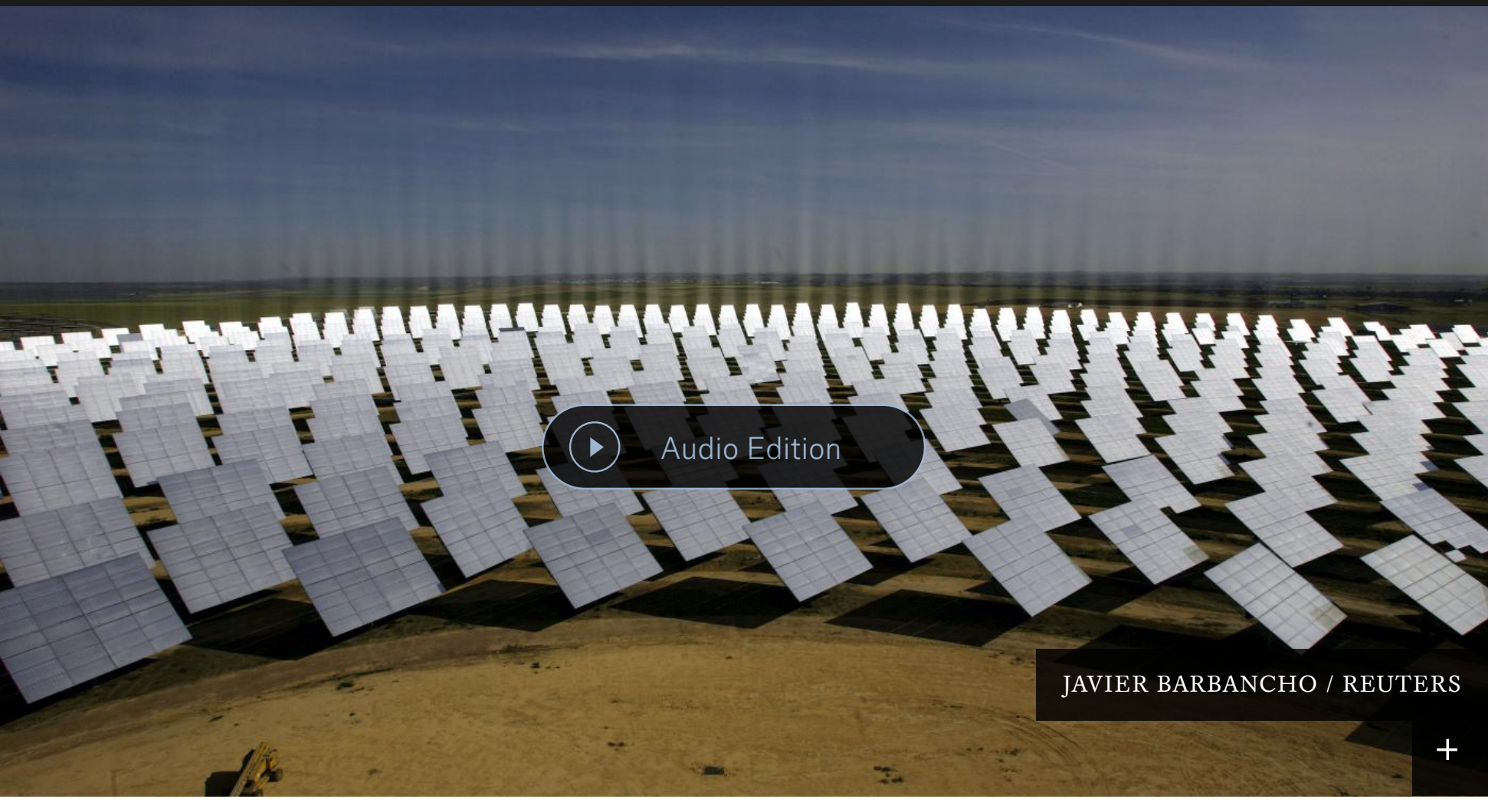


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# The Clean Energy Revolution

## Fighting Climate Change With Innovation

*By Varun Sivaram and Teryn Norris*

As the UN Climate Change Conference in Paris came to a close in December 2015, foreign ministers from around the world raised their arms in triumph. Indeed, there was more to celebrate in Paris than at any prior climate summit. Before the conference, over 180 countries had submitted detailed

plans to curb their greenhouse gas emissions. And after two weeks of intense negotiation, 195 countries agreed to submit new, stronger plans every five years.

But without major advances in clean energy technology, the Paris agreement might lead countries to offer only modest improvements in their future climate plans. That will not be enough. Even if they fulfill their existing pledges, the earth will likely warm by some 2.7 to 3.5 degrees Celsius—risking planetary catastrophe. And cutting emissions much more is a political nonstarter, especially in developing countries such as India, where policymakers must choose between powering economic growth and phasing out dirty fossil fuels. As long as this tradeoff persists, diplomats will come to climate conferences with their hands tied.

It was only on the sidelines of the summit, in fact, that Paris delivered good news on the technology front. Bill Gates unveiled the Breakthrough Energy Coalition, a group of more than two dozen wealthy sponsors that plan to pool investments in early stage clean energy technology companies. And U.S. President Barack Obama announced Mission Innovation, an agreement among 20 countries—including the world's top three emitters, China, the United States, and India—to double public funding for clean energy R & D to $20 billion annually by 2020. Washington will make or break this pledge, since over half of the target will come from doubling the U.S. government's current $6.4 billion yearly budget.

Fighting climate change successfully will certainly require sensible government policies to level the economic playing field between clean and dirty energy, such as putting a price on carbon dioxide emissions. But it will also require policies that encourage investment in new clean energy technology, which even a level playing field may not generate on its own. That will take leadership from the United States, the only country with the requisite innovative capacity. In the past, the United States has seen investment in clean energy innovation surge forward, only to collapse afterward. To prevent this from happening again, the government should dramatically ramp up its support for private and public R & D at home and abroad. The task is daunting, to be sure, but so are the risks of inaction.

DON'T STOP THINKING ABOUT TOMORROW

The key to a low-carbon future lies in electric power. Improvements in that sector are important not just because electric power accounts for the largest share of carbon dioxide emissions but also because reaping the benefits of innovations downstream—such as electric vehicles—requires a clean electricity supply upstream. Fossil-fueled power plants now account for nearly 70 percent of electricity globally. But by 2050, the International Energy Agency has warned, this figure must plummet to seven percent just to give the world a 50 percent chance of limiting global warming to two degrees Celsius. More fossil-fueled power is acceptable only if the carbon emissions can be captured and stored underground. And zero-carbon power sources, such as solar, wind, hydroelectric, and nuclear power, will need to grow rapidly, to the point where they supply most of the world's electricity by the middle of the century.

*Trying to create a zero-carbon power grid with only existing technologies would be expensive, complicated, and unpopular.*

The problem, however, is that the clean technologies now making progress on the margins of the fossil-fueled world may not suffice in a world dominated by clean energy. The costs of solar and wind power, for example, are falling closer to those of natural gas and coal in the United States, but this has been possible because of flexible fossil fuel generators, which smooth out the highly variable power produced by the sun and wind. Ramping up the supply of these intermittent sources will oversupply the electrical grid at certain times, making renewable power less valuable and requiring extreme swings in the dwindling output of fossil fuel generators. Nuclear and hydroelectric power, for their part, are more reliable, but both have run into stiff environmental opposition. As a result, trying to create a zero-carbon power grid with only existing technologies would be expensive, complicated, and unpopular.

Similarly, cleaning up the transportation sector will require great technological leaps forward. Alternative fuels are barely competitive when oil prices are high, and in the coming decades, if climate policies succeed in reducing the demand for oil, its price will fall, making it even harder for alternative fuels to compete. The recent plunge in oil

prices may offer a mere foretaste of problems to come: it has already put biofuel companies out of business and lured consumers away from electric vehicles.

*U.S. President Barack Obama and Microsoft cofounder Bill Gates launch 'Mission Innovation: Accelerating the Clean Energy*

Every one of those advances is possible, but most need a fundamental breakthrough in the lab or a first-of-its-kind demonstration project in the field. For example, the quest for the ideal catalyst to use sunlight to split water still hasn't produced a winning chemical, and an efficient solar power coating called "perovskite" still isn't ready for widespread use. So it is alarming that from 2007 to 2014, even as global financial flows to deploy mature clean energy doubled to $288 billion, private investment in early

stage companies sank by nearly 50 percent, to less than $2.6 billion. But the United States can reverse that trend.

## THIRD TIME'S THE CHARM?

Since the development of civilian nuclear power after World War II, the United States has experienced two booms in clean energy innovation, followed by two busts. The first boom, a response to the oil shocks of the 1970s, was driven by public investment. From 1973 to 1980, the federal government quadrupled investment in energy R & D, funding major improvements in both renewable and fossil fuel energy sources. But when the price of oil collapsed in the 1980s, the administration of President Ronald Reagan urged Congress to leave energy investment decisions to market forces. Congress acquiesced, slashing energy R & D funding by more than 50 percent over Reagan's two terms.

*The key to a low-carbon future lies in electric power.*

The second wave of investment in clean energy innovation began with the private sector. Soon after the turn of the millennium, venture capital investors began pumping money into U.S. clean energy start-ups. Venture capital investment in the sector grew tenfold, from roughly $460 million per year in 2001 to over $5 billion by 2010. Thanks to Obama's stimulus package, federal funding soon followed, and from 2009 to 2011, the government plowed over $100 billion into the sector through a mix of grants, loans, and tax incentives (although most of this influx subsidized the deployment of existing technologies). Some of the start-ups from this period became successful publicly traded companies, including the electric-car maker Tesla, the solar-panel installer SolarCity, and the software provider Opower.

But the vast majority failed, and the surviving ones returned too little to make up for the losses. Indeed, of the $36 billion that venture capital firms invested from 2004 to 2014, up to half may ultimately be lost. The gold rush ended abruptly: from 2010 to 2014, venture capital firms cut their clean energy investment portfolios by 75 percent. And the federal government, reeling from political blowback over the bankruptcies of

some recipients of federal loan guarantees (most famously, the solar-panel manufacturer Solyndra), pared back its support for risky ventures, too.

Yet all was not lost, for the failures of these two waves offer lessons for how to make sure the next one proves more enduring. First, they revealed just how important government funding is: after the drop in federal energy R & D in the 1980s, patent filings involving solar, wind, and nuclear power plunged. Today, although the United States is the largest funder of energy R & D in the world, it chronically underspends compared with its investments in other national research priorities. Its $6.4 billion clean energy R & D budget is just a fraction of the amount spent on space exploration ($13 billion), medicine ($31 billion), and defense ($78 billion). Given the gap, Congress should follow through on the Mission Innovation pledge and at least double funding for clean energy R & D. Already, Congress increased spending on applied energy R & D by ten percent in its 2016 budget, more than it increased spending on any other major R & D agency or program. But starting in 2017, doubling the budget in five years will require annual increases of at least 15 percent.

The second lesson is that the government should fund not only basic research but applied research and demonstration projects, too. Washington's bias goes back decades. In his seminal 1945 report, *Science, the Endless Frontier*, Vannevar Bush, President Franklin Roosevelt's top science adviser, urged the government to focus on basic research, which would generate insights that the private sector was supposed to translate into commercial technologies. Successive administrations mostly heeded his advice, and Reagan doubled down on it, slashing nearly all funding for applied energy R & D. By the late 1990s, basic research would account for 60 percent of all federal spending on energy R & D. Instead of creating space for the private sector to pick up where the government left off, however, the budget cuts scared it away. Private investment shrank by half from 1985 to 1995, stranding public investments in alternative fuels, solar photovoltaic panels, and advanced nuclear reactors.

*Heliostat mirrors reflect their surroundings in a field at the construction site of a 240 meter (787 feet) solar-power tower in Isra*

A similar story unfolded at the end of the second boom in clean energy innovation. When one-time stimulus funding expired after 2011, public funding for demonstration projects—which prove whether new technologies work in real-world conditions—fell by over 90 percent. Private investors had expected to share the risk of such projects with the federal government, but when government funding evaporated, investors pulled their money out—canceling, among others, several projects to capture and store carbon emissions from coal power plants.

Thus, policymakers should increase the kind of public investment that attracts private capital. To that end, the first priority should be to restore public funding for demonstration projects. The last redoubt of support for these projects can be found in the Department of Energy's politically embattled loan guarantee program. To insulate funding from political caprice, the American Energy Innovation Council, a group of business leaders, has proposed an independent, federally chartered corporation that would finance demonstration projects. Others have proposed empowering states or

regions to fund their own projects, with matching federal grants. If they make it past Congress, both proposals could unlock considerable private investment.

The Department of Energy has made more progress in supporting technologies not yet mature enough for demonstration. In 2009, with inspiration from the Defense Advanced Research Projects Agency, or DARPA, the U.S. military's incubator for high-risk technologies, it created the Advanced Research Projects Agency–Energy, or ARPA-E. Several ARPA-E projects have already attracted follow-on investment from the private sector. In 2013, for example, Google acquired Makani Power, a start-up that is developing a kite that converts high-altitude wind energy into power. The department has also curated public-private partnerships among the government, academics, and companies—dubbed "innovation hubs"—to develop advanced technologies. Obama has advocated tripling ARPA-E's budget to $1 billion by 2021 and creating ten new public-private research centers around the country. Congress should approve these proposals.

The Department of Energy should expand its support for one type of public-private partnership in particular: industrial consortia that pool resources to pursue shared research priorities. Once again, DARPA provides a model. In the 1980s, it helped fund a consortium of computer chip manufacturers called SEMATECH, through which the industry invested in shared R & D and technical standards. By the next decade, the United States had regained market leadership from Japan. Clean energy innovation, by contrast, suffers from corporate apathy. From 2006 to 2014, U.S. firms spent a paltry $3 billion per year on in-house clean energy R & D. They were also reluctant to outsource their energy R & D, acquiring clean energy start-ups only half as often as they did biomedical start-ups.

Public-private partnerships should help diversify the set of private investors funding clean energy innovation. Indeed, venture capitalists alone are insufficient, since clean energy investments require capital for periods longer than venture capitalists generally favor. The Breakthrough Energy Coalition may help solve that problem by infusing the sector with more patient capital. Gates has explained that he and his fellow investors would be willing to wait for years, even decades, for returns on their investments. But his vision depends on the government also ramping up support.

*If the world is to avoid climate calamity, it needs to reduce its carbon emissions by 80 percent by the middle of this century.*

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Past failures offer a third and final lesson for policymakers: the need to level the playing field on which emerging clean energy technologies compete against existing ones. In the electricity sector in particular, innovative start-ups are at a disadvantage, since they lack early adopters willing to pay a premium for new products. The biggest customers, electric utilities, tend to be highly regulated territorial monopolies that have little tolerance for risk and spend extremely little on R & D (usually 0.1 percent of total revenues). New York and California are reforming their regulations to encourage utilities to adopt new technologies faster; the federal government should support these efforts financially or, at the very least, get out of the way.

Indeed, government intervention can sometimes be counterproductive. Many current clean energy policies, such as state mandates for utilities to obtain a certain percentage of their power from renewable energy and federal tax credits for solar and wind power installations, implicitly support already-mature technologies. Better policies might carve out allotments or offer prizes for emerging technologies that cost more now but could deliver lower costs and higher performance later. The government could even become a customer itself. The military, for example, might buy early stage technologies such as flexible solar panels, energy-dense batteries, or small modular nuclear reactors.

## INNOVATING ABROAD

Clean energy innovation at the international level suffers from similar problems. Like Washington, other governments spend too little on R & D, with the share of all publicly funded R & D in clean energy falling from 11 percent in the early 1980s to four percent in 2015. Thanks to Mission Innovation, that trend could soon be reversed. But if spending rises in an uncoordinated way, governments may duplicate some areas of research and omit others.

Since governments prize their autonomy, the wrong way to solve this problem would be through a centralized, top-down process to direct each country's research priorities.

Instead, an existing institution should coordinate spending through a bottom-up approach. The most logical body for that task is the Clean Energy Ministerial, a global forum conceived by the Obama administration that brings together energy officials from nearly every Mission Innovation country. Yet the CEM has no permanent staff, and without support from the next U.S. administration, it might disband. The Obama administration should therefore act quickly to convince its Mission Innovation partners to help fund a permanent secretariat and operating budget for the CEM. Once that happens, the body could issue an annual report of each member's R & D expenditures, which countries could use to hold their peers accountable for their pledges to double funding. The CEM could also convene officials to share trends about the frontiers of applied research, gleaned from grant applications submitted to national funding bodies.

Then there is the problem of foreign companies' aversion to investing in innovation. Producers of everything from solar panels to batteries, mostly in Asia, have focused instead on ruthless cost cutting and in many cases have taken advantage of government assistance to build up massive manufacturing capacity to churn out well-understood technologies. Today, over two-thirds of solar panels are produced in China, where most firms spend less than one percent of their revenue on R & D. (In fact, it was largely the influx of cheap, cookie-cutter solar panels from China that caused U.S. solar start-ups to go bankrupt at the beginning of this decade.)

*Steam rises at sunset from the cooling towers of the Electricite de France (EDF) nuclear power station at Nogent-Sur-Seine, Fr*

Not only does this global race to the bottom stunt clean energy innovation; it also matches up poorly with the United States' competitive strengths. In other industries, leading U.S. firms generate economic gains both at home and abroad by investing heavily in R & D. In the electronics, semiconductor, and biomedical industries, for instance, U.S. companies reinvest up to 20 percent of their revenues in R & D.

To encourage foreign companies to invest more in clean energy R & D, the United States should embrace public-private collaboration. A good model is the U.S.-China Clean Energy Research Center, or CERC, which was set up in 2009 and is funded by the U.S. and Chinese governments, academic institutions, and private corporations. Notably, CERC removes a major obstacle to international collaboration: intellectual property theft. Participants are bound by clear rules about the ownership and licensing of technologies invented through CERC. And unless they agree otherwise, they must submit disputes to international arbitration governed by UN rules. More than 100 firms have signed on, and in 2014, China and the United States enthusiastically extended the

partnership. It's time for the United States to apply CERC's intellectual property framework to collaborations with other countries, such as India, with which it has no such agreement.

## THE NEXT REVOLUTION

By investing at home and leading a technology push abroad, the United States would give clean energy innovation a badly needed boost. Energy executives would at last rub elbows with top academics at technology conferences. Industrial consortia would offer road maps for dramatic technological improvements that forecast future breakthroughs. And institutional investors would bet on start-ups and agree to wait a decade or more before seeing a return.

To many in Washington, this sounds like an expensive fantasy. And indeed, transforming the energy sector into an innovative powerhouse would prove even harder and costlier than the Manhattan Project or the Apollo mission. In both cases, the government spent billions of dollars on a specific goal, whereas success in clean energy innovation requires both public and private investment in a wide range of technologies.

Yet the United States has achieved similar transformations before. Take the biomedical industry. Like clean energy start-ups, biomedical start-ups endured boom-and-bust investment cycles in the 1980s and 1990s. But today, partly thanks to high and sustained public funding, the private sector invests extensively in biomedical innovation. One might object that the biomedical industry's high profit margins, in contrast to the slim

ones that characterize the clean energy industry, allow it to invest more in R & D. But the clean energy sector need not be condemned to permanently small profits: innovative firms could earn higher margins than today's commodity producers by developing new products that serve unmet demands.

With clean energy, the stakes could hardly be higher. If the world is to avoid climate calamity, it needs to reduce its carbon emissions by 80 percent by the middle of this century—a target that is simply out of reach with existing technology. But armed with a more potent low-carbon arsenal, countries could make pledges to cut emissions that were both ambitious and realistic. Emerging economies would no longer face tradeoffs between curbing noxious fossil fuels and lifting their populations out of energy poverty. And the United States would place itself at the forefront of the next technological revolution.

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