

# Broadening our view on nanomaterials:

*Highlighting potentials to contribute to a  
sustainable materials management  
in preliminary assessments*

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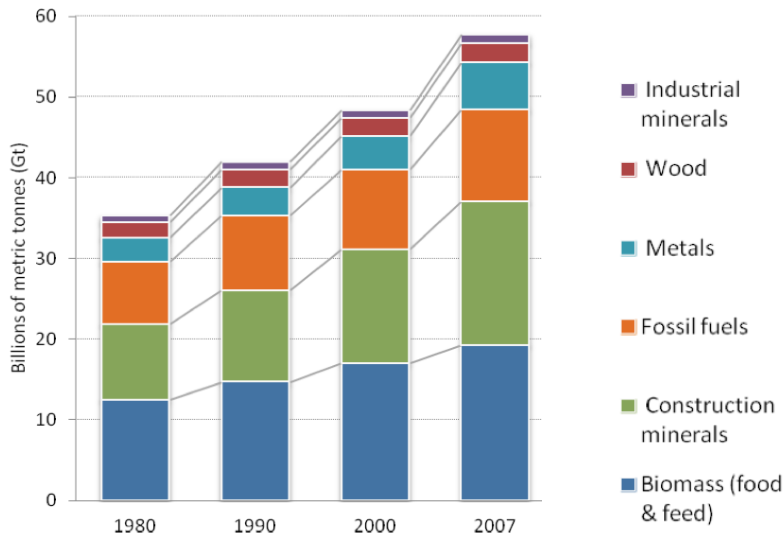
# Outline

- Background
- Role of Nanotechnology
- Sustainable Materials Management
- Framework for preliminary assessment
- Case studies
- Conclusion

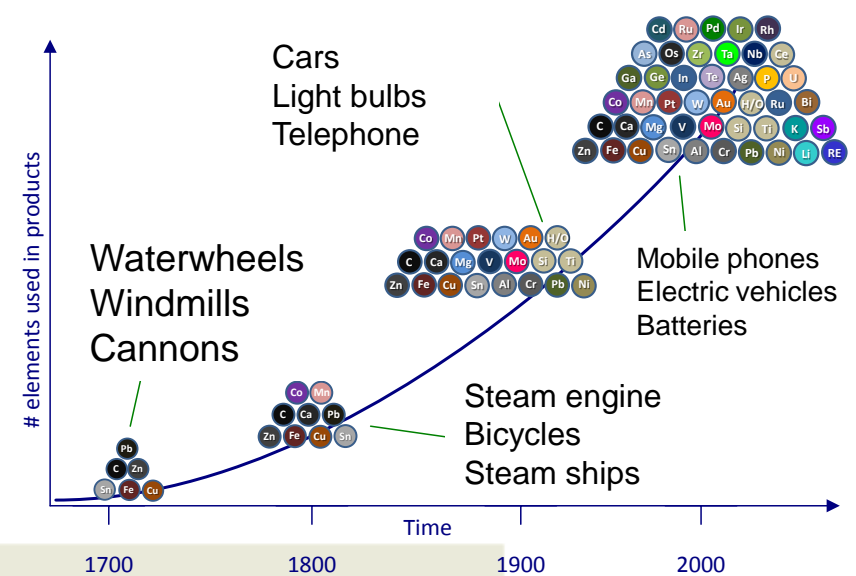
# Background and need for sustainable Materials Management

- Economic growth is related with increasing resource consumption

Global extraction of materials resources (OECD 2008)



Increasing use of a variety of elements



# Role of nanotechnology

- Nanotechnology offers many opportunities
    - New and enhanced functionalities
    - Contribution to higher efficiency (less material per product)
    - ...
  - ...but can also add higher complexity to products
    - Low amount of material
    - Higher variety of materials
    - New challenges in recycling at the end-of-life
  - Need for integrating further sustainability aspects in a comprehensive assessment
- Sustainable Materials Management in preliminary assessments

# Sustainable Materials Management

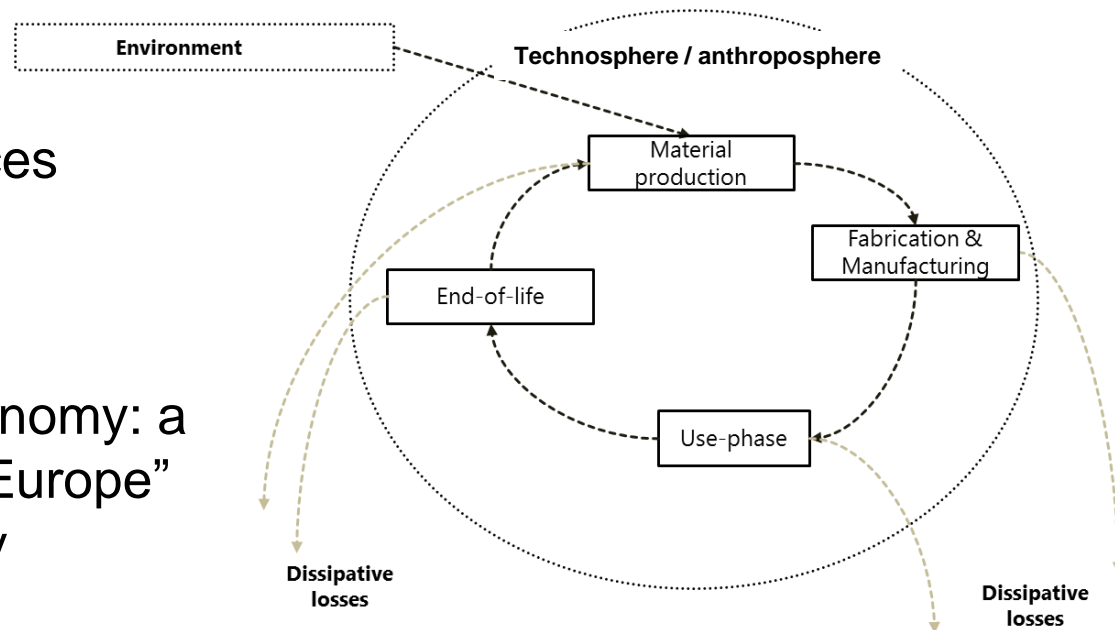
“...approach to **promote sustainable materials use**, integrating actions targeted at **reducing negative environmental impacts** and **preserving natural capital** throughout the **life cycle of materials**, taking into account **economic efficiency** and **social equity**” (OECD 2010)

## Aiming at:

- Less use of primary resources
- Circular economy
- Entire life cycle

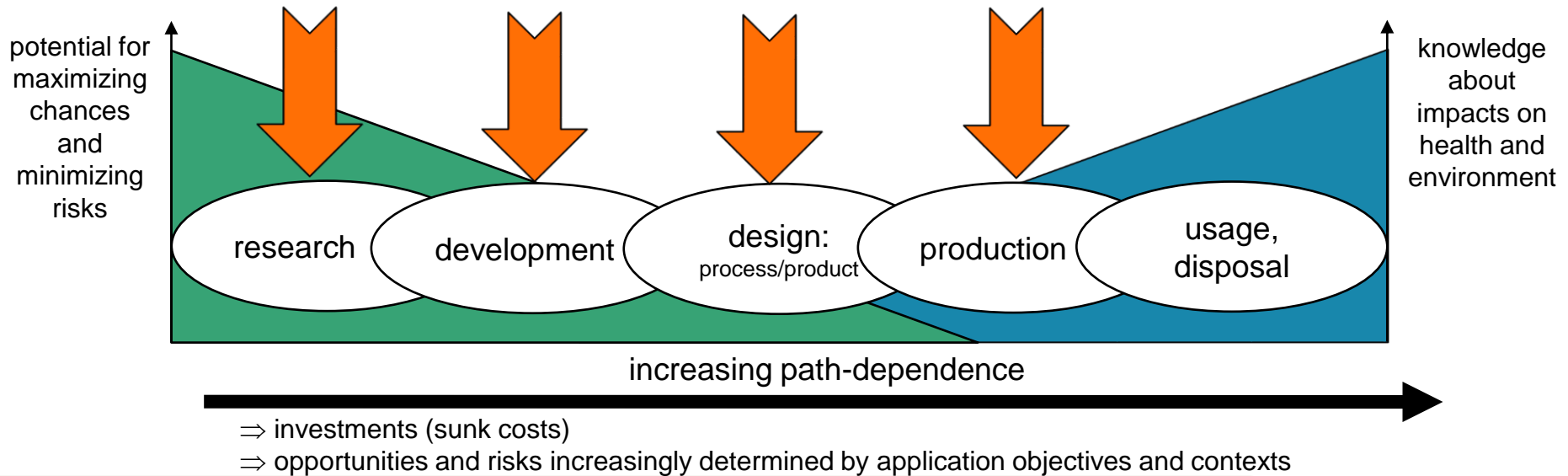
## Gained political relevance

- EC: "Towards a circular economy: a zero waste programme for Europe"
- Germany: Circular economy



# Challenges in early innovation stages

- analysis of paradigms
- guiding principles
- prospective assessment of potentials and hazards
- criteria for concerns & relief
- guiding principles
- technology characterization
- prospective evaluation of hazard and/or exposure potentials
- life cycle assessment
- toxicological analysis
- risk analysis
- life cycle assessment



# Proposed Framework categories

- Framework categories proposed to consider sustainable materials management:
  - Resource efficiency
  - Criticality
  - Dissipation and Release

# Category Resource efficiency

- Different definitions exist
  - Often narrow focus: material efficiency per functional unit
- Here: use of a broader understanding of resource efficiency:
  - Material and energy inputs,
  - Entire product life cycle including recycling, and
  - Related environmental impacts  
(i.e., emission of greenhouse gases, not comprehensively considered).



# Category Criticality

*Criticality is commonly understood as a function of a material's supply risk and its (economic) importance.*

Metal	# of criticality considerations	Color
REE	12	Red
PGM	10	Orange
Ge, In	8	Yellow
Ga	7	Light Yellow
Te, Co	6	Light Green
Li, Sb, Nb, W	4	Light Green
Ag, Se, Sn, Cr	3	Light Green
Ta, Ni, Mn, Mg	2	Light Green
Be, V, Cd, Re, Bi, Zn, Mo, Au, Sr, U	1	Light Green

- Several studies exist
- Differing in
  - Scope
  - Time horizon
  - Methodological aspects

1	H																						2	He											
	Hydrogen																							Helium											
3	Li	4	Be																																
	Lithium		Beryllium																																
11	Na	12	Mg																																
	Sodium		Magnesium																																
19	K	20	Ca	21	Sc	22	Ti	23	V	24	Cr	25	Mn	26	Fe	27	Co	28	Ni	29	Cu	30	Zn	31	Ga	32	Ge	33	As	34	Se	35	Br	36	Kr
	Potassium		Calcium		Scandium		Titanium		Vanadium		Chromium		Manganese		Iron		Cobalt		Nickel		Copper		Zinc		Gallium		Germanium		Arsenic		Selenium		Bromine		Krypton
37	Rb	38	Sr	39	Y	40	Zr	41	Nb	42	Mo	43	Tc	44	Ru	45	Rh	46	Pd	47	Ag	48	Cd	49	In	50	Sn	51	Sb	52	Te	53	I	54	Xe
	Rubidium		Strontium		Yttrium		Zirconium		Niobium		Molybdenum		Technetium		Ruthenium		Rhodium		Palladium		Silver		Cadmium		Indium		Tin		Antimony		Tellurium		Iodine		Xenon
55	Cs	56	Ba	57-71			Hf	72	Ta	73	W	74	Re	75	Os	76	Ir	77	Pt	78	Au	79	Hg	80	Tl	81	Pb	82	Bi	83	Po	84	At	85	Rn
	Caesium		Barium				Hafnium		Tantalum		Tungsten		Rhenium		Osmium		Iridium		Platinum		Gold		Mercury		Thallium		Lead		Bismuth		Polonium		Astatine		Radon
87	Fr	88	Ra	89-103			Rf	104	Db	105	Sg	106	Bh	107	Hs	108	Mt	109	Ds	110	Rg	111	Uub	112	Uut	113	Uuq	114	Uup	115	Uuh	116	Uus	117	Uuo
	Francium		Radium				Rutherfordium		Dubnium		Seaborgium		Bohrium		Hassium		Meitnerium		Darmstadtium		Roentgenium		Ununbium		Ununtrium		Ununquadium		Ununpentium		Ununhexium		Ununseptium		Ununoctium
89	La	90	Ce	91	Pr	92	Nd	93	Pm	94	Sm	95	Eu	96	Gd	97	Tb	98	Dy	99	Ho	100	Er	101	Tm	102	Yb	103	Lu						
	Lanthanum		Cerium		Praseodymium		Neodymium		Promethium		Samarium		Europium		Gadolinium		Terbium		Dysprosium		Holmium		Erbium		Thulium		Ytterbium		Lutetium						
89	Ac	90	Th	91	Pa	92	U	93	Np	94	Pu	95	Am	96	Cm	97	Bk	98	Cf	99	Es	100	Fm	101	Md	102	Np	103	Lr						
	Actinium		Thorium		Protactinium		Uranium		Neptunium		Plutonium		Americum		Curium		Berkelium		Californium		Einsteinium		Fermium		Mendelevium		Nobelium		Lawrencium						

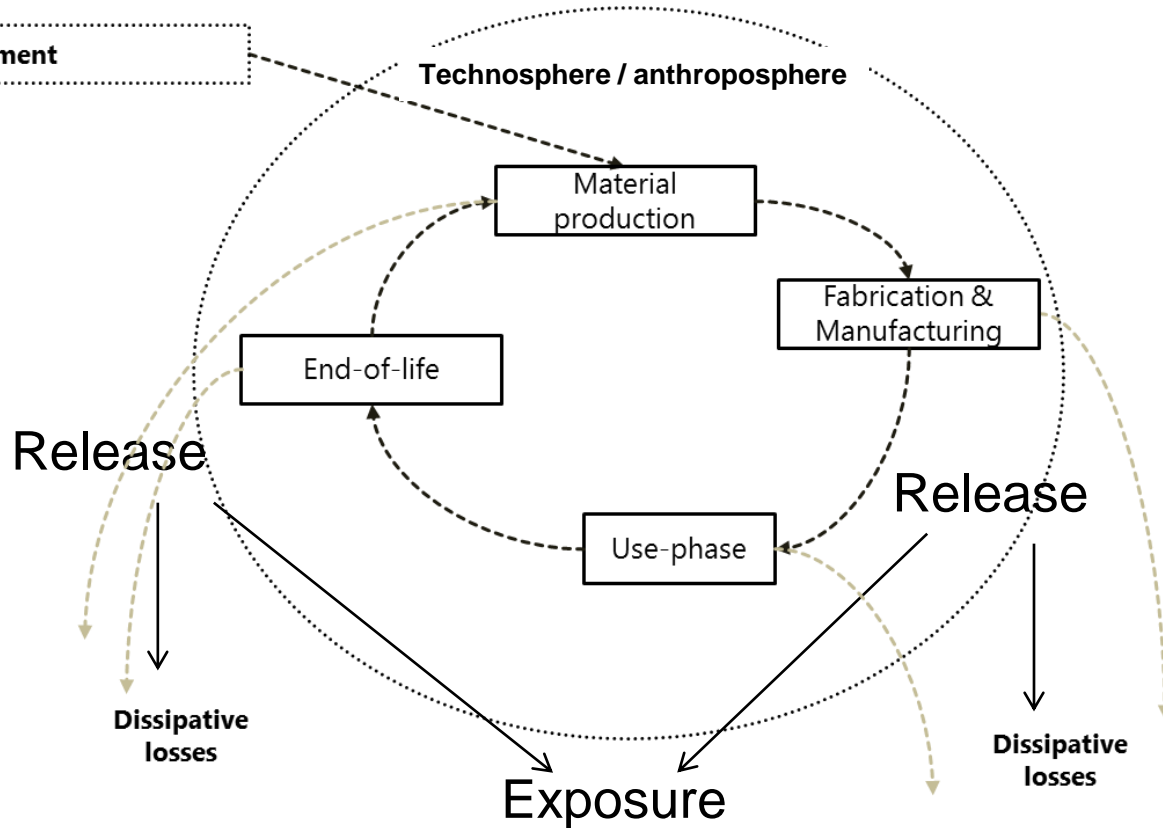
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# Category Dissipation and Release



Environment

Technosphere / anthroposphere


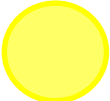
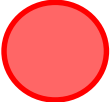



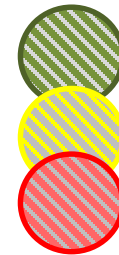
*“Releases are (intended or non-intended) emissions of a substance into the environment.”*

*“Dissipative losses are losses of material [...] such that a recovery of these materials is technically or economically unfeasible.”*

# Scoring in the Framework categories

Inspired by NanoRiskCat (EHS) by Hansen et al. (2014)

-  Probably *significant improvement* by applying NM.
-  Probably *no significant improvement* by applying NM.
-  Probably *significant deterioration* by applying NM.
-  *Insufficient information* available for a reasonable categorization, further research needed



*First indication given for the category, but further investigations for confirmation needed.*

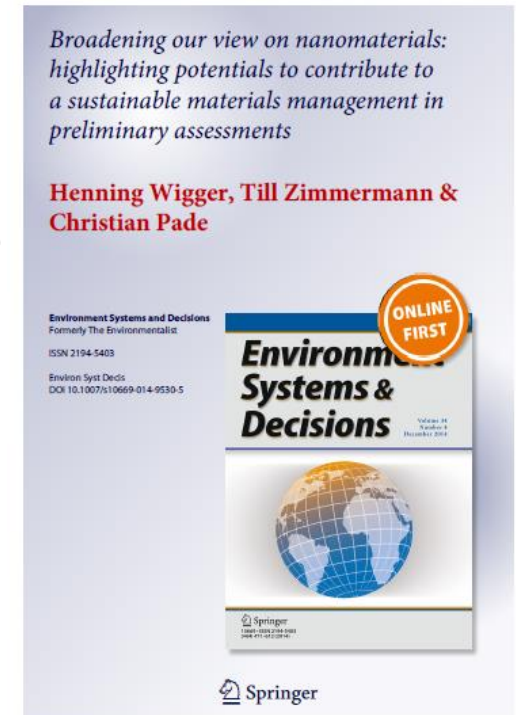
## Scoring in the categories:

- Analogous assumptions
- Precautionary manner


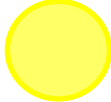





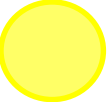
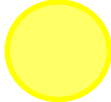
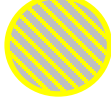

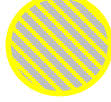
## Focus on the product

# Case studies

- **Photovoltaics**
- Permanent magnets  
(substitution of rare earth elements)
- Magnetic resonance imaging  
(substitution of gadolinium)
- Concrete  
(substitution of cement)



# Preliminary evaluation

Photovoltaic	Resource efficiency	Criticality	Dissipation & Release
Improved solar cell by plasmonic NP (Au or Ag)			
Rare earth elements-doped nanocrystals solar cells			
Si-nanowires arrays in thin film solar cells			
Substitution of gallium and indium with zinc and tin nanocrystals in thin film solar cells			

# Conclusions

- Need to broaden the view on nanomaterials
- Proposed framework for orientation can be used especially in preliminary assessments
- Dissipation and release not improved at all in the considered case studies
- Future studies should
  - also include other sustainable aspects (societal, economical) and
  - consider a weighting of the categories

# Discussion & Contact

## Thank you for your attention!



### Contact:

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### Further reading:

*Broadening our view on nanomaterials:  
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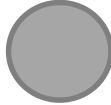


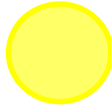
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# Other preliminary results

Case study	Resource efficiency	Criticality	Dissipation & Release
Permanent magnets (Substitution of rare earth elements)			
Magnetic resonance imaging (Substitution of gadolinium)			
Concrete (reduced cement use through carbon nanotubes)	