Center for Responsible Nanotechnology

SCENARIO #2: Positive Expectations

2008: ¡Fabbers Libre! When the first "late beta" version of RepRap—the "replicating rapid-prototyper"—is released in early 2008, critics have a field day. It's slow. It's clumsy-looking. It can't actually replicate itself without adding a few key commercial parts. But where critics see an ugly duckling, design students, DIY hackers, and open source enthusiasts see a swan-in-the-making. By the summer, dozens of novel fabber projects emerge (some forked from RepRap, but most based on original designs), and by the fall, some have actually produced devices that an adventurous home user could play with. Forward-looking strategists at mega-retailers and mass manufacturers feel a distinct chill run up their collective spine.

The open fabber era had begun, and through the end of the decade, free and open source software hackers around the world turn their attention to hardware. A few start-ups begin selling the (licensed... usually) work of the various amateur and academic fabrication research programs; using fabber-based production methods, they quickly get the price down to a few hundred dollars. These appliances, under constant improvement by the global user community, can make a growing catalog of simple solid polymer products. Most are based on standard digital designs available online, but there's a highly-regarded ad hoc community of user-creators, working at the cutting-edge of fabber product design.

Initially, for non-technical users, there are a couple of drawbacks to the adoption of a home fabber. The first, and for many critics the most obvious, is the question of just how cost-effective home fabbing can be in a world of globalized pennies-per-hour labor. On the surface, the purchase of a plastic doodad made literally half-a-world away and shipped by the millions makes more sense than home creation—at least at current prices. This surface advantage doesn't last, however; by the end of the decade, rising fuel costs, carbon taxes, and cyclical trade tensions have significantly eroded that cost difference.

2011: I Said, Do You Speak-a My Language? The more subtle drawback is the lack of interoperability of the various fabbers. With the first generation of low-cost fabbers, few designs share parts, and fewer still share software formats. This, too, changes: in 2011, the international Open Manufacturing and Fabrication Group (OMFG) publishes the Openfab Interconnect Specification version 1.0, laying out standards for the design of complex components and feedstock materials for easy integration into open fabrication devices.

A niche industry develops, based on the manufacture and retro-fitting of components whose complexity is, for the moment, beyond the capabilities of personal fabricators. Printed circuit boards and interconnection assemblies for electronics are easily fabbable, but polymer microchips remain slow and oversized. Major hardware chain stores begins dedicating aisle space to catalogs of Openfab-compatible components and refined feedstock materials.

The fears felt by manufacturers and major retailers a few years earlier turn out to be entirely warranted. In surprisingly short order, Openfabs become a significant competitive influence on the consumer products industry, in the same way free and open source software posed a robust competitive influence on the proprietary software market in previous decades. Scenarios of an entirely-Openfab world grab the public's attention, and popular technology journals are filled with exaggerated stories about places in the world where Openfabbed devices are the "only ones available."

The real importance of fabbing isn't in the replacement of all manufacturing, or even in providing local production of familiar low-cost products. Rather, the value of Openfab is best seen in its ability to engender whole new markets for specialized commodities. The first widely-recognized example of this hits in 2013, when an independent solar energy startup publishes an Openfab modification that allows for the manufacture of solar power cells from raw materials. The resulting cells are very inefficient, at first, but they undercut the pricing of commercial units so significantly that their popularity soars.

Environmental concerns become a key driver for fabrication system advances. In 2013, a UK-based Openfab researcher develops a corn-plastic derivative for use in Openfabs that replaces petroleum-derived plastics. In 2014, Intel releases as open source a fabber spec for a high-speed, ultra-low-power polymer chip that rapidly becomes the preferred CPU for home electronics. Not coincidentally, that success translates into substantial growth in the market for Intel's commercial high-speed, ultra-low-power silicon and carbon chips.

2014: Fantastic Voyage 2.0 But the action isn't only in the world of gadgets and gizmos. In research labs worldwide, medical research has been making steady progress on building devices at an ever-shrinking scale. By 2014, academic researchers publish positive results in the treatment of Alzheimer's with "microbot" drug-delivery devices that can be introduced into the blood stream and remotely controlled from outside the body through the use of magnetic fields and targeted radiation. FDA trials for the treatment begin that year, but confusion over the novel architecture (are the microbots considered drugs themselves, or just their payloads?) causes delays.

This delay has a result that surprises few observers outside of the government. "Medical tourism"—the practice of traveling abroad for major medical operations in order to save on costs—had already been growing in popularity for US patients chronically without health insurance. It experiences a significant bump as foreign medical practices in Singapore, Thailand, and India begin offering the Alzheimer's microbot treatments prior to FDA approval. They are soon undercut by ocean cruise startups which take patients into international waters for treatment outside US jurisdiction.

The theme of technology as a way of bypassing aggressive official control—a mantra of the 1990s Internet boom—comes back with a vengeance by the middle of the decade. By 2015, Openfab-assembled mesh-network routers can be had for less than two dollars in parts, available by mail order or through local PC and hardware chain stores. Telcos accustomed to restricting Internet broadband customers to protect them from malware epidemics find themselves increasingly bypassed by amateur and community Internetworks based on cheap mesh router networks. Perhaps ironically, the claims of both the mesh-network advocates (that the networks would trigger innovation) and the claims of traditional telcos (that the networks would unleash malware havoc) prove true.

Little Brothers Are Watching In 2016, a transparency activist group based in a high-crime neighborhood in Los Angeles adds cameras (made for about a dime in materials) to their Openfab meshnet routers. But instead of making private video archives, they simply grant universal worldwide Internet access to the cameras. Controversy and debate arise about the propriety and legalities of open surveillance and pervasive transparency, often derided as "vigilante surveillance".

In 2017, video analysis software run on archives of this public video network reveal new evidence that re-opens a domestic terrorism bombing case. The evidence overturns a previous conviction, and leads to the arrest and conviction of another suspect. The prosecution admits that the error never could have been corrected by conventional police surveillance networks then in place, which had strict warrant requirements for access.

The ACLU, EFF, and other civil liberties groups are less enthusiastic, arguing that warrant requirements are a way of hampering abuses of the system. Sporadic efforts to develop rules to control the use of pervasive transparency networks fall short, and the public is treated to a series of high-visibility criminal trials in California hinging on the accuracy and the legality of the recordings. Several of the convictions are later overturned by the state Supreme Court.

Is the Common Cold Next? That same year, medical researchers announce that a slightly modified version of the Alzheimer's microbot treatment is also surprisingly effective against most forms of cancer, and apply for FDA trials to begin for this treatment. This brings to seven the number of sub-micron-scale anti-cancer treatments under examination. While most show at least some level of utility, the microbot method offers the most customizable treatment. By the end of the year, medical and technology specialists alike talk casually about the "cure for cancer."

Despite accelerated clinical trials, the treatment proves another large boon for the medical tourism industry, and widely publicized cancer remissions appear all over the media, boosting public pressure on the federal government to approve the technology. Congress holds hearings on FDA reform, pitting those concerned about the second-rate state of American health care against those who argue that extensive, careful testing shouldn't change just because of a few extraordinarily effective treatments. The conflict continues into the following decade.

Take Me Home, HyperRoad In 2018, China rolls out a "smart roads" initiative, combining a form of asphalt that collects solar power, wireless traffic safety and navigation systems, reconfigurable lane markers, and telecommunications infrastructure into a unified architecture. Most of its components are manufactured by fabs at the work site, rather than imported from a factory. While trumpeted as a breakthrough in construction, such novel uses of fabrication technologies are becoming increasingly commonplace.

The hyperroad example is characteristic of the kinds of changes triggered by the advances in fabrication technologies: improving efficiency; empowering local production; offering small markets the kind of customized support once given only to major buyers; flattening the economic differences between developed and developing worlds. All very useful, very important... and very evolutionary, not revolutionary.

So where is nanotechnology in all of this?

The Evolutionary We Do Immediately; the Revolutionary Takes A Little While In many ways, the success of micro-scale fabrication has served both to slow *and* to advance nanofabrication. The power of fabbers means that the social and economic ends that might otherwise have pushed the development of nanomanufacturing are at least partially satisfied; the competitive advantage from a rapid development of nanoscale fabrication does not necessarily compensate for the expenses and risk such development would require. Conversely, experiences with fabber technologies and designs have allowed nanofactory researchers to avoid subtle stumbling blocks and dead-ends, and to adopt an already-familiar language for laying out programming interfaces and product designs. When nanofabbers do appear, they're not 100% mature, but they're much closer than they otherwise would have been.

Success with biological microscale and nanoscale devices also helps shape the emergence of "true" nanotechnology. Protocols for toxicity, control interfaces, and device standards have already appeared and been tested. While some nanotech developers deride Openfab systems and medical microbots as "training wheels" for nanotechnology, the truth is that these preliminary systems make it possible to adopt molecular manufacturing into the broader economy without significant social trauma. We've already dealt with similar systems; nanotech manufacturing isn't identical, but follows along a familiar path.

By the time molecular manufacturing applications do mature at the nanoscale, Openfabs are a ubiquitous fact of global life. It's not surprising, then, that the first atomically-precise devices are designed with Openfab-standard interconnects for integration into the existing open world standard for human-scale production infrastructures. While public safety concerns dampen the distribution of unrestricted atomically precise fabricators, the freedom and interoperability for integration of certified pre-built nanoscale components (dubbed "nanoblocks") in home nanofactories largely satisfies the consumer demand and expectations for applications requiring atomically-precise construction.

It's not the total transformation envisioned by turn-of-the-century pundits, and it doesn't immediately result in a hyper-accelerated arms race or ultra-intelligent AI. In the words of one disappointed futurist, the highly anticipated arrival of molecular manufacturing turns out to be "a little boring." However, for the billions of people around the world enabled not just as consumers of nanotech-built systems, but as designers and producers as well, the dawn of the nano era is anything but boring.

By the CRN Scenario Working Group (see INTRODUCTION)