Nanomaterials and the Environment: Regulatory Implications & Research Needs

Lorraine Sheremeta, LL.M.

REMTECH 2009, October 15, Banff, Alberta

ALBERTA INGENUITY FUND

Overview

To provide an historical overview of relevant developments in nanoscience/nanotechnology.

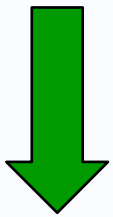
To consider implications of this context to regulators in Canada (and internationally).

Nanotechnology Defined

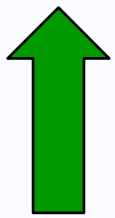
» Nanotechnology enables the atom-by-atom design and fabrication of structures that are very small, typically 1-100 nanometres, and which have new properties and powerful application in medicine and biotechnology, in energy and the environment, and in computing and telecommunications.

» Nanoscale science and engineering

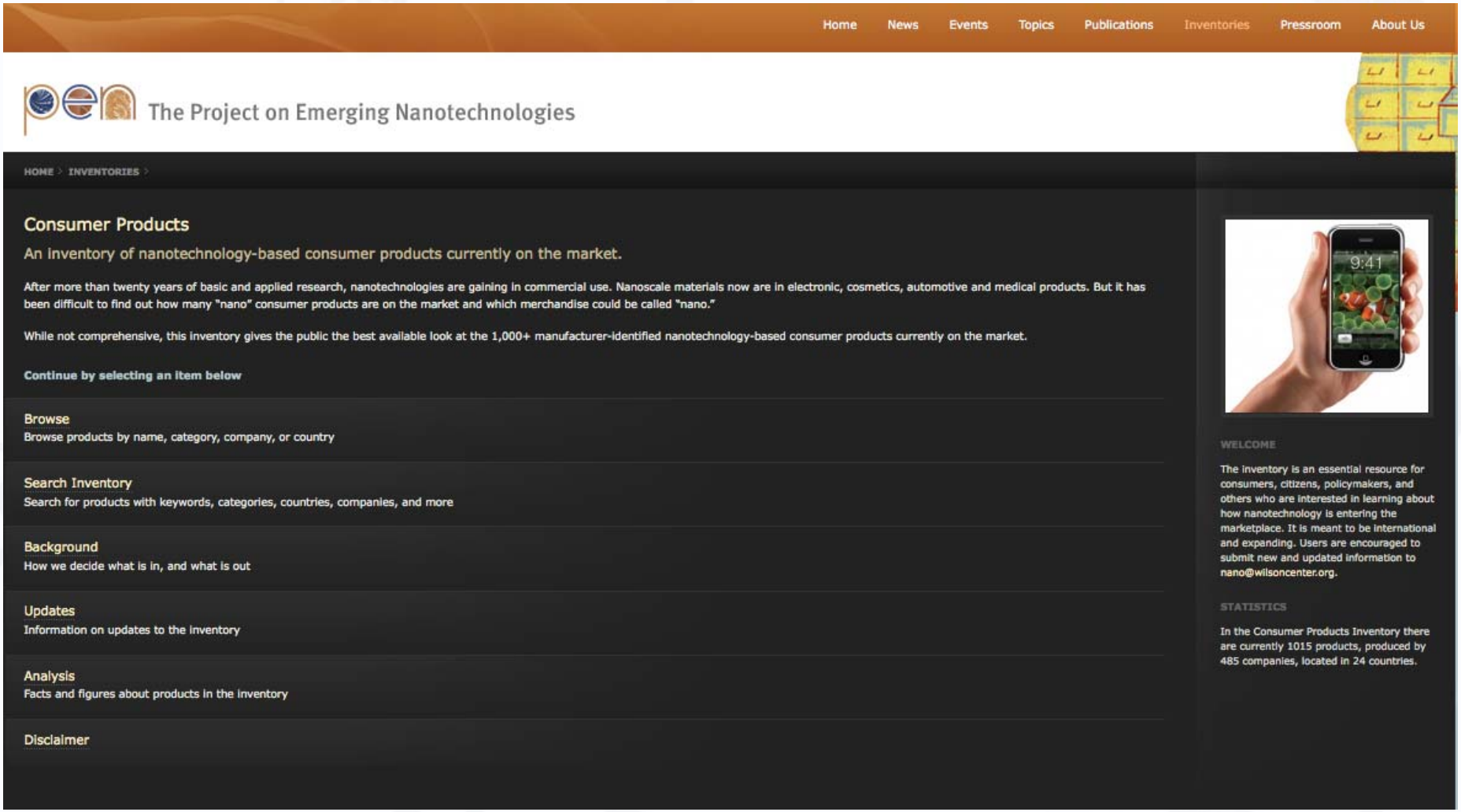
The Top Down, Bottom Up Dichotomy



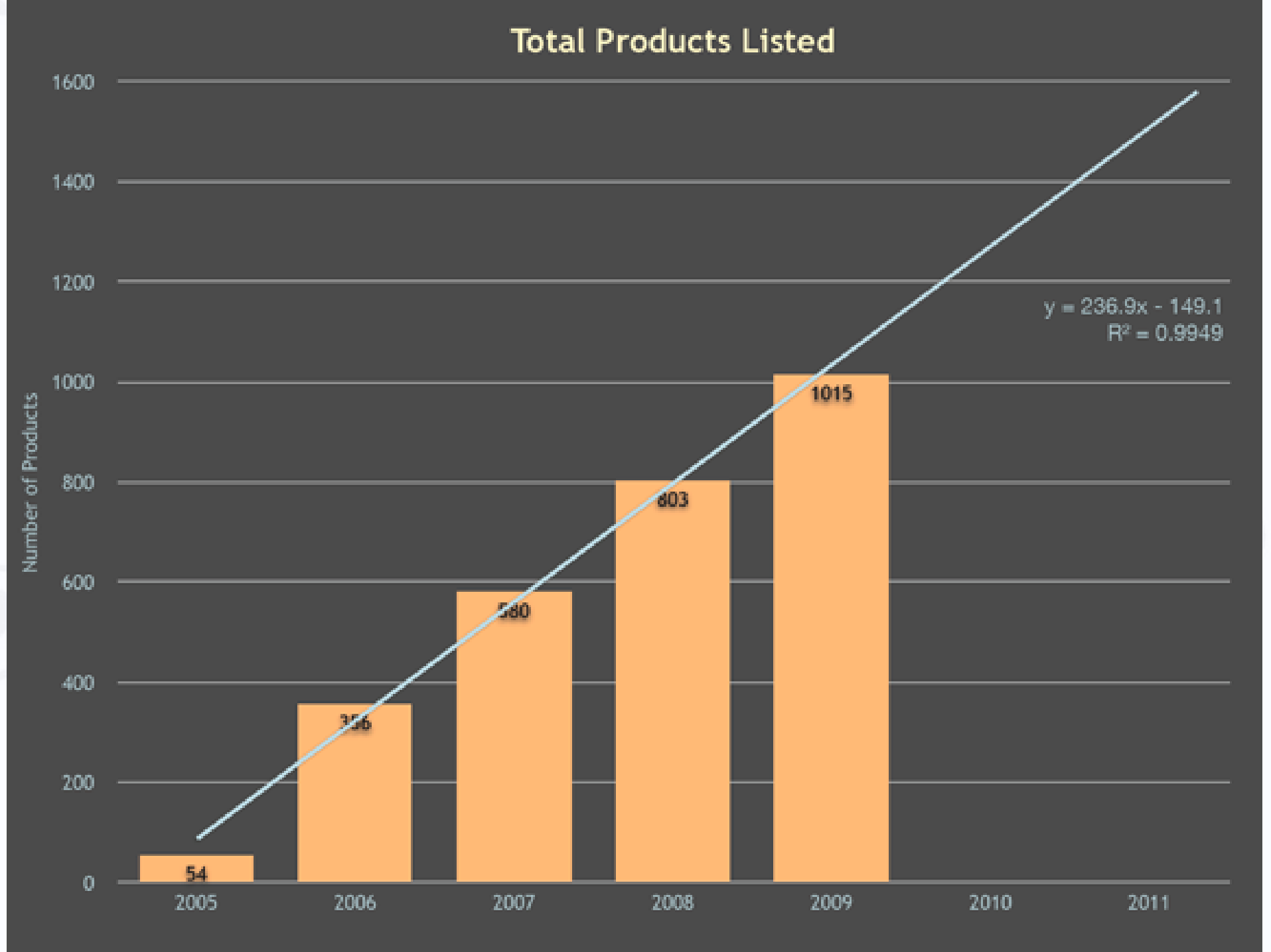
Top Down (Breaking Down)	**Bottom Up** (Piecing Together)
Dry milling to create nanoscale materials with enhanced properties	Nano Sensors
Nano-filtration/Molecular sieving for purification	Novel encapsulation systems/Smart delivery
Supercritical fluid techniques	Molecular self-assembly to create functional materials and devices

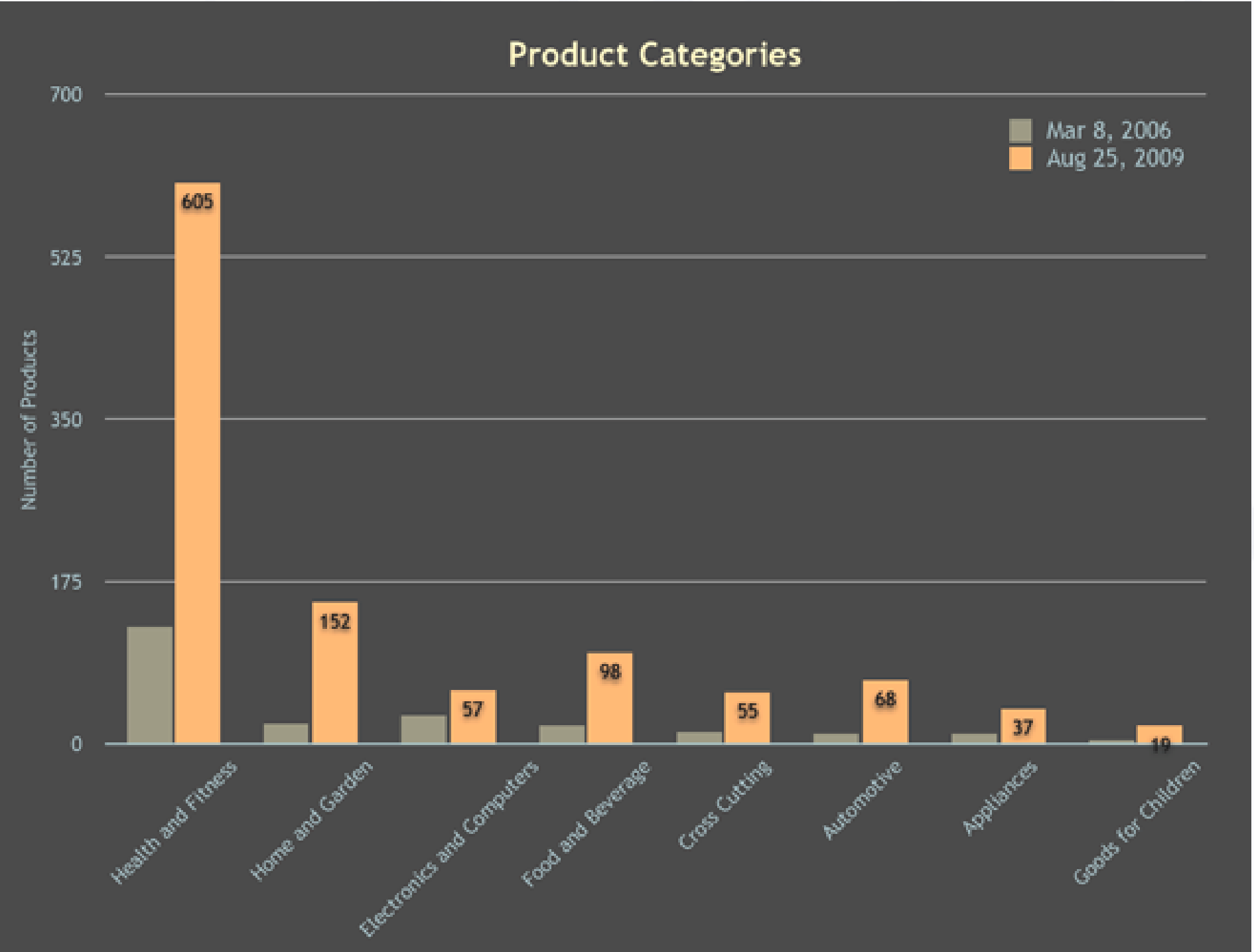


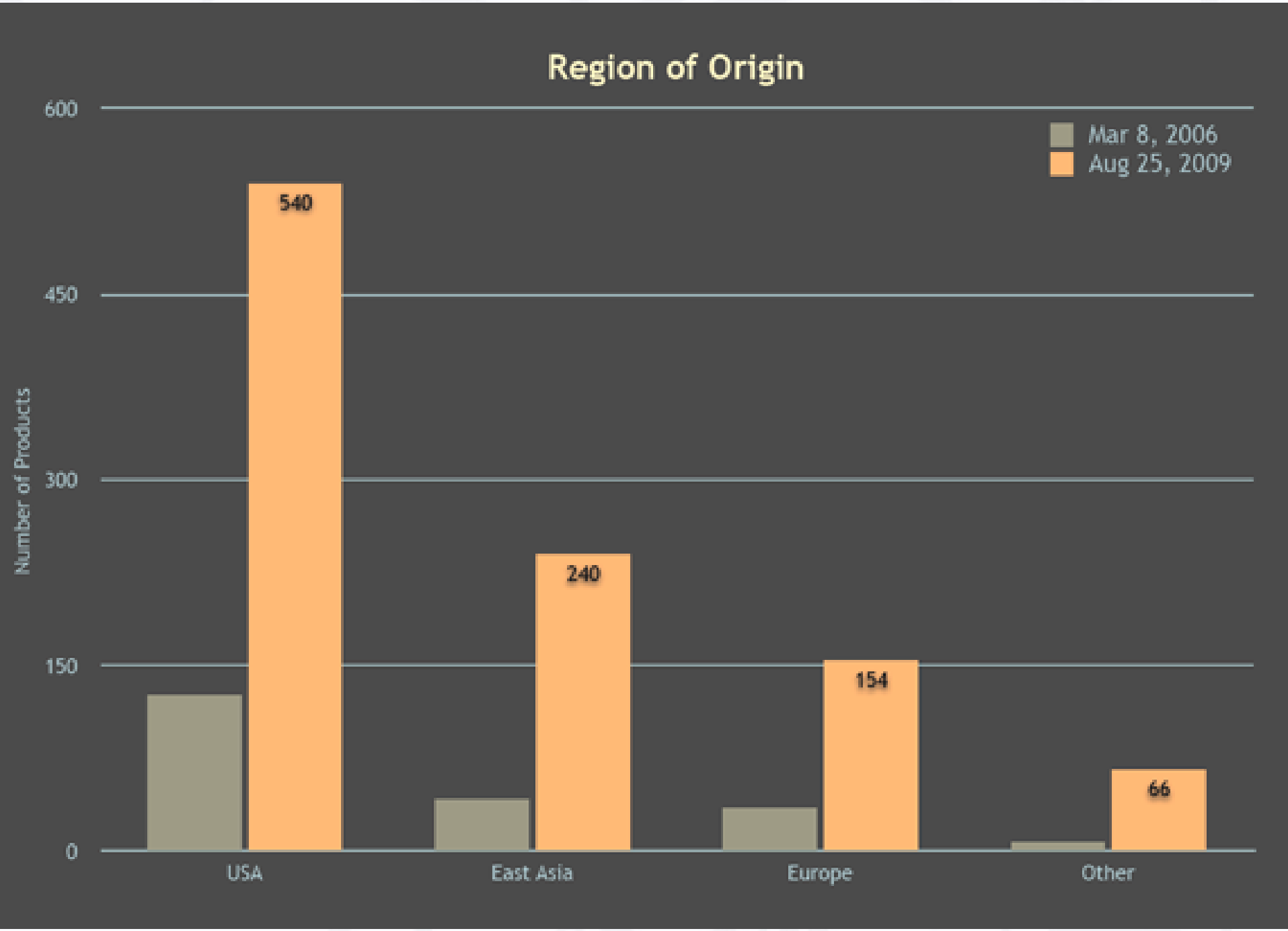
Nanotechnology Product Inventory

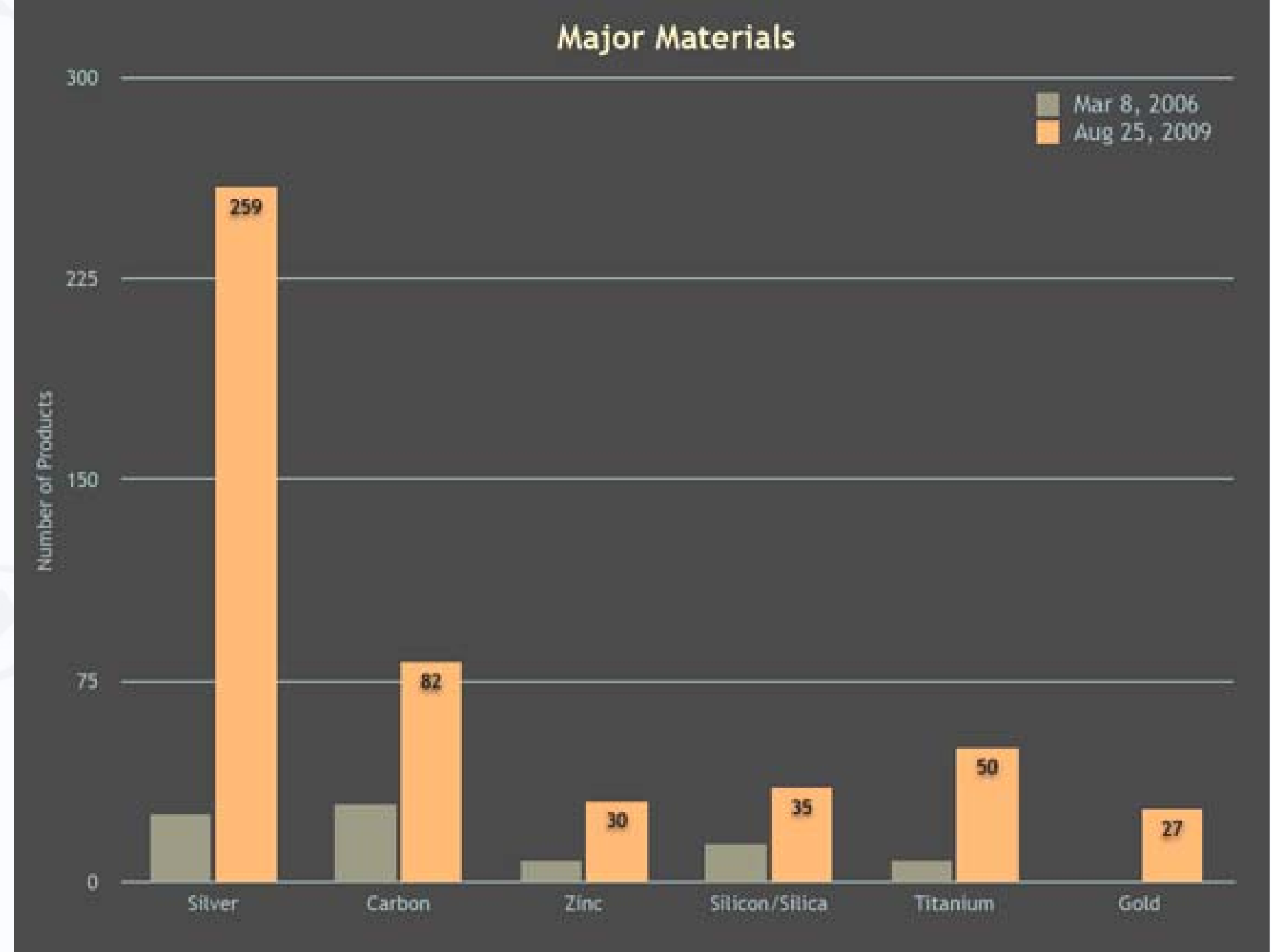


»**http://www.nanotechproject.org/inventories/consumer/**


Total Products Listed
1600
1400
1200
1000
800
600
400
200
0
Number of Products
y = 236.9x - 149.1
R² = 0.9949
54
356
580
803
1015
2005
2006
2007
2008
2009
2010
2011


Product Categories
Mar 8, 2006
Aug 25, 2009
Number of Products
700
525
350
175
0
605
152
57
98
55
68
37
19
Health and Fitness
Home and Garden
Electronics and Computers
Food and Beverage
Cross Cutting
Automotive
Appliances
Goods for Children

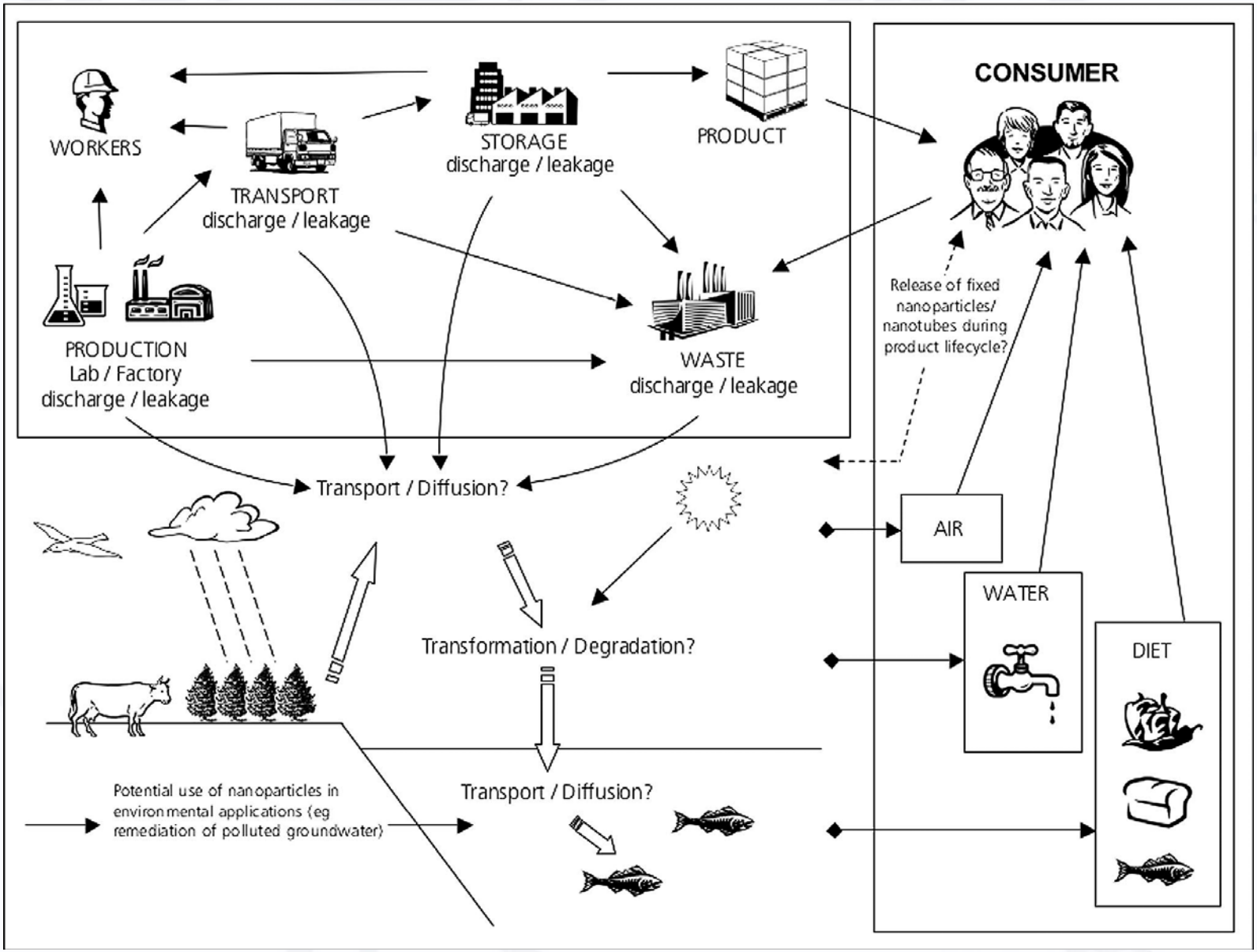

Region of Origin
600
450
300
150
0
Number of Products
Mar 8, 2006
Aug 25, 2009
540
240
154
66
USA
East Asia
Europe
Other


Major Materials
Mar 8, 2006
Aug 25, 2009
Number of Products
300
225
150
75
0
259
82
30
35
50
27
Silver
Carbon
Zinc
Silicon/Silica
Titanium
Gold

Materials of Particular Interest to Regulators

Fullerenes (C60)	Aluminum Oxide
Single Walled Carbon Nanotubes	Cerium Oxide
Multi Walled Carbon Nanotubes	Zinc Oxide
Silver Nanoparticles	Silicon Dioxide
Iron Nanoparticles	Polystyrene
Carbon black	Dendrimers
Titanium Dioxide	Nanoclays

OECD Working Party on Manufactured Nanomaterials
Priority Testing List



http://www.nanotec.org.uk/finalReport.htm

Regulatory Complexity

Environment Canada
Canadian Environmental Protection Act •New Substances Notification Regs •Persistence and Bioaccumulation Regs
Canadian Environmental Assessment Act
Fisheries Act, Oceans Act
Agricultural Products, Pest Control and Fertilizers Acts
Health Canada
Food & Drugs Act •Food & Drugs Regs •Medical Devices Regs •Cosmetics Regs •Natural Health Products Regulations
Hazardous Products Act •Controlled Products Regulations •Work Hazardous Materials Information System

In the context of environmental technologies, what, exactly, are we talking about?

- ***Applications of Nanotechnology***
  - *Direct Soil Remediation*
  - *Sensing Technologies*
  - *Water Purification/Desalination Technologies (membranes)*
  - *(Nano-Bio interface: enablement of genomics and synthetic biology)*
  - *(Green Chemistry, Green Energy)*

What's special about the nanoscale?

- Materials, known to us in their bulk form can behave differently at the nanoscale
- Physico-chemical properties are mutable as size changes
  - Size ↓; Surface Area ↑
  - How does surface area impact biological reactivity?
- Does size materially affect the toxicological profile of materials?
- Can the toxicological question be made predictable?
- Does this issue lead to the conclusion that NMs should be regulated differently than other new chemical substances?

etc group

action group on erosion, technology and concentration

News Release
ETC Group
18 October 2006
www.etcgroup.org

EPA's Nanotech Regs: Ironic Parameters
Clean-up – Clam-up – Screw-up?

During summer vacation, the lead US environmental regulatory agency acknowledged it has approved at least 15 novel nanoscale chemicals. Earlier this year EPA sanctioned the unproven use of iron nanoparticles to clean up a pesticide dump. Hearings this week.

"Nanotech companies are telling patent examiners and venture capitalists that they are taking advantage of nanoscale, quantum effects to create novel materials while telling EPA that the chemicals are the same-old, same-old."

Kathy-Jo Wetter, ETC Group

Canadian Patent Database

Search: (nano* AND environment) *in claims*

Result: 258 patent applications/patents

Major areas of focus appear to be:

»Functional, protective nanoscale materials

»Methods for flow-through remediation

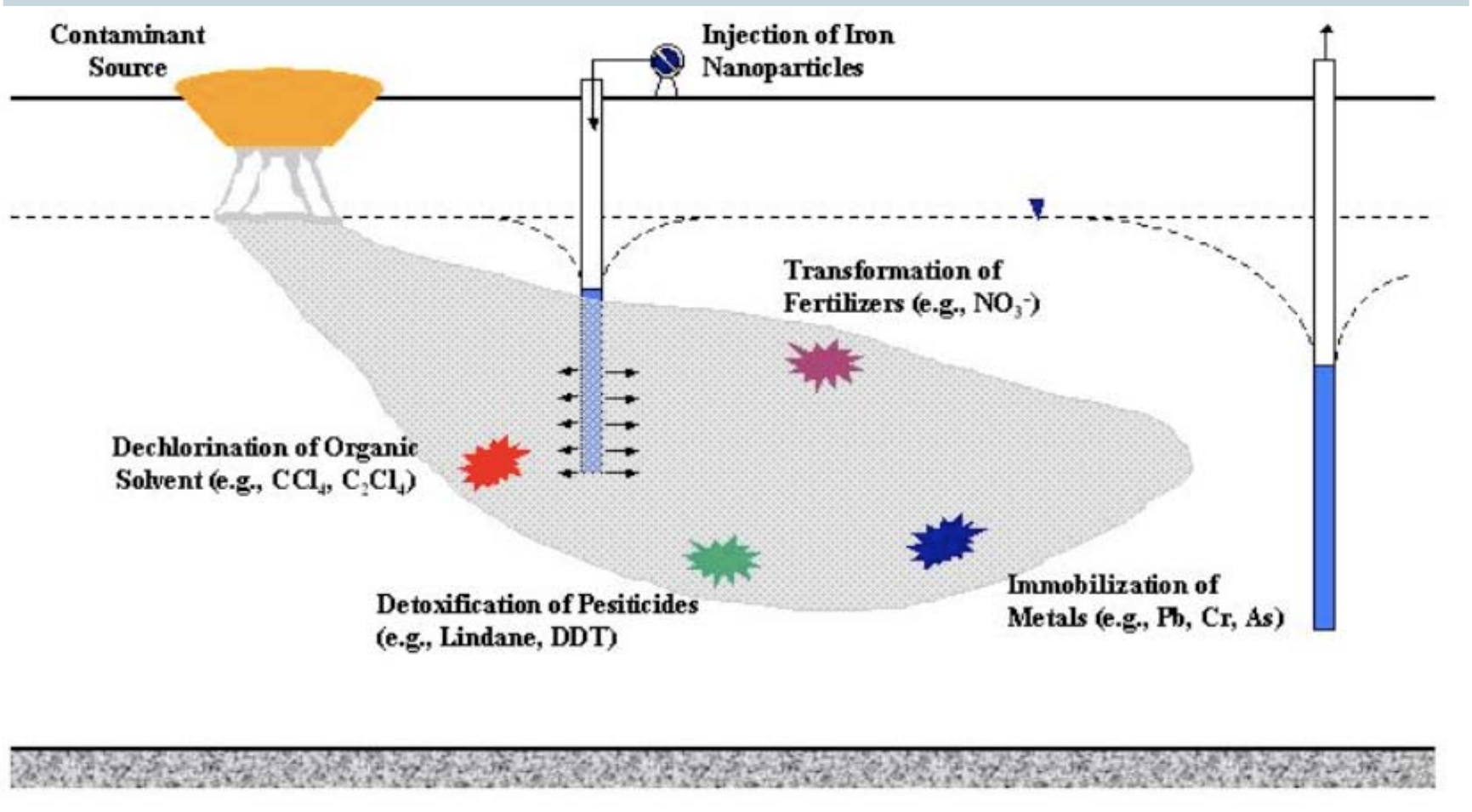
»Sensing devices (contamination, spoilage)

As at Oct 2009

Nanotools for Contaminated Site Remediation

- Nanoscale iron particles can provide cost-effective solutions to some of most challenging environmental challenges.
- Large surface area and high surface reactivity
- Provide flexibility for in situ application
- Can be mounted on a solid matrix such as activated carbon and used to treat wastewater or gaseous process streams.
- Effective transformation and detoxification of chlorinated organic solvents, pesticides and PCBs

Direct Soil Remediation



W. Zhang "Nanoscale Iron Particles for Environmental Remediation: An Overview" (2003) 5 *J. Nanoparticle Res*. 323-332.

etc group
action group on erosion, technology and concentration

ETC Group
News Release
May 3rd, 2007
www.etcgroup.org

Geoengineers to Foul Galapagos Seas
-Defying Climate Panel Warning

As the UN's top climate science panel, the IPCC, prepares to criticise the idea of geoengineering, one maverick geoengineering company, Planktos Inc, has announced it is about to dump several tonnes of tiny particles into the waters around the Galapagos Islands, covering an area larger than Puerto Rico. Doing so, they claim, will re-engineer the atmosphere, win them commercial carbon credits and perhaps a shot at the $25 [illegible] Richard Branson. Mainstream scien[illegible] are crying foul.

POLICYFORUM

ENVIRONMENT

(2008) 319 *Science* 162, 11 Jan 2008.

Ocean Iron Fertilization—Moving Forward in a Sea of Uncertainty

Ken O. Buesseler,[1]* Scott C. Doney,[1] David M. Karl,[2] Philip W. Boyd,[3] Ken Caldeira,[4] Fei Chai,[5] Kenneth H. Coale,[6] Hein J. W. de Baar,[7] Paul G. Falkowski,[8] Kenneth S. Johnson,[9] Richard S. Lampitt,[10] Anthony F. Michaels,[11] S. W. A. Naqvi,[12] Victor Smetacek,[13] Shigenobu Takeda,[14] Andrew J. Watson[15]

Planktos Indefinitely Postpones Ocean Iron Fertilization Project

February 13, 2008 http://www.planktos.com

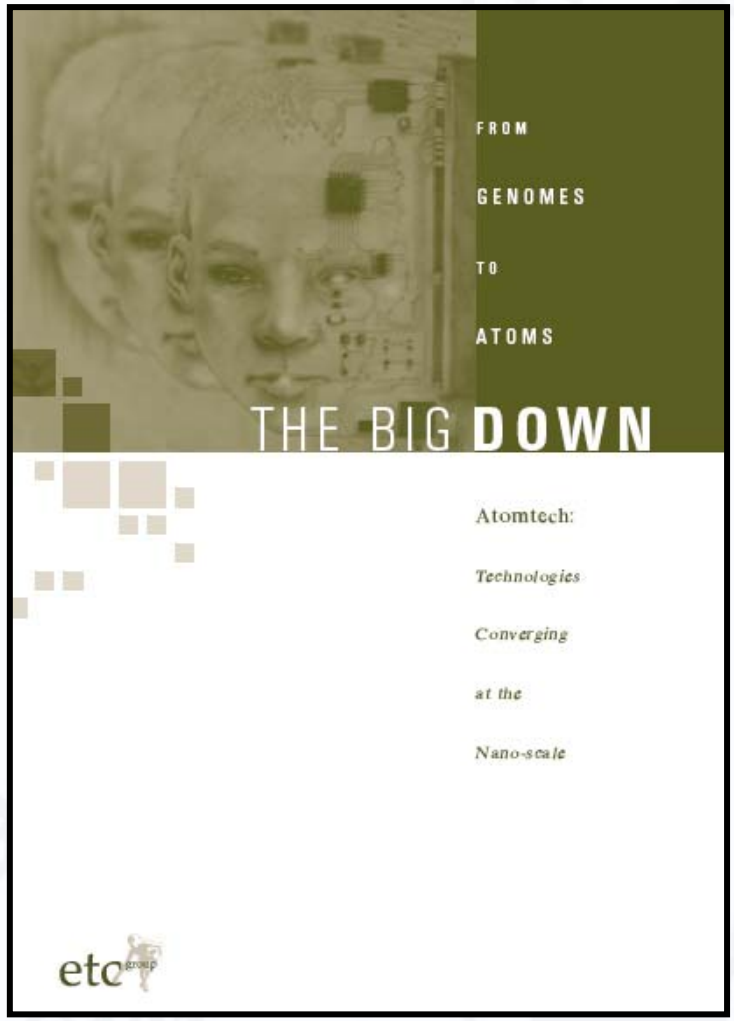
The board of directors of Planktos Corp. (Pink Sheets:PLKT) today announced that the company has been forced to indefinitely postpone its ocean fertilization efforts once intended to restore marine plant life and generate ecological offsets for the global carbon credit market.

A highly effective disinformation campaign waged by anti-offset crusaders has provoked widespread opposition to plankton restoration in the environmental world, and has caused the company to encounter serious difficulty in raising the capital needed to fund its planned series of ocean research trials.

Public Action Groups Rise Against Nanotechnology

January 2003

- Ottawa based ETC Group publishes major report focussing on risks of nanotechnology
- Anti-globalization in tenor
- Express position re need for moratorium on the release of engineered nanoparticles



Nanoscience and Nanotechnologies: Opportunities and Challenges, UK Royal Society & Royal Academy of Engineering

July 2004

- Moratorium not feasible; exposure to NMs should be limited insofar as possible.
- The regulatory framework at the EU and UK level are sufficiently broad and flexible to accommodate the development of nanomaterials; regulations may need to be tailored.
- Relevant regulatory bodies should consider whether existing regulations are appropriate to protect humans and the environment from NMs/NPs.
- Life Cycle Assessment should be used to examine exposure risk from cradle to grave.

http://www.nanotec.org.uk/finalReport.htm

Nanoparticles: health impacts?

The DuPont Company,
Newark, DE, USA
E-mail: David.B.Warheit@USA.dupont.com

32 materialstoday February 200

by David B. Warheit

3856 Biophysical Journal Volume 89 December 2005 3856–3862

C_{60} Binds to and Deforms Nucleotides

Xiongce Zhao,* Alberto Striolo,† and Peter T. Cummings*†
*Nanomaterials Theory Institute, Center for Nanophase Materials Sciences, Oak Ridge National Laboratory, Oak Ridge, Tennessee; and †Department of Chemical Engineering, Vanderbilt University, Nashville, Tennessee

Review

Nanoparticles – known and unknown health risks

Peter HM Hoet[1], Irene Brüske-Hohlfeld[2] and Oleg V Salata*[3]

Published: 08 December 2004
Journal of Nanobiotechnology 2004, 2:12 doi:10.1186/1477-3155-2-12

ehp Environmental Health PERSPECTIVES
ehponline.org
Journal of the National Institute of Environmental Health Sciences

Manufactured Nanomaterials (Fullerenes, C_{60}) Induce Oxidative Stress in Brain of Juvenile Largemouth Bass

Eva Oberdörster

doi:10.1289/ehp.7021 (available at http://dx.doi.org/)
Online 7 April 2004

LETTERS

Carbon nanotubes introduced into the abdominal cavity of mice show asbestos-like pathogenicity in a pilot study

CRAIG A. POLAND[1], RODGER DUFFIN[1], IAN KINLOCH[2], ANDREW MAYNARD[3], WILLIAM A. H. WALLACE[1], ANTHONY SEATON[4], VICKI STONE[5], SIMON BROWN[1], WILLIAM MACNEE[1] AND KEN DONALDSON[1]*

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[2]School of Materials, University of Manchester, Grosvenor Street, Manchester M1 7HS, UK
[3]Woodrow Wilson International Center for Scholars, 1300 Pennsylvania Avenue, NW, Washington DC 20004-3027, USA
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Published online: 20 May 2008; doi:10.1038/nnano.2008.111

Eur Respir J 2009; 34: 559–567
DOI: 10.1183/09031936.00178308

Exposure to nanoparticles is related to pleural effusion, pulmonary fibrosis and granuloma

Y. Song*, X. Li# and X. Du*

ABSTRACT: Nano materials generate great benefits as well as new potential risks. Animal studies and *in vitro* experiments show that nanoparticles can result in lung damage and other toxicity, but no reports on the clinical toxicity in humans due to nanoparticles have yet been made.

The present study aimed to examine the relationship between a group of workers' presenting with mysterious symptomatic findings and their nanoparticle exposure.

Seven young female workers (aged 18–47 yrs), exposed to nanoparticles for 5–13 months, all with shortness of breath and pleural effusions were admitted to hospital. Immunological tests, examinations of bacteriology, virology and tumour markers, bronchoscopy, internal thoracoscopy and video-assisted thoracic surgery were performed. Surveys of the workplace, clinical observations and examinations of the patients were conducted.

AFFILIATIONS
Depts of *Occupational Medicine and Clinical Toxicology, and #Pathology, Beijing Chaoyang Hospital, Capital University of Medical Sciences, Beijing, China.

CORRESPONDENCE
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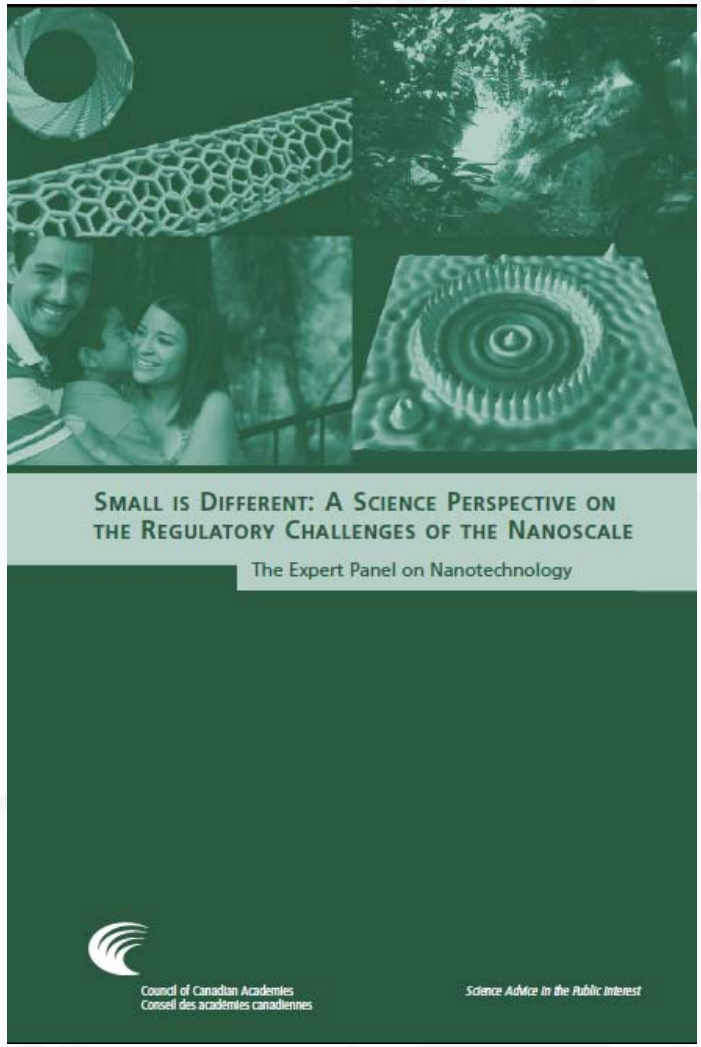
Canadian Council of Academies

July 2008

- Physico-chemical properties of NMs may lead to unanticipated behaviours.
- No unique biological effects associated with exposure to NMs; but poor general understanding of effects.
- NMs require new ways of measuring exposure, dose and response.
- Truly evidence-based risk management/regulation not yet possible.
- Strategic research needed.

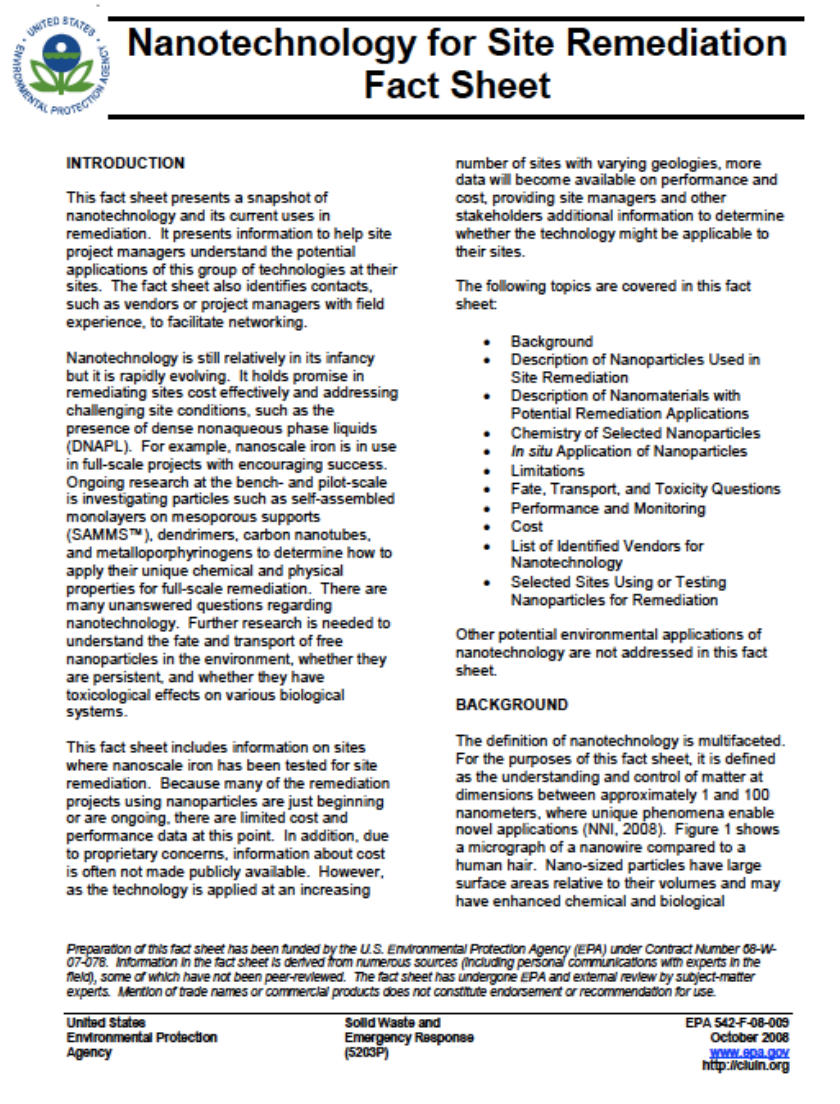


United States, EPA – Nanotechnology for Site Remediation (fact sheet)

October 2008

- » Snapshot of NT and uses in remediation.
- » Identifies sites where nanoscale iron has been tested for site remediation.
- » Identifies contacts (vendors and project mgrs) with field experience.
- » Outlines need for EHS research to inform practice and regulation.
- » See also “Emerging Contaminants – Nanomaterials”

»**www.clu-in.org**



Nanotechnology for Site Remediation Fact Sheet

INTRODUCTION

This fact sheet presents a snapshot of nanotechnology and its current uses in remediation. It presents information to help site project managers understand the potential applications of this group of technologies at their sites. The fact sheet also identifies contacts, such as vendors or project managers with field experience, to facilitate networking.

Nanotechnology is still relatively in its infancy but it is rapidly evolving. It holds promise in remediating sites cost effectively and addressing challenging site conditions, such as the presence of dense nonaqueous phase liquids (DNAPL). For example, nanoscale iron is in use in full-scale projects with encouraging success. Ongoing research at the bench- and pilot-scale is investigating particles such as self-assembled monolayers on mesoporous supports (SAMMS™), dendrimers, carbon nanotubes, and metalloporphyrinogens to determine how to apply their unique chemical and physical properties for full-scale remediation. There are many unanswered questions regarding nanotechnology. Further research is needed to understand the fate and transport of free nanoparticles in the environment, whether they are persistent, and whether they have toxicological effects on various biological systems.

This fact sheet includes information on sites where nanoscale iron has been tested for site remediation. Because many of the remediation projects using nanoparticles are just beginning or are ongoing, there are limited cost and performance data at this point. In addition, due to proprietary concerns, information about cost is often not made publicly available. However, as the technology is applied at an increasing number of sites with varying geologies, more data will become available on performance and cost, providing site managers and other stakeholders additional information to determine whether the technology might be applicable to their sites.

The following topics are covered in this fact sheet:

- Background
- Description of Nanoparticles Used in Site Remediation
- Description of Nanomaterials with Potential Remediation Applications
- Chemistry of Selected Nanoparticles
- *In situ* Application of Nanoparticles
- Limitations
- Fate, Transport, and Toxicity Questions
- Performance and Monitoring
- Cost
- List of Identified Vendors for Nanotechnology
- Selected Sites Using or Testing Nanoparticles for Remediation

Other potential environmental applications of nanotechnology are not addressed in this fact sheet.

BACKGROUND

The definition of nanotechnology is multifaceted. For the purposes of this fact sheet, it is defined as the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications (NNI, 2008). Figure 1 shows a micrograph of a nanowire compared to a human hair. Nano-sized particles have large surface areas relative to their volumes and may have enhanced chemical and biological

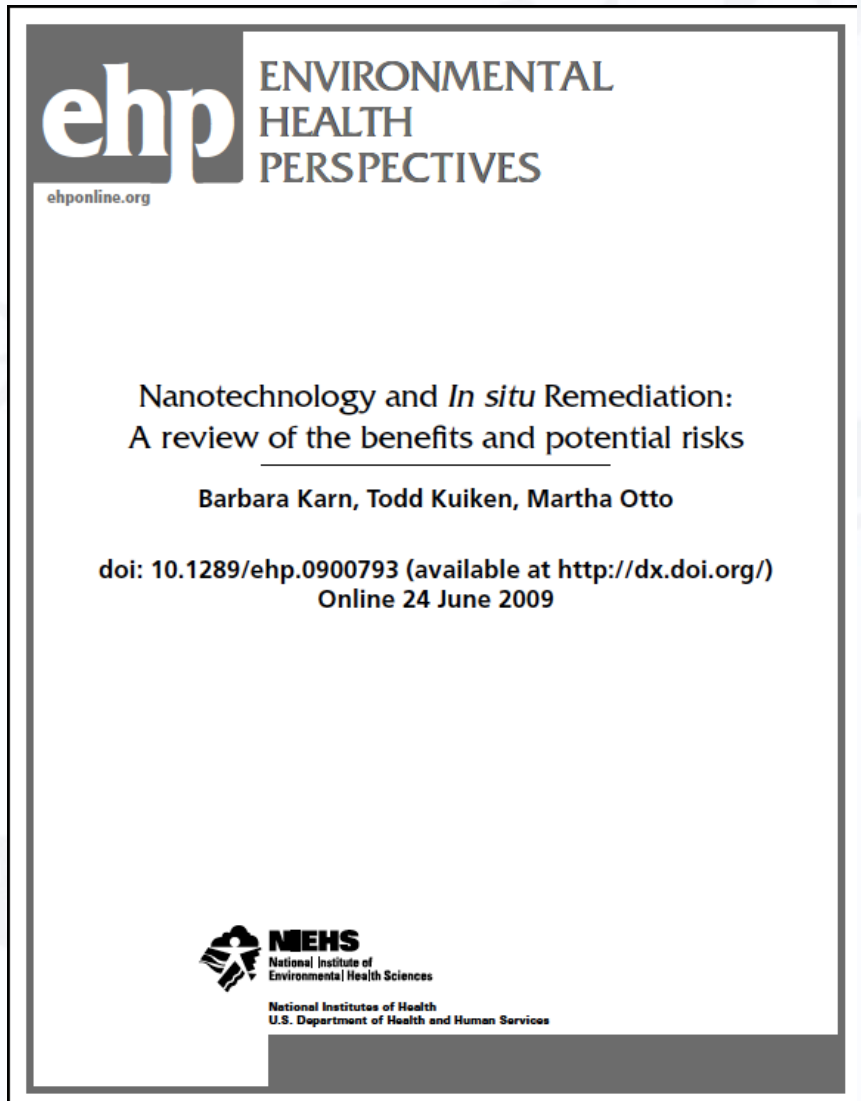
Preparation of this fact sheet has been funded by the U.S. Environmental Protection Agency (EPA) under Contract Number 68-W-07-078. Information in the fact sheet is derived from numerous sources (including personal communications with experts in the field), some of which have not been peer-reviewed. The fact sheet has undergone EPA and external review by subject-matter experts. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

United States Environmental Protection Agency | Solid Waste and Emergency Response (5203P) | EPA 542-F-08-009 October 2008 www.epa.gov http://cluin.org

Key Review of NT and in situ Remediation

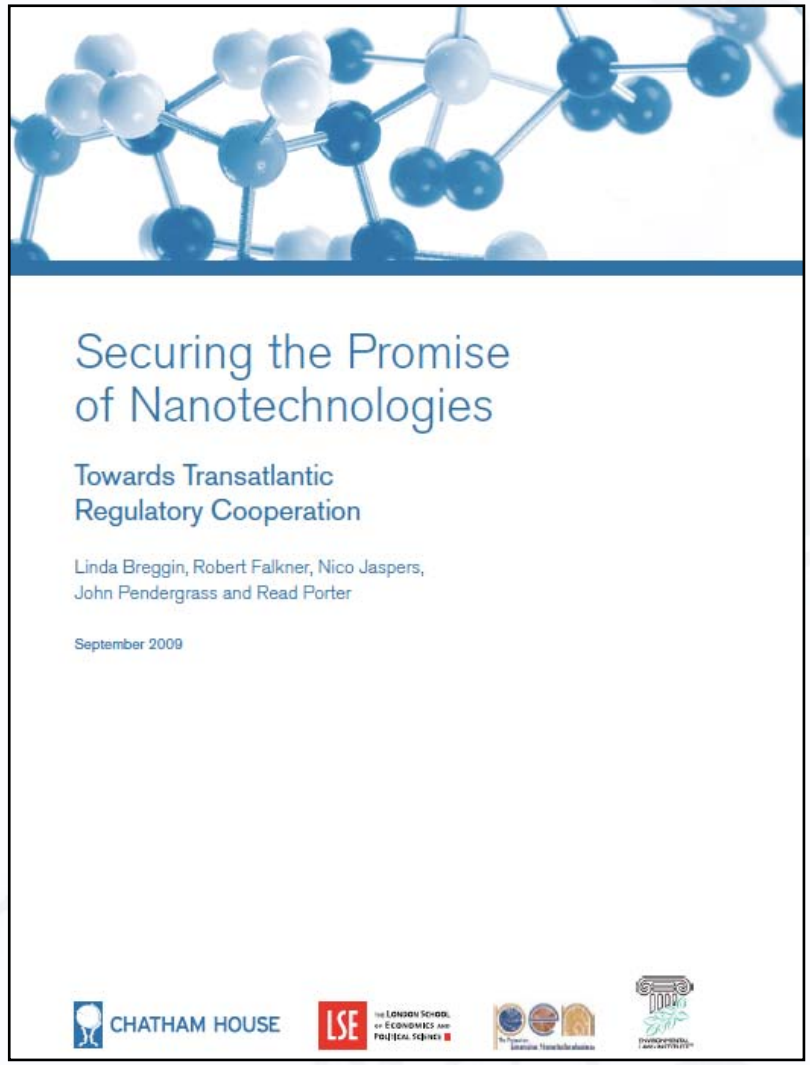
June 2009

- Woodrow Wilson International Center for Scholars & EPA
- Comprehensive overview of what is known.
- Recommendations:
  - Develop analytical tools to measure and monitor manufactured NMs in the environment
  - Increase research to evaluate the effects of NPs on the full ecosystem
  - Improve engineering applications using nanotechnology for in situ remediation



International Cooperation

- EU and US are leaders in NS and EHS regulation
- Opportunity to cooperate and converge
- Recognize need for global policy responses
- Canada is active participant in OECD and ISO committees
- US/Canada legal comparison remains to be done



»**www.chathamhouse.org**

Main Policy Challenge

- Maintaining public trust
- Opposition to NT may be mounting (?)
- Expect that something will go wrong
- Public trust is not unconditional
- Education, engagement and communication strategies around nanotechnology are needed

Conclusions

- Major gaps exist in our understanding of the health, safety and environmental impacts of nanotechnology.
- Coordinated, strategic research is essential to develop the foundational knowledge that will empower the responsible development of key technologies
- Nanotechnology will be used to enable controversial frontiers in science (e.g. reproductive and genetic technologies, regenerative medicine, synthetic biology, food science); it has sparked public interest.
- Public trust in the scientific enterprise depends on a coherent and rational approach to stewardship.
- National and international dialogue, cooperation and coordination is necessary to ensure that: risks are mitigated as quickly as possible; and all nations have the opportunity to implement appropriate strategies to deal with the challenges.

Acknowledgements

- National Institute for Nanotechnology/University of Alberta
- Health Canada
- Advanced Food and Materials Network