นาโนเทคโนโลยีเพื่อ
ความปลอดภัยและยั่งยืน

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งานสร้างความตระหนักสู่สังคม (NSA)

ศูนย์นาโนเทคโนโลยีแห่งชาติ (NANOTEC)

สำนักงานพัฒนาวิทยาศาสตร์และเทคโนโลยีแห่งชาติ (สวทช.)

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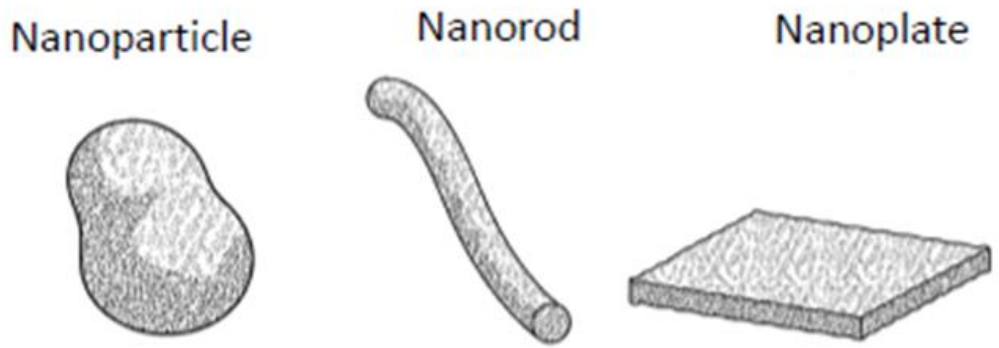
Nano definition

ISO/TS 27687:2008 **(revised by ISO/TS 80004-2:2015)**

Nanoscale: size and range from approximately 1 nm to 100 nm

Nano-object: material with one, two or three external dimensions in the nanoscale



Regulation (EC) No 1223/2009:

Nanomaterial means an insoluble or biopersistent and intentionally manufactured material with one or more external dimensions, or an internal structure, on the scale from 1 to 100 nm

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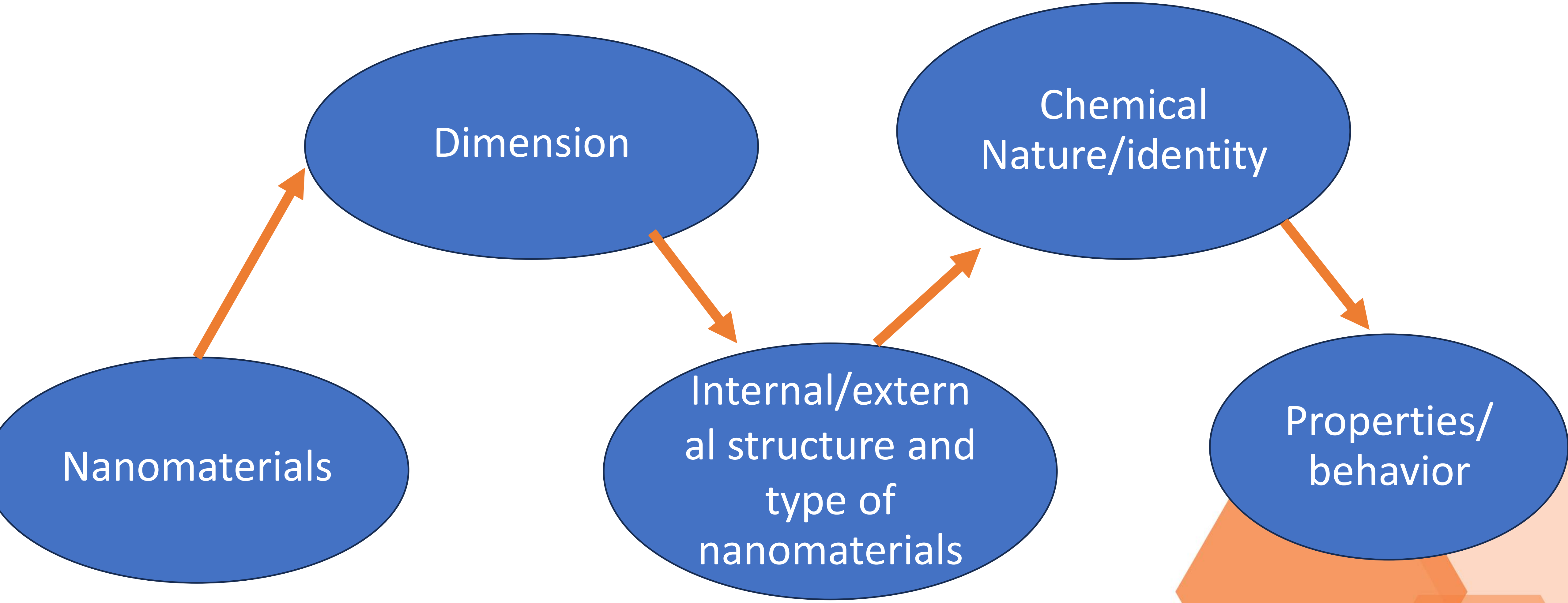
Category base on dimension



1 Dimension (1D)

Single- Component nanoobjects
- Nanolayers and Nanofilms
- Nanoplates

Multi- Component nanoobjects
- Nanolayers and Nanofilms
- Nanoplates

Nanostructure materials
- Nanocomposites (e.g. Nanoclay)

2 Dimension (2D)

- Single- Component nanoobjects
  - Nanofibers
  - Nanotube
  - Nanorod
  - Nanowires
- Multi- Component nanoobjects
  - Nanofibers
  - Nanotube
  - Nanorod
  - Nanowires
- Nanostructure materials
  - Nanocomposites (e.g. Nanotube composites)
  - Future Development

3 Dimension (3D)

- Single- Component nanoobjects
  - Nanoparticles
  - Nanocapsule
  - Quntum dots
  - Dendrimers
  - Fullerenes
  - Diamondoids
  - Nano-onions
- Multi- Component nanoobjects
  - Nanoparticles
  - Core-Shell
- Nanostructure materials
  - Bulk nanoporous materials
  - Bulk nanocrystalline materials
  - Bulk nanocomposites
  - Future Development

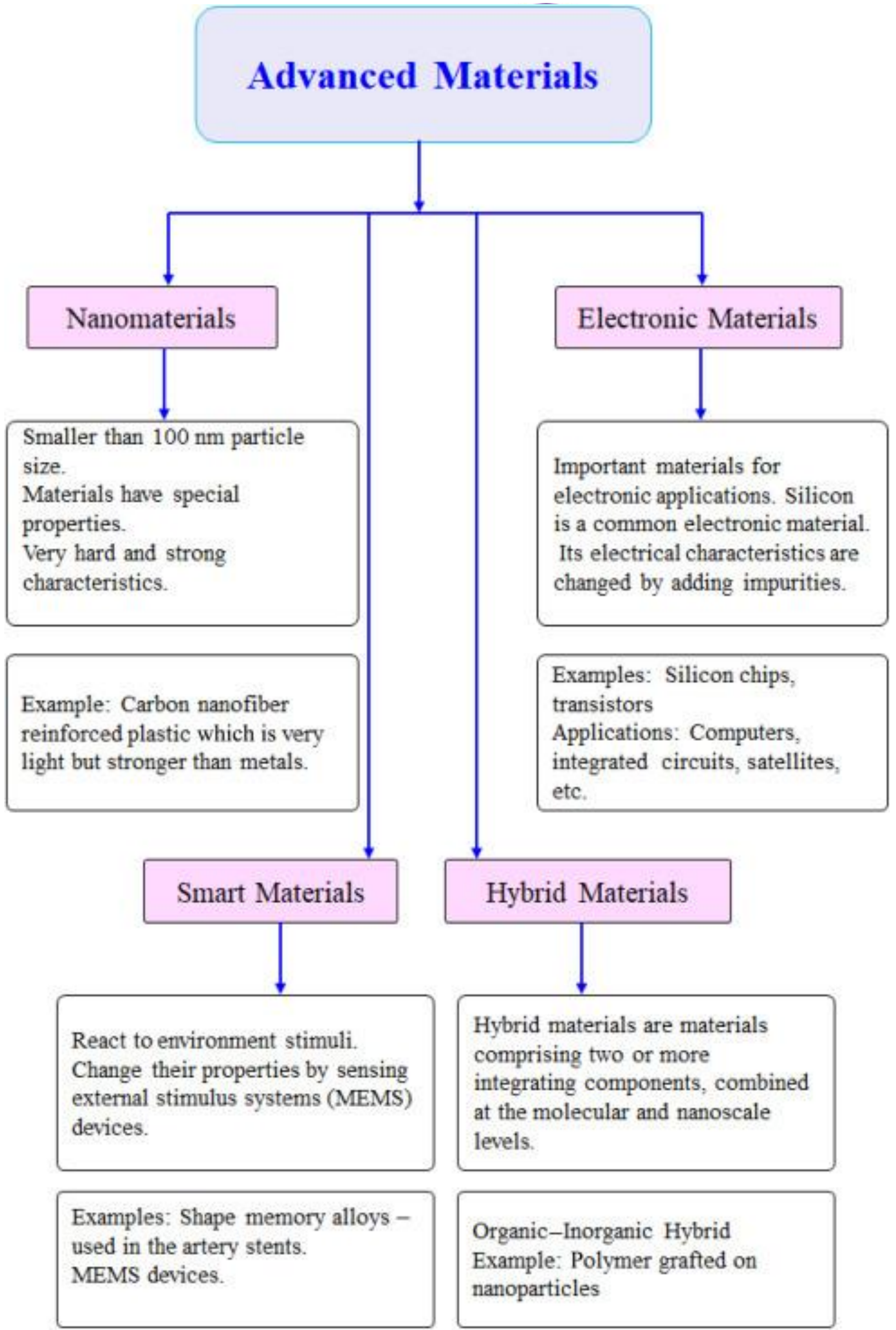
Advance Materials (AdMa) from OECD

- new or enhanced properties, and/or
- targeted or enhanced structural features

with the objective to achieve specific or improved functional performance

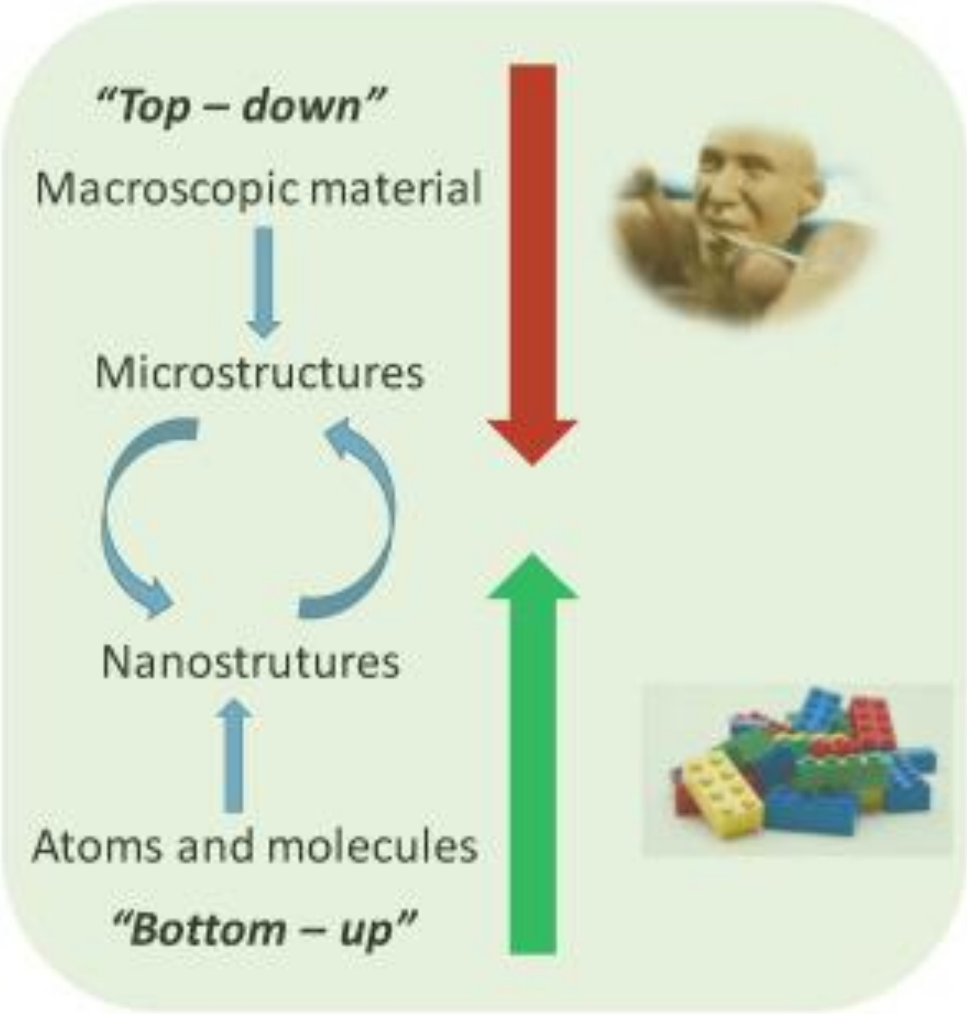
This includes both new emerging manufactured materials, and materials that are manufactured from traditional materials. This also includes materials from innovative manufacturing processes that enable the creation of targeted structures from starting materials, such as bottom-up approaches. It is acknowledged that what are currently considered as AdMa will change with time.

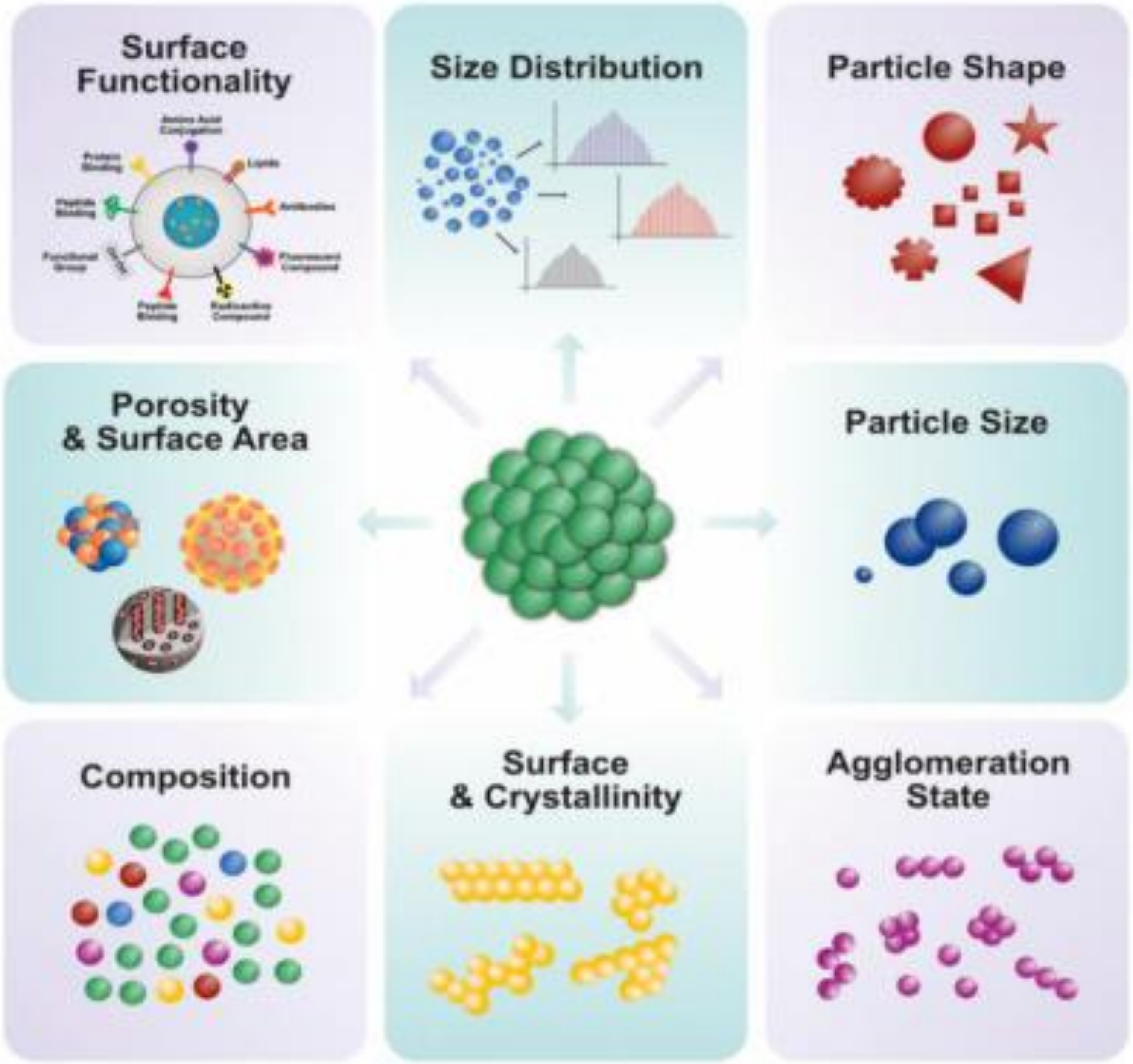
https://pubs.rsc.org/en/content/articlehtml/2023/va/d2va00128d



https://www.sciencedirect.com/topics/materials-science/advanced-material

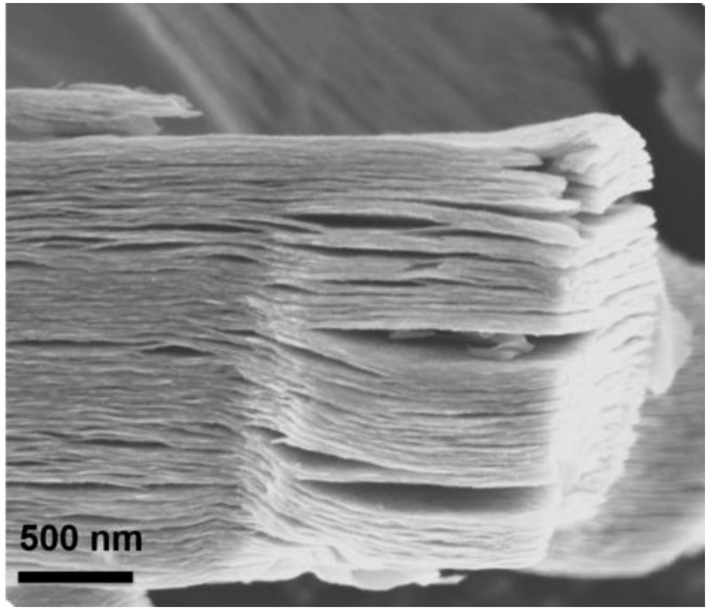
Material properties depend on processing method and their physical characteristics





https://www.sciencedirect.com/topics/materials-science/advanced-material

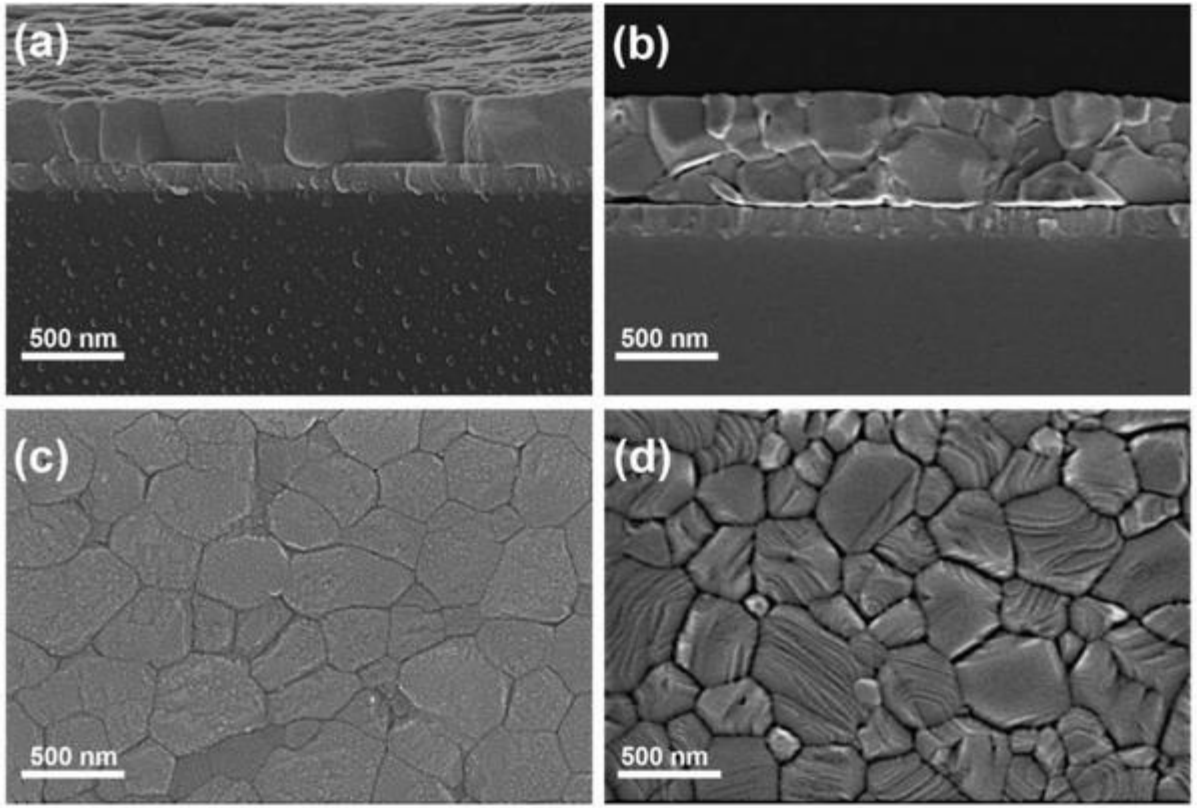
MXenes



Titanium aluminum carbide, Ti_3AlC_2

Top down

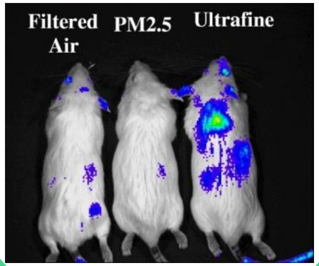
Perovskite



Cross section SEM image of a) $Pb(Ac)_2$-perovskite film and b) PbI_2-perovskite film. Top view SEM image of c) $Pb(Ac)_2$-perovskite film and d) PbI_2-perovskite film.

Top-down and bottom-up

Potential Risks of Nanomaterials



Human Health (consumer) Concerns

Worker Health & Safety Considerations

Environmental Impact

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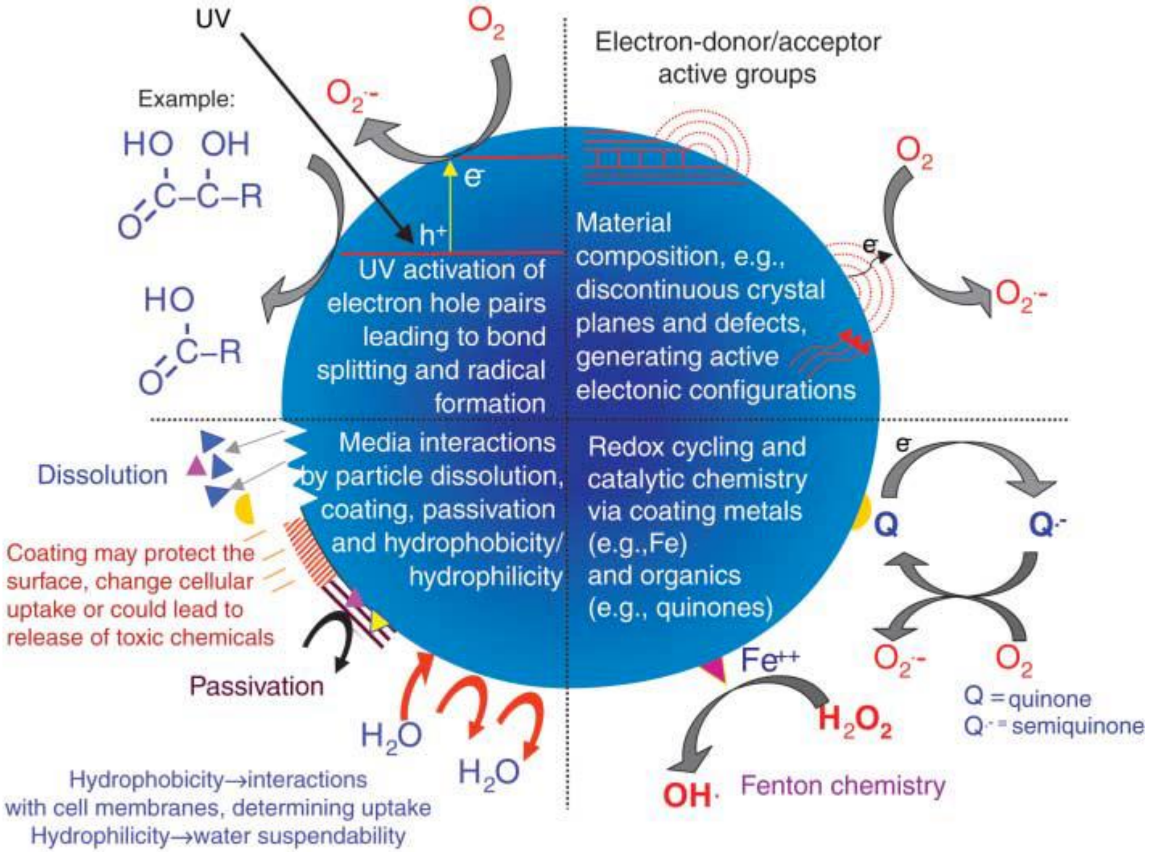
5S Factors involved in toxicity of nanomaterials



Nel, et al.. Science (2006) 311: 622-627

- **S**ize
- **S**hape
- **S**urface area
- **S**urface chemistry
- **S**olubility

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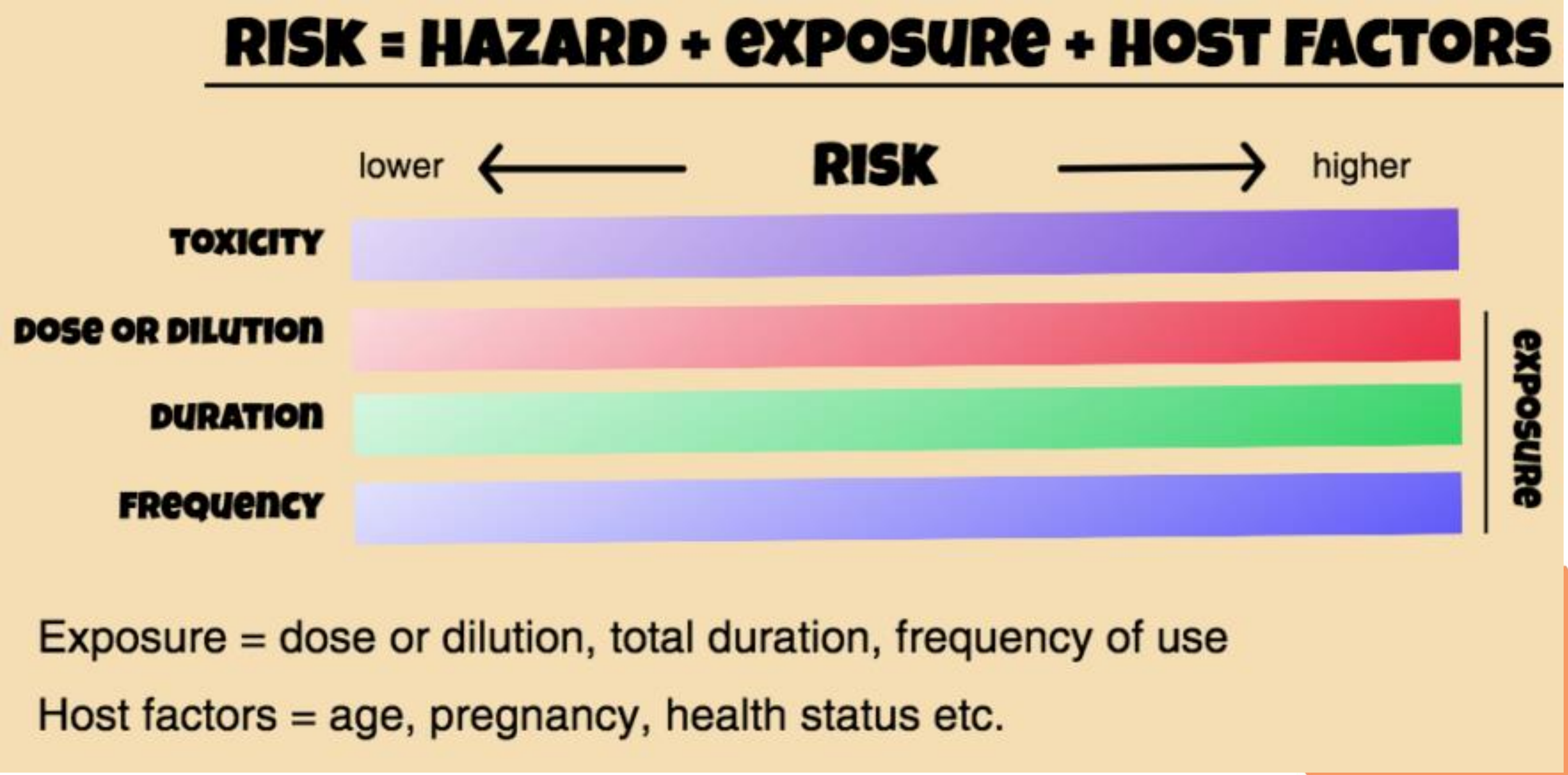
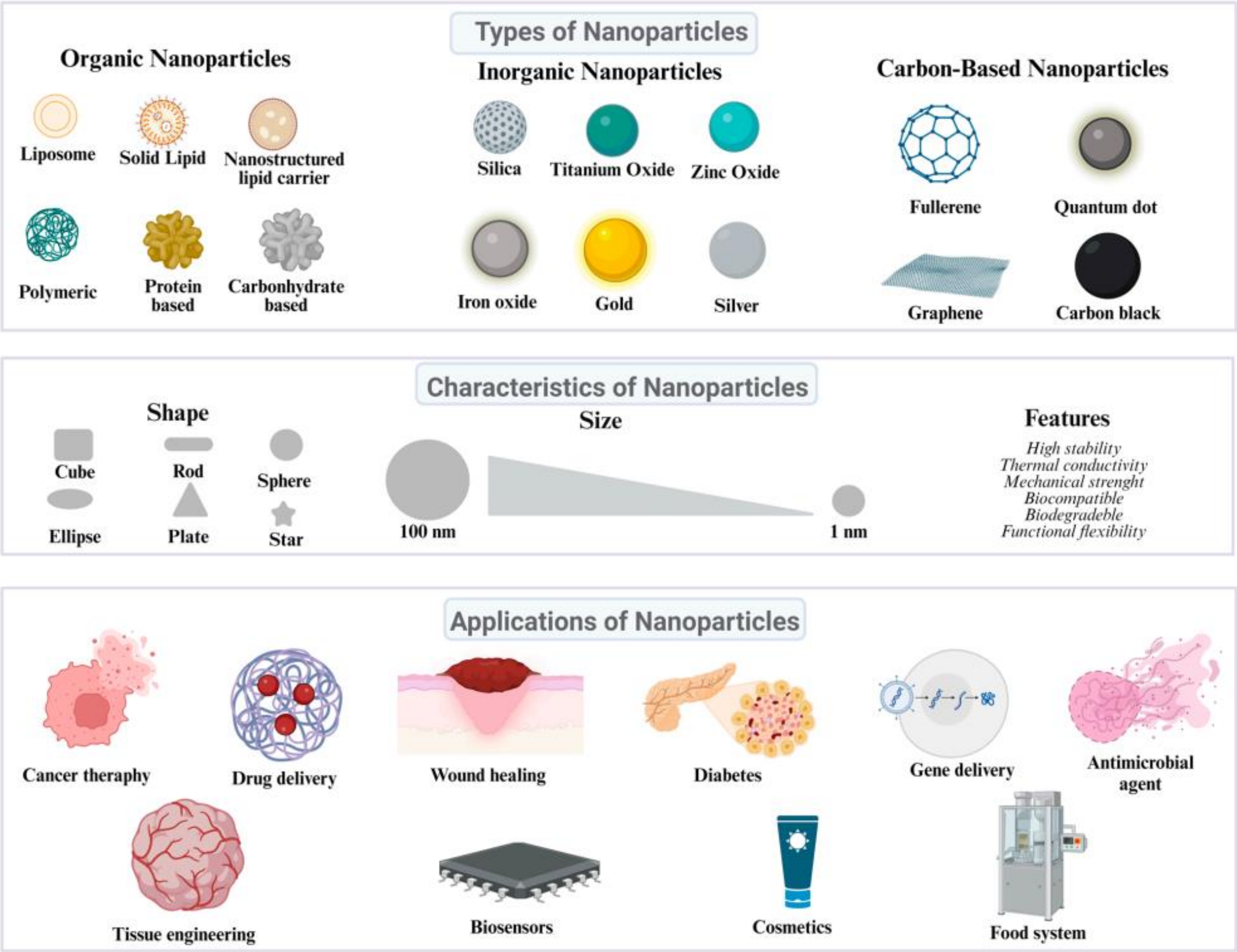
Dose and Dose rate (Toxic)

Risk = Hazard x Exposure

More factor to consider

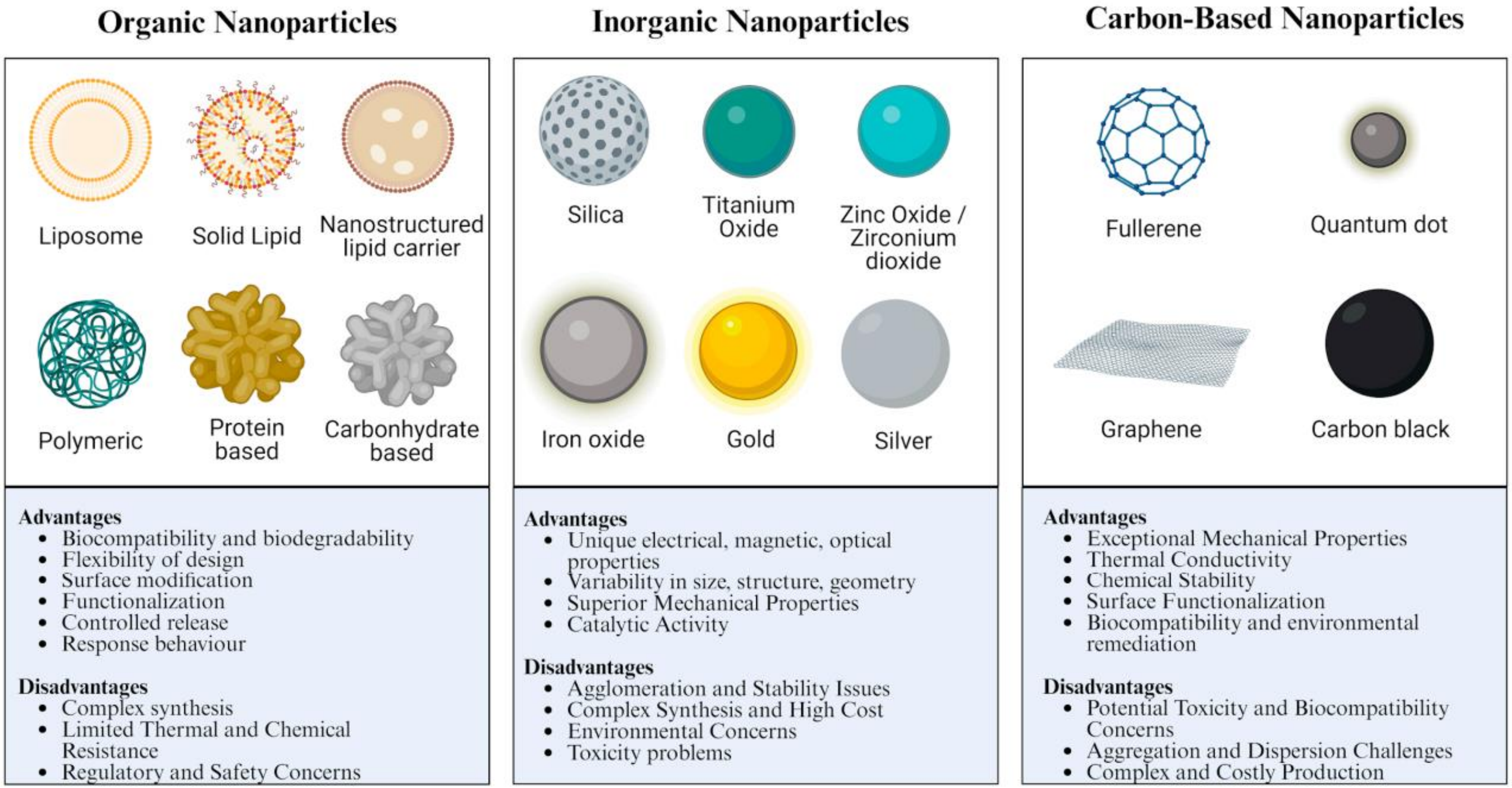


Representative scheme of NPs



https://www.mdpi.com/1420-3049/29/15/3482

Classification of nanoparticles



https://www.mdpi.com/1420-3049/29/15/3482

Evaluation

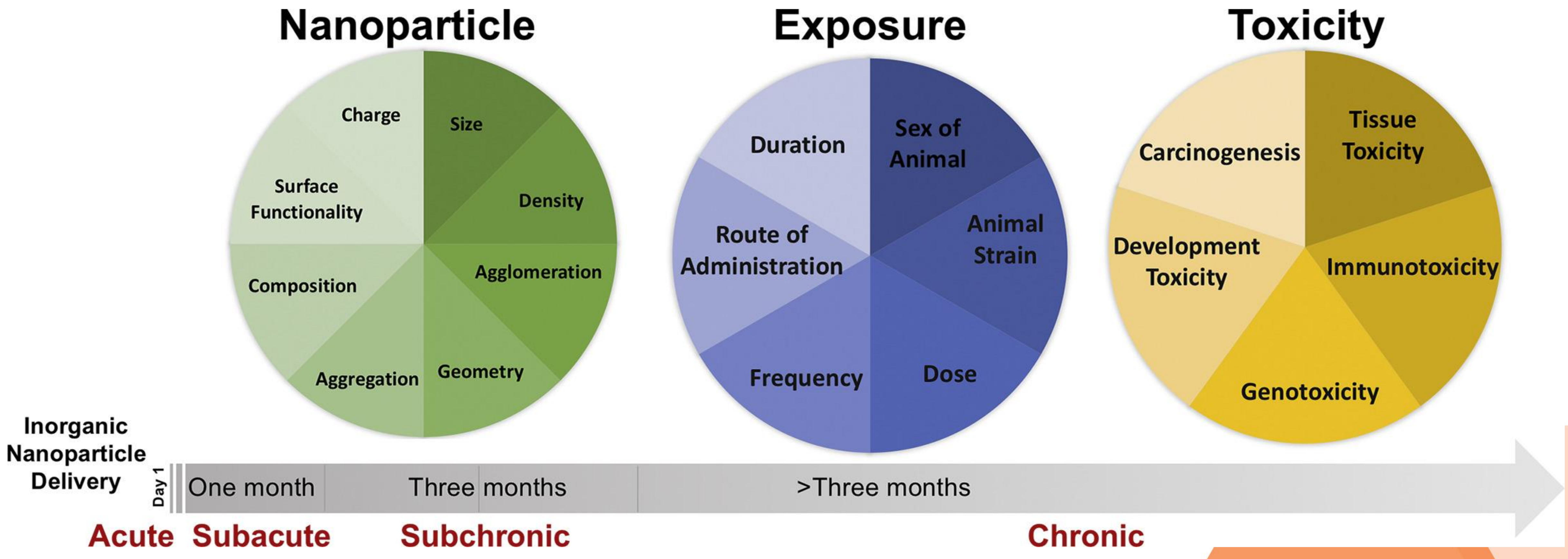
STEP 1: Gather typical dose descriptors and/ or other information on potency

STEP 2: Decide on mode of action (threshold or non-threshold) and which next step(s) to choose

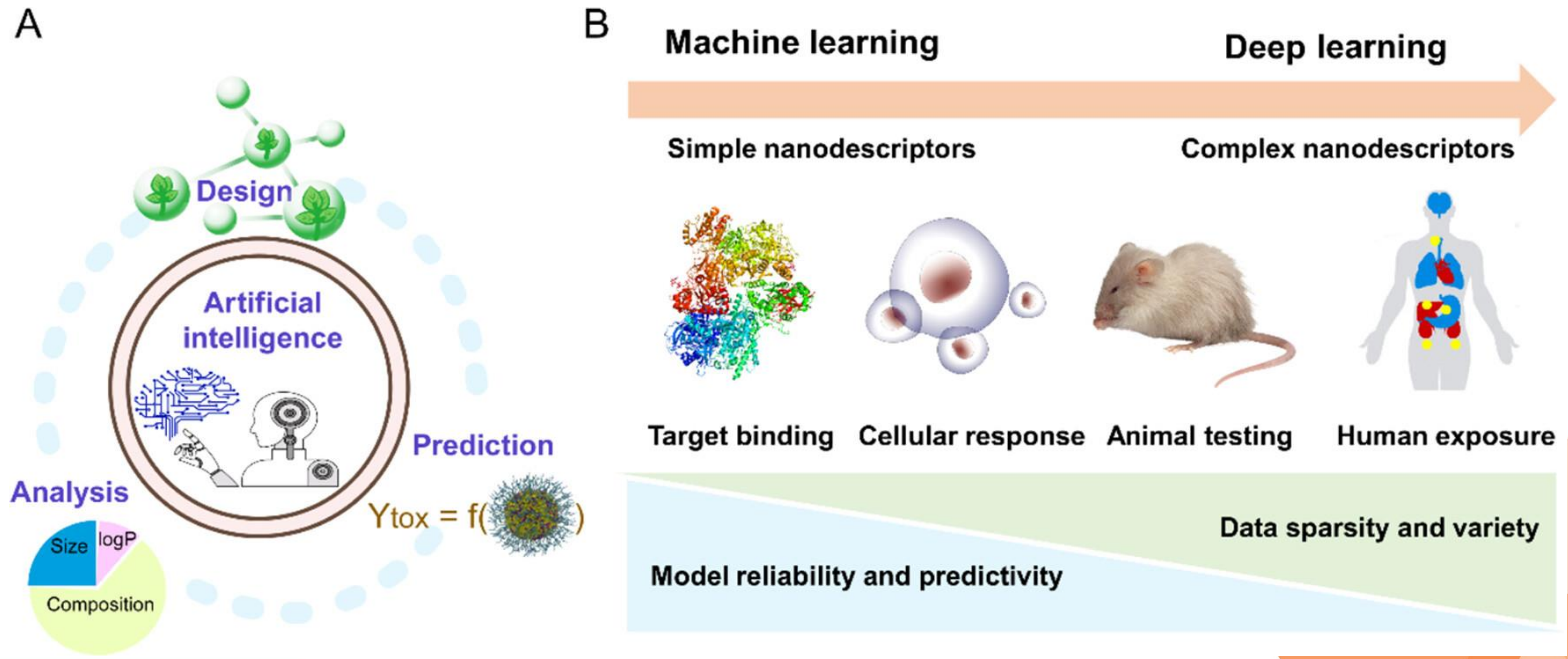
STEP 3: Derivation of effect levels

- Route to route extrapolation
- Assessments factors
  - Interspecies differences
  - Intraspecies differences
  - Differences in duration of the exposure
  - Quality of the whole database

Testing consideration



Application of AI approaches to unravel the QNTR. (A) AI has three essential roles in nanotoxicology, i.e., prediction of nanotoxicity, design of novel NMs, and analysis of toxicity mechanism. (B) The applications of AI in nanotoxicology are typically data-dependent. With the advancement of nanotoxicology research, the sparsity and variety of nanotoxicity data have increased and brought multiple challenges for AI modeling



https://pubs.acs.org/doi/10.1021/acs.chemrev.3c00070

Data source for AI learning

Material characterization	Biological characterization	Details of experimental protocols
synthesis method	the cell line	details of material characterization
composition	the number of cells	details of biological characterization
size	incubator conditions	details of data analysis
morphology	the administered dose	raw data
surface ligands	the type of animal model	
zeta potential	the exposure route	
octanol–water coefficients	exposure time	

https://pubs.acs.org/doi/10.1021/acs.chemrev.3c00070

Nanomaterials in Cosmetic

List name	Type	CAS
Carbon black	Colorant	1333-86-4
Titanium dioxide	Colorant/UV Filter	13463-67-7
Zinc oxide	Colorant/UV Filter	215-222-5
Tris-Biphenyl Triazine/Tris-Bihenyl Triazine (Nano)	UV Filter	31274-51-8
Methylene bis-Benzotriazolyl (Nano)	UV Filter	103597-45-1
Fullerenes C60/C70	Other functions	131159-39-2
Gold	Other functions	7440-57-5
Platinum	Other functions	7440-06-4
Silver	Other functions	7440-22-4
Copper	Other functions	7440-50-8
Aluminium oxide	Other functions	1344-28-1
silicon dioxide; synthetic amorphous silicon dioxide (nano)	Other functions	7631-86-9

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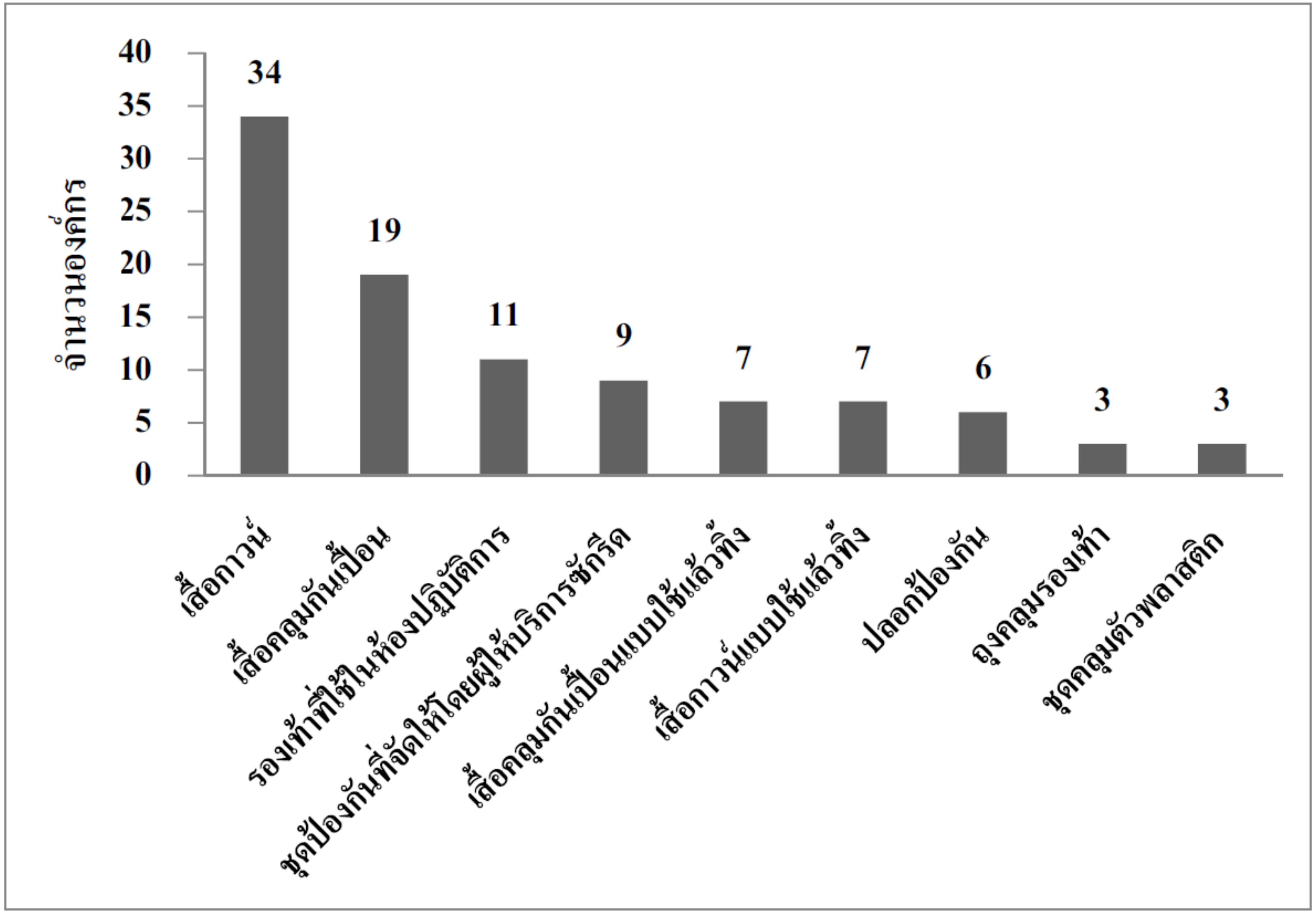
Risk level of Nanomaterials in matrix

NM-Matrix	Hazard/Exposure to Human body	Risk
Dry power	Fire, explosion and catalytic reactions, Inhalation, skin and ingestion	**High**
Aerosol	Inhalation, skin and ingestion	**High**
Liquid colloids/suspensions	Spill containment and reactivity, Skin and ingestion	**Moderate**
Embedded in solid matrix	Abrasion, machining, grinding, etc. Inhalation, skin and ingestion	**Low**

Powder > Aerosol >Cream or emulsion > Composite

ชุดป้องกันที่แนะนำเพื่อการใช้ในงานวิจัย หรือในองค์กร



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Occupational exposure limit values (OELs) specific to nanomaterials

Product	Proposed	Organization
Carbon nanotubes (SWCNT and MWCNT)	1 $\mu g/m^3$	NIOSH
Fibrous nanomaterial	0.1 fiber/ml	Safe work Australia
TiO_2 (10-100 nm)	0.3 mg/m^3	NIOH
TiO_2 (21 nm)	1.2 mg/m^3	AIST
Fullerenes	0.8 mg/m^3	AIST
Insoluble nanomaterials (<100 nm)	20,000 part/ml	Dutch Social Partner
Soluble nanomaterials	0.5 ×TLV*	Dutch Social Partner

* TLV : threshold limit value

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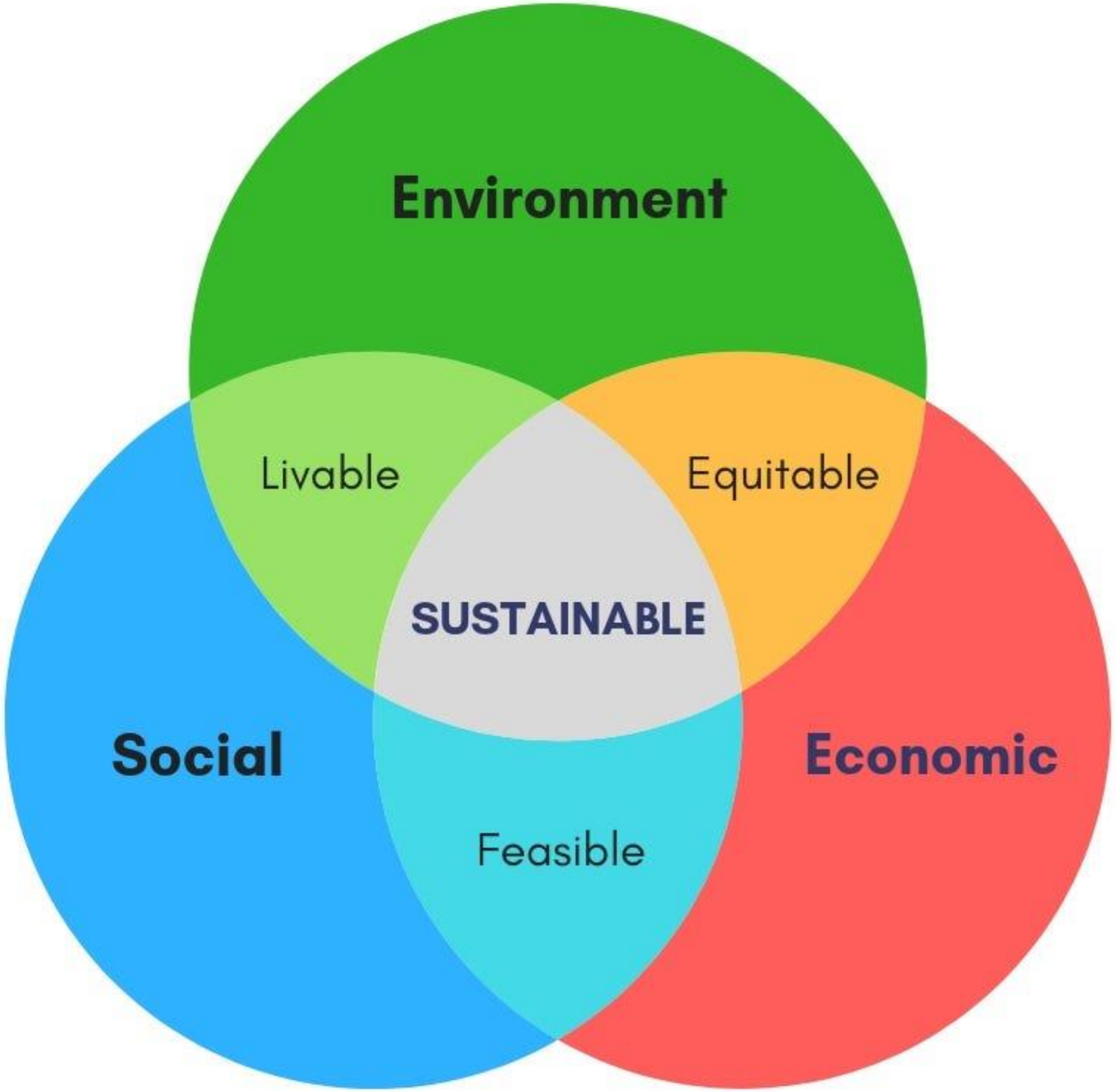
Applications for environmental

- Remediation of water contaminated by heavy metals
- Removal of pollutants from car engine exhausts through the use of high surface area nanomaterials in catalytic converters
- The use of nanomaterial-based fuel additives to improve fuel combustion efficiency
- Clean-up of oil spills
- Reduction of emissions and fuel consumption through the use of lighter nanotechnology-based materials
- Self-cleaning surfaces with a capacity to break down pollutants

The three dimensions of sustainable development



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Sustainability has three main aspects, all of them overlapping and cross linked by safety

1. Planet/Biosphere/Environment: – Remaining within the planetary boundaries by preserving the environment and natural resources and ensuring biological quality in order to enable them to provide ecosystem services to society for the present and future generations (maintenance of ecosystem services for humanity). – Aiming at using green and sustainable chemistry principles4 to minimize the toxicity and environmental footprint, in particular regarding climate change, pollution and resource use.

2. People/Society: – Ensuring beneficial social impact as e.g. social welfare, human health safety, and respect of human rights, including equality and education

3. Prosperity/Economy: – Ensuring economic growth and innovation within the planetary boundaries. In summary, sustainability could be described as the ability of a material or chemical to provide products/services with desired functionalities without exceeding planetary boundary

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Safe and sustainable by design in Nanotechnology

1. Safe and Sustainable material/ chemical/ product: minimizing, in the R&D phase, possible hazardous properties and sustainability issues (promoting traceability, sustainable sources of raw materials/natural resources, minimizing resource consumption and sources, promoting social responsibility) of the designed material/ chemical/ product while maintaining its function.

2. Safe and Sustainable production: ensuring industrial safety during the production of materials/ chemicals/ products, more specifically occupational, environmental and process safety aspects. The pillar should also ensure processes for the production of materials /chemical/ products minimize emissions (to air, water and soil) and resource consumption (e.g. energy, water), and optimizing waste management

3. Safe and Sustainable use and end-of-life: minimizing exposure and associated adverse effects through the entire use life, recycling and disposal of the material/ chemical/ product. Materials/chemicals/products should be designed in a way that demand of resources is minimized during the use phase as well as during recycling, and that the material/ chemical/ product supports the waste hierarchy and circular economy

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Life Cycle Assessment

Waste Container

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Classification of nanowaste on the basis of their potential toxicity and causative sources

Type of waste	Toxic effect	Causative sources
Type I	Toxicity level very low Negligible harm to the ecosystem	Solar panels Memory chips Television screens Silicon nanowires
Type II	Toxicity may be between low to high depending on the time of exposure	SW CNTs (Single walled-carbon nanotubes)
Type III	Toxicity is moderately toxic with low or medium exposure time	Pesticides Polishing agents Food additives Food packaging materials
Type IV	Toxicity ranges between very toxic and lethal causing death of an organism	Personal care products Paints and coatings Pesticides
Type V	Toxicity level is very dangerous and is severely toxic	Pesticides Sunscreen lotions Food, and beverages Containing colloidal Suspensions of fullerenes

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https://www.researchgate.net/figure/Waste-hierarchy-and-strategies-for-sustainable-waste-management-Source-The-Figure-was_fig5_377497320

Thank you

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Table 4. Decision Framework for PC parameters for Exposure and Fate Assessment

Mechanism of Concern	Relevant exposure route	Potential Initiating Physico-Chemical Properties	Modifying Physico-Chemical Properties
Fiber-like Toxicity	Inhalation	Aspect Ratio Length	Flexural rigidity Dissolution rate in lung fluid Surface Area
Surface Reactivity	All	Surface Chemistry Surface Layer thickness	Surface Area Surface Wettability Surface Charge
Reactive Oxygen Species Generation	All	Surface & Chemical Composition Surface defect sites	Surface Area Adsorption from solution Passivation propensity Surface defect density
Interference with Intracellular Redox processes	All but dermal	Conduction Band Energy level	Particle Surface Structure and Composition Fermi Levels Homo-Lumo Levels of interacting biomolecules Adsorbed molecules (e.g., protein corona)
Photocatalytic Activity	Environmental	UV-Visible Light Adsorption	Band Gap Crystallinity Recombination Rate Surface Area Adsorbed Molecules Adhesion to Impacted Organisms
Trojan Horse Phenomena	All	Surface Chemistry / Affinity	Surface Area Surface Ionisation/Charge Adsorbed molecules Hydrophobicity
Affinity to Aquatic and Terrestrial Organisms	Environmental	Surface Affinity	Hamaker Constant Surface Charge Hydrophobicity Adsorbed Molecules Shape Size Porosity
Soluble Compound Release	All	Chemical/Structural Composition	Surface Area Dissolution Rate Agglomeration State Stability of coating

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