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Preparing for nanotechnology

Maximizing Benefits and Minimizing Downsides of Nanotechnology

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1st Conference on Advanced Nanotechnology

October 2004

www.foresight.org

Funding levels rising

- U.S. Nanotech Nanotech Initiative $3.7 billion over 4 years (plus military)
- European Union and Japan gov’ts spending roughly similar to U.S.
- Other Asian nations, Australia, Israel also competing
- China has cost advantage
- Increasing amounts being spent in private sector; figures vary widely; can rationalize almost any number

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Timeframes in nanotechnology

- Near term: 1 to 5 years
- Mid-term: 5 to X years
- Long term: X years+
- X depends on focus, funding

Timeframes in nanotechnology

- Near term: 1 to 5 years
- Relatively well understood: mostly improved materials
- Can use standard industry info sources
- Benefits and challenges are relatively modest
- Nanoparticles have new properties, need to be treated as new entities for regulation — by existing agencies
- Process just beginning, but starting earlier than previous innovations

Near-term products (< 5 yrs): Mostly materials

- Drug delivery, medical implants, sensors (bio & chemical), solar energy (photovoltaic or direct hydrogen production), batteries, displays & e-paper, nanotube and nanoparticle composites, catalysts, coatings, alloys, insulation (thermal & electrical), filters, glues, abrasives, lubricants, paints, fuels & explosives, textiles, hard drives, computer memory, optical components, etc. (from *TNT Weekly*)
- Not an integrated "industry" — incremental products in many industries

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Near-term: Nanoparticles

- Just one sector of nanotechnology
- Positive example: gold-coated particles with biological functionality bind to tumor cells and then heated, to treat cancer
- Recent result: control of toxicity by design
- Regulatory agencies need awareness and expertise: environmental protection (EPA), occupational safety (OSHA), food and drug (FDA). Process has begun, not complete.
- Similar to regulation of new chemicals

Near-term results not fundamentally new

- Advance of chemistry and materials science
- Convergence of top-down and bottom-up miniaturization
- Continuation of work to improve control of matter, in progress for centuries

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Timeframes in nanotechnology

- Mid-term: 5 to X years
- Sensors, actuators, active materials, molecular electronics, targeted drug delivery
- See Institute for Soldier Nanotechnologies to get ideas for what is coming in this timeframe (not easy to find reliable info)
- Order of innovation arrival very hard to project
- Important economic/strategic changes, but not deeply revolutionary

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Timeframes in nanotechnology

- Long term: X years+
- Easier to project than mid-term
- Based more on physics than economics: specific breakthrough is foreseeable
- “This changes everything,” has anticipation effects — there will be a race to complete this systems engineering development project
- Timing of X depends on funding, focus
- Not a race one can afford to lose

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Tools for looking ahead to advanced nanotech

- Laws of physics
- Laws of economics
- Laws of human nature
- Result: technological advance to the limits allowed by nature
- Process does not result in a time estimate
- Does result in 4th generation nanotech: nanoscale productive systems

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Molecular manufacturing

- New way of viewing matter
- Today, can have atomic precision **or** large complex structures, not both
- Want both at the same time
- Goal: Direct control down to molecular level, not indirect control as today (e.g. drugs, surgery) for products of any size
- Can change/repair structure of all physical things including human body

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Basis of advanced nanotech: Molecular machines

- Found in nature (e.g. molecular motors)
- Now learning to design and build new molecular machine systems
- Goal: nanosystems for manufacturing complex, atomically-precise products of any size (from cubic-micron mainframes to aircraft carriers)

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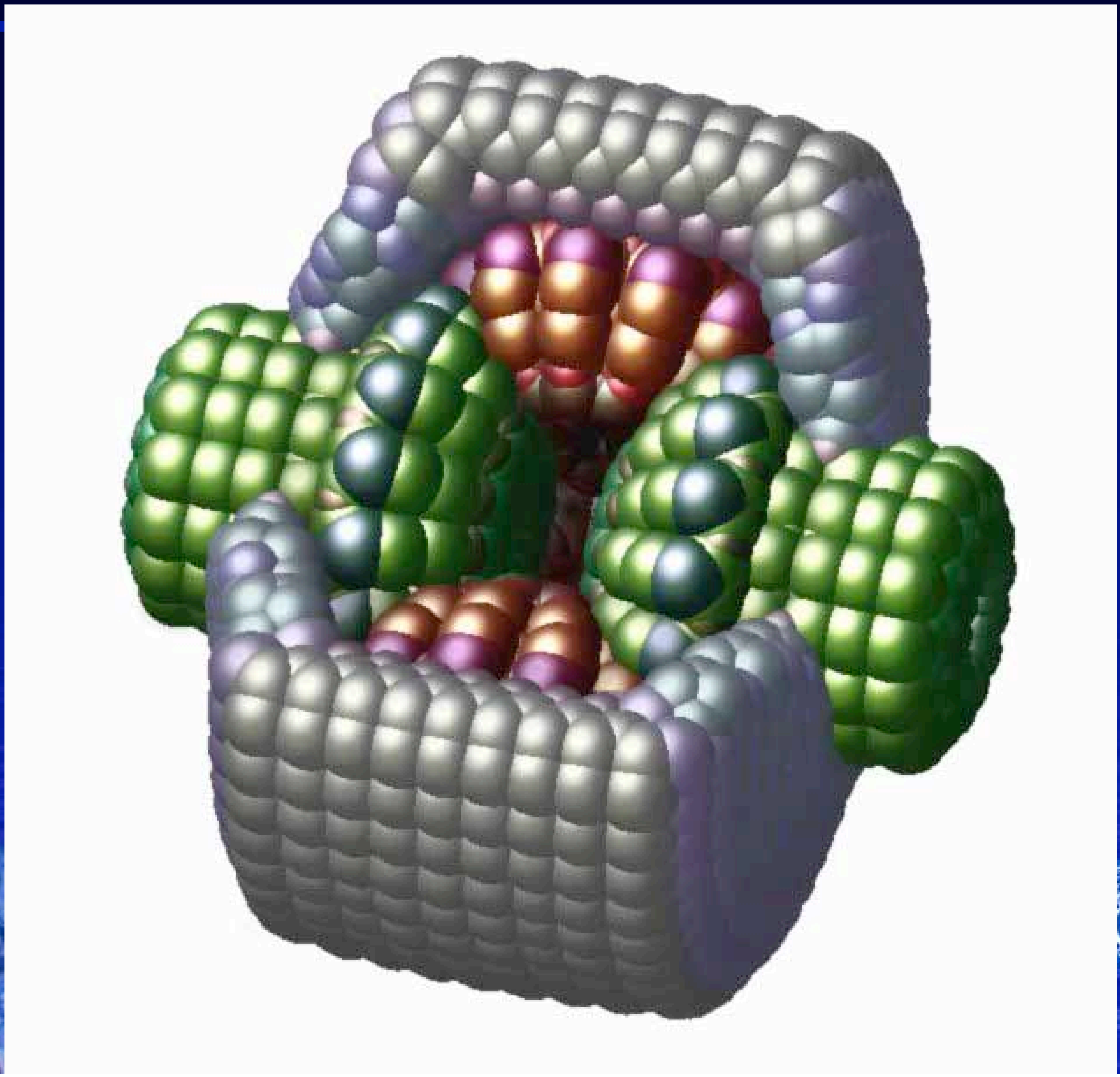
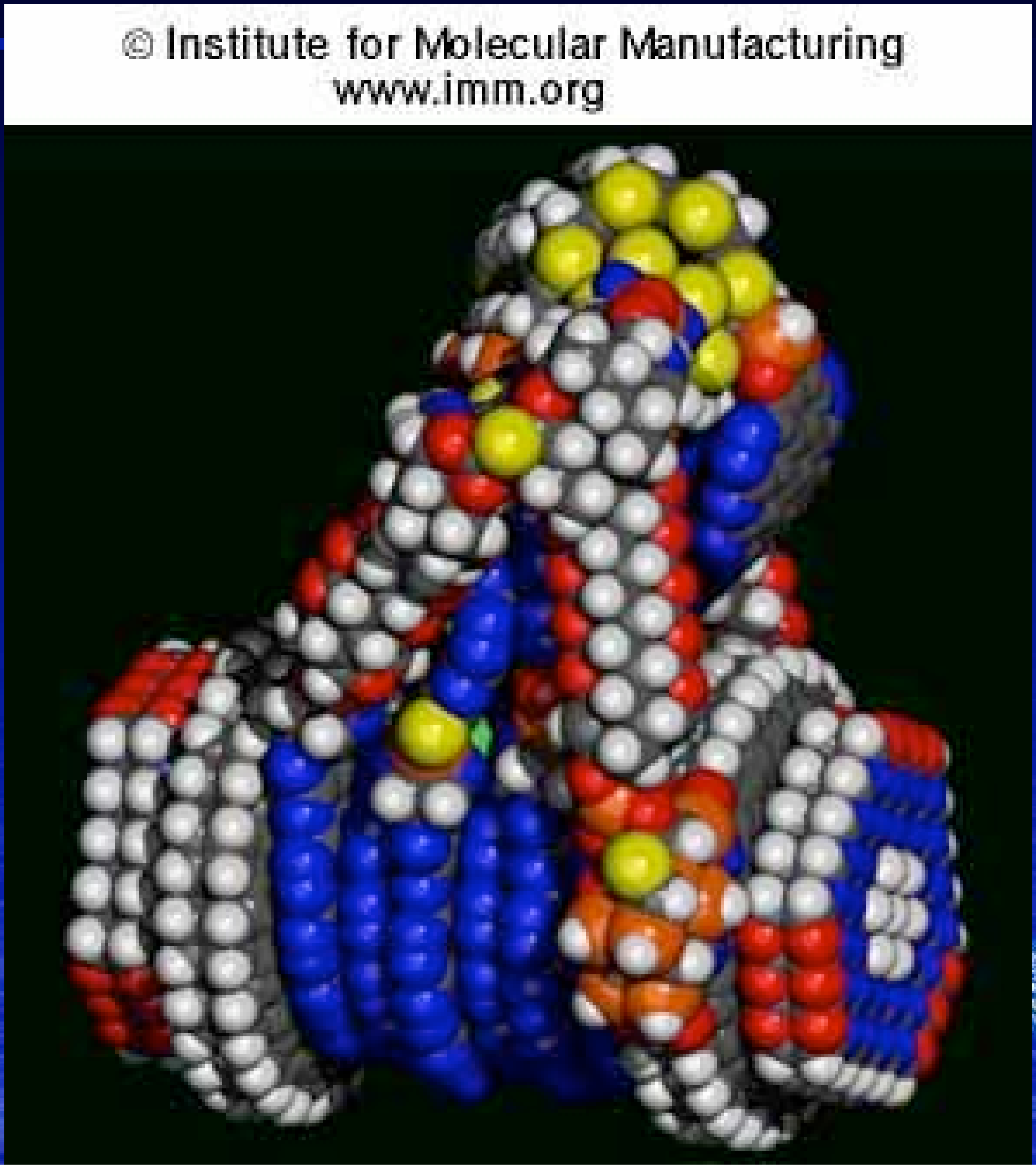
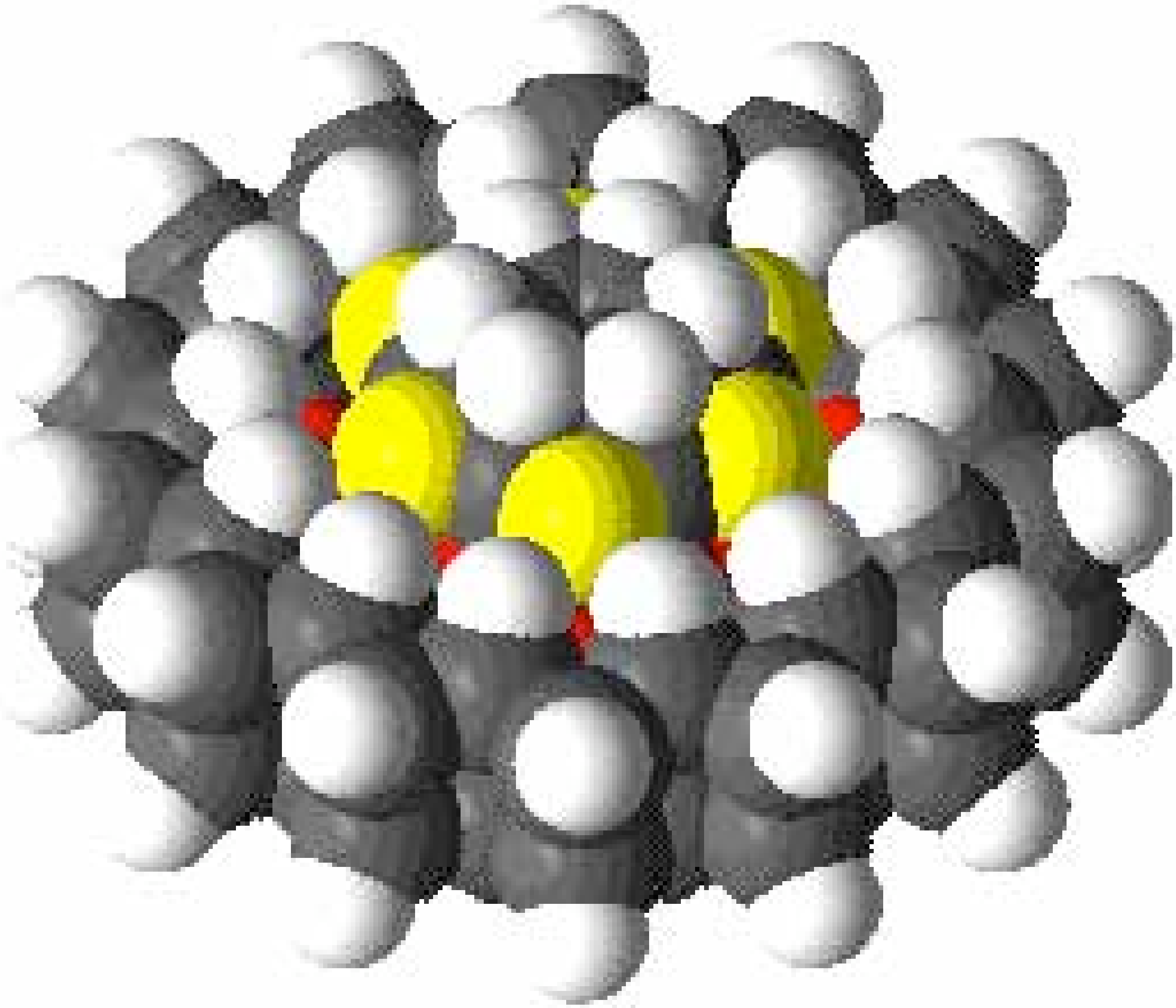
Differential gear (cutaway)



Fine motion controller, partial



Atom contact bearing model
(~2 nanometers)



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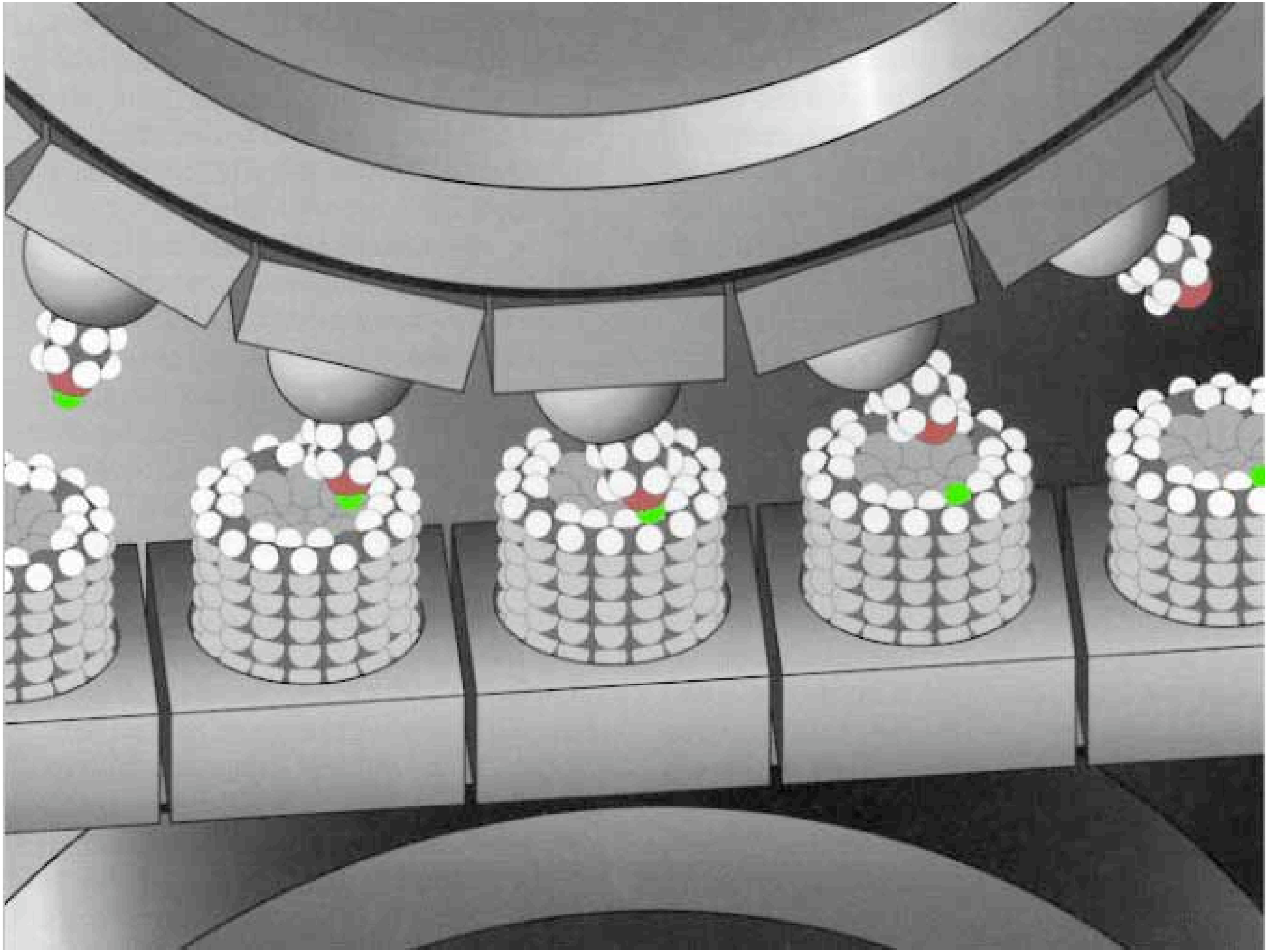
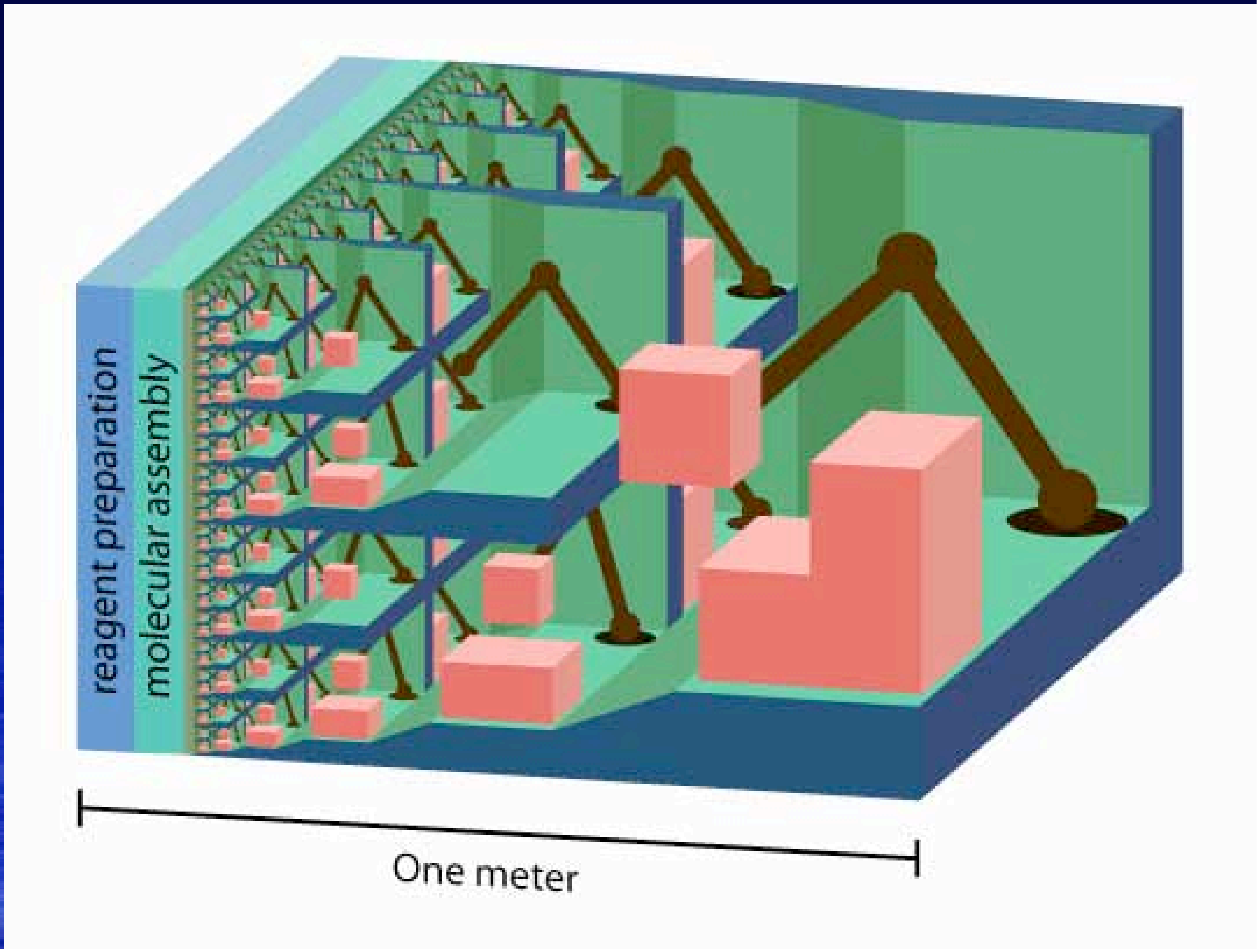


Convergent assembly using highly parallel systems



Molecular manufacturing of nanosystems (4th gen.)

- Extreme decrease in direct manufacturing costs (not including insurance, legal, IP licensing, etc)
- Extreme decrease in pollution
- Extreme increase in device complexity possible (e.g. medical nanorobots)

Uses of molecular manufacturing: a disruptive technology

- Medicine
- Environmental remediation, clean manufacturing and clean water: affordable
- Energy, resources, transportation, space
- Surveillance, crime reduction
- National security/defense, military offense
- Basically, all physical technologies and products are potentially affected
- Third Industrial Revolution

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Timing of advanced nanotech

- "We tend to overestimate short-term tech change, underestimate long-term"
- Timing estimates are guesses
- As an engineering goal, it depends on funding and focus. If delay in focused effort: 25 years?
- Probable international competition for economic, military advantage. Crash program estimate 10-15 years?
- Prefer civilian program, in democracies

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Opportunities: Long-term and Now

- Long-term nanotech goals
  - _ Setting “Millennium Challenges”
  - _ How nanotech can help
- Near-term policy options
  - _ Basic research on advanced nanotech
  - _ Intellectual property system improvements
  - _ Bridging the “funding gap” to commercialization
  - _ Increasing US talent and attracting non-US talent

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Nanotech Millennium Challenges

1. How can sustainable development be achieved for all?
2. How can everyone have sufficient clean water without conflict?
3. How can population growth and resources be brought into balance?
6. How can the global convergence of information and communications technologies work for everyone?
8. How can the threat of new and reemerging diseases and immune micro-organisms be reduced?
10. How can shared values and new security strategies reduce ethnic conflicts, terrorism, and the use of weapons of mass destruction?
13. How can growing energy demands be met safely and efficiently?
14. How can scientific and technological breakthroughs be accelerated to improve the human condition?

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Clean water

- Need inexpensive, reliable water filtration without frequent filter changes
- Molecular nanotech enables molecularly precise filtration
- Same basic technology will enable filtration of blood, replacing dialysis
- See talk on Saturday morning

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Resources: Molecular Separation

- "Element separation, whether for pollution control or resource extraction, is not intrinsically energy-intensive, as is shown by the capabilities of biosystems. The enormous energy costs of present-day pyrometallurgy largely result from the application of heat to force phase changes to exploit the partitioning of elements between phases. Biosystems achieve their efficiencies by eschewing phase changes in favor of <u>direct molecular separation via specialized molecular machinery</u>."

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Resources: Carbon, not Metals

- "As nanoscale fabrication makes accessible the ultimate materials strengths set by covalent chemical bonds, the structural metals that dominate present technology will become obsolete. If carbon becomes the "ultimate material", the carbonate rock that forms the bulk of the crustal carbon reservoir becomes an important backstop resource. Indeed, the very silicates that make up most of a rocky planet become a valuable feedstock for a mature nanotechnology."

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Energy: Affordable fuel cells

- “Energy is used grossly inefficiently at present because it is largely used as heat, both in Carnot-limited engines and in thermal processing to manipulate matter via phase changes. Fuels are "burned"; that's what fuels are for, a mindset that might be termed the "Promethean paradigm." However, burning a fuel wastes most of its energy. Utilizing chemical energy without thermalizing it, as organisms do, requires molecular structuring. A near-term technological example is fuel cells.”

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Energy: Affordable solar, geothermal, etc.

- "More importantly, cheap large-scale fabrication of nanostructured materials, which would eliminate moving parts, promise a suite of energy applications including:

  - Direct use of solar power, via photovoltaics or artificial photosynthesis.

  - Thermoelectric materials to exploit small thermal gradients (e.g., geothermal or marine, as in ocean thermal energy conversion);

  - Piezoelectric materials to convert mechanical stress directly into electric potential."

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Energy: Strong materials enable efficient space transportation

- "Superstrength materials. As materials having strengths approaching the ultimate limits set by chemical bonds become available, they will make transportation considerably more efficient through savings in vehicle mass. This will have a particularly pronounced effect on near-Earth space access."

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Sustainable development

- Nanomanufacturing
  - _ Bottom-up
  - _ Massively-parallel
  - _ "Zero waste" and energy efficient
- Building with atomic precision using molecular machine systems: molecular manufacturing
- Inspired by how nature builds so cleanly
- Complete control of known molecules greatly reduces costs of recycling leftover materials

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Information and Communications Technology for All

- Molecular manufacturing lowers direct costs of building products to lowest possible level – like the cost of another product of molecular machines: potatoes
- Does not impact indirect costs: patents, insurance, marketing, legal, etc.
- May want to consider open source approaches to intellectual property for some government-funded basic nanotech
- Analogy to HTML

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Reducing Ethnic conflict, terrorism, WMD

- Largely social problems, but technology can help
- Inexpensive, molecularly-precise sensors could detect and communicate presence of dangerous materials (replacing dog noses at airports)
- Abuse of powerful sensing technology is US public's current greatest concern regarding potential problems from nanotech

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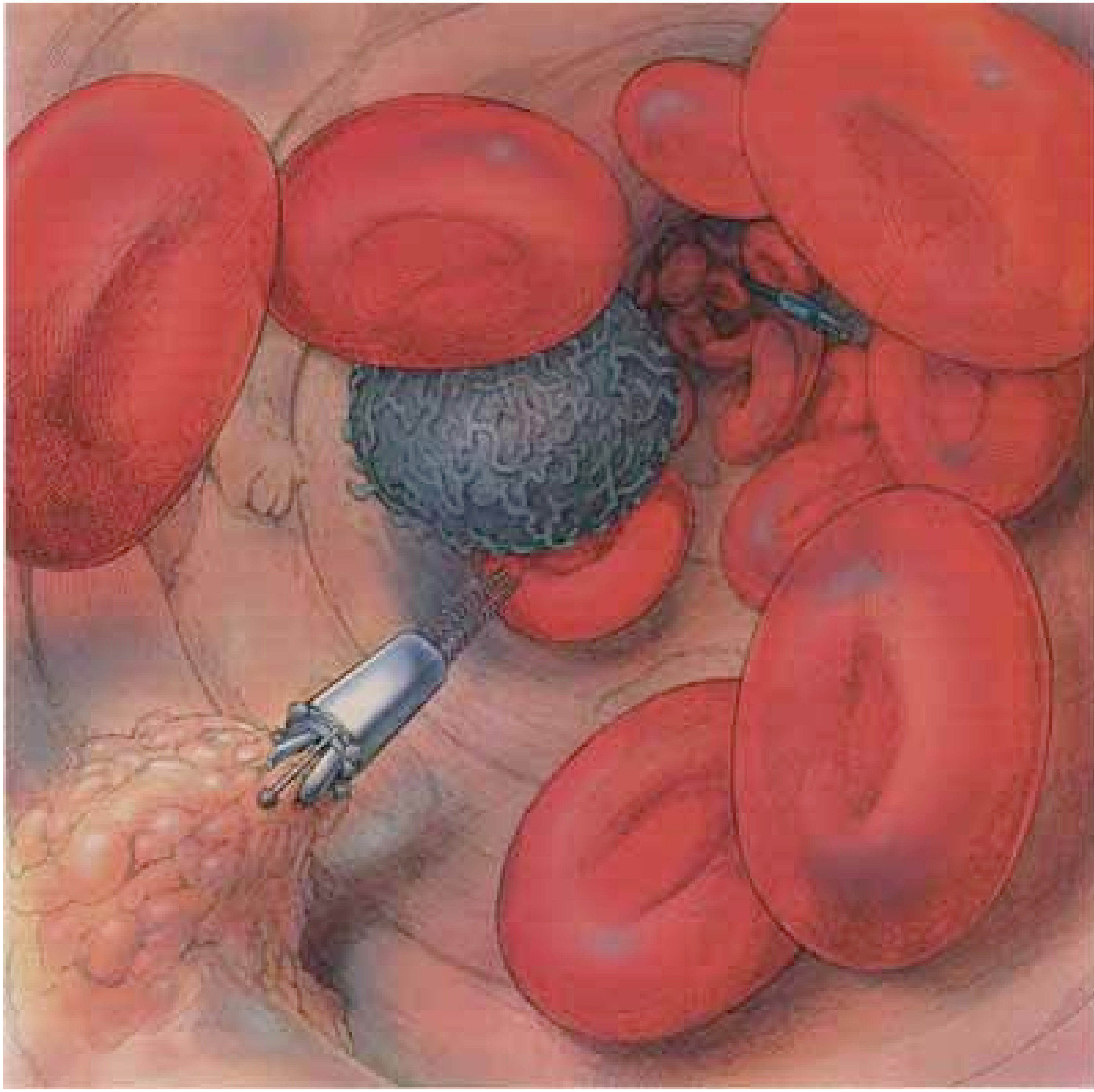
Combating disease and harmful microorganisms

- Now can have molecular action of drugs, <u>or</u> the 3D action of surgery, but not both
- For medical applications, want both at the same time
- Molecular manufacturing should enable the construction of nanoscale surgical devices with the ability to carry out molecular changes with atomic precision
- Most ambitious application considered so far



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Speeding the benefits

- “How can scientific and technological breakthroughs be accelerated to improve the human condition?”
- Greatest leverage is through nanotech, especially advanced nanotech (molecular machine systems)
- How can we speed these advances, maximizing benefits while minimizing downsides?

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How to speed the benefits?

- Delivering advanced nanotech benefits (medical, environmental, economic, security, etc.) to society will require:
- Focused, long-term systems engineering project (similar to Apollo Program)
- Then, commercialization within reasonable IP framework
- More funding + more focus = earlier societal benefits

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Near-term policy options

- Nanotech has bipartisan support
- Basic research on advanced nanotech
  - _ Percentage of NNI funds to molecular machine systems
  - _ Make the R&D tax credit permanent
- Intellectual property system improvement
- Bridging the “funding gap” to commercialization
- Increasing US talent
- Attracting non-US talent

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Focusing our basic research

- Current NNI goals extremely broad
- Greatest leverage from nanotech is expected from molecular machine systems (MMS)
- MMS goal was used to promote NNI to Congress, but no targeted R&D program has been set up as yet
- Set specific percentage of NNI funding targeted on molecular machine systems (perhaps 5 to 10 percent)

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Encouraging R&D by industry

- Want to encourage R&D on advanced nanotech by US industry
- As with all advanced research, R&D on advanced nanotech has relatively high financial risk
- Current R&D tax credit requires repeated renewal, creating uncertainty for long-term projects
- Make R&D tax credit permanent

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Intellectual property improvements

- Nanotechnology patents are interdisciplinary and challenging
- Patent office funded by user fees
- Examiners have under 6 hrs/patent to find prior art
- Overly-broad patents lead to litigation, especially bad for entrepreneurial firms, which are a particular strength of the US in innovation
- Since 1990, portion of fees diverted to US Treasury
- Need to end diversion of patent fees, to improve quality of US patents and reduce litigation

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Bridging the "funding gap"

- For average person to benefit, nanotech R&D innovations need to reach commercial product status
- Gap between government-funded research and venture capital-funded products. (Pre-commercialization: DARPA & SBIR can't do it all!)
- Congressman Honda (Calif) has proposed Nanomanufacturing Investment Partnership at Dept of Commerce: H.R. 4656

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Nanomanufacturing Investment Act

- Requires $250 million private investment to trigger $750 million public funds
- At least 85% to startups
- Fair & reasonable return to partnership, with federal % capped after gov't funds recovered
- Applications undergo peer review and review by Advisory Board; awards by Sec. of Comm.
- Advisory Board: 40% investors, 60% independent experts appt. by President

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Increasing US talent

- Congressman John Sweeney (NY) has proposed:
- GI Advanced Education in Science and Technology Act (HR 5023). Three-year enlistment triggers $1200/mo for 60 mo. For PhDs in math, sci, eng, tech
- Higher Education Science and Technology Act (HR 5022): coordination between 2- and 4-year colleges to increase tech degrees
- National Congressional Science Fair, similar in structure to Congressional High School Art Competition. Stimulate specific awards, e.g. "Foresight Prize in Nanotechnology for Millennium Challenges"

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Attracting non-US talent

- US graduate programs in science and technology heavily dependent on foreign students
- US industry heavily dependent on those who choose to stay in US after completing PhD
- Post-9/11 security procedures made student entry more difficult; foreign student applications down (Europe or staying home)
- Need to communicate welcome, continue to improve visa turnaround time

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Guidelines for Responsible Development

- Foresight Guidelines Version 4.0: Self Assessment Scorecards for Safer Development of Nanotechnology
- Scorecards for nanotech professionals, industry, and government policy
- Need to work on separate guidelines for preventing offensive military/terrorist use
- Ongoing process: your comments greatly encouraged
- www.foresight.org/guidelines

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Ethical issues for nanotech

- Lowering direct costs (industry, w/some government contracts): *In progress*
- Lowering IP costs: *Open source? Example of AIDS drugs for Africa*
- Preventing accidents (industry/ government partnership): *Doable: more control enables more responsibility*
- Reducing use in war, terrorism (mostly government, w/ industry cooperation): *Very difficult challenge*

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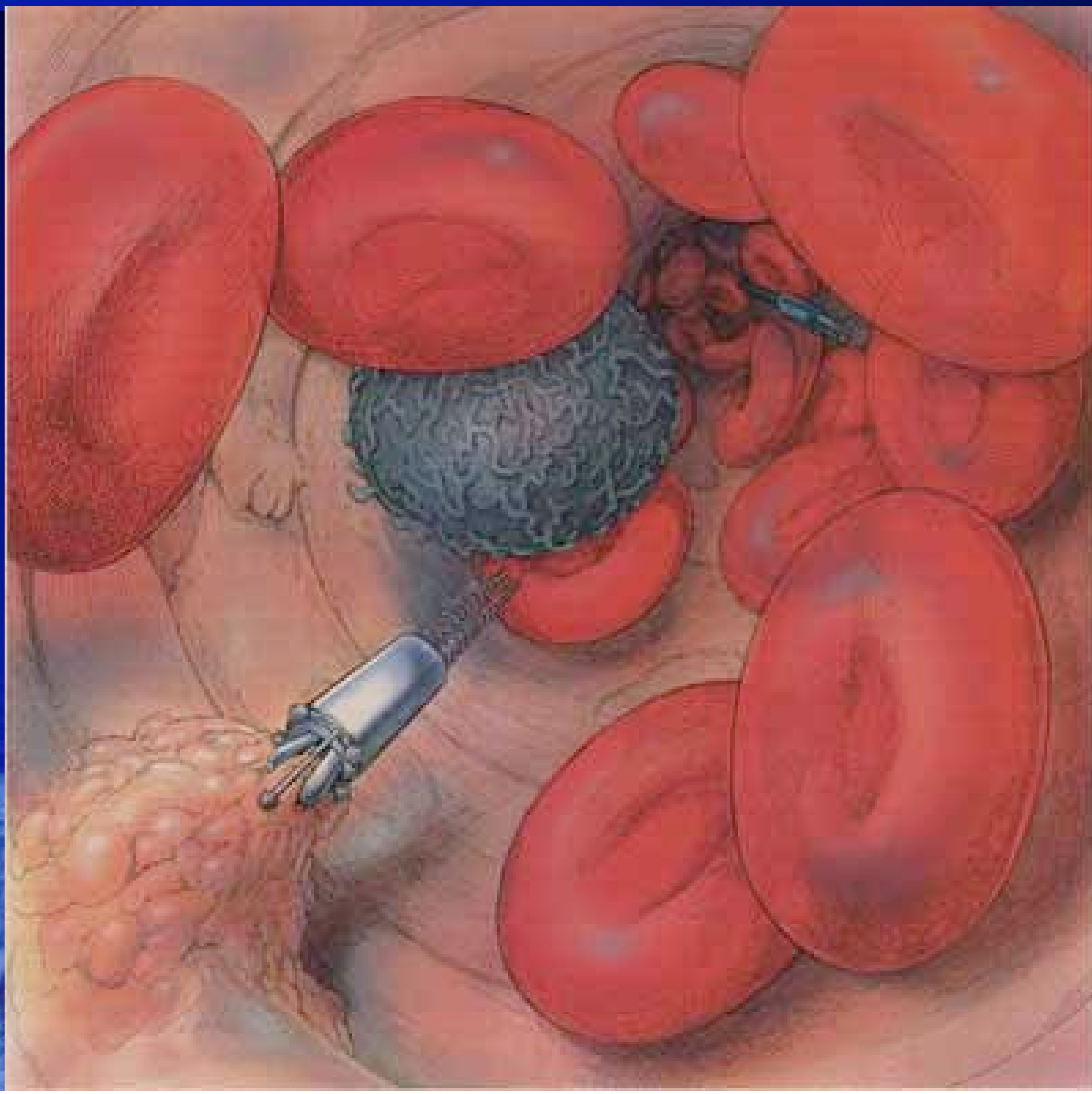
Is the development of advanced nanotech optional?

- Multiple technical fields drive in this direction
- Many countries & companies are competing on this path
- Advance is incremental: hard to track across disciplines, national borders
- Inexorable advance: a Juggernaut
- Stopping is not a workable option

“Sounds like science fiction”



If you’re trying to look far ahead, and what you see seems like science fiction, it might be wrong. But if it doesn’t seem like science fiction, it’s definitely wrong.

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For more information

- www.foresight.org
  - Electronic membership is free
- www.nanodot.org
- 2005 Foresight Vision Weekend
- 2005 Conference on Advanced Nanotechnology
- Books: *Engines of Creation*, *Unbounding the Future* (text free on web); new book *Nanofuture* by J. Storrs Hall (May 2005)

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