Applications and future directions of nanotechnology

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Basic advancements in science and technology come about twice a century and lead to massive wealth creation.

**Revolutionary Forces**

- **Textiles**: 1800
- **Railroad**: 1853
- **Automobile**: 1913
- **Computer**: 1969
- **Nanotech?**: 2025
- **2081**

**Timeline**

- **Industrial Revolution**: 1771-1853
- **Information Revolution**: 1853-2081

**Sources**

- **Norman Poire, Merrill Lynch**
- **Red Herring, 2003**

**Questions**

- **Hype?**
Moore’s Law and IC evolution

• Revolutionized Computer and Communication
**What is Nanotechnology?**

Working at the atomic, molecular and supramolecular levels, in the length scale of approximately 1 – 100 nm range, in order to understand and create materials, devices and systems with fundamentally new properties and functions because of their small structure.

**NNI definition encourages new contributions that were not possible before.**

- novel phenomena, properties and functions at nanoscale, which are nonscalable outside of the nm domain
- the ability to measure / control / manipulate matter at the nanoscale in order to change those properties and functions
- integration along length scales, and fields of application

MC. Roco, 9/29/03
Optical Properties of Quantum Dots

Tuning Resonance Energy (Bandgap) in Nanoparticles
Birck Nanotechnology Center – Today

- A **multidisciplinary** center for **collaborative** research
- **160+** affiliated faculty representing **25** academic departments
• **NanoPhotonics** (*metamaterials*)
• **Computational Nanotechnology** (*home of NSF nanoHUB*)
• **NanoElectronics** (*2D/Graphene electronics*)
• **Bio-Nanotechnology** (*with Bindley Bioscience Center*)
• **Microelectromechanical Systems (MEMS), Nano metrology**
• **Nano-Energy** (*solar, thermal/thermoelectrics, batteries*)
4.9 billion connected devices (enabled by IoT) will be in use by 2015 and will likely increase to 25 billion by 2025.

Nanotechnology in:
- Mobile Internet
- Internet of Things
- Advanced Robotics
- Autonomous Vehicles
- Next-generation genomics
- Energy Storage
- Advanced materials
- Renewable energy
1/4 to 1/3 of all food produced for human consumption is lost or wasted.

Here's the breakdown:

- Approximately 1 billion metric tons
- 56% in developed countries
- 44% in developing countries

Those lost calories could fill hunger gaps in the developing world.

Calories lost or wasted per person, per day (out of a recommended 2,000):
- North America + Oceania: 1,520
- Europe: 748
- Industrialized Asia: 746
- North Africa, West + Central Asia: 594
- Sub-Saharan Africa: 545
- Latin America: 453
- South / Southeast Asia: 414

87% lost or wasted in production, storage, transport, etc.

Learn more at www.worldbank.org/foodpricewatch

Sources: FAO and World Resources Institute
Food Safety Sensor Needs

- Rapid high throughput screening (low cost)
- Packaging integrity, storage, transportation
- Indicators for: pH, Temp, moisture, chemical, color, texture.

Humidity & Temperature Indicators

3M™ introduces the new smart label…the MonitorMark™ Time Temperature monitor label

The MonitorMark™ Time Temperature monitor label visually tells you if refrigerated products have been stored at the proper temperature.

Lisa Mauer (Food Science)
EU Nitrates Directive

Fertilizer nutrient consumption in the European Union 27

Source: EFMA, 2009
Smarter Agriculture

Spatial Data Collection (GPS, geo-referenced)
  - soil water availability, soil compaction, soil fertility, biomass yield, leaf area index, leaf temperature, leaf chlorophyll content, plant water status, local climate data, insect-disease-weed infestation, grain yield

=> Precision Irrigation
=> Variable-rate Technology

Karen Plaut, College of Ag, Plant Science Big Move
Smart system integration

Babak Ziaie; Byunghoo Jung; Vijay Raghunathan (ECE)
Low-cost Smart Dressing for Chronic Wound and Burn Management

Babak Ziaie (ECE), Rajiv Sood (IUPUI)
• Scalable Manufacturing of Adaptive and Responsive Thin (SMART) Films can revolutionize healthcare, precision Ag and smart food packaging.
• Need to integrate microsystems, nanomaterials, soft materials on flexible substrates.
Roll-to-roll nanomanufacturing for smart films

Microgravure
Slot Die

Inkjet/Laserjet

• Potential for distributed manufacturing

Installed June 2015

Installed Sept. 2013
Ag Grand Challenge: Feed 9 Billion People by 2050

- **Climate Change, Energy and Water** Grand Challenges (Full life-cycle analysis is necessary)

- Technology and Society (public acceptance of GMOs)

- Solutions for US (developed countries) vs. Rest of the World
  - Importance to reduce manual labor?
  - High tech infrastructure needed to support sophisticated sensors/machinery?
World Marketed Energy Use 1990-2040

US Department of Energy; Energy Information Administration (2013)
(2000)

1 Quad = 1.055 \times 10^{18} J

13TW

2050: 25-30TW
CO₂ Emission Goals (2000-2100)

Every 12-15 years, World population increases by 1B.

David McKay, Sustainable Energy -Without the Hot Air
More than 90% of primary energy is first converted to heat.

Overall end-use exergy (12% of sources):
- Motion 0.95 TW
- Heat 0.73 TW
- Cooling/Light/Sound 0.06 TW
- Illumination 0.04 TW
Direct Conversion of Heat into Electricity

Seebeck coefficient (1821)

\[ S = \frac{\Delta V}{\Delta T} \]

Radioisotope Thermoelectric Generators
(Voyager, Galileo, Cassini, …)

- 55 kg, 300 \( W_e \), ‘only’ 7 % conversion efficiency
- But > 30 years without a single failure
TE for topping cycle applications

Prof. Chenn Zhou
Purdue Calumet

Coal Power Plant

\[ T_{\text{hot}} = 1900 \text{K} \]

- Highest exergy lost is between the flame and the working fluid (steam).
- Highest steam temperatures/pressures are limited by the turbine materials.
Thermoelectric Cooking Stove + Charger
Current crops dryer


Figure 4. Modified crossflow dryer with reverse-airflow (suction) cooling.
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nanoHUB: GLOBAL INFRASTRUCTURE

M. Roco, Senior National Advisor, National Nanotechnology Initiative
Calculate:
System Efficiency, Output power, $/W