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CLEAN COAL

U.S. - China Cooperation In Energy Security

David Wendt

CLEAN COAL:

U.S.-CHINA COOPERATION

IN ENERGY SECURITY

David Wendt

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EXECUTIVE SUMMARY

As major consumers of the world's energy resources, the United States and China are in dire need of secure energy solutions that can keep pace with their large appetites for energy. Enter coal. Both countries possess abundant coal reserves measured in the hundreds of billions of tons. But the approach to coal policy has been one of favoring cheap extraction rather than taking into serious consideration the societal costs of coal. For the United States, coal represents a major source of electrical power—and a major source of pollution. In China, the accessibility of coal has overtaken the environmental and health arguments against its widespread use. China uses more coal than the United States and European Union combined. The damaging side effects of coal mining and consumption have been overlooked in the face of easy availability and undeveloped or less accessible alternatives. In the current context of global energy uncertainty, coal has been forgiven much.

Clean coal technologies represent the new and improved face of coal-based energy. Unlike its predecessor, clean coal offers a reliable source of energy while minimizing its adverse health and environmental effects. Yet, to date, political and business leaders in the United States and China have done little to advance clean coal technology. Fears of a backlash over carbon capture and storage (CCS) sites have paralyzed U.S. government and industry, while China has shrunk away from imposing the real cost of cleaner energy on its citizens. The battle for public perception has been ceded and the political hurdles dodged in favor political expediency.

As users of over half of the world's coal, with no let-up in sight through the year 2030, the United States and China have a mutual interest and responsibility in showing the world the way to a cleaner energy future that includes continued reliance on coal. In no other two countries does coal use pose a greater threat to global environmental sustainability, and nowhere else are cleaner energy solutions more urgently needed. Although other cleaner energy options must continue to be explored (solar and wind power, biofuels, etc.) and energy conservation promoted, given the political, economic, and resource realities in China and the United States, research and development of clean coal technology is crucial so that the benefits of clean coal can be realized sooner rather than later. That is not to say that there are not obstacles to clean coal—including lingering questions about emissions and a timeline for diffusion of some technologies that will reach into decades—but the costs of not moving forward for both countries, and indeed globally, far outweigh the costs associated with developing clean coal technologies, which are clear improvements over its predecessor.

Together, the two countries have both the means and the incentive to ensure a sustainable domestic energy supply. Technological exchange and cooperation could reap significant environmental, commercial, and political benefits for the world's two largest producers and consumers of coal. A sustainable energy partnership would fast-track clean coal as a viable and long-term energy solution. The United States and China should leverage their complementary knowledge and expertise to guarantee a clean and reliable energy supply for generations to come.

INTRODUCTION

As the United States and China look toward a future in which (relatively cheap and accessible) oil, natural gas, and other energy supplies are increasingly constrained, coal's abundance assures it a prominent place in both countries' national energy strategies. Both countries are blessed with vast coal supplies—each has proven reserves of hundreds of billions of tons. Even under the most optimistic projections for the development of alternative energy sources, China will continue for at least another generation to rely on coal for over half of its total energy supplies. In the United States, 50 percent of all electric power is generated from coal.

The coal option, however, also has drawbacks. Coal is the most carbon intensive fossil fuel source. In the two countries combined, coal combustion accounts for over six billion tons of annual carbon dioxide emissions, or over one-fifth of world emissions from all fossil fuel sources. China is also responsible for almost half of the world's total coalmine methane emissions, accounting for another 200 million tons of carbon dioxide equivalent.[1] In other respects as well, coal mining and use in both countries constitutes a threat to health, safety, and the environment. In China, thousands of miners die each year in coal mining accidents. Coal mining and inefficient methods of coal combustion in power plants and coke ovens have contributed to severe pollution and the depletion of surface and underground water supplies throughout China. Emissions of particulates, sulfur dioxide, and mercury resulting from the transportation, storage, and combustion of coal produce hundreds of thousands of deaths each year from lung and heart disease. Some of these effects, such as acid rain from sulfur dioxide emissions, carry to neighboring countries, and mercury pollution travels all the way across the Pacific to the United States.

Coal also has adverse environmental impacts in the United States in the eastern part of the country, the controversial new practice of mountaintop mining has disfigured the landscape, eroded hillsides, deposited silt in riverbeds, and poisoned ground and surface water supplies. In the west, coalbed methane extraction has flooded hundreds of thousands of acres of

[1] The methane issue in China is driven more by economics than technological challenges. In the United States, it is standard practice to drain methane from coal seams before extraction. The methane is captured into manifolds, sent to the surface, compressed, and sold. Methane emissions in China could be radically reduced by implementing this relatively simple procedure—but it would not be without costs.

ranchland with brine and salty water, whose release from underground seams is necessary in order to access the methane. The transportation by rail of low-sulfur coal from western mines to eastern markets—a consequence of the stringent sulfur dioxide controls imposed by the 1991 revision of the Clean Air Act—uses additional energy and results in fugitive dust emissions.

These issues have given rise to much controversy within policy circles and among the broader public in both China and the United States. Importantly from the perspective of this policy paper, they have now also begun to enter into the policy dialogue between U.S. and Chinese policy experts concerned with promoting U.S.-China cooperation on these subjects. A leading sponsor of these exchanges has been the U.S.-China Energy and Environmental Technology Center (EETC), a joint effort of the U.S. Department of Energy (through Tulane University) and China's Ministry of Science and Technology (through Tsinghua University). EETC has also joined recently with the Atlantic Council of the United States and the Institute for Sino-American International Dialogue (ISAID) at the University of Denver in organizing a series of U.S.-China Energy Security Cooperation Dialogues that includes clean coal at the state and provincial government level, the Jackson Hole Center for Global Affairs (JHCGA) has organized a clean coal partnership between Wyoming and Shanxi province, the two largest coal-producers in their respective countries.

But the heavy lifting of real technology transfer has yet to begin. This work includes policy coordination, research partnerships, and joint project development. How, then, does coal fit into the strategies of the United States and China to attain energy security while avoiding adverse environmental impacts? What comparative advantages do both countries have and how should these comparative advantages guide their future investments in climate mitigation strategies and clean coal technologies? Most importantly, what is the role of bilateral cooperation in assuring a peaceful and sustainable outcome to this process?

CHINA'S POLICY CHOICES IN CLEAN COAL

Despite the fact that China already relies disproportionately on coal to fuel its economy, the pursuit of an energy strategy based primarily on clean coal would entail a fundamental shift of priorities. A national energy security strategy based on clean coal will demand a more comprehensive system of energy policy decision-making and controls. The current system of decentralized decision-making extends extraordinary discretion to local party officials, who, through their control over local branches of banks, power companies, and environmental protection bureaus, are able to approve and finance power projects in accordance with their own local interests and priorities. As a result, the central government finds it extremely difficult to deliver on its energy and environmental promises. Policies set at the national level with national goals in mind inevitably encounter resistance or outright disregard at local levels.

Within the coal and power sectors themselves, there are further impediments to coordinated policy. The coal industry in China has tended to be highly fragmented, while power production is concentrated in five major companies. The resulting disparity in bargaining power gives an advantage to power companies, who would therefore tend to resist moves by coal producers to gain greater control over power supplies through clean coal operations based at minemouth power plants. To this extent, the power companies have little interest in encouraging this or the other elements of a large-scale clean coal infrastructure, including electric power transmission lines and pipelines for the efficient utilization and distribution of methane, town gas, and heat derived from mining, gasification, and power generation operations.

However, increases in the price of coal over the past several years have tended to equalize the bargaining position between coal producers and power providers. As power companies find their profit margins increasingly squeezed between rising coal prices and controlled prices of power, coal companies have gained greater leverage in acquiring power production capabilities at the minemouth. Recently, a number of coal producers have sought to move “downstream” into expanded power production operations at the same time as power producers have sought to increase their profit margins by acquiring “upstream” capabilities in coal.

A further consequence of this complex and highly fragmented decision-making system is the scramble for competing energy security strategies among regions. Instead of a unified national energy security strategy, each region is left to pursue its own strategy, sometimes at the expense of the others. This competition and lack of coordination is particularly acute between the eastern and western regions of the country. The more well-developed coastal regions of the east, lacking confidence in the reliability of electric power supplied from the coal-rich western regions, have insisted on building their own power plants while relying on western China for the coal. In many cases, they have also started importing liquid natural gas (LNG) from abroad to fuel gas-fired power plants.

To overcome these conflicts of interest and priorities between local and central government agencies, the coal and power sectors, and China’s geographical regions, the Chinese government will have to adopt a much more coordinated and streamlined approach to energy policy decision-making. Recently, China has reorganized its national energy policy structure to assign responsibility for setting strategy and priorities to a high-level energy commission while assigning administration and oversight of the energy sector to the energy bureau of the National Development and Reform Commission (NDRC).

These moves are a step in the right direction. But much more remains to be done to assure uniform compliance with the central government's mandates. A national energy security strategy based on clean coal will, under the best of circumstances, be an enormously costly and time-consuming national undertaking. Wastefulness or inconsistency in its implementation will be its death knell. Nothing less than a wholesale reordering of the system of priorities and incentives will be needed to avoid such an outcome, sending a signal to government officials and enterprise managers at every level of the bureaucracy that they are no longer at liberty to make their own policy.

No set of incentives is probably more important in this regard than that of energy prices. China's current energy pricing policy is driven largely by social concerns. In its eagerness to continue delivering the benefits of economic growth to urban populations, China has made affordability a priority over resource conservation or technological innovation.

This policy has had severe consequences in a number of areas. In the electric power and coal chemicals sectors, for example, priority is given to providing heat and power to residential and industrial consumers at subsidized rates at the expense of more efficient operations and more rigorous environmental controls (e.g., sulfur dioxide emissions, water conservation). In other areas of heavy industry, such as steel, aluminum, and concrete manufacture, huge inefficiencies are tolerated, owing largely to pressures of competitiveness that dictate keeping the cost of energy inputs low.

A very different approach toward the pricing of environmental externalities will be needed if China is to mount a successful national energy security strategy based on clean coal. The key to such a strategy will be China's capacity to set energy prices at levels that will encourage the greater conservation of energy and the more rigorous enforcement of environmental standards. The government, of course, is reluctant to impose these burdens at a time when it has based much of its legitimacy on the promise of universal access to a middle class lifestyle.

The problem is that rising social unrest throughout China already threatens the legitimacy of the regime. Much of this unrest relates to protests over conditions of environmental abuse and neglect. There is little point in a policy of continued subsidization of urban energy consumers when this can only perpetuate these conditions by adding to resource scarcities that will increase pressures on the environment. In other words, if energy security is a national security concern for China, so, too, is rising social unrest. And from a national security perspective, there is no real conflict between the requirements of energy security and the requirements of social peace. The same sacrifices that are needed to enhance energy security—higher energy prices and greater resource conservation—can also, in the long run, help to promote social stability by reducing the pressure on the environment. The appeal to patriotism offers the Chinese government a way to achieve these gains by demanding sacrifices of the Chinese people without having to put its own legitimacy on the line—and, in fact, while enhancing it.

IMPLICATIONS OF A CLEAN COAL STRATEGY FOR CHINA

Social and Political Stability

A national energy security strategy based on clean coal has implications for social and political stability in China, especially concerning widening economic disparities between the richer coastal regions and the poorer regions of the interior. A national energy security strategy based on clean coal would provide an opportunity to address this imbalance, which now poses a greater threat to social and political stability than any other single issue in China.

Specifically, a national energy security strategy based on clean coal demands will likely require a significant reallocation of resources from the energy-consuming eastern regions of China to its coal-producing regions in the west. Such a strategy would entail large-scale investments in research and development (e.g., gasification technologies, hydrogen production), human resources (e.g., managerial and technical expertise), and physical facilities (pipelines and transmission lines)—all of which could create millions of new jobs. Accelerated development of the interior regions could lead to increased public revenues to pay for expanded social services and other public goods such as education and health, thereby elevating the quality of life of the average citizen. Enhanced environmental quality would also be possible by virtue of increased public revenues to pay for environmental externalities.

In all of these respects, investment in a national clean coal infrastructure would amount to a large-scale public works program, helping to close the growing gap between the richer coastal and the poorer interior regions of the country. The pay-off for the coastal regions would be the prospect of cleaner and more secure sources of electric power and, ultimately, coal-based transportation fuel supplied from the interior—a prospect that has thus far proven elusive. By bringing these win-win benefits to both the east and the west of China, a national energy security strategy based on clean coal could, in the most optimistic scenario, link the two regions more closely not only in terms of a shared energy future but also of shared perceptions of economic prosperity.

Opportunities for Global Technological Leadership

A national energy strategy carried out in accordance with these priorities would also present China with an opportunity to attain global technological leadership in the area of clean coal. Coal is among the oldest industrial fuels but in many respects it can also help provide a bridge to the new industrial economy of the future. China is poised for such a transition. By taking advantage of its capacity to mobilize human and financial resources on a grand scale, it can use its coal reserves to show how, in a number of areas, coal can point the way to such an economy.

First, coal gasification based "polygeneration" of multiple outputs, including electric power, coal chemicals, and other fuel sources, creates a gateway to a more broadly sustainable energy base. Other fuel sources that can be derived from syngas[2] produced from coal include di-methyl ether, a convenient substitute for liquid petroleum gas, particularly in rural regions, and methanol, a transportation fuel. In addition, retrofitting coal gasification systems (e.g., integrated gasification combined cycle) with the capability for a hydrogen "shift" reaction provides a means for separation of both hydrogen and carbon dioxide from the initial syngas stream, comprised largely of hydrogen and carbon monoxide. The carbon dioxide is then available for underground storage, in a process called carbon capture and storage (CCS), while the hydrogen can be combined with ambient oxygen in fuel cells to generate electricity. Fuel cells hold great promise as a clean source of electric power in the future and a clean and cost-effective means of producing a hydrogen feedstock is the key to their widespread deployment.

A second area where China stands poised to leapfrog into the future is in the area of coal mining productivity. In place of today's cumbersome and antiquated structures, the coal mines of the future are likely to incorporate

[2] Synthesis gas, or syngas, is a combination of carbon monoxide, hydrogen, methane, and other gases produced when coal slurry is combined under high pressure with oxygen.

features that will make the transition from coal production to coal consumption a seamless process. New technologies could be implemented in China—as they already exist in the United States—to make it possible to begin mining operations while methane drainage operations are still underway, thereby saving time and reducing fugitive methane emissions. Advanced reciprocating gas engines installed at the minemouth will make it possible to recover the methane as it is drained or ventilated from the mines and to use it as a clean-burning fossil fuel to generate electric power.[3] Modern circulating fluidized bed systems can also be installed to allow waste coal to be "recycled" for electric power production rather than simply accumulating to the point where the entire mining operation eventually becomes a huge waste site.

Looking further into the future, within 20-30 years underground coal gasification may provide the ultimate solution for a process of seamless extraction and utilization of coal. This technology, once implemented, would employ large-scale rigs to pressurize oxygen and pump it deep into the ground, where it reacts with coal seams to produce syngas. The syngas is then returned to the surface, where it can be used to produce electric power. Hydrogen can also be separated and produced through this process, as a result of the hydrogen "shift" reaction with water which takes place at high temperatures and pressure underground.

The above advances in productivity will transform the nature of modern mining operations. The new advances can help to ease the pressure on China's electric power grid; they can also ease its transition to a future based on clean energy sources (e.g., hydrogen). The possibilities of coal conversion endow coal with a dual role in satisfying the needs of the present while addressing the possibilities of the future, including, as we have seen, hydrogen production through coal gasification. By investing in this and the other processes described, China can turn its vast underground coal reserves to its advantage, bringing coal to the surface in the form of clean-burning sources of energy to meet both today's and tomorrow's needs.

The third area where China has an opportunity to show the way to the future is in the development of a clean energy infrastructure. China is relatively well-positioned in comparison with other industrial countries to move ahead decisively with the transition to the next generation of clean energy technologies. First, it is not burdened by an obsolete energy infrastructure that would constrain its future energy technology choices—there are no sunk costs to be recovered, no expensive retrofits to be made. Instead, China has the

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[3] In the United States, the methane is simply manifolded, compressed, and fed into a natural gas grid.

ability, as it has already done in the area of telecommunications, to leapfrog over an entire generation of technology to the clean energy technology infrastructure of the future. Second, China has the capacity to mobilize investment capital on a grand scale. Whatever the infrastructure requirements of the next generation of energy technologies, China has the access to foreign reserves and other sources of savings needed to meet them.

These advantages create for China the possibility of a rapid transition to an advanced clean energy economy based on a set of mutually supportive systems for the distribution of energy based on coal and other sources. Instead of being transported by rail or—worse—by truck, coal can be sent "by wire"[4] from advanced clean coal power plants located at the minemouth in the western part of China to electricity markets located in coastal areas in the east, as is already done in the coal industries of countries like the United States and Australia. Carbon dioxide captured at these advanced gasification and other facilities can be transported by pipeline to underground storage sites waiting to receive it in more remote areas located further to the west. Hydrogen separated from the syngas at these facilities can be pumped into waiting tank cars to be distributed by rail to fueling stations for use in fuel cell vehicles. Heat and waste gas from other advanced clean coal facilities, located outside cities, can be delivered into district heating systems or made available for home use within the city limits.

U.S. CHOICES IN A COAL-BASED STRATEGY OF ENERGY SECURITY

The United States approaches the issue of mobilizing its coal reserves for national energy security from a completely different position of natural resource endowment. Unlike China, the United States also has vast reserves of natural gas, which are available not only for purposes of home heating and power generation but also for current and future transportation needs. The most cost-effective approach to a coal-based energy security strategy will take these other resources into account, utilizing coal in ways that will conserve them for other purposes for which they can more cost-effectively be applied.

For example, the development and deployment of coal-to-liquids (CTL) technology would appear to have little national security justification outside military uses. Although most commonly accepted CTL technologies rely on

[4] "Coal by wire" refers to the process of transmitting electric power from the source of its generation at the coal mine to the destinations for its end-use via high-voltage power lines, rather than transporting the coal by rail or other means to power plants located nearer to the destinations for end-use of the power.

coal gasification as an intermediate step, even this indirect form of CTL is very carbon intensive because, unlike coal gasification for power generation, it requires a second stage of combustion. CTL produces diesel fuel, the energy from which must in turn released through the process of internal combustion. By contrast, integrated gasification combined cycle technology (IGCC) provides a means of releasing the energy from coal gasification directly in the form of electricity, generated from a gas combustion turbine. In effect, CTL uses more energy—and therefore releases more carbon—by burning the coal twice, although it does create a transportable fuel.

Therefore, to match the carbon footprint of conventional diesel fuel or gasoline, full-scale deployment of CTL as a transportation fuel would require a very comprehensive, and probably prohibitively expensive, system of carbon capture and storage (CCS). Moreover, even taking this additional step into account, CTL as well as other conventional and even alternative transportation fuels (e.g., biofuels) still fall short of the potential for carbon reduction of compressed natural gas (CNG), which outperforms all other fossil fuel sources in terms of efficiency. A full-scale CNG transportation infrastructure—comparable in the area of transportation to the interstate highway system of the 1950s—would take advantage of this potential of CNG to provide an environmentally cost-effective basis for meeting the U.S.'s national security and energy needs. Such an infrastructure could encompass natural gas pipelines, compressors, and fueling stations, coupled with a relatively simple set of engine modifications in the U.S. automotive fleet.

That is not to say, however, that CCS has no place in a clean coal future for the United States. The United States currently relies on coal for 50 percent of its electric power. For economic, political, or technological reasons, no energy source—nuclear, solar, wind, geothermal, or otherwise—singly or in combination can come anywhere near to replacing this source of electric power in the foreseeable future. Coal gasification is not only a more efficient means of power generation than conventional pulverized coal combustion, it also provides a much more cost-effective basis for capturing carbon dioxide by separating it from the exhaust gas stream before it reaches the smokestack. Carbon capture is in turn the first step in preventing its escape into the atmosphere by burying it underground.

Many other steps then need to follow. These include characterization of the proposed underground storage sites through geological surveys and analyses, computer simulations, and so-called measurement, monitoring, and validation (MMV) through pilot projects and other technical demonstrations. All this research and demonstration needs to be conducted on a site-by-site basis, taking into account varying conditions and circumstances. In addition, extensive public policy work is needed to build a regulatory regime addressing such issues as liability and property ownership and to build public acceptance and support for the approach of CCS in general. Then, before full-scale CCS can be undertaken, a network of pipelines needs to be developed to transport the carbon dioxide to the designated sites from its points of origin.

When all of these steps are considered in the aggregate, it is clear that nothing approaching the necessary level of national effort is currently being undertaken to build a comprehensive system of CCS addressing the country's power production and carbon reduction needs. The IGCC plants (complete with the necessary carbon-capture capabilities) are not being built. The funds are not being allocated to research and development to support the trial-and-error process of site preparation and development. And, most importantly, a system of economic incentives has not been put into place to make it prohibitive for industry—and, by extension, consumers of electric power—*not* to make these necessary investments.

In short, CCS has not been made a national priority. The true test of the U.S.'s seriousness about climate change will be its commitment to a system of legislation, budgets, program plans, and management tools—like the Manhattan project of the 1940s or the Apollo project of the 1960s—commensurate in scale to the magnitude of the challenge.

A JOINT U.S.-CHINA CLEAN COAL STRATEGY FOR ENERGY SECURITY

The Technology Sharing Option

Given the proper circumstances and choices, therefore, an energy security strategy based on domestic coal supplies could go a long way to helping both the United States and China insulate themselves somewhat from the worldwide scramble for oil and natural gas. In itself, however, such a strategy may not go far enough. Indeed, if pursued in mutual isolation, such a strategy promises only conflict in another form.

The reason is that, left to its own devices, each country will find itself facing sub-optimal range of energy choices, each of which can ultimately be pursued only at the expense of the planet. Accessing unconventional energy sources such as oil shale or tar sands or gasifying coal to produce liquid transportation fuel are very expensive processes that require very high energy inputs in relation to energy outputs. When the cost of addressing environmental externalities like carbon controls is added, the cost of developing these sources becomes prohibitive.

Faced with the mounting pressures of the search for secure sources of energy, it is extremely unlikely that either the United States or China would chose to pay the full cost of these environmental externalities as opposed to deferring them to future generations. Sooner or later, however, these costs will need to be confronted. Worsening climate change and a deteriorating global environment will lead to resource scarcities, cross-border pollution, and other pressures on natural and human resources that can only increase the potential for bilateral conflict.

Pursued independently, therefore, energy security strategies based on clean coal are no more a prescription for avoiding conflict between the United States and China than a strategy of subsidizing urban consumers of energy is a prescription for avoiding social unrest in China. In both cases, it is the environment that stands in the way. A more feasible model for the pursuit of energy security based on clean coal may be for the United States and China to engage in a cooperative effort, each compensating for the other's clean coal vulnerabilities by sharing technologies in its areas of comparative strength.

CCS provides an obvious focus from the U.S. standpoint for such a strategy of clean coal technology exchange with China. Unlike China, the United States has many capabilities already in place for the full-scale development, demonstration, and deployment of CCS. These resources include world-class geological expertise, extensive experience in computer modeling, simulation and mathematical computation, and advanced capabilities in chemical process engineering and analysis. Even though, as we have seen, the United States has barely scratched the surface in terms of allocating these resources in the service of CCS, the lessons are there, waiting to be learned and shared with China.

This disparity in resources and expertise relevant to CCS presents an opportunity for the United States to help China accelerate its own program of CCS demonstration, development, and deployment in the interests of peace as well as the future of the planet. Although China is probably now not ready for full CCS deployment, it cannot defer this option indefinitely as it contemplates future development of CTL and other coal-based transportation fuels (e.g., methanol) in addition to its current focus on advanced clean coal power generation.

In the absence of accompanying measures for CCS, however, the prospect of China's development of CTL presents extremely serious implications for the global environment and, ultimately, U.S security. It is at least as much in the U.S.'s long term national security interests to prevent such an outcome as it is, for example, to forestall the prospect of a world-wide grab for oil. As Gen. Richard L. Lawson (USAF-ret.) has said with respect to CCS, "We need to develop it, test it, and take it over there [to China] and share it as our investment in peace in the second half of the twentieth century."

Coal gasification fits this same description from a Chinese perspective. The Chinese are already moving forward aggressively with "polygeneration" processes based on coal gasification. These processes include not only electric power generation but also the utilization of byproducts contained in the waste gas stream, while separating the hydrogen for other uses (e.g., fuel cells) and capturing the carbon dioxide for underground storage. The byproducts of this process can also include fertilizers and other coal chemicals, methane, methanol, di-methyl ether, and other fuel sources. In addition, China utilizes waste gas from coal gasification for the heating of homes and apartments.

Why cannot this same experience be utilized and replicated in the United States? Currently in the United States, most of the contents of the coal that are not consumed in the power generation process are either vented into the atmosphere, as is the case with carbon dioxide, or processed as waste (e.g., sulfur dioxide, nitrous oxide and nitrogen dioxide). Coal gasification, by contrast, provides significant environmental advantages over conventional pulverized coal-fired power production. These advantages include 10-15 percent greater thermal efficiencies, resulting in less coal use and fewer emissions. With the installation of capabilities to conduct a hydrogen shift reaction, this process also permits the more cost-effective separation of hydrogen and capture of carbon dioxide than conventional combustion processes. Finally, it conserves water and, by separating pollutants (e.g., sulfur dioxide) from the waste stream before they reach the flue, provides a more cost-effective basis for their treatment or conversion.

This approach of "comprehensive resource utilization" obviously fits the needs of the United States for a cost-effective energy security strategy, defined in terms of full environmental cost accounting. But the United States cannot do this alone. It needs China's experience, derived over decades as the world's leading coke producer, in testing out practical alternatives that do not involve expensive retrofits. Through its experience in coke production, China has also acquired extensive expertise in determining the suitability of various coal types for purposes of coal gasification. These are fields on which the United States is only now beginning to embark. Cooperation with China provides the United States with an opportunity to leapfrog an entire phase of trial-and-error, and to go directly to the solutions that cost least, make best use of the coal, and produce the most useful byproducts.

The Question of Intellectual Property Rights

In short, the possibility of the United States and China helping to compensate for each other's vulnerabilities in clean coal production and utilization through a strategy of cooperation based upon their own strengths is a win-win situation. But how would the rules of such an exchange of experience and expertise to be negotiated?

One set of rules that has yet to be adequately negotiated concerns intellectual property rights. The sharing of technology might be a win-win strategy for both countries as a whole, but not everyone within each country stands to benefit. Private sector investors in research and development efforts, who have put their resources at risk in the expectation of future gains, stand to see others reap these gains at their expense. Scarce public resources, initially allocated to these same purposes at the expense of other pressing priorities, will now have new applications. In the view of some, this will no longer justify the original sacrifices. Shared access to technological information and innovation, in other words, changes the rules of the game.

If the possibility exists for the United States and China to compensate each other for their respective vulnerabilities in clean coal, however, why could they not similarly compensate those who stand to lose from such cooperation within their own societies? The United States, for example, already has such a system in place to compensate those within its society placed at a disadvantage by free trade. The government compensates workers for job losses through a system of economic supports, including unemployment compensation, job retraining programs, and job placement services. Tax and other incentives help attract businesses to invest in the economic revitalization of depressed communities. Small business loans enable those who have lost their jobs to get back on their feet by starting their own businesses.

There is no reason such a system could not also be adopted in the area of clean coal technology transfer, so as to compensate technology providers for the loss of business opportunities resulting from the sharing of technology. Public funds could be used, for example, to help private sector providers of gasifiers and other clean coal technologies identify China's most lucrative markets for these products, based on assistance in testing them over a wide range of circumstances and with a wide range of coal types. Subsidies could be extended to provide broad initial dissemination of these products, thereby conditioning the development of a future infrastructure conforming to their specifications and positioning them for de facto dominance of the market. As the first to have developed and perfected these products, technology providers have everything to gain from a competition in which their loss of an information advantage is offset by adjustments such as these.

CONCLUSION AND NEXT STEPS

Is coal, then, the answer to energy security for the United States and China? Ironically, coal provides an answer to their energy self-sufficiency only in the context of a mutual strategy of cooperation. Undoubtedly, China's capacity to mobilize capital for clean coal technology creates many future options. As noted, these include polygeneration of electric power, hydrogen, and other byproducts of coal gasification; investment in the productivity of mining operations and their byproducts; and the creation of a large-scale clean coal infrastructure. But along the way, China will also probably have to hedge its bets with the development of some less cost-effective options, particularly in the area of transportation fuels (e.g., CTL). Cooperation with the United States on CCS will be essential to the sustainable pursuit of this alternative.

The United States is in many ways the mirror image of this situation. It, too, has other options: the possibility, for example, of an alternative transportation system based on CNG, supplementing biofuels in relieving our dependence upon foreign oil supplies. CTL, as we have seen, runs a poor third to both CNG and biofuels as a source of transportation fuel. It is hard to avoid the conclusion that for sources of electric power, the United States, like China, will continue to be dependent for many years on coal.

The option of clean coal, however, is unsustainable in the absence of a large-scale transition to a system of coal gasification-based polygeneration of electric power and the conservation and utilization of its byproducts. Like the U.S.'s emerging experiment with CCS, China's experience in these areas is a work in progress that can save the United States many years and dollars in mistakes. Interestingly, this also presents an opportunity in the area of information access for the United States to effectively steal a leaf from China's book, just as China has done so often in the past with the United States. And, in a sense, China needs for this to happen as much as the United States does. It needs to be able to demonstrate that the United States, too, stands to benefit from the process of technology transfer as China has long proclaimed through its principle of cooperation based on "mutual benefits."

Given the benefits that a clean coal strategy would entail for both China and the United States, the following recommendations are made to policymakers in each country to lay the groundwork for such a transition:

For the Chinese government

- Establish a coherent national energy strategy based on clean coal and a radically improved energy infrastructure to promote coordinated distribution of electric power supplies across all regions.
- Rationalize energy pricing to provide incentives for increased investment in clean coal solutions, more efficient processing, and energy conservation.

For the U.S. government

- Support significant research and development into clean coal technologies.
- Pursue in particular coal gasification technology, including expert surveys, feasibility studies, and demonstration projects to characterize and develop storage sites for carbon capture and storage (CSS).
- Ensure CCS facilities are installed in all coal gasification plants and a pipelines infrastructure is in place to support the CCS initiative.

As pointed out by John F. Turner, former Assistant Secretary of State for Global Environmental Affairs and now a director of Peabody Energy, however, the effectiveness of these measures also hinges on the “ingenuity, creativity, and resources of the private sector” on both sides of the Pacific. Even in advance of governments on both sides taking the necessary steps to reduce uncertainties and to assure that energy prices fully reflect environmental costs, the private sector needs to anticipate and, wherever possible, to precipitate these moves. This means:

For the private sector

- *Chinese enterprises:* anticipate public policy reforms by adopting proactive business strategies, including innovation in clean coal technologies through increased investment for R&D.
- *U.S. electric utilities:* anticipate public policy reforms by adopting proactive business strategies, including asset diversification through increased investment in coal gasification-based generation and carbon capture facilities.

- *U.S. and Chinese enterprises:* create increased incentives for joint ventures in clean coal technology development through market sharing agreements in China.

The key to a U.S.-China strategy for energy security based on clean coal is the recognition of mutual vulnerabilities. Each needs to recognize areas of vulnerability in the other—CCS for China, coal gasification-based polygeneration technologies for the United States—that its own comparative advantages can help overcome. Each needs to be sufficiently open to the other to be willing to channel its own strengths into this effort in the interests of both mutual security and the future of the planet. To this end, each also needs to be prepared to relax its guard over trade secrets and to compensate those disadvantaged by their loss of control over information. Only then, perhaps, can both emerge from the lengthening shadows of a competition for world energy supplies into a new dawn of confidence building, technology sharing, and energy saving based on clean coal. Thus, the following recommendations are made to promote cooperation on clean coal technology:

- Utilize Chinese expertise in coal gasification to promote ‘polygeneration’ processes from coal.
- Accelerate the trial-and-error process of CCS site preparation and development in the United States and engage Chinese government, industry, and research partners in applying the results of this process.
- Establish an agreed framework for intellectual property rights compensation to offset commercial losses from technological exchange and facilitate cooperation.

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洁净煤:

能源安全领域的中美合作

David Wendt

2008年8月

作者简介*

David Wendt博士于2002年合作建立了杰克逊侯全球事务中心（Jackson Hole Center for Global Affairs），并一直担任该中心主任。三十多年来，他一直是构建全球政策问题意识和共识的主要推动者，包括在费城世界事务理事会（World Affairs Council）（1975-77）提出有关全球相互依存的美国200年计划；于华盛顿国际战略研究中心（Center for Strategic and International Studies）提出的全球健康、人口和环境问题计划（1977-98）；以及在爱达荷州波卡特罗市所提出的爱达荷州立大学国际计划（1998-2006）。Wendt博士毕业于哈佛大学，于1967年获得了社会科学学士学位，并于1975年在哥伦比亚大学获得政治学博士学位。

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**东西方研究所一般并不代表政策问题的立场。本文的观点仅代表作者的观点，并不一定反映该机构、及其董事会或者其它学者的看法。*

目录

执行摘要

作为世界上最大的能源消耗国，中国和美国都迫切地需要找到可靠的能源解决方案，以满足巨大的能源需求。两国就煤炭而言都拥有数以千亿吨计的丰富储量。但是，煤炭政策一直以廉价的开采为主，而没有认真考虑煤炭的社会成本。以美国为例，煤炭是一种主要的电力能源，同时也是一种主要的污染源。在中国，为了开采煤炭，全然不顾来自四面八方对有关环境和健康的质疑。中国消耗的煤炭比美国与欧盟的总和还多。由于煤炭容易获得，而且还没有其它可以利用或者容易获得的资源，一直忽视了煤炭开采和消耗带来的破坏性副作用。在当前全球能源不确定性形势下，煤炭仍然被大量使用。

洁净煤技术代表了最新最先进的以煤炭为基础的能源技术。与过去不同，洁净煤提供了可靠的能源，同时最大程度地减少了对健康和环境的副作用。不过直到今天，美国和中国的政界和商界领袖为洁净煤技术的推进做得还很不够。由于担心对碳捕获和存储（CCS）地点的反对，使美国政府和工业面临瘫痪，同时，对于向获得更清洁能源的公民征收实际成本费，中国已经退缩。已经放弃了加强公众认识的努力，同时回避政治阻碍已成为政治权宜之计。

中国和美国消耗了一半以上的全球煤炭量，预计这种形势会持续到2030年。在向世界表明一个包括可持续的煤炭资源在内的更加清洁的能源未来方面，中国和美国具有共同的利益和责任。没有其它任何两个国家的煤炭消耗给可持续全球环境带来如此大的威胁，也没有任何别的国家如此迫切地需要清洁能源解决方案。尽管其它清洁能源必将继续发展（如太阳能、风能、生物燃料等），节能行动必将广泛实施，但是在中国和美国面临的政治、经济和资源现状下，研究和开发洁净煤技术势在必行，以便尽早实现洁净煤带来的好处。这并不是说实现了洁净煤就没有障碍，仍然存在排放问题，以及技术的推广甚至需要数十年，但是对于中美国两国，甚至对于整个世界，踟蹰不前的代价远远超过发展对既往技术具有明显进步的洁净煤技术所付出的努力。

总而言之，两国都要采取激励措施，确保国内可持续能源供应。对于世界上两个最大的煤炭生产国和消耗国，通过技术交流和合作可以获得重要的环境、商贸和政治好处。建立可持续的能源伙伴关系，是将洁净煤作为一种行之有效的长期能源方案的捷径。中美两国应当在知识和技能方面优势互补，确保为下一代提供清洁可靠的能源供应。

引言

由于美国和中国将面临（相对便宜和容易获取的）石油、天然气和其它能源日益受到限制的问题，因而丰富的煤炭资源在两国的国家能源战略中占有突出的地位。两国都拥有丰富的煤炭储量，已证实储量均超过数千亿吨。即使对替代能源发展按照最乐观的预计，中国超过一半的总能源供应量会依赖于煤炭，这种状况至少会持续到下一代。而美国的一半发电量来自于煤电。

然而，煤炭资源也有缺点。煤炭是最主要的碳密集型矿物燃料来源。两国煤炭燃烧每年的CO_2排放量达到60亿吨，或者说占据了世界整个矿物燃料源排放量的五分之一。中国还占据了将近一半的总煤层气排放量，相当于另外的2亿吨CO_2排放量。[1]1而且在其它方面，两国的煤炭开采和使用均对健康、安全和环境造成了威胁。中国每年有成千上万的矿工在煤矿事故中遇难。煤炭开采以及发电厂和焦炉中煤炭的不充分燃烧，使得中国的地面和地下水资源普遍受到严重的污染和枯竭。在煤炭的运输、贮存和燃烧过程中产生的固体尘埃、SO_2和汞，每年都会导致数以万计的人死于肺部和心脏疾病。有时候排放的硫化物还会形成酸雨，被带到邻国，甚至汞污染物会穿过太平洋进入美国。

煤炭对美国的东部环境也会造成不利影响，山上采煤的新作法引起了争议，使景观遭到了破坏，山坡遭到了侵蚀，河床沉积了淤泥，地下和地下水资源被污染。而在西部，煤层气的开采导致成千上万亩的牧场被得到煤层气所必需的盐水淹没。要从西部矿场将低硫煤运输到东部市场，尽管1991年修订的《清洁空气法》对此实施了严格的SO_2限制，但是使用了更多的能源，且产生了扬尘。

这些问题在中国和美国的决策部门和广泛大众中都引起了极大的争议。重要的是从这份政策文件的角度表明，为了推动这些问题上的中美合作，中美两国的政策专家间现在开始了政策对话。美中能源环境技术中心（EETC）由美国能源部（通过杜兰大学）和中国科技部（通过清华大学）共同建立，是这些交流活动的主要发起者。EETC最近也已加入了美国大西洋理事会和设立于丹佛大学的中美国际对话研究所（ISAID）,组织了一系列的美中能源安全合作对话，包括国家和省（州）级政府的洁净煤对话，杰克逊全球事务中心（JHCGA）已在美国怀俄明州和中国山西省这两个分别为两国最大的煤炭生产地间建立了洁净煤合作伙伴关系。

[1]中国面临的甲烷问题主要是经济问题，而非技术问题。在美国，通过标准的规程在吸取之前将甲烷从煤层中排放出来。甲烷被捕获到管汇中，并输送到地表进行压缩，然后出售。通过这种相对简单的规程，中国的甲烷排放可以得到根本性减少，但仍然需要付出成本。

但是，真正的技术转让还没有得到显著改善。包括政策协调、研究合作和共同项目开发。煤炭怎样才能适应中美两国的能源安全政策，同时又要避免对环境的不利影响呢？两国具有哪些比较优势，又怎样利用这种比较优势来引导在气候变迁战略和洁净煤技术方面的未来投资？最重要的是，为确保得到和平与可持续的成果，在双边合作中扮演什么角色？

中国的洁净煤政策抉择

尽管中国为了经济发的发展已经十分严重地依赖于煤炭，但是制定主要基于洁净煤的能源战略需要首先进行根本的转变。以洁净煤为基础的国家能源安全战略需要一个更加全面的能源决策和监管体系。目前的分散决策体系给予了地下官员太多的自主权力，他们通过对地方银行、电力公司和环境保护机构的控制，有权批准和为电力项目投资，优先考虑当地的自身利益和发展。结果，中央政府很难进行能源和环境方面的承诺。以国家目标为重的国家政策难免遭到地下政策的抵制或者完全漠视。

即使在煤炭和电力部门内部进行政策协调，也存在进一步的障碍。中国的煤炭工业倾向于高度分散，然而电力生产又主要集中在五大公司。所以这种不平等的交易能力给电力公司带来了好处，它们可以抵制煤炭生产商的行动，通过在坑口电厂的洁净煤运作对电力供应实施更多的控制。这种情况下，电力公司很少有兴趣鼓励这种行为，或者其它大规模洁净煤基础设施的建设，包括采矿、气化和发电产生的煤层气、民用煤气和热能的高效利用和分配所使用的电力输电线路和管道。

然而，由于过去几年里煤炭价格增长，会逐步平衡煤炭生产商和电力供应商间的交易地位。电力公司发现它们的利润空间日益受到煤炭价格的上升和电力管制的挤压，同时煤炭企业在井口进行电力生产的优势得到了提升。最近，大量的煤炭生产商正寻求从“下游”产业转移到更广泛的发电运营，与此同时，电力生产企业也在寻求通过收购煤炭产业的“上游”业务拓宽它们的利润空间。

这种复杂且高度分散的决策体系带来的进一步后果是区域能源安全战略斗争。由于没有统一的全国能源安全战略，各个地区各有各的战略，有时损害其它地区的利益。这种缺乏协调的竞争在东西部之间尤其激烈。更多的东部沿海发达地区缺乏对煤炭丰富的西部地区提供的电力可靠性的信任，转而坚持利用中国西部的煤炭建立自己的发电厂。大多数情况下，他们还从国外进口液化天然气（LNG）为天然气发电厂提供燃料。

为了克服地方和中央政府机构、煤炭和电力部门以及中国的各地理区域间的利

益和优先权冲突，中国政府必须采用更加协调、更加畅通的能源政策决策体系。最近，中国已经对国家能源政策结构进行了重组，赋予高层能源委员会制定战略和优先权的职责，同时由国家发改委（NDRC）的能源局负责监管能源行业。

这些举措迈出了正确的一步。但是更多的是为了保证对中央政府政令的统一执行。以洁净煤为基础的国家能源安全战略最有可能成为相当昂贵和耗时的国家事业。如果不珍惜和坚持实施，将会寿终正寝。为了避免这种结果的发生，完全有必要对现有的优先和激励体系进行彻底地改进，向不同层次政府机构的政府官员和企业管理人员表明，再也不能自行随意制定政策。

从这方面讲激励措施的缺失可能比能源价格更加重要。中国目前的能源定价政策主要由社会关注程度决定。中国迫切需要为城市人口提供经济增长所带来的好处，因而与资源保持或技术创新比较，更加关注支付能力。

这种政策已经在多个领域带来了严重的后果。比如在电力和煤化工行业，不顾高效运营和更加严格的环境控制（比如SO_2排放和水保持），不惜通过补贴优先为居民和工业用户提供热能和电力。在其它重工业领域，比如钢铁业、铝业、混凝土加工业等，容许了极低的效率，这主要是由于要求保持低能源产出成本的竞争压力。

如果中国要制定以洁净煤为基础的成功的国家能源安全战略，有必要采用一种大为不同的环境外部性定价方法。这种战略的关键在于中国设定的能源价格应能够鼓励进一步的节能和更加严格地实施环境标准。当然，如果政府的法规很大程度上立足于允诺让广大民众过上中产阶级的生活，政府不太愿意强制实行。

问题是遍布中国的社会动荡加剧，已经威胁到政权的合法性。多数动荡事件与对环境滥用和漠视的现状有关。对城市能源消耗者的持续补贴政策没有多大意义，这只能因为增加了资源稀缺性，进而增加了环境压力，使滥用和漠视环境的现状继续存在。换句话说，如果能源安全成为中国的一个国家安全问题，也将上升为社会动荡。而且从国家安全的角度讲，能源安全要求和社会和平要求之间不存在真正的冲突。同样，有必要增强国家安全，提高能源价格和加强资源保持，从而降低环境压力，最终也将有助于促进社会稳定。诉诸爱国主义，为中国政府提供了一种实现这些目标的途径，要求中国人具有奉献精神，而不必不惜追求合法性，事实上相反得到了加强。

洁净煤战略对于中国的意义

社会和政治稳定

以洁净煤为基础的国家能源安全战略对于中国的社会和政治稳定具有重要意义，特别是关于富裕的沿海地区和贫穷的内陆地区间不断加大的经济差距。以洁净煤为基础的国家能源安全战略提供了解决这种不平衡的可能性，地区不平衡比起中国其它任何一个问题给社会和政治稳定带来的威胁都大。

具体来说，以洁净煤为基础的国家能源安全战略可能要求对消耗了多半能源的中国东部地区和西部的煤炭生产地区的资源重新进行有效地分配。这种战略要求对研究开发（比如气化技术、氢气生产技术）、人力资源（比如管理和技术人才）以及物理设施（管路和传输线）进行大量投资，所有这些投资将创造数以百万计的新工作。内陆地区的加速发展也将增加公共收入，可以广泛地用于社会服务和其它公共领域，比如教育和健康，从而提高普通市民的生活水平。公共收入的增加也有利于对环境保护的投入，从而改善环境质量。

其中，对全国洁净煤基础设施的投资意味着要推动一项大规模的公共服务计划，帮助弥合中国富裕的沿海地区和贫穷的内陆地区间日益加剧的差距。沿海地区将享受到更加清洁和更加安全的电力资源，最终以煤炭为基础的运输燃料来自于内陆，因此前景已证明难以捉摸。以洁净煤为基础的国家能源安全战略为中国的东部和西部实现了双赢，按照最乐观的估计，将会使两个地区更加紧密地联系在一起，不仅有一个共同的能源未来，也可以共同感受经济繁荣。

成为全球技术领袖的机遇

与这些优先发展战略相适应的国家能源战略也将为中国在洁净煤领域赢得全球技术领袖地位的机遇。煤炭是最古老的工业燃料，但是在许多方面也可以成为通往未来新工业经济的桥梁。中国有信心实现这种转变。中国可以利用大规模动员人力和金融资源的能力，使用自己的煤炭含量在多个领域展示煤炭如何铺就这样一条经济之路。

首先，以煤炭气化为基础的包括电力、煤化工和其它燃料源在内的“多联产”技术，为建立更加广泛的可持续能源基地创造了一种途径。其它燃料源可以源于煤炭中生成的合成气[2]，包括特别是可以在农村地区方便使用的液化气替代品二甲醚，和运输燃料甲醇。而且，具有氢“转移”反应能力的改装式煤炭气化系统（比如整体煤气化联合循环系统）为从主要含有氢气和CO的初始合成气流中分离氢气和

[2]合成气是CO、氢气、甲烷以及其它气体的混合物，当煤浆与氧气高压混合时产生。

CO_2提供了一种方法。然后可通过碳捕获和存储工艺（CCS）将CO_2贮藏于地下，同时氢气可与燃料电池外面的氧气联合发电。燃料电池作为未来的一种清洁电力资源具有美好的前景，同时清洁高效的氢原料生产方法是燃料电池广泛应用的关键。

中国希望跳跃式进入的第二个领域是煤炭开采生产率。未来的煤炭开采将取代今天繁琐陈旧的结构模式，可能包括的特点将实现从煤炭生产到煤炭消耗的无缝转变。中国可能会采用在美国已经实施的新技术，这样可以使在开始采矿作业的同时，开展瓦斯排放作业，因此可以节约时间，减少了逸散瓦斯排放。坑口安装先进的往复式燃气发动机，可以回收井中泄露或排放出的甲烷，并用作清洁燃料来发电[3]3。现代循环流化床系统也可以用来"回收"垃圾煤进行发电，而不是简单的收集起来，导致整个采矿作业场最终变成一个巨大的垃圾场。

展望未来，20-30年内地下煤气化技术可以为煤炭的无缝提取和利用工艺提供最终的解决方案。这种技术一旦投入实施，将使用大型钻机对氧气加压并注入深层地下，与煤层发生反应产生合成气。合成气然后返回到地下，可用来发电。氢气也可以在这个过程中进行分离和生成，结果在地下高温和压力下发生与水的氢"转移"反应。

上面所述的生产率的进步将从根本上改变现代采矿作业。新的进步有助于减弱对中国电网的压力；也可以轻松地实现向清洁能源（如氢气）的转变。煤炭转化的可能实现，使煤炭具有双重角色，不仅可以满足现在的需要，也为满足未来需要提供了可能。比如我们所看见的，通过煤气化技术制造氢气。通过对煤氢化技术以及其它方面的投资，中国可以将其巨大的地下煤炭储量转化为优势，将煤炭以清洁燃料能源的形式带到地面，满足现在和未来的需要。

中国可以面向未来的第三个领域是清洁能源基础设施的发展。与其它工业化国家相比，中国占据相对有利的地位，坚决朝着下一代清洁能源技术的方向转变。首先，不用负担废旧的能源基础设施，不然会阻碍未来的能源技术发展，即没有需要补偿的沉淀成本，也没有昂贵的改装成本。相反，正如已在电信领域所做的一样，中国有能力实现从一代技术向未来清洁能源技术基础设施的跳跃。第二，中国有能力进行大规模投资。无论下一代能源技术对基础设施有什么要求，中国都可以利用外汇储备和其它储蓄资源来满足要求。

这些优势为中国创造了快速向先进清洁能源经济转变的可能，这种能源经济模式以一系列的互相支持体系为基础，以利于煤炭和其它资源为主的能源分配。不用

[3]在美国，只是将甲烷收集、压缩，并输送到天然气管网。

通过铁路，甚至更糟糕的是用卡车运输煤炭，而是“通过线路”[4]从中国西部地区的先进坑口洁净煤发电厂输送到东部沿海地区的电力市场，这在美国和澳大利亚等产煤国家已经得以实现。通过这些先进的气化系统和其它设备捕获到的CO_2可以通过管路传输到地下存储场，以待西边更远的地区来吸收。利用这些设备从合成气中分离出的氢气可以注入准备好的罐车，然后通过铁路配送到加气站供燃料电池汽车使用。位于城外的其它先进洁净煤设施产生的热量和废气可以输送到区域供热系统，或者供城市家庭使用。

美国的能源安全煤基战略抉择

美国从自然资源禀赋的完全不同的立场来处理动用国家安全战略煤炭储备的问题。美国也具有丰富的天然气储量，但与中国不同的是，不仅可以用于家庭供热和发电，也可以满足现在和将来的运输需要。以煤炭为基础的能源安全战略中最高效的方法，也将考虑转变为其它资源，在利用煤炭时要使其用于其它更为高效的场合。

比如，煤变油（CTL）技术的开发和使用，除了军事用途之外似乎没有多少国家安全意义。虽然最流行的CTL技术依赖于煤气化这个中间步骤，即使这种间接的CTL形式也是具有相当的碳密集性，因为与发电时的煤气化不同，CTL技术中需要二次燃烧。CTL产生柴油，这种能量必须紧接着通过内部燃烧过程进行释放。与之相对的是，整体煤气化联合循环技术（IGCC）提供了一种直接以燃气轮机发电的形式释放煤气化产生的能量。实际上，尽管CTL制造了便于运输的燃料，但是使用了更多的能量，而且因为煤炭的二次燃烧而释放出更多的碳。

因此，为了适应传统的柴油或汽油的碳足迹，大量使用CTL作为运输燃料需要一个非常复杂，可能极其昂贵的碳捕获和存储系统（CCS）。而且，既然将这个额外的系统考虑进来，CTL以及其它的传统运输燃料，甚至替代运输燃料（比如生物燃料）仍然不具备压缩天然气（CNG）的碳减少能力，这种压缩天然气从效率上讲比所有其它的矿物燃料都强。全面的CNG运输基础设施，可与上世纪50年代州际公路运输系统相比，将利用CNG的这种能力可以为满足美国国家安全和能源需求奠定环保高效的基础。这样的基础设施可能包括天然气管道、压缩机组和加气站，还需要对美国汽车的发动机做比较简单的改造。

但是，这并不是说CCS对于美国的洁净煤未来没有用武之地。美国目前有一半的发电量来自于煤电。由于经济、政治和技术方面的原因，还没有任何一种能

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[4]“通过线路输煤”指的是通过高压电缆从煤矿场发电位置到终端用户的输电过程，而不采用铁路或其它方式将煤炭运输到靠近电力终端用户的电厂。

源，比如核能、太阳能、风能、地热能，或者其中一种甚至多种联合能源，能够在可以预见的将来取代这种电力资源。煤炭气化不只是一种比传统的粉煤燃烧更高效的发电方式，还为在到达烟囱前将CO_2从废气流中分离捕获奠定了相当高效的基础。为防止碳逸入大气而将其埋入地下，碳捕获是要依次进行的第一步。

还需要其它很多步骤。包括通过地质调查和分析对建议的地下存储场进行评定、计算机仿真以及通过试点项目和其它技术示范手段进行所谓的测量、监控和验证（MMV）。考虑到环境条件的变化，所有的研究和示范都必须在各个现场逐一进行。另外，需要开展广泛的公共政策工作，旨在建立一套管理制度来处理责任和产权方面的问题，并赢得公众对CCS方法的认可和支持。因此，在进行全面的CCS工作之前，必须铺设管网将CO_2从原来的位置输送到指定的地点。

当从整体上对这些步骤进行考虑时，很明显目前还没有达到国家层次的必要努力来建立一个全面的CCS系统，满足美国的电力生产和碳减排需要。IGCC电厂（连同必须的捕碳设施）还不准备建设。资金不打算用于支持反复试验的现场准备和开发研究。而且，更重要的是，经济激励制度还未形成，使得工业，广泛的讲，对于电力用户还望而却步，*无法*进行必要的投资。

总之，CCS还没有得到国家重视。对于美国严肃对待气候变化的真正考验，将在于它承诺建立一个包含司法、预算、项目计划和管理工具的系统，正如上世纪40年代的曼哈顿计划或60年代的阿波罗计划，规模上勘比这种重大挑战。

考虑能源安全的中美洁净煤共同战略

技术共享

因此，假定在合适的境遇和选择下，以国内煤炭供应为基础的能源安全战略为了帮助中美两国一定程度上避免世界石油和天然气的争夺还有很长的路要走。但是，这种战略本身可能不会走得太远。事实上，如果相互隔离，这种战略只会表现为另一种形式的冲突。

原因在于，如果任其发展的话，每一个国家都将发现自己面临次优范围的能源选择，每种选择最终可能都会付出整个地球的代价。对非传统能源进行评估，比如油页岩或者沥青砂或者可以用来制造液化运输燃料的气化煤，都是十分昂贵的，都需要很高的与能源产出有关的能源投入。如果解决环境外部性比如碳控制的成本增加，开发这些资源的成本会让人望而却步。

面对寻找安全能源的沉重压力，美国和中国完全不可能付出这些环境外部性的全部代价，不会将其延续到后代。然而，这些成本迟早都需要面对。气候变化和全球环境的恶化会造成资源短缺、跨界污染以及对于自然和人力资源的压力，这样只会增加双边冲突的可能。

因此，独立考虑的话，以洁净煤为基础的能源安全战略不再是避免美中冲突的良方，正如补助城市能源消费者战略不是避免中国社会动荡的良方一样。两种情况下，都是环境起到了妨碍作用。追求洁净煤为基础的能源安全更为可行的模式可能是美中两国共同努力，在洁净媒方面技术共享、优势互补。

CCS从美国的立场上对与中国进行洁净煤技术交流战略给予了重点关注。与中国不同，美国在许多方面能够进行CCS的全面开发、示范和利用。这些资源包括世界一流的地质专家和在计算机上建模、仿真和数学运算方面的广泛经验，还包括化学工程应用和分析。正如我们看见的，即使在CSS服务中就这些资源分配而言仅仅涉及地面，也有些经验教训需要学习和与中国分享。

与CCS有关的资源和技术不平衡，使美国有机会帮助中国加快自己的CCS示范、开发和使用计划，以利于全世界的和平与未来。虽然中国可能现在还没有为全面采用CCS作好准备，但也不能无限期推迟，因为除了目前着眼于先进的洁净煤发电技术外，中国也打算在将来开发CTL和其它煤基运输燃料（比如甲醇）。

然而，由于缺乏CCS配套措施，中国CTL发展前景对于全球环境甚至美国的安全都有着相当严峻的影响。至少考虑到美国的长期国家安全利益，要防止这种结果的出现，比如从世界各地抢夺石油的前景进行预测。正如Gen. Richard L. Lawson (USAF-ret.)谈到有关CCS说，“我们必须开发和测试CCS，并带到那儿（中国），与其分享，便于在20世纪的下半叶进行和平投资。”

从中国的角度讲，煤炭气化也符合这种情况。中国已经在以煤气化基础的“多联产”工艺上取得了积极进展。这些工艺不仅包括发电，也包括废气流中的副产品利用，同时将氢气分离出来作为其它用途（比如燃料电池），并捕获CO_2埋藏于地下。副产品可能还包括肥料及其它煤化工产品，甲烷、甲醇、二甲醚和其它燃料。而且，中国还利用煤气化过程中产生的废气为家庭和公寓供热。

美国为什么不可以借鉴利用这种经验呢？在美国，目前大多数没有在发电中利用的煤炭要么直接排放到大气中，比如CO_2，要么作为废气处理（比如SO_2、N_2O、NO_2）。比较而言，煤气化比传统的粉末燃煤发电具有明显的环境好处。这些优势包括热效率提高10-15%，达到了节能减排的效果。随着氢转移反应设施的安装，采用这种“多联产”工艺也能够比传统的燃烧工艺更加高效地分离出氢气和捕获CO_2。最终实现了节水排污（如SO_2），使污染物质在进入烟囱之前从废气流

中分离出来，并为污染处理或转化奠定了更加高效的基础。

根据完全环境成本核算，这种“综合资源利用”方法符合美国高效能源安全战略的要求。但是美国无法独自完成。美国需要中国的经验，中国数十年来作为世界领先的焦煤生产国，证实了这种实用的技术不需要昂贵的改装。利用焦煤生产经验，中国还在判定不同种类的煤炭是否适合煤气化这个方面获得了广泛的技术知识。这些正是美国开始实施的领域。与中国合作，美国有机会跳过整个试验阶段，直接获得最节俭的解决方案，充分利用煤炭。制造出最有用的副产品。

知识产权问题

总之，美国与中国立足于自身实力建立战略合作关系，在洁净煤生产和利用方面进行优势互补将会获得双赢的结果。但是，怎样协商经验和技术的交流规则呢？

有关知识产权的规则还未进行深入谈判。总的来说，技术共享对于两国来说可以是双赢的战略，但并不是每一个国家人人都能从中受益。私人部门投资者在研究开发中作出了贡献，他们冒着资源风险期望获得未来收益，可能发现他们付出代价却让其它人获益。对于稀缺的公共资源，最初不管是否紧迫按照相同的用途分配，但目前有了新的用途。在某些人看来，这将不再表明起初的贡献。换句话说，通过技术信息和创新成果的共享，改变了游戏规则。

然而，如果美国和中国可以实现洁净煤技术的取长补短，为什么两国不同样地对自己国家中在合作中的失利者进行补偿？比如，美国已建立了这样一种制度，对在自己国家在自由贸易中处于劣势者进行补偿。政府通过经济支持系统对失业者进行补偿，包括失业补偿、职业再培训计划和就业服务。通过税收和其它激励措施，有助于吸引企业对不景气的组织投资帮助他们实现经济复苏。小额商业贷款可以使失业者重新开展他们的业务。

为了对由于技术共享失去商业机会的技术提供者进行补偿，在洁净煤技术转让领域没有理由不推行这样的制度。比如，可以采用公共基金帮助私营气化器和其它洁净煤技术供应商发现这些产品在中国最有利的市场，比如协助他们对各种环境以及不同种类的煤炭进行试验。可以提供补助来促进这些产品在初期的广泛传播，因而调整未来基础设施的发展，使其符合相应的技术规范，并在市场中占据优势地位。作为这些产品的最早开发和完善者，通过这些方法调整，可以弥补技术提供商在竞争中失去的信息优势，使他们在竞争中可以稳稳获利。

结论与展望

那么煤炭就是美国和中国能源安全的解决方案吗？出乎意料的答案是，煤炭只能够在互相合作战略框架下实现能源的自给自足。中国利用启用洁净煤技术资本的能力的确创造了许多对于未来的期待。正如前面提到的，包括电力、氢气和其它煤气化副产品的多联产技术；高效采煤和副产品投资；大规模洁净煤基础设施的建设。但是与此同时，中国也可能采取两面下注的方式，发展一些效率比较低下的产品，特别是在运输燃料领域（比如CTL）。与美国进行CCS合作对于这种技术的可持续发展至关重要。

美国在许多方面反映了这种现状。还有其它可能情况：比如，如果基于CNG的新型运输系统可以补充生物燃料的缺乏，缓解对于进口石油的依赖。正如我们看到的，CTL作为一种运输燃料能源，排在CNG和生物燃料之后。就象中国一样，美国将在未来很多年仍将依赖于煤炭发电，这是我们不得不面对的结论。

然而，如果不全面地转向以煤气化为基础的多联产发电及其副产品保护和利用体系，洁净煤的发展难以持续。如同美国进行的CCS新实验，中国在这些领域进展过程中获得的经验，为美国减少了误判，节省了大量的时间和美元。有趣的是，这也为美国富有成效地向中国学习提供了获取信息的机会，正如过去中国经常向美国学习一样。而且，从某种意义上讲，中国需要像美国那样不断学习。必须要表明，正如中国长期主张的"互利互惠"的合作原则，美国也要受益于技术转让。

如果洁净煤战略为中国和美国带来了好处，下面的建议对于两国的决策者来说可以为这种转变奠定基础：

对于中国政府

制定一个连贯的基于洁净煤的国家能源战略和建设根本改善的能源基础设施，有利于促进全国各地电力供应的协调分配。

制定合理的能源价格，可以为洁净煤技术投资增长、高效处理和节能提供动力。

对于美国政府

支持重大洁净煤技术的研究与开发。

突出重视煤气化技术，包括专家调研、可行性分析、示范项目，对碳捕获和存储（CCS）场地进行描述和开发。

确保在所有煤气化厂安装CCS设备，同时要有良好的管网基础设施来支持CCS计划。

然而,正如原负责全球环境事务的助理国务卿，现担任煤炭生产商Peabody Energy总裁的John F. Turner所指出，这些措施的效果还要取决于太平洋两岸“私营机构的创新能力和资源”。即使面对双方政府采取必要的措施降低这种不确定性并且保证能源价格充分反映环境成本，私营机构也必须有所准备，且只要有可能就立即投入这些行动。

私营机构：

*中国企业：*通过主动性企业战略促进公共政策改革，包括不断增加研发投资创新洁净煤技术。

*美国电力企业：*通过主动性企业战略促进公共政策改革，包括通过增加煤气化为基础的发电和碳捕获设备投资，实现资产多元化。

*美国和中国政府：*通过中国的市场分割协定为洁净煤技术发展领域的合资企业创造更多的动力。

基于洁净煤的美中能源安全战略的关键是认识各自的弱点。两国都必须认识自身弱点领域，比如对于中国的CCS技术和对于美国的基于煤气化的多联产技术，这样利用自身的比较优势有助于克服自己的弱点。双方都必须向对方充分坦诚，且愿意为了双方的共同安全和地球的未来贡献自己的力量。为此，还需要准备好放松对贸易机密的管制，并对信息失灵的弱势者提供补偿。也许只有这样，两国才能从对世界能源供应的漫长竞争阴影下走出来，进入在洁净煤基础上建立互信、技术共享和节约能源的新天地。因此，下面的建议有助于推动洁净煤技术合作：

利用中国的煤气化技术促进以煤为基础的“多联产”工艺。

加快美国CCS现场准备和开发的试验过程，使中国政府、工业和研究伙伴分享CCS的成果。

建立知识产权补偿协议框架，弥补技术交流造成的商贸损失和促进合作。

理事会

共同创办人

Ira D. Wallach
(1909-2007)