Linking Nanoscience and nanotechnology
Research
Education
Business Development
In the Northwestern United States

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Battelle

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

What Ingredients are Necessary for Nano to have **IMPACT?**

Two Different Perspective Lead to Similar Conclusions

New Growth Theory: A Paul Romer Perspective

Ingredients	*Recipes*	*Results*
• Intellectual capital	• New ideas	• Productivity
• Human capital	• Entrepreneurs	• Prosperity
• Financial capital	• Networks	• Cluster vitality

From Presentation by Mary Jo Waits, Morrison Institute for Public Policy, Arizona State University
Advantages of the Industry Cluster Approach to Economic Development
Workshop on Regional, State and Local Initiatives in Nanotechnology
September 30, 2003

Viola Vogel's (University of Washington) **Components for Nano success**

- **Research Activity** → Intellectual Capital and Capabilities
- **Education** → Human Capital → Trained Workforce
- **Business Development** → Financial Capital → Ideas to Practice → Jobs

Since we cannot be great at everything, we need

A Signature, Visibility, an Identity, Infrastructure, a Community, Resources, Skills, Focus

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Topics:

- Operating Assumptions: **The status, role and potential impact of Nanoscience and Nanotechnology**
- Identity, resources, community and focus development in three different contexts:

U.S. Department of Energy
Pacific Northwest National Laboratory

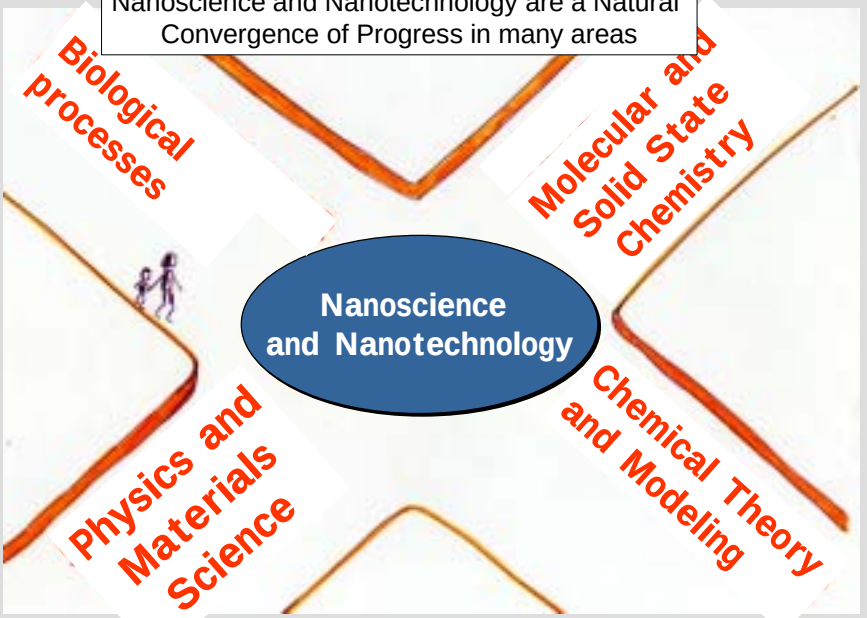
The role of Nanoscience and Nanotechnology at Pacific Northwest National Laboratory

Joint Institute for NANO Science, Engineering and Technology

The PNNL and University of Washington - Joint Institute of Nanoscience

Linking regional activities –The Northwest Nanoscience and Nanotechnology Network, N^4)

Nanoscience and Nanotechnology are a Natural Convergence of Progress in many areas



Adapted from Design of Organometallic Molecular and Ionic Materials
D. Braga, et al. **Coord. Chem. Rev.** 2001, 216, 225-248

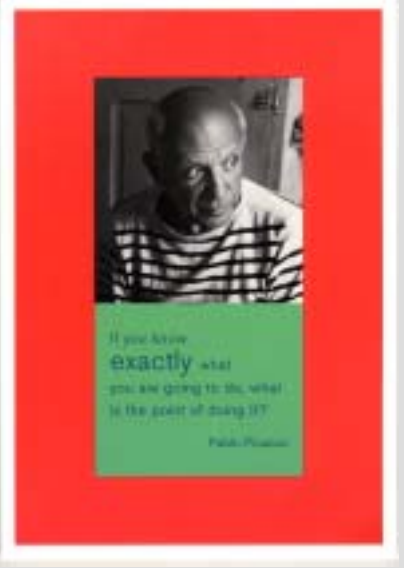
Although Nanoscience and Nanotechnology are part of a natural progression, we don't really know what they are!

At the May 2001 National Academy of Science Nanoscience Colloquia George Whitesides, one of the colloquia organizers, noted that:

"Those of us doing nanoscience do not really know what nanoscience is!"

"We certainly do not know what nanotechnology is!"

Although this may appear to be a flippant or negative comment, I think it reflects an understanding of how little we know now and how large the impact may be in 50 years.



Three (of several) Senses of Nano

"Nano-effect" is used to describe many different processes. Therefore, when someone uses the term we often don't know what they mean.

- **Size and surface area effects**

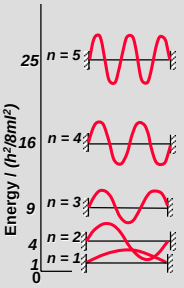
1 nm – 100 nm **Fundamental materials properties remain** the same but size, shape and surface area alter some behaviors.

- **Critical Size and Characteristic Length Scale** - unusual properties because the **size of the system approaches some critical length** (includes quantum effects). **Many characteristics** of material may have normal or nearly **normal** behavior

- **New (Non-extensive) Properties**

Systems not large enough to have extensive properties. Particles become effectively polymorphs of "bulk" materials.

- Kelvin equation for solubility
- Gibbs-Thompson relation for chemical potential



size ≈ ς ≈ d

ς= correlation length

d = range of intermolecular forces

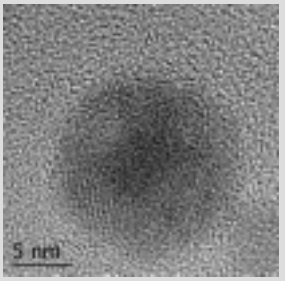
The state of our understanding

Nebula M100

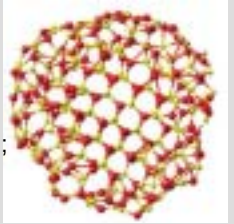
Kitt Peak 1.1 M

Nanoparticle Images

TEM of Fe



Molecular Dynamics ZnS



Hubble Space Telescope

Need more and advanced **tools**; greater development and application of **theory and modeling**; expand **conceptual framework**

Status, role and potential impact of Nanoscience and Nanotechnology

- As a natural extension of progress in several areas, **Nanoscience and Nanotechnology are unstoppable**
- We do not have a good understanding of what nanoscience really means
- Nanoscience and Nanotechnology have benefited form tools developed in the past 20 years, but much greater advances will **require even better tools**.
- Many different effects are labeled *nano* and an appropriate and consistent **nomenclature** is needed.
- We have **only the slightest sense** of the ultimate impact of Nanotechnology. To date we have seen important but evolutionary changes in technology, truly **revolutionary** impacts (disruptive technology) are likely.
- **Long term success requires a realistic understanding of current status, building from existing strengths, an adequate infrastructure (tools, capabilities and community) and developing a "guiding" vision (signature).**

Topics:

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Linking regional activities –The Northwest Nanoscience and Nanotechnology Network, N^4)

Pacific Northwest National Laboratory

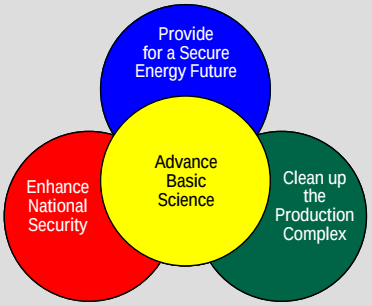
- Located in Richland, Washington
- Approximately 3,500 employees
- We deliver breakthrough science and technology to meet key national needs:
  - Fundamental Science
  - Environmental Science and Technology
  - Energy Future
  - National & Homeland Security

PNNL Nanoscience Targets Specific Areas that Relate to Laboratory and DOE Missions

Two focus areas

- **Nano-structured Reactive Materials Systems (Nanochemistry of Hierarchical Materials Systems)**
- **Linking Biological Function to Nano-Materials (Nano-Biological Machines)**

Build from strengths and relate to lab business areas

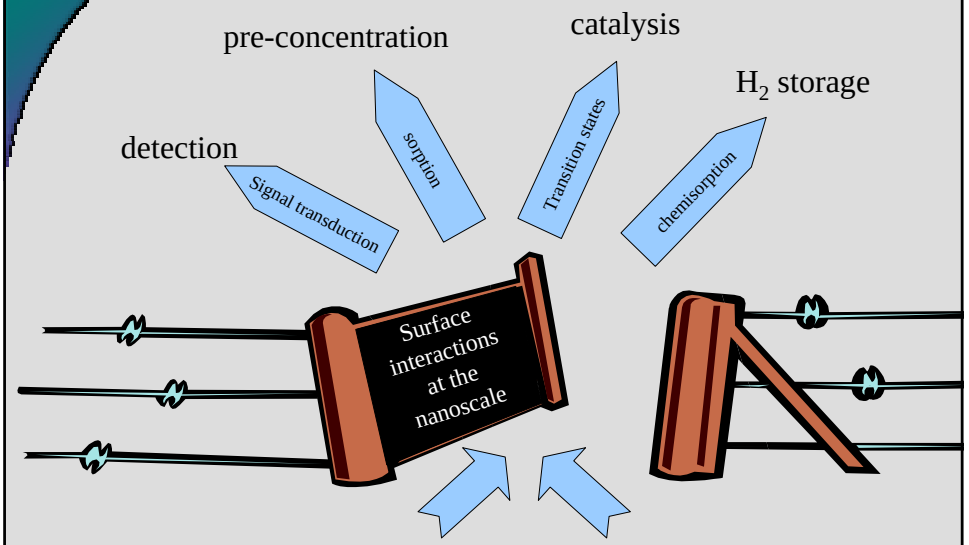


Application Areas

- *Hydrogen generation /storage*
- *Fuel cells*
- *Solar power*
- *Biodetection*
- *Bioconversion*
- *Waste reduction*
- *Carbon management*
- *Secure communications*
- *High density memory*

One portion of the Nanoscience and Nanotechnology Landscape

Control of nanostructure is a gateway

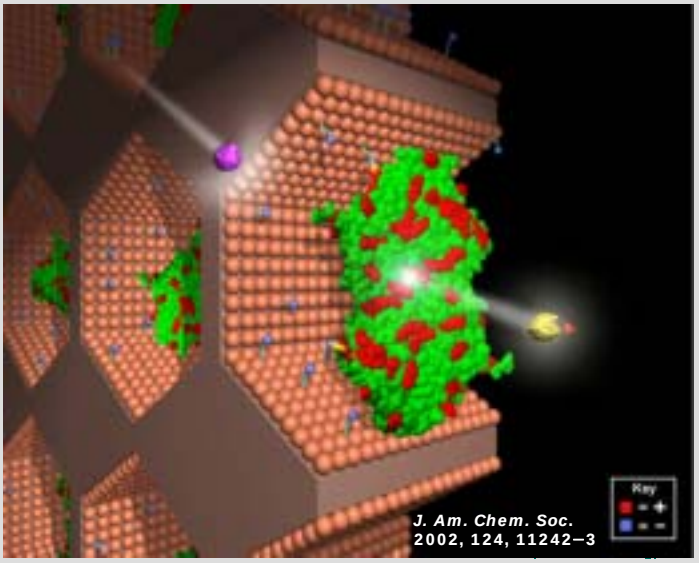


Harnessing Enzymes: An Application of Proteins

Stable enzymes entrapped in nanopores may one day be routinely used to inactivate pollutants.

Enzymes in this environment are stable for extended periods of time.

Sensors, catalysts and separations



Pacific Northwest National Laboratory

EMSL National User Facility

Wiley's vision: An innovative multipurpose user facility providing "*synergism between the physical, mathematical, and life sciences*."

- **EMSL's Mission**
  - Provide advanced **resources** to the scientific community.
  - Conduct fundamental **research** in molecular and computational sciences in support of DOE missions.
  - **Educate** scientists in molecular and computational sciences.
- **Signature Characteristics**
  - Integration of **theory,** modeling, and simulation with **experiment**.
  - **Multidisciplinary** teams and collaborative mode of operation to solve major scientific problems of interest to DOE and the nation.
  - Teams who develop extraordinary **tools and methodologies**.

www.emsl.pnl.gov

Extraordinary Tools and Staff

- **EMSL Facilities**
  - Chemistry and Physics of Complex Systems
  - Environmental Spectroscopy & Biogeochemistry
  - High Field Magnetic Resonance
  - High Performance Mass Spectrometry
  - **Interfacial & Nanoscale Science**
  - Molecular Science Computing
- **Support**
  - Computer and Network Services
  - Instrument Development Laboratory
  - User Services & Outreach

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Joint Institute for Nanoscience and Nanotechnology

Established April 2001

Joint Institute for NANO Science Engineering and Technology

University of Washington

Pacific Northwest National Laboratory

- **Enhance Relationships, UW, PNNL and others**
  communication, collaborative research, multidisciplinary research and multi-institutional research
- **Expand Education and (Re)Training Opportunities in Nanoscience**
  staff, faculty, students and postdocs, conferences, short courses for professionals
- **Enhance Research Impact and Funding Opportunities footprint, visibility, communication, team formation, available skills, combine strengths**
- **Facilitate Equipment and Facility Availability and Development**
  access to needed capabilities and skills, new capability development

Joint Institute Activities

PNNL/UW Joint Institute **Awards** for Collaboration

- **Joint Institute Graduate Fellowships**
- **Joint Institute Postdoctoral Fellowships**
- **Joint Institute Faculty Appointments**
- **Joint Institute Travel Grants**

Workshops to Encourage Interactions

- Nanoscience Science and Technology Workshops 2001, 2002, 2003
- Nanotech meets business information exchange (2002)
- Exploiting opportunities in nanoscience and nanotechnology 2002

Intensive Courses in Nanoscience and Nanotechnology

- **Introduction/Overview**
- **Synthesis & Characterization**
- **Theory of Nano-Systems**

http://www.nano.washington.edu/pnnl/outline.html

Defining Focus Areas

January 2003

Area 1) **Nano-biological nano-materials based functional systems**

The integration of biomolecular functions to nanostructured hierarchically organized inorganic materials systems raises a wide range of fundamental science questions and have potential impact in a wide variety of technological areas.

Area 2) **Nano-structured Reactive Materials Systems**

The chemical and physical properties of materials structures containing nano-sized components will revolutionize the ability to control and optimize material and chemical reactivity in many environments relevant to a wide variety of applications.

The sciences and technologies impacted by these two focus areas strongly benefit from differing scientific skills and technology foci of the two institutions and represent two areas of major scientific and technological importance that are under-represented in many Nanoscience and Technology efforts.

Results of JIN Activities

- **28 Students and Postdocs involved in Joint Projects**
  - 25+ presentations
  - 20+ papers submitted or published
- **New Research Program Development**
  - PNNL staff support UW photonics center and spintronics proposal
  - PNNL new spintronics DARPA program – students contribute
  - New Focus Areas large targets
- **Enhanced Interaction** between PNNL/UW
  - PNNL Initiative Leader observe that UW staff very responsive
  - Very active participation in workshops
- **Education**
  - Joint Nanoscience courses (Fumio Ohuchi PI)
  - PNNL participation in UW nanocourses and seminars
- **Informal Education** – Seattle Times, Small Tech Hot Spots, NPR, Visit by Gov., CEPAC meeting, Battelle Tech Platform Meeting, UWTV, Grand Rounds Harborview Hospital
- Joint UW-PNNL presentations/discussions with **Venture Capitalists**
- **Jobs** - Some students hired as Post Docs or Staff Members

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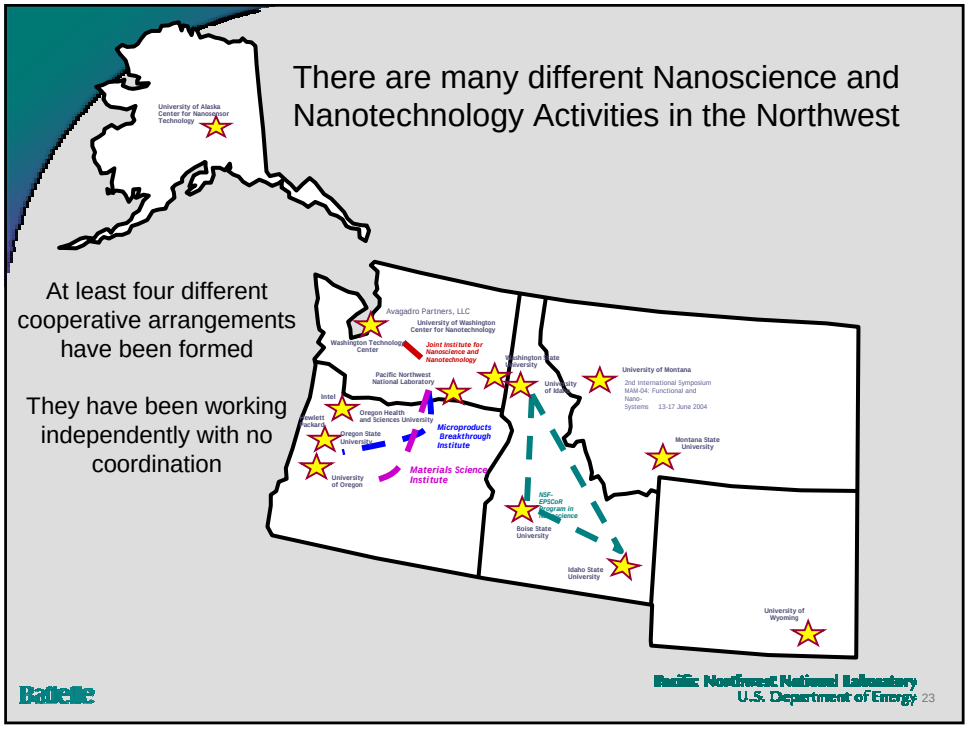
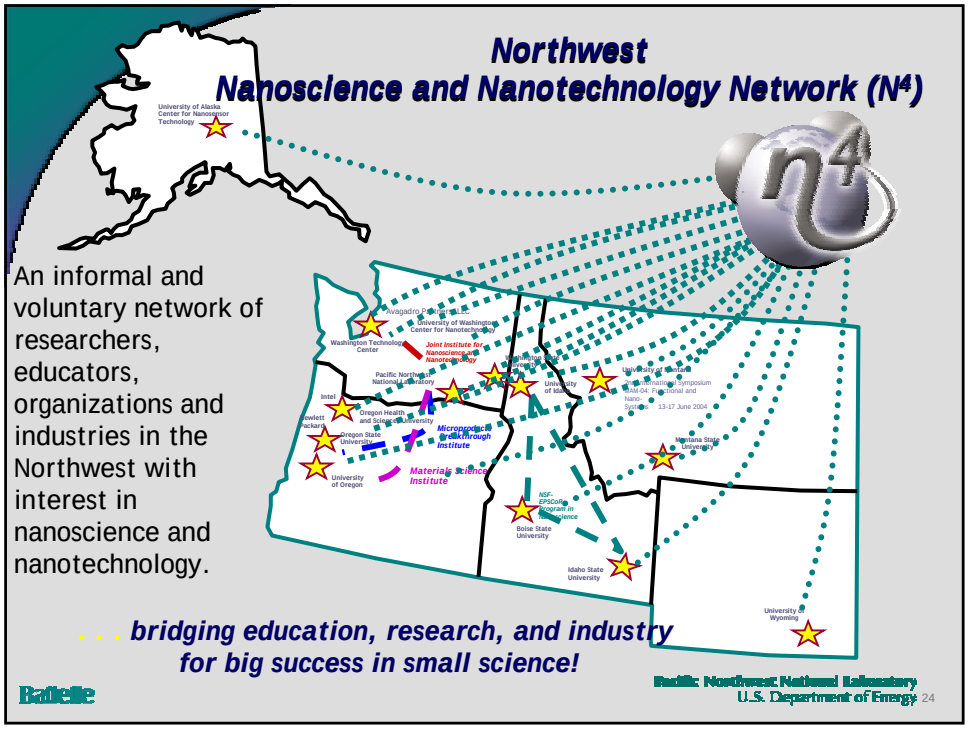

There are many different Nanoscience and Nanotechnology Activities in the Northwest
At least four different cooperative arrangements have been formed
They have been working independently with no coordination
University of Alaska Center for Nanoenergy Technology
Avagadro Partners, LLC
University of Washington Center for Nanotechnology
Washington Technology Center
Joint Institute for Nanoscience and Nanotechnology
Pacific Northwest National Laboratory
Washington State University
University of Idaho
University of Montana
2nd International Symposium MAM-04: Functional and Nano-Systems 13-17 June 2004
Intel
Hewlett Packard
Oregon Health and Sciences University
Oregon State University
Microproducts Breakthrough Institute
Materials Science Institute
University of Oregon
Montana State University
NSF-EPSCoR Program in Nanoscience
Boise State University
Idaho State University
University of Wyoming
Battelle
Pacific Northwest National Laboratory
U.S. Department of Energy
23


Northwest
Nanoscience and Nanotechnology Network (N4)
An informal and voluntary network of researchers, educators, organizations and industries in the Northwest with interest in nanoscience and nanotechnology.
. . . bridging education, research, and industry for big success in small science!
University of Alaska Center for Nanoenergy Technology
Avagadro Partners, LLC
University of Washington Center for Nanotechnology
Washington Technology Center
Joint Institute for Nanoscience and Nanotechnology
Pacific Northwest National Laboratory
Washington State University
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Oregon Health and Sciences University
Oregon State University
Microproducts Breakthrough Institute
Materials Science Institute
University of Oregon
Montana State University
NSF-EPSCoR Program in Nanoscience
Boise State University
Idaho State University
University of Wyoming
Battelle
Pacific Northwest National Laboratory
U.S. Department of Energy
24

Overall Umbrella Association

Northwest Nanoscience and Nanotechnology Network [N4]

www.pnl.gov/nwnano

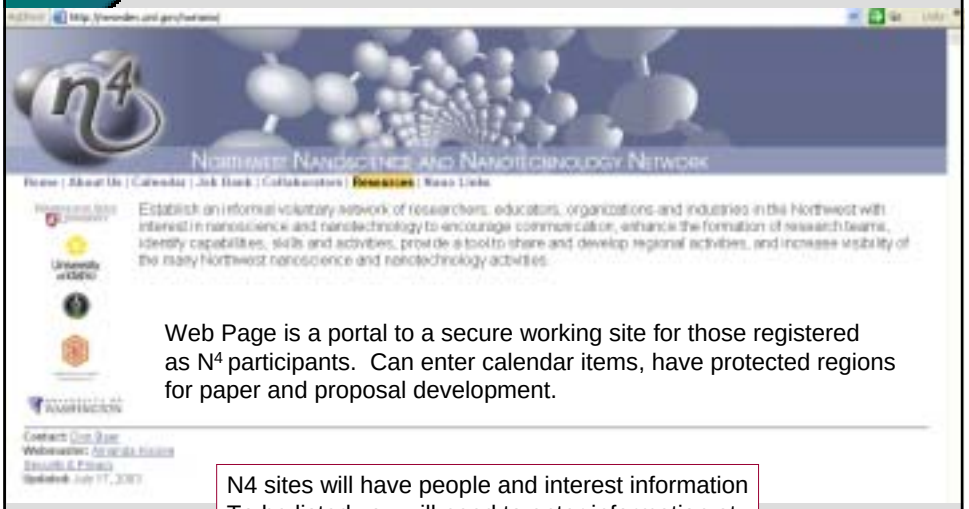
Network Nodes or Interest Groups

- NW NS&NT R&D Network
- Nano-Business Alliance of the NW
- NW NS&NT Education Network

Information and Network Functions

- NW NS&NT Email and Contact lists
- NW NS&NT Calendar
- NW NS&NT Position & Job Bank
- NW NS&NT Discussion website
- NW NS&NT Resource & Interest Data
- NW NS&NT Network Seminars
- NW NS&NT Information Exchange Meetings

Web Page for N4 www.pnl.gov/nwnano

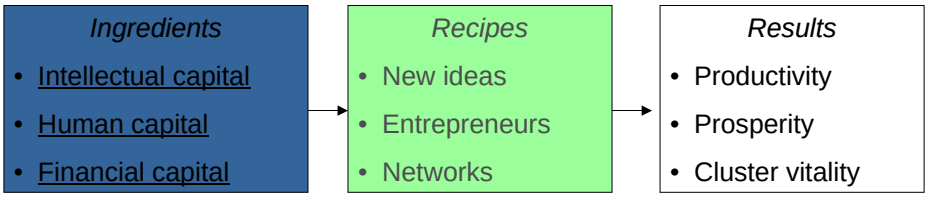


Web Page is a portal to a secure working site for those registered as N4 participants. Can enter calendar items, have protected regions for paper and proposal development.

N4 sites will have people and interest information To be listed you will need to enter information at https://secure2.pnl.gov/nano/n4.nsf or www.pnl.gov/nwnano.

What Ingredients are Necessary for Nano to have **IMPACT?**

Shown examples of efforts to assemble or link critical elements to enhance impact of nanoscience efforts in the northwest. We are assembling or enhancing the ingredients and now working to mix in a useful fashion.



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Components for Nano success

- Research Activity
- **Education**
- Business Development
- **Resources**
- **Signature/Identity**/Cluster
- **Community/Network/**Team Formation

PNNL and EMSL Contact Information

Don Baer don.baer@pnl.gov
Pacific Northwest National Laboratory Home page and directory
http://www.pnl.gov
EMSL User Facility
http://www.emsl.pnl.gov
EMSL Interfacial and Nanoscale Science Facility
S. "Theva" Thevuthasan Technical Lead – theva@pnl.gov
http://www.emsl.pnl.gov/capabs/insf.shtml
PNNL Nanoscience and technology Initiative
Paul Burrows - burrows@pnl.gov and Don Baer
http://www.pnl.gov/nano/
PNNL Office of Fellowships
Kelly Sullivan – kelly.sullivan@pnl.gov
http://science-ed.pnl.gov/
Intensive Nanoscience and Nanotechnology Courses
Don Baer and Fumio Ohuchi (ohuchi@u.washington.edu)
http://www.nano.washington.edu/pnnl/outline.html
Nanotech Workshop Seattle September 22 and 23
http://nano.washington.edu/workshop2003/
Northwest Nanoscience and Nanotechnology Network N^4 (Don Baer)
http://www.pnl.gov/nwnano and https://secure2.pnl.gov/nano/n4.nsf

Focus Area 2

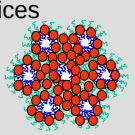
Nano-biological nano-materials based functional systems (Nanoscale Biological Systems)

- The integration of biomolecular functions to nanostructured hierarchically organized inorganic materials systems
- Application Areas
  - Remediation of hazardous waste,
  - The production of energy feedstocks and commodity chemical products
  - The development of carbon management systems,
  - The formation of low temperature fuel cells,
  - The detection, quantification and inactivation of chemical and biological threats
  - Development of medical diagnostic and disease-treatment systems.
- Science Needs
  - Understanding and controlling chemical transformations and signaling process in biological machines at the nanoscale;
  - Coupling biomolecular machines (functions) to inorganic materials to enable signal transduction and enhance chemical processes.
  - Development of theory and process modeling

Focus Area 1

Nano-structured Reactive Materials Systems (Nanochemistry)

- Control of the chemical and physical properties of hierarchal materials structures containing nano-sized components to control and optimize material and chemical reactivity
- Application Areas
  - Catalysts for fuel cells, bioprocessing, waste reduction and the chemical industry
  - Inexpensive photovoltaic and other energy conversion devices
  - Highly selective sensing materials and systems
  - Structure optimized for energy transport



- Science Issues
  - Tune nanomaterial physical and chemical properties
  - Place structures in appropraite hierarchal environments
  - Integrate structures into mescopic and macroscopic systems
  - Develop theory and computation approaches to predict properties

Interfacial and Nanoscale Science Facility

is involved in researching a variety of oxide mineral films and interfaces, nanoscale materials, electronic and catalysis materials, microfabrication and microanalytical separations, and sensing.

- **Instrumentation**
  - Synthesis - Molecular beam epitaxy, chemical vapor and sputter deposition
  - Clean-room capabilities and research tools for microfabrication
  - Ion accelerator – implantation and characaterizaton
  - State-of-the-art surface science tools
  - High-resolution electron microscopes and x-ray diffraction instumentation
  - Ultrahigh vacuum, liquid, and ambient environment scanning probes
  - Gas chromatography, NOx analyzer, and RX100 testing and characterizing system

Contact: Theva Thevuthasan, theva.thevuthasan@pnl.gov

PACIFIC NORTHWEST NATIONAL LABORATORY
AND UNIVERSITY OF WASHINGTON, THROUGH
THE
JOINT INSTITUTE FOR NANOSCIENCE AND
NANOTECHNOLOGY, ALONG WITH
WASHINGTON STATE UNIVERSITY
PRESENT

Intensive Courses in Nanoscience and Nanotechnology

For more information, or to register go to
http://www.nano.washington.edu/pnnl/outline.html

Course development supported by a grant from the National Science Foundation

Pacific Northwest National Laboratory

Three Nanoscience Courses
Develoed with NSF Funding

Given in Richland and/or Seattle

- **Introduction/Overview**
- **Synthesis & Characterization**
- **Theory**

Overview courses given winter quarter at UW and in late May in Richland 2003 (20 students attended)

Theory course Scheduled for September 16-20 2003 in Seattle

Synthesis and Characterization Courses to be given January 5-23 2004

Fumio Ohuchi UW NSF PI
Lai-Sheng Wang, WSU coordinator
Don Baer, PNNL Coordinator