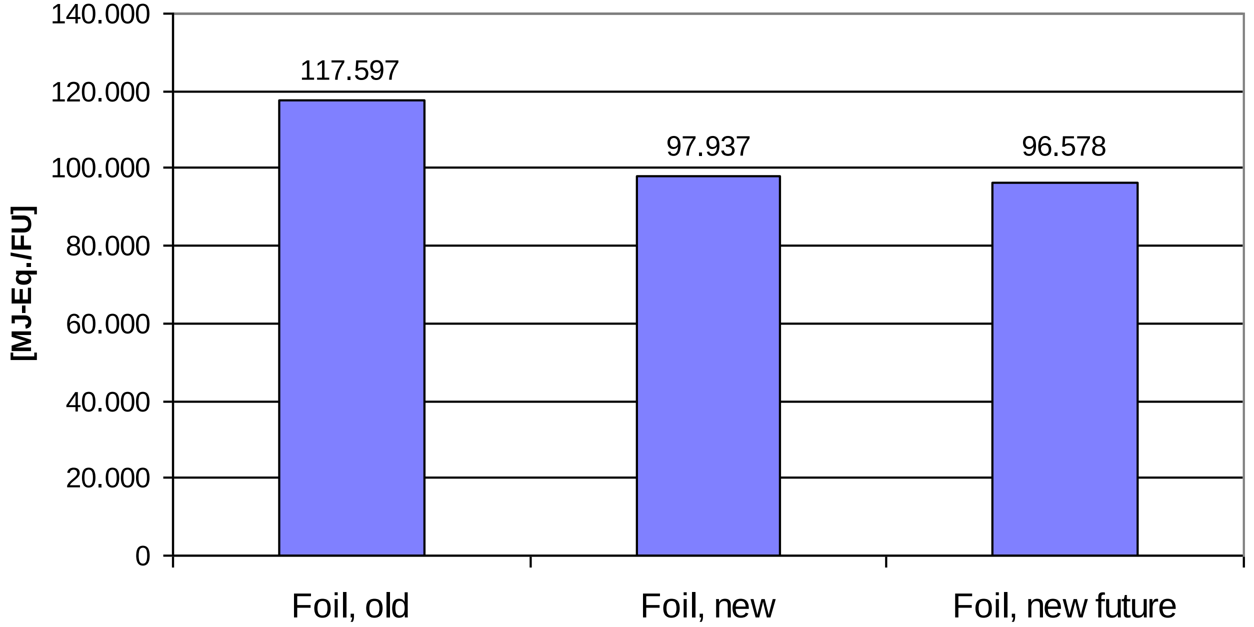
System limits for the comparative life cycle assessment



System boundaries only supply chain up to product (incl. MWCNT production - excl. use phase and incineration)

Select results:

Primery energy consumption old foil vs. new foil: – 17%



Future: Production of MWCNT in large scale plant

Global warming potential old foil vs. new foil: – 12,5 – 13%

Eutrophication potential old foil vs. new foil: – 20%

……

Source: Steinfeldt et al. 2010

Case study: Eco-efficient Nanocoatings

Coating of aluminium

Variants:

conventional

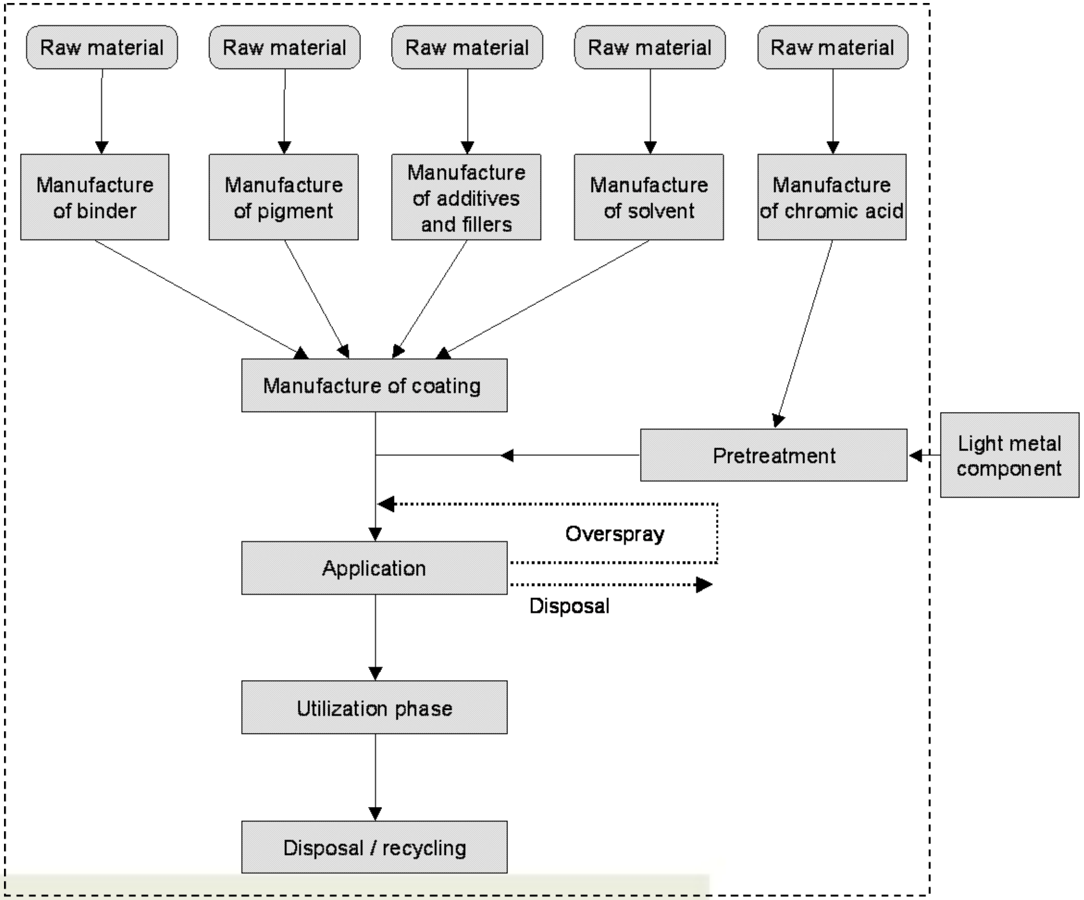
- **1 component clear coat (1 KKC)**
- **2 components clear coat (2 KKC)**
- **Water based clear coat (Water CC)**
- **Powder clear coat (Powder CC)**

nanotechnology-based

- **Nano clear coat (Nano-coat) (Nano Tech Coatings, sol-gel technology)**

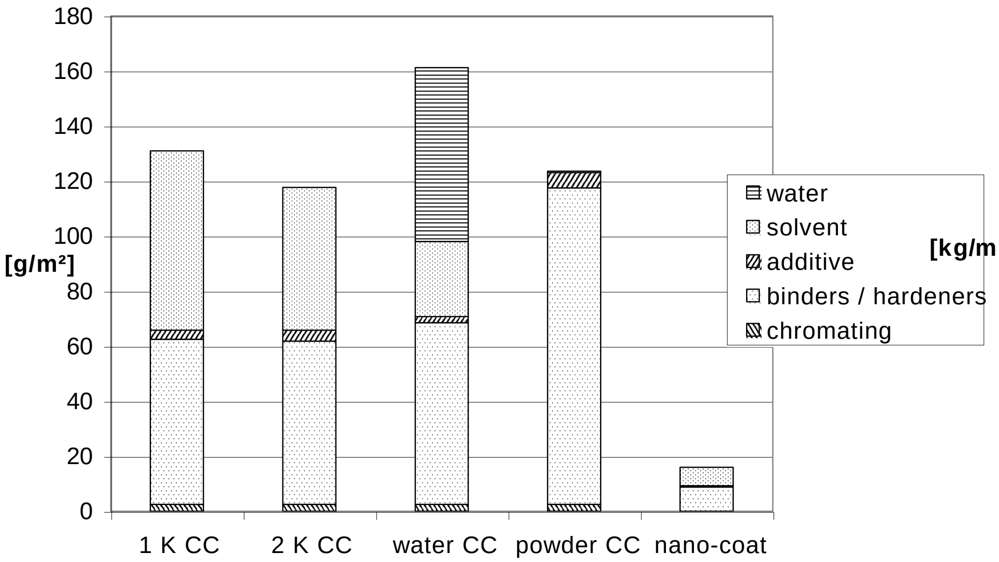
=> Critical: ‚chromate‘ in pre-treatment not necessary for ‚nano clear coat‘

System limits for the comparative life cycle assessment

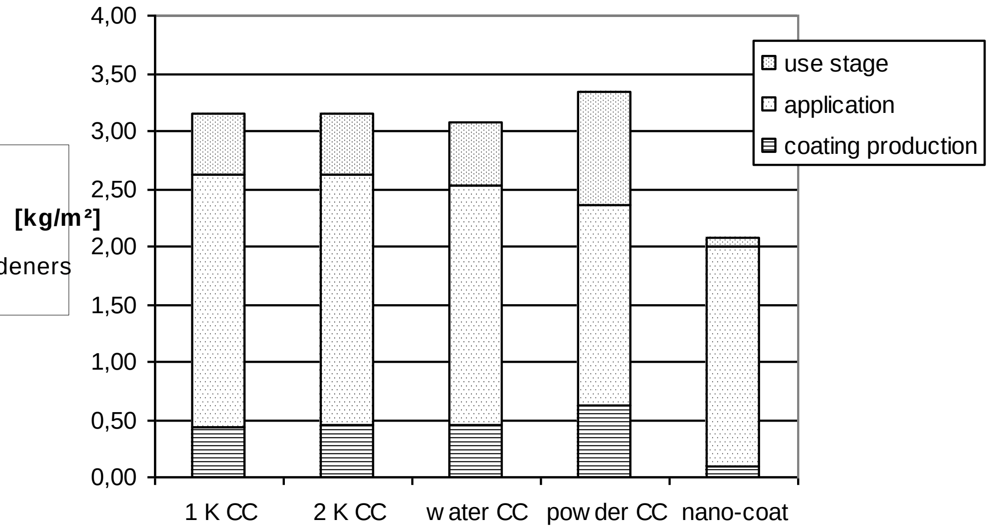


Selected results:

Coating and Chromating Quantities
(g/m² coated aluminum automobile surface area)



Global Warming Potential
(kg/m² coated aluminium automobile surface area)



Source: Steinfeldt et al. 2007

Case study: Nano-applications in Lighting

Variants:

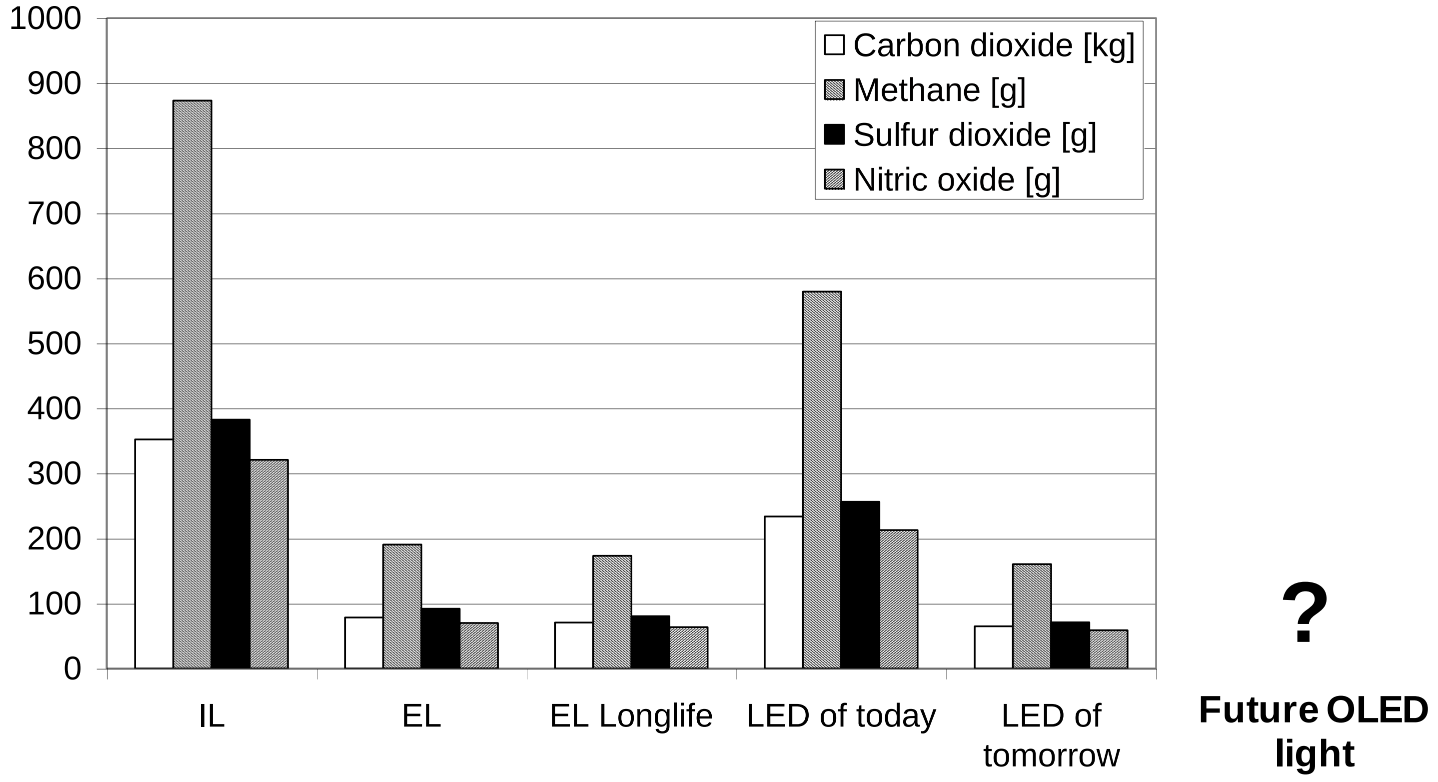
- 1 incandescent lamp (IL)
- 2a energy-saving lamp (compact fluorescent) (EL)
- 2b energy-saving lamp, longlife (compact fluorescent) (EL Longlife)
- 3a white light-emitting diode of today (LED of today)
  3a white light-emitting diode of tomorrow (LED of tomorrow)

- (4) Future: OLED light ? => so far no data available

=> 97−99% of the life-cycle energy consumption in the use phase

=> Materials consumption, in comparison, is of much lesser consequence

Selected emission quantities of the case-study variants relative to the RLQ



Reference light quantity (RLQ): 6.579 million lumen hours

Source: Steinfeldt et al. 2007

Conclusions

- The potential and prospects for reducing environmental load by nanotechnological products and processes depends on the type and level of innovation (nanotechnology generation, incremental vs. radical, end-of-pipe vs. integrated)
- A varying potential for gains in resource efficiency could be shown and quantified in the case studies (also in life cycle view), but also a great lack of data
- Today mostly nanotechnological-based applications on the market are incremental innovations
- Many applications with higher level of innovation still in the development, the ‘classical’ **Eco-Efficiency** must be still examined in the future

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Selected projects, publications and links:

- Steinfeldt, M.; Gleich, A. von; Petschow, U.; Pade, C.; Sprenger, R.-U. (2010): **Entlastungseffekte für die Umwelt durch nanotechnische Verfahren und Produkte (Environmental Relief Effects through Nanotechnological Processes and Products).** UBA-Texte 33/2010, Dessau.
- German NanoCommission: **Responsible Use of Nanotechnologies – Report and Recommendations of the German Federal Government‘s NanoKommission for 2008,** Bonn 2009 http://www.bundesumweltministerium.de/files/pdfs/allgemein/application/pdf/nanokomm_abschlussbericht_2008_en.pdf
- Gleich, A. von; Steinfeldt, M.; Petschow, U. (2008): **A suggested three-tiered approach to assessing the implications of nanotechnology and influencing its development.** In: Journal of Cleaner Production, 16 (8), p.899-909.
- Steinfeldt, M.; Gleich, A.von; Petschow, U.; Haum, R. (2007): **Nanotechnologies, Hazards and Resource Efficiency.** Springer Heidelberg.
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- Haum, R.; Petschow, U.; Steinfeldt, M.; Gleich, A. von (2004): **Nanotechnology and Regulation within the Framework of the Precautionary Principle.** Schriftenreihe des IÖW 173/04, Berlin