Nanomanufacturing Advancements and Nanoinformatics

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National Nanomanufacturing Network

CMMI-1025020

2014 Korea US Nano Forum

Regarding Manufacturing

- The *process* must work at a commercially relevant scale
- Part of a value chain
- Cost is certainly a factor
- Access to tools, raw materials and workforce
- Reproducible and reliable
- EHS under control
- Standards –terminology, nomenclature, measurement
- For versatility and to optimize, need data and models - informatics

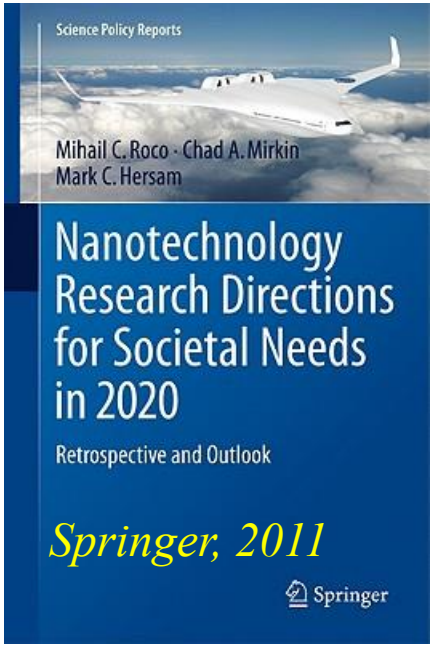
Nanomanufacturing Goals for the Future

• A robust platform of inherently **scalable processes**—including self-assembly, directed assembly and bioinspired synthesis—for high volume nanomanufacturing, including roll-to-roll production.

• A library of building-block (unit) processes to fabricate **complex and multicomponent 3D nanosystems**, having designed heterogeneous structure and different spatial properties.

• Science-based **process-structure-property relationships** for nanoscale synthesis and processing -- enabling scale up, process control, modeling and optimization.

• **Data, models and tools** enabling materials by design and design rules for manufacturing



National Nanomanufacturing Network

Funded by NSF

An open access network for the advancement of ***nanomanufacturing*** R&D and education

- Network of centers with a *nanomanufacturing* focus
- Cooperative activities (*workshops, roadmapping*)
- Information and informatics (*InterNano.org*)

NNN: Open Network of Partners and Affiliates

- **Center for Hierarchical Manufacturing** (CHM)
  - UMass Amherst/UPR/MHC/MIT/Rice/Binghamton

- **Center for High-Rate Nanomanufacturing** (CHN)
  - Northeastern/UMass Lowell/UNH

- **Center for Scalable and Integrated Nanomanufacturing** (SINAM)
  - UC Berkeley/UCLA/NWU/UCSD/Stanford/UNC Charlotte

- **Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems** (Nano-CEMMS)
  - UIUC/CalTech/NC A&T

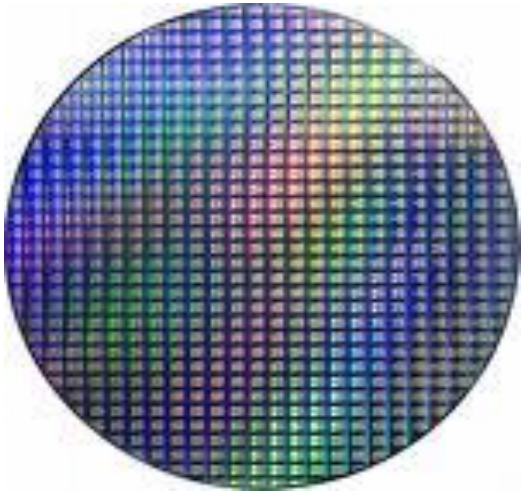
- **Center for Integrated Nanotechnologies** (CINT)
  - Sandia National Laboratories

- **Center for Nanoscale Science and Technology** (CNST - NIST)

Also, CEIN, NASCENT, and many others from government, industry, and universities

Cost

Manufacturing Platform Drives Cost

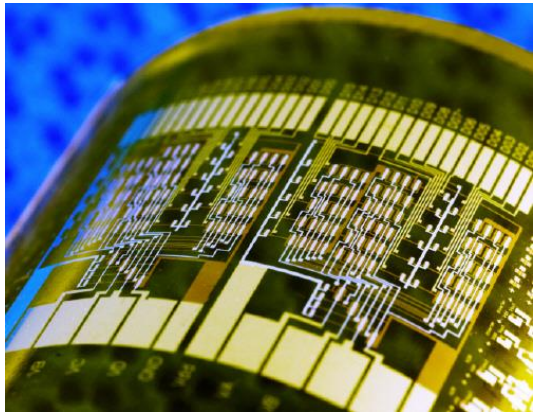


$25,000/m^2

Si wafer-based, precision devices

Now: 32 nm features in production

New Fab = $4-6 Billion



$25/m^2

Flexible Devices via Roll-to -Roll

Now: Macroelectronics, limited functionality

Low cost, high volume

Center for Hierarchical Manufacturing (CHM)
at The University of Massachusetts Amherst

J. Watkins, Director; M. Tuominen, Co-Director; J. Morse, Managing Director NNN

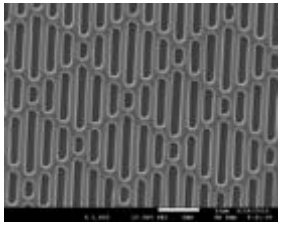
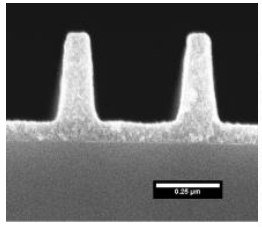
CHM
Center for Hierarchical Manufacturing

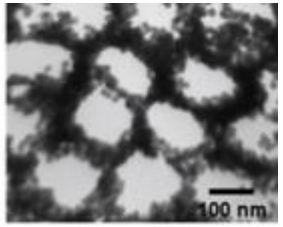
Nanoscale Science and Engineering Center

Snapshot: An NSF Nanoscale Science and Engineering Center funded through the Division of Civil, Mechanical and Manufacturing Innovation

- 32 Faculty in 7 disciplines at 6 Institutions
- Partners include MIT, Univ. of Michigan, Rice, Univ. of Puerto Rico, Mt. Holyoke College, NIST
- 40+ Industry Partners, Pre-competitive Research Consortium
- The CHM Develops Scalable Nanomanufacturing Technology and Tools
- Significant Focus on Roll-to-Roll Processing
- The CHM Hosts the National Nanomanufacturing Network

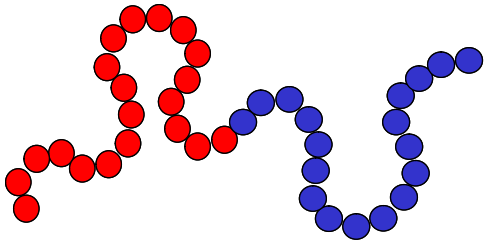
Mission: The CHM translates fundamental research on nanoscale materials, processes and devices into manufacturing technologies for next generation nano-enabled products using scalable, cost-effective platforms and tools.

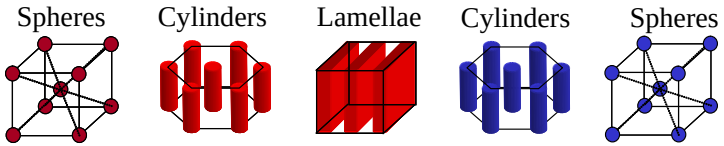






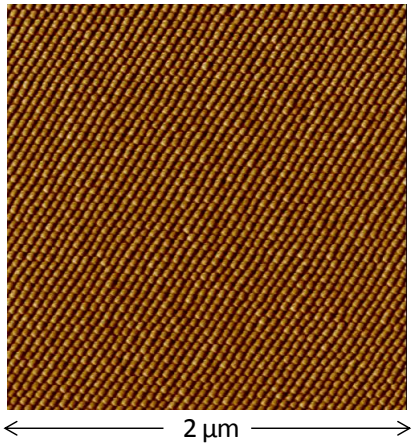

Ordered Structure at Length Scales Less Than 50 nm
Self-Assembly from Solution; Control of Morphology

Block Copolymer Assembly

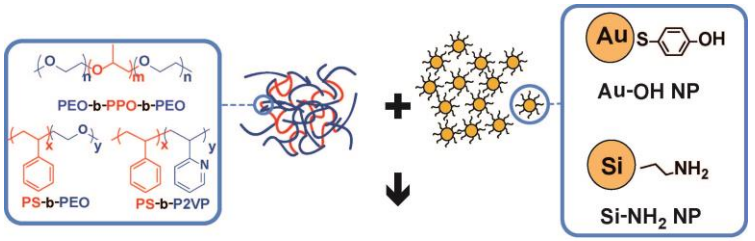


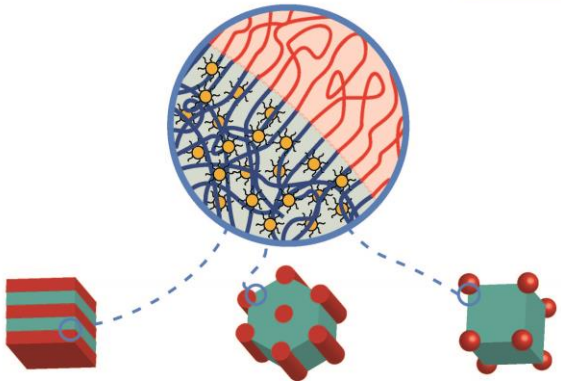


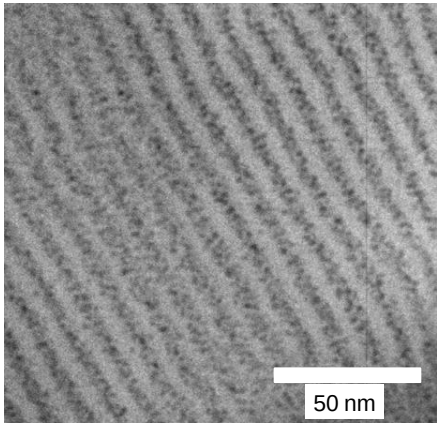
Increasing f →



Additive-Driven Assembly of Hybrids





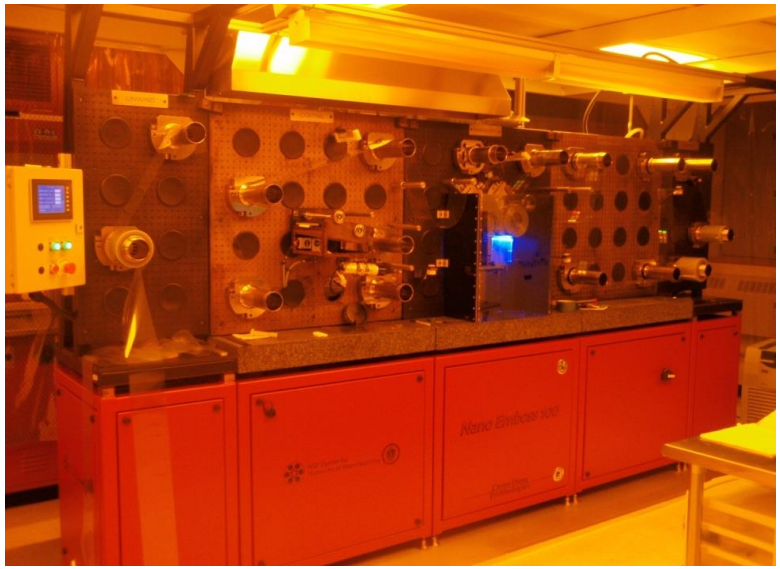


CHM
Center for Hierarchical Manufacturing

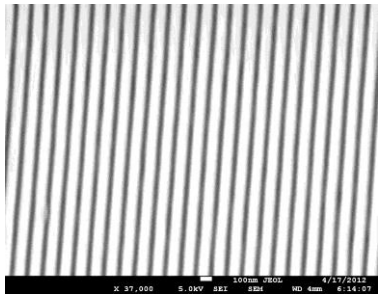
Roll-to-Roll Process Facilities

CHM
Center for Hierarchical Manufacturing

UV-Assisted Nanoimprint Lithography
May 2011

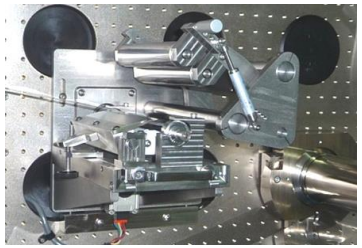


MI Wafer Tool



70 nm grating

R2R Coater for Nanostructured Hybrids
April 2012



Dual Microgravure

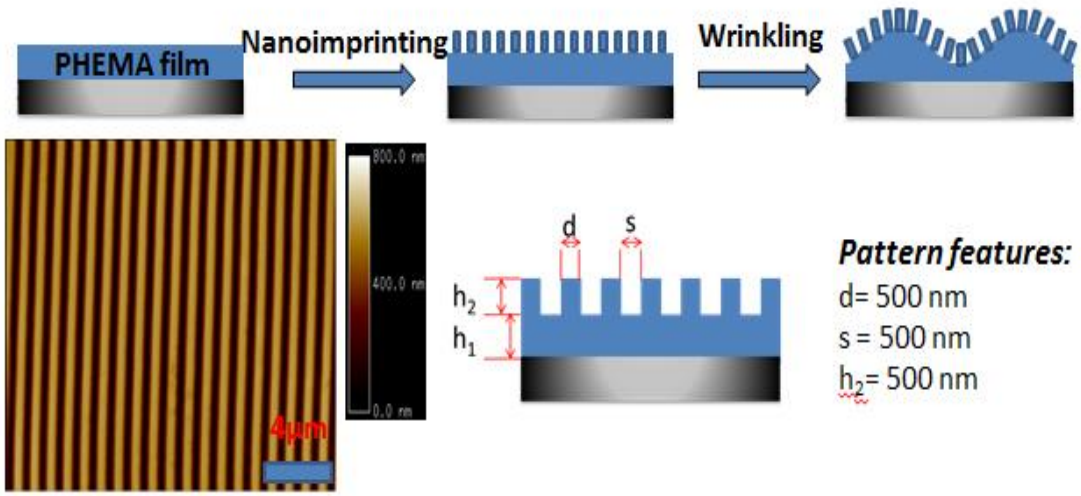
Slot Die

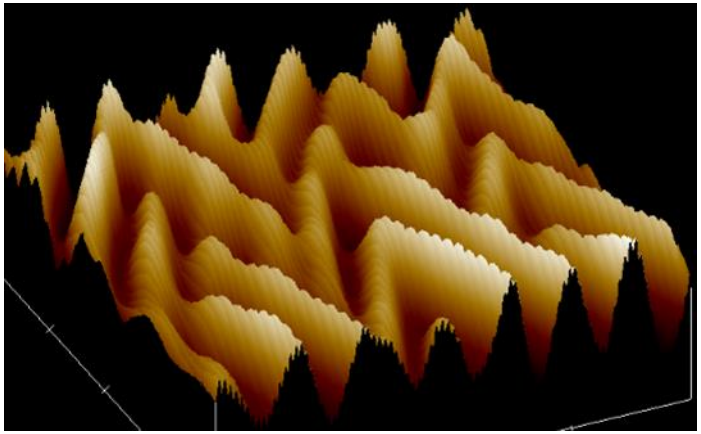
$26M in new R&D tools on order!

Unique R2R Tools Built with Qualified Partners

Roll-to-Roll Fabrication of Biomimetic Self-Cleaning Surfaces

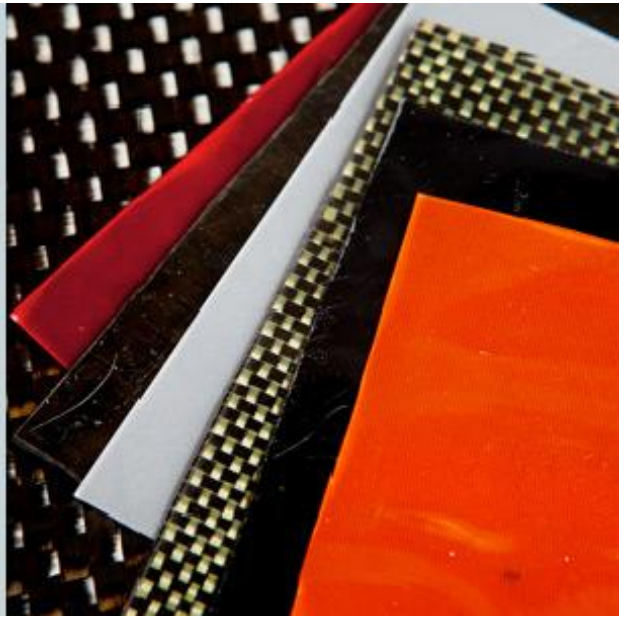
- Fabrication of hierarchical wrinkle patterns
- Develop hydrophobic resin suitable for R2R process: modified Norland Optical Adhesives (NOA)
- R2R nanoimprint of hierarchical wrinkle patterns to achieve superhydrophobic surfaces (SHS) and lubricant imbibed surfaces (LIS)

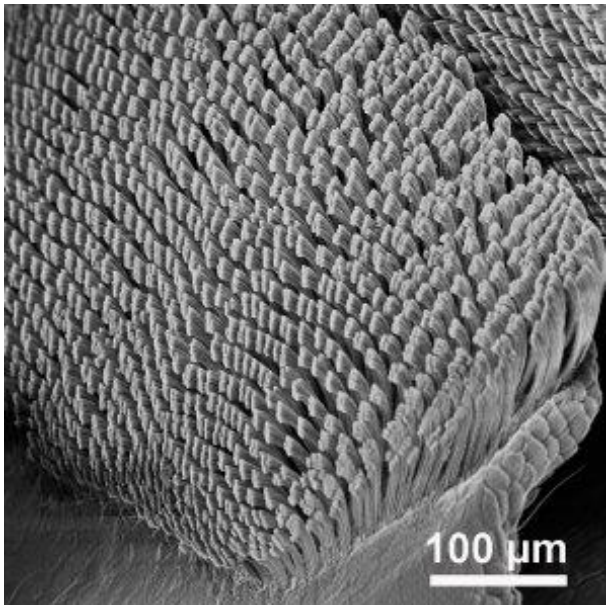


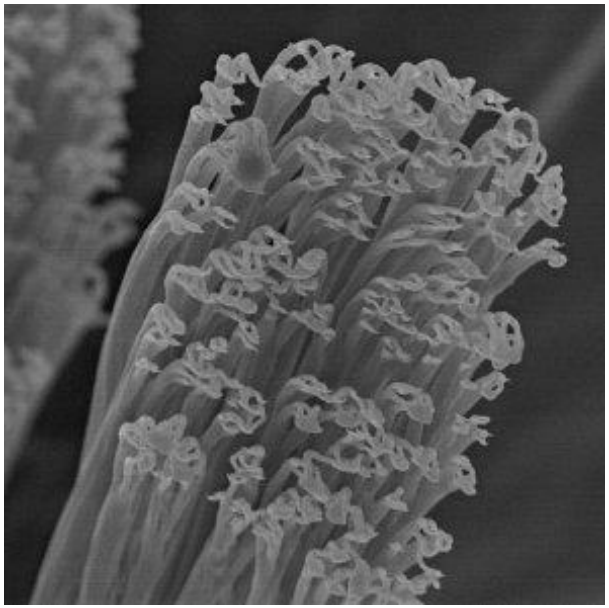


CHM
Center for Hierarchical Manufacturing

Geckskin™



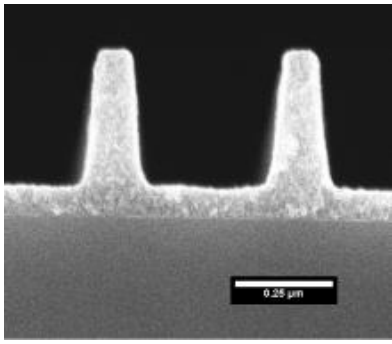




Al Crosby
Duncan Irschick

UMASS
AMHERST

Direct "Printing" of Patterned Crystalline Metal Oxide Films for Devices



Potential Impacts

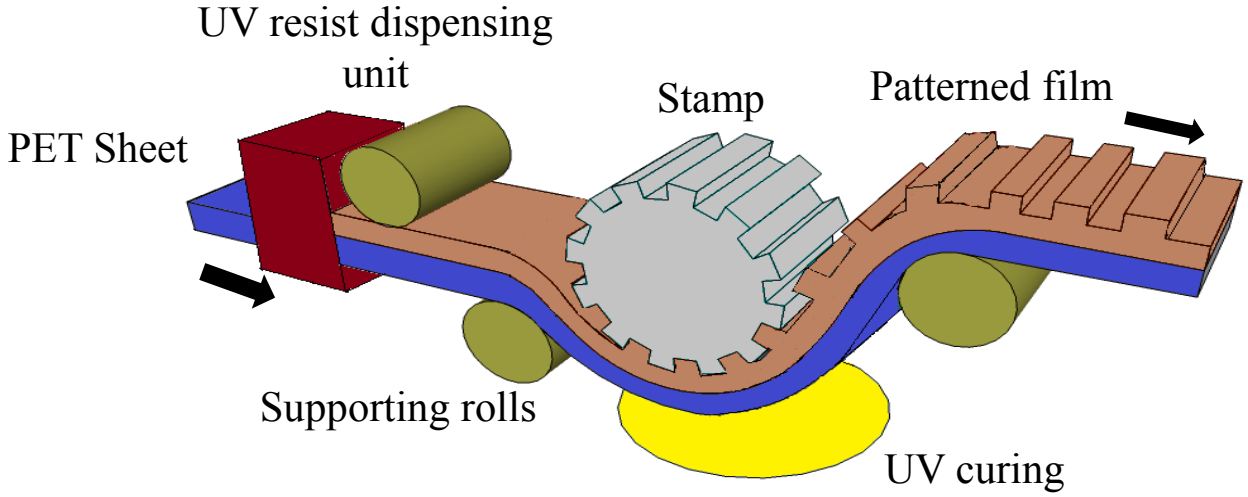
- Direct Printing of Inorganic Devices
- Have Demonstrated Conductors and Dielectrics
- Avoid Performance Limitations of Printed Organic Devices
- R2R Platform, Additive
  - low cost alternative to traditional Fabs
- Combine with Pulse Flash Lab Cure for Low T Substrates
- Combine with Ink Jet for Metal, Semiconductor Inks
- Versatile: Transistors to Fuel Cells

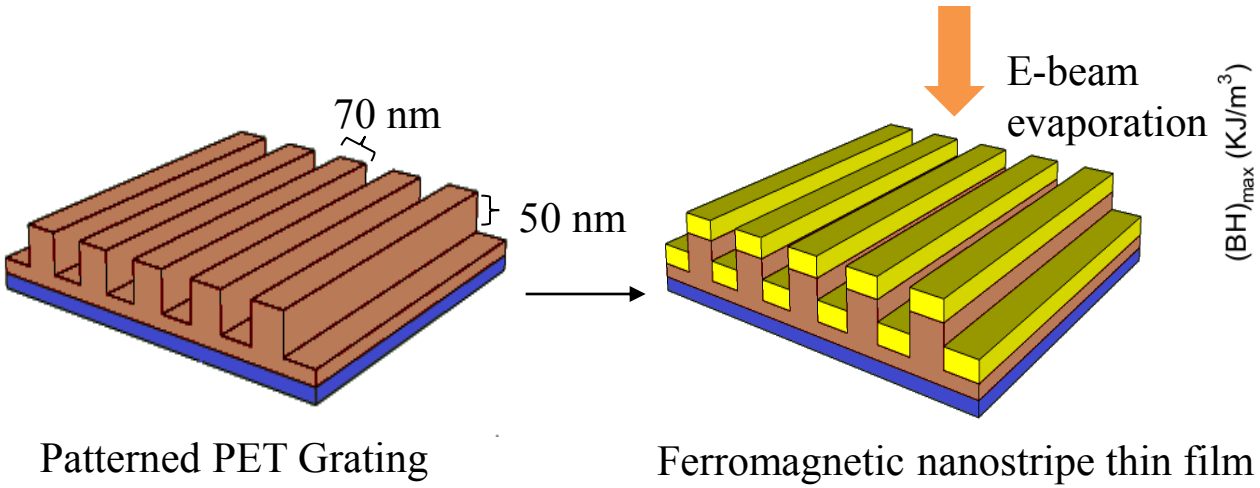
Novacentrix Pulse Forge Installed at UMass Jan 2014

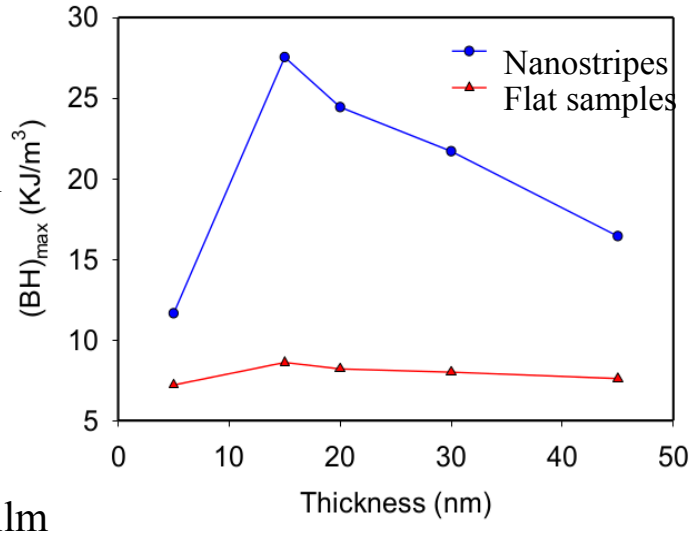
CHM
Center for Hierarchical Manufacturing

Magnetic Nanostructures by Roll-to-Roll

R2R fabrication for *high energy product* (BH) magnets

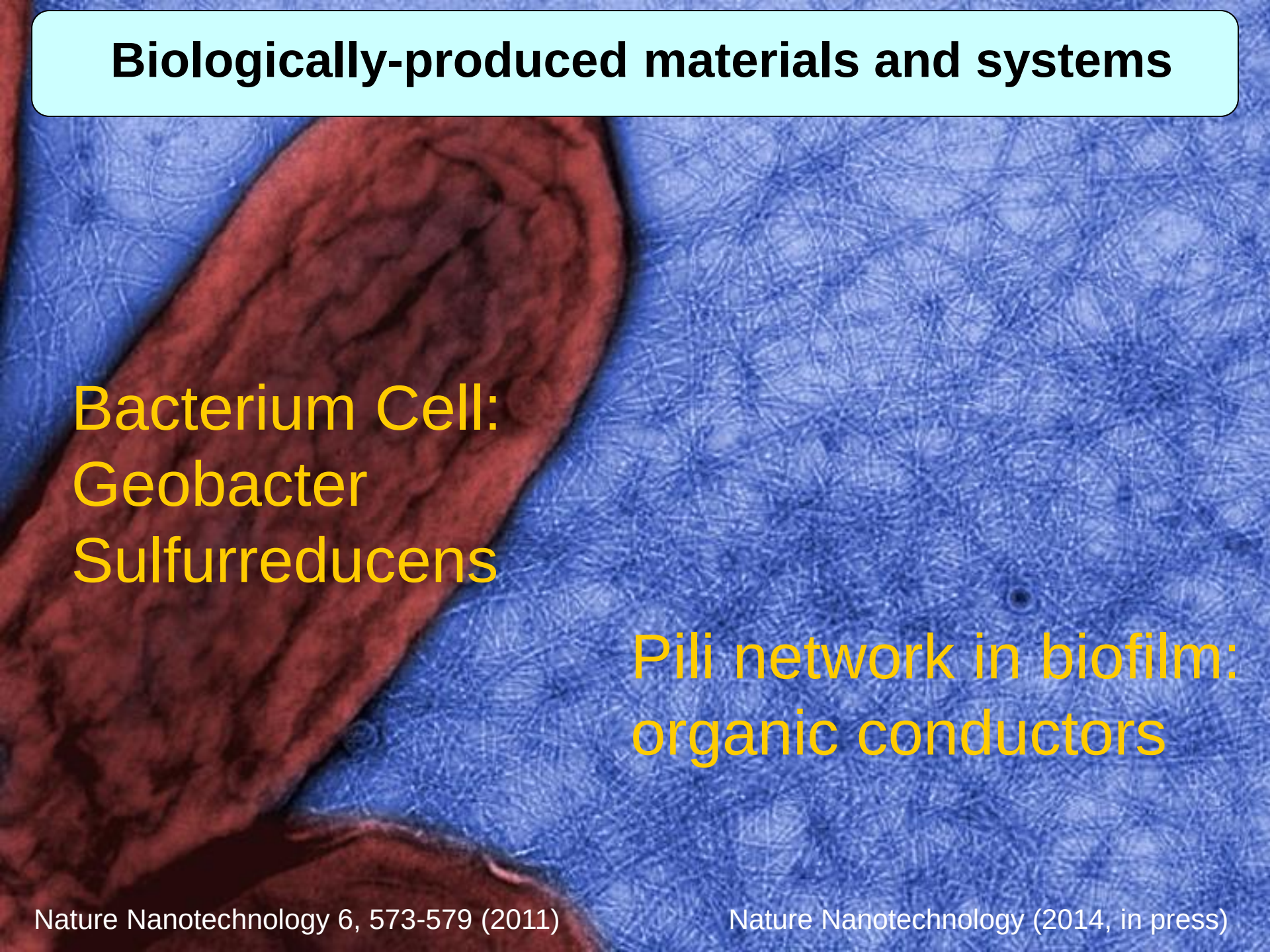






CHM
Center for Hierarchical Manufacturing

Biologically-produced materials and systems



Nature Nanotechnology 6, 573-579 (2011)

Nature Nanotechnology (2014, in press)

Nanoinformatics

Nanoinformatics is the science and practice of determining which information is relevant to the nanoscale science and engineering community, and then developing and implementing effective mechanisms for collecting, validating, storing, sharing, analyzing, modeling and applying that information.

- from Nanoinformatics 2020 Roadmap

Nanoinformatics

Efficient Nanoinformatics Integrates the Different Perspectives of Diverse Domains

Physical Properties

Applications Development

Modeling and Simulation

Engineering

Materials

Manufacturing

Education

EHS

Biological Interactions

Business

Nanoinformatics 2013

Informatics for Nanomanufacturing

Streamlining product and manufacturing design

- Nanomanufacturing process-property relationships
- Nanomaterial properties data - with statistics and metadata
- Experts and facilities
- Suppliers of materials and tools
- Documentary standards
- Design tools
- Federation of data and information

ISO TC 229 Nanomanufacturing Terminology Standard

TECHNICAL SPECIFICATION

ISO/TS 80004-8

First edition

Nanotechnologies — Vocabulary —

Part 8:
Nanomanufacturing processes

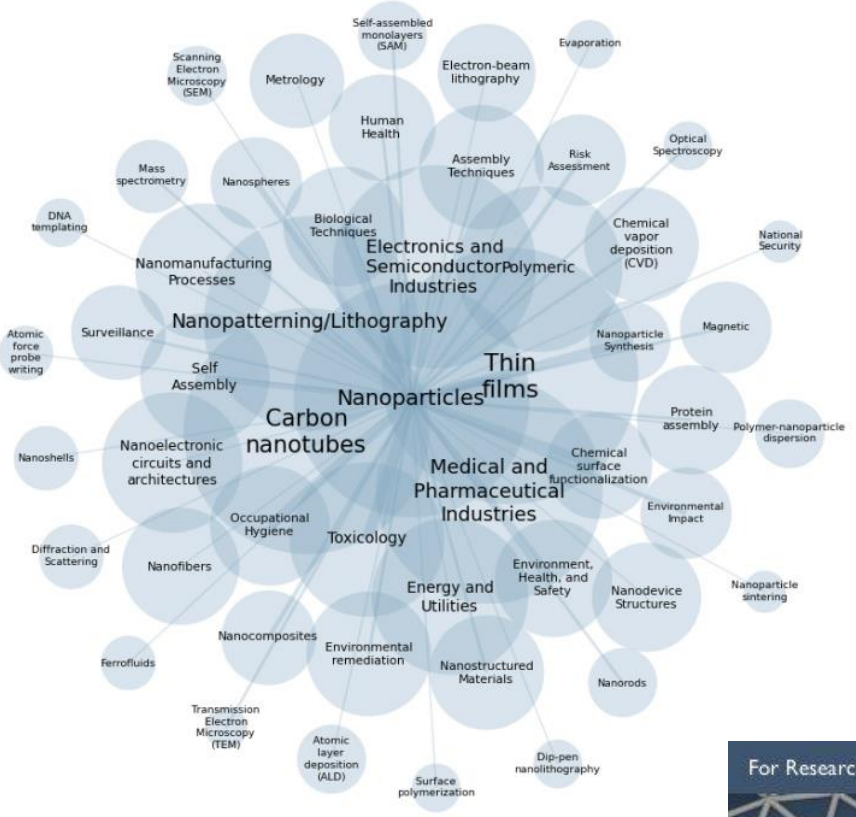
Nanotechnologies — Vocabulaire —
Partie 8: Processus de nanofabrication

"Nanomanufacturing" - Intentional synthesis, generation or control of nanomaterials, or fabrication steps in the nanoscale, for commercial purpose.

- 156 terms and definitions: focusing on various types of **nanomanufacturing processes**
- Sections:
  - General terms
  - Directed assembly
  - Self assembly
  - Synthesis
  - Fabrication
- 31 participant countries
- Access terms for free via the ISO Concept Database

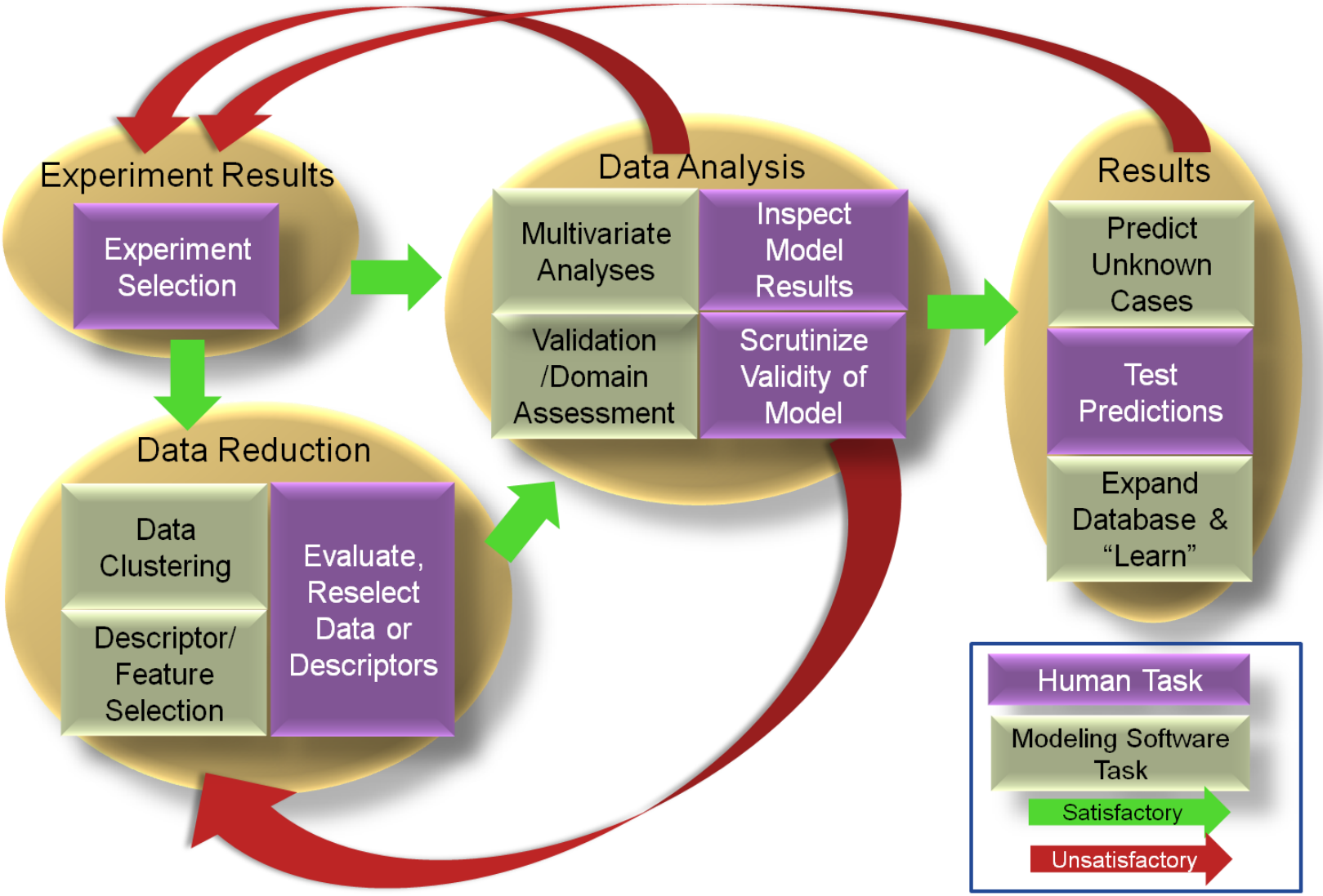
InterNano

InterNano is the NSF-funded information resource for the nanomanufacturing community. InterNano is the informatics arm of the National Nanomanufacturing Network.

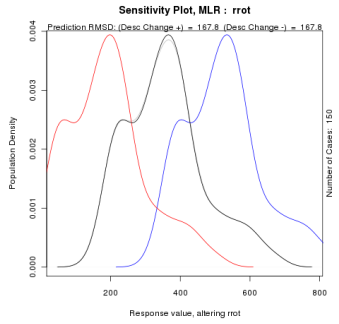


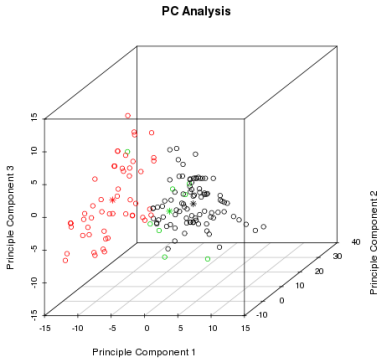
Informatics Methods Applied to Process Development

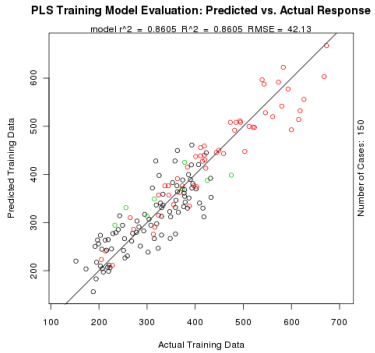
LOCKHEED MARTIN



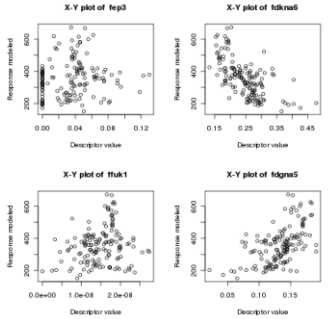
Informatics Tool Developed by Lockheed Martin

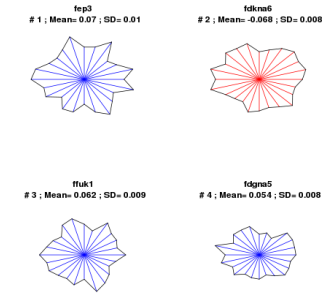


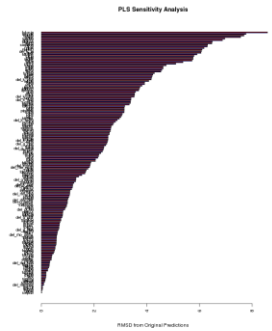




- The "Nanotechnology Material Data – Mining, Modeling and Management (NMD-M3)" Tool.
- Applications of the **NMD-M3 Tool**:
  - Analyzing trends in data sets, e.g. product performance (drug efficacy), treatment efficacy
  - Determining inter-measurement relationships and dependencies, medical data trends/analysis
  - Creating virtual systems in a matter of seconds
  - Comparing resulting system properties side-by-side
- Successfully demonstrated the benefits of the tool on various nanomaterial experiments
- Has over 10 analysis algorithms that run in series or in parallel to predict results based on input numerical data, the next set of experiments (configurations)
- Significant visualization techniques to provide the user with insights that are not clearly apparent







Saves time and money on development efforts by creating virtual configurations that focus future efforts more efficiently

Nanoinformatics for EHS: Predictive Approach Assists nano EHS Decision Making and Risk Identification

Nanomaterial libraries

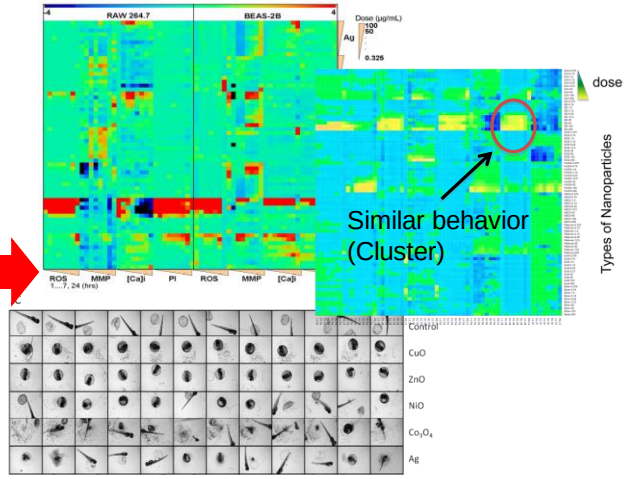
Compositional
Me Oxides
Metals
CNTs

Property accentuation
Size, Shape, AR
Dissolution
Band gap

High throughput screening

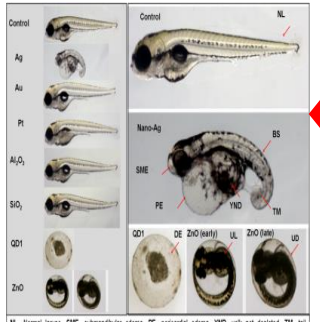
Cells, bacteria, yeasts, zebra fish embryos

In silico decisions, in vitro ranking

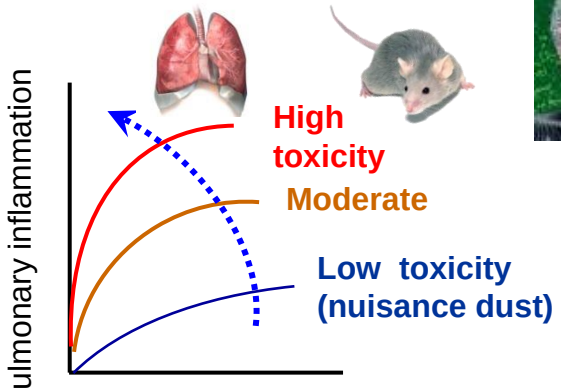


Prioritize
Speed up
Dosimetry

Validate
Exposure
Dosimetry



Organism
Animal testing



In vivo hazard ranking

Risk Identification

and decision making to

- **Reduce risk**
- **Influence governance**
- **Dosimetry calculations**
- **Safer design**

UC CEIN

Nel et al. ACR. 2012

Is this Engineered Nanomaterial Environmentally Safe?

Information/Data Management

Experimental Studies / Models

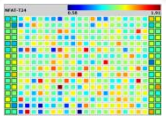
Hazard Identification

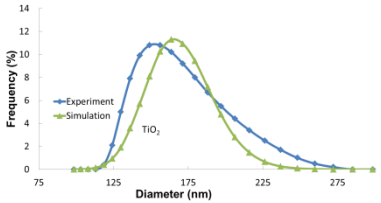
Physicochemical Characterization

Exposure Assessment

In Vitro
In Vivo
Toxicity

In Silico Toxicity





Transport and Fate studies/ Modeling

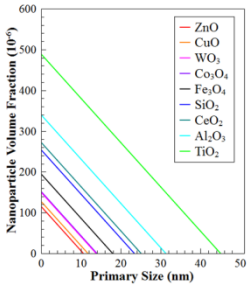
Monitoring

HT Exp.

LT Exp.

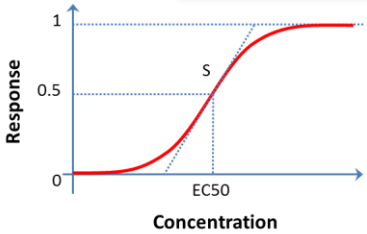
Mechanistic Conceptual

Quantitative Nano-SAR



Environmental Concentrations

- Dose- Response
- Hazard Thresholds



Environmental Impact Assessment

Decision Analysis

Product manufacturing & use approval

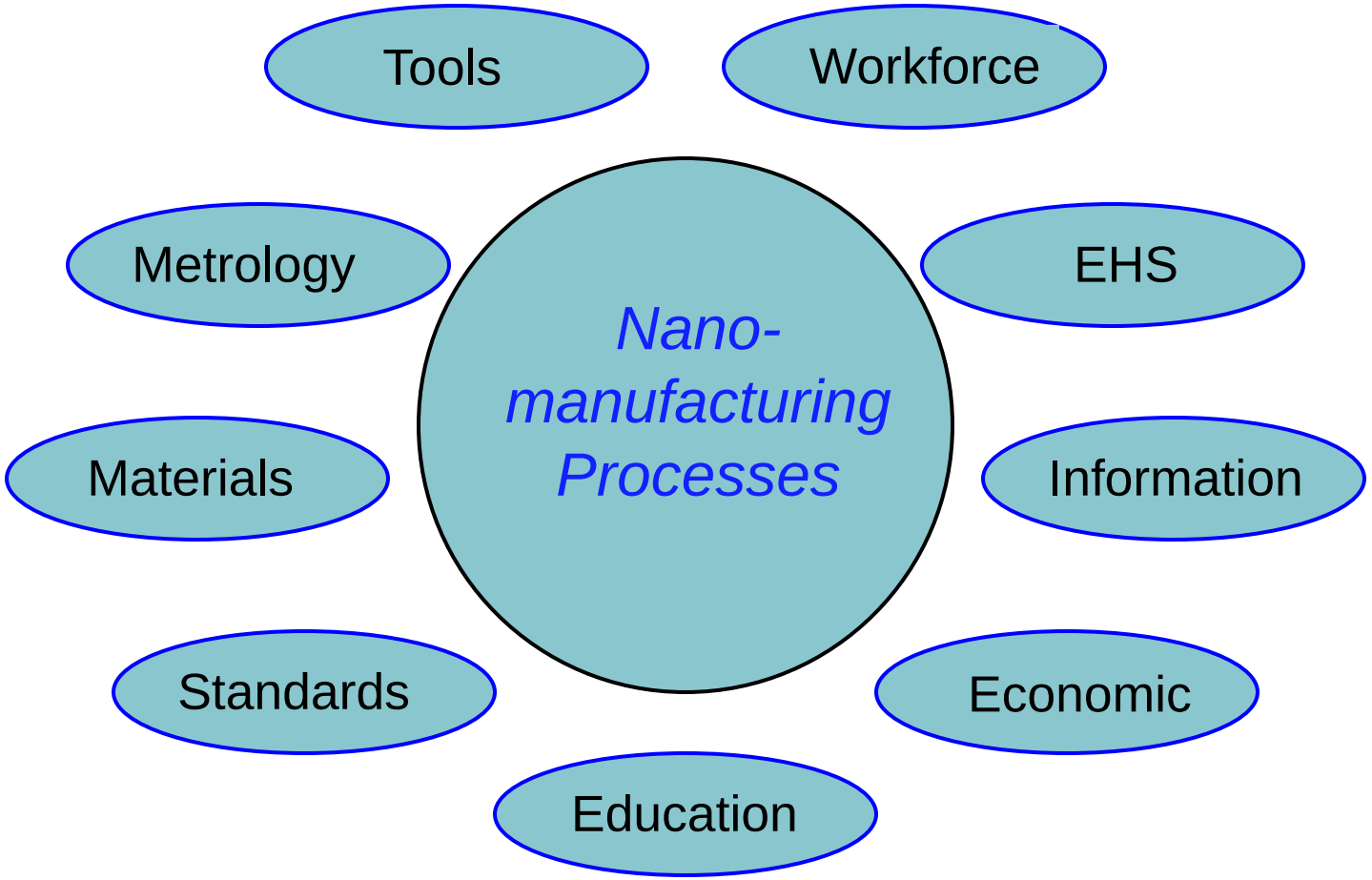
Product/process redesign

Exposure control

UC CEIN

Cohen et al., "In Silico Analysis of Nanomaterials Hazard and Risk," Accs. Chem. Research, doi:10.1021/ar300049e

Nanomanufacturing Enterprise



All factors are needed for effective implimentation