COAL

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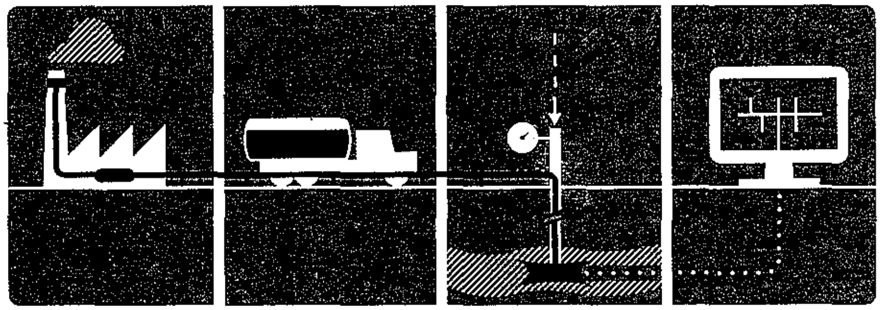
Wild Pets

THE DEBATE OVER OWNING EXOTIC ANIMALS

Carbon Capture and Storage (CCS)

DISPOSING OF WASTE CO_2

Venting CO_2 from a smokestack is usually free, like littering. Capturing and storing CO_2 underground would cost up to a quarter of a power plant's energy—and a lot of money. It won't become the norm unless governments make it happen.



The four steps of capturing and storing carbon dioxide

Capture
CO_2 is separated from other stack gases and compressed into a liquid-like state. This is the most costly step in CCS.

Transport
Fluid CO_2 is moved to a storage reservoir. Pipelines are the most efficient carrier, but trucks, trains, and ships can do the job.

Injection
CO_2 is injected deep underground into a porous formation—an old oil field, say, or a saline aquifer—under a cap rock that deters leaks.

Monitoring
The reservoir must be watched in perpetuity for leaks. Even slow ones could defeat the purpose of preventing climate change.

Underground formations could hold 1,000 years' worth of emissions.

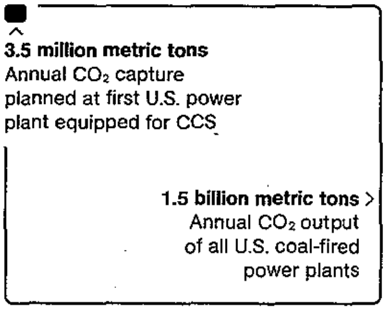
or at any of the handful of other large storage sites around the world. Scientists consider the risk of a catastrophic leak to be extremely low.

They worry more about smaller, chronic leaks that would defeat the purpose of the enterprise. Geophysicists Mark Zoback and Steven Gorelick of Stanford University argue that at sites where the rock is brittle and faulted—most sites, in their view—the injection of carbon dioxide might trigger small earthquakes that, even if otherwise harmless, might crack the overlying shale and allow CO_2 to leak. Zoback and Gorelick consider carbon storage "an extremely expensive and risky strategy." But even they agree that carbon can be stored effectively at some sites—such as the Sleipner gas field in the North Sea, where for the past 17 years the Norwegian oil company Statoil has been injecting about a million tons of CO_2 a year into a brine-saturated sandstone layer half a mile below the seabed. That formation has so much room that all that

ART: ÁLVARO VALIÑO
SOURCES: HOWARD HERZOG, MIT; U.S. ENERGY INFORMATION ADMINISTRATION

CO_2 emitted by fossil fuels, 2011

21% of global fossil fuel CO_2 comes from burning natural gas, mostly for heat and electricity.



A small beginning for CCS

One U.S. power plant, in Mississippi, is now being equipped for CCS. It would take a whole new industry to make a dent in U.S. emissions.

CO_2 hasn't increased its internal pressure, and there's been no sign of quakes or leaks.

European researchers estimate that a century's worth of European power plant emissions could be stored under the North Sea. According to the DOE, similar "deep saline aquifers" under the U.S. could hold more than a thousand years' worth of emissions from American power plants. Other types of rock also have potential as carbon lockers. In experiments now under way in Iceland and in the Columbia River Basin of Washington State, for example, small amounts of carbon dioxide are being injected into volcanic basalt. There the gas is expected to react with calcium and magnesium to form a carbonate rock—thus eliminating the risk of gas escaping.

The CO_2 that Statoil is injecting at Sleipner doesn't come from burning; it's an impurity in the natural gas the company pumps from the seabed. Before it can deliver gas to its customers, Statoil has to separate out the CO_2, and it used to just vent the stuff into the atmosphere. But in 1991 Norway instituted a carbon tax, which now stands at around $65 a metric ton. It costs Statoil only $17 a ton to reinject the CO_2 below the seafloor. So at Sleipner, carbon storage is much cheaper than carbon dumping, which is why Statoil has invested in the technology. Its natural gas operation remains very profitable.

AT A COAL-FIRED POWER PLANT the situation is different. The CO_2 is part of a complex swirl of stack gases, and the power company has no financial incentive to capture it. As the engineers at Mountaineer learned, capture is the most expensive part of any capture-and-storage project. At Mountaineer the CO_2 absorption system was the size of a ten-story apartment building and occupied 14 acres—and that was just to capture a tiny fraction of the plant's carbon emissions. The absorbent had to be heated to release the CO_2, which then had to be highly compressed for storage. These energy-intensive steps create what engineers call a "parasitic load," one that could eat up as much as 30 percent of the total energy output of a coal plant that was capturing all its carbon.

One way to reduce that costly loss is to gasify the coal before burning it. Gasification can make power generation more efficient and allows the carbon dioxide to be separated more easily and cheaply. A new power plant being built in Kemper County, Mississippi, which was designed with carbon capture in mind, will gasify its coal.

Existing plants, which are generally designed to burn pulverized coal, require a different approach. One idea is to burn the coal in pure oxygen instead of air. That produces a simpler flue gas from which it's easier to pull the CO_2. At the DOE's National Energy Technology Laboratory in Morgantown, West Virginia, researcher Geo Richards is working on an advanced version of this scheme.

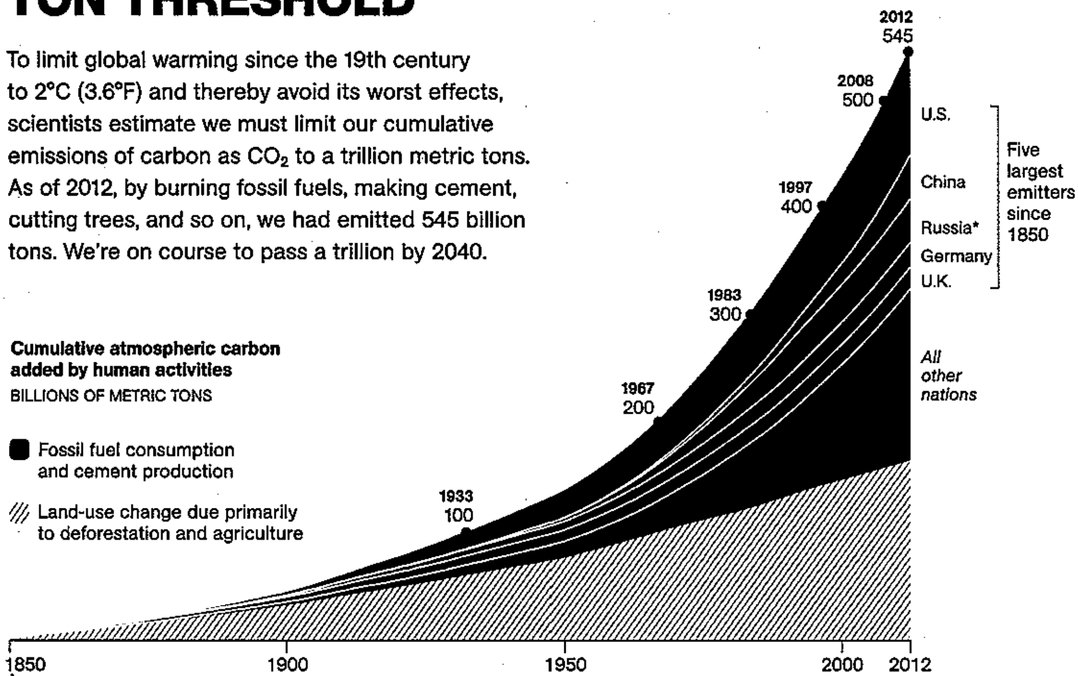
35% comes from oil, which is used primarily to make various transportation fuels.

44% comes from burning coal—the cheapest and dirtiest fossil fuel, used primarily for electricity.

CO_2 and Climate Change

THE TRILLION-TON THRESHOLD

To limit global warming since the 19th century to 2°C (3.6°F) and thereby avoid its worst effects, scientists estimate we must limit our cumulative emissions of carbon as CO_2 to a trillion metric tons. As of 2012, by burning fossil fuels, making cement, cutting trees, and so on, we had emitted 545 billion tons. We're on course to pass a trillion by 2040.



"Come and see our new toy," he says, hunching his shoulders against a bitter Appalachian winter day and walking briskly toward a large white warehouse. Inside, workers are assembling a five-story scaffold for an experiment in "chemical looping." Making pure oxygen from air, Richards explains, is costly in itself—so his process uses a metal such as iron to grab oxygen out of the air and deliver it to the coal fire. In principle, chemical looping could radically cut the cost of capturing carbon.

Richards has dedicated more than 25 years of his career to making carbon capture more efficient, and for him the work is largely its own reward. "I'm one of those geeky people who just like seeing basic physics turned into technology," he says. But after decades of watching politicians and the public tussle over whether climate change is even a problem, he does sometimes wonder if the solution he's been working on will ever be put to practical use. His experimental carbon-capture system is a tiny fraction of the size that would be required at a real power plant. "In this business," Richards says, "you have to be an optimist."

IN WEST VIRGINIA THESE DAYS, century-old coal mines are closing as American power plants convert to natural gas. With gas prices in the U.S. near record lows, coal can look like yesterday's fuel, and investing in advanced coal technology can look misguided at best. The view from Yulin, China, is different.

Yulin sits on the eastern edge of Inner Mongolia's Ordos Basin, 500 dusty miles inland from Beijing. Rust-orange sand dunes surround forests of new, unoccupied apartment buildings, spill over highway retaining walls, and send clouds of grit through the streets. Yulin and its three million residents are short on rain and shade, hot in summer and very cold in winter. But the region is blessed with mineral resources,

*U.S.S.R. DATA PRIOR TO 1992
SOURCES: THOMAS BODEN, CARBON DIOXIDE INFORMATION ANALYSIS CENTER/OAK RIDGE NATIONAL LABORATORY, U.S. DEPARTMENT OF ENERGY; R. A. HOUGHTON, WOODS HOLE RESEARCH CENTER; EPA

The rising CO_2 threat

84% Portion of U.S. greenhouse gases emitted by human activity that is CO_2

including some of the country's richest deposits of coal. "God is fair," says Yulin deputy mayor Gao Zhongyin. From here coal looks like the fuel of progress.

The sandy plateaus around Yulin are punctuated with the tall smokestacks of coal power plants, and enormous coal-processing plants, with dormitories for live-in workforces, sprawl for miles across the desert. New coal plants, their grids of dirt roads decorated with optimistic red-bannered gateways, bustle with young men and women in coveralls. Coal provides about 80 percent of China's electric power, but it isn't just for making electricity. Since coal is such a plentiful domestic fuel, it's also used for making dozens of industrial chemicals and liquid fuels, a role played by petroleum in most other countries. Here coal is a key ingredient in products ranging from plastic to rayon.

Coal has also made China first among nations in total carbon dioxide emissions, though the U.S. remains far ahead in emissions per capita. China is not retreating from coal, but it's more than ever aware of the high costs. "In the past ten years," says Deborah Seligsohn, an environmental policy researcher at the University of California, San Diego, with nearly two decades' experience in China, "the environment has gone from not on the agenda to near the top of the agenda." Thanks to public complaints about air quality, official awareness of the risks of climate change, and a desire for energy security and technological advantage, China has invested hundreds of billions of dollars in renewable energy. It's now a top manufacturer of wind turbines and solar panels; enormous solar farms are scattered among the smokestacks around Yulin. But the country is also pushing ultraefficient coal power and simpler, cheaper carbon capture.

These efforts are attracting both investment and immigrants from abroad. At state-owned Shenhua Group, the largest coal company in the world, its National Institute of Clean-and-Low-Carbon Energy was until recently headed by J. Michael Davis, an American who served as assistant U.S. secretary for conservation and renewable energy under the first President Bush and is a past president of the U.S. Solar Energy Industries Association. Davis says he was drawn to China by the government's "durable commitment" to improving air quality and reducing carbon dioxide emissions: "If you want to make the greatest impact on emissions, you go where the greatest source of those emissions happens to be."

Yesterday's fuel? In China coal looks like the fuel of progress.

Will Latta, founder of the environmental engineering company LP Amina, is an American expat in Beijing who works closely with Chinese power utilities. "China is openly saying, Hey, coal is cheap, we have lots of it, and alternatives will take decades to scale up," he says. "At the same time they realize it's not environmentally sustainable. So they're making large investments to clean it up." In Tianjin, about 85 miles from Beijing, China's first power plant designed from scratch to capture carbon is scheduled to open in 2016. Called GreenGen, it's eventually supposed to capture 80 percent of its emissions.

LAST FALL, AS WORLD COAL CONSUMPTION and world carbon emissions were headed for new

800,000 yrs | Minimum time since the CO_2 level was as high as it is today

108% | Increase in global per capita emissions between 1950 and 2010 records, the Intergovernmental Panel on Climate Change (IPCC) issued its latest report. For the first time it estimated an emissions budget for the planet—the total amount of carbon we can release if we don't want the temperature rise to exceed 2 degrees Celsius (3.6 degrees Fahrenheit), a level many scientists consider a threshold of serious harm. The count started in the 19th century, when the industrial revolution spread. The IPCC concluded that we've already emitted more than half our carbon budget. On our current path, we'll emit the rest in less than 30 years.

The first U.S. power plant that will capture most of its CO_2 is under construction.

Changing that course with carbon capture would take a massive effort. To capture and store just a tenth of the world's current emissions would require pumping about the same volume of CO_2 underground as the volume of oil we're now extracting. It would take a lot of pipelines and injection wells. But achieving the same result by replacing coal with zero-emission solar panels would require covering an area almost as big as New Jersey (nearly 8,000 square miles). The solutions are huge because the problem is—and we need them all.

"If we were talking about a problem that could be solved by a 5 or 10 percent reduction in greenhouse gas emissions, we wouldn't be talking about carbon capture and storage," says Edward Rubin of Carnegie Mellon University. "But what we're talking about is reducing global emissions by roughly 80 percent in the next 30 or 40 years." Carbon capture has the potential to deliver big emissions cuts quickly: Capturing the CO_2 from a single thousand-megawatt coal plant, for example, would be equivalent to 2.8 million people trading in pickups for Priuses.

The first American power plant designed to capture carbon is scheduled to open at the end of this year. The Kemper County coal-gasification plant in eastern Mississippi will capture more than half its CO_2 emissions and pipe them to nearby oil fields. The project, which is supported in part by a DOE grant, has been plagued with cost overruns and opposition from both environmentalists and government-spending hawks. But Mississippi Power, a division of Southern Company, has pledged to persist. Company leaders say the plant's use of lignite, a low-grade coal that's plentiful in Mississippi, along with a ready market for its CO_2, will help offset the heavy cost of pioneering new technology.

The technology won't spread, however, until governments require it, either by imposing a price on carbon or by regulating emissions directly. "Regulation is what carbon capture needs to get going," says James Dooley, a researcher at DOE's Pacific Northwest National Laboratory. If the EPA delivers this year on President Obama's promise to regulate carbon emissions from both existing and new power plants—and if those rules survive court challenges—then carbon capture will get that long-awaited boost.

China, meanwhile, has begun regional experiments with a more market-friendly approach—one that was pioneered in the U.S. In the 1990s the EPA used the Clean Air Act to impose a cap on total emissions of sulfur dioxide from power plants, allocating tradable pollution permits to individual polluters. At the time, the power industry predicted disastrous economic consequences. Instead the scheme produced innovative, progressively cheaper technologies and significantly cleaner air. Rubin says that carbon-capture systems are at much the same stage that sulfur dioxide systems were in the 1980s. Once emissions limits create a market for them, their cost too could fall dramatically.

If that happens, coal still wouldn't be clean—but it would be much cleaner than it is today. And the planet would be cooler than it will be if we keep burning coal the dirty old way. ☐

The world gets huge
into extracting it fron
is just a ghostly echo

Photographs by Rob

JHARKHAND, INDIA
A young boy carries a chunk of coal into the mining camp where he lives. His family will burn the coal to make coke—a cleaner and hotter-burning fuel—which they'll either sell or use themselves for heating and cooking.