What It Would Really Take to Reverse Climate Change

IEEE SPECTRUM

Today’s renewable energy technologies won’t save us. So what will?

By Ross Koningstein & David Fork
Posted 18 Nov 2014 | 20:00 GMT

Google cofounder Larry Page is fond of saying that if you choose a harder problem to tackle, you’ll have less competition. This business philosophy has clearly worked out well for the company and led to some remarkably successful “moon shot” projects: a translation engine that knows 80 languages, self-driving cars, and the wearable computer system Google Glass, to name just a few.

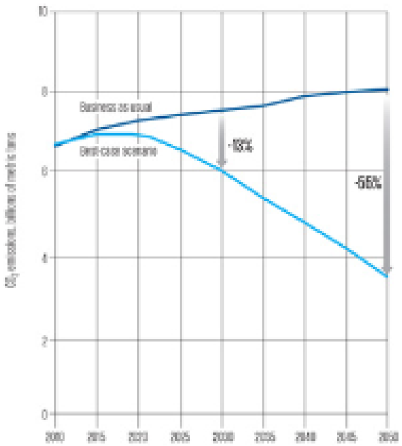
Starting in 2007, Google committed significant resources to tackle the world’s climate and energy problems. A few of these efforts proved very successful: Google deployed some of the most energy-efficient data centers in the world, purchased large amounts of renewable energy, and offset what remained of its carbon footprint.

Google’s boldest energy move was an effort known as RE<C, which aimed to develop renewable energy sources that would generate electricity more cheaply than coal-fired power plants do. The company announced that Google would help promising technologies mature by investing in start-ups and conducting its own internal R&D. Its aspirational goal: to produce a gigawatt of renewable power more cheaply than a coal-fired plant could, and to achieve this in years, not decades.

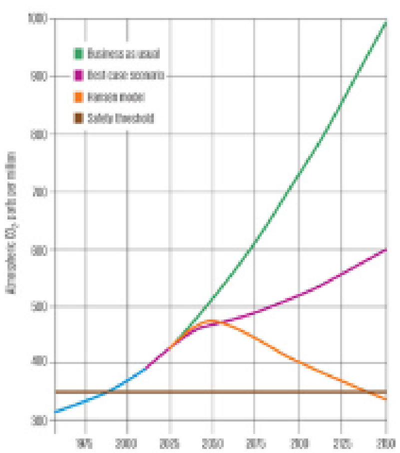
Unfortunately, not every Google moon shot leaves Earth orbit. In 2011, the company decided that RE<C was not on track to meet its target and shut down the initiative. The two of us, who worked as engineers on the internal RE<C projects, were then forced to reexamine our assumptions.

At the start of RE<C, we had shared the attitude of many stalwart environmentalists: We felt that with steady improvements to today’s renewable energy technologies, our society could stave off catastrophic climate change. We now know that to be a false hope—but that doesn’t mean the planet is doomed.

The Climate Conundrum



In the energy innovation study's best-case scenario, rapid advances in renewable energy technology bring down carbon dioxide emissions significantly.



Yet because CO2 lingers in the atmosphere for more than a century, reducing emissions means only that less gas is being added to the existing problem. Research by James Hansen shows that reducing global CO2 levels requires both a drastic cut in emissions and some way of pulling CO2 from the atmosphere and storing it.

Data Sources: "The Impact of Clean Energy Innovation," Google-McKinsey, 2011; "Target Atmospheric CO2: Where Should Humanity Aim?," James Hansen et al., 2008

As we reflected on the project, we came to the conclusion that even if Google and others had led the way toward a wholesale adoption of renewable energy, that switch would not have resulted in significant reductions of carbon dioxide emissions. Trying to combat climate change exclusively with today's renewable energy technologies simply won't work; we need a fundamentally different approach. So we're issuing a call to action. There's hope to avert disaster if our society takes a hard look at the true scale of the problem and uses that reckoning to shape its priorities.

Climate scientists have definitively shown that the buildup of carbon dioxide in the atmosphere poses a looming danger. Whether measured in dollars or human suffering, climate change threatens to take a terrible toll on civilization over the next century. To radically cut the emission of greenhouse gases, the obvious first target is the energy sector, the largest single source of global emissions.

RE<C invested in large-scale renewable energy projects and investigated a wide range of innovative technologies, such as self-assembling wind turbine towers, drilling systems for geothermal energy, and solar thermal power systems, which capture the sun's energy as heat. For us, designing and building novel energy systems was hard but rewarding work. By 2011, however, it was clear that RE<C would not be able to deliver a technology that could compete economically with coal, and Google officially ended the initiative and shut down the related internal R&D projects. Ultimately, the two of us were given a new challenge. Alfred Spector, Google's vice president of research, asked us to reflect on the project, examine its underlying assumptions, and learn from its failures.

We had some useful data at our disposal. That same year, Google had completed a study on the impact of clean energy innovation, using the consulting firm McKinsey & Co.'s low-carbon economics tool. Our study's best-case scenario modeled our most optimistic assumptions about cost reductions in solar power, wind power, energy storage, and electric vehicles. In this scenario, the United States would cut greenhouse gas emissions dramatically: Emissions could be 55 percent below the business-as-usual projection for 2050.

While a large emissions cut sure sounded good, this scenario still showed substantial use of natural gas in the electricity sector. That's because today's renewable energy sources are limited by suitable geography and their own intermittent power production. Wind farms, for example, make economic sense only in parts of the country with strong and steady winds. The study also showed continued fossil fuel use in transportation, agriculture, and construction. Even if our best-case scenario were achievable, we wondered: Would it really be a climate victory?

A 2008 paper by James Hansen [PDF], former director of NASA’s Goddard Institute for Space Studies and one of the world’s foremost experts on climate change, showed the true gravity of the situation. In it, Hansen set out to determine what level of atmospheric CO_2 society should aim for “if humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted.” His climate models showed that exceeding 350 parts per million CO_2 in the atmosphere would likely have catastrophic effects. We’ve already blown past that limit. Right now, environmental monitoring shows concentrations around 400 ppm. That’s particularly problematic because CO_2 remains in the atmosphere for more than a century; even if we shut down every fossil-fueled power plant today, existing CO_2 will continue to warm the planet.

We decided to combine our energy innovation study’s best-case scenario results with Hansen’s climate model to see whether a 55 percent emission cut by 2050 would bring the world back below that 350-ppm threshold. Our calculations revealed otherwise. Even if every renewable energy technology advanced as quickly as imagined and they were all applied globally, atmospheric CO_2 levels wouldn’t just remain above 350 ppm; they would continue to rise exponentially due to continued fossil fuel use. So our best-case scenario, which was based on our most optimistic forecasts for renewable energy, would still result in severe climate change, with all its dire consequences: shifting climatic zones, freshwater shortages, eroding coasts, and ocean acidification, among others. Our reckoning showed that reversing the trend would require both radical technological advances in cheap zero-carbon energy, as well as a method of extracting CO_2 from the atmosphere and sequestering the carbon.

Those calculations cast our work at Google’s RE<C program in a sobering new light. Suppose for a moment that it had achieved the most extraordinary success possible, and that we had found cheap renewable energy technologies that could gradually replace all the world’s coal plants—a situation roughly equivalent to the energy innovation study’s best-case scenario. Even if that dream had come to pass, it still wouldn’t have solved climate change. This realization was frankly shocking: Not only had RE<C failed to reach its goal of creating energy cheaper than coal, but that goal had not been ambitious enough to reverse climate change.

That realization prompted us to reconsider the economics of energy. What’s needed, we concluded, are reliable zero-carbon energy sources so cheap that the operators of power plants and industrial facilities alike have an economic rationale for switching over soon—say, within the next 40 years. Let’s face it, businesses won’t make sacrifices and pay more for clean energy based on altruism alone. Instead, we need solutions that appeal to their profit motives. RE<C’s stated goal was to make renewable energy cheaper than coal, but clearly that wouldn’t have been sufficient to spur a complete infrastructure changeover. So what price should we be aiming for?

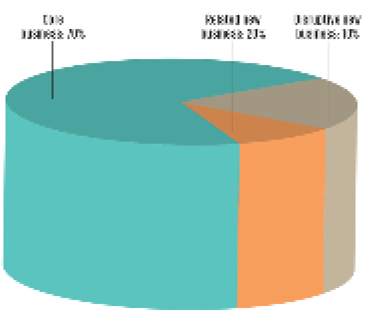
What’s needed are zero-carbon energy sources so cheap that the operators of power plants and industrial facilities alike have an economic rationale for switching over within the next 40 years

Consider an average U.S. coal or natural gas plant that has been in service for decades; its cost of electricity generation is about 4 to 6 U.S. cents per kilowatt-hour. Now imagine what it would take for the utility company that owns that plant to decide to shutter it and build a replacement plant using a zero-carbon energy source. The owner would have to factor in the capital investment for construction and continued costs of operation and maintenance—and still make a profit while generating electricity for less than \$0.04/kWh to \$0.06/kWh.

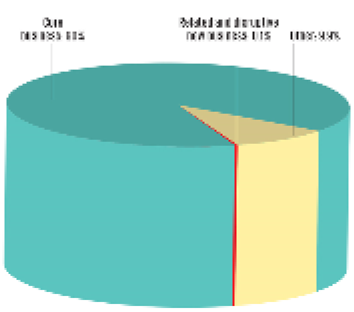
That’s a tough target to meet. But that’s not the whole story. Although the electricity from a giant coal plant is physically indistinguishable from the electricity from a rooftop solar panel, the value of generated electricity varies. In the marketplace, utility companies pay different prices for electricity, depending on how easily it can be supplied to reliably meet local demand.

“Dispatchable” power, which can be ramped up and down quickly, fetches the highest market price. Distributed power, generated close to the electricity meter, can also be worth more, as it avoids the costs and losses associated with transmission and distribution. Residential customers in the contiguous United States pay from $0.09/kWh to $0.20/kWh, a significant portion of which pays for transmission and distribution costs. And here we see an opportunity for change. A distributed, dispatchable power source could prompt a switchover if it could undercut those end-user prices, selling electricity for less than $0.09/kWh to $0.20/kWh in local marketplaces. At such prices, the zero-carbon system would simply be the thrifty choice.

How to Revolutionize R&D



A balanced energy R&D portfolio proposed by the authors would allocate the bulk of resources to proven technologies like hydro, wind, solar photovoltaics, and nuclear; devote 20 percent of funds to related technologies like thin-film solar PV and next-generation nuclear fission reactors; and keep a pot of money for “crazy” ideas like cheap fusion.



Today In the United States, the vast bulk of funding for energy R&D goes to established technologies. Essentially no money is allocated to related and potentially disruptive technologies, and about 10 percent is spent on projects that don’t seek to produce economically competitive energy.

Unfortunately, most of today’s clean generation sources can’t provide power that is both distributed and dispatchable. Solar panels, for example, can be put on every rooftop but can’t provide power if the sun isn’t shining. Yet if we invented a distributed, dispatchable power technology, it could transform the energy marketplace and the roles played by utilities and their customers. Smaller players could generate not only electricity but also profit, buying and selling energy locally from one another at real-time prices. Small operators, with far less infrastructure than a utility company and far more derring-do, might experiment more freely and come up with valuable innovations more quickly.

Similarly, we need competitive energy sources to power industrial facilities, such as fertilizer plants and cement manufacturers. A cement company simply won’t try some new technology to heat its kilns unless it’s going to save money and boost profits. Across the board, we need solutions that don’t require subsidies or government regulations that penalize fossil fuel usage. Of course, anything that makes fossil fuels more expensive, whether it’s pollution limits or an outright tax on carbon emissions, helps competing energy technologies locally. But industry can simply move manufacturing (and emissions) somewhere else. So rather than depend on politicians’ high ideals to drive change, it’s a safer bet to rely on businesses’ self interest: in other words, the bottom line.

In the electricity sector, that bottom line comes down to the difference between the cost of generating electricity and its price. In the United States alone, we’re aiming to replace about 1 terawatt of generation infrastructure over the next 40 years. This won’t happen without a breakthrough energy technology that has a high profit margin. Subsidies may help at first, but only private sector involvement, with eager money-making investors, will lead to rapid adoption of a new technology. Each year’s profits must be sufficient to keep investors happy while also financing the next year’s capital investments. With exponential growth in deployment, businesses could be replacing 30 gigawatts of installed capacity annually by 2040.

While this energy revolution is taking place, another field needs to progress as well. As Hansen has shown, if all power plants and industrial facilities switch over to zero-carbon energy sources right now, we'll still be left with a ruinous amount of CO_2 in the atmosphere. It would take centuries for atmospheric levels to return to normal, which means centuries of warming and instability. To bring levels down below the safety threshold, Hansen's models show that we must not only cease emitting CO_2 as soon as possible but also actively remove the gas from the air and store the carbon in a stable form. Hansen suggests reforestation as a carbon sink. We're all for more trees, and we also exhort scientists and engineers to seek disruptive technologies in carbon storage.

Incremental improvements to existing technologies aren't enough; we need something truly disruptive to reverse climate change. What, then, is the energy technology that can meet the challenging cost targets? How will we remove CO_2 from the air? We don't have the answers. Those technologies haven't been invented yet. However, we have a suggestion for how to foster innovation in the energy sector and allow for those breakthrough inventions.

Consider Google's approach to innovation, which is summed up in the 70-20-10 rule espoused by executive chairman Eric Schmidt. The approach suggests that 70 percent of employee time be spent working on core business tasks, 20 percent on side projects related to core business, and the final 10 percent on strange new ideas that have the potential to be truly disruptive.

Wouldn't it be great if governments and energy companies adopted a similar approach in their technology R&D investments? The result could be energy innovation at Google speed. Adopting the 70-20-10 rubric could lead to a portfolio of projects. The bulk of R&D resources could go to existing energy technologies that industry knows how to build and profitably deploy. These technologies probably won't save us, but they can reduce the scale of the problem that needs fixing. The next 20 percent could be dedicated to cutting-edge technologies that are on the path to economic viability. Most crucially, the final 10 percent could be dedicated to ideas that may seem crazy but might have huge impact. Our society needs to fund scientists and engineers to propose and test new ideas, fail quickly, and share what they learn. Today, the energy innovation cycle is measured in decades, in large part because so little money is spent on critical types of R&D.

Perhaps technology would change the economic rules of the game by producing not just electricity but also fertilizer, fuel, or desalinated water

We're not trying to predict the winning technology here, but its cost needs to be vastly lower than that of fossil energy systems. For one thing, a disruptive electricity generation system probably wouldn't boil water to spin a conventional steam turbine. These processes add capital and operating expenses, and it's hard to imagine how a new energy technology could perform them a lot more cheaply than an existing coal-fired power plant already does.

A disruptive fusion technology, for example, might skip the steam and produce high-energy charged particles that can be converted directly into electricity. For industrial facilities, maybe a cheaply synthesized form of methane could replace conventional natural gas. Or perhaps a technology would change the economic rules of the game by producing not just electricity but also fertilizer, fuel, or desalinated water. In carbon storage, bioengineers might create special-purpose crops to pull CO2 out of the air and stash the carbon in the soil. There are, no doubt, all manner of unpredictable inventions that are possible, and many ways to bring our CO2 levels down to Hansen's safety threshold if imagination, science, and engineering run wild.

We're glad that Google tried something ambitious with the RE<C initiative, and we're proud to have been part of the project. But with 20/20 hindsight, we see that it didn't go far enough, and that truly disruptive technologies are what our planet needs. To reverse climate change, our society requires something beyond today's renewable energy technologies. Fortunately, new discoveries are changing the way we think about physics, nanotechnology, and biology all the time. While humanity is currently on a trajectory to severe climate change, this disaster can be averted if researchers aim for goals that seem nearly impossible.

We're hopeful, because sometimes engineers and scientists do achieve the impossible. Consider the space program, which required outlandish inventions for the rockets that brought astronauts to the moon. MIT engineers constructed the lightweight and compact Apollo Guidance Computer, for example, using some of the first integrated circuits, and did this in the vacuum-tube era when computers filled rooms. Their achievements pushed computer science forward and helped create today's wonderful wired world. Now, R&D dollars must go to inventors who are tackling the daunting energy challenge so they can boldly try out their crazy ideas. We can't yet imagine which of these technologies will ultimately work and usher in a new era of prosperity—but the people of this prosperous future won't be able to imagine how we lived without them.

About the Authors

Ross Koningstein and David Fork are engineers at Google, who worked together on the bold renewable energy initiative known as RE<C. They dedicate this article to the memory of Tim Allen, who led the project. Allen inspired them to question their assumptions about what it would take to reverse climate change. "He wasn't married to one approach," Koningstein says. "He was intent on solving the problem."