WHOLE EARTH DISCIPLINE

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For
JOHN BROCKMAN,

who gives scientists direct voice
in the public discourse

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• 1 •

Scale, Scope, Stakes, Speed

We are as gods and HAVE to get good at it.

—*Whole Earth Discipline*

Climate change. Urbanization. Biotechnology. Those three narratives, still taking shape, are developing a long arc likely to dominate this century. How we frame them now will affect how they play out. Illusions abound on all three subjects, but their true nature is knowable.

In the face of climate change, everybody is an environmentalist. That's tough not just for people who have been comfortable thinking of themselves as antienvironmentalist; it's even tougher for long-time Greens. Activist Bill McKibben recently noted: "The environmental movement has morphed steadily into the climate change movement." That means that Greens are no longer strictly the defenders of natural systems against the incursions of civilization; now they're the defenders of civilization as well. It's a whiplash moment for everyone.

When roles shift, ideologies have to shift, and ideologies hate to shift. The workaround is pragmatism—"a practical way of thinking concerned with results rather than with theories and principles." The shift is deeper than moving from one ideology to another; the shift is to discard ideology entirely.

We are still realizing how much radical rethinking we will need to comprehend the forces now loose in the world and to figure out

how to deal with them. The scale of forces, this time, is planetary; the scope is centuries; the stakes are what we call civilization; and it is all taking place at the headlong speed of self-accelerating human technologies and climatic turbulence. Talk of “saving the planet” is overstated, however. Earth will be fine, no matter what; so will life. It is humans who are in trouble. But since we got ourselves into this fix, we should be able to get ourselves out of it.

• The best way to think about climate change I found in a book that seems to be about something else—*Constant Battles* (2003), by Harvard archaeologist Steven LeBlanc (with Katherine Register). Drawing on abundant archaeological and ethnological evidence, LeBlanc argues that humans have always waged ferocious war. In all societies from hunter-gatherers on up through agricultural tribes, then chiefdoms, to early complex civilizations, 25 percent of adult males routinely died from warfare. No one wanted to fight, but they were constantly forced to choose between starvation and robbing the neighbors. Their preferred solution was the total annihilation of the neighbors.

The book is full of harsh revelations. Close examination of human burials shows that wholesale slaughter was common, and so was cannibalism—for nutrition, not ceremony. The abundant “cooking stones” at many archaeological sites turn out to be ammunition—sling missiles (David killed Goliath with one). Dogs were the first animals to be domesticated because they make such good sentries, and that’s why all dogs bark (and wolves don’t). Most cities were walled.

Humans perpetually fight, LeBlanc says, because they always outstrip the carrying capacity of their natural environment and then have to fight over resources. Native peoples developed arcane knowledge of how to find and prepare difficult foods because they’d eliminated all the easy food sources. Peace *can* break out, though, when carrying capacity is pushed up suddenly, as with the invention of agriculture, or newly effective bureaucracy, or remote trade, or technological breakthroughs. Also a large-scale dieback from pestilence can make for peaceful times—Europe after its major plagues, the Americas after European diseases nearly

obliterated the native populations. Such interludes are short: Population quickly rises to once more push against carrying capacity, and normal warfare resumes.

Only in the last three centuries, LeBlanc points out, have advanced states steadily lowered the overall body count to where just 3 percent of the world's people die from warfare these days, even though a few of the remaining wars and genocides have grown to world-war scale. Instead of butchering all their enemies in the traditional way, states merely kill enough to achieve a victory; then they put the survivors back to work. States also use their bureaucracies, advanced technology, and international rules of behavior to raise carrying capacity and sometimes even develop a careful relationship to it.

But all of that civilized sophistication could collapse if carrying capacities everywhere are lowered by severe climate change. Humanity would revert to its norm of constant battles for diminishing resources. Peace lovers would be killed and eaten by war lovers.

That's the prospect, I realized, reading LeBlanc. With climate change under way, we have to make a choice. If we do nothing or not enough, we face a carrying-capacity crisis leading to war of all against all, this time with massively lethal weapons and a dieback measured in billions. Alternatively, LeBlanc concludes,

> For the first time in history, technology and science enable us to understand Earth's ecology and our impact on it, to control population growth, and to increase the carrying capacity in ways never before imagined. The opportunity for humans to live in long-term balance with nature is within our grasp if we do it right. It is a chance to break a million-year-old cycle of conflict and crisis.

Up until 2003, I had only the usual concerns about climate change. Back in 1982, my wife and I bought an old tugboat to live on because it was impervious to the California hazards of earthquake and wildfire, and what the hell, because it was a cheap way to own a bayfront home with never a care about rising sea levels from global warming. Climate change was fun to think about, dire but distant.

I am employed half-time by a consulting company I helped found in 1987 called Global Business Network/Monitor (GBN). What happened in 2003 was that GBN got a request from the office of the U.S. Secretary of Defense to build a scenario about "abrupt" climate change. My role was peripheral; I did a few of the phone interviews with climatologists and contributed one idea. We delivered the report that fall—"An Abrupt Climate Change Scenario and Its Implications for United States National Security," by Peter Schwartz and Doug Randall.

Our scenario was based on an event that took place 8,200 years ago, when temperatures suddenly dropped 2.7° Celsius (5° Fahrenheit) in less than a decade. On the temperature charts, it's a one-century blip, nothing like the Younger Dryas event that humans endured 12,700 years ago, when world temperatures abruptly plummeted 15°C (27°F) and stayed that way for a thousand years. One explanation for both events is that the Gulf Stream was slowed or stopped by an excess of fresh water in the North Atlantic caused by global warming. (Data collected since 2003 variously challenge and support that theory; nobody denies that the violent climate events occurred).

Because our current global warming is melting Arctic ice and freshening North Atlantic waters, GBN's scenario examined what would happen if in, say, 2010 we entered an abrupt "minor" cooling like the one 8,200 years ago. The suddenly cooler, drier, windier world would experience droughts in the major agricultural areas, along with harsh winters and vicious storms and floods in unexpected places. By 2020, we said, Europe's climate would be more like Siberia's. Global food, water, and energy supply would be stressed. Earth's carrying capacity for humans would suddenly drop below what the 7.5 billion population of 2020 would require to survive. GBN concluded the report with my realization from LeBlanc, that whenever societies bash against carrying-capacity limits, they revert to the million-year-old norm of fighting over resources. By the 2020s, war, disease, and famine would be reducing human population until it came back into balance with the new carrying capacity. The Pentagon was an appropriate client for the scenario.

Deliberately kept unclassified, the report went public online and was summarized in *Fortune* magazine. At first a few keepers of the climate literature disparaged the scenario, but soon enough it became a widely cited part of that literature. The idea of abruptness (in our paper and a number of others) changed the public conversation about climate change. For the first time, climate was understood as a clear and present danger, the responsibility of currently serving officials worldwide instead of some future generation's problem. Public opinion on the subject began its own abrupt change.

• If GBN's scenario worries you, don't worry. In 2007 the Intergovernmental Panel on Climate Change (IPCC) consulted twenty-three climate models and concluded that the widespread concern of climatologists about the Gulf Stream was misplaced. A Norwegian professor, Helge Drange, said, "The bottom line is that the atmosphere is warming up so much that a slowdown of the North Atlantic Current will never be able to cool Europe." Or worry harder. A 2008 study of Greenland ice cores revealed that changes in the Gulf Stream appear to have triggered severe climate changes twelve thousand years ago that occurred not over decades but in one to three *years*.

Following climate science these days is a lot like the kid joke: Two men were flying in an airplane. Unfortunately one fell out. *Fortunately* there was a haystack. *Unfortunately* there was a pitchfork in the haystack. *Fortunately* he missed the pitchfork. *Unfortunately* he missed the haystack.

Fortunately, the IPCC climate models enabled thousands of scientists to publicly declare that global warming is real, that it is largely driven by human-generated greenhouse gases (CO_2 and methane mostly), and that the global consequences will become quite serious by 2040 and grow worse thereafter. *Unfortunately*, the IPCC models failed to predict the extremely rapid melting of Arctic ice—the ice was half gone in the summer of 2007 instead of the predicted 2050s.

In 2006 and again in 2008, Global Business Network ran a

scenario workshop for the Arctic Marine Council on the future of shipping in the Arctic. I learned that sixty-five surface ships have been to the North Pole, that hundreds of cruise ships now visit the Arctic, that fish and fisheries are moving north, that the once-mythic Northwest Passage above Canada is opening for navigation, and that the Russians are pouring concrete for a series of ports along the Northern Sea Route, which will offer a shipping shortcut above all of Europe and Asia. The salty group in attendance at the first workshop—twenty-four assorted skippers, Coast Guard officers, polar scientists, diplomats, and CEOs—came up with four scenarios exploring the effects of various traffic demands and potential national and international policies concerning freedom of navigation, safety, and environmental protection in the new Arctic ocean passages. All four scenarios took as a given that the ice will keep right on melting.

• The reason is positive feedback. White ice reflects sunlight, 85 percent of it. Dark ocean absorbs sunlight, reflecting only 5 percent. Less ice leads to more absorption of solar heat in the Arctic, which leads to still less ice, which leads to ever more heat absorption, melting ever more ice: That's positive feedback. This particular phenomenon is called the ice-to-water albedo flip, *albedo* meaning reflectance.

Note that the word *positive* in the cybernetic term *positive feedback* does not mean "good." It usually means trouble, because it amplifies change. In the Wikipedia definition:

> *Positive feedback*, sometimes referred to as *cumulative causation*, is…a feedback loop system in which the system responds to perturbation in the same direction as the perturbation. In contrast, a system that responds to the perturbation in the opposite direction is called a *negative feedback* system…. The end result of a positive feedback is often amplifying and "explosive," i.e. a small perturbation results in big changes.

Another case of positive feedback in the Arctic is the melting of tundra permafrost (no longer so perma-), which releases vast

quantities of the super-greenhouse gas methane from the rotting of formerly frozen vegetation, along with the evaporation of a weirdly flammable ice in the permafrost called methane hydrate. More methane in the atmosphere leads to more melting of permafrost, and so on. Oh, and also, with Arctic warming, the tree line rapidly moves north, so dark conifer forest replaces pale tundra, absorbing yet more solar heat, and another positive feedback gets going.

One important negative feedback may be operative, but its mechanisms are mysterious. Either because of atmospheric changes or human behavior, the world's land areas are absorbing more carbon dioxide than they're releasing lately. "The amazing truth is that on a global scale, photosynthesis is greater than decomposition and has been for decades," says atmospheric scientist Scott Denning. "Believe it or not, plant life is growing faster than it's dying. This means land is a net sink for carbon dioxide, rather than a net source." It might be simple carbon-dioxide fertilization—additional CO_2 stimulates plant growth; that's why it's used in commercial greenhouses. It might be that longer growing seasons in boreal regions are causing greater forest growth. On the other hand, forest fire suppression by humans could be the cause; or countless abandoned farms growing back as forest; or overgrazing by cattle, leading to woody shrublands replacing grasslands; or excess nitrogren from agriculture and automobiles, fertilizing additional wild growth. Until the "mysterious sink" for carbon is figured out, our climate models will remain frustratingly vague and unpredictive.

For hundreds of millions of years a "crazily jumping climate" has been the norm on Earth, says glaciologist Richard Alley. These days, apparently, we are returning to that jumpy norm, thanks to abruptness mechanisms like positive feedback, trigger events, and threshold effects, none of which are well incorporated into the climate models yet. It may take some breakthroughs in nonlinear mathematics before that can happen. A good book on the subject is Fred Pearce's *With Speed and Violence: Why Scientists Fear Tipping Points in Climate Change* (2007).

• There have been some cataclysmic trigger events in the past. A vast freshwater lake in North America suddenly emptied into the North Atlantic 12,800 years ago, and that was the Younger Dryas instant deep freeze. Another bizarre event occurred 55 million years ago, when a trillion tons of methane burped out of the oceans from thawing methane hydrates (also called clathrates) on the sea floor. The sudden temperature rise of 8°C (14.5°F) extinguished two thirds of oceanic species and was nearly as catastrophic on land as the dinosaur-killing asteroid 10 million years earlier. According to Fred Pearce's book, something between 1 trillion and 10 trillion tons of frozen methane clathrates lurk on the seabed now. Their potential sudden release is fondly known as the clathrate-gun hypothesis. David Archer, a climate modeler at the University of Chicago, has said, "The worst-case scenario is that global warming triggers a decade-long release of hundreds of gigatons of methane, the equivalent of ten times the current amount of greenhouse gas in the atmosphere. We'd be talking about mass extinction."

There's another potential trigger at the South Pole. The vast West Antarctic Ice Sheet, *fortunately,* is safely perched on land, held in place by the Ross Ice Shelf. *Unfortunately*, the Ross Ice Shelf is melting with surprising speed. If the West Antarctic Ice Sheet slides and melts into the ocean, sea levels will suddenly rise by 16 feet. (Higher, really, because the Greenland ice sheet is also melting).

Threshold effects are sneaky. Incremental change goes along and everything looks fine, and then before you know it, the system has shifted massively and irreversibly into another state. These decades the tropical rain forests are as busy as ever creating their own rain and reflective clouds, locking up lots of carbon, helping to slow global warming, apparently untroubled by it. At some point, though, a threshold is reached. Then in an unstoppable cascade the rain forests melt like Arctic ice, leaving savannah, scrub, and desert in their place. The carbon sink is gone, the reflective clouds are gone, a zillion species are gone, and we can't get them back. What is the fatal threshold for rain forests? Researchers Richard Betts and Peter Cox think it is just 3°C (5.4°F) above what we

have now. The 2007 IPCC report predicts that the demise of the rain forests will be under way by 2050.

There are known and unknown thresholds in the ocean. At around 14°C (57.2°F) the surface stratifies, keeping cold-water nutrients out of reach of sunlight. Algae can't grow, and a whole swath of ocean goes dead, its carbon-fixing capacity crippled. A similar critical point involves the acidification of seawater by excess CO_2 in the air. With greater acidity, the carbonate-forming organisms, like reef coral, shellfish, and the teeming diatoms of the open ocean, are disabled, and their existing carbonate structures start to dissolve. The oceans, which now absorb a third of humanity's CO_2 emissions, flip from carbon sink to carbon source, from solution to problem. Where is that threshold? We don't know yet.

In his 2005 book, *Climate Crash: Abrupt Climate Change and What It Means for Our Future,* science writer John Cox summarizes the depth of uncertainty that explains why climate models have thus far been unable to predict the past or present with the kind of accuracy we want:

> The climate system is nonlinear, which means its output is not always proportional to its input—that, occasionally, unexpectedly, tiny changes in initial conditions provoke huge responses. It is chockablock with feedbacks, loops of self-perpetuating physical transactions, operating on their own timescales, that amplify or impede other processes. This constant cross talk of positive and negative feedbacks is said to be balanced, more or less, at various critical thresholds in the system. Forced across such a threshold, by whatever external or internal triggering mechanism, important variables begin gyrating or flickering, and the system suddenly lurches into a significantly different semistable mode of operation, a new equilibrium. All of these variables, all of these timescales, make for a system that is full of surprises…. Climate is a precariously balanced nonlinear system that lurches between very different states of coldness, dryness, wetness, and warmth.

Climate is so full of surprises, it might even surprise us with a hidden stability. Counting on that, though, would be like playing Russian roulette with all the chambers loaded but one.

• Some climate events are already having an impact on humans. Despite our suppression efforts, forest fires are increasing everywhere because, as one science writer puts it, “with global warming, we don’t get fire; we get fire squared.” Large fires in the drying forests and newly cleared peat bogs (such as those in Indonesia) dump vast quantities of CO_2 into the atmosphere, which further warms and dries land vegetation, making it ever more flammable. A 2007 megafire in southern Greece caused the government of the once-popular Costas Karamanlis to fall. Persistent drought in Australia led, in 2007, to a switch from a climate-denialist prime minister to one whose first official act was to ratify the Kyoto Protocol. His administration soon had its own megafires to deal with.

In Europe, studies show warmer temperatures are moving north at 25 miles a decade, whereas animals and plants are moving north at only 3.75 miles a decade. That’s a formula for extinction. Olive and avocado trees now grow outdoors in London, at Kew Gardens. With the overfished ocean becoming warmer and more acidic, vast swarms of jellyfish are drifting north, killing whole fish farms in the Irish Sea. In Africa, warmth-loving mosquitoes are carrying malaria and dengue fever to higher elevations, and even bringing tropical diseases to southern Europe.

The glaciers of the Tibetan Plateau, which feed all the rivers of China, north India, and Southeast Asia with meltwater, are now vanishing. Three billion people depend on those rivers. In addition the billion in India live, as they say, “at the whim of the monsoon” for rain. The monsoon in turn lives at the whim of the El Niño cycle, which is being disrupted at the whim of the mid-Pacific trade winds, which are slackening due to ocean warming.

How human societies will respond to climate calamities remains to be seen. At Global Business Network, we’ve been studying the likely consequences of a growing frequency of extreme events such as the 2003 heat wave that killed thirty-five thousand in France and Italy. Nils Gilman at GBN notes that “while a single extreme event may be relatively easy to withstand, a second in succession is likely to be far more devastating, as normal resiliency measures are built to deal with one but not multiple

consecutive extreme events." Governments, he concludes, "will experience climate change not as a smooth transformation, but rather as a series of radical discontinuities—as a series of bewildering 'oh shit' events. Environmentally failed states are a nontrivial possibility."

Repetition knocks you down; duration kills you. Complex societies can handle drought, but not multidecade drought. That's the historic civilization killer, says archaeologist Brian Fagan. It brought down the ancient empires of the Middle East and Central America. When the rains fail, agriculture fails, the cities convulse and empty, and what's left of the society builds shacks in the ruins of its former glory. In this century, the effects of rising sea levels, catastrophic as they may be, could look temporary and fixable compared to the effects of permanent drought.

• "We have to understand that the Earth system is now in positive feedback and is moving ineluctably toward the stable state of one of the past hot climates," atmospheric chemist James Lovelock told a Royal Society audience of scientists in 2007. "I can't stress too strongly the dangers inherent in systems in positive feedback."

Two of Lovelock's books, *The Revenge of Gaia* (2007) and *The Vanishing Face of Gaia* (2009), give the clearest warning yet of the extreme dangers we face and how radical our measures may have to be to deal with them. I've learned to trust Lovelock's judgment ever since 1974, when a magazine I edited, *CoEvolution Quarterly,* was the first to publish his Gaia hypothesis, coauthored with microbiologist Lynn Margulis. Since then, their idea of Earth as a self-regulating living system "comprised of physical, chemical, biological, and human components" steadily matured from hypothesis into theory; it became formalized as Earth System Science, and it has won Lovelock no end of prizes.

I phoned Jim Lovelock after his Royal Society talk to get details on why the gentle optimist I've known for three decades is so alarmed. "The year 2040 is when the IPCC is estimating that Europe, America, and China become uninhabitable for the growth of food," he said. "They're grossly underestimating the rate of

temperature rise, so that 2040 may be 2025. People don't realize how little time we've got. The planet really is on the move."

"On the move toward what?" I asked.

He said: "I don't think there's much doubt at all now amongst those few of us that have worked on the problem, that the system is in the course of moving to its stable hot state, which is about 5 degrees Celsius globally higher than now. Once it gets there, negative feedback sets in again, and the whole thing stabilizes and regulates quite nicely. What happens is, during that period, the ocean ceases to have any influence on the system, or hardly any. It's run entirely by the land biota. That's what happened in the past, anyway. There's a good deal of geologic evidence; the best evidence comes from the 55-million-years-ago event. The Arctic ocean temperature was about 23° Celsius [73.4° F]—crocodiles swam around in it. The whole damn planet was tropical, probably. And will be again, if it goes on the way it's going. The equatorial regions were a hell of a lot drier than they are now. You see that already happening."

I asked him what might be the human carrying capacity in that hotter, stable Earth. "Oh, I think it's less than a billion," he said. "It will be too hot for things to grow." Then he added: "The earth will continue to move to its hot state almost regardless of what we do. Peter Cox at the Hadley Centre in our country has done some very careful analysis on how little CO_2 is needed to start the automatic jump from the cool to the hot state, and it's an astonishingly and worryingly small quantity. He probably doesn't want to be quoted. It turns out to be about a quarter of a gigaton of carbon per year. Now that compares with the eight gigatons that we're actually emitting to the atmosphere. So you'd have to cut back below that level to keep it stable, and you wouldn't succeed if it's already on course up towards its hot state. You're not going to turn it back."

• That's bleak. If the transition to a less livable Earth is already under way, we're ants on a burning log. We can rush around all we want; there's nothing in our ant repertoire that can fix the problem.

But we know a couple of things. We know the worst that can happen. We know that we probably have to extend our repertoire of capabilities to either head it off or live with it. The three broad strategies for dealing with climate change are *mitigation, adaptation,* and *amelioration*. Mitigation, cutting back on greenhouse gas emissions, has been called avoiding the unmanageable. Adaptation, then, is managing the unavoidable—moving coastal populations to higher ground, developing drought-tolerant agriculture, preparing for masses of climate refugees, and keeping resource warfare localized. And amelioration is adjusting the nature of the planet itself through large-scale geoengineering.

Civilization is at risk, but civilization is the problem. The key positive feedback in the current Earth system is us. Accelerating wealth (especially in developing countries these days), a still-growing human population, and accelerating industry are pouring overwhelming quantities of greenhouse gases into the atmosphere. As Australian biologist Tim Flannery puts it, "The metabolism of our economy is now on a collision course with the metabolism of our planet."

• If Lovelock's is the worst-case climate scenario—Earth stabilizes at 5°C (9°F) warmer; a fraction of the present human population survives—then what is the best case? What can we hope for? The person with the most realistic numbers is Saul Griffith, a materials scientist and inventor who received a MacArthur "genius" award in 2007. To begin with, he says, "It is not accurate to say, 'We can still stop climate change.' We are now working to stop worse climate change or much-worse-than-worse climate change."

The most common statement of an achievable goal for dealing with climate these days is leveling off at 450 parts per million (ppm) of CO_2 in the atmosphere, so Griffith builds his analysis around that outcome. We are currently at about 387 ppm and rising fast—each year it goes up more than 2 ppm. Griffith reminds everyone that the hope with the 450 ppm goal is that it will involve a global temperature rise of only about 2°C (3.6°F), and that is expected to mean "large loss of species, more severe

storms, floods and droughts, refugees from sea level rise, and other unpalatable, expensive and inhumane consequences."

A convenient measure of energy generation is the gigawatt: a billion watts. A large coal-fired plant generates a gigawatt of electricity; so does Hoover Dam; so does a nuclear reactor. Multiply that times a thousand, and you have the terawatt—a trillion watts. Humanity currently runs on about 16 terawatts of power, most of it from the burning of fossil fuels. It's like leaving 160 billion 100-watt lightbulbs on all the time. That's what is loading the atmosphere with lethal quantities of carbon dioxide. Griffith calculates that, in order to keep the atmospheric concentration of CO_2 at no more than 450 ppm, humanity has to do something that is almost unimaginably difficult. We have to cut our fossil fuel use to around 3 terawatts, which means we have to produce all the rest of our power from non-fossil-fuel sources, *and* we have to do it in about twenty-five years or it will be too late to level off at 450 ppm.

So, Griffith says, "Imagine someone said you need 2 terawatts of wind, 2 terawatts of photovoltaic solar, 2 terawatts of solar thermal, 2 terawatts of geothermal, 2 terawatts of biofuels, and 3 terawatts of nuclear to give you 13 new clean terawatts. You add the existing 1.5 terawatts of biofuels and nuclear that we already use. You can also get 3 terawatts from coal and oil. That would give humanity around 17.5 terawatts—that allows for a little growth over the 16 terawatts we currently use. What would it take to do all that in 25 years?"

Here's the answer: "Two terawatts of photovoltaic would require installing 100 square meters of 15-percent-efficient solar cells every second, second after second, for the next 25 years. (That's about 1,200 square miles of solar cells a year, times 25 equals 30,000 square miles of photovoltaic cells.) Two terawatts of solar thermal? If it's 30 percent efficient all told, we'll need 50 square meters of highly reflective mirrors every second. (Some 600 square miles a year, times 25.) Two terawatts of biofuels? Something like 4 Olympic swimming pools of genetically engineered algae, installed every second. (About 61,000 square miles a year, times 25.) Two terawatts of wind? That's a 300-foot-

diameter wind turbine every 5 minutes. (Install 105,000 turbines a year in good wind locations, times 25.) Two terawatts of geothermal? Build three 100-megawatt steam turbines every day—1,095 a year, times 25. Three terawatts of new nuclear? That's a 3-reactor, 3-gigawatt plant every week—52 a year, times 25."

Add it up, and when you're done, you've got an area about the size of America—"Call it Renewistan," says Griffith—covered with stuff dedicated to generating humanity's energy. That's not counting transmission lines, energy storage, materials, and support infrastructure, plus the costs of shutting down all the coal plants, oil refineries, etc. I asked Saul Griffith if he thinks we can really do it. "Technically," he said, "it is possible. Industrially, humanity has the collective capacity. But politically, I don't see how." Then he added, "But we have to try. Why else bother to be human and be in this game?"

✦

A tranquil climate, we're coming to realize, is one of the "ecosystem services" that civilization requires in order to prosper; indeed, to survive. The only nonjumpy period in all of climate history (apart from the vast frozen stillnesses of the nine major ice ages) is the relatively benign "long summer" of the past ten thousand years during which humans developed agriculture, cities, and complex societies. Of course we take a gentle climate for granted; civilization has never experienced anything else.

How do we value ecosystem services? The usual panoply (food, water, air, energy, drugs, decomposition, delight, and so on) defies economic valuation, but that doesn't stop people from trying. One ecology textbook puts the number at more than $40 trillion a year, close to the world's current gross domestic product. The hope seems to be that once we know how to value ecosystem services, we'll know how to manage ourselves in relation to them.

Once upon a time, I dreamed that economics would eventually swell up and include ecology, and we would no more be misled by

notions of “externalities.” Now I’m not so sure. I recall a friend leaning on me to admit that ecology and economics are the same thing. “No, damn it,” I said. “Ecology is devoid of intention, and economics is made of little else.” (I suspect that my friend was on to something, though, because economics enthusiasts and ecology enthusiasts share an affliction. Conservatives think that the self-organizing properties of a market economy are a miracle that must not be messed with. Greens think that the self-organizing properties of ecologies are a miracle that must not be messed with.)

In one of the most influential Green books, *Natural Capitalism* (1999), Paul Hawken and Amory Lovins propose replacing industrial capitalism, which “liquidates its [natural] capital and calls it income,” with a natural capitalism based on higher efficiency in everything, biology-inspired industrial processes, a focus on services instead of products, and restoration of the all-sustaining envelope of natural systems. It’s a good book with a helpful metaphor.

• But I find it more fruitful to think of ecosystem services as infrastructure. A bridge is infrastructure, and so is the river under it. Both support our life, and both require maintenance, which has to be paid for somehow. Radio spectrum is infrastructure, and so is an intact ozone layer. Both support our life, and both require international agreements to avert a “tragedy of the commons.”

Between headlong industrial capitalism and a necessarily patient natural capitalism is a pace gap that is hard to bridge. With infrastructure, however, we already think in terms of duration and responsibility, so it’s no stretch to extend that thinking to natural systems. When there are problems with built infrastructure, we’re used to solving them with science, engineering, collaborative public agreements, and financial instruments such as bonds and public-private contracts. Those tools apply just as well to natural infrastructure.

Oddly enough, although humans have been building infrastructure for thousands of years, it’s still an intellectual no-man’s-land. I’ve yet to find any economic theory of infrastructure.

One wry definition of infrastructure is: “something gray, behind a chain-link fence.” The message is: “Don’t look, don’t touch, don’t even think about what this gray thing is for.” We’re trained to overlook infrastructure.

There are some exceptions. People like the romanticism of railroads and admire bridges and ships. Small towns decorate their water towers. But working mines, containership ports, power plants, power lines, cellphone towers, refineries, dumps, sewerage—all bear one sign: KEEP OUT. Those places are left to the workers, who are low-status.

One might say exactly the same about ecosystem infrastructure, such as watersheds, wetlands, fisheries, soil, and climate. As the truism says, we only notice infrastructure when it doesn’t work. And so, a deep bow of thanks is due to the environmentalists who for decades have been drawing attention to dangerous breakdowns of natural infrastructure and setting about the protection and restoration of watersheds, wetlands, fisheries, soil, climate, and the rest. Without their warnings and work, we would be in a far worse situation than we are.

• How did we start worrying about climate? In 1948 a conservationist named Fairfield Osborn wrote a book titled *Our Plundered Planet* (the first jeremiad of its kind) and, with Laurance Rockefeller, founded the Conservation Foundation in New York. In 1958 Charles Keeling began his epic project measuring the atmospheric concentration of CO_2. When the worrying upward trend of that concentration became apparent, Osborn’s Conservation Foundation assembled the first climate change conference in 1963; this resulted in a paper, “Implications of Rising Carbon Dioxide Content of the Atmosphere.” According to Spencer Weart’s *Discovery of Global Warming* (2004), “Their report warned that the doubling of CO_2 projected for the next century could raise the world’s temperature some 4°C (7.2°F), bringing serious coastal flooding and other damage.” The Conservation Foundation urged renewed funding for Keeling’s CO_2 project and pressed the National Academy of Sciences to pay

attention to the subject. From then on, awareness of climate change ascended right along with the Keeling Curve. In 1971 Barry Commoner's environmentalist bestseller, *The Closing Circle,* gave an early public warning about greenhouse gases. In 1978 a young congressman from Tennessee, Albert Gore, held hearings on global warming, starring his Harvard teacher Roger Revelle, who had sponsored the Keeling CO_2 research.

After the OPEC oil embargo of 1973 focused the world's attention on energy, efficiency and renewability became core doctrine for environmentalists. Solar was hip. Wind-generated electricity began developing toward the mega-infrastructure it is now. Insulated windows were invented and refined. A by-product of all that innovation, especially from the drive toward efficiency, was that gigatons of carbon dioxide stayed out of the air. I was part of that, and you're welcome.

Unfortunately for the atmosphere, environmentalists helped stop carbon-free nuclear power cold in the 1970s and 1980s in the United States and Europe. (Except for France, which *fortunately* responded to the '73 oil crisis by building a power grid that was quickly 80 percent nuclear.) Greens caused gigatons of carbon dioxide to enter the atmosphere from the coal and gas burning that went ahead instead of nuclear. I was part of that too, and I apologize.

• One more climate book to invoke here is *Plows, Plagues and Petroleum* (2005), by paleoclimatologist William Ruddiman. He examines the last 2.75 million years, dominated by dozens of ice ages, their period and amplitude driven by three intersecting astronomical cycles affecting solar intensity. Ice-core data from Greenland matches the cyclic theory closely until about five thousand years ago, when, in the midst of our current routine interglacial, the standard steep drop in atmospheric methane suddenly reversed and headed up. It's still going up. What the hell happened?

We happened. Ruddiman surmises that the cause was the sudden adoption of irrigation in China and South Asia for an

agricultural innovation, wet rice cultivation. Vegetation rotted in the new artificial wetlands and emitted methane. As rice farming expanded, so did methane emission. Add the ever-growing numbers of methane-burping livestock, plus increasing forest burning for agriculture, and the anomaly is explained. Ruddiman wondered if a similar mysterious reversal and climb in atmospheric CO_2 eight thousand years ago might have a related explanation. It did. As human population took off with agriculture, forests were burned to make new fields and pasture. Whole societies grew and migrated, forests shrank, and the atmosphere became a greenhouse. On the old astronomical schedule, a new ice age should have begun a couple of thousand years ago. Ruddiman concludes, “A glaciation is now overdue, and we are the reason.”

One further detail. What would explain the peculiar sudden dips in atmospheric CO_2 between 200 and 600, 1300 and 1400, and 1500 and 1750? Those dates happen to match major human diebacks from pandemics—Roman-era epidemics, the Black Death in Europe, and the devastation of North American native populations by European diseases. Each time, forests grew back rapidly over empty agricultural land and drew down carbon dioxide.

If Ruddiman is right, climate has been a human artifact, a highly sensitive one, for a long time. “The end of nature,” to use Bill McKibben’s famous book title, didn’t begin two hundred years ago with the Industrial Revolution but ten thousand years ago with the agricultural revolution. Farm and pasture land now takes up over a third of the world’s ice-free land surface. Ruddiman notes that “farming is not nature, but rather the largest alteration of Earth’s surface from its natural state that humans have yet achieved.” Furthermore, “A good case can be made that people in the Iron Age and even the late Stone Age had a much greater per-capita impact on the earth’s landscape than the average modern-day person.”

• Never mind terraforming Mars; we already live on a terraformed

Earth. We've been inadvertently adroit at it for ten millennia, even heading off an ice age. *Unfortunately*, we're now excessively carbon-loading the atmosphere toward inferno, though *fortunately* some of the overheating has been masked by our other major air pollutant, particulate aerosols causing "global dimming." How much longer can we count on such a string of dumb good luck?

The terraforming thus far has been unintentional. Now that we have the curse and blessing of knowing what's going on, unintentional is no longer an option. "Nature" can't be counted on, having been compromised long ago. Gaia is no savior, since "she" likes ice ages and doesn't mind hot ages either. We're left with intention, with conscious design, with engineering. We finesse climate, or climate finesses us.

Of the tools that come to hand, this book will examine four that environmentalists have distrusted and now need to embrace, plus one we love that has to be scaled up. The unwelcome four are urbanization, nuclear power, biotechnology, and geoengineering. The familiar one is natural-system restoration, which may be better framed as megagardening—restoring Gaia's health at every scale from local soil to the whole atmosphere.

One more positive feedback to take account of in the overall climate system is the autocatalytic—self-accelerating—technologies that can be deployed against the self-accelerating problems of world industrialization and against the positive feedbacks in climate itself. Our management of future technology acceleration has to reverse the effects of past technology acceleration. (Stopping present technology where it is would lead to Lovelock's uninhabitable hot world.) The goal is for the climate-plus-humans system to settle down to a healthy, stable negative-feedback regime.

Not all technologies are autocatalytic: New discoveries don't make every technology advance faster. Progress in automobile technology and wind technology makes better cars and wind generators but not better tools for the engineering itself. The current autocatalytic technologies that goose themselves into exponential growth are infotech (including computers, communications, and artificial intelligence), biotech, and nanotech

(which is blurring into biotech). What's more, they stimulate each other in a mutual catalysis that at times results in hyperexponential growth of power.

Forty years ago, I started the *Whole Earth Catalog* with the words, "We *are* as gods, and might as well get good at it." Those were innocent times. New situation, new motto: "We are as gods and *have* to get good at it." The *Whole Earth Catalog* encouraged individual power; *Whole Earth Discipline* is more about aggregate power.

The scale of the climate challenge is so vast that it cannot be met solely by grassroots groups and corporations, no matter how Green. The situation requires government fiat to set rules and enforce them. Specifically, the four major energy-using governments—the European Union, the United States, China, and India—have to get tough. If all four do the right thing, there's hope. So far the European governments have led the way.

Our civilization caused climate change, and now it is undertaking to cause climate nonchange. At the end of the exercise (if it's successful), climate will be the same but civilization probably won't. We will be more transformed by our efforts to stabilize climate than by anything else we do in this century. If we fail to stabilize climate, our civilization will either be gone or unrecognizable.

Who wrote this book?

I turned seventy during the writing in 2008 and 2009. In seven decades, I've enjoyed the instruction of living downstream from a good many of my own and other people's mistakes. As the old joke goes: How do you build good judgment? (Experience!) How do you build experience? (Bad judgment!) Because I'm an ecologist by training, a futurist by profession, and a hacker (lazy engineer) at heart, my bent is scientific rigor, geoeconomic perspective, and an engineer's bias, which sees everything in terms of solvable design problems.

In keeping with professional forecaster practice, my opinions are strongly stated and loosely held—strongly stated so that clients can get at them to conjure with, loosely held so that facts and the persuasive arguments of others can get at them to change them. My opinion is not important; it's just a tool. The client's evolving opinion is what's important. Your evolving opinion is what's important. If you're reading this book just to reinforce your present opinions, you've hired the wrong consultant.

I'm a lifelong environmentalist. My voice piped at age ten: "I give my pledge as an American to save and faithfully to defend from waste the natural resources of my country—its air, soil, and minerals, its forests, waters, and wildlife." I got infected by that Conservation Pledge through the magazine *Outdoor Life* and proceeded to paste it on everything and everyone around me. Since the concept of *pledge* has long been rendered meaningless by the surreal Pledge of Allegiance that American schoolchildren have to recite, what I meant in 1948—and mean now—is: "I declare my intent to save and defend from waste the world's natural resources—its air, soil, and minerals, its forests, waters, and wildlife."

I graduated with a degree in biology from Stanford in 1960, having focused mainly on evolution and what was then the very low-status field of ecology. One of my teachers, the later-renowned Paul Ehrlich, encouraged me to publish the results from my only fieldwork, concerning two species of tarantulas out back of Stanford that appeared to be permanently mingled, in violation of Gause's principle, which states that no two species can long occupy the same niche together. Instead of publishing, I went off to the army to be an officer.

Some of the Green adventures I had after that will turn up later in these pages. My previous books (on new media and adaptive buildings) have been journalistic essays—reports by an outsider. This one is journalistic too, but it's written from inside its subject. Some of the issues I'm writing about I have a stake in; some of the people I'm writing about are friends. Where I think my personal experience has some relevance, I'll throw it in.

There are two things I won't attempt in this book. The goal of

the environmental movement is to manage the commons well—meaning for everyone and for the long term. A great service would be to inventory and praise the countless environmental organizations and success stories that have kept the commons—air, forests, soil, oceans, animal life—as healthy as they are. I'm not doing that here. Another important service would be to inventory and condemn the innumerable cases in which governments, companies, and property owners have done their best to mismanage the commons for private and short-term gain, meanwhile disparaging and thwarting environmentalists. It would be fun and useful to compile a bestiary of such behaviors and examine their constituent pathologies, but I have other fish to fry.

Whole Earth Discipline carries on something that began in 1968, when I founded the *Whole Earth Catalog.* I stayed with the *Catalog* as editor and publisher until 1984, adding a magazine called *CoEvolution Quarterly* along the way. The Whole Earth publications were compendia of environmentalist tools and skills (along with much else) and explicitly purveyed a biological way of understanding. Peter Warshall wrote and reviewed about watersheds, soil, and ecology. Richard Nilsen and Rosemary Menninger covered organic farming and community gardens. J. Baldwin was an impeccable source on "appropriate technology"—solar, wind, insulation, bicycles. Lloyd Kahn wrote about handmade houses. We promoted bioregionalism, restoration, and "reinhabitation" of one's natural environment. There's now an insightful book about all that by Andrew Kirk—*Counterculture Green: The Whole Earth Catalog and American Environmentalism* (2007).

These days I divide my time between Global Business Network and an idiosyncratic foundation. In the 1990s, when inventor Danny Hillis came up with an idea to help people think long-term by building a monumental ten-thousand-year clock, I responded by cofounding The Long Now Foundation with him in 1996. "Fostering long-term responsibility" is its mission. The "long now" is defined as the last ten thousand years and the next ten thousand years. That is the reach of humanity's current decisions.

• Lovelock said, “The planet really is on the move.” So is civilization, now completing a process it began ten millennia ago—moving to town. Ecopragmatism in this century has to begin with understanding what humanity’s momentous transition from rural to urban is made of, and what it portends. The subject has so much news, I’ll give it two chapters.

A “city planet” needs city power—grid electricity. At present, the best low-carbon source is nuclear. I’ll explore a chapter’s worth of how that fits into a climate-driven Green agenda and then do the same for genetic engineering for two chapters, because I believe biotech offers a major tool for reducing the overwhelming impact of agriculture on natural infrastructure, and new discoveries about genes and microbes are transforming the science of ecology.

Science has long informed the environmental movement. Now it must take the lead, because we are forced to enter an era of large-scale ecosystem engineering, and we have to know what the hell we’re doing. That sermon gets a chapter. Beavers are benevolent ecosystem engineers; so are soil-enriching earthworms; so were American Indians, who terraformed a continent; so are all of us who work on restoring natural infrastructure. A chapter on that subject leads straight to the book’s conclusion: our obligation to learn planet craft, to be as life-enhancing as any earthworm, in the big yard.

Live-linked footnotes for this chapter, along with updates, additions, and illustrations, may be found online at **www.sbnotes.com**.

what's going on now.

The move to town is a liberation. A *New York Times* story in 2005 related that

> Gandhi idealized villages as the way to return Indians to their precolonial state. B. R. Ambedkar, the Dalit, or untouchable, leader who helped write India's Constitution, saw it differently: he called villages a cesspool, "a den of ignorance, narrow-mindedness and communalism," and urged untouchables to flee them for urban anonymity.

The same article gave an example of the strongest reason to migrate from India's 600,000 villages to cities such as Surat, with a population of 3.5 million:

> Rajesh Kumar Raghavji Santoki, 28, had tried farming for a year at home, and given up in the face of a water shortage. After just three years in Surat, he was earning in a month more than the $500 his farmer father earned in a year. He owned a house, a motorcycle and a van.

Multiply his motivation by 900 million—the 70 percent of India's 1.3 billion still living in rural areas. Multiply it by 2.8 billion, the number of people still rural throughout the developing world. At the same time that opportunity in the cities is becoming more attractive, in many places the countryside keeps getting rougher. The land is depleted by overuse, landholdings shrink as they are divided among successive generations, and civil strife is a frequent threat. Many of my contemporaries in the developed world regard subsistence farming as soulful and organic, but it is a poverty trap and an environmental disaster. When subsistence farms are abandoned, the trees and shrubs, no longer gathered for firewood, quickly return, and so do the wild animals no longer hunted and trapped for bush meat.

• In developed regions like North America and Europe, the rural push and urban pull are different but just as compelling. Lou Reed sings, "When you're growing up in a small town / You know you'll grow down in a small town./ There's only one good use for a small

town: / You hate it, and you know you'll have to leave." In America's northern high plains, cities like Fargo, Bismarck, and Grand Forks are thriving, but the rest of the vast grasslands is emptying, leaving ghost towns and decaying farmhouses. *National Geographic* describes "a sense of things ebbing, of churches being abandoned, schools shutting down, towns becoming ruins." Some megafauna—moose and mountain lions—are coming back. The whole high-plains region from eastern Montana to northern Texas is headed toward becoming the "buffalo commons" that environmentalists long for.

In developed countries like the United States the migration is from boring, lonely, and hard to exciting, busy, and pleasant—toward coasts, sun, and densely citified regions called megapolitan areas, such as the one encompassing everything on the eastern seaboard from Boston to Richmond, Virginia, or the one I live in, reaching from San Francisco to Reno, Nevada —"from sea to ski." All over the developed world, once-thriving remote fishing villages are emptying. The fishing, alas, carries on more intensely than ever, but now in urban-based factory ships. When Communism collapsed, the formerly subsidized small towns of central Russia and Eastern Europe instantly lost their young people and their future.

But the main event is not in Europe or North America. The United States has 49 cities with populations over a million; China has 160. Since 1950 in China, 300 *million* people have moved to the cities, and *another* 300 million are expected in the next few decades. That's nearly half of China's total population of 1.3 billion on the move. It is typical of the developing world.

According to some historians, "Civilization is what happens in cities." (*Civilization* and *city* are in the same Latinate word group, along with *civil, civics, citizen,* etc.) I live in California, but I avidly read the *New Yorker* and the *New York Times,* just as the French read *Paris Match* and the English read the London newspapers. You can characterize any nation by its largest city, and study the progress of any era by examining the largest cities of its time. Most of the people I know think of the world in terms of London, New York, Paris, Berlin—the great Western metropolises. Those

were indeed the largest cities a hundred years ago. In 1900 London had a population of 6.5 million; New York had 4.2 million; followed by Paris, Berlin, Chicago, Vienna, Tokyo, Saint Petersburg, Manchester, and Philadelphia. Tokyo is the only surprise in that top-ten list.

Fifty years later, in 1950, the leading ten cities had doubled in size, and Shanghai, Buenos Aires, and Calcutta had joined the list. Fifty years after that, in 2003, the top ten cities had further tripled in size, but that was the least of their changes. The leaders now were Tokyo with 35 million, Mexico City with 19 million, New York still in the game with 18 million, São Paulo with 18 million, Mumbai with 17 million, Delhi with 14 million, Calcutta with 13 million, Buenos Aires with 13 million, Shanghai with 13 million, and Jakarta with 12 million. Those big numbers are big events. By 2015, according to United Nations predictions, the top-ten roster will be joined by Dhaka, in Bangladesh, and Lagos, in Nigeria; and coming on fast will be Karachi, Cairo, Manila, Istanbul, Lima, Tehran, and Beijing.

The trend is pretty clear. The “rise of the West” is over. The world looks the way it did a thousand years ago, when the ten largest cities were Córdoba, in Spain; Kaifeng, in China; Constantinople; Angkor, in Cambodia; Kyoto; Cairo; Baghdad; Nishapur, in Iran; Al-Hasa, in Saudi Arabia; and Patan, in India. As Swedish statistician Hans Rosling says, “The world will be normal again; it will be an Asian world, as it always was except for these last thousand years. They are working like hell to make that happen, whereas we are consuming like hell.”

• It may be distracting, though, to focus just on the world’s twenty-four megacities—those with a population over 10 million. The real action is in what the United Nations calls small cities (fewer than 500,000 inhabitants; home to half of the world’s city dwellers) and intermediate cities (1 million to 5 million, where 22 percent of urbanites live). A UN report points out: “They are often the first places where the social urban transformation of families and individuals occurs; by offering economic linkages between rural and urban environments, they can provide a ‘first step’ out of

poverty for impoverished rural populations and a gateway to opportunities in larger cities."

The Marxist scholar Mike Davis gives perspective on the phenomenon in his 2006 book, *Planet of Slums*:

> In Africa…the supernova-like growth of a few giant cities like Lagos (from 300,000 in 1950 to 10 million today) has been matched by the transformation of several dozen small towns and oases like Ouagadougou, Nouakchott, Douala, Antananarivo and Bamako into cities larger than San Francisco or Manchester. In Latin America, where primary cities long monopolized growth, secondary cities like Tijuana, Curitiba, Temuco, Salvador and Belém are now booming.

In other words, more and more news will be coming from cities most people in the West have never heard of. Developing countries are urbanizing at a rate and volume qualitatively different from what happened in Europe and North America—three times faster and nine times bigger. Beyond our horizon of attention, the world is being transformed.

• Of all human organizations, cities are the longest-lived. The oldest surviving corporations, Stora Enso in Sweden and the Sumitomo Group in Japan, are about 700 and 400 years old, respectively. The oldest universities, in Bologna and Paris, have lasted only 1,000 years so far. The oldest living mainstream religions, Hinduism and Judaism, date back about 3,500 years. But the town of Jericho has been continuously occupied for 10,500 years. Its neighbor Jerusalem has been an important city for 5,000 years, even though it was conquered or destroyed thirty-six times and endured eleven conversions from one religion to another. Many cities die or decline to irrelevance, but some thrive for millennia.

I suspect that one cause of their durability is that cities are the most constantly changing of organizations. In Europe they consume 2 to 3 percent per year of their material fabric (buildings, roads, and other construction) through demolition and rebuilding. Effectively, a whole new city takes shape every fifty years. In the

United States and the developing world, the turnover is even faster. Yet despite all the physical metamorphosis, something about a city remains deeply constant. Some combination of geography, economics, and cultural continuity ensures that even a city destroyed by war (Warsaw, Tokyo) or fire (London, San Francisco) will often be rebuilt and retain its identity.

• Cities are horrendously expensive, both environmentally and economically, but they more than earn their keep. “Cities make countries rich. Countries that are highly urbanized have higher incomes, more stable economies, stronger institutions. They are better able to withstand the volatility of the global economy than those with less urbanized populations.” So notes the United Nations Human Settlements Programme (UN-HABITAT), which was impelled to its city-boosting position by revelations in the worldwide data it has been gathering since 1978.

The reversal of opinion about fast-growing cities—from bad news to good news—began with *The Challenge of Slums,* a 2003 UN-HABITAT report. The book’s reluctant optimism came from its groundbreaking fieldwork—thirty-seven case studies in slums worldwide. Instead of just compiling numbers and filtering them through remotely conceived theories, the researchers hung out in the slums, talking to people. They came back with an unexpected observation: “Cities are so much more successful in promoting new forms of income generation, and it is so much cheaper to provide services in urban areas, that some experts have actually suggested that the only realistic poverty reduction strategy is to get as many people as possible to move to the city.”

In 2007 the United Nations Population Fund gave that year’s report the upbeat title *Unleashing the Potential of Urban Growth.* The lead author, Canadian demographer George Martine, wrote, “Cities concentrate poverty, but they also represent the best hope of escaping it.” He declared in a talk that “80 to 90 percent of GNP growth occurs in cities” and that “the half of the world’s population living in cities occupies only 2.8 percent of the world’s land area.” He went on to say, “In cities, concentration and density make it easier to provide social services. Education, health, sanitation,

making our cities bigger. We need more metropolises." (I am a contributing editor to *Conservation*.)

In Peter Ackroyd's *London: The Biography* (2000), he quotes William Blake—"Without Contraries is no progression"—and ventures that Blake came to that view from his immersion in London. "Wherever you go in the city," Ackroyd observes, "you are continually being assaulted by difference, and it could be surmised that the city is simply made up of contrasts; it is the sum of its differences." What drives a city's innovation engine, then—and thus its wealth engine—is its multitude of contrasts. The more and greater the contrasts, and the more they are marbled together, the better. The most productive city is one with many cultures, many languages, many neighborhoods, and more kinds of urban experience available than any citizen can keep track of. In this formulation, it is the throwing together of great wealth and great poverty in the urban stew that is part of the cure for poverty.

The common theory of the origin of cities states that they resulted from the invention of agriculture: Surplus food freed people to become specialists. You can't have full-time cobblers, blacksmiths, and bureaucrats, the theory goes, without farms to feed them. Jane Jacobs upended that supposition in *The Economy of Cities* (1969). "Rural economies, including agricultural work," she wrote, "are directly built upon city economies and city work." It was so in the beginning, she argued, and continues to this day. Most farming innovations, for example, are city-based. When Rome collapsed, European agriculture collapsed. When crop rotation was reinvented in the twelfth century, it began around European cities and took two centuries to reach remote farms. In the eighteenth century, the revolutionary use of fodder crops like alfalfa to fix nitrogen in the soil was developed first in city gardens. American agriculture soared in the 1920s when hybrid corn was invented, not on a farm but in a New Haven, Connecticut, laboratory.

If agriculture didn't create cities, what did? Jane Jacobs thought it was trade. My guess, based on the "constant battles" view of history, is defense. The first urban invention, I'll bet, was a defendable wall, followed by rectangular buildings that allowed close packing of maximum residents within a minimum amount of wall. (Pastoral and hunter-gatherer buildings—yurts, tipis, hogans, wikiups, bomas, and the like—are round.) Just like the most ancient town dwellers of Mesopotamia, the agricultural Pueblo tribes of the American Southwest lived in dense fortresses several stories high, with no openings in the outer walls. Entry was by retractable ladders. When defense against raids by nomadic Apaches and Navajos became irrelevant after the conquest by whites, the Pueblos all dispersed into scattered buildings (except where high-rise density is maintained partly for tourists, as at Taos and Acoma). "The earliest meaning of 'town,' said the urban scholar Lewis Mumford, "is an enclosed or fortified place."

Agriculture, it appears, was an early invention by the dwellers of walled towns to allow their settlements to keep growing, as in Geoffrey West's formulation. Today's megacities rely on the same flow of innovation. A 2006 UN-HABITAT report proposed that

> Cities are engines of rural development…. Improved infrastructure between rural areas and cities increases rural productivity and enhances rural residents' access to education, health care, markets, credit, information and other services. On the other hand, enhanced urban-rural linkages benefit cities through increased rural demand for urban goods and services and added value derived from agricultural produce.

Nothing saves a village like a good road to town and a good cellphone connection.

When urban migration leaves fewer people on the land, the ones remaining can shift from subsistence farming on marginal land to more concentrated cash-crop agriculture on prime land. That's better for the city, better for the locals, and better for natural systems in the area. Aquifers recover; forests recover. A study in Panama showed what happened when people abandoned slash-and-burn agriculture to move to town: "With people gone, secondary forest has regenerated. Crucially, if protected from

hunters, nearly every bird and mammal species found in primary forest has also been found in secondary." Fifty-five times more tropical rain forest is growing back each year than is being cut, according to a 2005 report on world forests from the UN: 38 million acres of primary forest is cut, but 2.1 billion acres of secondary forest is growing back on land that was once farmed, logged, or burned.

Yet another urban innovation is the environmentalist idea of protecting, preserving, and restoring natural systems. As societies become more urban, they become Greener in their sensibilities. As their cities become more globally oriented they pick up environmentalist ideas and practices—and demands—from abroad. All of that can, if encouraged, contribute to increasing protection for the countryside emptying of people and refilling with biodiversity.

Peasants who leave the land take rural skills and values to the city slums with them. Building their own shelter is what they've always done, at a minuscule fraction of the cost of city-provided housing. Collaborating with extended family and neighbors in close proximity is nothing new to them, and neither is doing without elaborate infrastructure. Those are all the abilities they need to build the most creative urban phenomenon of our time, the squatter cities—the teeming slums of the uninvited that house a billion people now, two billion soon.

Let no one romanticize what the slum conditions are. New squatter cities typically look like human cesspools and often smell like them. Usually there are no facilities at all for sanitation, for water, for electricity, for transportation. Everyone lives in dilapidated shacks that are jammed together wall to wall, every room full of people. A typical squatter city, which may stretch for miles, has grown without a plan or government, in an area generally deemed uninhabitable: a swamp, a floodplain, a steep hillside, or a municipal dump; clustered in the path of a highway

project or squashed up against a busy railroad line.

But the squatter cities are *vibrant*. Their narrow lanes are bustling markets, with food stalls, bars, cafés, hair salons, dentists, churches, schools, health clubs, and mini-shops trading in cellphones, tools, trinkets, clothes, electronic gadgets, and bootleg videos and music. This is urban life at its most intense. It is social capital at its richest, because everybody in a slum neighborhood knows everybody else intimately, whether they want to or not. What you see up close is not a despondent populace crushed by poverty but a lot of people busy getting out of poverty as fast as they can.

Perhaps the most extreme case is Mumbai, with 17 million people more densely packed than anywhere else in the world. The city is half slum, yet it generates one sixth of India's gross domestic product. Suketu Mehta, author of *Maximum City* (2004), wrote in 2007:

> Why would anyone leave a brick house in the village with its two mango trees and its view of small hills in the East to come here? So that someday the eldest son can buy two rooms in Mira Road, at the northern edges of the city. And the younger one can move beyond that, to New Jersey. Discomfort is an investment….
>
> One brother works and supports the others, and he gains satisfaction from the fact that his nephew takes an interest in computers and will probably go on to America. Mumbai functions on such invisible networks of assistance. In a Mumbai slum, there is no individual, only the organism. There are circles of fealty and duty within the organism, but the smallest circle is the family. There is no circle around the self.
>
> It's a place where your caste doesn't matter, where a woman can dine alone at a restaurant without harassment, and where you can marry the person of your choice. For the young person in an Indian village, the call of Mumbai isn't just about money. It's also about freedom.

By 2004 I knew something important was up with the rampant urbanization of the developing world, but I couldn't find much in the way of ground truth about it until the publication of *Shadow Cities: A Billion Squatters, a New Urban World,* by journalist

Robert Neuwirth. His research strategy was to learn the relevant language and then live for months as a slum resident—in Rocinha (one of seven hundred *favelas* in Rio de Janeiro), in Kibera (a squatter city of 1 million outside Nairobi), in the Sanjay Gandhi Nagar neighborhood of Mumbai, and in Sultanbeyli, a now fully developed squatter city of 300,000 with a seven-story city hall, outside Istanbul. In each seemingly scary shantytown, Neuwirth found he could just walk in, ask around, find a place to rent, and start making friends. In Kibera he was the only white person for miles, and no one cared. He was frightened just once, when city police in Rio threatened him, apparently because he had neglected to bribe them.

Contrary to a standard assumption, Neuwirth discovered that the wretched quality of housing in squatter cities is never the main concern of the inhabitants. The sad fact is that when governments and idealistic architects try to help by providing public housing, those buildings invariably turn into the worst part of the slum. The people who build the shanties take pride in them and are always working to improve them. The real issues for the squatters, Neuwirth found, are location—they want to be close to work—and what the UN calls security of tenure: They need to know that their homes and community won't be suddenly bulldozed out of existence.

They don't worry about unemployment: Everyone works, including the children. They don't worry about telephone service: Everyone has a cellphone or access to one. Medical care is available, and so is food; famine is now a rural phenomenon. The greatest need in every squatter city is infrastructure—water, electricity, and sanitation. Not always the hotbeds of criminal activity that everyone assumed, some squatter communities are victimized by criminals from outside because they have no police protection. Though the squatters join forces for what the UN researchers describe as "cultural movements and levels of solidarity unknown in leafy suburbs," they are seldom politically active beyond defending their own community interests.

A depiction of contemporary slum reality even more vivid than Neuwirth's is an autobiographical novel by an escaped Australian

soul-bond to the land could be a great asset for assuring eventual environmental recovery in the developing countries, when love of the land plays out as protection of the land.

Religious groups have a stronger support role in the slums than most people realize. As Mike Davis wrote in *Planet of Slums,*

> Populist Islam and Pentecostal Christianity (and in Bombay, the cult of Shivaji) occupy a social space analogous to that of early-twentieth-century socialism and anarchism. In Morocco, for instance, where half a million rural emigrants are absorbed into the teeming cities every year, and where half the population is under 25, Islamicist movements like "Justice and Welfare," founded by Sheik Abdessalam Yassin, have become the real governments of the slums: organizing night schools, providing legal aid to victims of state abuse, buying medicine for the sick, subsidizing pilgrimages and paying for funerals…. Pentecostalism is…the first major world religion to have grown up almost entirely in the soil of the modern urban slum…. Since 1970, and largely because of its appeal to slum women and its reputation for being color-blind, [Pentacostalism] has been growing into what is arguably the largest self-organized movement of urban poor people on the planet.

In the 2007 UN report, George Martine noted that "Rapid urbanization was expected to mean the triumph of rationality, secular values and the demystification of the world…. Instead… the growth of new religious movements is primarily an urban phenomenon…. In China, where cities are growing at a breakneck pace, religious movements are fast gaining adherents."

• To me the most compelling image of hope in squatter communities is something you see everywhere—masonry and concrete building walls with rebar sticking out the top, ready for further construction. On the upper floors of hand-built high-rises, the rebar is there in the expectation that eventually another story will be added to the building—space for a related family or another source of rent. All around urban Turkey, you see heaps of tile bricks in people's yards. When they get a little money, they buy some bricks, which are impervious to currency inflation. When they get some more money, they build a wall or two. Unfinished

masonry holds up fine against weather.

In new squatter communities, and in ones that are constantly threatened by demolition, the shack materials are cardboard, cloth, plastic, scrap wood, flattened oil drums, and—the most prized—corrugated steel sheets. Rob Neuwirth chants in *Shadow Cities*:

> Praise be to plastic pipe. All honor the prefab window. Bow down to sheets of old plywood, stock-model sinks, mass-produced tile. Three cheers for cement and cinderblock. Exalt the lowly rebar. Let's hear it for quick-drying concrete. Hooray for easy plastic wiring, easy plug outlets, and modular telephone service.

Over time, the walls get solider and higher, the materials more durable. The magic of squatter cities is that they are improved steadily and gradually, increment by increment, by the people living there. Each home is built that way, and so is the whole community. To a planner's eye, squatter cities look chaotic. To my biologist's eye, they look organic.

Prince Charles has the same opinion. After visiting Mumbai's Dharavi slum, he told an audience in London, "I find an underlying, intuitive grammar of design that subconsciously produces [a place] that is walkable, mixed-use, and adapted to local climate and materials—which is totally absent from the faceless slab blocks that are still being built around the world to warehouse the poor."

According to urban researchers, squatters are now the predominant builders of cities in the world.

• Inside the homes of the older squatter communities is another surprise. Field researchers in Thailand for the 2003 UN report found that

> All slum households in Bangkok have a colour television. The average number of TVs per household is 1.6…. Almost all of them have a refrigerator. Two-thirds of the households have a CD player, a washing machine, and 1.5 cellphones. Half of them have a home telephone, a video player and a motorcycle.

Back in 1970, Janice Perlman interviewed 750 residents in the *favelas* of Rio. Her resulting book, *The Myth of Marginality* (1976), observed that the *favelados* "have the aspirations of the bourgeoisie, the perseverance of pioneers, and the values of patriots." Thirty years later, in 2001, she went back to interview her original informants and their children. The changes were dramatic. While the residents of the *favelas* still suffer discrimination because of where they live, their literacy rate has gone from 5 percent among the original migrants to 94 percent in their children. Everyone now lives in brick buildings, with electricity, water, and indoor bathrooms. All have refrigerators, TVs, cellphones, and washing machines, and are more likely to have microwave ovens and computers than are middle-class people elsewhere in Rio. Two thirds had left the *favelas* for more legitimate neighborhoods, but many who stayed now have genuinely luxurious wall tiling and furniture sets in their homes.

A reporter from the *Economist* who visited Mumbai wrote that "Dharavi, which is allegedly Asia's biggest slum, is vibrantly and triumphantly alive…. In fluorescent-strip-lit shops, in snatched exchanges in the pedestrian crush, as a hookah is passed around a tea-stall, again and again, the stories are the same. Everyone is working hard and everyone is moving up."

Slums are the scene of a world-changing economic event, but it escapes notice because it's designed to escape notice. Squatters don't formally own land or property. They don't pay taxes. They take no part in any permit or licensing process. They pay no attention to government-approved exchange rates. And yet they thrive economically, charging each other rent for space in buildings with no legal ownership, employing each other in unlicensed businesses, and selling each other all manner of services and goods—some of the goods pirated, some of the services criminal. This is what is called the "informal economy." It is to economic theory what dark energy is to astrophysical theory.