Nanosensors in the Age of Terror: Business Trends and Opportunities

Raj Bawa, PhD

Bawa Biotechnology Consulting LLC, Arlington VA

Rensselaer Polytechnic Institute, Troy NY

Andrea D'Ambrosia, MBA

Dynamic Biomarketing, Arlington VA

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World Nano-Economic Congress

What the Experts Predicted

X rays are a hoax.

-- New York Times headline, 1911

I think that there is a world market for about five computers.

-- Thomas Watson, Chairman of IBM, 1943

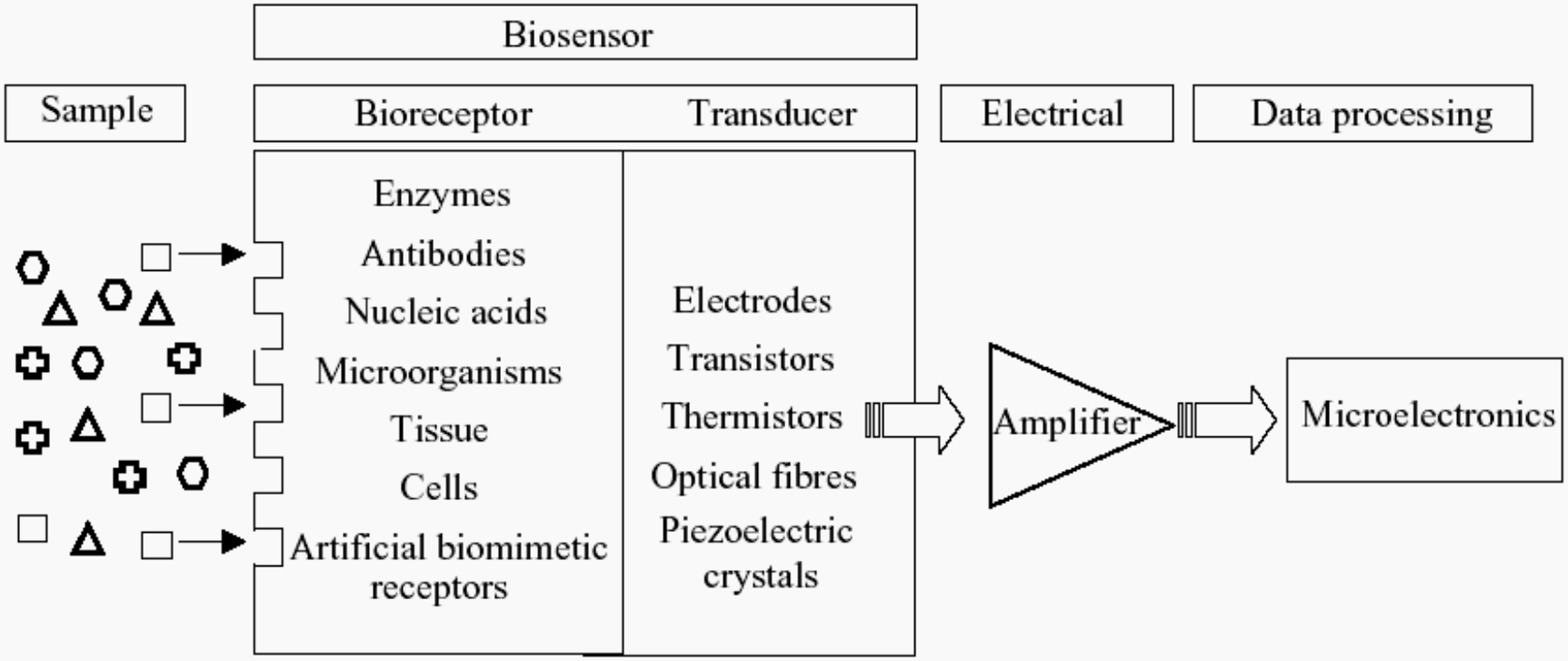
640K [of memory] ought to be enough for anybody.

-- Bill Gates, CEO of Microsoft, 1981

The cloning of mammals…is biologically impossible.

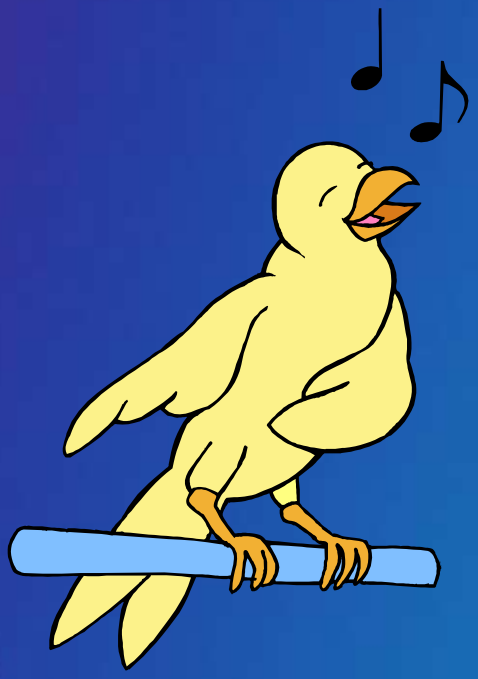
-- Science, 1984

What is a Biosensor?



Source: Biosystems Engineering (2003) 84 (1), 1–12

Biosensors



Canary in Coal Mine

Sensing Elements	Transducers
Enzyme	Electrochemical detection
Antibody	Optical detector (fluorescence)
Aptamer	Ion selective electrode
Receptor	NADH fluorescence or absorbance
Ion channel	Chemiluminescence
Oligo-nucleotide	Surface plasmon resonance
Structural protein	Piezoelectric (acoustic signal)
Peptide	Cantilever deflection
Living cells	Resonant light scatter

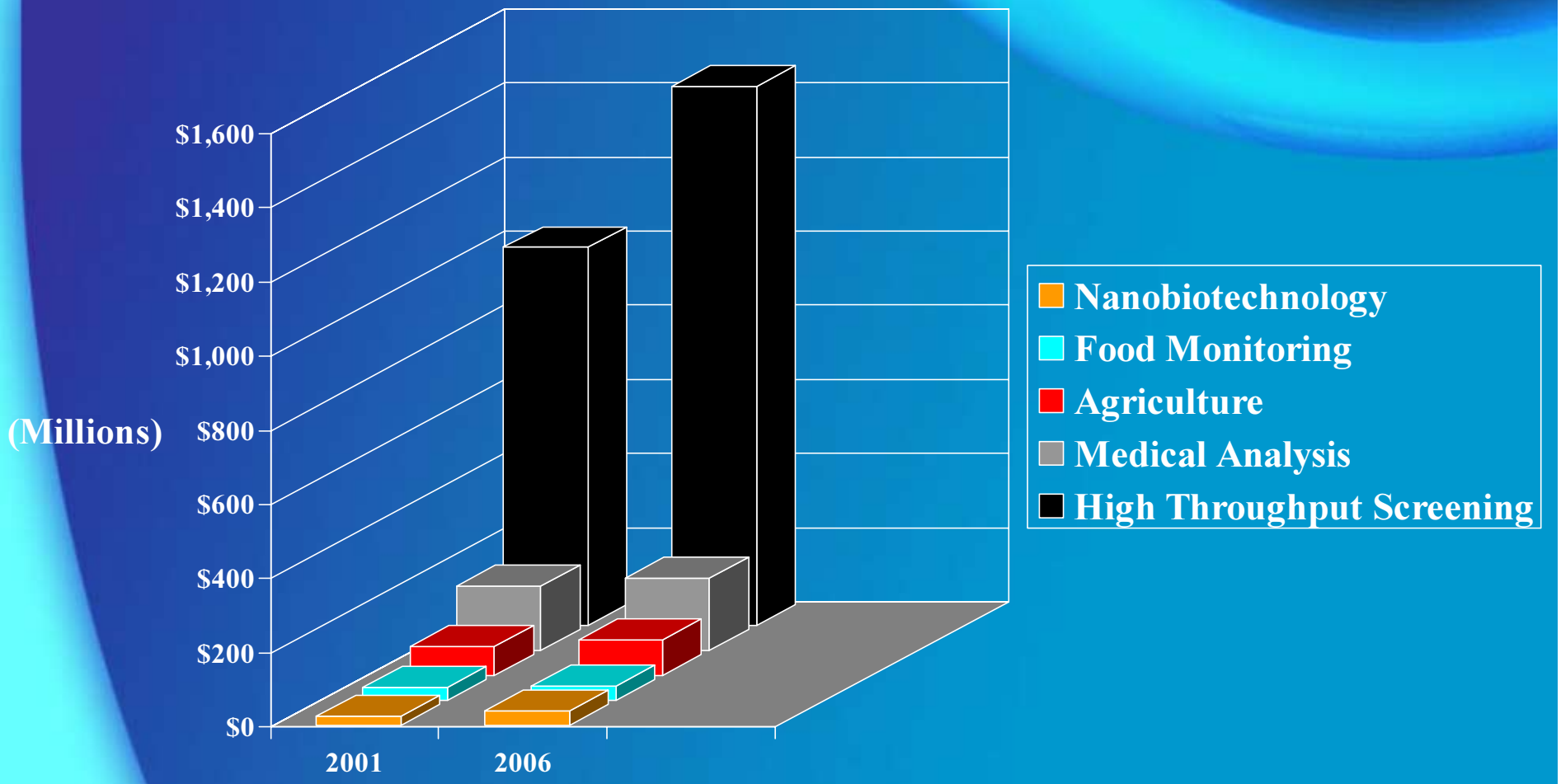
Courtesy of Steven Edwards, BCC, Inc.

Sensor Market

- $1.9 billion to $2.7 billion in 2006 – primarily gas and biosensors*
- Driven by large diagnostic market
  - $1.5 billion in 2003 – dominated by glucose monitors for diabetics
- Growing use of chemical sensors in large scale environmental and industrial applications
  - $14 million in 2003

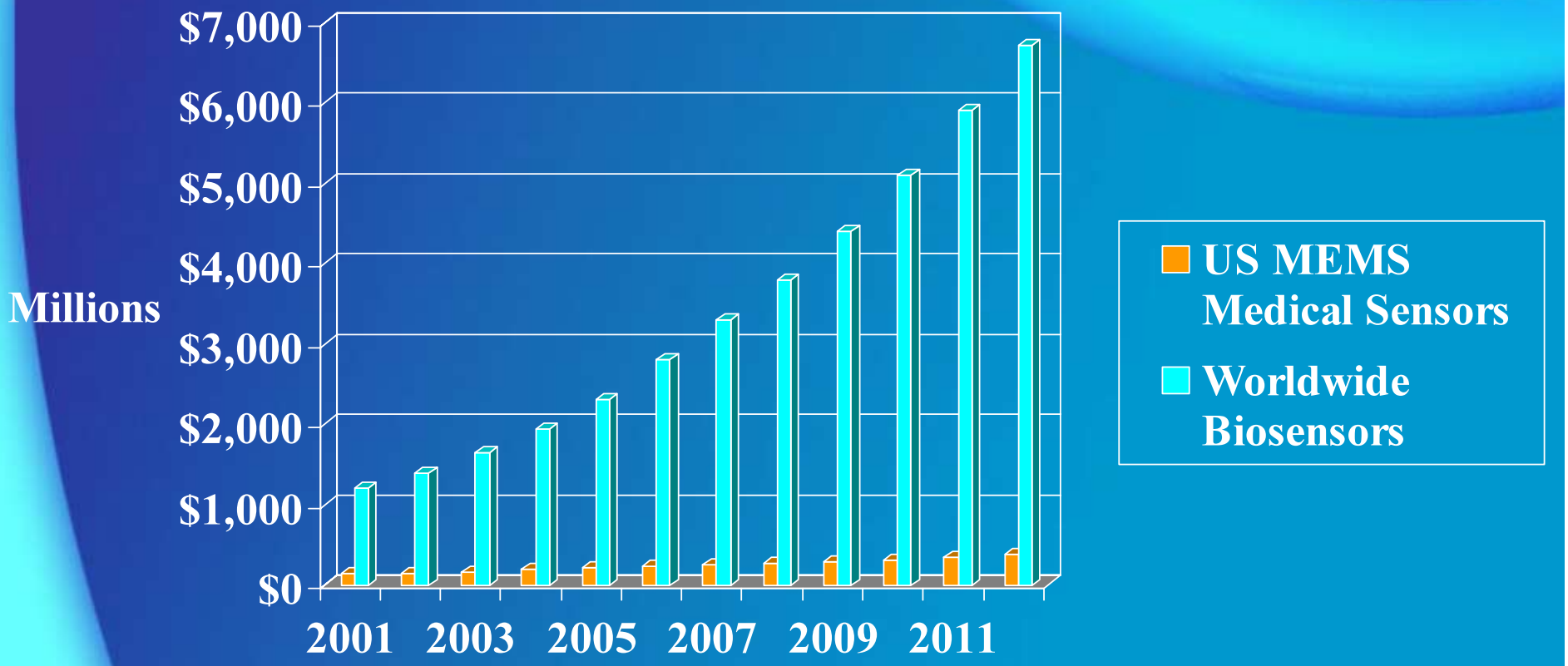
*Source: Chemical Sensors, April 2002, Freedonia Group

Biosensor Market



Data: US Market for Biosensors and Bioelectronics, Sept 2002, BCC, Inc.

More Market Data



Data: MedMarket Diligence, Report # T601, January 2003

Current Sensor Applications

- Medical Diagnostics
  - Glucose sensors
  - Pressure sensors
  - Accelerometers
  - Instant cholesterol and cardiac risk tests
  - Blood alcohol breath analyzers
  - Faster, more accurate cancer diagnostics
- Chemical and Biological Warfare Agent Detectors

Current Sensor Applications

- Environmental Sensors
  - Auto oxygen sensors
  - Auto cabin air quality monitors
  - Fuel cell vehicle safety monitors
  - CO sensors for home smoke detectors
  - Auto emissions testing analyzers
  - Portable water pollution water monitors
- Food Pathogen Testing
  - Quick tests for food pathogens (e.g., *E. coli*)

Market Drivers for Sensors

- Need for improved detection of
  - Chemicals, biologics, radioactive materials, explosives (CBRE)
  - Food borne pathogens
  - Environmental conditions
  - Disease diagnosis

- Need for increased terror security
- Desire for reduced cost, better performance
- Financial commitment of US government
  - BioShield, NNI, etc.

The Promise of Nanotechnology

- Extreme specificity
- Ultra-high sensitivity (nM-pM; fM possible; single molecule detection)
- Size Miniaturization – offers lower costs, reduced weight, potential for high integration, less power consumption, integration of all steps (arrays, lab-on-a-chip, etc.)
- Greater speed – real-time analytical information (even *in vivo)*
- Accuracy
- Option for multi-analyte analysis

Side Note: Nanoscale *per se* is no advantage.

The Promise of Nanotechnology

- Less sample preparation/pre-treatment, less sample volume (<1ul)
- Processing of data locally into information
- Reliability, reproducibility
- Small size offers better signal to noise ratio
- Durability; Susceptibility to temperature and environmental changes
- Cost (disposable)
- Safety
- Background
- Portability

Impact of War on Terror

- National security is currently driving demand (national priority)
- Increase in the perceived need for detection
- Expanded market demand
- Some concern that shift in funding will effect the development of non-biowarfare applications
- Has changed some of the requirements for detection

War on Terror: Change in Requirements

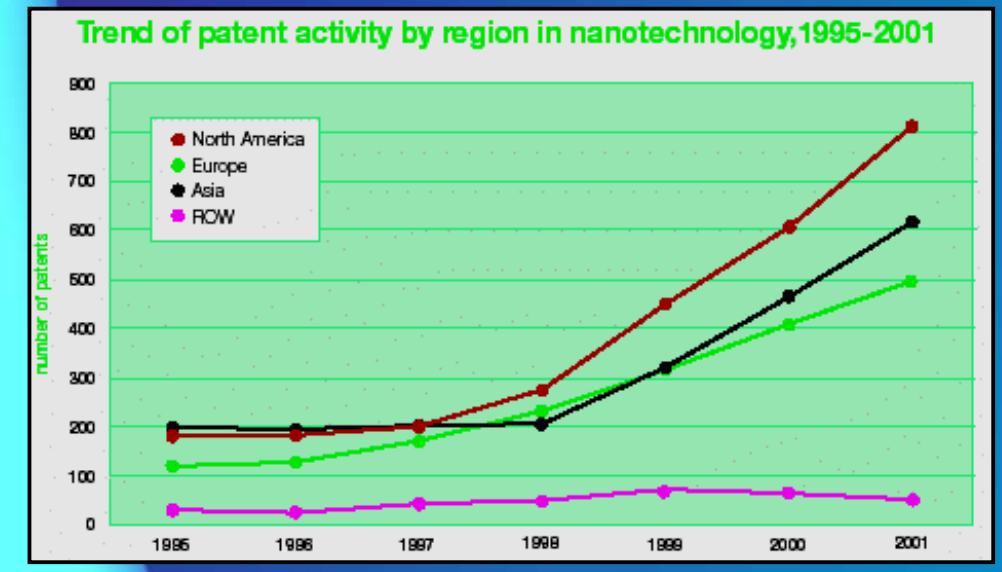
- Battlefield vs. homeland detection
  - Different requirements
  - Standardization, different guidelines
  - Durability, portability, size, etc.
- Simultaneous detection of wide variety of agents (universality)
- Detection and transmission of information for troops in the field
- Increased detection for homeland security
  - Air, water, public buildings, ports, transportation

Obstacles to Commercialization

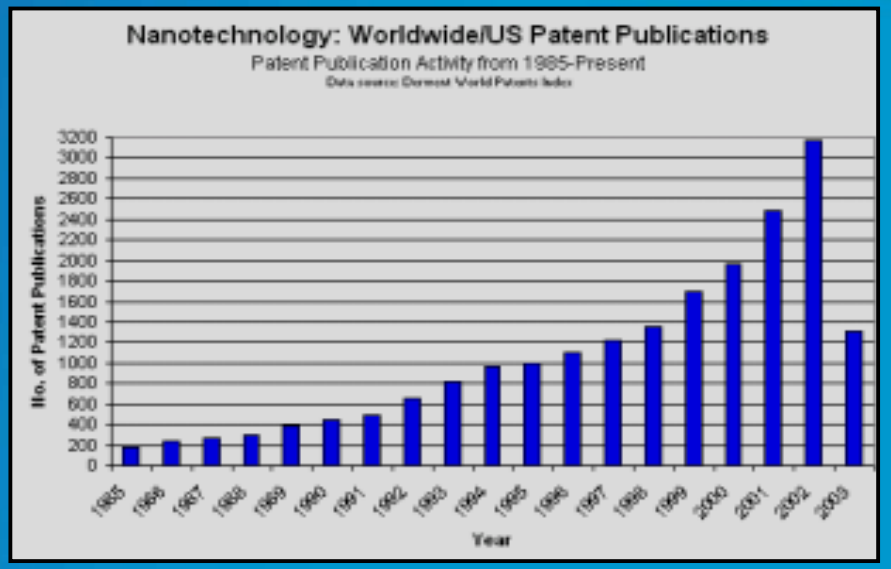
- Time to market for medical diagnostics
- Physical concerns (Moore's Law)
- Economic concerns (fabrication Costs)
- Regulatory hurdles (FDA, EPA, FTC, CPSC)
- Societal implications of nanotechnology
  - Ethical/moral
  - Public trust
  - Environmental/health concerns
  - Legal challenges: control; monitoring; ownership
  - International viewpoints/laws

Obstacles to Commercialization

- Intellectual property challenges



Source: NSF



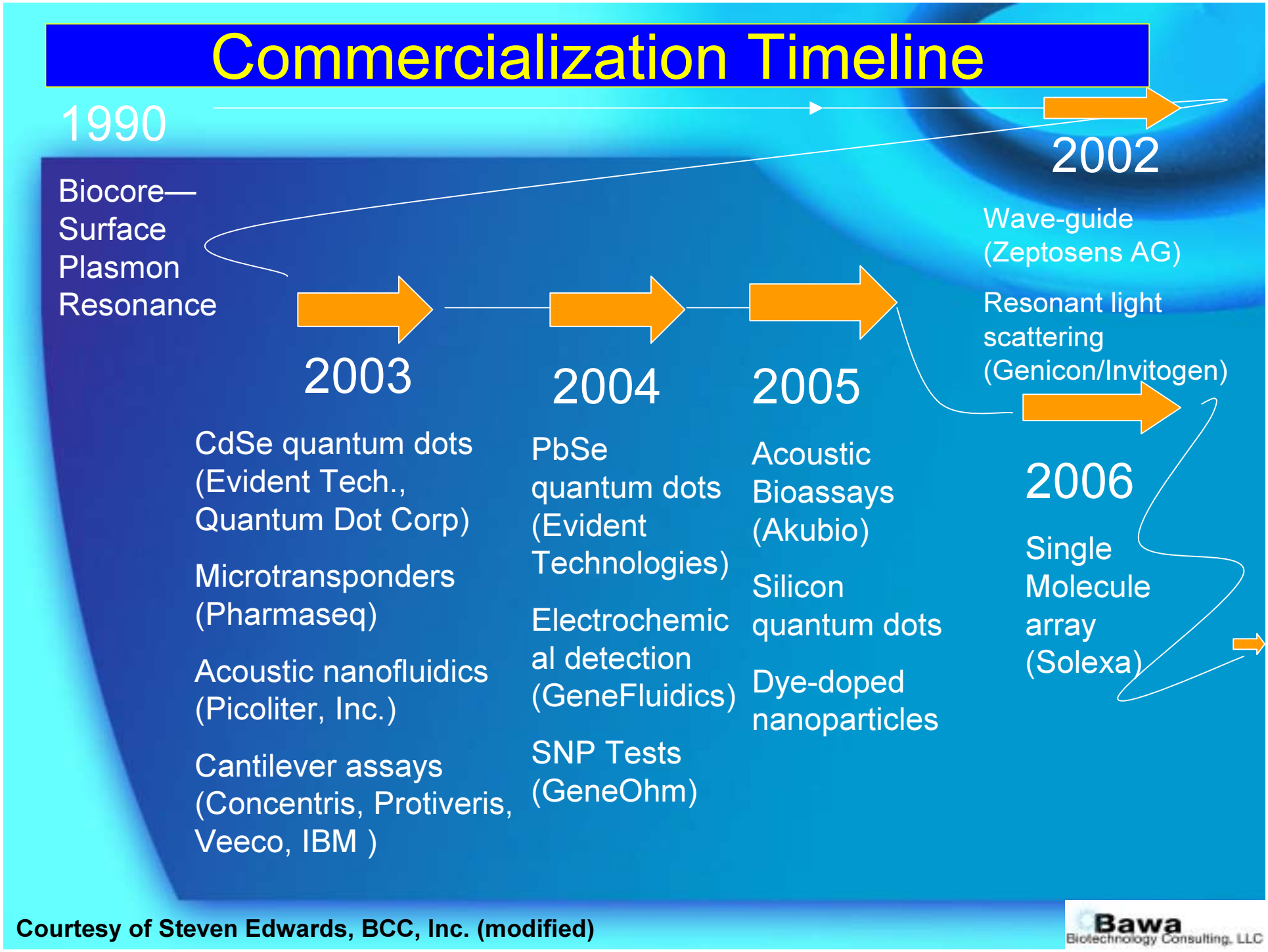
Source: InteCap, Inc.

Side Note: There is a special status granted to patent applications relating to bioweapons.

The Challenge for Nanosensors

- Reliability
- Upgradeability (problematic for implants)
- Thermal management
- Component biocompatibility
- Communication/data link (wireless ideal)
- Robustness (e.g., towards concentration changes)
- High cost
- Large volume manufacturing

Commercialization Timeline



Courtesy of Steven Edwards, BCC, Inc. (modified)

5-10 year Biosensor Technologies

- Transduction/actuation mechanisms for greater sensitivity/selectivity
- Biotic/abiotic interfaces to marry semiconductors with in-vivo biology
- Environmental energy sources to minimize battery requirements
- Incorporate separation and detection technologies at micron scales with lab-on-a-chip

Source: AVS Science and Technology Society, 2002

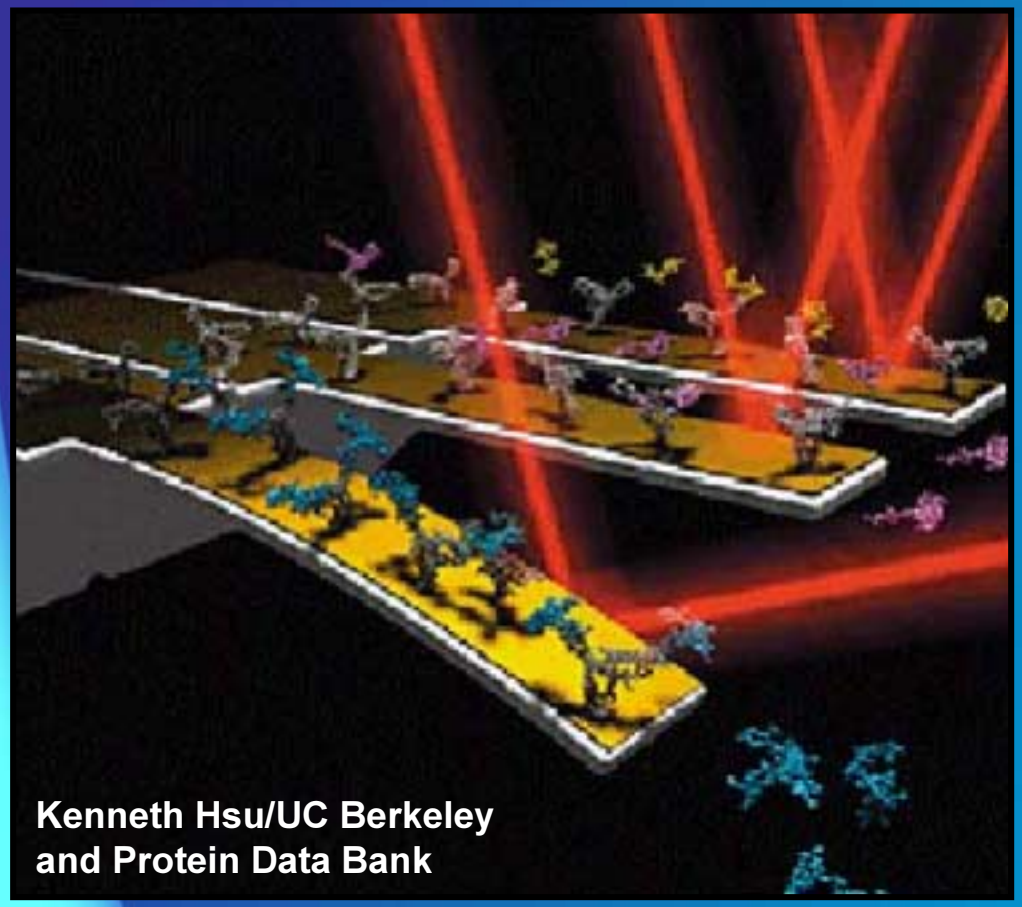
10-20 Year Biosensor Technologies

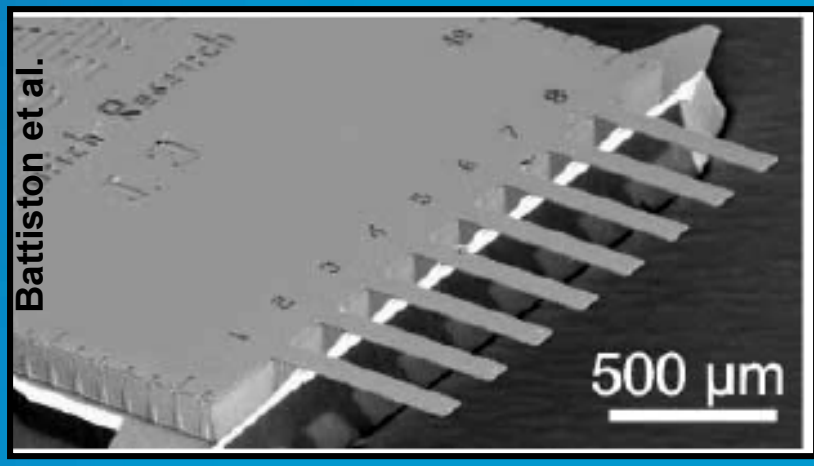
- Application of nanoscience to integration of complex components
- system (sensor suites) for providing sufficient insights into complex systems (cell physiology) enabling innovative nanotechnologies
- Multifunctional surfaces - Develop surfaces that contain sensing and reactive moieties for protection, self-decontamination, and self-sterilization

Source: AVS Science and Technology Society, 2002

Nanosensor Technology - *Examples*

Cantilever-based Sensing: MEMS Sensors





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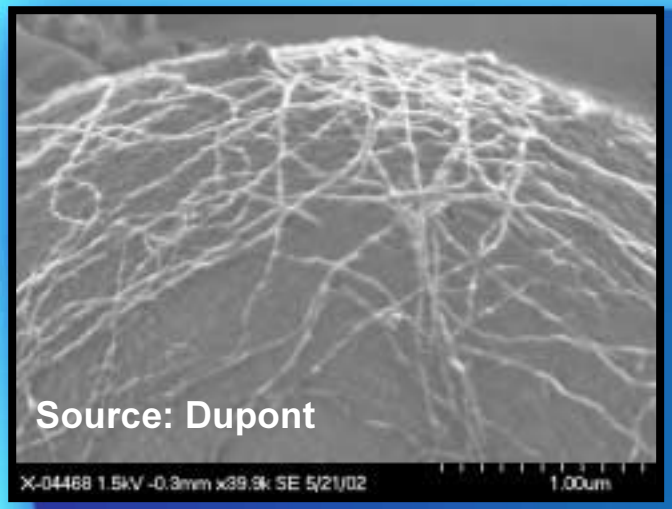
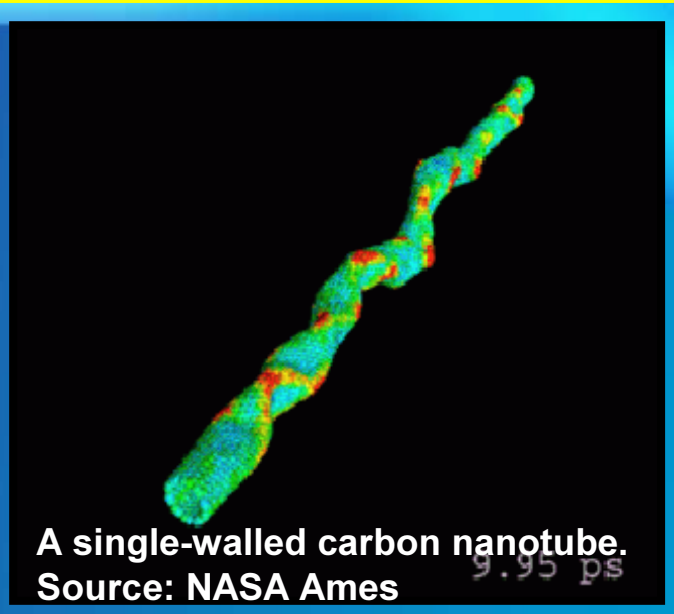
"…what we can do depends upon what we can build."

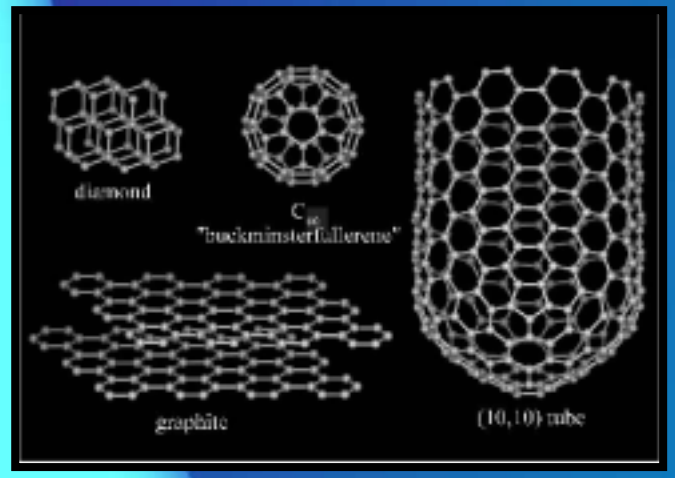
-- Marvin Minsky, MIT, 1986



Source: Dupont



A single-walled carbon nanotube.
Source: NASA Ames



Annual Growth of US Nanomaterial Market (2002-20): 33%
Source: Freedonia Group

2002 Revenues for the N. American gas sensor market: ~$754.3 million
Source: Sensor Business Digest

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Conclusions

- There are clearly significant market opportunities in biosensors
  - Greater opportunities projected for medical diagnostics; however, there will be significant challenges due to reliability and time to market.
  - Strategy may be to pursue industrial or environmental applications concurrent with medical applications.
- These opportunities have only been enhanced by the demands of counter-terrorism
  - Technological issues for broader market will likely be addressed by needs of counter-terrorism.

Conclusions

- Many technical, business, IP, societal and regulatory challenges exist
- However, significant strides have been made
- Usefulness and affordability must be judged in the context of needs of certain applications and end-users.
- We are beginning to see technologies come to market along the continuum to nanotechnology

Contact Information

Raj Bawa, PhD, Patent Agent

President, Bawa Biotechnology Consulting
1801 Crystal Drive, Suite 907
Arlington, Virginia 22202, USA
Office Phone: 703-271-1240
Cellular Phone: 703-582-1745
Fax: 703-271-8588
E-Mail: doctorhockey@aol.com

Andrea D'Ambrosia, MBA

President, Dynamic Biomarketing
3000 S. Randolf Street
Arlington, Virginia 22206, USA
Cellular Phone: 505-249-0104
E-mail: andrea@dynamicbiomarketing.com
Web: dynamicbiomarketing.com

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