Robot, Build Thyself

And when you finish that, build some more of you. Go ahead, fill a whole desert valley. And then produce unlimited energy while eliminating the greenhouse effect. Okay? Thanks.

by Thomas Bass

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According to the vision of Klaus Lackner and Christopher Wendt, a few short decades from now the desert chaparral of what was once the White Sands Missile Range in southern New Mexico will be transformed into a strange new world. For hundreds of miles in every direction the alkali flats will be covered with a blinking array of solar panels. These might look familiar enough, but not the little suitcase-size robots scurrying among the panels on a grid of white ceramic tracks.

The robots, called auxons (from the Greek auxein, to grow), are designed for specialized tasks. Digger auxons scrape an inch of dirt off the desert floor. Transport auxons carry the dirt to a beehive of electrified ovens. Out of these ovens, which work at superhigh temperatures, come useful metals, like iron and aluminum, or the silicon required for making computer chips. Production auxons shape these materials into machine parts and solar panels. Assembly auxons fit them into place. Then the process begins all over again as a new batch of self-replicating automatons rolls into the desert to scoop up another load of dirt.

This electrified grid of tracks and bustling robots grows exponentially across the New Mexican mesas, doubling in size every six months. Though it started out the size of a football field, in ten years it could cover the continent. Before this happens, however, some built-in constraint will tell the system to stop growing. Instead of continuing to reproduce itself, the huge array of solar panels will feed its electricity into the national power grid. This one colony of auxons alone, limited to the test site where the world's first atomic bomb was exploded, will produce enough power to meet the current electrical energy needs of the United States.

Elsewhere on the continent, other auxon colonies stretch inland from the coasts. When switched from reproduction to production, the colonies will desalinate seawater, pump freshwater to the nation's farmland, and suck greenhouse gases out of the atmosphere, transforming carbon dioxide into mountains of limestone. Another exponentially growing auxon colony, once it covers a bit more than 10 percent of the Sahara, will be able to meet the world's total energy demands three times over. No longer starved for power or limited to the polluting technologies once used to get it, people will be looking forward to the twenty-second century, when things should really get interesting.

The vision began to take shape in the summer of 1992. Klaus Lackner, a 43-year-old physicist in the Los Alamos National Laboratory's theoretical division--which researches such classified phenomena as bomb blasts, and such unclassified ones as climate--and his friend Christopher Wendt, a 36-year-old particle physicist at the University of Wisconsin, were enjoying a beer in Lackner's house on the Los Alamos mesa when they began wondering why scientists no longer think about big projects. Back in the 1950s people weren't afraid to pop off ideas about interplanetary travel or terraforming Mars into a space colony. But today, with fear of technology in the air, no one talks about building big projects on the scale of the pyramids or the great cathedrals of Europe.

After a few more beers, Lackner and Wendt started thinking big themselves. They talked about the problem of global warming and how it could be solved by transforming carbon dioxide into carbonate rock--a stable form of matter that would give us no more trouble than the cliffs of Dover. But to make these chalky white cliffs of stabilized CO2 would require so much machinery that the cost of buying or manufacturing it would bankrupt you. The only way you could do it would be to produce the machinery automatically. So we concluded that the means of production, as part of their job, would have to build copies of themselves, says Lackner. The number of these self-replicating machines at work, then, would increase exponentially.

Lackner and Wendt did some back-of-the-envelope calculations. During the day, some 300 to 1,000 watts of solar power rains down on every square meter of land. Harness this power into a self-reproducing system and two things happen. The system grows big fast, and it produces a phenomenal amount of energy. A million-square-kilometer auxon system, which represents 4 percent of North America, or half the cropland in the United States, could produce 25 times the world's current output of electricity. A 10- million-square-kilometer auxon system would provide all the elements for a sustainable world economy. The price tag for developing this system? Anywhere from $1 billion to $100 billion--cheap compared with, say, the current military budget of $264.7 billion.

Once you start talking about projects this big, says Wendt, the amount of energy available to you becomes staggering.

We live in an energy-starved society, says Lackner, and here was an idea for getting virtually unlimited energy, which would be a great thing to have.

At this point in their discussion, they had only a vague idea of what could be done with an automated industrial process growing like algae over the surface of the planet, but they knew it was big and powerful and could be programmed for a wide variety of human uses. They would bring the dark, satanic mills of the nineteenth century into today's sunlight. They would scoop up the free energy raining down on Earth and use it to put the spark of life into dirt, water, and air, which were all that were needed to build artificial life.

We fell in love with this idea of making something really huge, says Wendt. Then we tried to justify our love by thinking of useful things for it to do.

When they met over breakfast the next morning, Lackner and Wendt looked at each other and said, That wasn't such a crazy idea we had last night. They agreed to pursue the project. They would moonlight in their spare time, researching the industrial processes and chemical reactions required to build self-reproducing machines. They couldn't think of one, but they imagined that somewhere there had to be a bottleneck, a first principle or fundamental law that made the idea impossible. They never found one.

Laus Lackner, a tall, well-knit man with a domed forehead and graying hair curling over his ears, is a naturalized American, born in Germany. He wears sandals with socks, speaks English with a German accent, and is gracious to a fault. He also tends to wander. He picks up new ideas and calculates their feasibility with so much gusto that in his company one often feels like Alice tumbling down the rabbit hole.

At such moments, Wendt interrupts to say, Oh, Klaus, don't get into that. The two men have known each other since they shared a computer in a research lab at Caltech in the early 1980s, when Lackner was a postdoc in high-energy physics and Wendt was an undergraduate. They found themselves together again after Lackner moved to the Stanford Linear Accelerator Center in Palo Alto and Wendt began graduate school next door at Stanford. Their friendship now includes their wives and Lackner's three young daughters.

With hair clipped short on the sides and pointy ears, Wendt has a Vulcan air about him. He wears high-tech metal-frame glasses, collarless shirts, chinos, and hiking boots, which give him the hip look of someone still young enough to get carded at the university pub. Although he too was born in Germany, where his father was a visiting academic, Wendt is basically an American whiz kid, the product of some of the country's best schools and laboratories. He now researches Z bosons, muons, and other abstruse forces in high-energy particle physics. I still have this nagging idea that physics should be good for something, he says. And since I don't know what high-energy physics is good for, I'm always looking around for something useful. No wonder he fell in love with auxons.

After spending a few weeks refining their original big idea via E-mail, Lackner and Wendt had outlined a self-reproducing system with closure. This means it was capable of making copies of itself without the addition of material from outside. Designed into the system were the powers of production, replication, growth, and self-repair.

The tools required for building an auxon system are borrowed from experimental physics, chemistry, robot design, and Boy Scout inventiveness. Start with common dirt and break it into its components. Dirt from anywhere, your backyard included, is filled with iron ore, aluminum, silicon, copper, carbon, and virtually every other element required for industrial production.

So why isn't your backyard being strip-mined? Because the concentration of metals in ordinary dirt is low--down in the range of 5 percent for iron, for example, while the metal in a good iron mine might be concentrated at 30 percent. But low concentrations present no problem to a system with unlimited energy; it can simply crunch up more dirt.

Slightly more problematic for the backyard miner is that the metals in dirt often exist in the form of oxides. Before you can obtain usable iron or aluminum, you have to strip away the oxygen. Ripping oxygen off the molecules to which it is attached is an energy-intensive process, requiring high heat, electricity, or both. Scientists have developed ways to make the procedure more efficient--by reducing the melting temperatures of ores and improving the electrolytic processes by which they separate the good stuff from the bad. Aluminum oxide, for example, is mixed with cryolite, a fluoride, to cut its melting temperature in half.

But fluoride is rare, and to avoid bottlenecks, Lackner and Wendt wanted to steer clear of any substance in short supply. So they developed the chemistry for a new kind of industrial process. They would strip away the oxygen molecules in metallic oxides by binding them to silicon (which abounds in dirt) or carbon (which abounds in air). The one sticking point in making this process work is the heat it requires. Ores break down in the presence of carbon and release their constituent metals only when fired at temperatures ranging up to 4000 degrees Fahrenheit; the silicon reaction does work at lower temperatures, but more heat makes it go faster. These temperatures, although feasible in today's industrial processes, are too expensive to maintain--unless the system is being run by auxons with plenty of solar energy to spare.

Lackner and Wendt's element separation cycle has another unique feature: it requires no outside materials beyond those created in its ten steps. After an initial priming with silicon and carbon, the system recycles all the elements required to keep itself going. You scoop up dirt and heat it. Into the furnace goes silicon. The silicon gloms on to the oxygen atoms, ripping them away from the iron, sodium, potassium, and magnesium. There they are--the metals you were after, in the form of a liquid or a gas.

The oxygen stolen from the metals turns the silicon into silicon dioxide, or quartz. Carbon rips away the oxygen atoms again, turning the quartz back into silicon and carbon monoxide. Carbon monoxide, in the presence of hydrogen, becomes carbon and water. Carbon reduces aluminum. Electricity splits water into hydrogen and oxygen, and the process starts all over again, with silicon, carbon, and hydrogen being dumped into dirt- filled high-temperature furnaces.

After they'd outlined their process, Lackner and Wendt checked their work by searching the literature on industrial techniques for making metals. Iron, magnesium, calcium--all at one time or another have been extracted by applying intense heat to ores, as Lackner and Wendt suggested doing. Even aluminum, which requires the highest temperatures, has been extracted this way. Reynolds Metals Company went so far as to build a pilot plant that used carbon instead of cryolite to make aluminum. The technology worked fine, even if it was too expensive at today's prices. It would not be too expensive, of course, for an auxon.

We reinvented the wheel, says Lackner, which makes me feel quite comfortable. Industry has experimented with all these ideas. They just never put them into a coherent system.

Once dirt is broken down into piles of metals, there's no conceptual difficulty with the rest of the technology required for shaping these piles into rods, panels, cogs, conductors, insulators, computer chips, and the other stuff of modern machine tools. Robots are now very good at rolling ingots, hammering them into sheets of metal, cutting and shaping machine parts, and then assembling them into usable tools. A close cousin to all the automated steps required to build auxons already exists in industry, says Lackner. A car can be made in 16 hours almost entirely by robots. Robots controlled by Apple computers assemble parts of Apple computers. Lackner and Wendt consider their auxon system a logical extension of automated methods already in place. The difference will not be how the robots work but what they produce: more of themselves.

Lackner and Wendt were not trying to draw up blueprints for actual robots; they were merely trying to prove that their idea wasn't impossible. Still, they had a sense of the problems they'd encounter in founding an auxon community, and the kinds of solutions they would propose.

Once the suitcase-size bolt cutters and nut fasteners were up and running, they knew, the trick to keeping the system going would be simplicity. Rather than smart robots--which have a history of taking three steps and falling over--Lackner foresaw a decentralized system of dumb machines, each performing its dedicated task. You want them cheap and dispensable, he says. An auxon can jump off a cliff and you won't miss it.

The auxon system wouldn't have any brain or automatic administrative center, like the one a NASA research team envisioned in 1980 when it proposed building self-growing mining modules on the surface of the moon. Those visionaries pictured a lunar industrial park complete with 3 billion robots, some of which would be devoted to keeping the American flag flying over Central Control. But Lackner and Wendt considered such a centralized control system cumbersome and unnecessary. They proposed instead to manage their auxons using remote, localized sensors that work by reflex. Each auxon would be able to sense what was going on in its immediate neighborhood and respond in a simple, appropriate way--perhaps by speeding up or slowing down production.

Generally the system would be left to its own devices, spreading across the desert like an automated kudzu vine. But while the auxons were busy copying themselves, outside observers might want to keep an eye on the system through satellite monitoring or feedback loops. Humans might occasionally enter the scene to reprogram some machines, either to improve their design or to root out bugs; they might also want to keep an eye on auxons threatening to trespass beyond their allotted bounds.

The ultimate control, of course, would lie in turning off the energy. The system could be designed to respond to a broadcast radio signal that would shut down the solar panels. Even if some of them ignore you, the bulk of the system would collapse, says Lackner.

Other controls could be provided by what Lackner jokingly calls administrative auxons--regulators that scuttle around enforcing production specs and preventing mutations from reproducing themselves. The system's strategy could be changed--from growth to maintenance, for example--by injecting new blueprints into the assembly robots, which would be retrofitted with new computer chips or reprogrammed. The system will not evolve, Lackner says, unless you approve it.

When they were satisfied that they'd addressed all the important issues, Wendt and Lackner looked at the system critically. Suspicious that it might be too good to be true, they devised various productivity measures for proving it would work. Then they tested the design with a barrage of imaginary disasters.

A rainstorm washes out part of the grid? Put up a sign saying track closed and reroute your auxons down a stretch of elevated track. An auxon dies on the perimeter? Tow it into a furnace to have its parts recycled. Nowhere in the scheme was there a bottleneck or an insurmountable obstacle. The system was go. Lackner and Wendt wrote up their idea in a paper, Exponential Growth of Large Self-Reproducing Machine Systems, which was published in May in Mathematical and Computer Modeling.

Even if an auxon system could be built, of course, some question whether it should be built. What if it turns into an ecological nightmare? After all, one reason big projects are out of favor may be that they carry big risks.

The potential of self-reproducing machines to wreak ecological havoc was addressed back in the 1970s, when physicist Freeman Dyson conducted some famous thought experiments on the future of machinery. Among other ideas, Dyson proposed building a rock-eating automaton that would fill the Sonoran Desert with self-reproducing machines. Devoted to collecting sunlight and producing electric power, these machines would generate so much power that the rock eaters could easily support another colony, this one of rock restorers--automatons devoted to putting the desert back to its original form. Auxons owe an obvious debt to Dyson's rock eaters, and Dyson has said some kind words to Lackner and Wendt about their idea.

The developers of the rock eaters' auxonal progeny face not only the Frankenstein problem of runaway machines but also the question of real estate. Sure, you need a certain amount of land for it, says Lackner. Just as in your house you have to commit a certain number of square feet to the bathroom. We plowed under the state of Iowa and turned it into a cornfield, which is not all that natural either. Clearly he and Wendt think the benefits of self-reproducing machines outweigh the costs of siting them in various parts of the world, or elsewhere in the universe.

Maybe it's unhealthy thinking about these ideas, muses Wendt. It requires hubris.

But that's what makes it fun, says Lackner.

The two scientists admit that their ideas are out of tune with a fashionable present-day notion that the way out of our problems is not more technology but less. Lackner and Wendt argue that there is no going back to preindustrial days. They believe we will need new technologies to live in an increasingly energy-hungry world. They are serious about getting their system built, and they hope to design prototype auxons and start researching the alchemy of dirt within the next few months. As their work moves forward, self-reproducing machines are scuttling one step closer to reality.