
DTU

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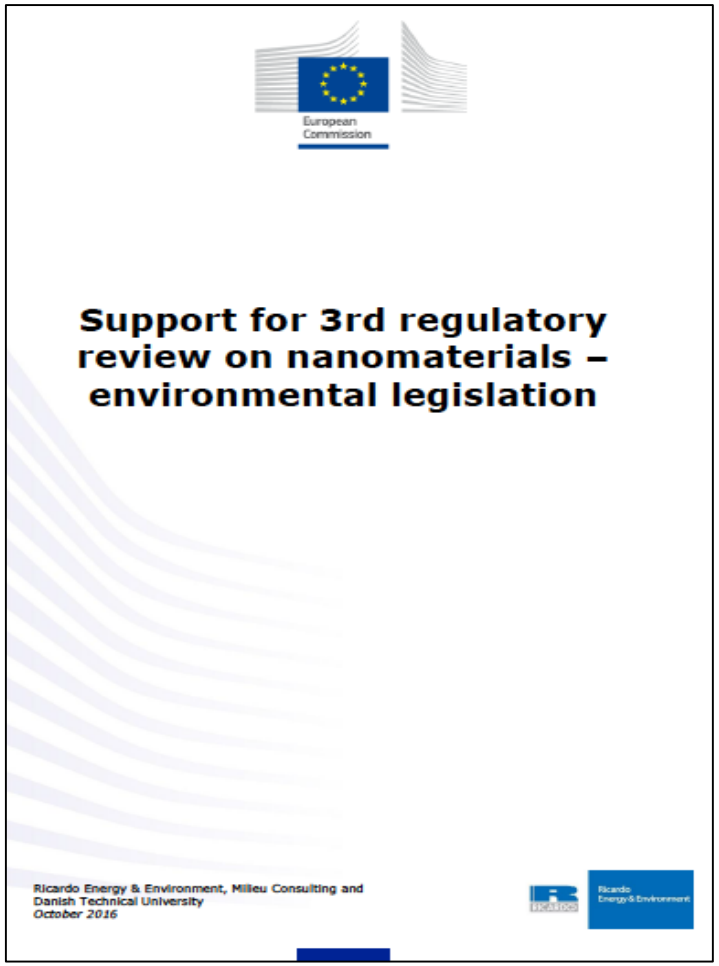
Kategorisierung von Neuartige Materialien

Background



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Scope

Prospective view regarding advanced materials

- Determine classes and definitions of advanced materials
- Estimate exposure potential and future envrionmental presence
- Provide regulatory review
- Identify gaps and provisions of recommendations

Methodology

+

Expert Interviews

What are AMs?

- No formal definition
- A few in the literature
- Commonalities
  - High value-added products
  - Novel and unique functionalities
  - Improved properties
  - Superior compared to traditional materails

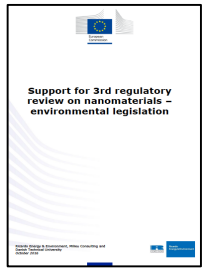


Table 14: Overview of the definitions of Advanced materials identified in this study

Institution/entity/author	Definition
UK Technology Strategy Board[245]	Materials, and their associated process technologies, with the potential to be exploited in high value-added products
UK Technology Strategy Board *cited in* Featherston and O'Sullivan[246]	Materials designed for targeted properties. Both completely new materials such as graphene or high temperature superconductors and those that are developments on traditional materials such as alloys or composites may be described as an advanced material. Such materials show novel or improved structural (strength, hardness, flexibility) and/or functional properties (electronic, magnetic, optical).
National Institute for Standards and Technology[247]	Materials that have been developed to the point that unique functionalities have been identified and these materials now need to be made available in quantities large enough for innovators and manufacturers to test and validate in order to develop new products.
Rensselaer[248]	All new materials and modifications to existing materials to obtain superior performance in one or more characteristics that are critical for the application under consideration. Advanced materials are materials that are early in their product and/or technology lifecycle, that have significant room for growth in terms of the improvement of the performance characteristics (technology lifecycle) and their sales volume (product lifecycle.)
Lukkassen and Meidell [249]	High-performance materials or advanced engineering materials, which are used in products that must have superior properties (extreme service environments, superior chemical resistance, wear resistance, and loading properties)
DAMADEI[250]	An advanced material is any material that, through the precise control of its composition and internal structure, features a series of exceptional properties (mechanical, electric, optic, magnetic, etc) or functionalities (self repairing, shape change, decontamination, transformation of energy, etc) that differentiate it from the rest of the universe of materials; or one that, when transformed through advanced manufacturing techniques, features these properties or functionalities.

Classical classification of AM

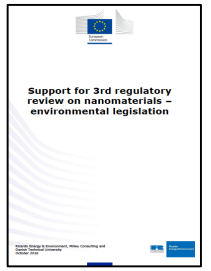
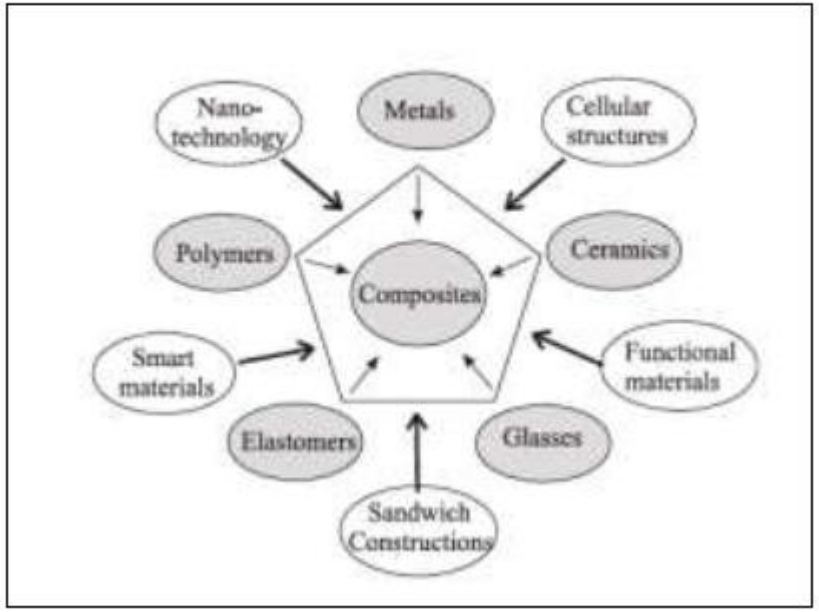
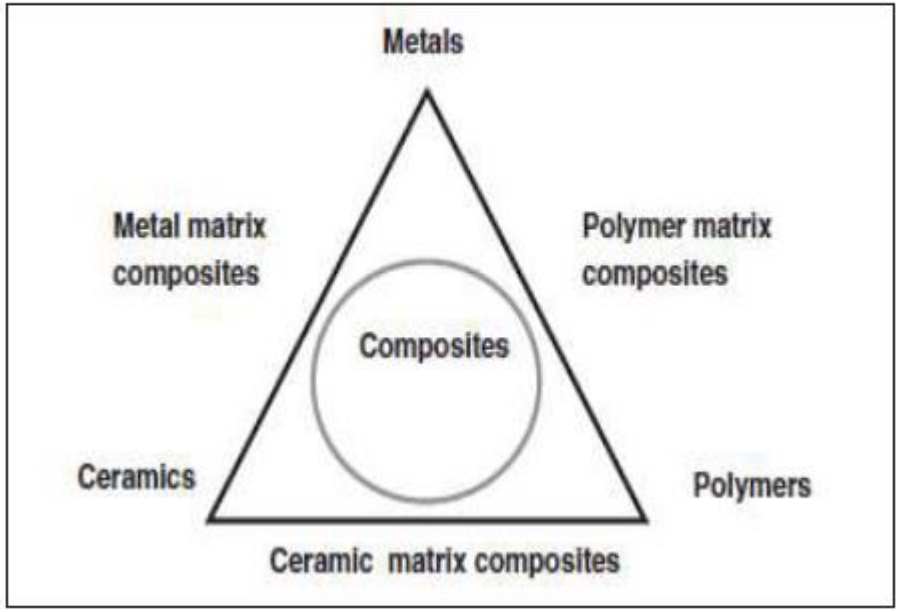


Table 15: Classical schemes for advanced materials classification (Source: Lukkassen and Meidell[258] and Baykara et al.[259])

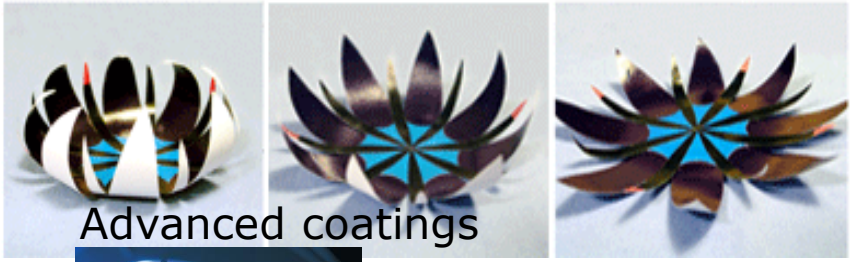




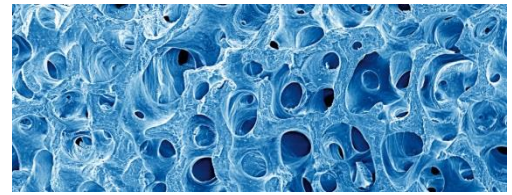
Multifunctional AM

C o

Active materials

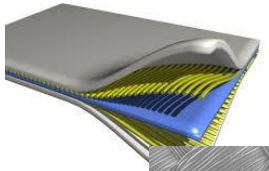


Biomaterials



Advanced coatings

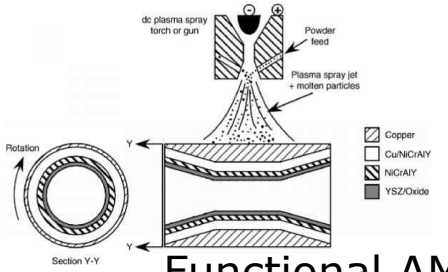
Composites



Po

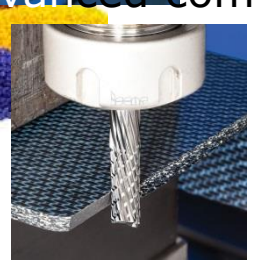
Structural AM

Functional (FGM) gradient

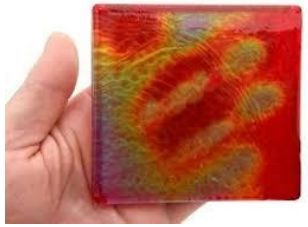


Advanced composites

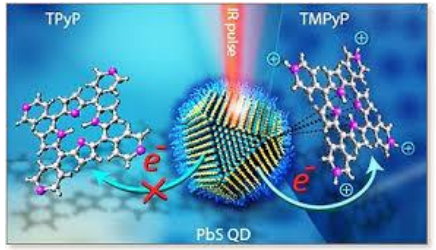
Advanced Textiles & Fibers



Smart materials



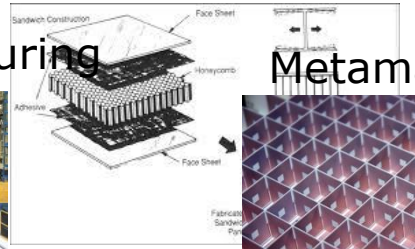
Functional AM



Nanotechnology

Cellular solids and structures

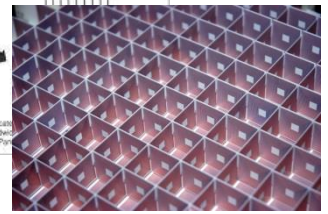
Sandwich constructions



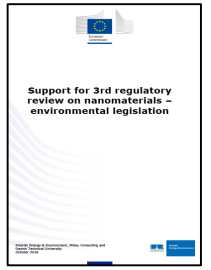
Metal Alloys

Advanced manufacturing

Metamaterials



AM categorizations id’ed



- Table 16: Categorisation of Advanced Materials based on Lukkassen and Meidell (2007)
- Table 17: Categorisation of Advanced Materials based on Technology Strategy Board (2008)
- Table 18: Categorisation of Advanced Materials based on DAMADEI (2013)
- Table 19: Potential categorization and definitions of key categories of Advanced Materials based on MatSEEC (2013)

Table 17: Categorisation of Advanced Materials based on Technology Strategy Board[265]

Category	Definition	Examples
Structural	n.a.	Metals, metallic alloys and metal matrix composites (MMC); polymers and polymer matrix composites; ceramics and ceramic matrix composites; together with concretes, glasses and natural materials, e.g. wood.
Functional	Materials which generally exhibit some non-structural properties	Electronic, magnetic or optical, and are incorporated into associated functional devices and systems; for example, microelectronics, photonics and electrical machines.
Multifunctional	n.a.	Damage tolerant, self-diagnostic and self-healing materials; fully-integrated structural/power generating materials.
Biomaterials	Materials applied to a biological system or materials derived from a biological source. In some cases, these may be combined.	Bioresorbables and bioactive materials, together with novel manufacturing routes to achieve new properties in existing materials; new interfacial structures for the control of biomaterial-tissue interactions; and the integration of sensing systems into biomaterials for in-situ implant monitoring; biopolymers and biomass-generated polymers including celluloses, starches, chitosan and proteins
Nanotechnology	Less than 100 nm.	Thin films and surface coatings (1-D); nanotubes, wires and fibres (2-D); and nanoparticles, quantum dots and nanocrystalline materials (3-D).

MatSEEC

Table 19: Potential categorization and definitions of key categories of advanced materials

Category	Definition	Examples
1. Multi-functional materials	Structural materials designed to have integrated electrical, magnetic, optical, locomotive, power generative, and possibly other functionalities that work in synergy to provide advantages that reach beyond that of the sum of the individual capabilities[287].	Thin-Wire Plasmonic Composites, Thermo-reversible cross-linked polymer, sensors for structural health monitoring[288]
2. Multistructural materials		
3. Metamaterials and artificially structured functional materials	Metamaterials are engineered structures designed to interact with electromagnetic radiation in a desired fashion. They usually comprise an array of structures smaller than the wavelength of interest. These so-called meta-atoms can interact with the electric and magnetic components of light in a way that natural atoms do not.[289] Metamaterials are an arrangement of artificial structural elements, designed to achieve advantageous and/or unusual (electro-magnetic) properties[290]	Biosensors, superlensing, cloaking, light emitting diodes[291], nanocomposites with graded electrical and magnetic composites providing broadband response, anisotropic architectures using top-down 3D printing or bottom-up self-assembly and clustering; new inorganic crystalline materials with contrived permittivities and permeabilities derived from inter-penetrating lattices with decoupled magnetic and electrical field responses; and tuneable metamaterials where external magnetic or electric fields, temperature or even light are used to contrive anisotropic properties gradients or variable frequency response.[292]
4. Nano-enabled materials in metallurgy, forestry, energy	Materials improved enabled the use of some form of nanotechnology	Nanoscale magnetic material mixtures, doped, micro- and nanostructured high-ZT thermoelectric alloys, nanostructured energetic metal/alloy powders, novel

MatSEEC, 2013, Materials Science and Engineering Expert Committee (MatSEEC) Materials Science and Engineering in Europe: Challenges and Opportunities Science Position Paper http://www.esf.org/fileadmin/Public_documents/Publications/MatSEEC_ChallengesOpportunities.pdf

MatSEEC cont'ed

Category	Definition	Examples
efficiency, etc.		nanocrystalline metal hydrides, bulk nanostructured Al and Cu alloys[293]
5. Bio and bio-based materials	A bio-based material is a material intentionally made from substances derived from living (or once-living) organisms[294] whereas a biomaterial is defined as a substance that has been engineered to take a form which, alone or as part of a complex system, is used to direct, by control of interactions with components of living systems[295,296]	Bio-based materials include cellulose fibers, soy oil based plastic and lubricants made from vegetable oils[297] whereas biomaterials include joint replacement, bone cement, heart valves and surgical sutures[298]
6. Bio-inspired materials	Synthetic materials whose structure, properties or function mimic those of natural materials or living matter[299]	Light-harvesting photonic materials that mimic photosynthesis, structural composites that imitate the structure of nacre, and metal actuators inspired by the movements of jellyfish[300]
7. Materials for targeted surface properties		
8. Metals and alloys	Metals and alloys are materials that are typically hard, malleable, and have good electrical and thermal conductivity. Alloys are made by melting two or more elements together, at least one of them a metal. They have properties that improve those of the constituent elements, such greater strength or resistance to corrosion[301]	TiAl intermetallics for the use in turbine blades, aero engines and gas turbines[302]. NiAl alloy catalysts, bulk nanostructured Al and Cu alloys for advanced electrical conductors with high strength and electrical conductivity[303]
9. Ceramics,	Ceramics are inorganic, nonmetallic materials (such as carbides, oxides and nitrides) made by shaping at a high temperature. Ceramics are hard, brittle, heat- and corrosion-resistant, and most often have a crystalline structure[304]	Cement, glass, and composites including natural fibres reinforcement
10. Polymers	Polymer is already defined by OECD and in REACH Article 3(5): *"a polymer is defined as a substance meeting the following criteria: (a) Over 50 percent of the weight for that substance*	Highly stretchable autonomous self-healing elastomer[305], self-assembled block copolymers[306]. Bio-mimetic molecules, Recycled plastic boardwalks[307]

MatSEEC cont'ed

Category	Definition	Examples
	consists of polymer molecules (see definition below); and, (b) The amount of polymer molecules presenting the same molecular weight must be less than 50 weight percent of the substance". In the context of the above definition: *A "polymer molecule" is a molecule that contains a sequence of at least 3 monomer units, which are covalently bound to at least one other monomer unit or other reactant.* *A "monomer unit" means the reacted form of a monomer substance in a polymer (for the identification of the monomeric unit(s) in the chemical structure of the polymer the mechanism of polymer formation may, for instance, be taken into consideration).* *A "sequence" is a continuous string of monomer units within the molecule that are covalently bonded to one another and are uninterrupted by units other than monomer units. This continuous string of monomer units can possibly follow any network within the polymer structure.* *"Other reactant" refers to a molecule that can be linked to one or more sequences of monomer units but which cannot be regarded as a monomer under the relevant reaction conditions used for the polymer formation process.*	
11. Soft materials	Soft materials are materials that can be easily deformed by thermal stresses or thermal fluctuations at about room temperature[308]	Liquids, polymers, foams, gels, colloids, granular materials, as well as most soft biological materials[309]

Strength and weaknesses

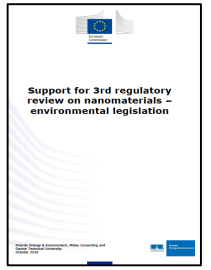
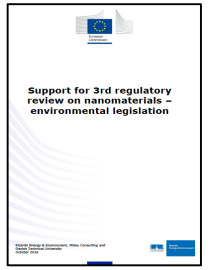


Table 20: Analysis of categorisation schemes

Categorization scheme	Clear classification?	Key characteristics sufficient?	Unique material categorization?	Internationally consistent?	Future-proof?
Lukkassen and Meidell[292]	Y	Y	N	N	Y
Technology Strategy Board[293]	N	N	N	Y	Y
DAMADEI[294]	Y	Y	N	Y	Y
Potential categorization based on MatSEEC[295]	Y	Y	Y	Y	Y

Strength a ces



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Lukkassen and Meidell[292]	Y	Y	N	N	Y
Technology Strategy Board[293]	N	N	N	Y	Y
DAMADEI[294]	Y	Y	N	Y	Y
Potential categorization based on MatSEEC[295]	Y	Y	Y	Y	Y

Environmental estimation of the future Advanced Materials (AM) presence

Want:

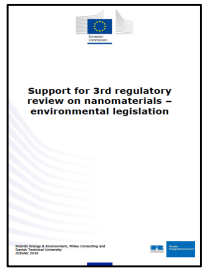
- Current AM production and use
- Emerging AM production and use trends
- Environmental release of AM

Haves:

- Marked- value (gu)estimates for some AM

Seems to be pointing in two different directions

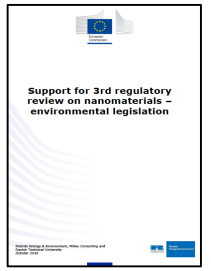
A few quotes from Expert interviews



- ”Providing **supporting evidence for an emerging trends seems in contradiction** to one another”

- “**Impossible to answer the question** of whether there are key gaps in the existing evidence with regard to fate of advanced materials”

Regulatory review of AMs



Findings from the expert consultations

- ”No knowledge”’
- ”Do not know the terms and applications”
- ”No one knows how to do this for AMs”

Part 3 Prospective view regarding advanced materials	
11. What specifications are you aware of for categorising advanced nanomaterials? What is your experience of using these definitions in dealing with regulators or other stakeholders?	N
12. Are you aware of existing data on the production or use of advanced materials?	N
13. Are you aware of any quantitative estimates related to the releases of advanced materials to the environment?	N
14. How would you describe emerging trends (with supporting evidence if available)?	N
15. What are the key gaps in the existing evidence with regard to fate of advanced materials in the environment (with supporting evidence if available)?	N
16. What is your experience with the implementation of environmental legislation to advanced materials?	N

Regulatory review

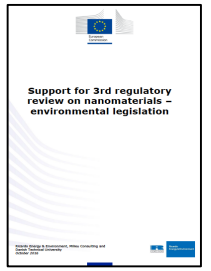
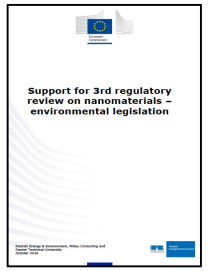


Table 1 allocating EU legislation to main categories of advanced materials

Category	Example	EU legislation	Potential legal issues
1. Multi-functional materials	Thin-Wire Plasmonic Composites	REACH, Medical Device Directive	Problems of identification under REACH?
3. Metamaterials and artificially structured functional materials	Biosensors, LEDs	REACH, RoHS and WEEE Directive	Problems of identification under REACH ?
4. Nano-enabled materials in metallurgy, forestry, energy efficiency, etc.	Nanostructured AlCu alloys	REACH, RoHS and WEEE Directive	Problems of identification under REACH ?
7. Materials for targeted surface properties		Not enough information available	Not enough information available
10. Polymers	Self-assembled block copolymers	REACH	Criteria for the registration of polymers not yet been established REACH definition of polymers may not be adequate for advanced polymers

- For most categories of AM, we do not foresee any potential legal issues

Problem with definitions?



- Polymer according to REACH

  "*Substance consisting of molecules characterised by the sequence of one or more types of monomer units*"

- Polymer according to AM literature

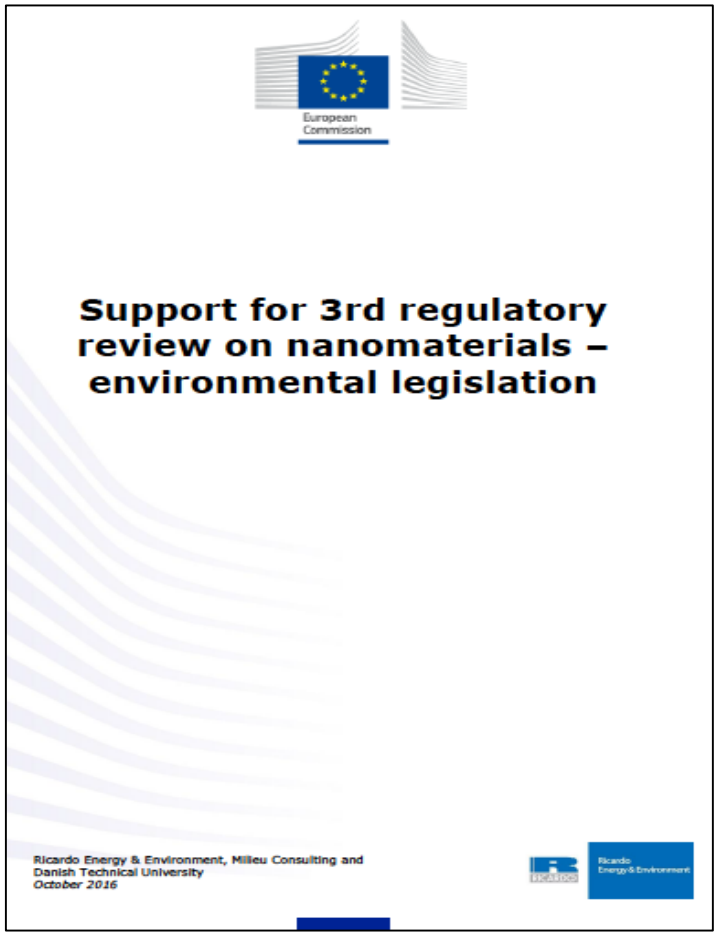
  "*Polymers modified and reinforced with bio-fibers and/or nanocharges that result in materials with very advanced properties for innovative applications*"

My ?s for U ☺

Emerging Advanced Materials (AM)

- Do we need to AM definition?
- Preferred definition of AM?
- Preferred classification of AMs
- How to assess emerging trends?
- Any regulatory gaps that we have obviously missed?

Acknowledgement



Sweden's largest nanosafety research programme – Mistra Environmental Nanosafety – launches phase two

The interdisciplinary programme Mistra Environmental Nanosafety examines environmental risks associated with nanomaterials. It focuses specifically on engineered nanoparticles, which for example are used for coatings in the construction and auto mobile industries, as well as on developing policies and risk assessments to ensure a safe and innovative development of nanotechnology in Sweden and internationally.

Thank you for your attention!

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