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MAGAZINE: FEATURE

Praying for an Energy Miracle

Every clean-tech startup these days claims to have a breakthrough that will finally make renewable and clean energy sources cheap enough to compete with fossil fuels. But are we really on the brink of a clean-energy economy?

MARCH/APRIL 2011 | BY DAVID ROTMAN

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The company's breakthrough is strictly off-limits to outsiders. Work on the technology goes on in an unseen part of the sprawling one-story building, beyond the machine shop, the various testing and fabrication instruments, the large open office space stuffed with cubicles. What a visitor gets to see instead is a thin wafer of

Silicon savior: Emanuel Sachs, founder of the solar startup 1366, has invented a cheaper way to turn chunks of silicon into the thin wafers used in photovoltaic cells. Credit: Jordan Hollender

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silicon that would be familiar to anyone in the solar-power industry. And that's exactly the point. The company's advance is all about reducing the expense of manufacturing conventional solar cells.

In its conference room is a large chart showing the declining cost of electricity produced by solar panels over the last three decades. The slightly bumpy downward-sloping line is approaching a wide horizontal swath labeled "grid parity"—the stage at which electricity made using solar power will be as cheap as power generated from fossil fuels. It is the promised land for renewable power, and the company, 1366 Technologies, believes its improvements in manufacturing techniques can help make it possible for solar power to finally get there.

It's an ambitious target: even though silicon-based photovoltaic cells, which convert sunlight directly to electricity, have been coming down in price for years, they are still too expensive to compete with fossil fuels. As a result, solar power accounts for far less than 1 percent of U.S. electricity production. And 1366 founder Emanuel Sachs, who is the company's chief technology officer and an MIT professor of mechanical engineering, says that even though solar might be "within striking distance" of natural gas, existing solar technology won't be able to compete with coal. "To displace coal will take another level of cost reduction," says Sachs. That's where 1366's breakthrough comes in. The company is developing a way to make thin sheets of silicon without slicing them from solid chunks of the element, a costly chore. "The only way for photovoltaics to compete with coal is with technologies like ours," he says.

Once photovoltaics can compete with coal on price, "the world very much changes," says Frank van Mierlo, the company's CEO. "Solar will become a real part of our energy supply. We can then generate a significant part of our energy from the sun."

In a number of ways, 1366 (the name refers to the average number of watts of solar energy that hit each square meter of Earth over a year) reflects the ambition of a whole generation of energy startups. These companies often refer to "game-changing" technologies that will redefine the economics of non-fossil-fuel energy sources. Many were founded over the last decade, during a boom in venture capital funding for "clean tech"—not only in solar but also in wind, biofuels, and batteries. Many have benefited from increases in federal support for energy research since President Obama took office. Though the companies are working on different technologies, they share a business strategy: to make clean energy sources cheap enough, without any government subsidies, to compete with fossil fuels. At that point, capitalism will kick into high gear, and investors will rush to build a new energy infrastructure and displace fossil fuels—or so the argument goes.

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The problem, however, is that we are probably not just a few breakthroughs away from deploying cheaper, cleaner energy sources on a massive scale. Though few question the value of developing new energy technologies, scaling them up will be so difficult and expensive that many policy experts say such advances alone, without the help of continuing government subsidies and other incentives, will make little impact on our energy mix. Regardless of technological advances, these experts are skeptical that renewables are close to achieving grid parity, or that batteries are close to allowing an electric vehicle to compete with gas-powered cars on price and range.

In the case of renewables, it depends on how you define grid parity and whether you account for the costs of the storage and backup power systems that become necessary with intermittent power sources like solar and wind. If you define grid parity as "delivering electricity whenever you want, in whatever volumes you want," says David Victor, the director of the Laboratory on International Law and Regulation at the University of California, San Diego, then today's new renewables aren't even close. And if new energy technologies are going to scale up enough to make a dent in carbon dioxide emissions, he adds, "that's the definition that matters."

FIELD OF MIRRORS

Few people have more faith in the power of technology to change the world than Bill Gross. And few entrepreneurs are as familiar with the difficulty of turning clever ideas into commercial technology. In the dot-com era, he and his company Idealab, an incubator that creates and runs new businesses, started up several of the era's hottest firms, only to struggle when the bubble burst.

Gross latched onto the clean-tech craze, founding a company called eSolar in 2007 to work on solar thermal technology (*see Q&A, March/April 2010*). These days, Web, social-computing, and energy projects are intermingled in Idealab's tightly packed offices in downtown Pasadena, California. In keeping with its dot-com-era heritage, the offices occupy a large loftlike space

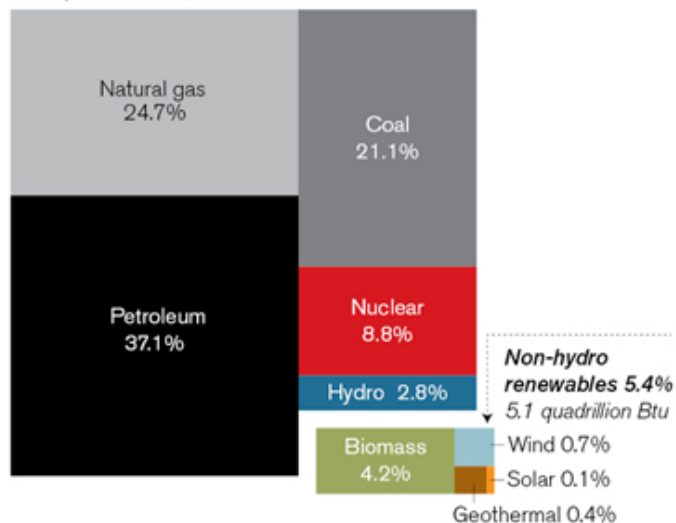
RENEWABLE CHALLENGE

It will cost billions to scale up and increase the use of energy sources such as solar and wind.

Despite their potential, new types of renewables still account for only about 1 percent of energy use in the United States.

U.S. energy consumption

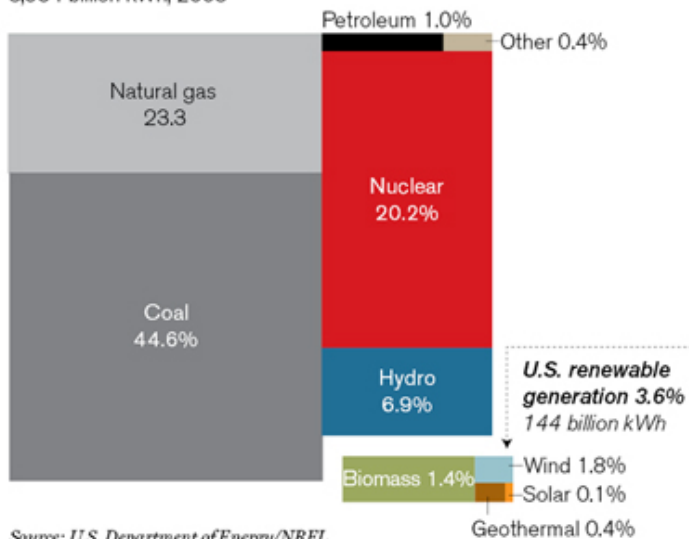
94.9 quadrillion Btu, 2009



Electricity production is dominated by coal-fired plants, a leading source of carbon dioxide emissions.

U.S. net electricity generation

3,954 billion kWh, 2009



Source: U.S. Department of Energy/NREL

full of various companies or hope-to-be companies, some of them consisting of no more than a few desks dominated by large computer screens. Somewhere in all the brushed metal, exposed ventilation systems, track lighting, and designer desk chairs is Bill Gross's office, a small glassed-in cubicle.

Like almost every other founder of a renewable-energy startup, Gross gets right to the numbers. Pulling up a screen that compares the costs of energy from various sources, he points out how a technology being developed by eSolar could make solar thermal power less

Credit: Tommy McCall

expensive and help it
become competitive with

fossil fuels. Solar thermal plants produce electricity by using a huge field of mirrors to focus sunlight on a tall central tower, where water is heated to produce steam that generates electricity. Large power plants using the technology can produce electricity more cheaply than ones using silicon solar panels, although the thermal approach is still more expensive than power derived from coal or even wind. Several such plants are operating around the world, and more are being built (see "*Chasing the Sun*," *July/August 2009*). In 2006, when the giant California utility PG&E put out a bid for a 300-megawatt solar thermal plant (now being built by a company called BrightSource), Gross got excited and began working with his employees to improve the economics.

Not surprisingly, Gross's solution is based on software. Large solar thermal plants cost more than a billion dollars to build, and one reason for the high cost is that tens of thousands of specially fabricated mirrors have to be precisely arranged so that they focus the sunlight correctly. But what if you used plain mirrors on a simple metal rack and then used software to calibrate them, adjusting each one to optimize its position relative to the sun and the central tower? It would take huge amounts of computing power to manipulate all the mirrors in a utility-scale power plant, but computing power is cheap—far cheaper than paying engineers and technicians to laboriously position the mirrors by hand. The potential savings are impressive, according to Gross; he says that eSolar can install a field of mirrors for half what it costs in other solar thermal facilities. As a result, he expects to produce electricity for approximately 11 cents per kilowatt-hour, enticingly close to the price of power from a fossil-fuel plant.

Still, it's not good enough—at least in the United States, where natural-gas plants can produce power for around 6 cents per kilowatt-hour. In Lancaster, California, at the edge of the Mojave Desert, eSolar has built a facility with 24,000 mirrors; it is capable of producing five megawatts of power. But eSolar has gotten no new deals to build utility-scale projects based on the company's technology in the United States. Instead it is doing business in parts of the world where electricity prices are higher or subsidies for renewable energy are greater; it is building a 2.5-megawatt plant in India and has signed an agreement for a large facility in China. The problem in the United States is the same one facing all alternative-energy dreams: cost. Prices for natural gas have fallen to historically low levels, which means that solar thermal must get even cheaper to compete. To stand a chance in the United States, Gross acknowledges, eSolar needs its electricity to cost no more than 7.5 cents per kilowatt-hour.

Getting there will take yet another advance in the technology. One disadvantage of solar power is that it produces electricity only during part of the day. Photovoltaic

panels efficiently produce power for about five and half hours a day, when the sun is most directly overhead. Solar thermal systems can operate a bit longer, because the heated water can drive turbines later into the afternoon; eSolar's technology makes power for about seven hours daily without storage. And Gross says that using molten salts instead of water to transport the heat from the central tower to the steam generator will enable a solar thermal facility to store the heat for much longer and produce electricity for up to 16 hours a day. That will bring down the cost of its electricity to the targeted 7.5 cents per kilowatt-hour. He predicts that eSolar will have a commercial plant with the molten-salt design running next year.

If the goalposts keep moving just beyond the reach of new energy technologies, Gross doesn't seem fazed. Eventually, he says, eSolar's technology won't need subsidies to compete with natural gas, and the sky will be the limit. "Solar is perfect for a huge swath of the planet," he says, happily showing a world map with a large belt around the middle in red and dark orange, indicating high levels of solar radiation. Even in this country, Gross says confidently, solar power will account for half of all electricity production by 2050—with at least 50 percent of that produced by solar thermal plants.

"NO BUGS"

While Bill Gross tries to squeeze a few critical pennies out of the cost of solar power, researchers at Caltech, a few miles up the road, are working on a different solution. They are trying to invent a fundamentally new way of producing liquid fuels directly from sunlight, inspired by the way green plants convert sunlight to sugars. If this quest for "artificial photosynthesis" succeeds, it will address one of solar energy's fundamental challenges: how to store the power until it's needed. The potential of this vision seems to animate the director of the effort, Nate Lewis. He speaks at times in bullet points punctuated by a mix of excitement and impatience. "No bugs, no wires," he says. "No bugs, no wires. I mean what I say: no wires. Leaves have no wires. In come sunlight, water, and CO₂, and out come fuels."



Solar Mirage? An eSolar demonstration facility in Lancaster, California, uses 24,000 mirrors and can produce five megawatts of electricity. But eSolar has no U.S. deals for similar plants. Credit: Misha Gravenor

This research—a joint project of Caltech and Lawrence Berkeley National Lab—will be supported by \$122 million over five years from the U.S. Department of Energy, pending Congressional appropriation of the funds. "We have pieces. Making fuels from sunlight with photoelectric chemistry works," says Lewis, a professor of chemistry at Caltech. But a practical device needs to be cheap, efficient, and robust. "Right now, I can give you any two of the three at the same time," he says. "Our goal is all three." Basic scientific problems stand in the way. Among them: the researchers need to find cost-effective catalysts for the chemical reactions that break water into oxygen and hydrogen.

After 100 years of research, "you can count on one hand the classes of compound that are good catalysts for water oxidation," Lewis says; we "don't have another hundred years" to find better ones. Employing the kind of high-throughput experimental methods and automated techniques increasingly used in drug discovery, the center will screen a million compounds a day for catalytic activity. "We will evaluate, discover, and quantify the activity of more catalysts in one day than have been collectively

documented throughout history," he says.

Meanwhile, a team of system designers and hardware experts will begin to design and build prototype devices. "Their job is to build prototypes from day one," Lewis says. "We expect to have [the prototypes] within the first two or three years." Those first prototypes will "nearly absolutely fail," he says, but they're the only way to arrive at a practical system: "We don't know what it should look like. Where does the water come out? Where does the sunlight come in? If you don't build the thing, you can't build the thing."

The challenge of finding cheaper and cleaner energy has often been compared to the race to put a man on the moon. But there's at least one key difference: success at getting humans into space was not judged according to its cost. Regardless of how clever Lewis's technology might be, it won't solve the problem unless it can serve as the basis of a sustainable business. "We're not NASA going to the moon," says Lewis. "If you can't compete on cost, it's ultimately not worth doing." And, he adds, given the fluctuating price of oil, you've "got to have something that looks like it is really disruptive" in terms of cost: "If you're just close, it's no good for anyone."

WORLD OF AUSTERITY

In the last decade, many U.S. energy experts and economists have argued that the government must establish a price for emitting carbon dioxide. They say that a carbon price—in the form of either a tax or a cap-and-trade system—would be an economically efficient and technologically fair way to reduce our use of fossil fuels. It would drive up the cost of energy derived from those fuels, allowing cleaner technologies to challenge them in the market without requiring the government to back particular choices. The European Union implemented a cap-and-trade system in 2005, but the United States—until recently the world's largest user of energy and, arguably, still the leading center of energy innovation—has failed to do so.

That has left energy policy experts debating how to go forward—especially now that subsidies and other benefits for clean energy in the 2009 federal stimulus bill are winding down. Some see an opportunity to focus on inventing new ways to make clean energy cheaper than fossil fuels. Such innovation, they contend, is the only way to achieve massive reductions in fossil-fuel use. Microsoft founder Bill Gates is one of the investors who hope to stimulate such energy "miracles" (*see Q&A, September/October 2010*).

Critics of that view, however, believe it's more important to focus on increasing the use of clean energy technologies as soon as possible through government subsidies and

other incentives. It's dangerous to believe that "all these amazing technologies will come along and solve the problem," says Joseph Romm, a senior fellow at the Center for American Progress, a Washington-based think tank. The truth is, he says, breakthroughs "don't happen very often."

In fact, most technologies get better and cheaper as they are commercialized and used, not in the lab. That means we need both research into new energy technologies *and* government policies that support deployment, use, and improvement. There's an intimate connection between these efforts. "Until you start deployment, you don't know the challenges," says Romm. "So many great ideas happen in the lab but don't succeed in the market. It is the back-and-forth between deployment and R&D that gets you rapid innovation."

One of the most successful of the recent energy startups is A123, a battery company based in Watertown, Massachusetts. A123, which had a public offering of its stock in 2009, makes lithium-ion batteries that are designed to be safer and longer lasting than the more conventional versions; its secret is electrodes made of nanoscale composite materials. Remarkably, the company went from lab tests of its technology to commercial production in less than three years. It has benefited from strong demand from carmakers desperate to introduce electric vehicles and from a government grant of \$250 million to help fund construction of its manufacturing facilities (*see*

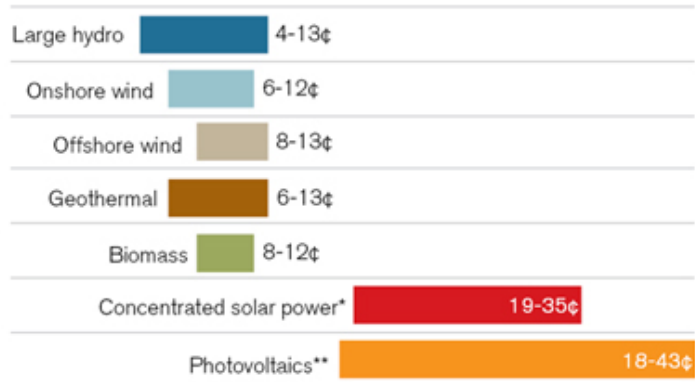
PRICEY POWER

Different types of solar power remain more expensive even than other renewables.

Concentrated solar power and photovoltaics have gotten cheaper recently but are still relatively expensive.

Levelized cost of renewable electricity

Cost per kWh, 2009

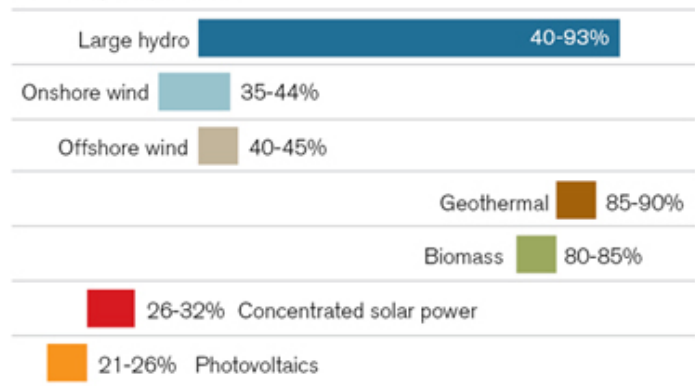


Notes: *Includes solar thermal and focusing mirrors on photovoltaic cells.
 **Current range of utility-scale photovoltaic installations in the U.S.

Solar plants produce electricity only during part of the day, limiting their ability to utilize their capacity.

Capacity factor for renewable resources

% capacity ranges, 2009



Source: U.S. Department of Energy/NREL

Credit: Tommy McCall

Demo).

But three years ago, even as A123 was still moving to commercialize its products, cofounder Yet-Ming Chiang, an MIT materials scientist, was already looking for his next breakthrough. Working initially at A123 and later with colleagues at MIT and Rutgers University, he set

out to invent a technology that would be far cheaper and easier to manufacture than existing lithium batteries. He wanted a battery that would allow electric cars to drive much farther on a charge, and one that would offer a practical way to store power on the electric grid. The solution: a completely new type of battery, again based on nanomaterials.

Last year A123 spun off 24M, a startup that will test and, possibly, commercialize the technology. The company wants to meet the Department of Energy's goal of developing electric-vehicle batteries that can supply energy for around \$250 per kilowatt-hour, as opposed to today's standard of around \$500 to \$600. The result would halve the cost of a battery for an all-electric vehicle. It would, Chiang says, "enable the widespread adoption of electric vehicles."

Even if Chiang's newest battery creation proves impractical, its invention and the founding of 24M illustrate the benefits that come from the commercialization of energy technologies and the iterative nature of innovation. A123's batteries helped establish a market in which newer advances can compete, and they clarified the limits of the first-generation technology. None of that would have happened without federal support. Government policy is "absolutely critical," Chiang says, both to researching new battery technologies and to scaling up existing ones.

Although some alternative energy technologies might eventually achieve grid parity, few, if any, can survive without subsidies now, as they improve their cost and efficiency. Even with subsidies, including tax incentives and cash grants, most are struggling to narrow the cost gap with fossil fuels. As Caltech's Lewis says, getting close is not good enough. The danger is that if we focus on energy "miracles" and exaggerate the potential of breakthrough technologies, the need for a coherent government policy in favor of energy change will be forgotten. "All the darling energy technologies—essentially all the renewables and all the grid-powered electric vehicles—depend on huge subsidies," says David Victor of UC San Diego. "And no one really knows what a world of fiscal austerity will look like for these technologies."

Clean energy options still have a long way to go, especially when it comes to storing electricity, lowering the cost of renewables, and improving the performance and cost of batteries. Companies like 1366 and eSolar are addressing these challenges. But depending on breakthroughs alone to solve our energy problems is unrealistic. Such advances must take place in the larger context of a coordinated effort to deploy these energy sources. That demands international government strategies that support not just research but testing, building, and commercialization.

Deploying energy alternatives will be far more expensive and, in some ways, far more

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difficult than inventing new ones. Given today's political climate and the lack of a coherent energy policy around the world, it might truly take a miracle.

David Rotman is Technology Review 's editor.

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"1366 (the average number of watts of solar energy that hit each square meter of Earth over a year)" It's more something like kWh of energy... And it looks like the radiation just outside earth atmosphere (~1367 W/m²).

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21 Comments

The Unknown,Unknown

How much do these calculations take into account the over 1 trillion dollars we spend on the Military.

Let alone the instability which would account to maybe 3 or 4 times if not more. In disrupted Markets and uncertainty due to the Political Situation in the Middle East.

Or the Climate Change costs which we have begun to see the implications of all around the world. This might be a process that has already been put into motion, but to not take this into account or the others mentioned above does not do your article justice.

Technology Does have Moral,Social and Environmental implications that will not show up on a spread sheet.

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