100 YEAR FORECAST

DEMATERIALIZATION

THE GROWTH OF ATOMICALLY PRECISE MANUFACTURING

THE CHALLENGE

Meeting the material needs of 10 billion people on a planet of increasingly limited natural resources

THE SHAPE OF TRANSFORMATION

From large-scale manufacturing to just-in-time manifestation

The manufacturing transition of the 21st century is the relentless push to escape the confines of a 19th-century industrial model. In that model, raw materials—often poorly distributed, hard to find, and toxic—are shaped through the application of massive amounts of energy into indistinguishable mass consumption products, often bound for the dumpster within a few years. Nations engage in "race-to-the-bottom" competitions to cut labor costs, beggaring both their neighbors and themselves. They look to unexploited reserves of raw materials, from the indium required for LCDs to the lead and zinc required for batteries, in hopes of thrusting their economies upward. Yet at current rates, we have only 13 years' worth of indium left, 42 years of lead, and 30 years of zinc. And while modern logistics have made the movement of all this material around the world the crowning achievement of the late industrial era, energy costs will increasingly constrain these global efficiencies of scale.

In the face of such limitations, a set of techno-social changes is shifting the foundations of our material manufacturing world—in effect, dematerializing it. Driving this transformation are three key processes. First, *digitization*, already well underway, is replacing physical goods and services with digital versions. Second, *atomization* is shifting manufacturing models towards additive assembly of very small, custom-designed components (also known as 3D printing). Finally, *eco-systemization*, where component materials are seen as part of a larger physical material ecosystem, moves beyond cradle-to-cradle concepts to a world of constant regeneration. This broad transformation will require changes not just to manufacturing processes, but to the very materials used to make things. And in fact, making materials from the atom up will increasingly displace natural resource mining.

This dematerialized economy will require a very different way of thinking about the production of goods and services than our familiar mass-production models. A first imperative will be to put most of a product or service's lifespan into the cloud, instantiating any needed goods as close to the place and time of use as possible. A second imperative will be to find ways to take advantage of products previously considered to be waste, including heat. Most important will be the requirement to shift the components of goods to readily reusable and reconfigurable materials. Carbon, which can be as soft as graphite or as hard as diamond, may be the material of choice. Instead of worrying about minimizing carbon outputs, we may find ourselves working to maximize carbon inputs.

The result, at the end of the century, will perhaps be a reincarnation economy—one where disposing of a physical object simply means releasing its component molecules back into the matter stream and its component information back into the cloud.

—Jamais Cascio

THE CORE DILEMMA

The core dilemma as we transition to a dematerialized world will be the dependence in both the developed and developing world on an industrial approach with diminishing value versus the growth of a lightweight, precise manufacturing paradigm that undermines traditional business practices and profit centers.

Dilemmas typically take shape when short-term benefits mask long-term costs—or when long-term benefits require short-term costs. These are particularly acute when one group experiences the costs while another experiences the benefits.

SHORT TERM

Costs

- Rapid increase in global unemployment as robots fulfill more of the demand for production
- Loss of revenue from mining rights to resources left in the ground
- Loss of value of many categories of manufactured goods
- Lower GDP for nation-states that depend on manufacturing exports

Benefits

- Greater energy, carbon, and cost efficiencies
- Novel solutions to pressing health, environmental, technological, and social problems
- Reinvigoration of R&D across institutional boundaries, especially on citizen-led platforms

LONG TERM

Costs

- Economic challenges for nation-states that depend on exports of raw materials
- Potential misuse and abuse of distributed molecular-scale manufacturing processes
- Diminished role of trade as a tool of international relations
- Large-scale social disruption as long-standing socioeconomic models fall away

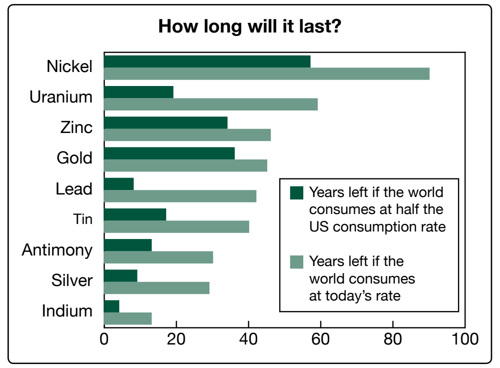
Benefits

- Escape from “resource-trap” development models for emerging economies
- Decoupling of trade and development
- Potential decoupling of labor and occupation
- Acceleration of ability to eliminate carbon emissions
- More sustainable material resources with lower impact on the planet

DEMATERIALIZATION KEY FRICTIONS

DEMATERIALIZATION
Continued automation of traditional manufacturing

SIGNALS



IFTF based on cache.gawker.com

Declining natural resources

Using today's technologies and levels of reuse and recycling, critical natural resources will be depleted before mid-century.

apple.com

The cloud as digital hub

Apple's iCloud system moves the "digital hub" from a central hardware device to the Internet, making all hardware easily replaced or shared.

THE MATERIALS
Mining vs. Making

- Shortages in raw materials spur innovation in use of existing materials—and invention of new materials.
- Lawsuits against mining operations grow as environmental degradation and land seizures reach a crisis point.
- Bio-based innovation in materials competes with more entrenched petro-chemical materials.
- Biotech and pharmaceutical companies become the new materials innovators.
- Open-source "maker" systems continue to spread as electroactive and electronic polymers (usable for components) drop in price.
- Maker communities play a growing role in original product design.
- Open-source materials drive the costs of goods steeply down.
- Designer materials have new unique light-emitting, energy-transforming, and chemically active properties.
- Microscopic biomachines are increasingly used to generate these designer materials.

THE FACILITIES
Factories vs. Fabricators

- Large-scale factories retool with fabricator technologies and robotics.
- Social disruption arises from increasing mismatch between jobs and populace as robot labor displaces human labor.
- Efforts emerge to ban or otherwise restrict the use of robotic labor replacements as well as "workers' rights" movements to limit the hours robots may work.
- Unemployment remains high in the West and starts to rise in Asia, with growing unrest, especially in China.
- Maker technologies get integrated into a wide range of consumer products, from toy fabricators to desktop electronics fabricators.
- Small-scale, local pop-up businesses use fabricators to compete with traditional manufacturers.
- Attempts to regulate the use and availability of small-scale manufacturing tools runs up against increasing ability of those tools to replicate themselves.
- As more maker systems connect to the Internet, maker spam and maker viruses become a real issue.
- Global shipping slows—except where driven by global tastes for local products.

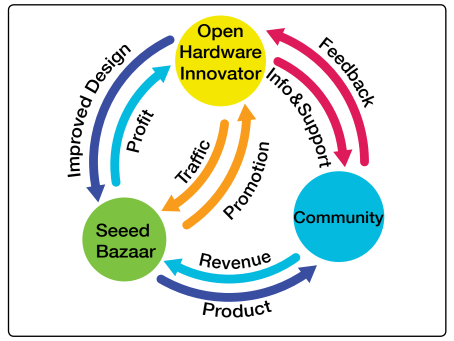
THE NAME OF THE GAME
Industrial Power vs. Pandustrial Agility

- Increased digitization means that physical media is less important, more easily swapped or shared.
- Imports drop as consumer goods shift to local production.
- "Digital-to-Physical Design" becomes a leading college major.
- Experiments to use captured carbon as a raw material for manufacturing show promise.
- Radical changes to industrial models serve as a trigger for experimentation with larger economic models.
- Economies that depend on exports of inexpensively produced goods suffer the most, as pandustry replaces industry.
- With cheap GPS and similar tracking location tags to physical goods become ubiquitous.
- Maker systems allow cheap production of guerrilla drones and other insurgency hardware, disrupting existing security.

DEMATERIALIZATION
"Wild west" era of maker technology

Open hardware ecosystems in China

Seeed Studio is a platform for the thousands of open-source design houses and product integrators in Shenzhen, China, who are remaking the landscape of electronic device production.



seeedstudio.com

3D printed drones

A University of Southampton team designed and printed a remote-control flyer, with a wingspan of 5 feet, a top speed of 100 miles per hour, and nearly silent operation. The only non-printed parts were a basic electric motor and a battery.

technabob.com

10 YEAR FORECAST THE BIG SHRINK

Over the next decade, the imperatives of declining resources and higher energy costs will accelerate the search for more sustainable building blocks for our goods and services. New manufacturing technologies and faster-than-anticipated efforts to move goods and services into the cloud will push us toward a world far less dependent upon material industry. Though still in its earliest stages, the transition will disrupt many markets and institutions without yet offering clear, reliable, and robust strategies for meeting diverse material needs around the world. In an already weakened global economy, this sort of disruption will pummel some groups already at risk from economic dislocation. And as the technologies continue to develop, the disruptive effects will spread rapidly, weakening any region that depends upon traditional export industries.

THE MATERIALS: MINING VS. MAKING

Around the world, companies and governments alike are racing to lock down access to critical material resources for today's manufactured goods. From oil reserves in Nigeria to gold in Peru and plantations in Asia, they are hoping to secure a global competitive advantage from materials in and on the ground. This strategy is not without economic and social consequences: traditional populations are often displaced from their lands and their livelihoods, fleeing to already overburdened cities.

Enter the material makers. Instead of harvesting or mining the planet's natural resources, these renegades are staking their claims in the lab. Companies like Amyris and its joint venture are creating designer molecules to replace petroleum—called "farnesene"—and opening facilities to produce them in relatively small, underutilized fermenters in the United States, Portugal, and Brazil. Meanwhile, work proceeds apace to create new kinds of biological building blocks for designer materials: the Foundation for Applied Molecular Evolution has announced two new bases to the standard four-base genetic code, expanding the alphabet for writing lifeforms. Many of these will lead to more sustainable materials, but cheap and dirty new materials may also flood the marketplace.

THE FACILITIES: FACTORIES VS. FABRICATORS

At the same time, factories are undergoing big changes that will make them smaller. More and more, they are eliminating humans—and the human-centered spaces that accommodate them—to use robotic components in assembly work. They are adopting additive technologies to build complex structures from maker molecules in small spaces that can quickly be repurposed for different kinds of products. But even these innovations may not secure the future of the factory. Hackers continue to push the boundaries of small-scale replicators and open-source hardware. At the same time, the hardware itself is changing so rapidly, companies already have a hard time developing viable business models for some classes of hardware products. In China, the government is actively promoting hacker spaces for developing these game-changing, open-source hardware innovations. But other governments will likely seek greater regulation of this kind of 3D printing and similar maker technologies that have undisputed uses for guerrilla and insurgent groups.

THE NAME OF THE GAME: INDUSTRIAL POWER VS. PANDUSTRIAL AGILITY

Perhaps the biggest shift in the coming decade will be the emergence of *pandustry*—the reorganization of manufacturing to happen at all scales, across a greatly distributed network of producers. Pandustry couples the personalization, independence, and distribution of traditional artisan production with the design sophistication, market spread, and speed of industrial production. Pandustrial technologies (for instance, 3D printers and similar maker tools) will slowly cannibalize 20th century industries, moving inexorably to take over numerous markets. A pandustrial approach also minimizes the differences between physical manufacturing and digital creation, recognizing that goods and services increasingly will span both realms.

INSTITUTE FOR THE FUTURE