By Steven Ashley

Nanobot Construction Crews

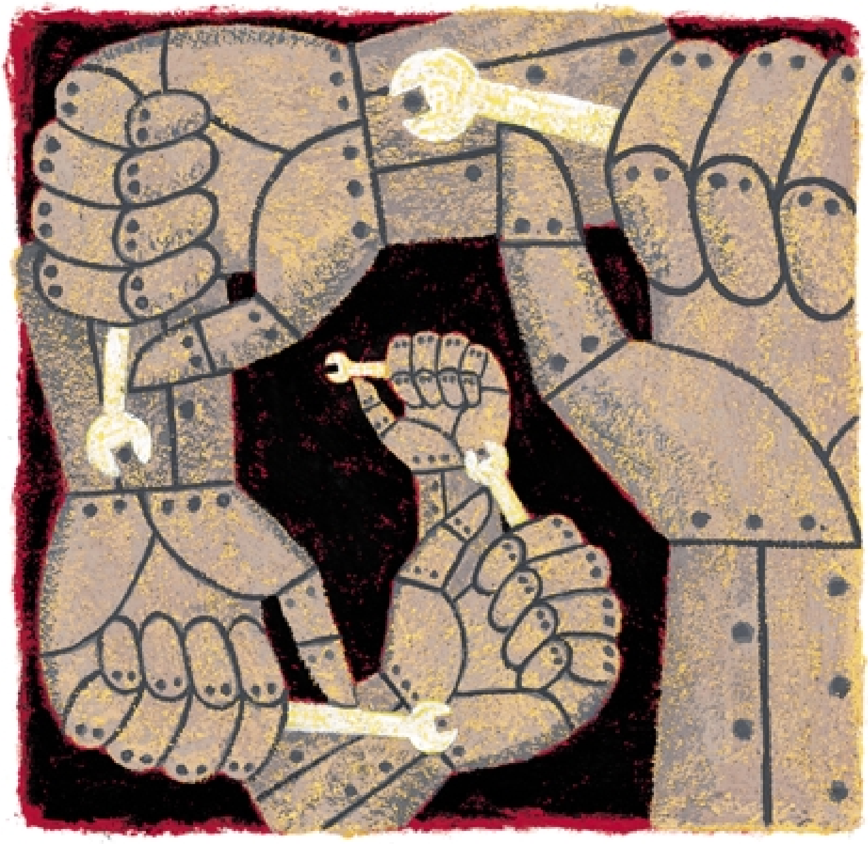
Nanotechnology visionaries find out how difficult it is to develop minuscule robots that can treat diseases or perform pollution-free manufacturing

MOLECULAR MANUFACTURING—the heady notion of assembling almost anything, from computers to caviar, from individual molecules—would change the world, if someone could just find a way to make it work. Imagine nanoassemblers: busy work gangs of "pick and place" robotic manipulator arms, each one tens of nanometers in size. Controlled from on high by a powerful computer, these simple devices would arrange blocks of molecules to make copies of themselves—and these machines would, in turn, build still other nanomachines, which, in turn, would create others, and so on in an exponential expansion. These nanobot construction crews could then be directed to accomplish astonishing tasks such as curing diseases from inside the body and fabricating intricately engineered materials from basic bulk feedstocks at extraordinarily low cost.

For years, futurist K. Eric Drexler and his colleague Ralph C. Merkle, the noted cryptographer, nurtured this vision, using computer simulations of nanometer-scale gears, pumps and other molecular machine subsystems. In these images, colored spheres indicate the position of each component atom. Several analytical critiques of these elaborate simulations suggested that the devices simply wouldn't work as hoped. But perhaps the most biting criticism focused on their status as mere digital representations and not real-world objects interacting with complex chemical bonding forces in the nanoscale environment, where macroscale physics doesn't always apply and quantum mechanics often prevails.

Then, in 1999, Merkle decided to leave a long-term position at the Xerox Palo Alto Research Center to try to give real substance to his computer-concocted concepts. He joined software mogul James R. Von Ehr II, an admirer of Drexler's ideas, who had decided to spend part of the "low-nine-figure" fortune he garnered from the sale of his company, Altsys, to start the first "molecular nanotechnology" company.

Zyvex, the Richardson, Tex.–based company Von Ehr founded, is aiming high. "We'd love to be the Applied Materials for the manufacturing base of the world," he says, referring to the world's leading semiconductor equipment manufacturer. But his molecular nanotechnology company is still in the early stages of its quest. Its experience has already demonstrated the difficulty of moving from software-wrought molecular machines to a real-world nanoassembler. One of the first things the company had to do was to pull back from the idea of building things atom by atom. Today the long-term focus is on fabricating nanoscale machine systems from large molecules or blocks of molecules. To that end, company scientists are experimenting with the bottom-up approach to making assemblers with molecular nanotechnol-



TOP-DOWN FABRICATION is one pathway Zyvex is taking toward molecular manufacturing.

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ogy—learning to put together structures molecule by molecule using atomic force microscopes and the like.

In the near term, Zyvex researchers are developing microelectromechanical systems (MEMS), whose structures measure in tens of microns. MEMS devices are manufactured using a top-down approach. They are lithographically patterned and etched out from silicon substrates or other materials.

Richard Feynman, the ur-guru of the field, did say that bigger machines could be used to make smaller machines. And that's where MEMS comes in. According to Merkle, MEMS fabrication methods can be used to build robotic assembly arms. These microelectromechanical "hands" can assemble submicron hands that can build even tinier hands, and so forth, step by step until the ultimate in mechanical smallness is achieved: the nanoassembler, a nanometer-scale manufacturing device. For Zyvex to accomplish its goal, the MEMS robots that it creates must be shrunk by a factor of 1,000 or so. Once the requisite downsizing has been completed, nanobots, as envisaged, will be used for "atomically precise manufacturing" to make virtually anything. Universal constructors could manufacture a Rolex watch, followed by a computer memory and then by nanomachines that can treat diseases.

Two basic ideas underlie Zyvex's road to nanorobotics, Merkle says. In positional assembly, mechanical manipulators pick up and precisely place objects into assemblies. Accurate positional control at scales of tens of nanometers means moving large molecules or blocks of molecules where you want them and causing them to bond to an assembly as desired.

A machine that can build a complex material or device from the bottom up—using an Erector set of molecules or chunks of molecules for components—will require one other critical technology: the machine must be able to make a copy of itself. "If you wish to achieve economical production of molecular devices in large numbers, some form of self-replication is necessary," Merkle explains. And unless you had hordes of nanoconstructors on the job, building macroscale objects molecule by molecule would take a very long time. Zyvex researchers note that a fully self-replicating machine would not be necessary to manufacture an assembler. Still, the task is a monumental one: any machine outside the biological sphere that could make any number of copies of itself would probably lead to a Nobel Prize, possibly several.

So how does Zyvex get to an assembler? Recently Zyvex joined with Standard MEMS in Burlington, Mass.—a company that fabricates microsystems—in a two-year collaborative program to develop lithographically formed micron-scale manipulator arms and grippers that can assemble smaller manufacturing devices from pallets of precisely positioned "active" parts produced on silicon wafers. "If the positional accuracy is good enough, the arm simply has to reach down and pick the part up. You don't need an elaborate sensing system," Merkle says.

According to Von Ehr, Zyvex researchers have developed a method by which the MEMS manipulator can detach the parts from the substrate so they are ready for microassembly using self-centering snap-connectors—a useful, if not exactly new, capability. Manipulator parts would be created lithographically, etched out and then disconnected from the surface substrate so they could be picked up by the MEMS manipulator and attached to the device by snapping them into place. Von Ehr hopes these MEMS manipulators will prove to be an intermediate technology that could serve as a moneymaking product, such as a device to align a fiber-optic cable, as the company pursues its goals.

Unfortunately, it's hard to find anyone in the MEMS field who would be interested in this kind of technology or anyone who can contemplate what kind of product it would actually be used to build, says Kaigham J. Gabriel, now professor of electrical and computer engineering and robotics at Carnegie Mellon University and former director of the MEMS program at the Defense Advanced Research Projects Agency.

And what about the nanoscale assembler? "There is significant controversy about how long it will take to achieve ultimate control at the molecular level," Merkle notes, adding that "it could take a decade or two."

So Zyvex has its work cut out for it. But it has embarked on a mission to achieve the nanoequivalent of a moon shot in relative isolation with a staff of only 37. In general, the scientific research community has distanced itself from this project. Several scientists working in the field of nanotechnology derided Zyvex's scheme but requested anonymity to avoid protests from amateur nanotech enthusiasts. Says one researcher, "We've seen no experimental proof that any portion of their scheme can actually be accomplished. We think it's a lot of nonsense." Merkle responds that "nothing we propose contradicts the laws of physics."

Meanwhile, with Von Ehr's fortune backing up the research effort, Zyvex can continue to function for many years without having to market a product, but the entrepreneur allows that it would be nice to make some money. "This whole thing is a lot harder than it first seemed," he admits. Von Ehr has reportedly already spent about $20 million on the project, but considering last year's stock market fall and the reality of the task looming on the horizon, he says he is planning to seek outside investment once financial conditions improve. "If we're going to grow," he says, "we'll need more money."

No matter how big the envisioned payoff, however, given the daunting technical difficulties and a 10- to 20-year timeline to possible success, one wonders just who would be willing to put up significant investment funds. Perhaps Zyvex's trek toward molecular nanotech could be financed by small contributions from its legions of true believers. SA

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