DOE Industrial Technologies Program

Overview of Nanomanufacturing Initiative

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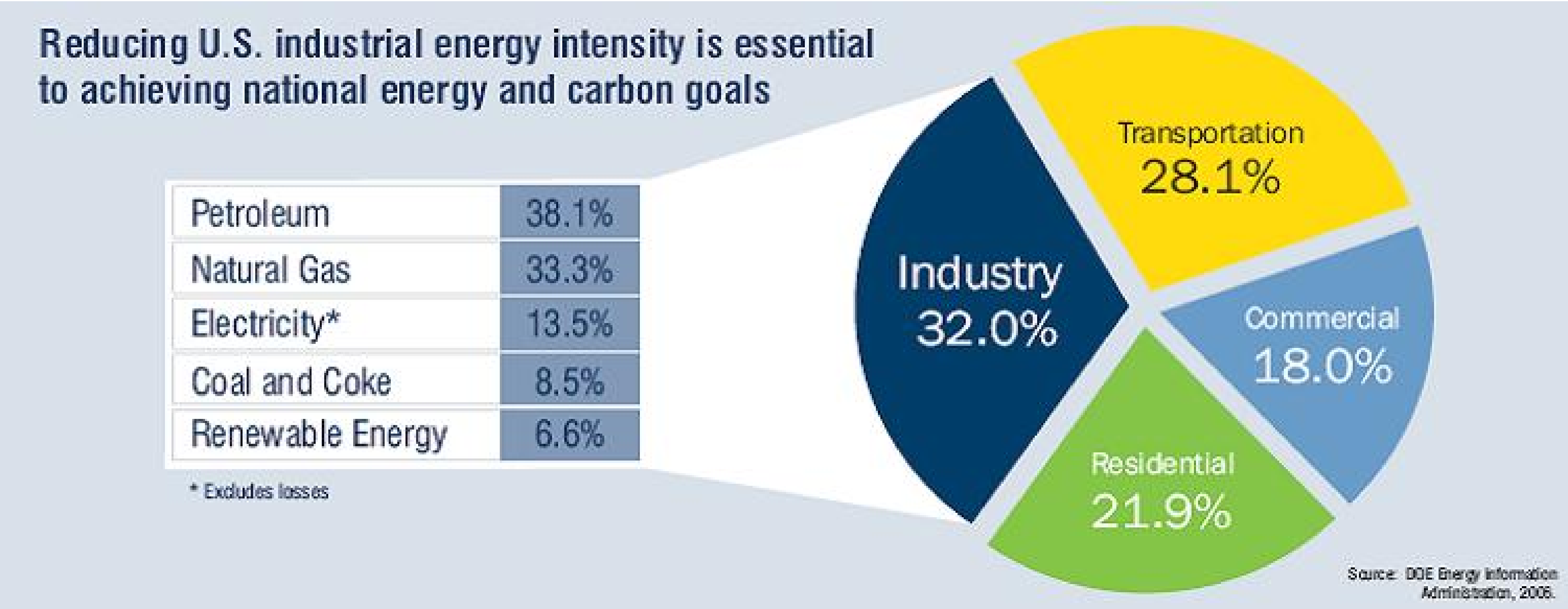
Nanotechnology: The purposeful engineering of matter at scales of less than 100 nanometers to achieve size-dependent properties and functions. (Lux Research)

Today's Outline

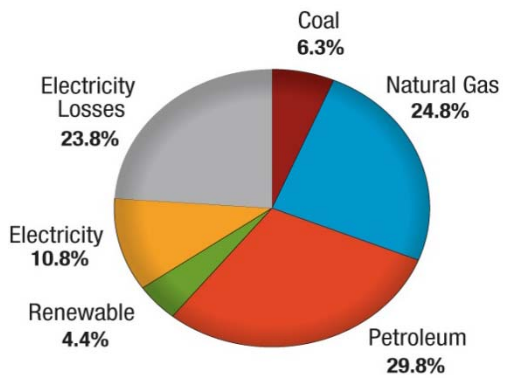
- ITP R&D Program
- ITP Nanomanufacturing Initiative
- Nanomanufacturing Project examples
- Questions

Industrial Technologies Program (ITP): Mission

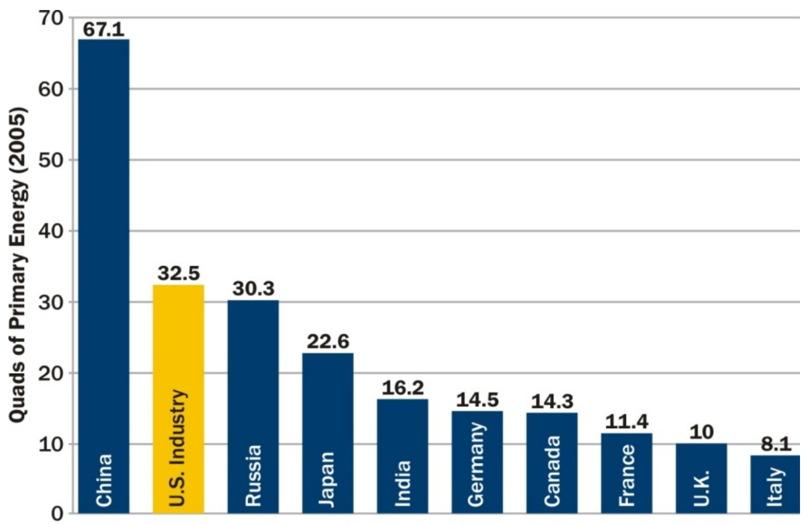
Improve our nation’s energy security, climate, environment, and economic competitiveness by transforming the way U.S. industry uses energy



U.S. Industry: Key Opportunity in Energy & Emissions



Industrial Sector Energy Consumption ~ 32 Quads



Source: U.S. Industry Data DOE/AER 2007; Other countries DOE/International Energy Annual 2005

U.S. Industrial Sector

- >200,000 sites
- Nearly 14 million manufacturing jobs
- Over $6 trillion in goods provided
- Over $1 trillion in exports
- Consumes more energy than any other sector of the economy (~32 quads)
- Responsible for ~1,660 MMTCO_2/year from energy consumption
- Manufacturing makes the highest contribution to U.S. GDP (12%)
- Produces nearly 1/4th of world manufacturing output
- Spurs job creation and investment in other sectors

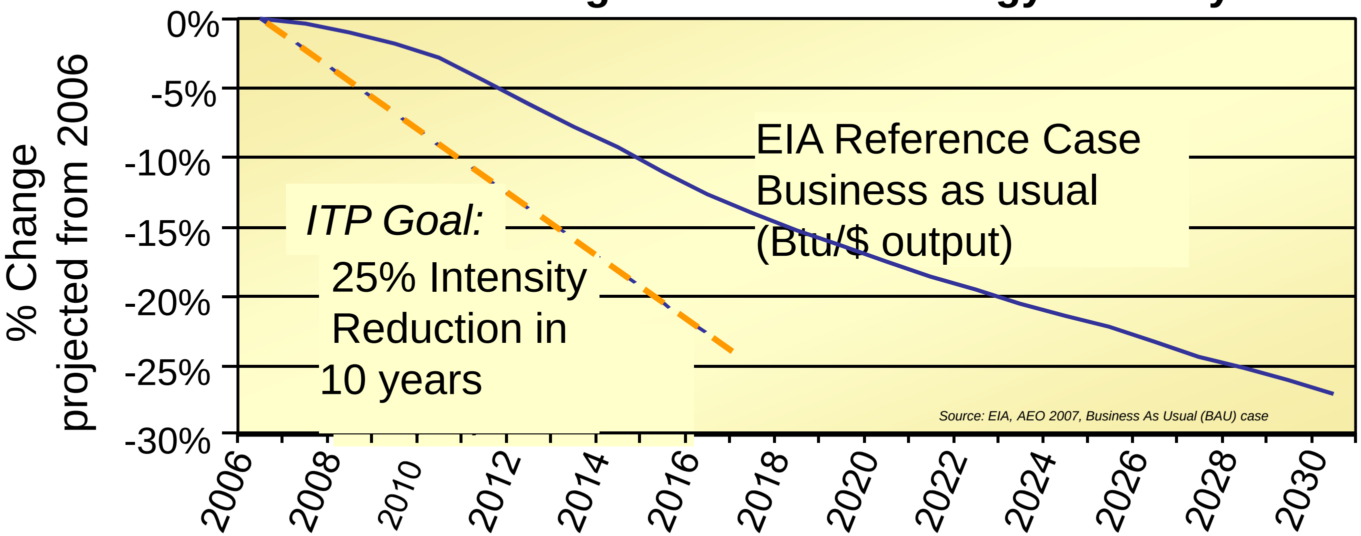
ITP Directly Supports DOE Strategic Goals

DOE Goals include
- Promote America's energy security
- Increase energy diversity
- Reduce environmental impacts of energy
- Increase energy productivity

EERE Goals include
- Dramatically reduce, or even end, dependence on foreign oil (Goal 1)
- Increase the efficiency/ reduce the energy intensity of industry (Goal 6)

ITP Goals
- Reduce industrial energy intensity by 25% in 10 years
- Reduce the projected growth of U.S. carbon emissions between 2006 to 2030 by 70%
- Establish the U.S. as the Global Leader in Energy Management

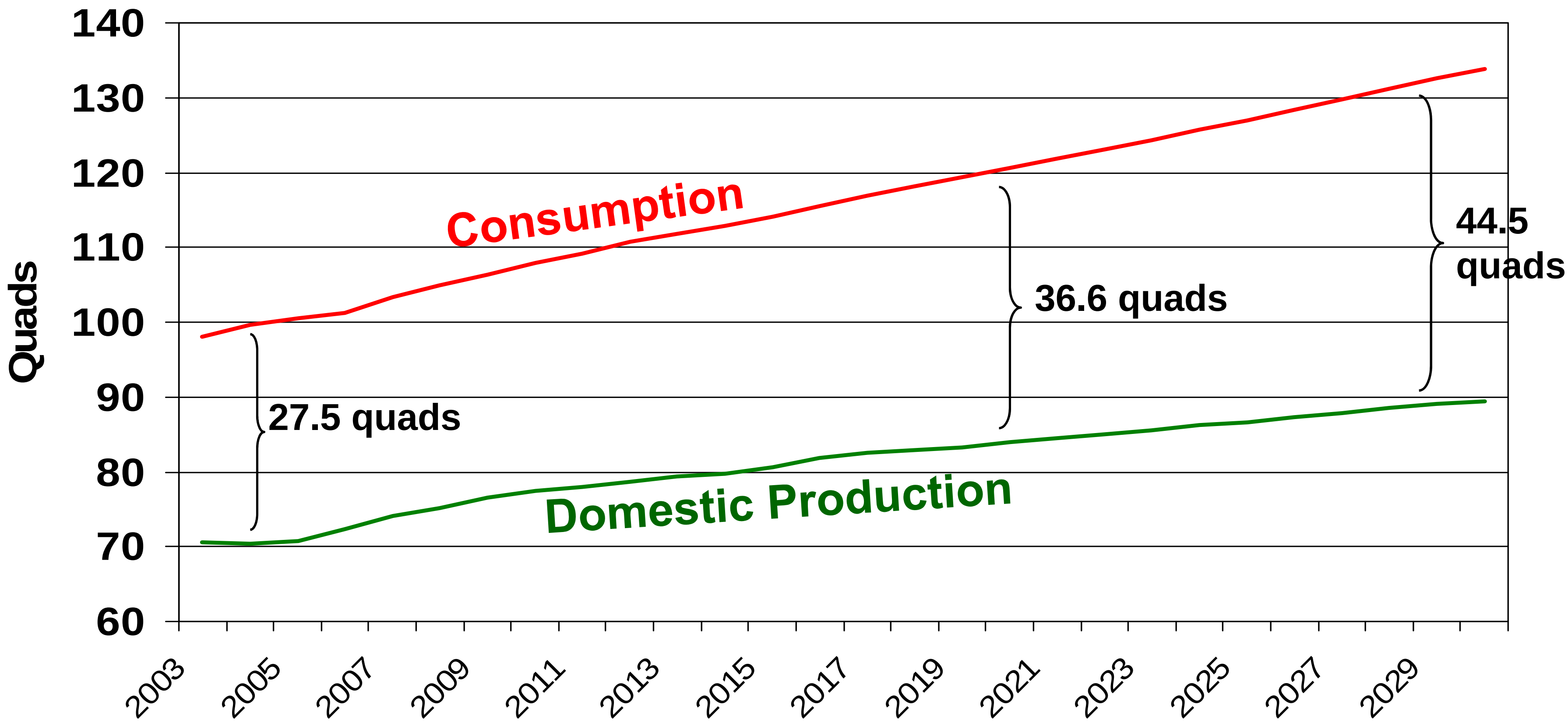
Percent Change in Industrial Energy Intensity



A recent McKinsey study stated energy efficiency is the most cost-effective near-term carbon reduction option

- *Industry represents 38% of the total global opportunity for reducing carbon through energy efficiency*

The Energy Gap Between U.S. Domestic Production and Consumption Projected to Worsen



We need to act on both ***supply*** *and* ***demand*****.**

Source: EIA AEO 2006

Energy Opportunities in the Industrial Sector

More Efficient Operating and Maintenance Practices: Best operating practices can be disseminated and implemented rapidly at negligible cost to enhance operating efficiency in manufacturing facilities in the near- to mid-term.

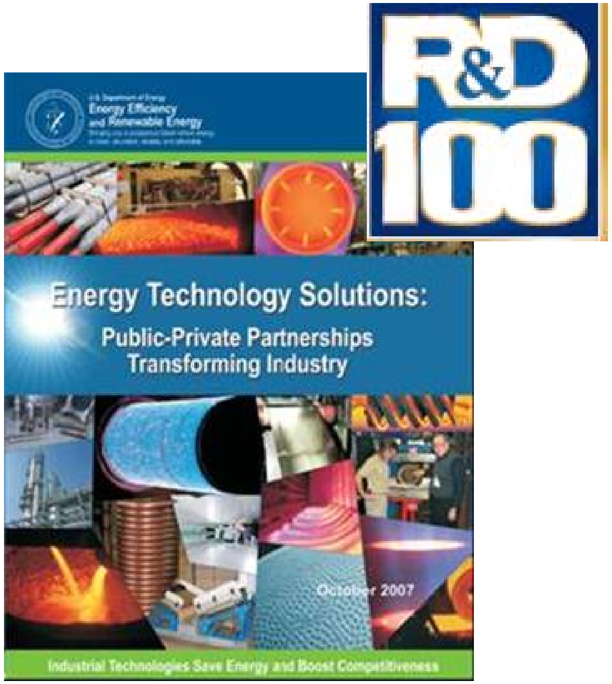
Increased Adoption of State-of-the-Art Technology: Improved energy efficiency through rapid adoption of currently available technology is the *best* near to mid-term strategy for better balancing energy supply and demand.

Fuel and Feedstock Substitution: Manufacturers need the flexibility to adapt to dynamic energy prices and supply issues.

Development of Advanced Technology: Progress toward long-term national goals for energy and the environment rely on continuous technology innovation. The technologies required to address today's challenges can require a decade or more to progress from basic science to commercialization.

ITP Delivers Results

- 48 R&D 100 awards between 1991 and 2008
- Over 220 technologies commercialized since program inception
- 5.7 quads of energy saved
- 103 MMTCe avoided
- Since 2006, 625 plant energy assessments completed



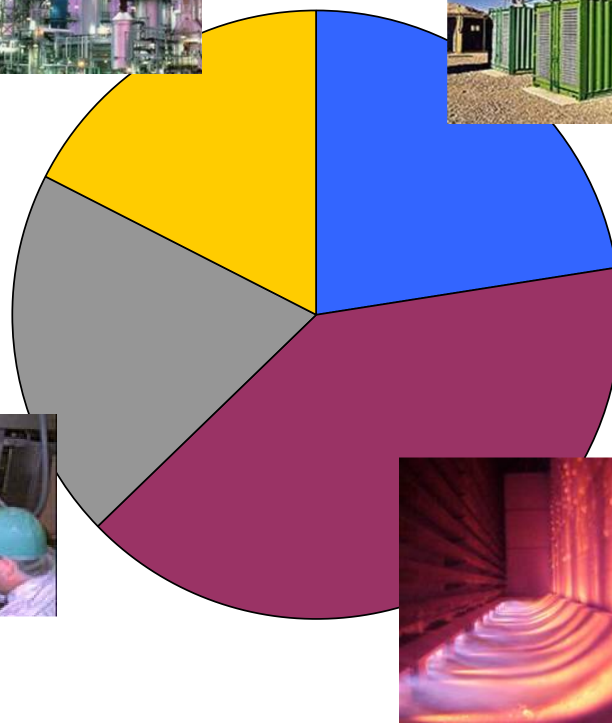
Other Accomplishments

- MOU with the NIST Manufacturing Extension Partnership (MEP) to conduct energy assessments at an additional 2,500 manufacturers each year
- MOU with the National Association of Manufacturers to reach 11,000 NAM member companies
- Grants awarded to 19 states to conduct local energy assessments

ITP FY08 Program Areas

17% **Industry-Specific**

R&D addressing top priorities in America's most energy-intensive industries, incl. chemicals, steel, and forest products



23% **Industrial Distributed Energy**

Activities to spur widespread commercial use of CHP and other distributed generation solutions

20% **Industrial Technical Assistance**

Helping plants save energy today using efficient energy management practices and efficient new technologies

40% **Other Crosscut**

R&D to develop technologies applicable to multiple industrial subsectors

ITP Delivers Technology Solutions

Energy Efficiency R&D

Develop cross-cutting technologies addressing the top energy savings opportunities across industry

Fuel and Feedstock Flexibility

Accelerate market penetration of emerging options for alternative fuels and feedstock; also CHP

Technology Delivery

Help plants save energy today by assessing opportunities and facilitating adoption of best energy management practices and efficient new technologies

Save ENERGY Now

Energy Efficiency R&D

- ***Industry-specific R&D*** to address top priorities in America's most energy-intensive industries
  - Aluminum
  - Chemicals
  - Forest Products
  - Metal Casting
  - Steel
  - Information Technology and Data Centers

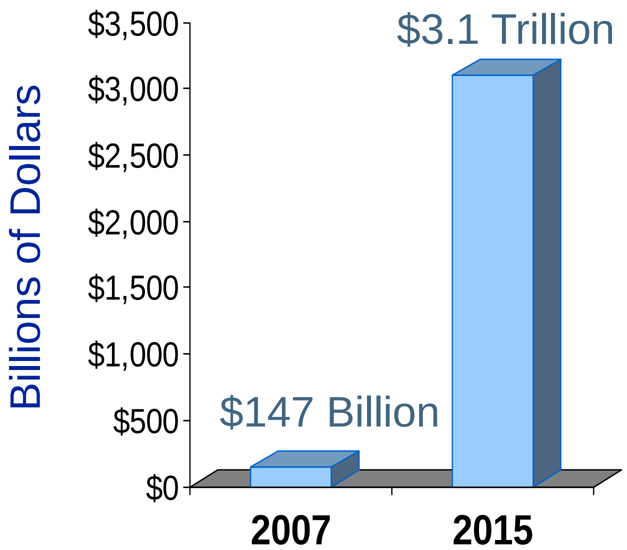
- ***Crosscutting R&D*** to develop technologies applicable to multiple industrial subsectors
  - Energy Intensive Process R&D
  - Industrial Materials
  - Sensors and Automation
  - Combustion
  - Fuel and Feedstock Flexibility
  - Industrial Distributed Generation
    - Advanced Reciprocating Engines
    - Clean Heat and Power (CHP)
  - Nanomanufacturing

Nanomanufacturing Overview

Integrate science and technology to accelerate the transition from discovery to application

- The projected growth in manufactured goods incorporating nanotechnology is tremendous.

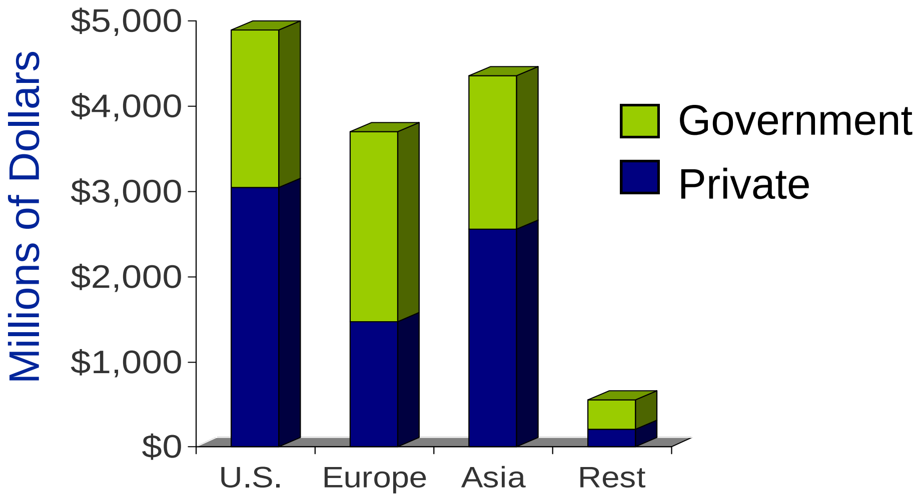
Manufactured Goods Incorporating Nanotechnology



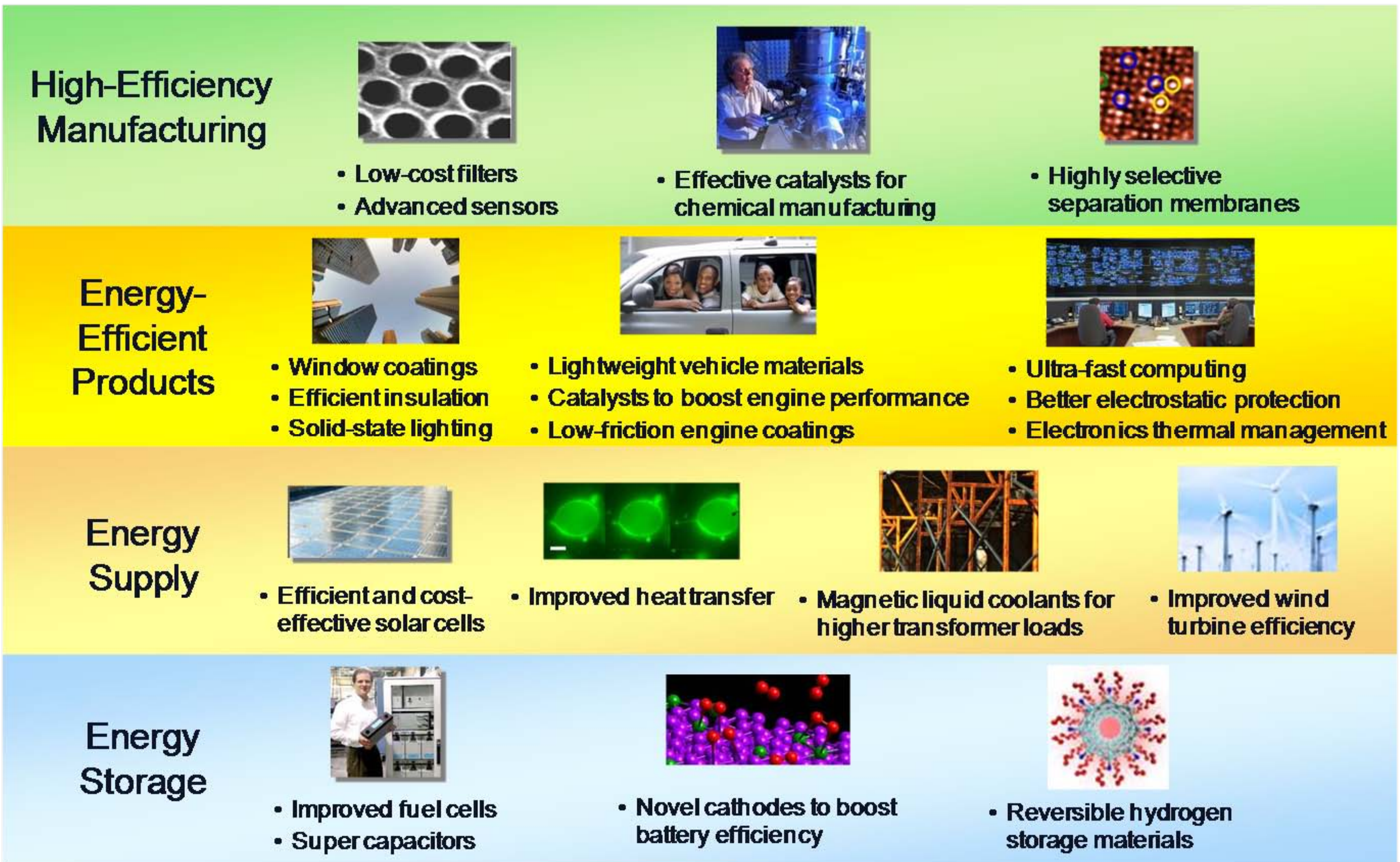
Source: Lux Research

- Global investment in nanotechnology rose to nearly $13.5 billion in 2007.
  - U.S. investment equals ~36% of total
  - The U.S. has the largest revenue from nanotechnology, but Europe is catching up
  - VC investment (not shown) is a lead indicator of potential. Energy investments lead for the first time in 2007

Investments in Nanotechnology

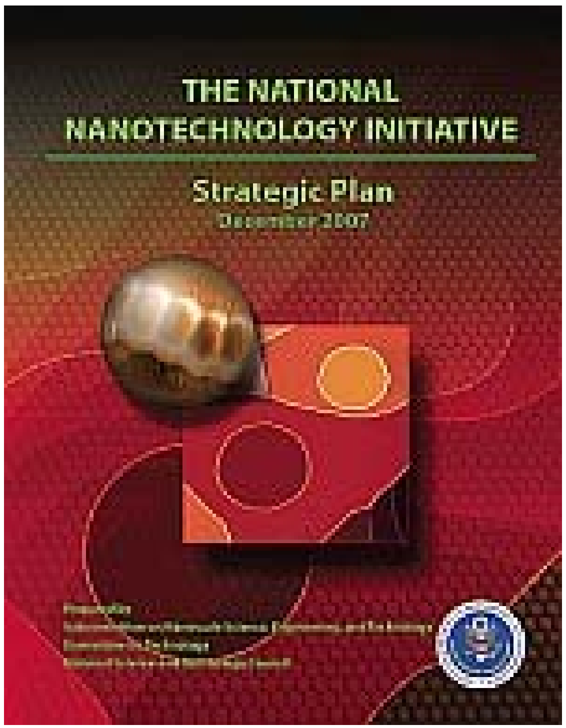


Advances in Nanotechnology Can Deliver Diverse Energy Benefits

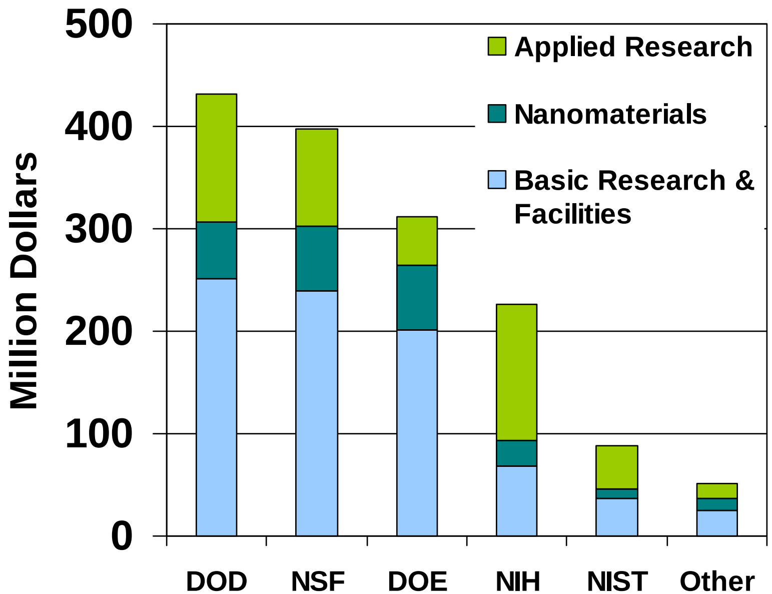


Nanomanufacturing: Supporting the Federal National Nanotechnology Initiative (NNI)

The U.S. government has invested $8.3 billion in nanotechnology over the past seven years – DOE has invested mostly in Basic Research

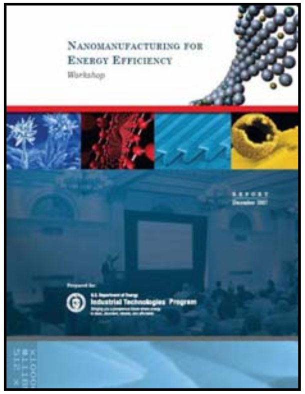


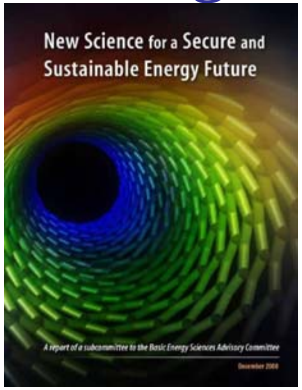
FY 2009 Proposed Government Investment in Nanotechnology

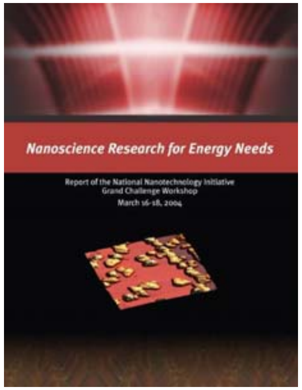


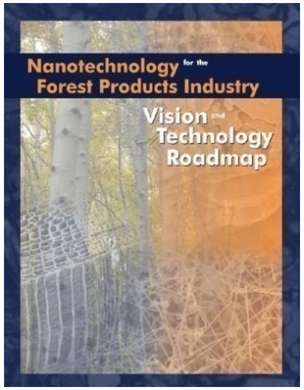
Only $62 million of $1.53 billion is devoted to the nanomanufacturing area

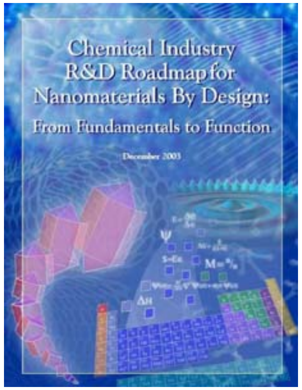
Nano Roadmaps – Calling Out the Need for Nanomanufacturing

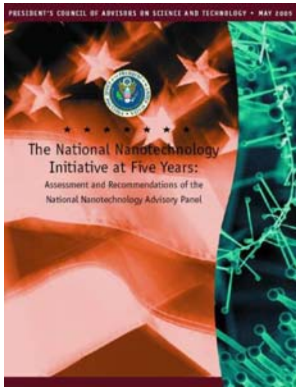


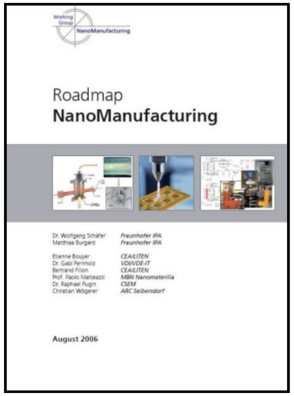


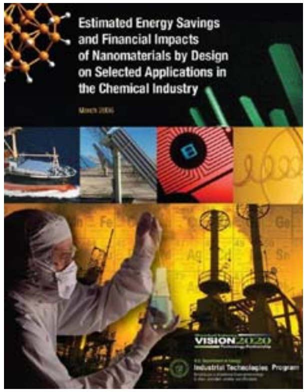


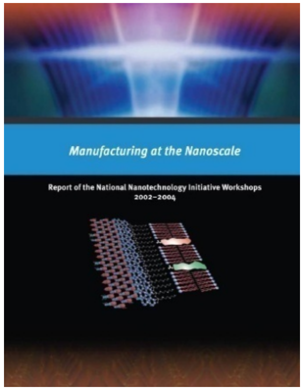


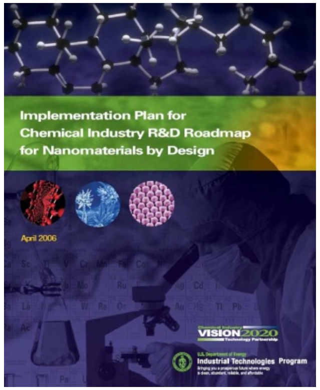












Nanomanufacturing - Where Did We Start?

Reviewed Technical and Market Analysis by Others

- Estimated Energy Savings and Financial Impacts of Nanomaterials by Design on Selected Applications in the Chemical Industry (LANL, 2006)
- The Nanotech Report (Lux Research, 2006)
- International Nanotechnology Development in 2003: Country, Institution, and Technology Field Analysis Based on USPTO Patent Database (NSF, 2004)
- Chemical Industry R&D Roadmap for Nanomaterials By Design (Chemical Industry Vision2020 Technology Partnership/Energetics, 2003)
- National Nanotechnology Initiative Grand Challenge Workshop (DOE, 2005)

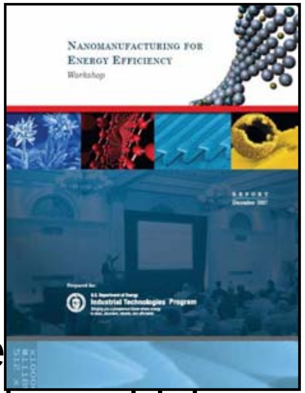
Nano Opportunities Relevant to ITP's Mission

- Up to 1.1 Quads/yr of total energy saving potential exists on nanotechnology applications in chemical, refining, and maritime industries
- Low-friction surfaces in bearings, gear boxes, seals, etc.
- Application of nano-enabled sensors in combustion control for process heating

Program Strategy Development

ITP worked with industry in developing its program strategy:

- Held *Nanomanufacturing for Energy Efficiency Workshop* in Baltimore in June 2007. Group identified key challenges in:
  - Nanomaterials production processes
  - Nanotech-enabled product manufacturing



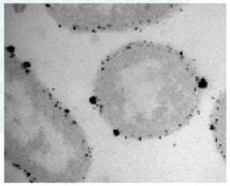
- Hired consultant (Lux) to help identify priorities for ITP:
  - Lux research drew upon their extensive database of technologies, companies and labs working in nanoscale science and engineering, which includes over 1000 entities
  - Evaluated 150 methods used in nanomanufacturing
  - Recommended focus on specific technology issues for five key processes: chemical vapor deposition, supercritical fluid processing, sputtering, printing, and thermal spray
- Engaged industry and business investment experts in R&D solicitation planning and merit review process

Program goals and description

- **Goal: to obtain comprehensive understanding of new technologies, global markets, trends, and commercialization challenges for nanomaterials and nano-enabled products that have impact on energy efficiency**

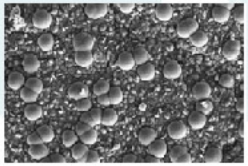
Nanomanufacturing processes

- Carbon nanotubes
- Graphene
- Ceramic nanoparticles
- Metal nanoparticles
- Dendrimers
- Fullerenes
- Nanowires
- Quantum dots
- Nanostructured metals
- Nanoporous materials
- Nanoscale encapsulation



Nanotechnology applications for energy efficiency

- Catalysts
- Nanocoatings
- Nanocomposites
- Separation media
- Renewable energy (solar, wind)
- Energy storage (fuel cells, batteries)
- Solid state lighting
- Thermoelectrics
- Biopolymers



Nanomanufacturing challenges

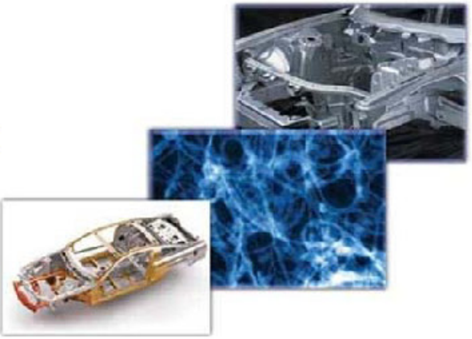
- Commercialization and manufacturing challenges in nanotechnology
- Need for a nanomanufacturing center

Nanotechnology applications for energy efficiency
Priority: high

Batteries and supercapacitors

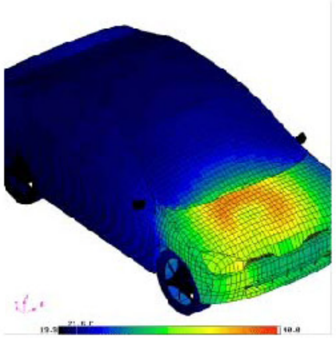
- **Market size**: $200 million* in 2007, $4,215 million in 2012
- **Lux Research Take**: Batteries will remain the key component in energy applications, playing in virtually all markets; their commercialization challenges are related to large-scale low-cost manufacturing

Light weight nanocomposites



- **Market size**: $151.9 million in 2007, $520 million in 2012
- **Energy savings:** 360 trillion Btu per year
- **Lux Research Take**: Nanotechnology is expected to greatly improve light weight composites that are important for aerospace, marine and other applications as they can greatly enhance energy efficiency. Performance issues and lack of adequate manufacturing processes need to be solved until they find wide-spread use

Nanocoatings/nanocomposites for thermal management

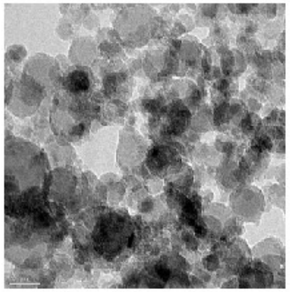


- **Market size**: $109 million in 2007, $403.5 million in 2012
- **Energy savings: :** 240 trillion Btu per year
- **Lux Research Take**: Nanostructured materials can either improve thermal conductivity for efficient heat dissipation or decrease thermal leakage via insulation. Technical advancement in this area can allow higher operating temperatures, increased efficiency and sizeable energy savings.

* Throughout this document, market size numbers are related only to *emerging* nanotechnology for *energy-efficient* applications

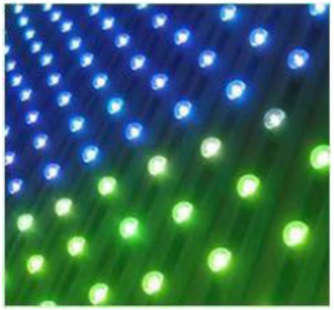
Nanotechnology applications for energy efficiency Priority: medium

- **Catalysts for Chemical, Industrial and Automotive applications**
  - **Market size**: $452 million* in 2007, $1,439 in 2012
  - **Energy savings:** 280 trillion Btu per year
  - **Lux Research Take:** Development of environmentally friendly catalysts that can enable more efficient processes are important for chemical industries. Automotive catalysts can increase fuel efficiency of vehicles and minimize harmful emissions. New controlled synthesis technologies are needed to accelerate developments of new catalyst materials.



- **Tribological nanocoatings**
  - **Market size:** $84 million in 2007, $618 million in 2012
  - **Energy savings:** 44 trillion Btu per year
  - **Lux Research Take:** Tribological coatings can provide significant efficiency gains, 5-10% for heavy machinery and other applications. Low-cost materials and processes are required for wide adoption of these technologies.

- **Solid state lighting (LED)**
  - **Market size**: $9.2 million in 2007, $86.2 million in 2012
  - **Energy savings:** 84 trillion Btu per year
  - **Lux Research Take:** : Lighting comprises around 20% of electricity usage in the US and wide adoption of LEDs can bring this number down significantly. In addition, there is some overlap in technological challenges that adversely affects other areas, such as solar cells and printed electronics.



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ITP Nanomanufacturing Program Focus

Help transform nanoscience into industrial processes and products

Focus:

- **Enabling Processes for Nanomaterials Production:** Improve reliability and scale up nanomaterials production processes
- **Nanomaterials Utilization in Industrial Processes:** Scale up manufacturing processes for utilization of nanomaterials in energy-related products

Top Priorities for Energy Efficiency (based on Lux analysis)

- Batteries and supercapacitors
- Light weight nanocomposites
- Nanocoatings/nanocomposites for thermal management
- Catalysts for chemical, industrial and automotive applications
- Tribological nanocoatings
- Solid state lighting (LED)
- Solar
- Nanomanufacturing research/commercialization center

Nanomanufacturing R&D Portfolio

- Concept definition studies
  - Projects focusing on technical and economic feasibility analyses as well as a complete lifecycle analysis for a proposed nanotechnology, from synthesis to disposal
  - One year
- Process development
  - Projects focusing on enabling processes for nanomaterials production or nanomaterial use in industrial processes
  - Up to 3 years

Active Projects in FY09: Concept Definitions

Project Title	Partners	Duration
Microwave and Beam Activities of Nanostructured Catalysts for Crude	Oak Ridge National Lab, Mach I	1 Year Stage 2
Highly Dispersed Metal Catalyst for Fuel Cell Electrodes	Savannah River National Lab	1 Year Stage 2
Nanoscale Interpenetrating Phase Composites for Industrial and Vehicle Applications	Oak Ridge National Lab, Fireline TCON	1 Year Stage 2
Nanoscale Electrodeposition Process for Manufacturing High Selectivity Catalysts	Argonne National Lab	1 Year Stage 2
High Power Impulse Magetron Sputtering of Ultra-Hard and Low Friction Nanocomposite Coatings for Improved energy Efficiency and Durability in Demanding Industrial Applications	Argonne National Lab	1 Year Stage 2
Development of an Advanced Technology to Manufacture surfaces with Nano-and Micro-Scale Features	Idaho National Lab, GE Global Research	PEP- 3 Years; Stage 3
Hydrogen and Wear Resistant Nanolaminate Coatings	Pacific Northwest National Lab	1 Year Stage 2
Large Scale Nanofermentation of Quantum Dots	Oak Ridge National Lab	1 Year Stage 2
Transformational Fabrication of Nanostructured Materials Using Plasma Arc Lamps	Oak Ridge National Lab	1 Year Stage 2

Active Projects in FY09: Process/Prototype Development

Project Title	Partners	Duration
Microchannel Assisted Nanomaterial Deposition Technology for Photovoltaic Material Production	PNNL, Oregon State U., CH2M Hill, Voxtell	3 Year Stage 3
Nanostructured Superhydrophobic Coatings for Breakthrough Energy Savings	ORNL, Stevens Institute of Tech., Ross Technology	3 Year Stage 3
Self-Assembled, Nanostructured Carbon for Energy Storage and Water Treatment	ORNL, Campbell Applied Physics, Honeywell	3 Year Stage 3
Erosion-Resistant Nanocoatings for Improved Energy Efficiency in Gas Turbines	NETL, MDS-PRAD Tech., DELTA Tech Ops., Calpine, U. of Cincinnati	1 Year Stage 4
Accelerated Deployment of Nanostructured Hydrotreading Catalysts	ANL, Evergreen Oil, Universal Lubricants	2 Year Stage 3
Development, Characterization, Production and Demonstration of Nano Fluids for Industrial Cooling Applications	ANL, Michelin, Saint-Gobain	3 Year Stage 3
Nano Catalysts for Diesel Engine Emission Remediation	ORNL, John Deere	3 Year Stage 3
Nano Particle Technology for Biorefinery of Non-Food Source Feed Stocks	Ames Lab., CatiLin, Institute for Physical Research & Tech.	3 Year Stage 3
Ultratough TSP Diamond/SIC Nanocomposites for Drill Bits	Los Alamos National Lab	3 Year Stage 3
Application of Wear-Resistant, Nano Composite Coatings Produced from IRON-Based Glassy Powders	ORNL, Carpenter Power Products	3 Year Stage 3
Large-Scale Manufacturing of Nanoparticulated-Based Lubrication Additives for Improved Energy Efficiency and Reduced Emissions	ANL, Valvoline, Primet Precision Materials	3 Year Stage 3

Active Projects Mid FY09: Concept Definitions

Project Title	Partners	Duration
Self-Assembled Biomimetic Nanostructured Anti-Reflection coatings for Highly Efficient Crystalline Silicon Solar Cells	Savannah River National Lab	1 year
Synthesis of Highly Ordered TiO_2 Nanotubes Using ionic Liquids for Photovoltaics	Oak Ridge National Lab	1 year
Pulsed Thermal Processing of Self-Assembled Quantum Dot Structures	Oak Ridge National Lab	1 year
Mesoporous Carbon Membranes for Selective Gas Separations	Oak Ridge National Lab	1 year
Nanocatalytic Conversion of Biomass into Second-Generation Biofuels	Oak Ridge National Lab	1 year
Oxide-Nanoparticle Containing Coatings for High Temperature Alloys	Oak Ridge National Lab	1 year
Nanocrystallization of $LiCoO_2$ Cathodes for Thin Film Batteries	Oak Ridge National Lab	1 year
Architectured Nanomembranes for In-Situ Energy Conversion	Oak Ridge National Lab	1 year
Filled Carbon Nanotubes: Superior Latent Heat Storage Enhancers	Argonne National Lab	1 year

Active Projects Mid FY09: Process/Prototype Development

Project Title	Partners	Duration
Modular Hybrid Plasma Reactor and Process for Low Cost Nanoparticle Production	Idaho National Lab	3 years
Infrared Absorbing Nanoparticles for Reducing Cure Temperatures in Industrial Coatings	National Energy Technology Lab	3 years
Development and Application of Processing for Nano-Composite Materials for Lithium Ion Batteries	Oak Ridge National Lab	3 year
Process Development for Nanostructured Photovoltaics	Argonne National Lab	3 year

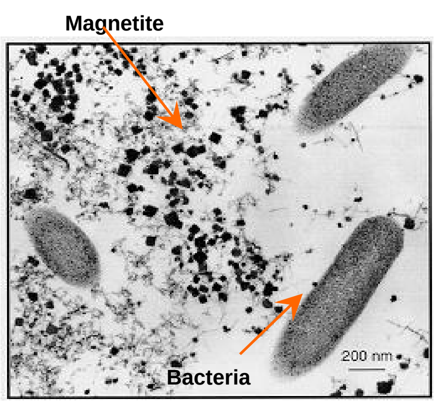
Large Scale Nanofermentation of Quantum Dots

Concept Definition Project

- Nanofermentation uses bacteria to synthesize nanomaterials
- Motivation
  - Important materials for many applications
    - Photovoltaics (copper-indium-gallium-diselenide: CIGS)
    - Solid state lighting (CdS)
    - Thermoelectrics
  - Scalable process
    - 50,000 gallon fermentor provides 500 kg/month
    - Equivalent to 10.8 MW of PV material/year at 10% efficiency
  - Energy efficient process
    - Nanofermentation occurs between 10°C to 60°C
  - Environmentally friendly
    - Naturally occurring phenomenon
  - Highly refined product
    - Nanofermentation combines (in-situ) particle synthesis with surfactant reducing lengthy and costly dispersion techniques

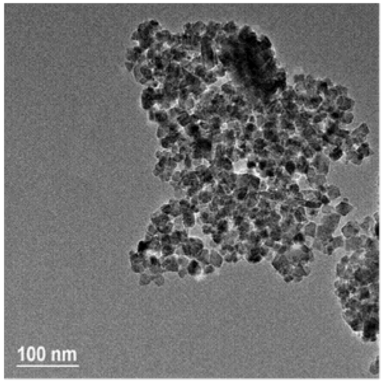
Background: Bio-Synthesis of Magnetic Nanoparticles

- Bacteria first discovered in oil and gas deposits in 1992
  - Geologically isolated (>1000 m below ground) for 100 to 140 million years
  - Strains of the bacteria produce nanocrystals of magnetite
    - 3 nm to 300 nm
  - Low cost (~$60/kg, at 30 nm) compared to $570/kg (98%, 50 nm) and $1340/kg (99.5%, 25 nm) magnetite
  - Bacteria available to public
- Able to control size and shape
- Until recently, focus of nanofermentation was on magnetic materials
  - Realized bacteria able to facilitate production of other nanomaterials
- Evaluating different strains of the bacteria for the production of other nanomaterials to use in such applications as:
  - Photovoltaics, thermoelectrics, and solid state lighting
- Possible to achieve low-cost high-quality nanoparticles for a multitude of applications

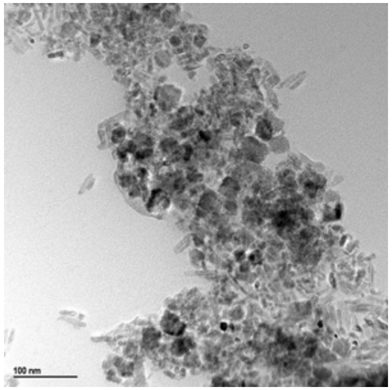


Novel


Scalable



Control size


Control Shape

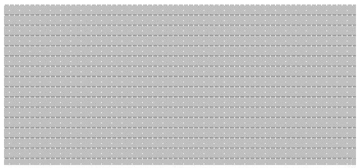
Nanostructured Superhydrophobic Coatings for Breakthrough Energy Savings

Process Development

- Project Objective:
  - Produce Commercially-Viable, General-Purpose, Powder-Based Coatings With Extreme Water-Repellent Properties
    - Reduced drag at water / solid interfaces
      - Less energy required to pump water through pipes
      - Less energy required to move watercraft
    - Reduced corrosion of metals in wet environments
    - Reduced biofouling of surfaces in seawater
- Basis for the energy savings potential:
  - Extreme water-repellant nano-patterned powder coatings
  - Hydrophobicity amplified by nano-scale texturing
- Nanomanufacturing solution to the problem:
  - Fabrication of nano-patterned superhydrophobic powders in large volumes at low costs used to create well bonded superhydrophobic coatings

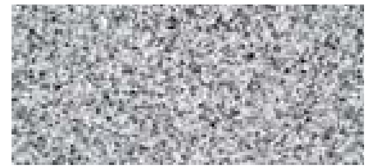
Technology Basis: Nanostructured Silica Powder Phased-Separated Spinodal Superhydrophobic Glass Powder

Phase Separating Glass



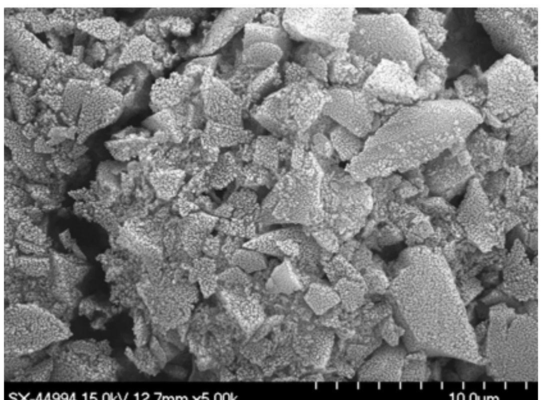
Heat Treatment ➔

Phase-Separated Spinodal Structure

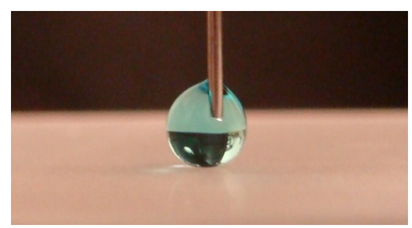


Crush Glass Powder ↓

Acid Etch Powder ←

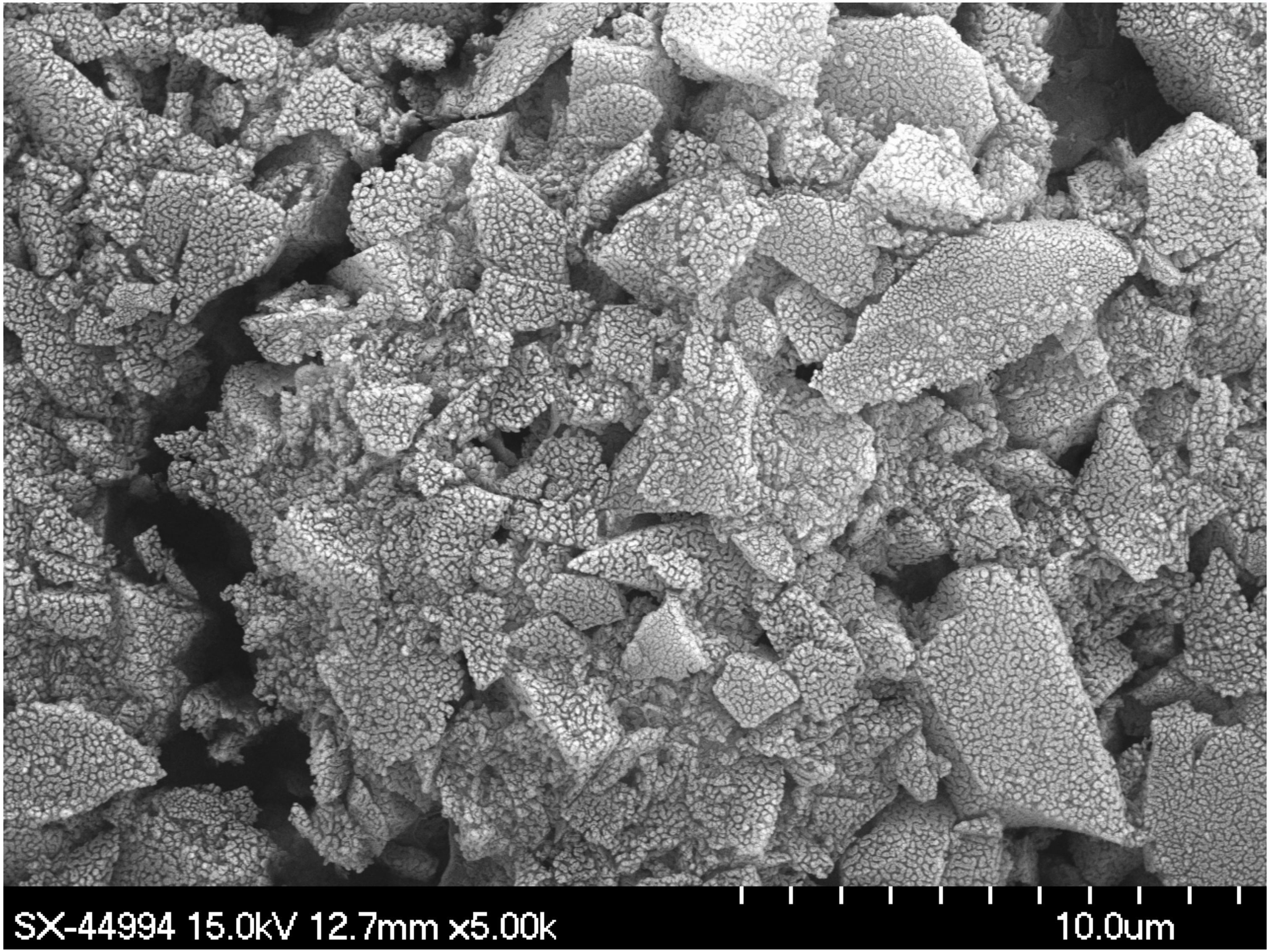


↓ Apply (SAM) Self Assembled Monolayer →

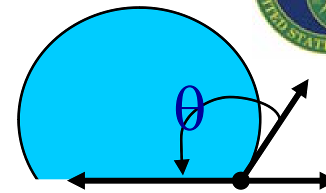


Superhydrophobic Glass Powder Coating

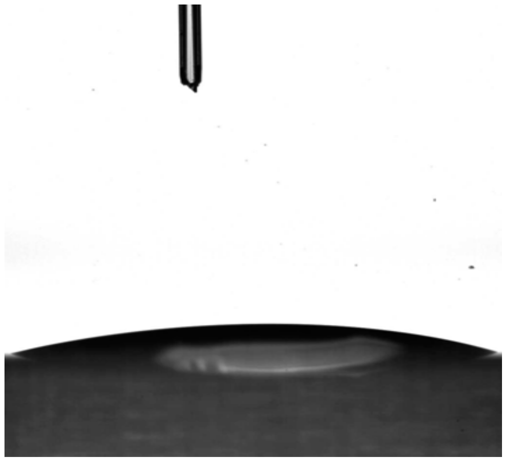
Superhydrophobic Nano-textured Glass Powder

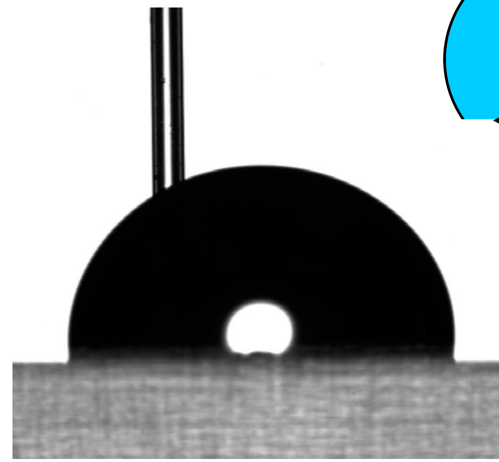


Contact Angle Images Using 1 μL Water Droplets



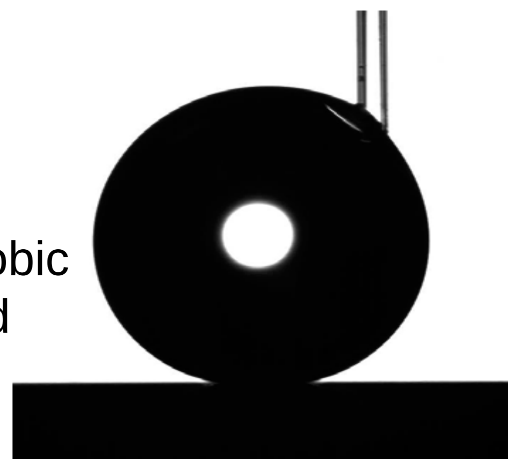
Uncoated
Glass Plate





Teflon
Coated
Glass Plate

Superhydrophobic
Powder Coated
Surface



Required Nanomanufacturing Advancements

- Optimize Powder Size and Binders to Produce Large, Uniform, and Durably Coated Areas for Various Substrates (esp. plastics and metals)
- Tailor Coatings for Drag Reduction and Corrosion Resistance
- Test Coated Surfaces for Hydrodynamic Response, Corrosion Resistance, and Durability
- Evaluate Prototype Performance
  - Pipes
  - Pumps
  - Boat Hulls

DOE Industrial Technologies Program
2008 Corporate Peer Review

Nanomanufacturing Portfolio Review

Large-scale Manufacturing of Nano-particulate-based Lubrication Additives for Improved Energy Efficiency and Reduced Emissions

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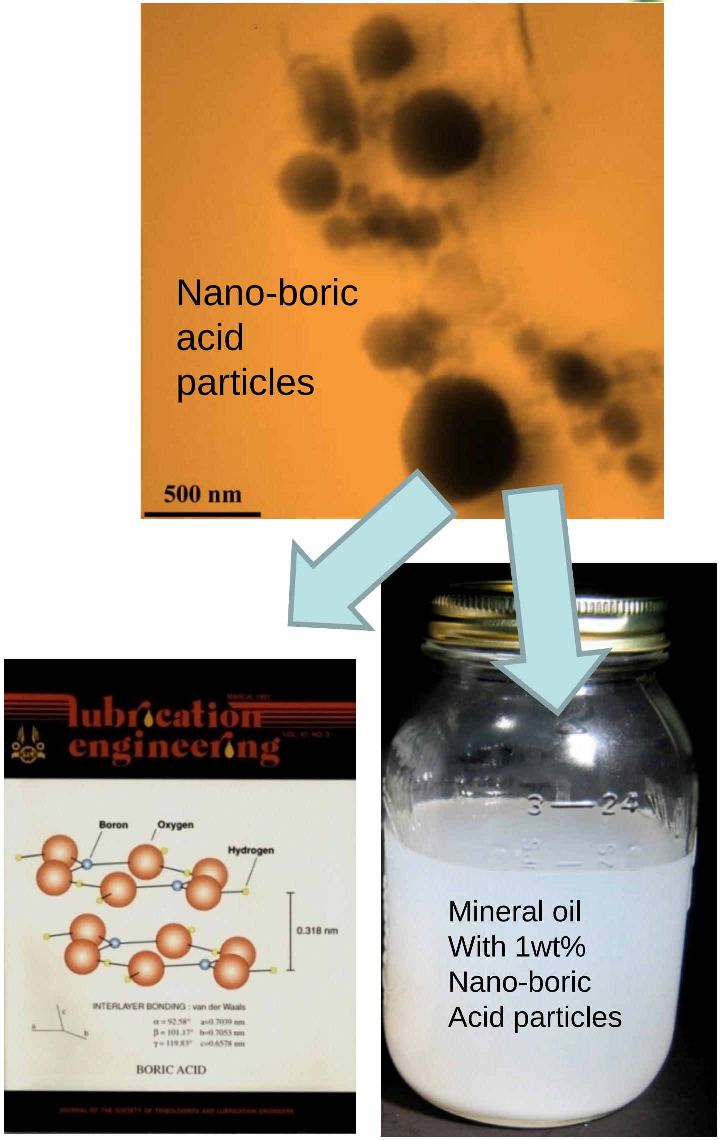
Large-scale Manufacturing of Nano-particulate-based Lubrication Additives for Improved Energy Efficiency and Reduced Emissions

Process Development

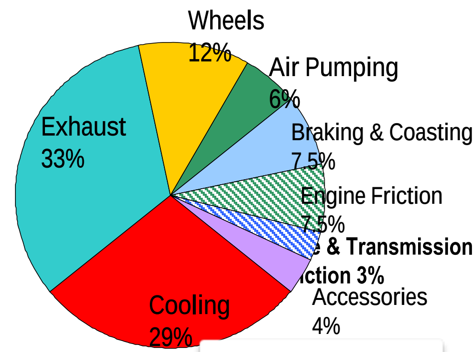
- Objective:
- This project addresses the increasing needs for advanced lubrication additives
  - Reduce friction and wear
  - Save energy and environment
  - Increase component reliability in transportation and manufacturing systems
- Boron-based nano-lubrication additives
  - Reducing friction by as much as 80%
    - Virtually eliminating wear
  - Displacing current lubrication additives that are harmful to the environment
  - Overcoming barriers for large-scale nano-powder manufacturing



Layered lattice structure

Project Description and Benefits

- Goal: Scale-up and commercialize boron-based nano-colloidal lubrication additives and confirm their energy saving, emission reduction, and component reliability benefits in transportation and manufacturing fields.
- Industrial Applications and Market Potential:
  - Applicable to many industrial sectors including transportation and manufacturing.



Energy Losses
In an Engine

Benefits

- Nano-lubrication technology saves energy by reducing friction
- Increases component durability/reliability by reducing wear
- Potential energy savings are estimated to be 1,000,000 barrels of petroleum per day in transportation alone
- Since less petroleum is used, less carbon emission is generated
- Additional environmental benefits
  - Reduction and/or elimination of carcinogenic additives from current lubricants that are detrimental to the after-treatment devices and catalysts in engines

Research Tasks

- Feasibility of producing and blending of nano-powders with lubricants
  - Validation of nanomanufacturing process
- Pilot-scale production, fuel efficiency and no-harm engine studies
  - Validation of process/product reliability and demonstration of efficiency in engines
- Large-scale production, fleet testing, certification/approval and initial commercial offer
  - Validation of scalability, cost competitiveness, energy efficiency, and reduced emissions

Thank You

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  - NETL Contact: Joseph Renk
  - ITP Technical Support: Ronald Ott

- Questions