

# Nanotechnology: Where is it Today and Is EHS an Element of Success?

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# Key Components of the Discussion

Nanotechnology is Alive and doing well

Responsible development is still a priority

Twelve years and \$11Billion in EHS: Any Progress?

Rapid move from Nano to 'Advanced'

Path forward

# Nanotechnology in 2018-2020

Building on the growth of 2006 to 2016 with focus on key areas

## 2D Materials

Graphene, Boron Nitride, Silicene. Energy, flexible electronics, conductive inks

## Quantum Dots

Scalability issues solved. Organic QD breakthroughs. Flat panel displays, lighting, etc. "Booming business".

## Carbon Nanotubes

CNT arrays, functional CNT, hybrid forms. Batteries, sensors, composites, filters.

## Nano Coatings

Metal and ceramic nanomaterials, Wear and corrosion resistance, 'smart', sensing, self-healing.

## Advanced Materials

Foundation in Nano. Enhanced activity or performance. Still size mediated but >100 nm.

## Nano Cellulose

Still promising. Crystal and Fibril forms. Element of the Green Economy?

All are contributing to Industry 4.0

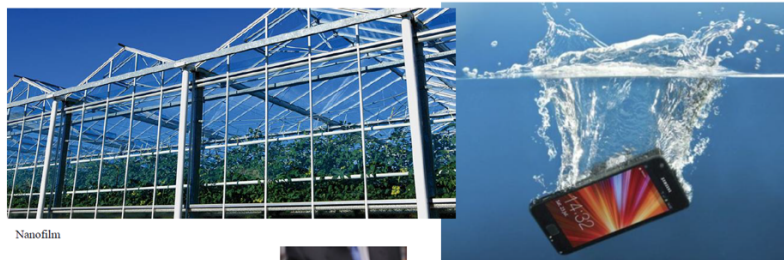
## Nanotechnology: Impacts on Products and Industry

<b>Agriculture</b>	More efficient and lower volumes through targeted delivery of plant nutrients, pesticides.
<b>Automotive</b>	Lighter, stronger materials; body panels as sensors
<b>Health Care</b>	New nanoparticle based therapeutics, advanced sensors, more sensitive imaging and diagnostics.
<b>Energy</b>	Better conductors for transmission lines, higher efficiency in solar generation, advanced insulation
<b>Environmental</b>	New pollution control and remediation tools, sensors, water treatment
<b>Food</b>	Safety sensors, preservatives, nutrient additives, smart packaging
<b>Materials</b>	Lighter, stronger composites and metals. More efficient catalysts. Pollution and corrosion fighting finishes.
<b>Electronics</b>	Smaller, faster computers

# Reality



## Films and Coatings



Nanofilm

<http://www.technoinnovationdaily.com/2013/06/05/p21-water-repellent-nano-coating/>



Zyx Marine

GM



NanoMech



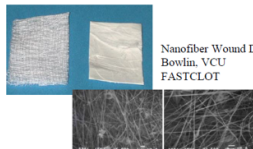
## Food, Health Care and Medical



RipeSense.co.nz



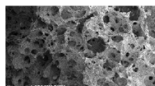
timestrip.com



Nanofiber Wound Dressings  
Bowlin, VCU  
FASTCLOT



3M's FilTek® restorative dental



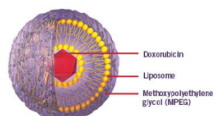
Stryker's Vitoss Bone Graft Substitute



Nanosphere



Acute lymphoblastic leukemia (ALL)  
Sigma-Tan Pharmaceuticals



Doxonitich  
Liposome  
Methoxy polyethylene  
glycol (MPG)



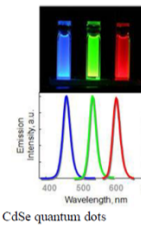
## Nano Electronics

### Quantum Dots now in Mass Market Applications

Consumer electronics already 'nano'



QD Vision's Color IQ Technology



CdSe quantum dots

Nanosys

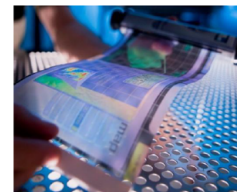


Samsung SUHD TV using Nanosys quantum dots



Sony Bravia LED TV

## Flexible Electronics and Sensors



Flexible Electronics (HP&ASU)  
<http://nanosys.com/>



[http://www.labmanager.com/news/2018/01/e-ngineers-make-wearable-sensors-for-plants-enabling-measurements-of-water-use-in-crops?\\_WPaqd-rE2w](http://www.labmanager.com/news/2018/01/e-ngineers-make-wearable-sensors-for-plants-enabling-measurements-of-water-use-in-crops?_WPaqd-rE2w)



<https://phys.org/news/2017-10-physicists-breakthrough-brittle-smartphone-screens.html>

Flexible Tablet concept, Samsung



<http://news.ssfedra.com/news/Samsung-Flexible-Tablets-Might-Become-a-Reality-Soon-Thanks-to-Graphene-Breakthrough-435805.shtml>



Ma, Wisconsin-Madison  
<http://spectra.free.org/tech/consumer-electronics/portable-devices/green-microchips-created-on-cellulose-nanofiber-paper>

# Federal Funding for EHS

6% of FY 2018 Investment.  
(\$91.8M of \$1,558M)

Healthy growth from an initial  
funding level of 2.7% in 2007

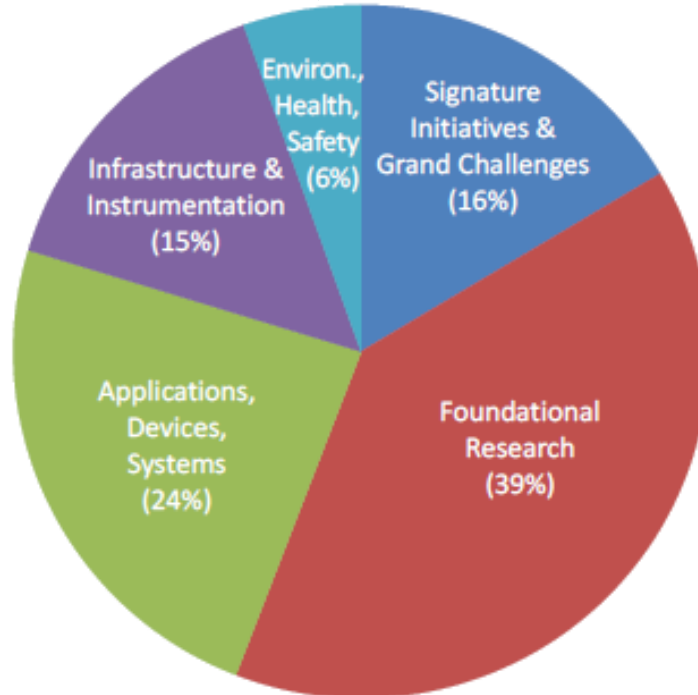


Figure 2. Breakout of NNI Funding by Program Component Area in the 2018 Budget.

# EHS Directions

Basic research is continuing

Applied research in occupational settings

Moving along the value chain/life cycle

Broader awareness and adoption of good practices

Risk governance versus regulation

Public-Private partnerships

Evolving regulatory landscape

# Are we Making any Progress?

Overall awareness has been raised across the value chain

**R&D:** Continued work to develop good practices for Nano and Advanced

**Occupational:** Adoption of proactive practices to minimize exposures and releases

**Commercial Use:** High-volume applications being identified and precautionary practices being developed

**Environmental:** Better understanding of fate and effects

**Consumer Products:** Still a challenge but awareness and response growing



# Movement?

From

“There are too many unknowns”

To

“A lot of progress has been made”

To

“There are good lessons learned that can be reapplied”

To

**“Consensus best practices meet EHS needs”**

# The View from NIOSH

## In the Occupational Element of EHS

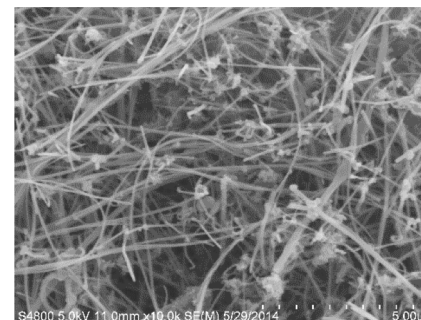
- Investigate specific materials and types
- Move hazard assessment along the value chain
- Assess and control exposure
- Use exposure data to evaluate risk
- Issue good practice guidelines

# Nanomaterials Investigated at NIOSH

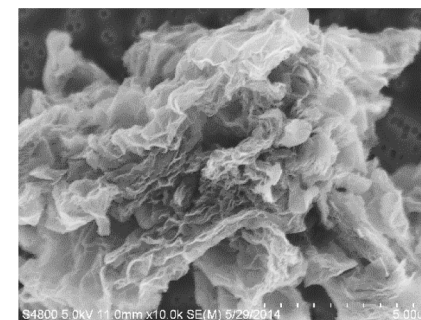
MWCNT – Mitsui 7  
DWCNT – double walled CNT  
MWCNT – amine and carboxyl  
functionalized  
MWCNT – Doped (Nitrogen,  
Aluminum)  
MWCNT – Heat Treated  
Vapor-grown Carbon nanofibers  
(CNF)  
CNT and CNF – 10 US Facilities  
in Epidemiology Study  
SWCNT – single-walled CNT  
Carbon Nanodots  
Graphite Nanoplatelets or  
Nanoplates  
Graphene  
Graphene Oxide

Nanocellulose Nanomaterials

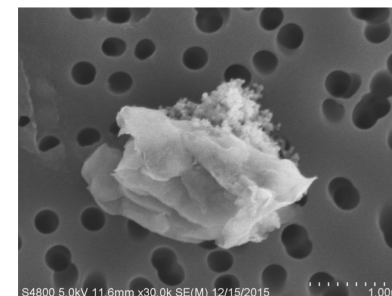
Natural and Organomodified  
Montmorillonite Nanoclay



MWCNT- Mitsui 7 – Courtesy of Bob Mercer



Layered Reduced Graphene Oxide

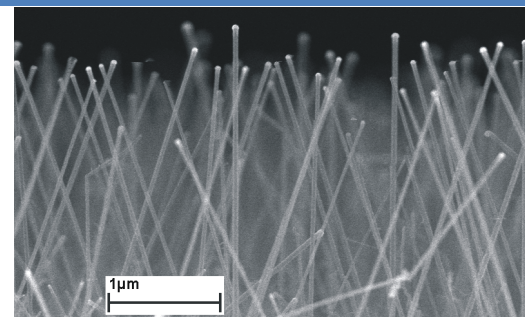


Stacked Plates of Nanoclay – courtesy  
of Todd Stueckle

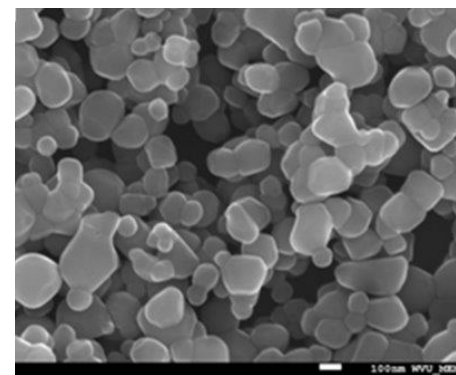


# Nanomaterials Investigated at NIOSH

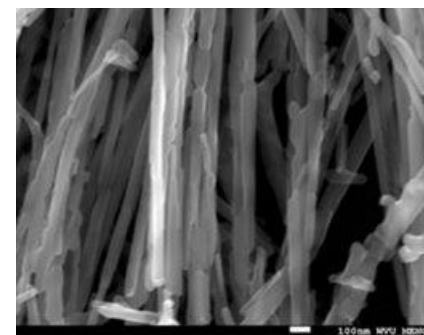
Boron Nitride Nanotubes  
Boron Nitride Nanopowder  
Silicon nanowires  
Elemental nano-silver  
Cerium Dioxide  
Lanthium Oxide  
Cobalt Oxides  
Nickel Oxide  
Iron Oxides – SiO<sub>2</sub> coated and uncoated  
Zinc Oxide Spheres and Nanowires  
Elemental Zn  
Titanium Dioxide Nanorods, nanowires, nanobelts  
SiO<sub>2</sub> – amorphous and crystalline  
Tungstate (particles and rods) CaWO<sub>4</sub>, SrWO<sub>4</sub>, BaWO<sub>4</sub>  
Tungsten carbide-cobalt  
Tungstate (particles and rods)  
    CaWO<sub>4</sub>  
    SrWO<sub>4</sub>  
    BaWO<sub>4</sub>  
Copper Oxide  
Quantum Dots – ZnS/CdSe



Si nanowires: Roberts et al., 2012



TiO<sub>2</sub> nanospheres: courtesy of Dale Porter



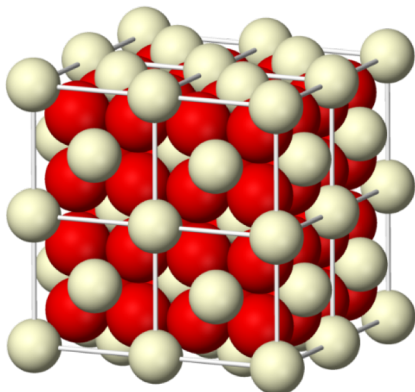
TiO<sub>2</sub> nanobelts: courtesy of Dale Porter



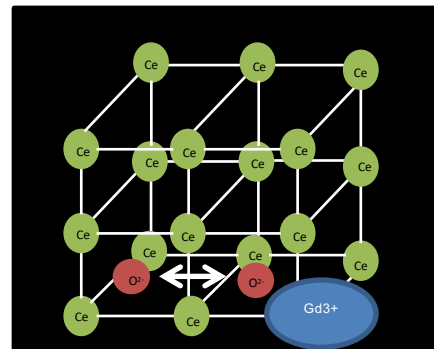
# Nanomaterials Investigated at NIOSH

## Functionally Modified Nanoparticles – Prevention through Design:

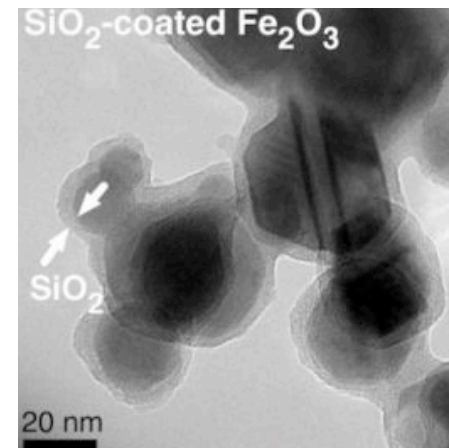
- Carboxylated and Humics Acid Titanium Nanobelts
- Nitrogen-doped MWCNT
- Carboxylated MWCNT
- Amine Functionalized MWCNT
- Heat-Treated MWCNT
- Amorphous silica coated Iron Oxide and Cerium Oxide
- Gadolinium-doped and SiO<sub>2</sub> coated cerium oxide



<http://goo.gl/vWa6HO>



Courtesy of Stephen Leonard



Gass et al., 2013

# 'NanoProducts' Investigated at NIOSH

## Exposure with Nanoparticle Components – NanoRelease/Life Cycle:

Crushed Preparation MWCNT

CNT Polymer Composites – Construction operations – Sanding/Sawing

Printer-Emitted Particles – Toners and Inks (CPSC and Harvard University)

Three Dimensional Printing Emissions (CPSC and West Virginia university)

Copper-Treated Wood – Dust from Construction Operations (CPSC)

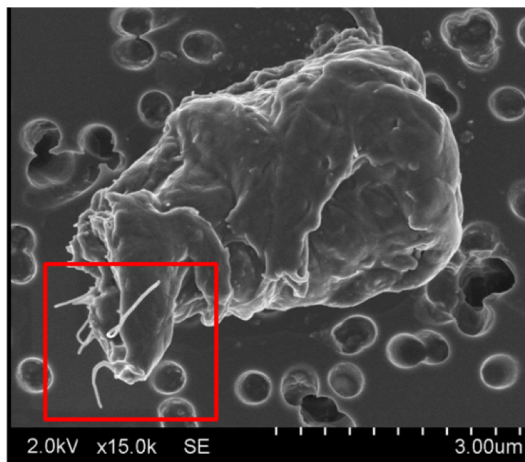
Sunscreen Spray – ZnO nanoparticles (FDA)

Disinfectant Sprays – ZnO or Silver Nanoparticles

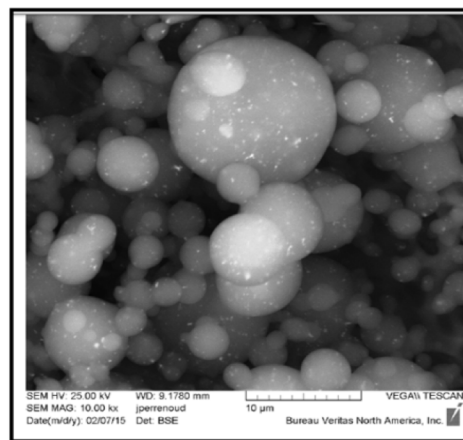
Wood Sealant/Stain Aerosol – Spraying Operations – ZnO Nanoparticles (CPWR)

Stain-Treated Wood Dust – Construction Operations – ZnO Nanoparticles (CPWR)

Welding Fume Exposure – mixture on metal nanoparticles



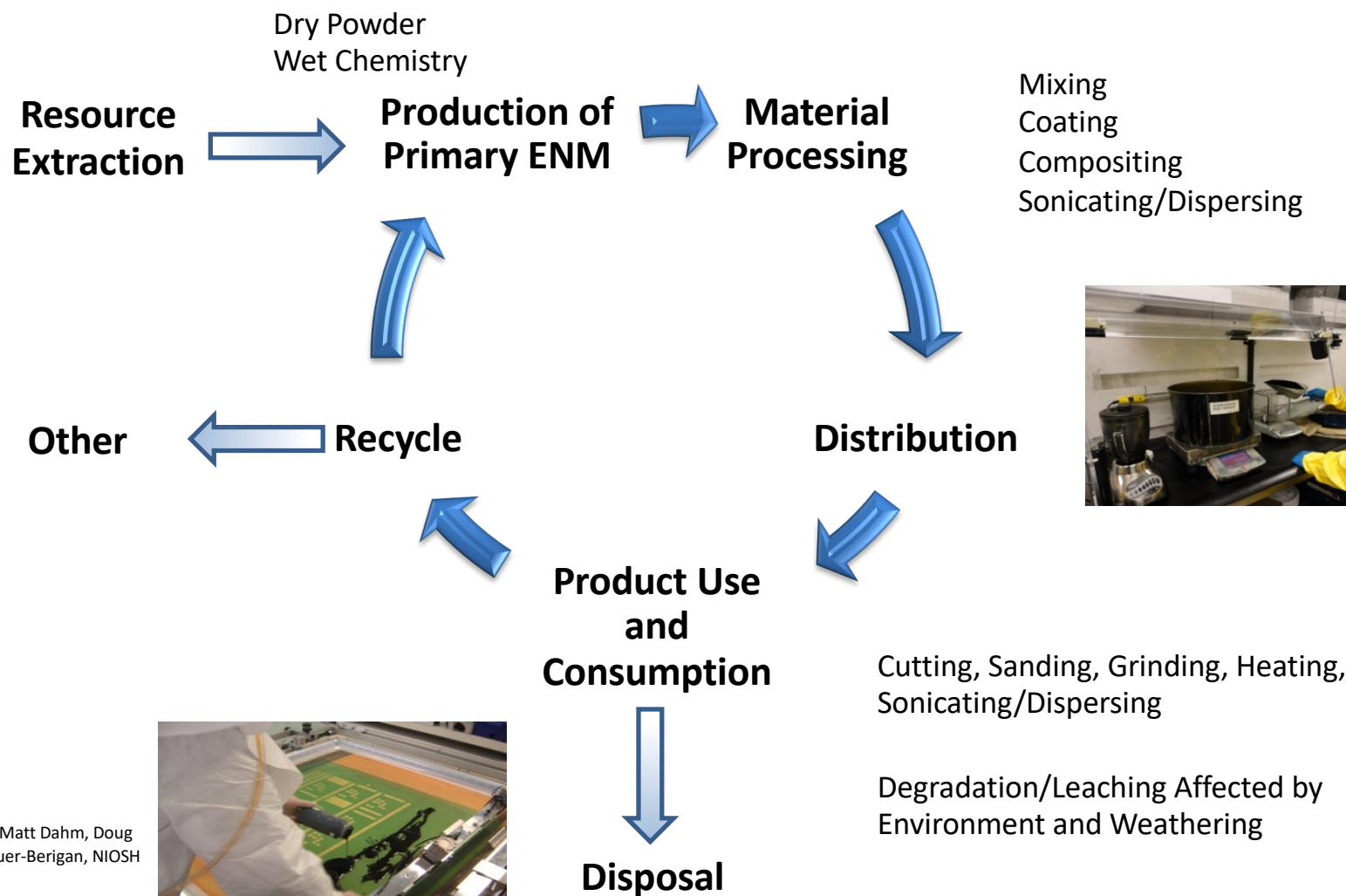
CNT in Composite  
– Courtesy of A. Erdely



ZnO particles on paint droplets  
– Courtesy of CPWR, B. Lippy

# Applied Research Approach

## Occupational Material Lifecycle

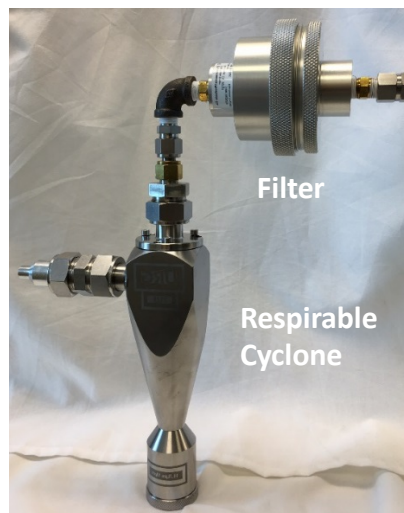
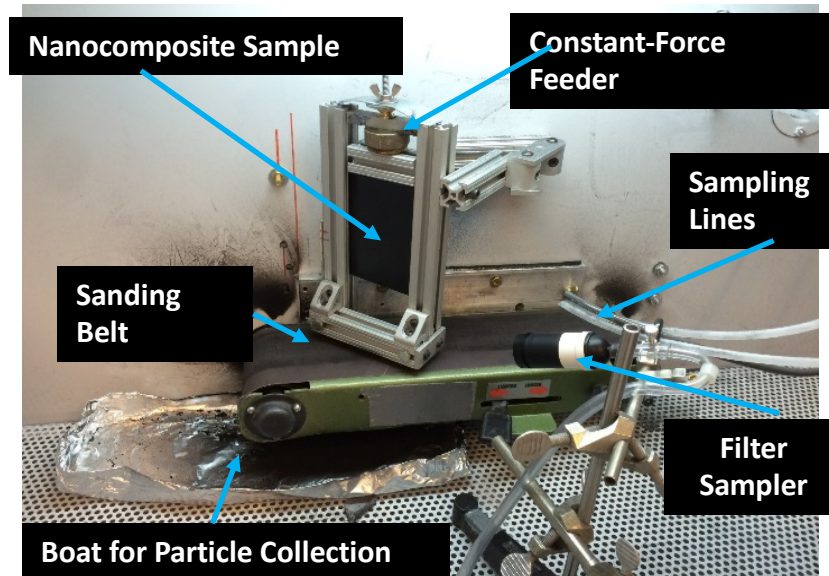


Images courtesy of Matt Dahm, Doug Evans, Mary Schubauer-Berigan, NIOSH

# Processing and Characterizing Aerosols from Nano-Enabled Materials



Internal View



# Moving Forward (2018 and Beyond)

- Focus on commercialization (not new)
- Nano is: mainstream, not a separate theme, stealth
- **Advanced Manufacturing** as a direct outlet for Nano
- Advanced Material quickly displacing Nanomaterial
- Growth in Bio-Manufacturing

# Advanced Materials and Manufacturing

## Advanced Materials

New materials and modifications to existing materials to obtain superior performance in one or more characteristics

## Advanced Manufacturing

Rapid transfer of science and technology into manufacturing products and processes



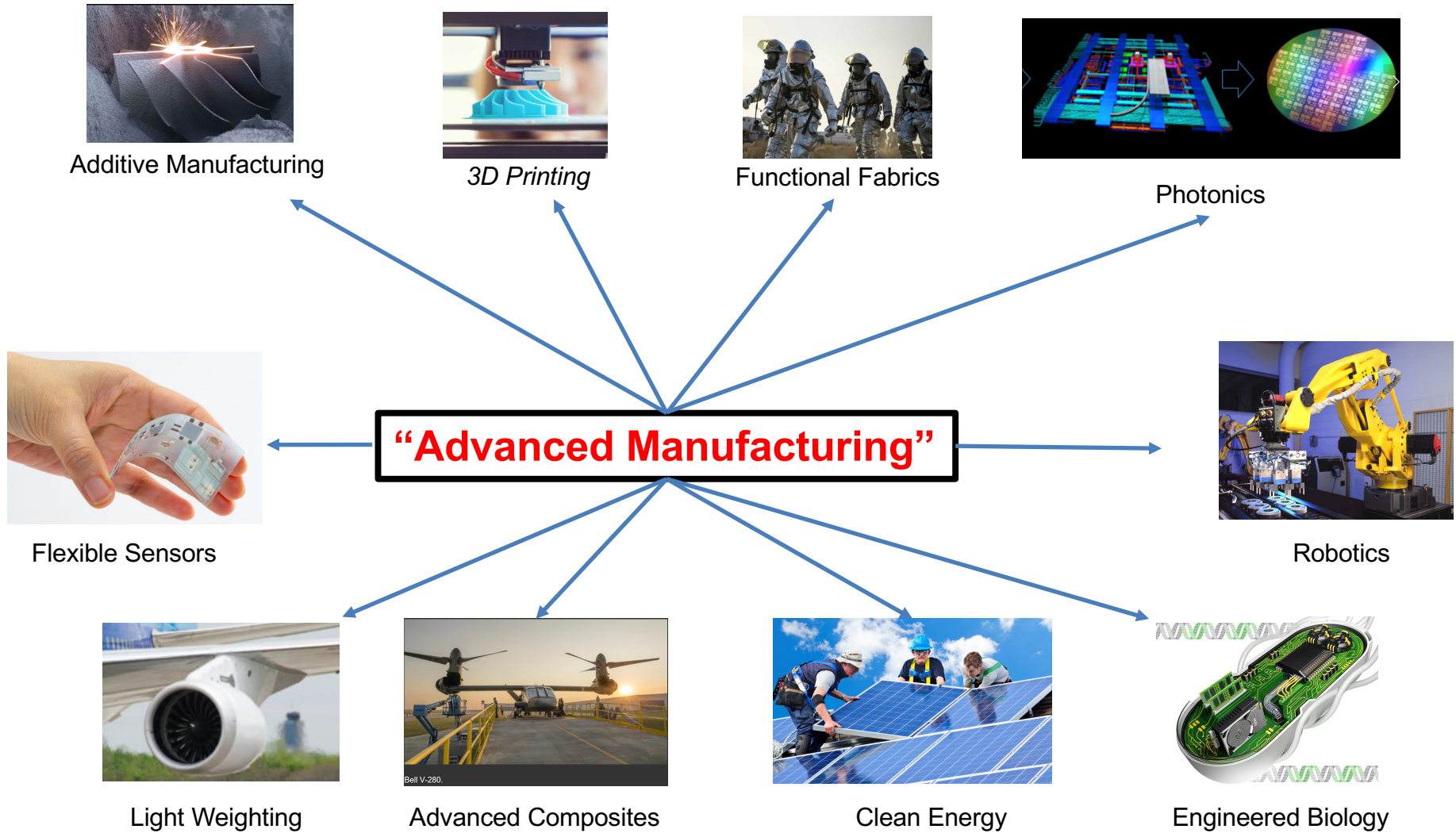
# Advanced (Nano) Material

Advanced (Nano) Materials refers to all new materials and modifications to existing materials that are specifically engineered (in the 1 to 100 nm scale) to have novel or enhanced properties that result in superior performance, relative to conventional materials (their bulk counterparts), that are critical for the application under consideration (that allow for novel applications),

CLGeraci-11/17



## Some processes, some products, but all have a Nano element





# Response to the need for EHS guidance



# Recent Guidance

**Workplace design solutions**

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

**Protecting Workers during the Handling of Nanomaterials**

**Summary**

Engineered nanomaterials (ENMs) are materials that are intentionally produced to have at least one primary dimension less than 100 nanometers (nm). These materials have new properties and behaviors that differ from those of bulk materials.

**Prevention through Design (PtD)**

Prevention through Design (PtD) can be defined as designing out or eliminating safety and health hazards associated with processes, structures, equipment, tools, or work organizations. The National Institute for Occupational Safety and Health (NIOSH) launched a PtD initiative in 2007. The mission is to reduce or prevent occupational injuries, illnesses, and fatalities by considering hazard prevention in the design, re-design, and retrofit of new and existing workplaces, tools, equipment, and work processes (NIOSH 2009a,b).

**Background**

The toxicity of many nanomaterials is presently unknown, but initial research indicates that there may be health concerns related to occupational inhalation exposures. Only a few types of ENMs have undergone extensive toxicological evaluation by NIOSH, e.g., titanium dioxide (TiO<sub>2</sub>) and carbon nanotubes (CNTs). Results from animal studies with TiO<sub>2</sub> and other poorly soluble, low toxicity particles of fine and submicron (nanoscale) sizes have shown adverse pulmonary responses in exposed rats, including persistent pulmonary inflammation and lung tumors (NIOSH 2011; Oberdorster 2002; Donaldson 2008; Poland et al. 2012). Similar toxicological responses have also been observed in rats and mice exposed to CNTs and carbon nanofibers (CNFs) (NIOSH 2011a; 2011b). Because of the potential for health effects, it is important to control worker exposure and to manage risks appropriately throughout the lifecycle of ENM production.

**Description of Exposure**

After production, many nanomaterials are further processed. Ding et al. (2016) reviewed the published literature of nanomaterial release during various industrial and laboratory processes. They found that the amount and type of nanomaterial released into the workplace was largely based on the process energy.

**NANOTECHNOLOGY RESEARCH CENTER**

**Controlling Health Hazards When Working with Nanomaterials: Questions to Ask Before You Start**

Here are some questions you should ask yourself before starting work with nanomaterials.

Here are some options you can use to reduce exposures to nanomaterials in the workplace. These options correspond with the questions on the left.

(1) FORM	DRY POWDER (typically highest potential for exposure)	SUSPENDED IN LIQUID	PHYSICALLY BOUND/ENCAPSULATED (typically lowest potential for exposure)
<p><b>(2) WORK ACTIVITY</b></p> <p>How are you using the nanomaterial? Could the work activity cause exposure? Is the likelihood of exposure low or high? Can you change the way you do the activity to reduce the exposure?</p>	<p><b>Applies to Dry Powder Nanomaterials</b></p> <ul style="list-style-type: none"> <li>Higher potential for exposure: Dumping bags of powder, bagging or sieving of products</li> <li>Lower potential for exposure: Scooping/weighing of product, transporting containers with light surface contamination or closed barrels/bottles/bags</li> </ul>	<p><b>Applies to Nanomaterial Suspended in Liquids</b></p> <ul style="list-style-type: none"> <li>Higher potential for exposure: Spraying, open top sonication, producing a mist</li> <li>Lower potential for exposure: Cleaning up a spill, pipetting small amounts, brushing</li> </ul>	<p><b>Applies to Physically Bound/Encapsulated Nanomaterial</b></p> <ul style="list-style-type: none"> <li>Higher potential for exposure: Cutting, grinding, sanding, drilling, abrasive blasting, thermal release</li> <li>Lower potential for exposure: Manual cutting and sanding, painting with a roller or brush</li> </ul>
<p><b>(3) ENGINEERING CONTROLS</b></p> <p>Based on the form and the work activity, what engineering controls will be effective? What are the key design and operational requirements for the control? How does the non-nanomaterial base material or liquid affect exposure?</p>	<p><b>Applies to Dry Powder Nanomaterials</b></p> <ul style="list-style-type: none"> <li>Chemical fume hood</li> <li>Glove box</li> <li>Nanomaterial handling enclosure</li> <li>Ventilated bagging or dumping stations</li> <li>High-efficiency particulate air (HEPA)-filtered local exhaust ventilation</li> </ul>	<p><b>Applies to Nanomaterial Suspended in Liquids</b></p> <ul style="list-style-type: none"> <li>Chemical fume hood</li> <li>Glove box</li> <li>Nanomaterial handling enclosure</li> <li>Local exhaust ventilation</li> <li>Ventilated spray booth</li> </ul>	<p><b>Applies to Physically Bound/Encapsulated Nanomaterial</b></p> <ul style="list-style-type: none"> <li>Chemical fume hood</li> <li>Glove box</li> <li>Local exhaust ventilation</li> <li>Downdraft table</li> <li>Wet cutting/machining</li> <li>Ventilated tool shroud</li> <li>Blasting cabinet</li> </ul>
<p><b>(4) ADMINISTRATIVE CONTROLS</b></p> <p>Have you considered the role of administrative controls? Have you set up a plan for waste management? Have you considered what to do in case of a spill or how you will maintain equipment?</p>	<ul style="list-style-type: none"> <li>Establish a chemical hygiene plan</li> <li>Perform routine housekeeping</li> <li>Train workers</li> <li>Use signs and labels</li> <li>Restrict access to areas where nanomaterials are used</li> </ul>	<p><b>Applies to All Nanomaterial Forms</b></p> <ul style="list-style-type: none"> <li>Handle and dispose of all waste materials (including cleaning materials/gloves) in compliance with all applicable federal, state, and local regulations</li> <li>Use sealed/closed bags or containers, and secondary containment</li> <li>Label containers, such as "contains nanoscale titanium dioxide"</li> </ul>	<ul style="list-style-type: none"> <li>Wet wipe or use a HEPA-filtered vacuum</li> <li>Do not dry sweep or use compressed air</li> <li>Incorporate nanomaterial safety into existing programs such as hazard communication</li> </ul>
<p><b>(5) PERSONAL PROTECTIVE EQUIPMENT</b></p> <p>If the measures above do not effectively control the hazard, what personal protective equipment can be used? Have you considered personal protective equipment for the non-nanomaterial base material or liquid?</p>	<ul style="list-style-type: none"> <li>Nitrile or chemical resistant gloves</li> <li>Lab coat or coveralls</li> <li>Safety glasses, goggles, or face shield</li> </ul>	<p><b>Applies to All Nanomaterial Forms</b></p> <ul style="list-style-type: none"> <li>Respiratory protection when indicated and engineering controls cannot control exposures, and in accordance with federal regulations (29 CFR 1910.134)</li> <li>NIOSH guidance on respirators can be found at <a href="http://www.cdc.gov/niosh/topics/respirators/">www.cdc.gov/niosh/topics/respirators/</a></li> </ul>	<ul style="list-style-type: none"> <li>Use personal protective equipment during spill cleanups and equipment maintenance</li> </ul>

**CDC**

**NIOSH**

Are you interested in learning more about how you can safely work with nanomaterials or want to stay up-to-date on nanotechnology safety? See the NIOSH NTRC website for more information and links to guidance documents: [www.cdc.gov/niosh/topics/nanotech/](http://www.cdc.gov/niosh/topics/nanotech/)

DHHS (NIOSH) Publication No. 2018-103 | February 2018  
<https://doi.org/10.26616/NIOSH-PUB2018103>

Practical approaches to evaluating hazards and controlling exposures.

<https://www.cdc.gov/niosh/topics/nanotech/pubs.html>

# Resources

NIOSH: [www.cdc.gov/niosh/topics.nanotech](http://www.cdc.gov/niosh/topics.nanotech)

NNI: [www.nano.gov](http://www.nano.gov)

Good Nano Guide: [www.nanohub.org/groups/gng](http://www.nanohub.org/groups/gng)

ACS: [www.dchas.org](http://www.dchas.org)

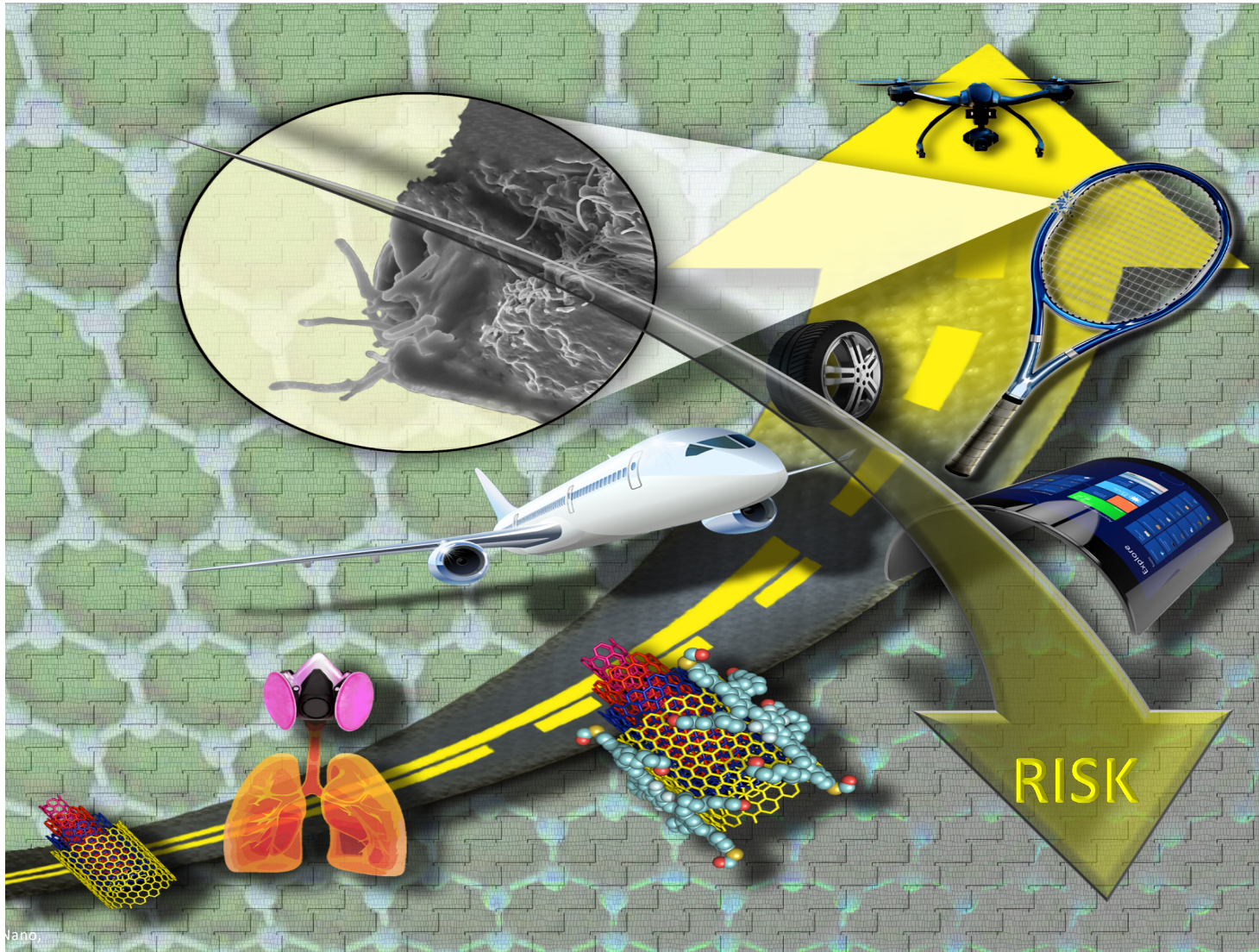
SafeNano: [www.safenano.org](http://www.safenano.org)

AIHA Nano Working group: [www.aiha.org/get-involved/VolunteerGroups/Pages/Nanotechnology-Working-Group.aspx](http://www.aiha.org/get-involved/VolunteerGroups/Pages/Nanotechnology-Working-Group.aspx)





## EHS : Support growth by minimizing risk



Thank You!

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