Nanofactory Concept Emerges from NASA Project

When Tihamer Toth-Fejel and Chris Phoenix met several years ago at a conference sponsored the nanotechnology think tank Foresight Institute, the two realized they had something in common. Toth-Fejel, a research engineer with General Dynamics Advanced Information Systems in Ypsilanti, and Phoenix, Director of Research with the Center for Responsible Nanotechnology in New York, had been working on molecular manufacturing projects. Molecular manufacturing involves building machines at the molecular level that can be programmed to precisely make copies of themselves or other products.

The researchers' respective efforts were geared toward solving some of the current challenges to space missions, including the need to reduce weight and to fabricate new exploration and research equipment while in flight. Toth-Fejel told Phoenix about his work using a kinematic cellular automata approach to replicating nanobots with self-assembling parts. Phoenix shared his vision for creating a desktop nanofactory.

Phoenix has been studying molecular manufacturing for some 13 years, he said, since taking a class from Foresight founder K. Eric Drexler. Phoenix invited Toth-Fejel to collaborate, and the pair recently completed work under Phase I of a Small Business Innovation Research grant from the NASA Institute for Advanced Concepts. Currently they are awaiting word on Phase II funding.

Their idea has been to build something akin to a desktop printer, explained Toth-Fejel, that would produce complex, three-dimensional, human-scale products made from nanosize input parts. But the execution is, not surprisingly, complex and yet to be demonstrated.

Toward that end, the two have been working on the design of nanomachines made of silsesquioxanes, or hybrid inorganic-organic composites in cubic form, from which molecules of silicon hang on each corner. The cubic cage with silicon atoms at the corners is connected by atoms of oxygen, forming a unit of one form of silica, Toth-Fejel explained.

"That's the basic building block,” Toth-Fejel said. “We'll take one cube and put some fancy organic molecules on each corner and attach another cube to that. You do it again so you have two layers of silica, and this second-generation cube has certain active sites. Under the right conditions, and if you position them correctly, you can use them as building blocks. It's like LEGOs at the nanoscale."

Phoenix and Toth-Fejel have been working with Richard Laine at the University of Michigan on chemically synthesizing the nanoscale cubes. To maneuver the cubes, the pair plans to use an atomic force microscope (AFM), with the assistance of John Mansfield, associate director of the Electron Microbeam Analysis Laboratory at U-M. "What we want to do is functionalize the tip of an AFM so that it will hold one cube in a particular position. It may take a millisecond or a second, but eventually another cube in solution will bump into the tip and stick (due to van der Waals’ force). We then need to detect that it's there and put it down where we want it."

Researchers plan to build a one-dimensional array, or a row of individually sensing and controllable AFM tips. They will then flip the array over and build the next-generation, two-dimensional array. From there, they can begin assembling the cubes, which will be connected by covalent bonds.

But that approach isn't as efficient as using, in effect, a silkscreen model. So Phoenix and Toth-Fejel have designed a simple pore that grabs a cube in a particular orientation. The receiving AFM tip gets a signal, moves and places the cube exactly where the product has been moved to receive it. "You can control the process to a greater extent. No blocks land accidentally," said Toth-Fejel.

The team plans to eventually work with at least four types of cubes: conducting, semiconducting, insulating and actuating. Electrostatic actuation appears the most promising right now, according to Toth-Fejel, since synthesizing cubes with electrically controlled molecular actuators seems too difficult.

If Phase II funding is received, he envisions the more primitive model will be validated within a year or two. "If we can get that working, we're halfway to the smart silkscreen, and if we get there, we can build an atomically precise water filter. For space missions, that's quite important."

The same technique would also make possible an artificial kidney, he said. Perhaps after some tweaking, fuel and solar cells and more powerful computers and displays, too.

The benefits are many, added Phoenix, including the ability to slash the transport and storage costs associated with manufacturing. "One manufacturing system could rapidly make a broad range of products, including new factories, where and when they're needed,” Phoenix said. “Due to scaling laws, small precise devices have higher performance. A nanofactory should be able to build motors a million times smaller and computers a billion times more compact and efficient. Well-formed covalent solids also should have far higher strength -- 100-times that of steel or better. Put together, these benefits look revolutionary, even disruptive."

Detractors say it's impossible. Phoenix says he's seen plenty of -- and done his own --calculations that prove it's not.

Toth-Fejel agrees. "I'm hopeful that within five years we'll have some pretty impressive tools, assuming funding. I used to think it would be 15 years, but that's no longer the case now."