Background Nanotechnology, What is BioNanoTech?

Biomaterials
- Biomacromolecules (DNA, RNA, protein) (structure & engineering)
- Other biomaterials (lipids, carbohydrates, inorganics)

Methods and Instruments
- Molecular biology, synthetic chemistry
- Microscopy (AFM, TEM, SEM, STM, etc.)

NanoMaterials
- nanoparticles, nanotubes, nanowires, nanocrystals, block co-polymers

Nucleic Acid Nanotech
- DNA-based computing, algorithmic self-assembly. RNA nanotech.

Protein Nanotech


BioNano with Protein, Virus, Cell Building Blocks.

Impacts: biosensors, molecular therapeutics, nanoelectronic, nanooptical, nanochemical, molecular manufacturing.
Nano and BioNano

- Nanotech--atomic control of matter
- Bionanotech--control of matter on low nanometer scale with inspiration, principles, or materials borrowed from biology.
There's Plenty of Room at the Bottom

- Encyclopaedia Brittanica on the head of a pin requires only 25,000 fold reduction.
  - \( \frac{1}{25,000} \) pixel = 80 Å (8 nm) = \( \sim 32 \) metal atoms in 2D or 1000 atoms in 3D
- Read- press metal stamp into soft plastic mold, evaporate silica onto plastic to make a thin film, shadow at low angle with gold to highlight raised letters, then examine using electron microscope.
- Write- focused ion beam (TV cathode ray spot), suggests photo process with light shining through holes in a screen could effect metal atoms on surface or some other chemical which could be patterned and recognized later (lithography).
- All books in the world would fit on 1 million pin heads (about 3 square yards). Can we encode to improve information density?
- Atomic info: 2D surface, 3D atomic crystal. If a bit could be encoded in a cube 5x5x5 atoms then “all books in world” would require \( 10^{15} \) bits and would fit in a cube 1/200 inch wide.
- Biological information density (~50 atoms per bit).
- Need better EM

5 atoms = 125 atoms
Feynman, 1959

- There's Plenty of Room at the Bottom
  - Physical arrangement of atoms -> chemistry
  - Miniaturize computers (heat, power, speed)
  - Miniaturize machines (smaller->smaller->smaller)
    - Parallelism
  - Molecular electronics
  - Mechanical tolerance

Only TOP-DOWN view [no self-assembly]
OBITUARY
Richard E. Smalley (1943–2005)
Chemist and champion of nanotechnology.

NATURE | Vol 438 | 22/29 December 2005
Drexler vs Smalley

- **Drexler**
  - Molecular assemblers will provide atom-by-atom manufacturing

- **Smalley**
  - “fat fingers problem”
  - “sticky fingers problem”
Drexler, 1981

- Drexler (1981) PNAS
  - Microtechnology
  - Protein design and engineering
  - Protein enzymes = molecular robots
  - Prediction: protein-based assemblers will be the tools needed to advance molecular manufacturing

- Bottom-up approach

- http://www.foresight.org

- What is your opinion?
  - “Visionary proponent of a new technology”
  - “Hype-man for the-next-big-flop”
- Molecular assemblers will perform molecular manufacturing.
- Atom-by-atom control via mechanical positioning of reactive molecules (not by manipulating individual atoms). “Smalley fingers” are not required.
- No by-products. No pollution.
- “Replicating assemblers and thinking machines pose basic threats to people and life on earth.” Gray goo hypothesis.
- Potential for abuse of advanced nanotechnologies means peaceful countries should invest and stay ahead.
Molecular assemblers are not physically possible.
Talks about the impossibility of computer controlled assemblers. Enzymes required.
Talks about the need for water. States that enzymes can not work in organic solvent.
Speculation about unrealistic potential dangers of nanotechnology threaten public support for it.
Quoting Smalley: “when a scientist says something is possible, they’re probably underestimating how long it will take. But if they say it’s impossible, they’re probably wrong.”

Some simple “machine phase” chemistry using STM manipulation of atoms has already been achieved.
Single-atom manipulation


See also: http://www.europhysicsnews.com/full/21/article4/article4.html
Inducing All Steps of a Chemical Reaction with the Scanning Tunneling Microscope Tip: Towards Single Molecule Engineering

Saw-Wai Hla, Ludwig Bartels, Gerhard Meyer, and Karl-Heinz Rieder

Chemistry by STM

Schematic drawing of the sequence of steps by which an STM probe can
(a) dissociate a C6H5I molecule on a terrace;
(b and c) draw iodine atom away;
(d) pull one C6H5 (phenyl) molecule toward another;
(e) weld them together; (f) pull one phenyl to confirm the association
Smalley

- Exaggerates about enzymes’ need for water.
- Not entirely correct about biological systems not utilizing metals.
- “If [there can be] a non-water-based life form, then there is a vast area of chemistry that has eluded us for centuries.” (His own work demonstrates that there are vast areas of chemistry that have eluded us for centuries!)
Drexler

- Makes leap of faith from something like “biology has already done it” to something like “everything is possible and controllable”
- Overly optimistic timeframes?
- Schematics show atoms at points of chemistry but mysteriously smooth materials elsewhere. Of course, on that scale it’s atomically bumpy everywhere. Problems?
If nanobots use enzymes and water then they cannot perform chemistry with materials that are unstable in water.

They will be restricted to biologic-like materials: rock, wood, flesh, bone.

They could not make Si crystals, steel, aluminum, titanium or other “key materials on which modern technology is built”...
Magnetosomes in Bacteria


Magnetite = Fe$_3$O$_2$

Fig. 3a–c Electron micrographs of *M. gryphiswaldense* cultures grown in the oxystat at defined pO$_2$ tensions of 0.25 mbar (a), 10 mbar (b), and 20 mbar (c). Arrows indicate the magnetosome chains (M) and the electron-dense particles (EP) found in magnetic and non-magnetic cells. The bright inclusions represent polyhydroxyalkanoate globules. Bar 0.5 µm
Nearly half of essays from high school and middle school students assumed that self-replicating nanobots were possible and most were worried about what would happen when they spread around the world.

“You and people around you have scared our children.”
ETC group - What’s to fear?

- Below ~50 nm quantum size-effect means quantum mechanics takes over from classical mechanics.
- Unpredictable properties - macro-gold is yellow, nano-gold is red.
- Powerful chemistry - Catalyst material made of particles 10 nanometers in diameter is about 100 times more reactive than the same amount of the same material made of particles one micrometer in diameter.
- “Green Goo”
Tech Review Process

ETC Evaluation

Laws of Technology Introduction

1. It takes a full human generation to comprehend the ramifications of a new technology. Therefore, decisions about whether or not or how to use a new technology will necessarily be ambiguous. Society must be guided by the Precautionary Principle.

2. In evaluating a new technology, the first questions must be: Who owns it? Who controls it? By whom has it been designed and for whose benefit? Who has a role in deciding its introduction (or not)? Are there alternatives? Is it the best way to achieve a particular goal? In the event of harm, with whom does the burden of liability rest and how can the technology be recalled?

3. The extent to which a new technology may be beneficial to society will be in proportion to the participation of society in evaluating the technology—including and especially those people who are most vulnerable.

4. A new technology cannot definitively be assessed as “positive,” “negative” or “neutral,” although certain technologies—in an equitable environment—may be intrinsically decentralizing, democratizing and helpful.

5. For every so-called “Luddite” attempting to establish social controls over the introduction of a technology, there is a powerful elite using social controls to impose new technologies on society.

6. The introduction of a new technology is not inevitable.

7. Any new technology introduced into a society that is not itself a just society can exacerbate the gap between rich and poor—and may even directly harm the poor.

8. A new technology cannot be a “silver bullet” for resolving an old injustice. Hunger, poverty, social disablement and environmental degradation are the consequences of inequitable systems—not of inadequate technologies.

9. The leaders of a society who permit injustice are the least likely to introduce a new technology that will correct injustice.