Dirty Coal, Clean Future

To environmentalists, "clean coal" is an insulting oxymoron. But for now, the only way to meet the world's energy needs, and to arrest climate change before it produces irreversible cataclysm, is to use coal—dirty, sooty, toxic coal—in more-sustainable ways. The good news is that new technologies are making this possible. China is now the leader in this area, the Google and Intel of the energy world. If we are serious about global warming, America needs to work with China to build a greener future on a foundation of coal. Otherwise, the clean-energy revolution will leave us behind, with grave costs for the world's climate and our economy.

By JAMES FALLOWS

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THROUGH THE PAST four years I've often suggested that China's vaunted achievements are less impressive, or at least more complicated, seen up close. Yes, Chinese factories make nearly all of the world's consumer electronic equipment. But the brand names, designs, and most of the profits usually belong to companies and people outside China. Yes, China's accumulated trade surpluses have made it the creditor for America and much of the world. But the huge share of its own wealth that China has sunk into foreign economies ties its fate to theirs. Yes, more and more Chinese people are very rich. But hundreds of millions of Chinese people are still very poor. Yes, Chinese factories lead the world in output of windmills and solar-power panels. But China's environmental situation is still so dire as to pose the main threat not just to the country's public health and political stability but also to its own economic expansion.

This report will have a different tone. I have been learning about an area of Chinese achievement that is objectively good for the world as a whole, including the United States. Surprising enough! And China's achievement dramatically highlights a structural advantage of its approach and a weakness of America's. It involves the shared global effort to reduce greenhouse-gas emissions, of which China and the United States are respectively the No. 1 and No. 2 producers, together creating more than 40 percent of the world's total output. That shared effort is real, and important. The significant Chinese developments involve more than the "clean tech" boom that Americans have already heard so much about. Instead a different, less publicized, and much less appealing-sounding effort may matter even more in determining whether the United States and China can cooperate to reduce emissions. This involves not clean tech but the dirtiest of today's main energy sources—coal.

Mining coal is notoriously dangerous, the remnants of those mines disfigure the Earth, and the by-products of coal's combustion fill the air not simply with soot, smoke, and carbon dioxide but also with toxic heavy metals like mercury and lead, plus corrosive oxides of nitrogen and sulfur, among other pollutants. When I visited coal towns in China's Shandong and Shanxi provinces, my face, arms, and hands would be rimed in black by the end of each day—even when I hadn't gone near a mine. People in those towns, like their predecessors in industrial-age Europe and America, have the same black coating on their throats and lungs, of course. When I have traveled at low altitude in small airplanes above America's active coal-mining regions—West Virginia and Kentucky in the East, Wyoming and its neighbors in the Great Basin region of the West—I've seen the huge scars left by "mountain top removal" and open-pit mining for coal, which are usually invisible from the road and harder to identify from six miles up in an airliner. Compared with most other fossil-fuel sources of energy, coal is inherently worse from a carbon-footprint perspective, since its hydrogen atoms come bound with more carbon atoms, meaning that coal starts with a higher carbon-to-hydrogen ratio than oil, natural gas, or other hydrocarbons.

The proposition that coal could constitute any kind of "hope" or solution, or that a major environmentalist action plan could be called "Coal Without Carbon," as one I will describe is indeed named—this goes beyond seeming interestingly contrarian to seeming simply wrong. For the coal industry, the term "clean coal" is an advertising slogan; for many in the environmental movement, it is an insulting oxymoron. But two ideas that underlie the term are taken with complete seriousness by businesses, scientists, and government officials in China and America, and are the basis of the most extensive cooperation now under way between the countries on climate issues. One is that coal *can* be used in less damaging, more sustainable ways than it is now. The other is that it *must* be used in those ways, because there is no plausible other way to meet what will be, absent an economic or social cataclysm, the world's unavoidable energy demands.

This is not an argument against all-out effort on all other fronts, from conservation and efficiency to improved battery technology to wind- and solar-power systems to improved nuclear facilities. Amory Lovins, of the Rocky Mountain Institute, has argued for years that designing buildings and transportation systems to waste less energy from the start is by far the cheapest way to reduce damaging emissions (a position reinforced by influential studies from McKinsey & Company). "Good ideas about climate change are not in competition with one another," Roger Aines, a climate scientist at Lawrence Livermore National Laboratory, told me when I visited this summer. "We need every possible solution, and then we need more."

This is an argument for recognizing that China has faced reality, in launching an all-out effort to "decarbonize" coal—and for recognizing America's difficulty in doing the same.

37 Billion Tons

Let's review the basics. This material will be elementary for some readers and controversial for a few others, but laying it out helps clarify the problem to be solved and the real options from which to choose. Also, the quantities and numbers involved here are so vast—the standard unit in discussing carbon-dioxide emissions is the gigaton, or 1 billion metric tons—that it helps to have some indicators of scale.

All human activity together puts roughly 37 billion tons (37 gigatons) of carbon dioxide into the atmosphere each year. That number has been rising, as the world's population grows and the number of cars, factories, and power plants increases. Twenty years ago, it was less than 25 billion tons. Twenty years from now, it could well be 50 billion tons. Carbon dioxide is not the only greenhouse gas—that is, a substance that affects the atmosphere's ability to absorb and emit heat, so that a growing portion of the sun's energy is trapped to warm the planet rather than radiating back into space. Methane, nitrous oxide, aerosols, and other emissions play a major role, and ton per ton can be more powerful in greenhouse effect. But the focus is on carbon dioxide because we produce so much of it, and because its effects are so long-lasting.

Carbon dioxide added to the atmosphere persists for many decades, even centuries—unlike methane, which can disperse within a single decade. This means that when more carbon dioxide is emitted than natural systems absorb, the concentration in the atmosphere continually goes up. Before James Watt invented the steam engine in the late 1700s—that is, before human societies had much incentive to burn coal and later oil in large quantities—the concentration of carbon dioxide in the atmosphere was around 280 parts per million, or ppm (meaning 280 carbon-dioxide molecules per million molecules of "dried air," or air with the water removed). It is thought to have fluctuated between about 180 and 280 ppm through the previous 800,000 years. By 1900, as Europe and North America were industrializing, it had reached about 300 ppm.

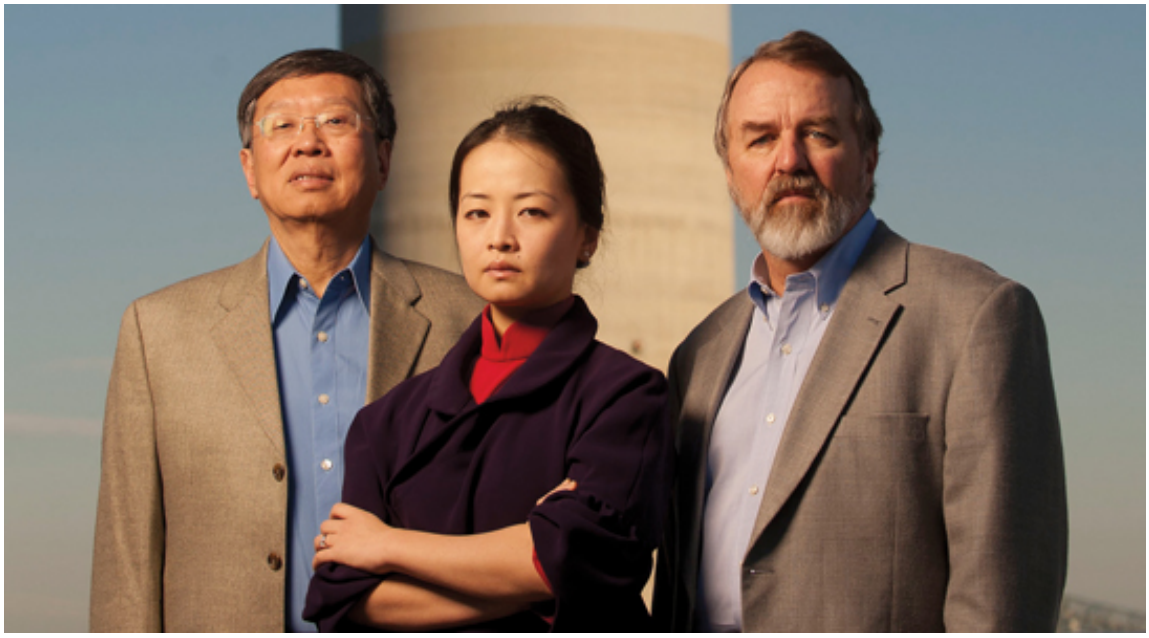
Now the carbon-dioxide concentration is at or above 390 ppm, which is probably the highest level in many millions of years. "We know that the last time CO2 was sustained at this level, much of the Greenland and West Antarctic ice sheets were not there," Michael Mann, a climate scientist at Penn State, told me. Because of the 37 billion annual tons of carbon-dioxide emissions, the atmospheric carbon-dioxide level continues to go up by about two ppm a year. For perspective: by the time today's sixth-graders finish high school, the world carbon-dioxide level will probably have passed 400 ppm, and by the time most of them are starting families, it will have entered the 420s.

Have we so far come across anything that is "controversial"? No: such political controversy as exists mainly concerns the exact connection between rising carbon-dioxide levels and future climate change, and how harmful (and to whom) that change would be. That the atmospheric carbon-dioxide level is rapidly going up, and that recent years have been on average the warmest in recorded history, no one bothers to dispute. And in any case, all parties to the negotiations I'm describing, including the heads of the major coal-mining and electric-power utilities in the United States and China, accept as settled fact that greenhouse-gas emissions are an emergency they must confront, because of the likely disruptive effects on the world's climate. At a U.S.-China environmental conference this summer in San Francisco, I heard one utility-company official after another testify, confession-meeting style, about the vast extent of their current emissions and their need to reform.

The main uncertainties involve what might happen as carbon-dioxide levels reach 450 ppm

and above. In particular, the question is how and when "positive feedback" loops would kick in, so that the hotter things get, the faster they will get even hotter. The main way this would happen would be through melting of the polar ice sheets, which would mean less white ice surface to reflect the sun's heat, and more blue water surface to absorb it. Similarly, the vast Arctic permafrost areas could have a positive-feedback effect as they thaw. They are essentially frozen peat bogs, which contain huge amounts of methane. As they began to melt, they would release their methane, which in turn could trigger even faster melting and more methane release.

"The reality of it is that in many cases, there may not be any fixed threshold for 'irreversible' change," Michael Mann told me. "What we have with rising CO2 levels in general is a dramatically increasing probability of serious and deleterious change in our climate." He went down the list: more frequent, severe, and sustained heat waves, like those that affected Russia and the United States this summer; more frequent and destructive hurricanes and floods; more frequent droughts, like the "thousand-year drought" that has devastated Australian agriculture; and altered patterns of the El Niño phenomenon, which will change rainfall patterns in the Americas. In other cases, he said, there could be important thresholds. For example, the possibility of dramatic rises in ocean levels, which could affect the habitability of New York, London, Shanghai, Miami, the entire Netherlands, and many other modern conurbations, along with coastal areas in India, Bangladesh, and elsewhere. "It would be nice to know where such thresholds are so we can avoid crossing them," Mann said. "We can't know that. What we do know for certain is that with each fraction of a degree of warming, the probability of such potentially catastrophic outcomes goes up."



The Inevitability of Coal

That's the big picture. Now come the parts of the background that are somewhat less familiar but bear on the argument that the only real salvation must involve coal.

Recall the 37 billion tons of worldwide annual carbon-dioxide emissions. On a per capita

basis, that would mean about six tons for each of the planet's 6-billion-plus people. But of course it doesn't work that way. For the United States, emissions are about 25 tons per person. For Europe as a whole, they're about 11 tons. (The difference is smaller houses, smaller cars, fewer sprawling suburbs, and in the case of France, much heavier reliance on nuclear power to generate electricity. Nuclear plants are expensive and obviously create waste-disposal problems, but they emit practically no greenhouse gases.) Japan's level is slightly below Europe's. For China, the emission level is about eight tons per person. Overall, China's economy is more energy-intensive than America's or Europe's—its bias toward construction and heavy manufacturing, plus its on-average shoddy standard of building insulation, mean that it takes more fuel, electricity, and raw energy to produce a dollar's worth of output in China than in the U.S. But overall living standards are still so much lower in China that per capita emissions there are barely one-third the U.S. level. India's per capita emission level is about three tons per year, less than half of China's (because India has so many fewer factories). For Kenya and other barely industrialized countries, it's about one ton per person per year.

The range of these figures suggests the technical challenges ahead. As one climate scientist put it to me, "To stabilize the CO2 concentration in the atmosphere, the whole world on average would need to get down to the Kenya level"—a 96 percent reduction for the United States. The figures also suggest the diplomatic challenges for American negotiators in recommending that other countries, including those with hundreds of millions in poverty, forgo the energy-intensive path toward wealth that the United States has traveled for so many years.

Indeed, in comparisons between the United States and China, the emissions figures probably understate the real gap in per capita energy use. David Mohler is the chief technology officer for Duke Energy Company, which is based in Charlotte and is a leading electricity and natural-gas provider in the Carolinas and parts of the Midwest. He travels frequently to China, and he took me through a comparison of electricity use in the two countries, as a proxy for overall energy use and emissions. At face value, he said, there was about a 5-to-1 difference between U.S. and Chinese per capita electricity-use levels. Each American is on average responsible for about 13.6 megawatt-hours of electricity use per year, counting residential heating and lighting, a pro-rated share of industrial and commercial demand, and so on. For each Chinese, the average is about 2.6. "But around half of that Chinese electricity consumption was for manufactured products for export," Mohler said. That is, China's surge in electric capacity has disproportionately gone toward its factory- export boom, rather than toward home air-conditioning and lighting, elevators, TVs and computers, electric cars, or any other in-China use by Chinese people (though to see a blazingly lit Chinese city at night is to recognize that plenty of power is already being used). "So in a sense, their 'real' per capita use is only about 1.5 megawatt-hours," Mohler said, "and ours, counting what went into the products we import, could be 10 times that much."

Mohler's point was less about abstract equity than practical reality. People in rural China, in my experience, don't really care that people somewhere else—Los Angeles or Houston, even Shanghai or Tianjin—are using more electricity and gasoline than they are. They just want to use more themselves! I assume the same to be true of their counterparts from Nigeria to India to North Korea. "You go in the countryside in China, and people don't have any power to pump their water," Mohler said. "Of course they're going to want those powered pumps. Anyone would." And hot water for their baths, and refrigerators for their kitchens, and air-conditioners for their bedrooms—and cars.

Thus the bind. The atmosphere needs to absorb dramatically less carbon dioxide, while people around the world are certain to want dramatically more of the products and comforts whose creation and operation send carbon dioxide and other gases into the sky.

Isn't "clean energy" the answer? Of course—because everything is the answer. The people I spoke with and reports I read differed in emphasis, sometimes significantly. Some urged greater stress on efficiency and conservation; some, a faster move toward nuclear power or natural gas; some, an all-out push for solar power and other renewable sources; others, immediate preparation for "geo-engineering" or "abatement" projects to offset the effects of climate disruption once they occur. But in a sense they were all in harmony, because everything on all the lists works toward the same end.

The best-known illustration of the need for an all-fronts approach is the "carbon wedge" analysis from the Carbon Mitigation Initiative at Princeton. Its premise is that to keep the carbon-dioxide level from going into the 500s, or twice its pre-industrial-age level, over the next 50 years, the world collectively will need to reduce its carbon-dioxide emissions by a total of about 26 billion tons per year. (Technically, CMI measures its goals in billions of tons of carbon contained within the carbon dioxide. For clarity, I've converted the figures.) To reach that total, CMI proposes seven "stabilization wedges" of a little less than 4 billion tons of carbon dioxide each. A 4-billion-ton "wedge" through efficiency efforts of all kinds; another wedge of that size through renewable power; another through avoiding deforestation and changing agricultural practices. Eventually it adds up. "There are many good options," Julio Friedmann, a geologist at Lawrence Livermore National Laboratory, told me soon after I first met him in Beijing two years ago. "But there are no *unlimited* options. Each is limited by cost, limited by scale, limited by physics and chemistry, limited by thermodynamics. For example, there's nothing wrong with switchgrass as a biofuel"—one of George W. Bush's novel proposals—"but there's not a lot of energy in it."

We'll hear from Friedmann again. This emphasis on limits is what begins pointing us back to coal.

"Emotionally, we would all like to think that wind, solar, and conservation will solve the problem for us," David Mohler of Duke Energy told me. "Nothing will change, our comfort and convenience will be the same, and we can avoid that nasty coal. Unfortunately, the math doesn't work that way."

The math he has in mind starts with the role that coal now plays around the world, and especially for the two biggest energy consumers, America and China. Overall, coal-burning power plants provide nearly half (about 46 percent this year) of the electricity consumed in the United States. For the record: natural gas supplies another 23 percent, nuclear power about 20 percent, hydroelectric power about 7 percent, and everything else the remaining 4 or 5 percent. The small size of the "everything else" total is worth noting; even if it doubles or triples, the solutions we often hear the most about won't come close to meeting total demand. In China, coal-fired plants supply an even larger share of much faster-growing total electric demand: at least 70 percent, with the Three Gorges Dam and similar hydroelectric projects providing about 20 percent, and (in order) natural gas, nuclear power, wind, and solar energy making up the small remainder. For the world as a whole, coal-fired plants provide about half the total electric supply. On average, every American uses the electricity produced by 7,500 pounds of coal each year.

Precisely because coal already plays such a major role in world power supplies, basic math means that it will inescapably do so for a very long time. For instance: through the past decade, the United States has talked about, passed regulations in favor of, and made technological breakthroughs in all fields of renewable energy. Between 1995 and 2008, the amount of electricity coming from solar power rose by two-thirds in the United States, and wind-generated electricity went up more than 15-fold. Yet over those same years, the amount of electricity generated by coal went up much faster, in absolute terms, than electricity generated from any other source. The journalist Robert Bryce has drawn on U.S. government figures to show that between 1995 and 2008, "the absolute increase in total electricity produced by coal

was about 5.8 times as great as the increase from wind and 823 times as great as the increase from solar"—and this during the dawn of the green-energy era in America. Power generated by the wind and sun increased significantly in America last year; but power generated by coal increased more than seven times as much. As Americans have read many times, Chinese companies are the world's leaders in manufacturing solar panels, often using technology originally developed in the United States. Many of the panels are used inside China for its own rapidly growing solar-power system; still, solar energy accounts for about 1 percent of its total power supply. In his book *PowerHungry*, Bryce describes a visit to a single coal mine, the Cardinal Mine in western Kentucky, whose daily output supports three-quarters as much electricity generation as all the solar and wind facilities in the United States combined. David MacKay, of the physics department at Cambridge University in England, has compiled an encyclopedia of such energy-related comparisons, which is available for free download (under the misleadingly lowbrow title *Sustainable Energy—Without the Hot Air*). For instance: he calculates that if the windiest 10 percent of the entire British landmass were completely covered with wind turbines, they would produce power roughly equivalent to half of what Britons expend merely by driving each day.

Similar patterns apply even more starkly in China. Other sources of power are growing faster in relative terms, but year by year the most dramatic increase is in China's use of coal. "Coal simply is going to be with us for decades," a technical adviser to China's energy ministry told me this summer in Beijing. "We hope someday to have 15 percent of our power from renewable sources. Even so, the percentage of power generated by coal will not drop by more than a few points, and the absolute amount will quickly grow." Another government energy expert in Beijing said that the only serious limit on how fast Chinese power companies can increase their use of coal is the capacity of the country's transportation system. "It's kind of an existential question, whether they can handle the physical volumes they are planning to consume," he said. "Right now railroads are at capacity, you have entire highways being blocked with coal trucks, and the problems cascade." Part of the reason China has committed some $80 billion over the next decade to build light-rail networks across the country is to get human passengers off the main rail lines, opening up more capacity to move coal.

"People without a technical background think, 'Coal is dirty! It's bad,'" I was told in Beijing by Ming Sung, a geologist and energy expert who was born in Shanghai, worked for decades in America and became a citizen, and has now returned to China. "But will you turn off your refrigerator for 30 years while we work on renewables? Turn off the computer? Or ask people in China to do that? Unless you will, you can't get rid of coal for decades. As [U.S. Energy Secretary] Steven Chu has said, we have to face the nightmare of coal for a while."

Coal will be with us because it is abundant: any projected "peak coal" stage would come many decades after the world reaches "peak oil." It will be with us because of where it's located: the top four coal-reserve countries are the United States, Russia, China, and India, which together have about 40 percent of the world's population and more than 60 percent of its coal. It will be with us because its direct costs are in most circumstances far lower than those of the alternatives—that's why so much is used. (Prices vary widely from place to place and company to company, but one utility executive said that the lowest-price coal plant might generate electricity for 2 cents per kilowatt-hour, while the same amount of power from a new wind farm in the same area might cost 20 cents.) It will be with us because its indirect costs, in miner deaths, environmental destruction, and carbon burden on the atmosphere are unregulated and "externalized." Power companies that answer to shareholders or ratepayers have a hard time justifying a more expensive choice. "Coal is so cheap because its dirtiness still doesn't count against it," an air-pollution expert with the Natural Resources Defense Council told *The Wall Street Journal* 10 years ago. In the absence of climate legislation in the United States and international agreements to reduce emissions, the dirtiness still doesn't count. Coal will be with us because changing a power infrastructure—like building a new transportation system or extending cable or fiber-optic connections through an entire country—is the very

opposite of a “virtual” process, and takes many years to complete.

And it will be with us because of a surprising constraint: after a century in which medical diagnosis and treatment, computer and communications systems, aerospace and nanotech industries, and nearly every other form of technology have routinely achieved the magical, energy production is essentially what it was in the time of James Watt. With the main exception of nuclear-power plants and the hoped-for future exception of practical nuclear-fusion systems, we mostly create electricity by burning something that was once underground —coal, oil, natural gas—to boil water and turn turbines with the steam. (Windmills use the wind’s force, and hydropower systems use falling water, to turn turbines directly.) The computer of 10 years from now will be unrecognizably more powerful than today’s, and its predictably increased capability will make medical, navigation, and other systems better, too. If the power plant of 10 years from now is even slightly more efficient than today’s, that will be a major achievement. The most advanced of today’s “ultra-supercritical” coal-fired plants, which operate at very high temperatures and pressures to maximize the efficiency of combustion, convert up to 48 percent of the coal’s potential energy to electric power; the rest is lost as heat. “Subcritical” plants typically have efficiencies in the mid-30s. The costliest and most advanced technology is an improvement—but not a breakthrough. A breakthrough is what it would take to move beyond reliance on coal.

“I know this is a theological issue for some people,” Julio Friedmann of Lawrence Livermore said. “Solar and wind power are going to be important, but it is really hard to get them beyond 10 percent of total power supply.” He pointed out the huge engineering achievement it has taken to raise the efficiency of solar photovoltaic cells from about 25 percent to about 30 percent; whereas “to make them useful, you would need improvements of two- or threefold in cost,” say from about 18 cents per kilowatt-hour to 6 cents. He recited a skeptic’s line used about the Carter administration’s clean-energy programs—“You’re not going to run a steel plant with solar panels”—and then made a point that summarized the outlook of those who have decided they can best wage the climate fight by working on dirty, destructive coal.

“It is very hard to go around the world and think you can make any difference in carbon-loading the atmosphere without some plan for how people can continue to use coal,” Friedmann said. “It is by far the most prevalent and efficient way to generate electricity. People are going to use it. There is no story of climate progress without a story for coal. In particular, U.S.-China progress on coal.”

The Technical Challenge

What would progress on coal entail? The proposals are variations on two approaches: ways to capture carbon dioxide before it can escape into the air and ways to reduce the carbon dioxide that coal produces when burned. In "post-combustion" systems, the coal is burned normally, but then chemical or physical processes separate carbon dioxide from the plume of hot flue gas that comes out of the smokestack. Once "captured" as a relatively pure stream of carbon dioxide, this part of the exhaust is pressurized into liquid form and then sold or stored. Refitting an existing coal plant can be very costly. "It's like trying to remodel your home into a mansion," a coal-plant manager told me in Beijing. "It's more expensive, and it's never quite right." Apart from research projects, only two relatively small coal-fired power plants now operate in America with post-combustion capture.

Designing a capture system into a plant from the start is cheaper than doing refits. But even then the "parasitic load" of energy required to treat, compress, and otherwise handle the separated stream of carbon dioxide can come to 30 percent or more of the total output of a coal-fired power plant—so even more coal must be burned (and mined and shipped) to produce the same supply of electricity. Without mandatory emission limits or carbon prices, burning coal more cleanly is inevitably more expensive than simply burning coal the old way. "When people like me look for funding for carbon capture, the financial community asks, 'Why should we do that now?'" an executive of a major American electric utility told me. "If there were a price on carbon"—a tax on carbon-dioxide emissions—"you could plug in, say, a loss of $30 to $50 per ton, and build a business case."

"Pre-combustion" systems are fundamentally more efficient. In them, the coal is treated chemically to produce a flammable gas with lower carbon content than untreated coal. This means less carbon dioxide going up the smokestack to be separated and stored.

Either way, pre- or post-, the final step in dealing with carbon is "sequestration"—doing

something with the carbon dioxide that has been isolated at such cost and effort, so it doesn't just escape into the air. Carbon dioxide has a surprisingly large number of small-scale commercial uses, starting with adding the sparkle to carbonated soft drinks. (This is not a big help on the climate front, since the carbon dioxide is "sequestered" only until you pop open the bottle's top.) All larger-scale, longer-term proposals for storing carbon involve injecting it deep underground, into porous rock that will trap it indefinitely. In the right geological circumstances, the captured carbon dioxide can even be used for "enhanced oil recovery," forcing oil out of the porous rock into which it is introduced and up into wells.

These efforts are in one way completely different from "advanced research and development" as we often conceive of it, and in another way very much the same. They are different in that the scientists and entrepreneurs involved do not seem to count on, or even hope for, the large breakthroughs we have come to assume in biological sciences and info-tech. Consistent with two centuries of incremental improvement in power systems since the time of James Watt, practical refinements and ever-improving efficiency are the goal. They are similar in the operational advantage conferred by *doing*. Because Google indexes more data and handles more queries than any competitor, it can more quickly determine which innovations are succeeding (News, Translate, Earth, Maps) and which are failing (Wave), and exactly how the promising products still need to be improved. The first million copies of each new chip that Intel produces help it debug the production process, so that subsequent millions are cheaper and increasingly defect-free. "Whenever you scale something up, there are always differences from what you planned," an engineer from a major American technology company told me. "It's never quite the same. China is *building* plants like mad, so they can afford to experiment. We are not."

In the search for "progress on coal," like other forms of energy research and development, China is now the Google, the Intel, the General Motors and Ford of their heyday—the place where the doing occurs, and thus the learning by doing as well. "They are doing so much so fast that their learning curve is at an inflection that simply could not be matched in the United States," David Mohler of Duke Energy told me.

"In America, it takes a decade to get a permit for a plant," a U.S. government official who works in China said. "Here, they build the whole thing in 21 months. To me, it's all about accelerating our way to the right technologies, which will be much slower without the Chinese.

"You can think of China as a huge laboratory for deploying technology," the official added. "The energy demand is going like this"—his hand mimicked an airplane taking off—"and they need to build new capacity all the time. They can go from concept to deployment in half the time we can, sometimes a third. We have some advanced ideas. They have the capability to deploy it very quickly. That is where the partnership works."

The good aspects of this partnership have unfolded at a quickening pace over the past decade, through a surprisingly subtle and complex web of connections among private, governmental, and academic institutions in both countries. Perhaps I should say unsurprisingly, since the relationships among American and Chinese organizations in the energy field in some ways resemble the manufacturing supply chains that connect factories in China with designers, inventors, and customers in the United States and elsewhere. The difference in this case is how much faster the strategic advantage seems to be shifting to the Chinese side.

In the normal manufacturing supply chain—Apple creating computers, Walmart outsourcing clothes and toys—the United States provides branding, design, and a major market for products, while China supplies labor, machines, and the ability to turn concepts into products at very high speed. In the quest for cleaner coal, America's contribution is mainly "soft power"—advice, coordination, prodding, and expertise—in hopes of influencing what Chinese

organizations do.

Ten years ago, at the end of the Clinton administration, the Chinese and American governments signed a "Fossil Energy Protocol," to coordinate research on better use of coal and oil. Political leaders have come and gone since then, but the cast of technicians, civil servants, and business officials on each side has been relatively stable and has gotten used to working together. After taking office as secretary of energy last year, Steven Chu—a celebrity in China because of his Chinese heritage and his Nobel Prize—gave a new push to these efforts, hiring additional staff members for the U.S.-China office and committing $75 million to a joint Clean Energy Research Center.

The efforts of two scientists we've already met, Julio Friedmann and Ming Sung, illustrate what Americans can and cannot do to shape what happens in China—and the mounting advantages on China's side relative to America's.

Friedmann, who is in his mid-40s, has become one of the world's experts on sequestration: how and where carbon dioxide can safely be stored underground. He was trained in geology at MIT and the University of Southern California and initially went to work for ExxonMobil. But by the early 2000s he had become fascinated with the emerging science of underground carbon-dioxide storage. "At that point, it was clear that nearly all of the really cool work was being done in the national labs," he told me. In 2004 he and his family moved from Maryland to California, where he joined Lawrence Livermore. He is now the head of the Carbon Management Program there and the technical leader of a government-university-business consortium that this summer won a Department of Energy competition to help develop carbon-sequestration projects in China. To give an idea of the consortium's range, it includes three universities, three national laboratories, two scientific nongovernmental organizations, and six large corporations, among them General Electric, Duke Energy, and AEP.

After talking with Friedmann many times in China, I finally asked about the ethnic derivation of his name. His grandparents were Ashkenazim from Poland and Hungary who left for Latin America in the 1930s; his parents, raised in Colombia and Venezuela, met on an arranged date at Grossinger's in the Catskills. Although Friedmann bikes to work through the bucolic Northern California setting of the Lawrence Livermore lab—a setting punctuated by the watchtowers and electrified fencing that surround the plutonium stockpile for the lab's weapons-research center—he comes across as a fast-talking, high-pressure East Coast urban type.

In many meetings in America and China in the past two years, I have seen him turn that intensity to one great question: how quickly geologists from America and elsewhere can work with their counterparts in China to improve systems for pumping carbon dioxide underground, and to identify the right rock formations where it can safely be stored. On a typical trip to China, he will spend half his time in Beijing or Shanghai, meeting with government and corporate officials—and the other half in Xi'an or the Inner Mongolian wilderness, where many of the most promising storage locations are found. What he and his team have to offer, from the American part of the supply chain, is expertise on geological formations, on computer models for how the "plume" of liquefied carbon dioxide will settle into porous rock, and on other benefits of America's decades of experience in petroleum geology. He can also put Chinese plant managers, scientists, and bureaucrats in touch with overseas counterparts they would otherwise never meet. "Projects like these are sort of like the school dance," he told me. "You're not getting married, but you're figuring out how to interact. We need to start the process in a way that gives people the confidence to do it again, and again, and again. The confidence *is* the product." The more often Chinese and foreign officials work together, the more easily they continue to work together. This might sound trivial, but I've become convinced that the steady expansion of these contacts will make a major difference in how an ever more powerful China deals with the rest of the world. What does Friedmann, or the

United States, get from the process? “More tons sequestered, rather than emitted, in China,” he told me. But also something unavailable in America: a chance to see new technology in new plants and learn how it works. “In the U.S. today, there is not a single demonstration of capturing CO2 from a coal-fired plant at large scale,” he said. “The technologies have been a little too expensive to actually implement. That’s why we started looking at China.” They can afford to build, and Americans can hope to watch and learn.

Ming Sung’s role illustrates a similar balance of influence and knowledge between the United States and China. Sung, who is in his early 60s, was born in Shanghai and raised there and in Hong Kong, where his family fled in 1958. Ten years later he came to the United States for college and graduate studies in geology. He became a U.S. citizen, worked in the newly formed Department of Energy during the Carter administration, and then left for a 25-year career around the world as an executive with Shell Oil. After he retired from Shell and founded a software company, he and his wife decided to move back to China. He now works in Beijing for a Boston-based nonprofit environmental group called the Clean Air Task Force. (Disclosure: my sister is on the board.)

In the early 2000s the task force, originally a conventional anti-air-pollution group, embraced the necessity of cleaning up coal. In Beijing, Sung gave me a copy of its latest working paper, in both Chinese and English, called “Coal Without Carbon.”

The group has sponsored research on sequestration, on post-combustion capture, and on the “cleanest” of the emerging pre-combustion coal technologies—“underground coal gasification.” In this process, jets of air (or pure oxygen), sometimes with steam or various chemicals, are blasted into coal seams deep underground. They interact chemically with the coal to produce a gas that flows back up a pipe and can be burned. It leaves in the ground much of the carbon, sulfur, nitrogen, and other elements that create greenhouse gases and other pollutants when coal is burned.

“And this can be very cheap,” Sung told me. “You don’t have to mine the coal. You don’t have to send men underground or haul coal around or dispose of ash. All the dirty stuff stays buried.” Because of these and other savings, he said, coal used this way could match or beat the price of today’s standard dirty power plant.

But in advocating the whole range of “clean coal” technologies, Sung and his team have the same problem Julio Friedmann has with carbon sequestration: it’s not happening in the United States. There’s one significant exception: the Texas Clean Energy Project, a plant being built outside Odessa, which will apply underground-gasification technology to capture 90 percent of its carbon, more than any other commercial plant in the world. It received a $450 million federal award, just over half from the Department of Energy’s Clean Coal Power Initiative and the rest from the American Recovery and Reinvestment stimulus program (toward the $2.1 billion total capital cost). If it works as promised, this facility will be an advance over any coal-fired plant operating anywhere: it will gasify coal underground, eliminating the cost and damage of mining; it will sell urea (for fertilizer) and other chemical by-products of the underground gasification; and it will use the captured carbon dioxide for enhanced oil recovery in the nearby Permian Basin oil fields—all in addition to generating power. [Correction: The decarbonization and other cleanup steps that make this plant distinctive are done above rather than underground. For full details, see texascleanenergyproject.com/about-tcep.] But otherwise, to see new technology in action and to influence the next dozen coal plants being built in the world, Ming Sung had to go back to China.

“For the last 30 years, we have not been able to build a coal-to-gas conversion plant in this country,” a U.S. coal-company official told me. “China has done many. That is what we need to learn from them, all that production and operating experience.” And in exchange? “We do

have safety and environmental information that we can definitely provide."

Ten years ago, the United States and many other countries set joint targets of building a series of experimental low- emissions, high-efficiency coal-fired power plants: FutureGen in America, ZeroGen in Australia, various European efforts without a "Gen" name, and GreenGen in China. America's FutureGen was proposed early, and China's GreenGen was proposed late. Now—surprise!—GreenGen is closest to being completed, with its scheduled opening moved up from 2015 to 2013, and FutureGen has only recently begun to move beyond the congressional-wrangling stage.

What Sung takes from the interaction is both operational knowledge and the chance to influence China's decisions in some way. What he has provided is another sort of connection, between Chinese organizations and the private businesses that mine coal and generate electricity in the United States. "That is the reason we are here—to get companies together," Sung said. "It is taking too long for governments to agree on policies, so we believe in B-to-B connections." At a crucial point, he arranged a meeting in Beijing between the CEO of Duke Energy, Jim Rogers, and Zhang Guobao, vice chairman of the National Development and Reform Commission, essentially China's director of industrial policy. "After the meeting, Zhang said, 'I fully support this collaboration,'" Sung told me. "With that sentence, what more could you ask for?"

Duke got serious about China only two and a half years ago, after Rogers, the CEO, took his grandson on a trip there in the summer of 2008 as a high-school graduation present. The elder Rogers, like so many first-time visitors, was stunned by the scale and dynamism of what he saw. He immediately urged his senior management team to learn about and visit China. "There is something you can't sense from your office in America," the director of Duke's China operations, a 30-year-old woman named River Lu, told me. She grew up in Shenzhen, just north of Hong Kong. "Here you feel the pollution, you feel the growth, you feel the energy." (Her Chinese name is Lu Yun; she chose the English name "River" in her teens. The creativity and often beauty of these chosen names is a dependable pleasure of meeting young English-speaking Chinese.) Although she did not leave China until her mid-20s, for graduate work at the Monterey Institute of International Studies, she has a native-American accent, which she says comes from watching *Friends* and *Ally McBeal* on Hong Kong TV.

David Mohler, Duke's chief technology officer, was one of the first visitors and most frequent return travelers. "We learned that China is preparing, by 2025, for 350 million people to live in cities that don't exist now," he told me. "They have to build the equivalent of the U.S. electrical system"—that is, almost as much added capacity as the entire U.S. grid—"by 2025. It took us 120 years." Rogers, Mohler, and the company as a whole moved quickly from being impressed or frightened by Chinese growth to determining how they could work with it.

"We realized there was no way we could duplicate their speed, the scale, or the constancy of energy policy within the United States," Mohler said. "So we wondered if we could find Chinese partners to work with in applying these clean technologies, so we could bring the benefits of their speed and scale back to the United States." In his speeches and interviews, Rogers frequently emphasizes that by 2050, Duke will need to replace or rebuild every one of its existing power plants in the United States, except for its hydroelectric facilities. Some, because of age; the rest, to meet what Duke considers to be inevitably tightening clean-energy standards. "We will have a huge need for capital," Mohler said. Duke's capital budget for the next three years is $18 billion, and only in China can the company find that plus the operational experience of seeing cleaner-coal technologies as they are deployed. Duke Energy supported the Obama administration's now-abandoned climate bill, because it would have added predictability to the future standards the company will have to meet. With or without a bill, it is looking to China for future financing.

Within months of Rogers's first visit, Duke had opened an office in China, headed by River Lu. Within a year of the visit, in the summer of 2009, Duke signed an agreement for joint research with China's largest energy company, Huaneng, and with the government's Thermal Power Research Institute. Within the clean-energy world, the institute's director of technology, Xu Shisen, is a celebrity known for his advocacy of clean-coal projects. Huaneng has bought a share in a new low-emissions Duke plant in Edwardsport, Indiana. [Correction: The Memorandum of Understanding between Duke and Huaneng, which involves employees of each company visiting the other's plants and sharing information and research, does not include direct investment by Huaneng. Duke has a joint-venture understanding with another Chinese company, the ENN group, toward developing merchant solar panel plants in the United States.]

"As China meets its capacity, it is likely that the best technologies will be commercialized and applied here faster than anywhere else," River Lu said. "We want to be involved in that process."

CHINA'S COOPERATION WITH the United States on coal is good news for the world. If the two countries had decided to make this another arena for demonstrating their respective toughness—if, as at the failed Copenhagen talks last winter, they had mainly exchanged accusations about who was more to blame for emissions problems—they would have guaranteed that the problems could not be solved. If that cooperation breaks down, Julio Friedmann said, "we'll end up paying twice as much to get the same learnings—and delaying the technology on both sides by another decade." Both sides seem to have looked for ways to keep the cooperation going. They have not been in the newspapers, but they deserve recognition for attempting to do the world's work.

But China's very effectiveness and dynamism, beneficial as they may be in this case, highlight an American failure—a failure that seems not transient or incidental but deep and hard to correct.

The manifestation of the failure is that China is where the world's "doing" now goes on, in this industry and many others. If you want to learn how the power plants of the future will work, you must go to Tianjin—or Shanghai, or Chengdu—to find out. Power companies from America, Europe, and Japan are fortunate to have a place to learn. Young engineers and managers and entrepreneurs in China are fortunate that the companies teaching the rest of the world will be Chinese.

The deeper problem is the revealed difference in national capacity, in seriousness and ability to deliver. The Chinese government can decide to transform the country's energy system in 10 years, and no one doubts that it will. An incoming U.S. administration can promise to create a clean-energy revolution, but only naïfs believe that it will.

"The most impressive aspect of the Chinese performance is their determination to do what is needed," Julio Friedmann told me. "To be the first, to be the biggest, to have the best export technology for cleaning up coal." America obviously is not displaying comparable determination—and the saddest aspect of the U.S. performance, he said, is that it seems not deliberate but passive and accidental, the product of modern America's inability to focus public effort on public problems.

"No one in the U.S. government could ever imagine a 10-year plan to ensure U.S. leadership in solar power or batteries or anything else," Joseph Romm, a former Department of Energy official who now writes the blog Climate Progress, told me. "It's just not possible, so nobody even bothers to propose it."

The Chinese system as a whole has great weaknesses as well as great strengths. Its challenges, as I have reported so often in these pages, make the threats facing America look

trivial by comparison. But its response to the energy challenge—including its commitment to dealing with the dirty, unavoidable reality of coal—reveals a seriousness about facing big problems that America now appears to lack.