Part I: China's Coal Future

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To prevent massive pollution and slow its growing contribution to global warming, China will need to make advanced coal technology work on an unprecedented scale.

By Peter Fairley

A visitor arriving in Shanghai immediately notices China's technological conundrum. Through the windows of the magnetically levitated train that covers the 30 kilometers from Pudong International Airport to Shanghai at up to 430 kilometers per hour, both the progress the country is making and the price it is paying for it are apparent. Most days, a yellow haze hangs over Shanghai's construction frenzy. Pollution is the leading cause of death in China, killing more than a million people a year. And the primary cause of pollution is also the source of the energy propelling the ultramodern train: coal.

To keep pace with the country's economic growth, China's local governments, utilities, and entrepreneurs are building, on average, one coal-fired power plant per week. The power plants emit a steady stream of soot, sulfur dioxide, and other toxic pollutants into the air; they also spew out millions of tons of carbon dioxide. In November, the International Energy Agency projected that China will become the world's largest source of carbon dioxide emissions in 2009, overtaking the United States nearly a decade earlier than previously anticipated. Coal is expected to be responsible for three-quarters of that carbon dioxide.

And the problem will get worse. Between now and 2020, China's energy consumption will more than double, according to expert estimates. Ratcheting up energy efficiency, tapping renewable resources with hydro dams and wind turbines, and building nuclear plants can help, but--at least in the coming two decades--only marginally. Since China has very little in the way of oil and gas reserves, its future depends on coal. With 13 percent of the world's proven reserves, China has enough coal to sustain its economic growth for a century or more. The good news is that China's leaders saw the coal rush coming in the 1990s and began exploring a range of advanced technologies. Chief among them is coal gasification. "It's the key for clean coal in China," says chemical engineer Li Wenhua, who directed advanced coal development for Beijing's national high-tech R&D program (better known in China as the "863" program) from 2001 through 2005.

Gasification transforms coal's complex mix of hydrocarbons into a hydrogen-rich gas known as synthesis gas, or "syngas." Power plants can burn syngas as cleanly as they can natural gas. In addition, with the right catalysts and under the right conditions, the basic chemical building blocks in syngas combine to form the hydrocarbon ingredients of gasoline and diesel fuel. As a result, coal gasification has the potential both to squelch power plants' emission of soot and smog and to decrease China's growing dependence on imported oil. It could even help control emissions of carbon dioxide, which is more easily captured from syngas plants than from conventional coal-fired plants.

Despite China's early anticipation of the need for coal gasification, however, its implementation of the technology in power plants has lagged. The country's electricity producers lack the economic and political incentives to break from their traditional practices.

In contrast, large-scale efforts to produce liquid transportation fuels using coal gasification are well under way. China's largest coal firm, Shenhua Group, plans to start up the country's first coal-to-fuels plant in 2007 or early 2008, in the world's most ambitious application of coal liquefaction since World War II. Shenhua plans to operate eight liquefaction plants by 2020, producing, in total, more than 30 million tons of synthetic oil annually--enough to displace more than 10 percent of China's projected oil imports.

China's progress in constructing coal-conversion plants puts it far ahead of the United States, where coal gasification is still recovering from a damaged reputation. Gasification demonstration programs initiated in the U.S. after the energy crises of the 1970s were orphaned when oil and gas prices plummeted in the 1980s. That left many with the impression that the technology itself was unreliable *(see "Carbon Dioxide for Sale," July 2005)*. In China, by contrast, oil never looked cheap, and coal has never lost its shine.

Coal and Cashmere

Northern China is fast becoming the epicenter of China's energy industry. The leading draw is the Shenfu Dongsheng coalfield, a 31,000-square-kilometer solid layer of shallow coal that stretches from the northern tip of China's Shaanxi Province to the southern edge of Nei Mongol, or Inner Mongolia. The Dongsheng field's estimated reserve of 223.6 billion tons of coal makes it the world's seventh largest; efforts to convert much of that coal to transportation fuels could make it the world's most profitable.

Until recently, Inner Mongolia's coal capital, Erdos, was largely untouched by the modern world, bounded by mountain ranges and the Great Wall to the south and by the Yellow River to the north. Its isolation is now over, thanks to freshly poured highways and new rail lines rolling over its fissured hills and steep valleys. An airport should open this year.

Erdos's GDP doubled between 2001 and 2004, largely because of coal, chemicals, and cashmere (Erdos supplies a quarter of the world's cashmere). To reach the coalfields, you drive 40 minutes south of the city, passing a 1950s-era mausoleum for Genghis Khan, the 13th-century warrior who conquered much of Asia. As you approach the dry floodplain of the Wulanmulun River, the imposing infrastructure of a dozen coal mines, including some of the world's largest and most mechanized, leaps out of the barren landscape. The region is also home to several hundred smaller, less modern mines (gases and cave-ins kill at least 6,000 Chinese coal miners a year). Miners on their day off zip by on mopeds, three or four to a vehicle, racing past 40-ton trucks heaped with coal. Along the highway, coal-sorting terminals load railcars destined for power plants and ports on the industrialized east coast.

None of that infrastructure and activity, however, prepares a visitor for Shenhua's coal-to-fuels complex, which rises from a plateau cut into the hills. It is an impressive site, with its own coal-fired power plant, gasification plants, and two massive reactors where coal will be liquefied, each weighing 2,250 metric tons (Shenhua claimed the world hoisting record when it lifted the reactors into place last June). Flush from a $2.95 billion IPO in 2005 and $5 billion in annual revenues from its integrated mines, railroads, and power plants, Shenhua is rapidly expanding its operations. It sold 113 million metric tons of coal in just the first half of 2006, nearly matching the previous year's total. If Shenhua maintains that pace this year, it may become the world's largest producer of coal.

China's government in Beijing created Shenhua a decade ago to bring economies of scale and modern technology to bear on the Dongsheng coalfields. The company's $1.5 billion coal-to-fuels plant is an expression of that strategy--a facility so technically ambitious that many experts, Chinese and Western alike, doubted it would ever be built.

The production of transportation fuels from coal dates to early-20th-century Germany, where chemists developed two approaches to converting coal's solid long-chain hydrocarbons into the shorter liquid hydrocarbons found in motor fuels. (Nazi Germany, with little access to oil, relied heavily on these processes to fuel its highly mechanized army and air force, producing gasoline, diesel, and aviation fuel from coal.) Franz Fischer and Hans Tropsch invented the better known of the two approaches in the 1920s. Fischer-Tropsch synthesis reduces coal to syngas, a mixture of hydrogen and carbon monoxide. A catalyst, often cobalt, then causes the carbon and hydrogen atoms to reconnect into new compounds, such as alcohols and fuels. Fischer-Tropsch synthesis is conventional chemistry today: in South Africa, for example, Johannesburg-based Sasol built Fischer-Tropsch coal-to-oil plants to ensure the country's fuel supply during the trade boycotts of the apartheid years; and by swapping in different catalysts, China's coal-to-chemicals gasification plants have employed Fischer-Tropsch for decades to yield products such as synthetic fertilizers and methanol.

Shenhua's plant, in contrast, chose Fischer-Tropsch's lesser-known rival, invented by Friedrich Bergius a decade earlier. Though used extensively by the Nazis, Bergius's process was subsequently abandoned. The process has come to be known as direct liquefaction, because it bypasses the syngas step. In direct liquefaction, the bulk of the coal is pulverized and blended with some of the plant's synthetic oil, then treated with hydrogen and heated to 450 °C in the presence of an iron catalyst, which breaks the hydrocarbon chains into the shorter chains suitable for refining into liquid fuels.

Direct liquefaction produces more fuel per ton of coal than Fischer-Tropsch synthesis. Experts at the Chinese Coal Research Institute in Beijing estimate that the process captures 55 to 56 percent of the energy in coal, compared to just 45 percent for Fischer-Tropsch. However, direct liquefaction is also far more complicated, requiring separate power and gasification plants to deliver heat and hydrogen and considerable recycling of oil, hydrogen, and coal sludge between separate sections of the plant. And breaking down hydrocarbons to just the right length requires exquisite control of the operating conditions and a consistent coal supply.

Shenhua redesigned the process over the last five years to boost efficiency and reduce waste but, at the same time, increased its complexity. And the company is taking a huge engineering and economic risk by pursuing so novel a technology on such a vast scale.

By the end of this year, Shenhua hopes to be pumping out 20,000 barrels of synthetic oil per day, nearly 500 times as much as its pilot plant in Shanghai produces. According to Jerald Fletcher, a natural-resource economist at West Virginia University in Morgantown, the Erdos plant constitutes a $1.5 billion experiment that could only take place in China. "It would be hard to get that kind of commitment of funds in the West without a more proven technology," says Fletcher. Eric Larson, an expert in energy technology and modeling at Princeton University, puts it more bluntly: "It doesn't make a lot of sense to build a huge plant like that, because it may not work."

But for the Chinese government, the rewards could be worth the risk. Despite its 2005 IPO of some assets, Shenhua remains a largely state-owned firm, and the direct-liquefaction plant serves a critical state interest: energy security. "No matter how big the cost, Shenhua will build it," says Zhou Zhijie, a gasification expert at East China University of Science and Technology's Institute of Clean Coal Technology in Shanghai. "China's government will support this project until the liquid flows."

Of course, if the new plant works, Shenhua stands to earn a substantial profit. The company predicts that its synthetic oil will turn a profit at roughly $30 a barrel, though many analysts say $45 is more realistic. (The U.S. Department of Energy's most recent price forecast predicts that crude oil will dip to $47 a barrel in 2014, then climb steadily to $57 a barrel in 2030.) Hedging its bets, Shenhua has also entered a preliminary agreement with partners Shell and Sasol concerning several similar-sized or bigger Fischer-Tropsch fuel plants in Northern China, which would start up in 2012.

Shenhua's Chinese coal competitors, too, are already breaking ground on their versions of coal-to-fuel plants. The Yankuang coal group, the second-largest coal producer in China, is planning a Fischer-Tropsch fuel plant near Erdos that will use a proprietary gasifier and catalyst.

Beyond the risks inherent in the large-scale deployment of unproven technology, the gasification building boom also is an environmental gamble. Indeed, what may ultimately check China's coal-to-oil ambitions is water. China's Coal Research Institute estimates that Shenhua's plant will consume 10 tons of water for every ton of synthetic oil produced (360 gallons of water per barrel of oil), and the ratio is even worse for Fischer-Tropsch plants. Last summer, China's National Development and Reform Commission, the powerful body charged with regulating China's economy and approving large capital projects, issued a warning about the environmental consequences of the "runaway development" of synthetic-oil and chemical plants, which it said will consume tens of millions of cubic meters of water annually.

That prediction sounds particularly ominous in northern China, where water is scarce. Erdos is a mix of scrub and desert whose meager water supplies are already overtaxed by population growth and existing power plants. Zhou Ji Sheng, who as vice manager of ZMMF, one of Shenhua's Erdos-based competitors, is seeking financing for a gasification project, acknowledges that water scarcity could put an end to coal gasification in the area. "Even though we have so much coal, if we have no water, we will just have to use the traditional way--to dig it out and transport it," he says. "Water is the key factor for us to develop this new industry." Zhou says his firm plans to supplement its water supply by building a 120-kilometer pipeline to the Yellow River. But evaporation from hydroelectric reservoirs, the increased demand of growing cities and industries, and the effects of climate change mean that in the summer, the Yellow River barely reaches the sea.

Part II of the story will be published January 5.

Peter Fairley, a Technology Review *contributing writer, traveled to China in October.*

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A billboard exhorts construction workers building Shenhua Group’s coal liquefaction plant in Inner Mongolia: “To make a better future we must work hard for the project of making coal into oil.”
Credit: Peter Fairley

Carbon Power

While China's desire to end its dependence on foreign oil is helping to drive huge capital investments in liquefaction technology, the country's power producers are moving much more slowly to take advantage of coal gasification. What they, like their American counterparts, are missing is an incentive to upgrade from conventional pulverized-coal plants to the more expensive gasification plants. According to Li Wenhua, the former 863 program manager (who now directs gasification research in China for General Electric), Chinese industrialists perceive pulverized-coal plants as a license to print money. "People say you shouldn't call it a power plant; it's a money-making machine," says Li. As yet, no power company has been willing to be the first to hit the off switch.

Ironically, China's move to a more open economy has hampered efforts to deploy more innovative technologies. In the 1990s, it looked as if China's power sector was headed for its own gasification revolution. In 1993, China's leading power engineering firm, China Power Engineering Consulting in Beijing, began designing the country's first gasification power plant. The monopoly utility of the era, the State Power Corporation, planned to build the commercial-scale plant in Yantai, a thriving seaport not far from the Bohai Sea. The Yantai plant was to be the beginning of a transition to cleaner coal technology, says Zhao Jie, the plant's designer, now vice president of China Power Engineering. "China wanted to take a cleaner and more efficient way to produce power," says Zhao. Instead, the demonstration plant she designed went on a roller-coaster ride to nowhere. Design work was temporarily halted in 1994 when the cost of the technology was deemed unacceptably high, revived in the late 1990s, and then cut adrift after 2002 by the breakup of the State Power Corporation.

The Yantai power plant was based on integrated gasification combined cycle (IGCC) technology. IGCC plants resemble natural-gas-fired power plants--they use two turbines to capture mechanical and heat energy from expanding combustion gases--but are fueled with syngas from an integrated coal gasification plant. They're not emissions free, but their gas streams are more concentrated, so the sulfurous soot, carbon dioxide, and other pollutants they generate are easier to separate and capture. Of course, once the carbon dioxide--the main greenhouse gas--is captured, engineers still need to find a place to stow it. The most promising strategy is to sequester it deep within saline aquifers and oil reservoirs. In preliminary analyses, Chinese geologists have estimated that aging oil fields and aquifers could absorb more than a trillion tons of carbon dioxide--more than China's coal-fired plants would emit, at their current rate, for hundreds of years.

The Huaneng Group, a power producer based in Beijing, has pulled together a consortium of power and coal interests (Shenhua included) called GreenGen to build the first Chinese IGCC demo plant by 2010; like the related FutureGen project organized by the U.S. Department of Energy, GreenGen is to start with power production, then add carbon capture and storage. China's vice premier, Zeng Peiyan, made an appearance at GreenGen's ceremonial debut last summer, indicating Beijing's support for the project.

The problem is that IGCC plants still cost about 10 percent to 20 percent more per megawatt than pulverized-coal-fired power plants. (And that's without carbon dioxide capture.) China's power producers--much like their counterparts in the United States and Europe--are waiting for a financial or political reason to make the switch. In part, what's been missing is regulation that penalizes conventional coal plants. And China's environmental agencies lack the resources and power to make companies comply even with regulations already on the books. Top officials in Beijing admit that their edicts are widely ignored, as new power plants are erected without environmental assessments and, according to some sources, without required equipment for pollution control.

Even advocates of IGCC technology expect that its widespread deployment in China will take at least another decade. Indeed, Du Minghua, a director for coal chemistry at the Chinese Coal Research Institute, predicts that it will be 2020 before application of IGCC technology begins in earnest.

Waiting to Inhale

Despite such pessimistic predictions, China's vast experience with advanced coal technologies and its proven ability to implement new technologies at a startling pace provide ample room for optimism. When you're racing into Shanghai at one-third the speed of sound on a train supported by an electromagnetic force field, it's hard to believe that a country capable of such an engineering feat will continue to ignore the deadly pollution engulfing its cities.

To some analysts, the switch to clean-coal technology seems almost inevitable. "China has to rely on coal for future electricity and fuel needs, and it will eventually have to cap its CO_2 emissions," says Guodong Sun, a technology policy expert at New York's Stony Brook University who has advised the Chinese government on energy policy. "Gasification is one of a very few technologies that can reconcile those conflicting scenarios at reasonable cost."

Still, the timing of such a technology transition is very much in question. Will China really wait until 2020 to start the process of cleaning up its coal-fired power plants? The answer will depend, ultimately, on when China begins to feel that using coal gasification to generate electricity is as urgent as using it to produce transportation fuels--when the costs of air pollution become as worrisome as the costs of relying on foreign oil.

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