FORESIGHT INSTITUTE®
Preparing for nanotechnology

The Foresight Institute

David Forrest and Christine Peterson

ANSI TAG Meeting to ISO TC/229 on Nanotechnologies
Washington, DC
7 April 2010

Overview

- What is the Foresight Institute?
- History
  - 501(c)3 Non-profit, founded in 1986
  - Public Education role—Nanotechnology
- Vision
- Programs (Conferences, Feynman Prize, Foresight Update)
- Accomplishments (OSTP, Guidelines, Roadmap)
- ANSI, ISO, consensus standards

Overview

- Founded 1986: Eric Drexler and Chris Peterson
- Largest civil society organization focused specifically on nanotechnology issues
- Currently 14,000 Individual members
- Office in Menlo Park, CA (Silicon Valley)
- President, Chris Peterson

Mission

"To ensure the beneficial implementation of nanotechnology"

Focused on nanosystems

The Vision

Molecular Manufacturing

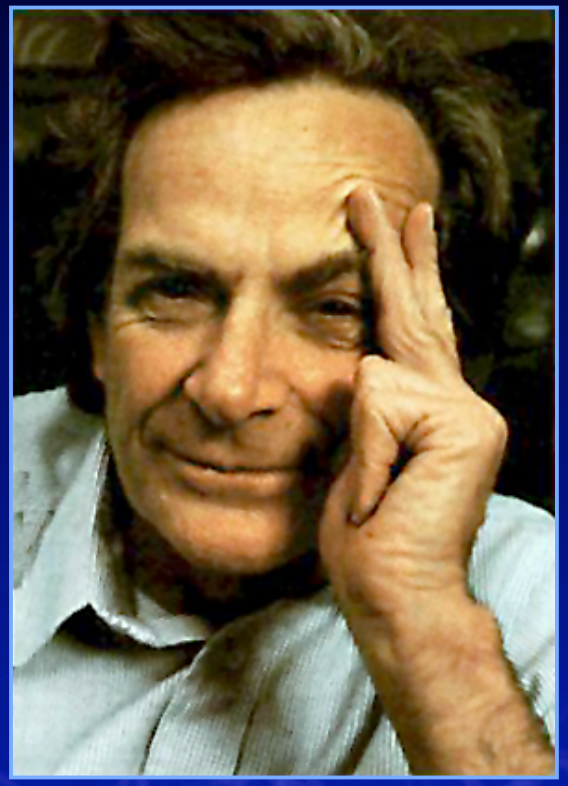
> The production of complex structures
> via nonbiological mechanosynthesis
> (and subsequent assembly operations)

Mechanosynthesis: chemical synthesis controlled by mechanical systems operating with atomic-scale precision, enabling direct positional selection of reaction sites.

Feynman's Plenty of Room at the Bottom Talk at CalTech

"The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom. It is not an attempt to violate any laws; it is something, in principle, that can be done; but in practice, it has not been done because we are too big."

Richard Feynman, 1959

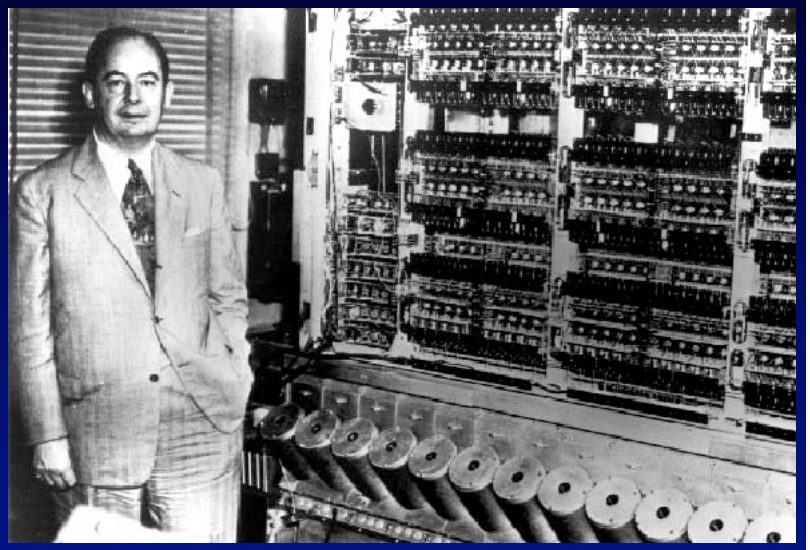


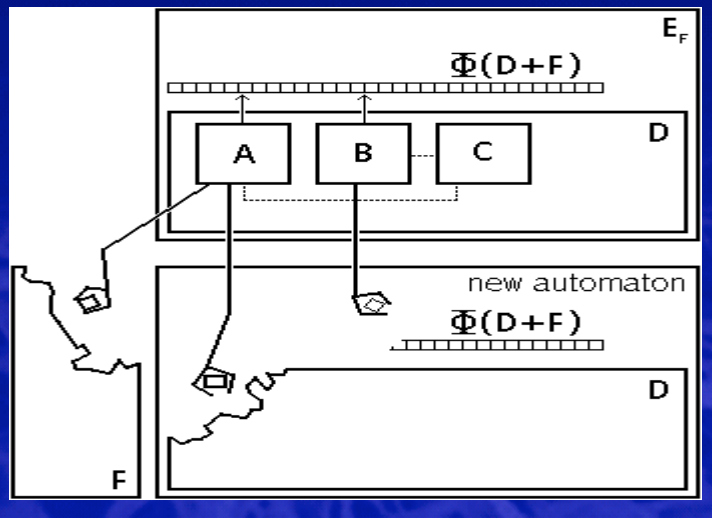
Self-Replicating Systems

John von Neumann

Theory of Self-Reproducing Automata (1966)

- Computer directs constructor
- Constructor makes both new computer and new constructor
- Constructor makes copy of program to construct itself
- But, other programs can direct constructor to make other things





Drexler's Paper PNAS, Sept. 1981

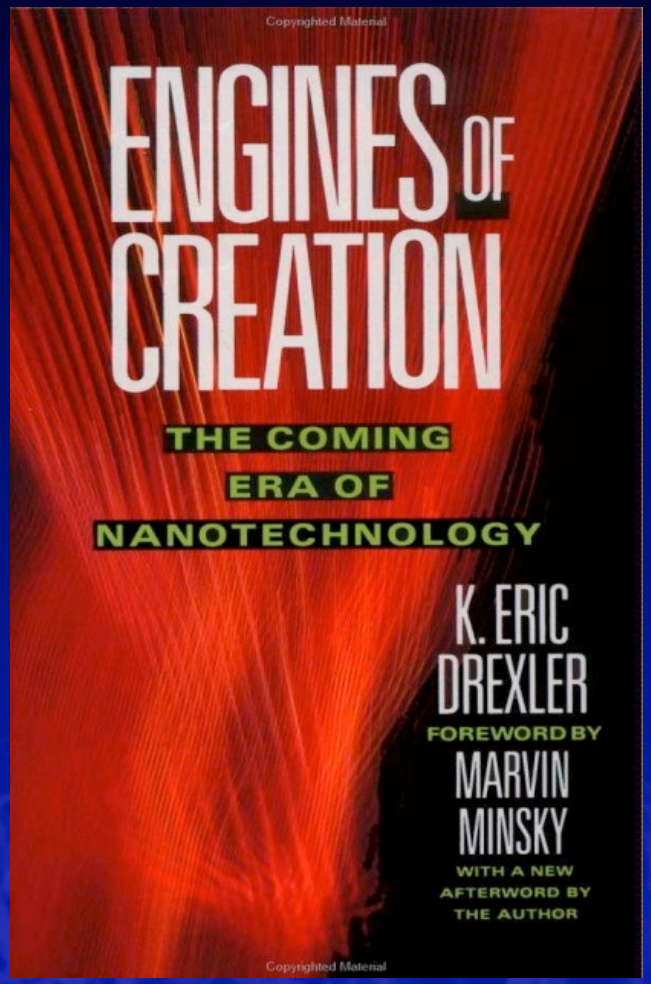
Molecular Engineering: An Approach to the Development of General Capabilities for Molecular Manipulation

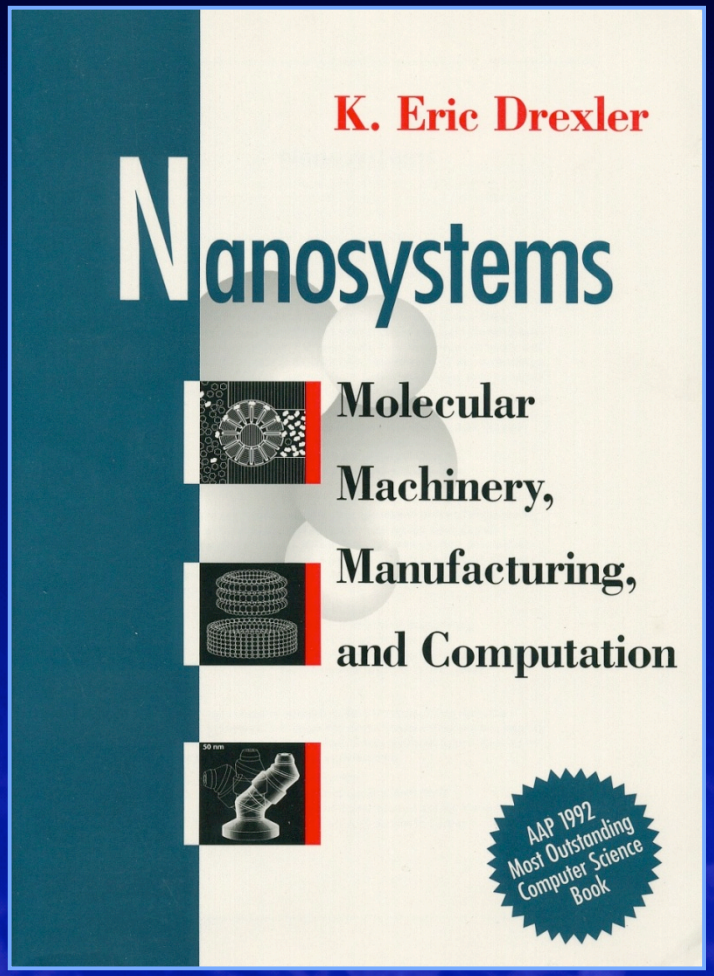
"By one path or another, we will eventually develop tools that enable us to assemble complex structures to atomic specifications. . . [These] assemblers, if supplied with materials and energy, will be able to build almost anything— including more assemblers and more systems for providing them with materials and energy."

Eric Drexler, 1985

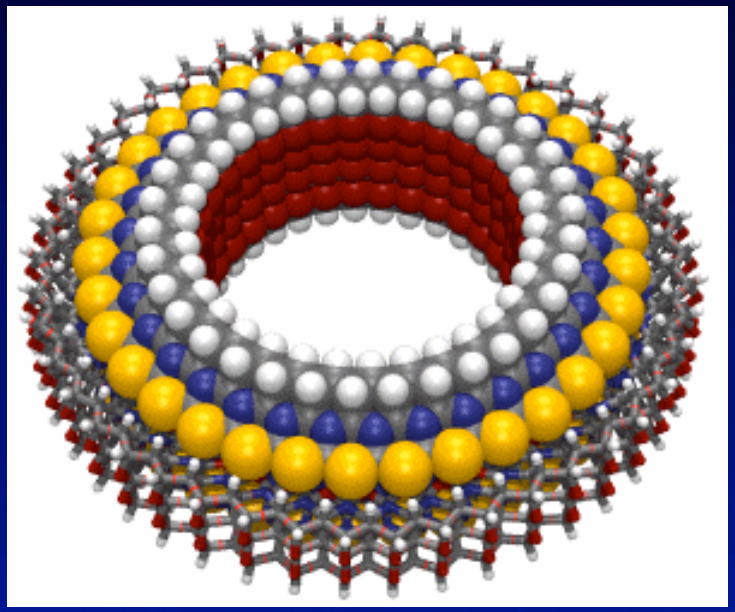
Proc. Natl. Acad. Sci. USA
Vol. 78, No. 9, pp. 5275-5278, September 1981

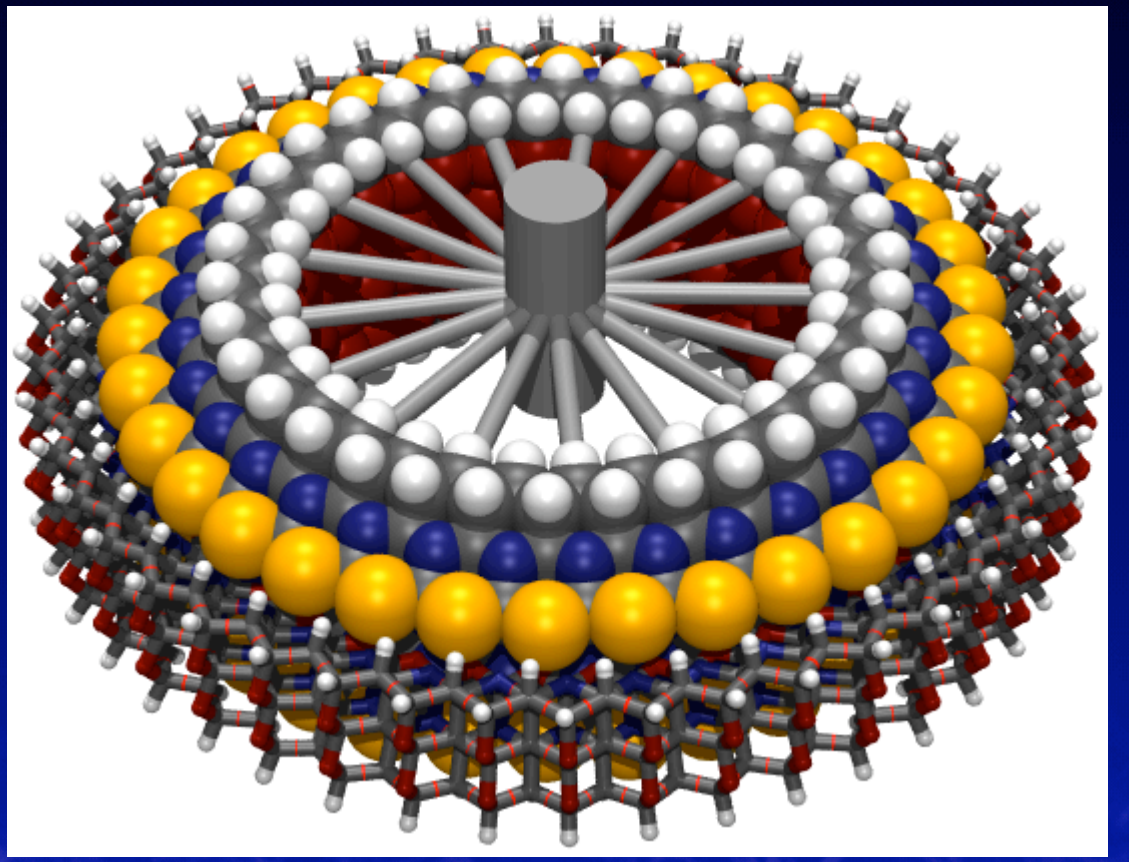
Popular and Technical Works





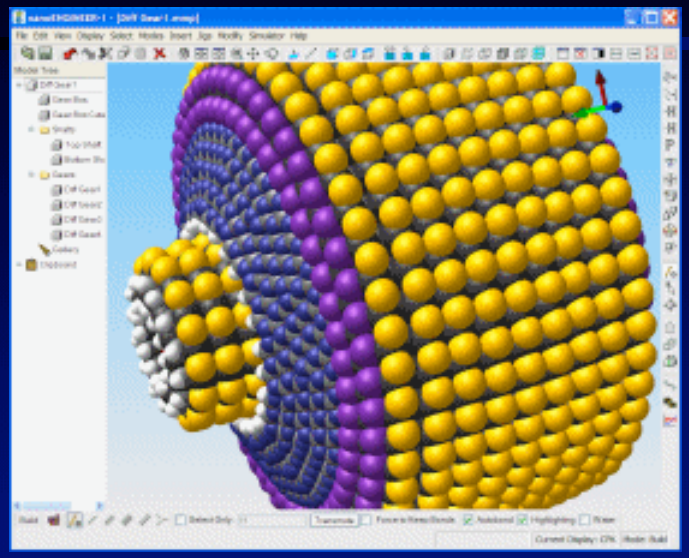
Sleeve Bearing

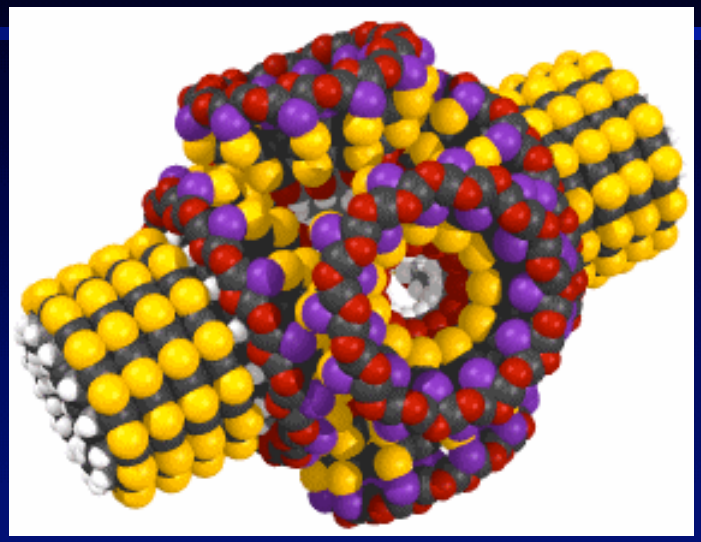




http://www.nanoengineer-1.com/mambo/ (click on Gallery)

Differential Gear



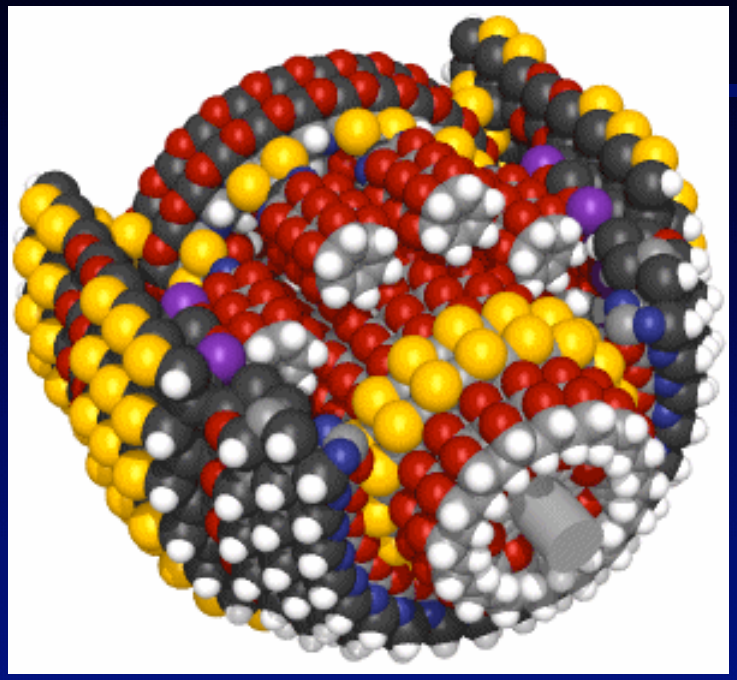


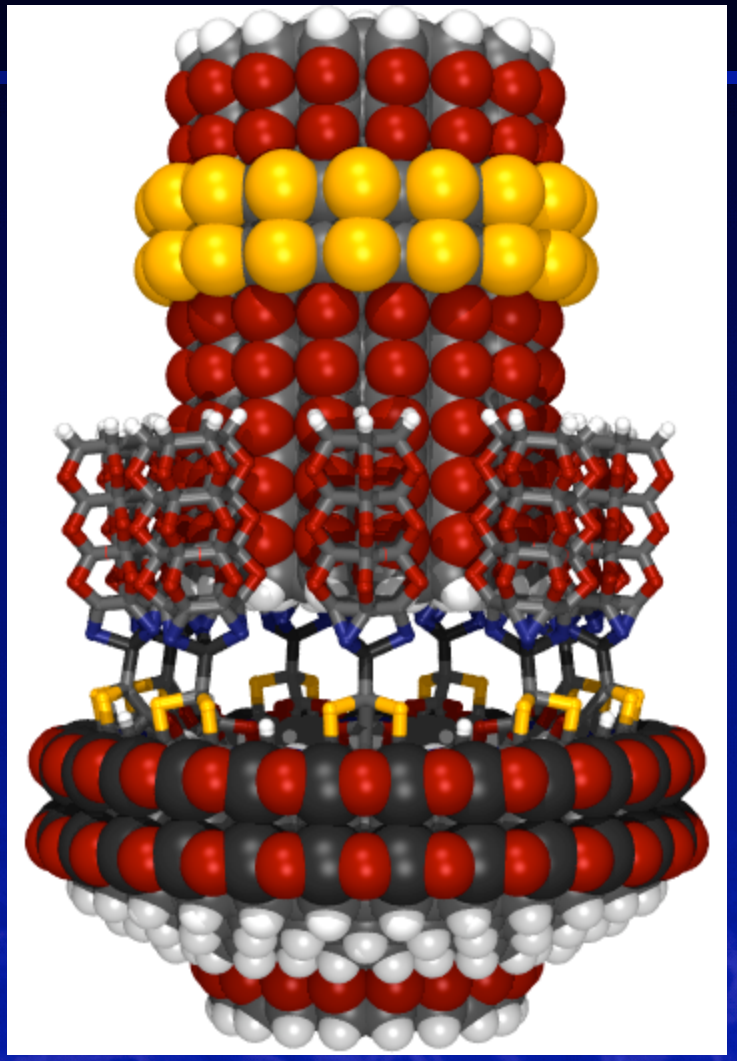
Name: Differential Gear
Designers: K. Eric Drexler and Ralph Merkle
Date: 1995
Number of components: 7

Number of atoms: 8,292
Width: 5.8 nm
Height: 5.8 nm
Depth: 5.8 nm

http://www.nanoengineer-1.com/mambo/ (click on Gallery)

Planetary Gear





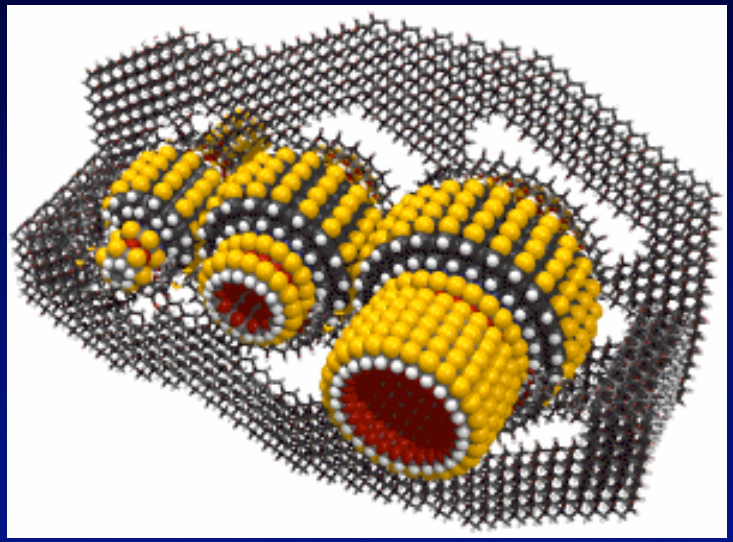
Name: MarkIII(k)
Designer: K. Eric Drexler
Date: 2004
Number of components: 12
Number of atoms: 3,853
Width: 4.2 nm
Height: 4.2 nm
Depth: 4.2 nm

Gear Ratio: 45:16
Speed Ratio: 2.8125:1
Output Torque: > 1×10^{-18} N-m
Angular Speed > 10 GHz
Power > 1 nW
Power Density > 10 GW/cm^2
Efficiency > 99.8%

http://www.nanoengineer-1.com/mambo/ (click on Gallery)

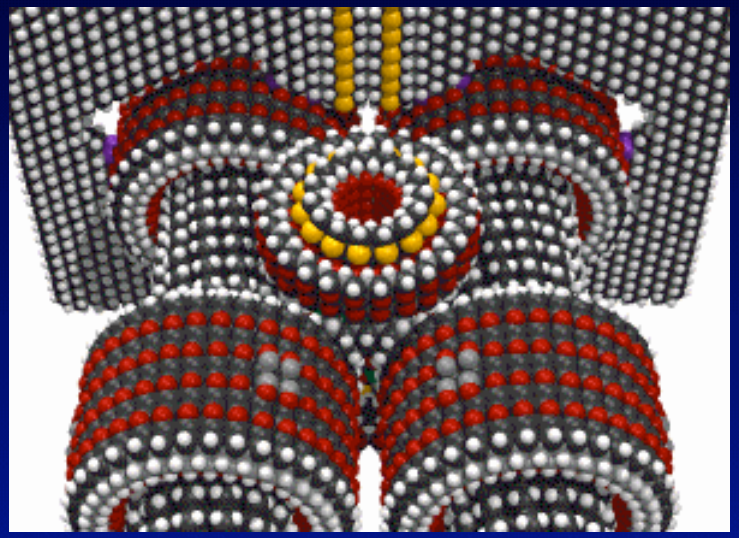
Speed Reducer Gears

Designer: Mark Sims
Date: August 31, 2005
Number of components: 4
Number of atoms: 15,342
Width: 11.3 nm
Height: 7.5 nm
Depth: 5.6 nm
Gear Ratio: 13:6
Speed Ratio: 2.167:1
Torque (large gear): 10 nN-nm



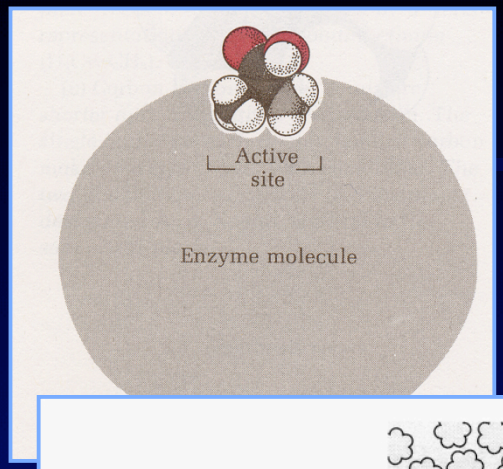
http://www.nanoengineer-1.com/mambo/ (click on Gallery)

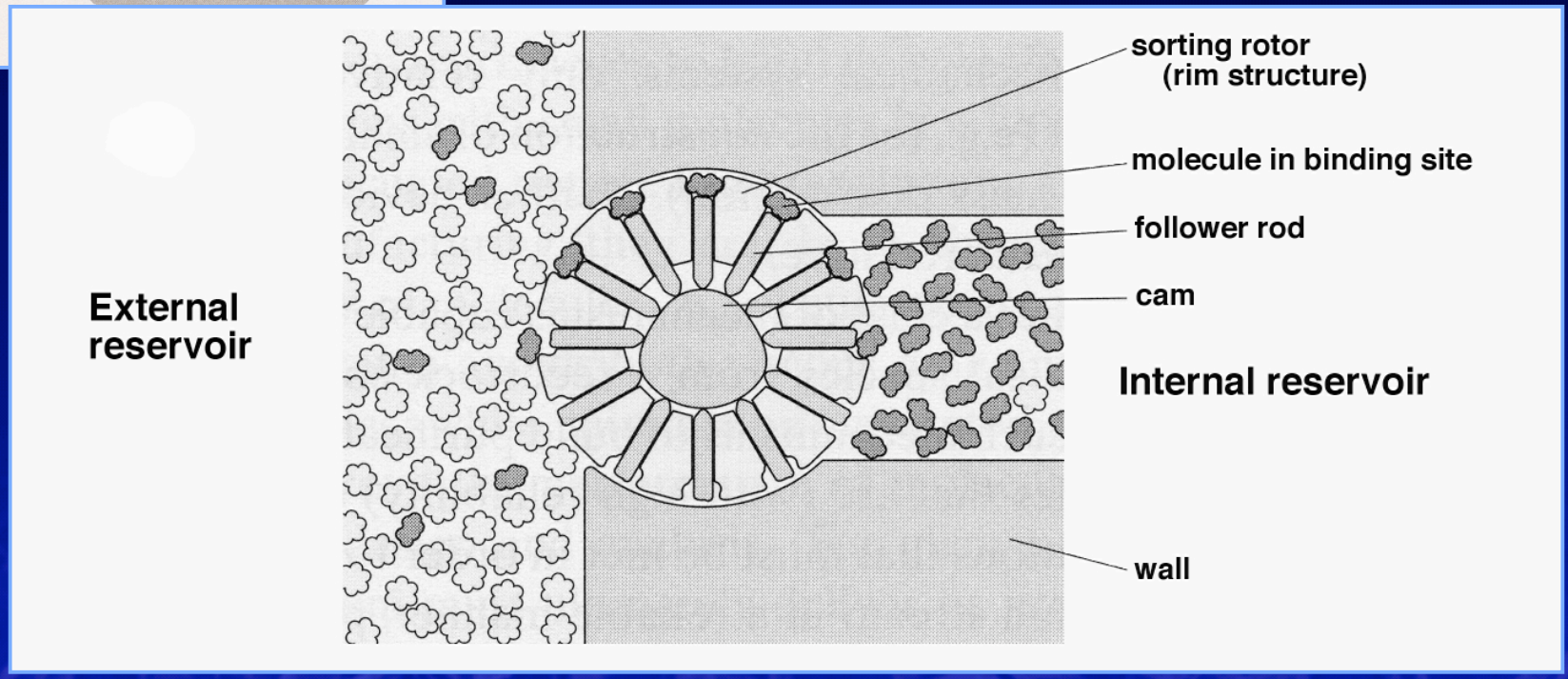
Worm Drive Assembly



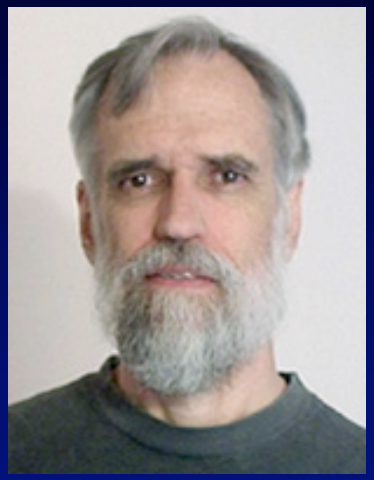
http://www.nanoengineer-1.com/mambo/ (click on Gallery)

Sorting Rotor

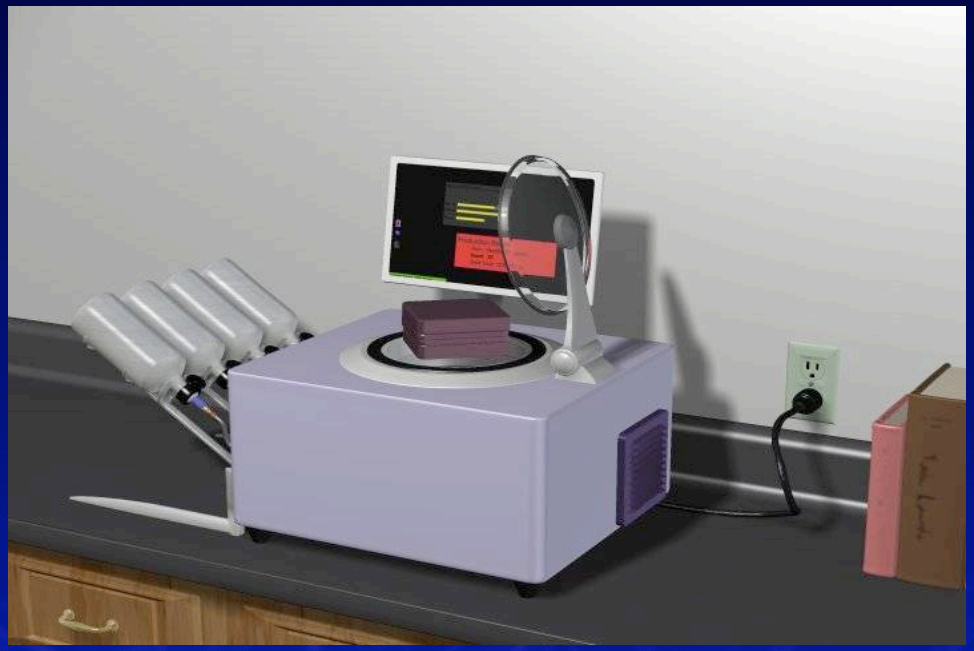




Desktop Assembler Animation



John Burch



Eric Drexler

http://davidrforrest.com/nanofactory_link.html

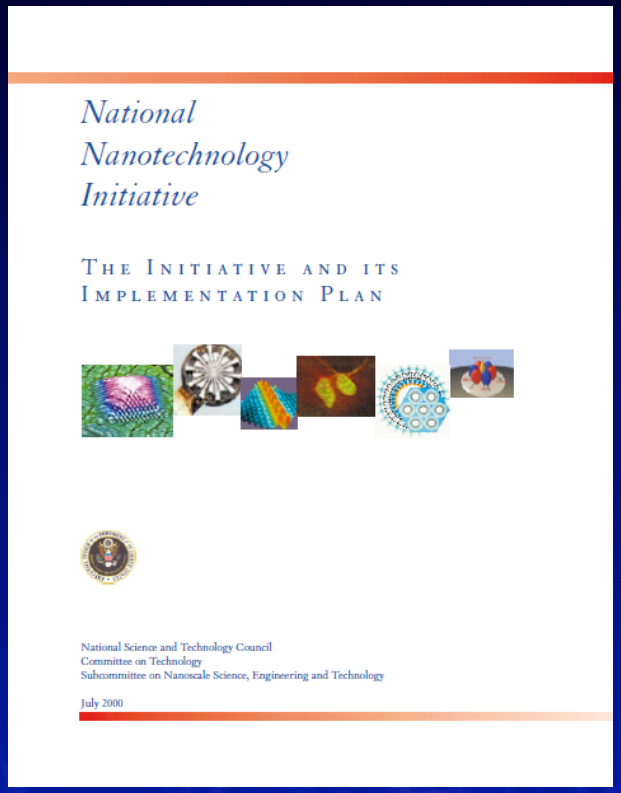
Envisioned Products

- Powerful desktop computers ~ billion processors
- Abundant energy (solar)
- Cures for serious diseases using medical nanorobots
- New materials 100 times stronger than steel
- A clean environment
- More molecular manufacturing systems

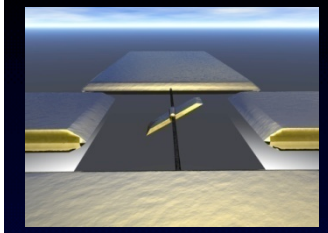
National Nanotechnology Initiative

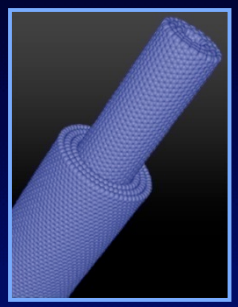
Foresight vision and language → NNI

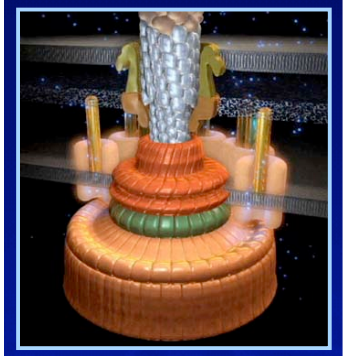
Nanotechnology described as "*the ability to work at the molecular level, atom by atom, to create large structures with fundamentally new molecular organization*" (emphasis added)

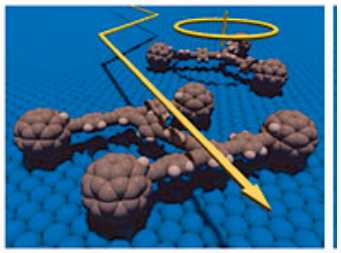


National Nanotechnology Initiative: The Initiative and its Implementation Plan, NSTC/NSET Report, July 2000, p. 13. http://www.nano.gov/html/res/nni2.pdf







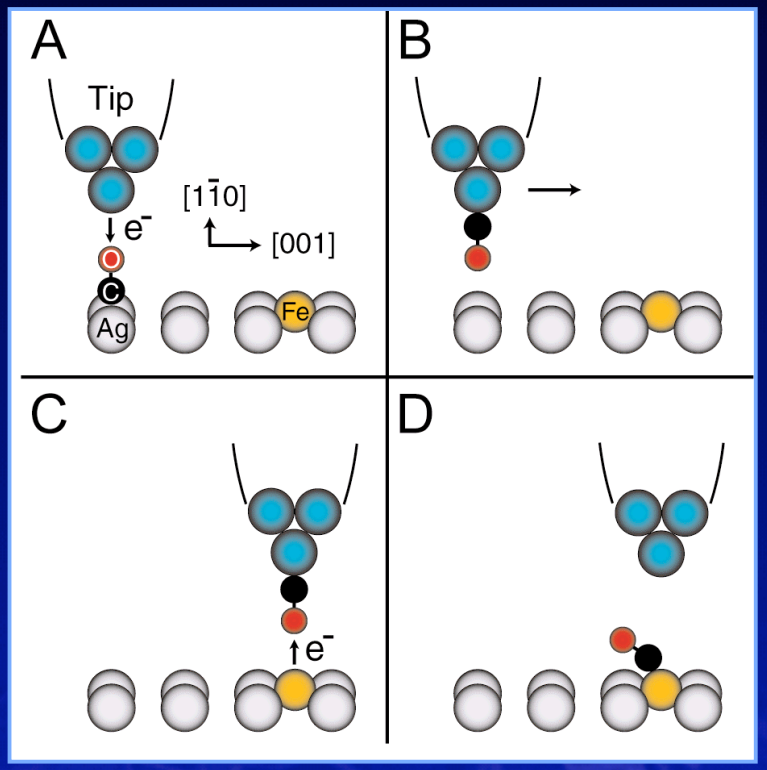


Nanotube Nanomotor	A. M. Fennimore, T. D. Yuzvinsky, Wei-Qiang Han, M. S. Fuhrer, J. Cumings, and A. Zettl, "Rotational actuators based on carbon nanotubes," Nature **424** (July 24, 2003): 408-410
Molecular Actuator	B.C. Regan, S. Aloni, K. Jensen, R.O. Ritchie and A. Zettl, "Nanocrystal-Powered Nanomotor," Nano Letters **5** (2005): 1730-1733.
Molecular Seal	Nguyen TD, et al., "Design and optimization of molecular nanovalves based on redox-switchable bistable rotaxanes" J Am Chem Soc. 2007 Jan 24;129(3):626-34
Molecular Bearings	Cumings, J.; Zettl, A. " Low-Friction Nanoscale Linear Bearing Realized from Multiwall Carbon Nanotubes," *Science* **289** (2000): 602-604.
Nanosprings	P. A. Williams, S. J. Papadakis, A. M. Patel, M. R. Falvo, S. Washburn, and R. Superfine, "Fabrication of nanometer-scale mechanical devices incorporating individual multiwalled carbon nanotubes as torsional springs," Applied Physics Letters, v. **82**, no. 5 (3 Feb 2003): 805-807.
Telescoping Arms	Cummings and Zettl, "Low-Friction Nanoscale Linear Bearing Realized from Multiwall Carbon Nanotubes". Science **289**, 602-604 (2000)
Biomotors	Montemagno, C. D., and Bachand, G. D., "Constructing nanomechanical devices powered by biomolecular motors." Nanotechnology **10** (1999): 225-331
Radio frequency controlled biomolecules	K. Hamad-Schifferli, J.J. Schwartz, A.T. Santos, S. Zhang and J.M. Jacobson, Nature **415**, 152 (2002);
"Nanocar"	Shirai Y, Morin JF, Sasaki T, Guerrero JM, Tour JM, "Recent progress on nanovehicles". Chem Soc Rev. 2006 Nov;35(11):1043-55
DNA-based robotic arm	Ding B, Seeman NC., "Operation of a DNA robot arm inserted into a 2D DNA crystalline substrate." Science. 2006 Dec 8;314(5805):1583-5
Light-driven rotaxane-based motor	Balzani V, Clemente-León M, Credi A, Ferrer B, Venturi M, Flood AH, Stoddart JF., "Autonomous artificial nanomotor powered by sunlight". Proc Natl Acad Sci U S A. 2006 Jan 31;103(5):1178-83

Positional Assembly — Experiment

(Ho and Lee, Cornell, 1999)

Wilson Ho and Hyojune Lee



CO bonded to Fe, 13 K

Foresight Activities

- Public policy activities
- Publications
- Guidelines
- Networking events
- Tutorials
- Conferences
- Roadmaps
- Prizes

Foresight Nanotechnology Challenges

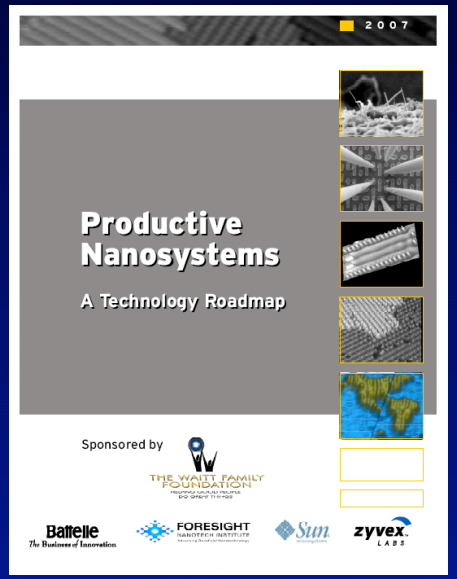
- Providing Renewable Clean Energy
- Supplying Clean Water Globally
- Improving Health and Longevity
- Healing and Preserving the Environment
- Making Information Technology Available To All
- Enabling Space Development

Public Policy

- Open Source Sensing (http://opensourcesensing.org)
- Policy Issue Briefs
  - U.S. Federal Nanotech R&D Funding
  - Human Enhancement and Nanotechnology
  - Nanotechnology, Poverty, and Disparity
  - "Valley of Death" in Nanotechnology Investing
  - Nanotechnology and Surveillance
  - Nanoparticle safety
  - Nanotech and IP
  - Nanotech Export Controls
- OSTP Brief: *Balancing the NNI's R&D Portfolio*
- Congressional committees
- Speaking engagements, surveys, press briefings

Technology Roadmap with Battelle (Jan 2008)

- Create DARPA-like agency to accelerate progress
- NSF to work with NNCO
  - Structure a university program to develop APM
- Recommended target areas
  - Energy
  - Medicine
- Create program manager positions
  - DOE Program Manager for Atomically Precise Technologies
  - NIH Program Manager for Atomically Precise Technologies
  - One each: NNCO Board



http://foresight.org/roadmaps/

Foresight Guidelines

- Outlines an approach to both consensus standards and regulations
- Distinguish between different classes of NT
  - Capabilities and risks to guide regulatory approaches
  - Non-autonomous vs. autonomous replicators
- Safe design—embedded controls
- Self-assessment scorecards (professional individuals, industry, policy developers)

Foresight Guidelines for Responsible Nanotechnology Development

Draft Version 6: April, 2006

Neil Jacobstein

Contents

Nanotechnology will alter our relationship with molecules and matter as profoundly as the computer changed our relationship with bits and information. Research on productive nanosystems will eventually develop programmable, molecular-scale systems that make other useful nanostructured materials and devices. These systems will enable a new manufacturing base that can produce both small and large objects precisely and inexpensively. The Foresight Guidelines are designed to address the potential positive and negative consequences of this new technology base in an open and scientifically accurate matter. The objective is to provide a basis for informed policy decisions by citizens and governments, and guidelines for the responsible development of productive nanotechnology by practitioners and industry.

The Guidelines are presented in the active format of self-assessment scorecards for nanotechnology practitioners, industry organizations, and regulatory agencies. Industry organizations for example can assess and score their own degree of compliance with the Guidelines, in much the same way they do with quality programs. This allows the dialog about nanotechnology safety to move from loose recommendations to self assessment of compliance with an operational set of nanotechnology development guidelines. Precise scoring is not necessary at this point, but the process of regular self assessment is critical. As the dialog progresses, more precise scoring guidelines are likely to evolve.

Version 6 includes consideration of near and long term forms of nanotechnology, and tradeoffs in balancing various risks with the spectrum of nanotechnology benefits addressed by the Foresight Challenges and longer term applications of the technology. This version utilizes a discussion of different types of replicator designs instead of relying only on the general term self-replication, which has many connotations. It distinguishes between specialized manufacturing machinery that utilizes designs with no autonomous replicators and assembler systems that may be general purpose and designed without embedded safety controls. This version of the Guidelines discusses the need for a mix of practitioner, industry, NGO, and government cooperation in enforcing controls. It also addresses some potential health, environmental, and military consequences of the technology and the implications of potential means of circumventing embedded controls. There are several new and reworded guidelines that address thoughtful critiques of the Guidelines that have appeared in books and articles over the past year. As always, feedback is welcome for the next version.

ANSI, ISO TC229

- TAG member since 2005
- Committed to supporting NT standard development
- Dual focus
  - Current: nanomaterials, nanomanufacturing
  - Future: nanosystems

FORESIGHT INSTITUTE®
Preparing for nanotechnology

ANSI
American National Standards Institute

ISO
International Organization for Standardization

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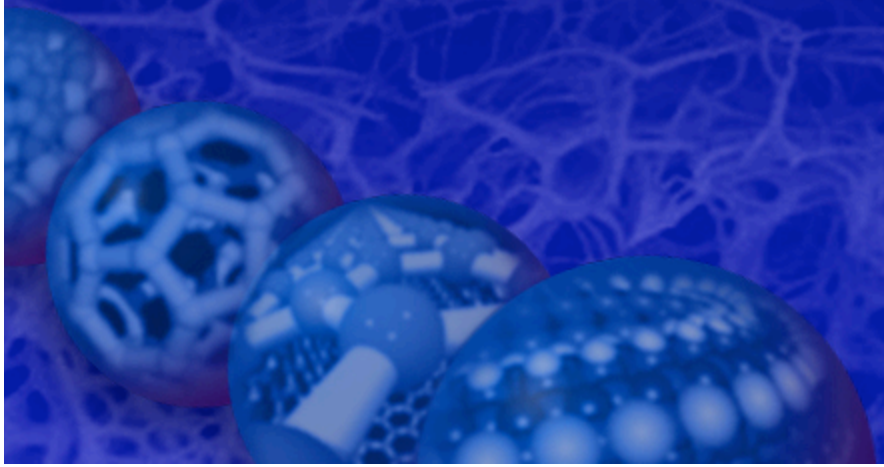
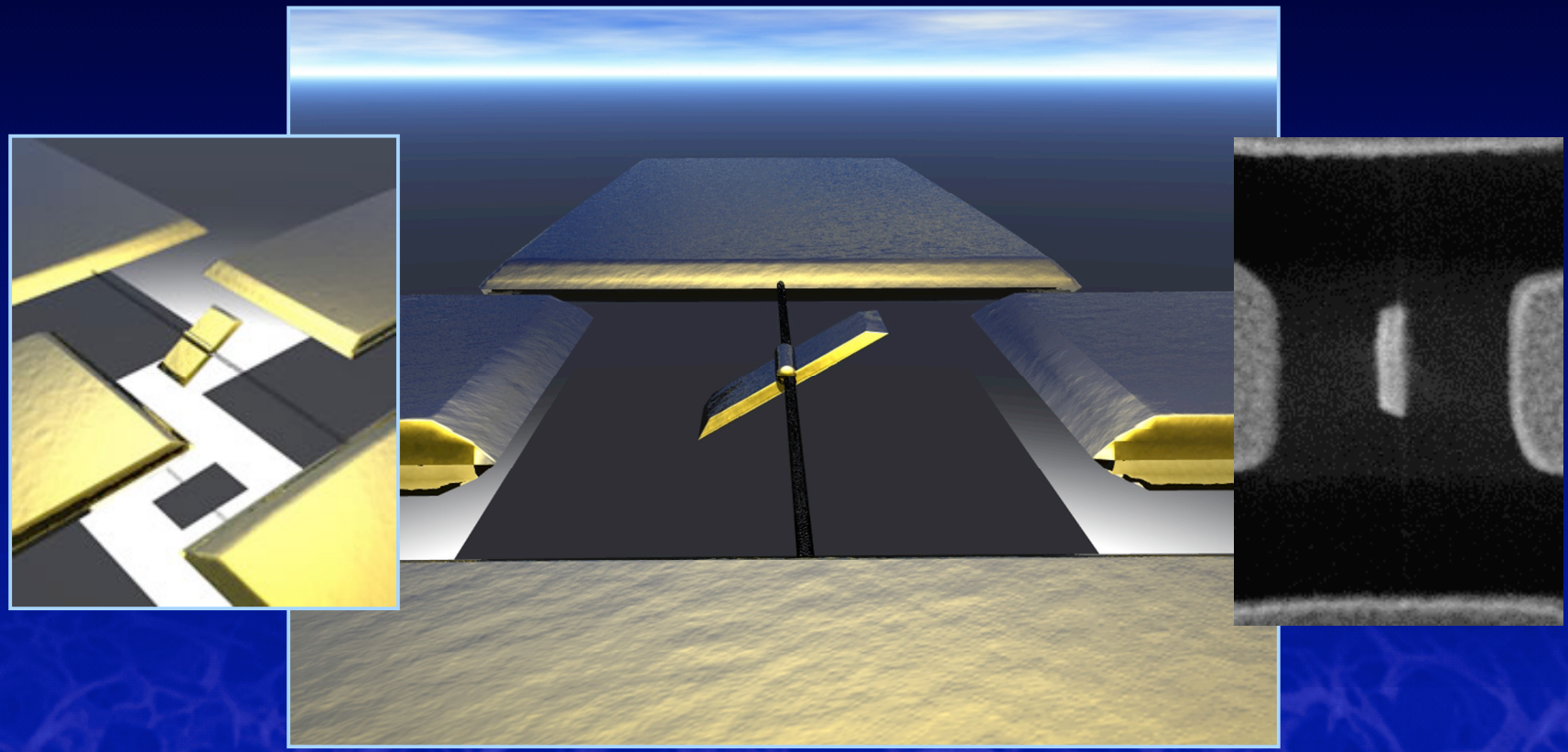
Further Information:

http://foresight.org/



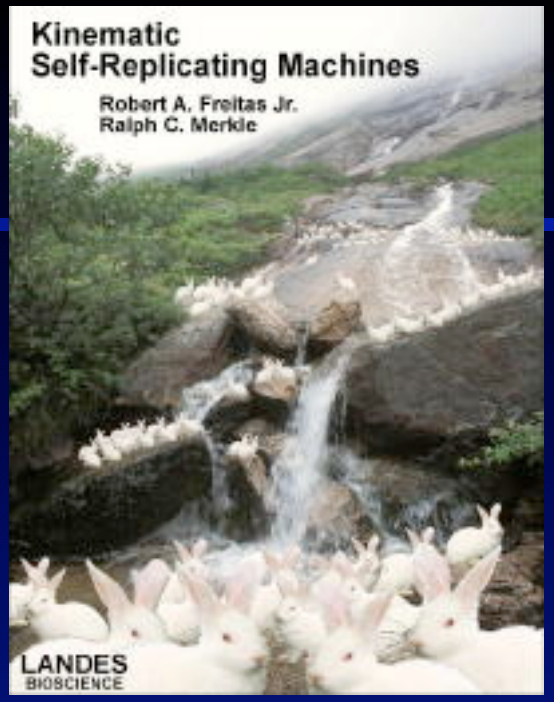
Molecular Motor

(Zettl, LLNL and U.C. Berkeley, 2003)

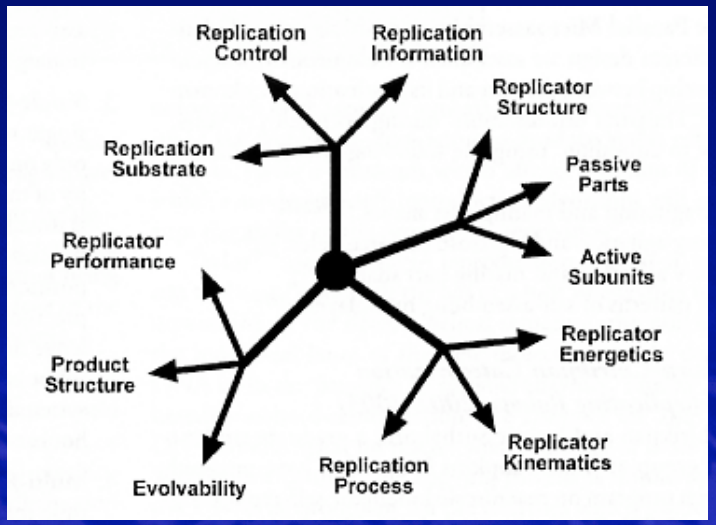


Self-Replication

http://www.molecularassembler.com/KSRM.htm



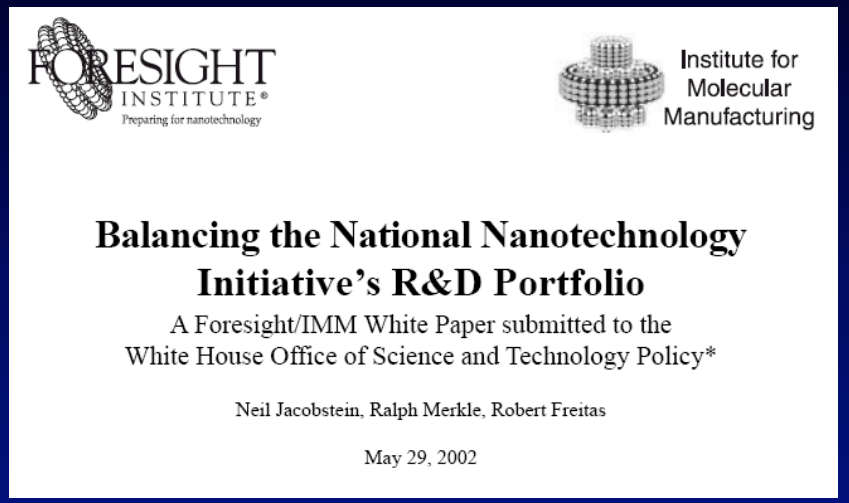
- Exhaustive review of historical and current work
- 137-dimensional map of the entire kinematic replicator design space
- Distinguishes between different kinds of replicators



Public Policy

2002: OSTP briefed.

- Time to end debate and move on
- Recommended that feasibility of MNT be studied
- Echoed in 2005 NNI Review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Institute for Molecular Manufacturing

Balancing the National Nanotechnology Initiative's R&D Portfolio

A Foresight/IMM White Paper submitted to the White House Office of Science and Technology Policy*

Neil Jacobstein, Ralph Merkle, Robert Freitas

May 29, 2002

http://www.foresight.org/Updates/Update52/Update52.1.html

http://www.imm.org/documents/NNI_White_paper.pdf