Green Synthesis and Green Nanotechnology: An Integral Part of Sustainable Nano

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Green nanotechnology is about doing things right in the first place—

About making green nano-products and using nano-products in support of sustainability.

Green Nanotechnology Framework

1. Production/Processes

Making nanomaterials and their products cause no harm

Making NanoX "greenly"

Right Green

e.g., Green chemistry, Green engineering, DfE, Smart business practices

Using NanoX to "green" up production

e.g., Nanomembranes, nanoscaled catalysts

Light Green

Pollution Prevention Emphasis

2. Products

Using nanomaterials and their products help the environment

Direct Environmental Applications

e.g., environmental remediation, sensors

Deep Green

Indirect Environmental Applications

e.g., saved energy, reduced waste,

Anticipating full life cycle of nanomaterials and nanoproducts

NEXT STEPS: Policies that offer incentives for developing green nanoproducts and manufacturing techniques

Nano “Greening” Production – Light Green

Nano Membranes

Separate out metals and byproducts

Clean process solvents

Product separations

Nano Catalysts

Increased efficiency and *selectivity*

Process Energy

More Efficient

Lower use

Other names: Clean production, P2, clean tech, environmentally benign manufacturing

Indirect Applications – Light Green

Dematerialization

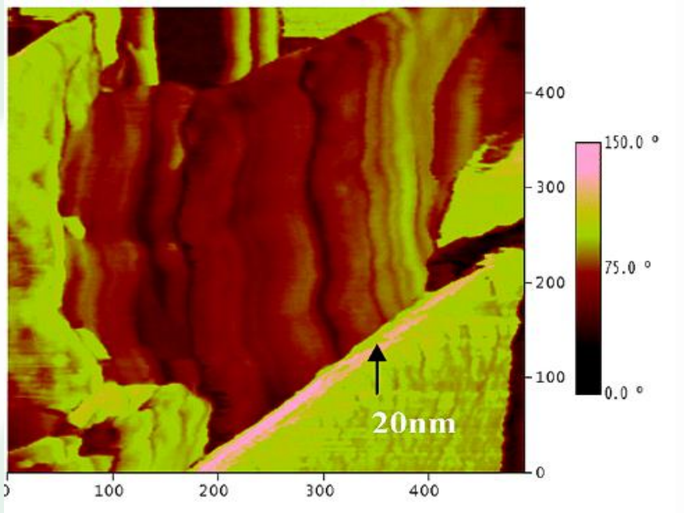
Energy Savings--Light Weight nanocomposites

Spun carbon nanotubes or other nanomaterials to replace copper wiring

Increased miniaturization

Renewables in Nanocomposites

Cellulose Acetate Bioplastic and Clay
Nanocomposite with triethyl citrate plasticizer (Park et al, 2004)



AFM of composite

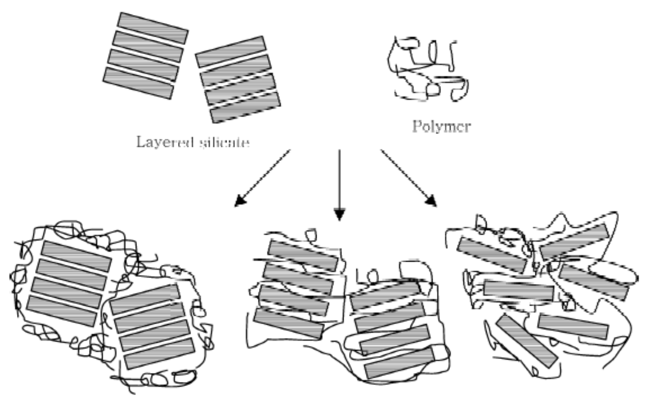


Figure 1 Types of composite structure of polymer-layered silicate clay materials. (Adapted from McGlashan and Halley, 2003)

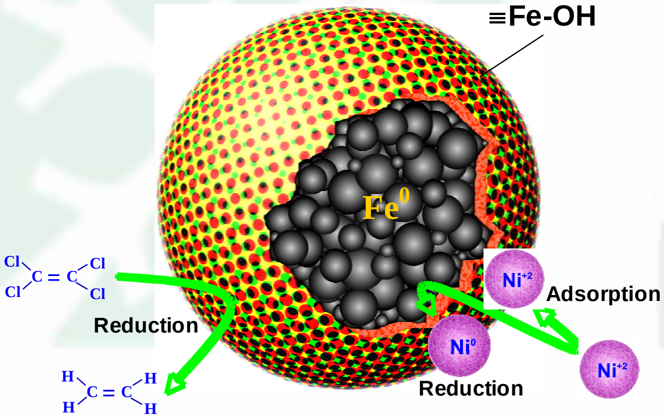
Direct applications – Deep Green

Green Nano Products

Nano Products that provide solutions to environmental challenges

Involves practical use of nano products in direct or indirect applications that solve environmental problems.

Environmental technologies—
Treatment, Remediation
Green materials
Green energy



Green Synthesis of Nanomaterials - Right Green

Green Chemistry Principles	Designing Greener Nanomaterial and Nanomaterial Production Methods	Practicing Green Nanoscience
P1. Prevent waste P2. Atom economy	Design of safer nanomaterials (P4,P12) →	Determine the biological impacts of nanoparticle size, surface area, surface functionality; utilize this knowledge to design effective safer materials that possess desired physical properties; avoid incorporation of toxic elements in nanoparticle compositions
P3. Less hazardous chemical synthesis P4. Designing safer chemicals	Design for reduced environmental impact (P7,P10) →	Study nanomaterial degradation and fate in the environment; design material to degrade to harmless subunits or products. An important approach involves avoiding the use of hazardous elements in nanoparticle formulation; the use of hazardless, bio-based nanoparticle feedstocks may be a key.
P5. Safer solvents/reaction media P6. Design for energy efficiency	Design for waste reduction (P1,P5,P8) →	Eliminate solvent-intensive purifications by utilizing selective nanosyntheses - resulting in greater purity and monodispersity; develop new purification methods, e.g. nanofiltration, that minimize solvent use; utilize bottom-up approaches to enhance materials efficiency and eliminate steps
P7. Renewable feedstocks P8. Reduce derivatives	Design for process safety (P3,P5,P7,P12) →	Design and develop advanced syntheses that utilize more benign reagents and solvents than used in "discovery" preparations; utilize more benign feedstocks, derived from renewable sources, if possible; identify replacements for highly toxic and pyrophoric reagents
P9. Catalysis P10. Design for degradation/Design for end of life	Design for materials efficiency (P2,P5,P9,P11) →	Develop new, compact synthetic strategies; optimize incorporation raw material in products through bottom-up approaches, use alternative reaction media and catalysis to enhance reaction selectivity; develop real-time monitoring to guide process control in complex nanoparticle syntheses
P11. Real-time monitoring and process control P12. Inherently safer chemistry	Design for energy efficiency (P6,P9,P11) →	Pursue efficient synthetic pathways that can be carried out at ambient temperature rather than elevated temperatures; utilize non-covalent and bottom-up assembly method near ambient temperature, utilize real-time monitoring to optimize reaction chemistry and minimize energy costs

Dahl et al Greener Nano Synthesis, Chem. Rev. 2007 107:2228.

Four fundamental routes to making nanomaterials.

Form in place
These techniques incorporate lithography, vacuum coating and spray coating.

Mechanical
This is a 'top-down' method that reduces the size of particles by attrition, for example, ball milling or planetary grinding.

Gas phase synthesis
These include plasma vaporization, chemical vapor synthesis and laser ablation.

Wet chemistry
These are fundamentally 'bottom-up' techniques, i.e. they start with ions or molecules and build these up into larger structures.

One Big Wet Problem

Volatile Organic Solvents

BTEX (benzene, toluene, ethylbenzene, xylene) common process chemicals

- Benzene -- drowsiness, dizziness, headaches, as well as eye, skin, and respiratory tract irritation, and, at high levels, unconsciousness, knowncarcinogen
- Toluene - potent CNS toxicity, chronic cognitive impairment
- Ethylbenzene - respiratory effects, such as throat irritation and chest constriction, irritation of the eyes, and neurological effects such as dizziness
- Xylene - mild CNS effects (headache, dizziness, nausea and vomiting)irritant to mucous membrances, esp. eye

Toolbox of Greener Techniques to make Nanomaterials

Self-assembly

Molten Salt or Ionic Liquid Synthesis

Bottom up Manufacturing

Improved synthesis, fewer steps

Bio-inspired nanoscale synthesis

Use of non-toxic solvents like supercritical CO2

Renewables in Nanocomposites

Microwave techniques

Aqueous processing

Photochemical synthesis

Renewable starting materials

Solvothermal/hydrothermal Processes

Templating processes

Non-toxic starting materials

Use of solid state/solventless processes

Nanocatalysis

What’s the current state of research in green synthesis of nano?

For 2013, a quick search reveals a variety of green tools in the literature:

9 ionic liquid and nano

30 templating

26 microwave and nano

12 natural

40 green

9 self-assembly

33 hydrothermal

9 supercritical

Improving

How does green synthesis of nanomaterials fit into the bigger picture of sustainability?

Green Nanotechnology is a **necessary** but **not sufficient** condition for sustainability

There is a need to go beyond environmental protection to <u>sustainability</u>

Social and economic aspects, in addition to the environment, are considered in <u>sustainability</u>

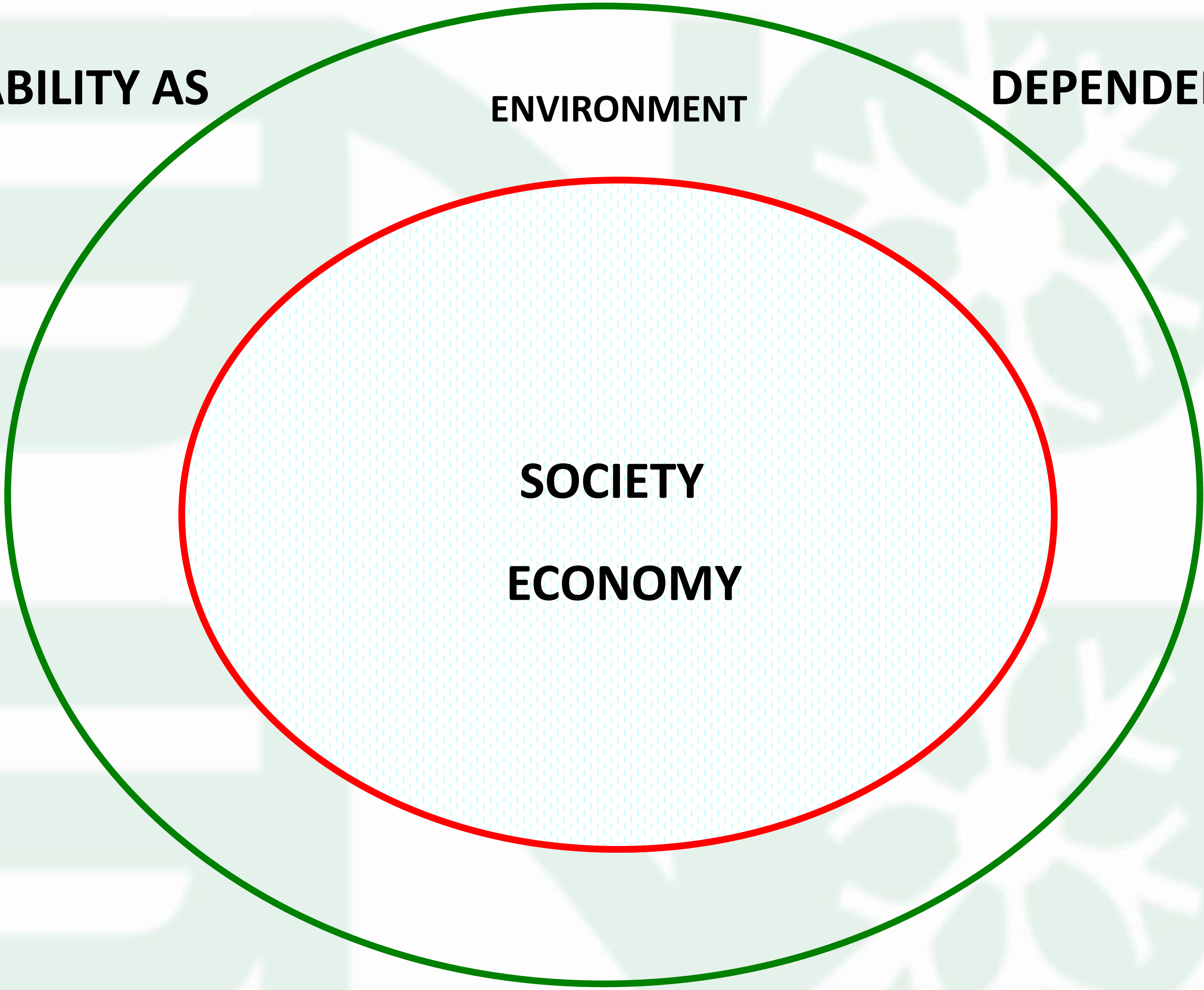
Sustainability

(Some commonly used definitions)

- "Development that meets the needs of the present without compromising the ability of future generations to meet their needs" [1]
- "The reconciliation of society's developmental goals with the planet's environmental limits over the long term" [2]
- "Meeting fundamental human needs while preserving the life-support systems of planet Earth" [3]

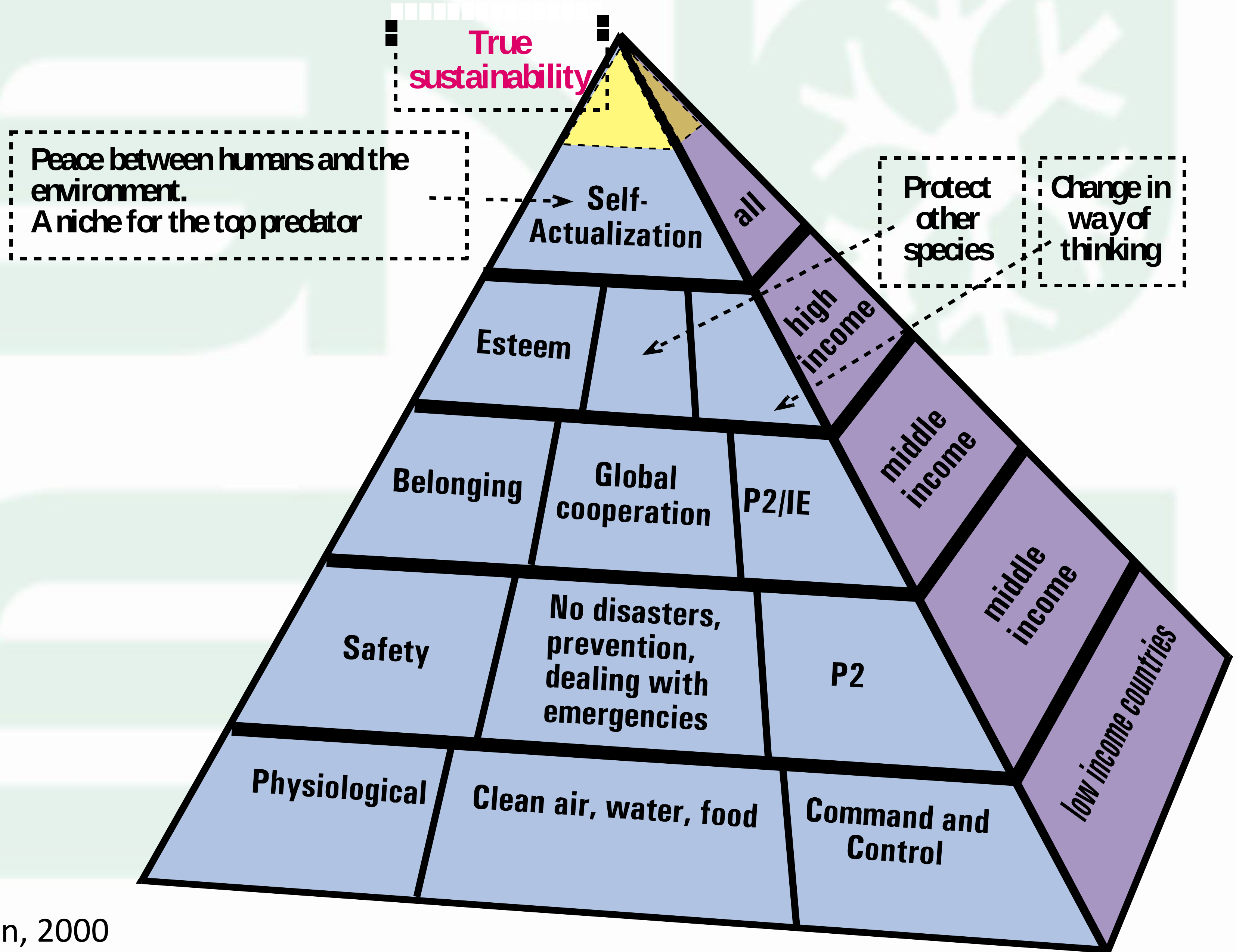
[1.] The Brundtland Report [2.] NRC, "Our Common Future" [3.] Kates, RW, et. al., (2001) *Science: 292* pp. 641-642.

SUSTAINABILITY AS DEPENDENCIES



Giddings et al, Sust. Dev.,2002

Maslow Sustainability Hierarchy



B. Karn, 2000

How does green synthesis of nanomaterials fit into the bigger picture of sustainability?

Environmental part of sustainability

Clean air, water, food on the pyramid

Nanotechnology can help alleviate Major Sustainability Issues

Climate change

Water

Disease

Food production

Renewable energy

Toxics

Natural resources

Humanity's Top Ten Problems for next 50 years

1. **ENERGY**
2. WATER
3. FOOD
4. ENVIRONMENT
5. POVERTY
6. TERRORISM & WAR
7. DISEASE
8. EDUCATION
9. DEMOCRACY
10. POPULATION

2003	6.5	Billion People
2050	8-10	Billion People

R. Smalley

Thought exercise

Insert nanotechnology solutions into the prior problems

Keep in mind

No technology alone will lead to sustainability

Technologies buy us time by slowing down the rate of non-sustainable practices

Only a change in human values and behavior in concert with responsible technologies can lead to true sustainability

Engineers and scientists have a responsibility to solve the technological problems

…because we can!

THANKS!

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