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COAL LIQUEFACTION POLICY IN CHINA: EXPLAINING THE POLICY REVERSAL SINCE 2006

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Coal Liquefaction Policy in China: Explaining the Policy Reversal Since 2006

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Abstract: China has emerged as a leader in coal liquefaction. While the country's abundant coal resources and acute concerns about oil security help explain China's interest in liquefaction, the driving forces for this industry are complicated and policy has been inconsistent. Since 2006 Beijing has tried to slow down the development of liquefaction; even as China has become more dependent on imported oil, the central government has been wary about the large impact of liquefaction technologies on scarce resources such as water. However, local government officials in coal rich areas have strong incentives to pour investment into the technology, which helps explain the uneven development and policy. The future of coal liquefaction will depend on how these forces unfold along with major Beijing-led reforms in the Chinese coal industry, which is closing smaller mines and favoring the emergence of larger coal producing firms. Those reforms will have mixed effects on liquefaction. They temporarily contribute to higher prices for coal while over the longer term creating coal companies that have much greater financial and technical skills needed to deploy technologies such as coal liquefaction at a scale needed if this energy pathway is to be competitive with conventional sources of liquid fuel.

Keywords: China; coal liquefaction; coal; energy security

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1. Introduction

Converting coal to liquid (CTL) fuels, a chemical process, has been attractive to many countries with scarce local supplies of oil yet abundant coal. CTL, along with an arsenal of other technical and policy options such as energy efficiency, offers the prospect of greater energy security through decreased reliance on imported fuels. Technologically, there are two main routes for CTL production: direct coal liquefaction (DCL) and the Fischer-Tropsch (F-T) processes, also called indirect coal liquefaction (ICL). In DCL the coal is directly contacted with a catalyst with added hydrogen at elevated temperatures and pressures. By contrast, the ICL process consists to two major steps: 1) gasification to produce a synthesis gas and 2) conversion of the gas to a liquid by synthesis over a catalyst in a F-T process. Therefore, the label ‘‘indirect’’ refers to the intermediate step of first making syngas. It is generally believed that DCL processes are more efficient—60% compared to 50-55%—but requires higher quality coal and a more complicated process (Williams and Larson, 2003; Liu, 2005).

Both processes were developed in pre-World War II Germany; both were used, but on fairly small scales, to meet Germany's and Japan's wartime needs for liquid fuel (Liu et al, 2010). Since the end of World War II, the only commercial experience in F-T coal liquefaction production has occurred in South Africa under government subsidy and in the face of severe apartheid-era restrictions on the country's ability to import liquid fuels. Today, South Africa's CTL industry continues—indeed, the South African firm Sasol is the world leader in deploying some of the technologies in CTL and a leader in many related processes such as gas to liquid (GTL) production (Couch, 2008). (Sasol uses ICL and thus is an expert in managing syngas operations—a skill useful in many aspects of the chemical industry.) However, many other countries show active interest in coal liquefaction technology including China, the USA, India, Japan, Australia, Botswana, Germany, Indonesia, Mongolia, and Philippines, particularly the first three key countries with large coal reserves but limited reserve of oil (Couch, 2008). Despite of dozens of coal liquefaction plants worldwide that are under consideration, by the end of 2010 there were only several that are under operation in South Africa and China, while three are under development in the United States and one in Mongolia (NETL, 2011).

This paper is about the Chinese experience. With its rapidly growing demand for transportation fuels, scant domestic oil and natural gas resources but abundant coal, China has been actively pursuing coal liquefaction technology since the 1950s. Over most of that history it treated CTL as a research and development (R&D) topic; over the last two decades, however, it has moved from laboratories to large-scale demonstration projects. Through its

R&D and demonstration efforts, China today has the most active coal liquefaction programme in the world (Fletcher, et al, 2004; Nolan, et al., 2004; Liu et al, 2010). China is developing the world's first and the largest DCL plant since WWII. This DCL project—located in Inner Mongolia and built by China's largest coal mining group, Shenhua Group Corporation Limited (we call this "Shenhua" for brevity hereafter)—began trial production in early 2010. Two other ICL plants are demonstrating as well by two other smaller coal groups and are the largest in the world after the Sasol projects in South Africa.

China's CTL industry hinges on government support, such as subsidies and policy mandates. Central government support for this industry has been highly uneven and volatile as government's priorities have changed over time. In July 2006, a year marking Beijing's policy shift on CTL, the government's top planning apparatus, the National Development and Reform Commission (NDRC) issued an order that requires local governments not to approve any CTL project with an annual fuel output below three million tonnes and to temporally suspend any new project review. Since then, the NDRC has issued three more project suspension notices to cool down the industry in 2008, 2009, and 2011, respectively.

This new policy shift since 2006, however, has not been well explained by existing literature. The most recent academic research on China's CTL policy—a study by Nolan, et al. (2004)—emphasized the role of energy security in driving decisions on the technology—a theme pursued also by Nkomo (2009) for the case of South Africa. Newer academic literature on coal liquefaction is mostly focused on technology details (e.g. Williams and Larson, 2003; Couch, 2008; Li et al. 2008; Tang, 2010; Liu et al., 2010), although a few policy-oriented studies discuss the driving forces and barriers in the development and implementation of coal liquefaction in Germany (Vallentin, D., 2008a) and the United States (Vallentin, D., 2008b). The new policy shift in Beijing on coal liquefaction is captured to some degree by media reports (Zhang, 2008; Lv, 2010), but they only achieve the purpose of asking questions rather than of giving systematic answers.

This paper looks at the history of China's decisions related to coal liquefaction. Our argument is that while energy security has played a major role, as in other countries that have pursued coal liquefaction, the actual Chinese policy reflects an array of other forces at work. Only by looking to those other forces is it possible to explain the country's policy cycles in this area—from extreme enthusiasm by the central government to shelving the technology a decade ago to Beijing's tepidness today. This paper offers a deep analysis of the circumstances under which the key policy decisions—by the central and local governments—have been made and the special role of the coal industry and other important stakeholders. We show that the country's CTL decisions are symptomatic of a many challenges in resource governance in China today. CTL policy involves simultaneous management of multiple scarce resources—oil, coal, water, and allocation of land notably—at multiple levels of government. How China has managed those issues in CTL can help reveal other, similarly structured resource decisions that China's central, provincial and local governments face.

This paper is organized as follows. Section two reviews the development history of China's coal liquefaction industry before 2006 and analyzes the major driving forces for Chinese planners to heavily invest in coal liquefaction. Section three presents the critical decision period in the most recent phase of support—the decision in 2006 to cool down the coal liquefaction industry and further tightened policies in 2008 and 2011. Section four explains the policy shift as a direct result of the central government's efforts to balance old (yet persistent) drivers such as energy security with new concerns such as depletion of local water resources. Section five presents a good illustration of how coal liquefaction policies have been played at the local level, using Ordos as an example, the host of China's biggest coal liquefaction project. The final section concludes the findings and the possible role of synthetic oil from coal in China's future energy profile.

2. China's CTL industry before 2006: history and driving forces

China's CTL industry has gone through different stages where the country has invested heavily or cooled its support for CTL. Before 2006, the industry has received extreme enthusiasm from the central government with enormous funding support and a series of favorable policies. The central government's enthusiasm for CTL during this stage has been driven by many factors, but three have been most important--one is energy security, a second is the country's desire to balance economic growth between the high growth east and the more sluggish western provinces, and third is the need to build infrastructure to move energy, notably coal, from where it is rich in supply (the north and west of the country) to where demand is greatest (the east and the south). Until 2006—especially since the oil crises of the 1970s—all three of these forces aligned and China's CTL policy unfolded according the standard view: the coal-rich but oil poor country pushed hard for CTL as a way to reduce dependence on imported oil.

2.1 The main development in China's coal liquefaction policy, 1950s to 2006

2.1.1 R&D initialized and suspended (1950s to 1967)

China started its research and development on synthetic oil as early as 1930s. During World War II, Japan established an indirect coal-to-liquids plant in Jinzhou, Liaoning Province, adopting Germany's wartime technology. Operations began in 1943 with an annual fuel output of 100 tons. Operations were suspended after Japan lost the war in 1945, but the plant remained physically in place. China resumed and expanded the Jinzhou plant shortly after the founding of the People's Republic of China (PRC) in 1949. The plant became operational again in 1951 and achieved its maximum annual fuel output of 47,000 tons in 1957 (Tang, 2010).

However, China suspended its R&D on CTL soon after it found, in 1959, a large deposit of oil at the Daqing field in northeastern China. Operations at the Daqing oilfield began in 1960 and annual production reached nearly 2.3 million tons of oil by 1963. Further important discoveries, including the major oilfields of Shengli in Shandong and Dagang in Tianjin, enabled China to meet domestic needs and eliminate nearly all imports by 1965 (Lim, 2009). The Jinzhou plant was therefore losing its strategic position and officially suspended its operation in 1967 (Tang, 2010).

2.1.2 Interests revived (late 1970s to mid of 1990s)

China's R&D on synthetic oil resumed in late 1970s as the government responded to dramatic rises in oil prices seen following the oil crises of 1973 and 1979. The country was a net exporter of oil at the time, but new production—including from possible CTL operations—would help it sustain that status and also possibly yield new export revenues. The gradual recovery of the economy from the end of the Cultural Revolution raised the prospect that the country's oil demand would recover as well. The research efforts were led by the Shanxi Institute of Coal Chemistry within the Chinese Academy of Science (ICC/CAS)—a research arm of the state located near one of China's richest coal provinces—and led to the establishment of China's own intellectual property on the F-T process for coal liquefaction. Meanwhile, China has also started its direct coal liquefaction experiments in early 1980s, which was led by China Coal Research Institute (CCRI) (Liu et al., 2010).

2.1.3 Strong government support provided (mid of 1990s to 2006)

Since the middle 1990s, the central government has channeled huge support to synthetic oil in the form of supportive policies as well as enormous financial support from policy banks (see Table 1). This support notably included the 1998 "Coal Replacing Oil Fund" of 11 billion RMB Yuan (US$1.3 billion) provided to China's first and world's first direct coal liquefaction plant, namely Shenhua direct coal liquefaction plant in Ordos, Inner Mongolia (Chu, 2008). At the same time the country launched a series of major, nation-wide science & technology programs aimed at improving the nation's innovative capabilities--including *State High-Tech Development Plan* (or simplified as "*863 Plan"*), *National Key Basic Research Program* (or simplified as "*973 program"*), and CAS's *Knowledge Innovation Program*

(KIP) (Karplus, 2007; Zhao and Gallagher, 2007). All of these nation-wide innovation programs also included substantial additional support for CTL.

Table 1: Key milestones in Beijing's coal liquefaction policy, 1986 to the present: from aggressive support to caution

Attitude	Time	Programs/regulations
Supportive	1986	Included in *State High-Tech Development Plan* or simplified as *863 program* initialed by the MOST
	1997	The State Council issued *The 9th Five-Year-Plan for Chinese Clean Coal Technology and the Compendium of 2010 Development* • Was placed as one of 14 key technologies to develop • A commercial coal liquefaction plant by 2010
	1997	Included in *National Key Basic Research Program* or simplified as *973 program* initialed by the Minister of Science and Technology (MOST)
	1998	"Coal Replacing Oil Fund" of 11 billion RMB Yuan (US$1.3 billion) provided to the Shenhua Group's DCL plant
	1998	Included in one of 19 key projects in CAS's *Knowledge Innovation Program (KIP)*
	October 2006	The MOST released *National 11th Five-Year Science and Technology Development Plan* • Was placed as one of prior developing technologies • Included into the list of key technologies and product catalogs that China should have independent intellectual property rights
Cautious	June 2006	Primer Wen Jiaobao warned during an inspection tour in Shenhua's DCL plant that enterprises should not rush to commercialize the CTL projects blindly before the test projects are proved successful.
	July 2006	The NDRC (formerly the NDPC) issued *Notice on Strengthening of Coal Chemical Industry Projects to Promote the Healthy Development of the Industry* • In principal, no approval for any CTL project with an annual fuel output below 3Mt • Responsible government agencies must temporally suspend any new project review before the completion of the Compendium of National Coal Liquefaction Development
	August	The NDRC issued *Notice on Reinforcing the Management of Coal Liquefaction*

2008	*Projects* • Restated that the CTL industry was still in an experimental stage • All coal liquefaction projects except two involving the Shenhua Group should be stopped
September 2009	Ten Ministers/Agencies jointed issued *Advices on Avoiding Problems of Overcapacity and Duplication to Guide the Health development in Certain Industries* and the State Council approved and forwarded it later • Restated that the industry is still in demonstration phase • In general, no more new projects within three years • Implementing local official accountability
April 2011	The NDRC issued *Notice on Regulation on the Coal Chemical Industry to Achieve the Orderly Development* • Ban any coal liquefaction plant with an annual fuel output 1 Mt and below • All demonstrations are required by the document of NDRC • Strictly regulate the coal chemical projects with high water consumption be constructed in water-stressed areas • In principal, one demonstration project only for one company

Source: The State Council of China (1999); The Minister of Science and Technology of China (2006); China Daily (2008a): NDRC (2006); NDRC (2008); NDRC (2011); the State Council of China (2009).

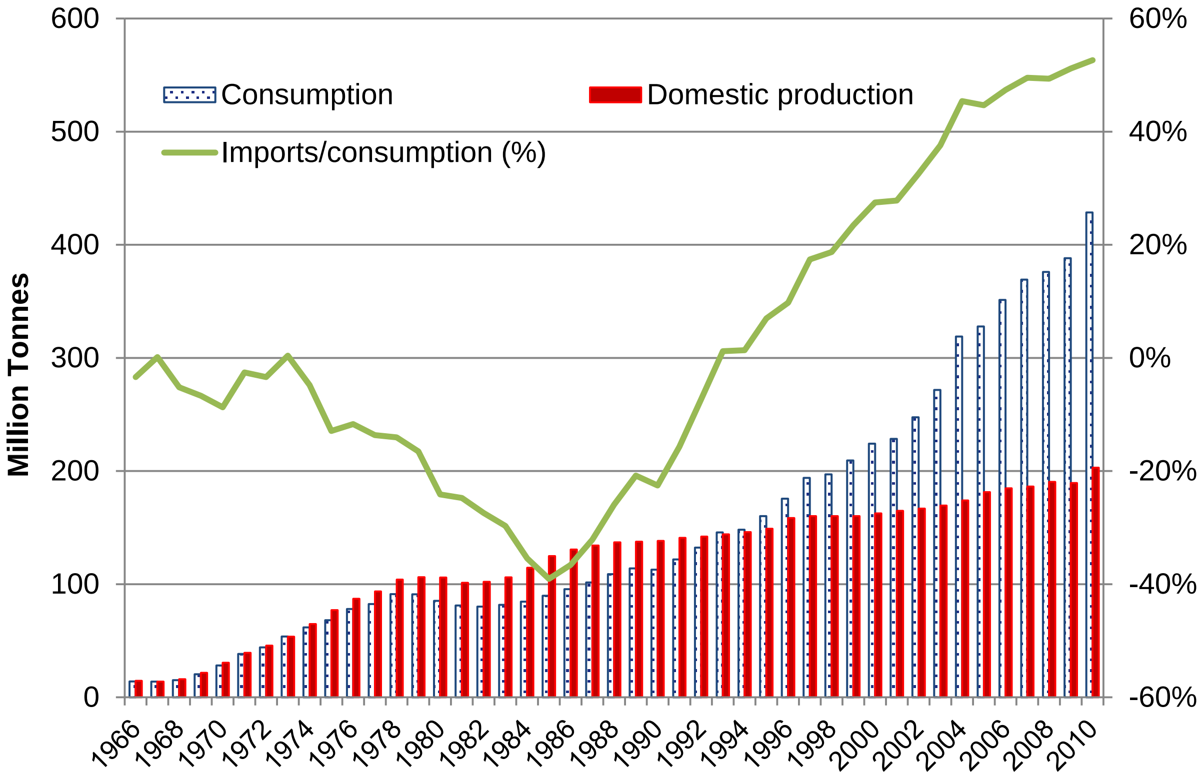
2.2 Explaining China's coal liquefaction policies from 1950s to 2006: three drivers

This new policy—of radically increasing financial and other policy support for CTL—was driven mainly by Beijing's severe concerns about oil security. China became a net oil importer in 1993 and since then the share of imported oil has been rising continuously. In tandem, this development of coal resources also aligned with the country's conscious plan to shift more development west (called "Western Development" or "the Great Leap West") and to develop coal resources in places where those are rich.

2.2.1 Energy security

Energy security is the single most important driver for Chinese policy makers to direct investment to coal liquefaction (Nolan 2004; Liu et al., 2010). Back in 1949, the domestic oil output in China was merely 0.12Mt (Lim, 2009). The oil embargo initiated by western countries during the Cold War taught China the first lesson of the importance of oil security. Since then, China had to rely heavily on imported oil from the Soviet Union and Eastern Europe. But the sudden Sino–Soviet split in the early 1960s and the cutoff of oil supplies by the Soviet Union made China feel for the second time the plight of oil shortages (Leung, 2011). After being self-sufficient for nearly 30 years, China became a net oil importer in 1993 (see Figure 1) and oil security concern rose sharply again since then. Today, China is the world's second-largest oil importer, only behind the US. According to China's Ministry of Industry and Information Technology (MIIT), the share of imported oil among total domestic consumption has exceeded 55 percent in 2010. By contrast, the U.S. oil-import dependency fell below 50 percent in 2010 for the first time in more than a decade and the moderating trend is expected to continue through the next decade (EIA, 2011).

Figure 1: China's oil dependence on foreign oil



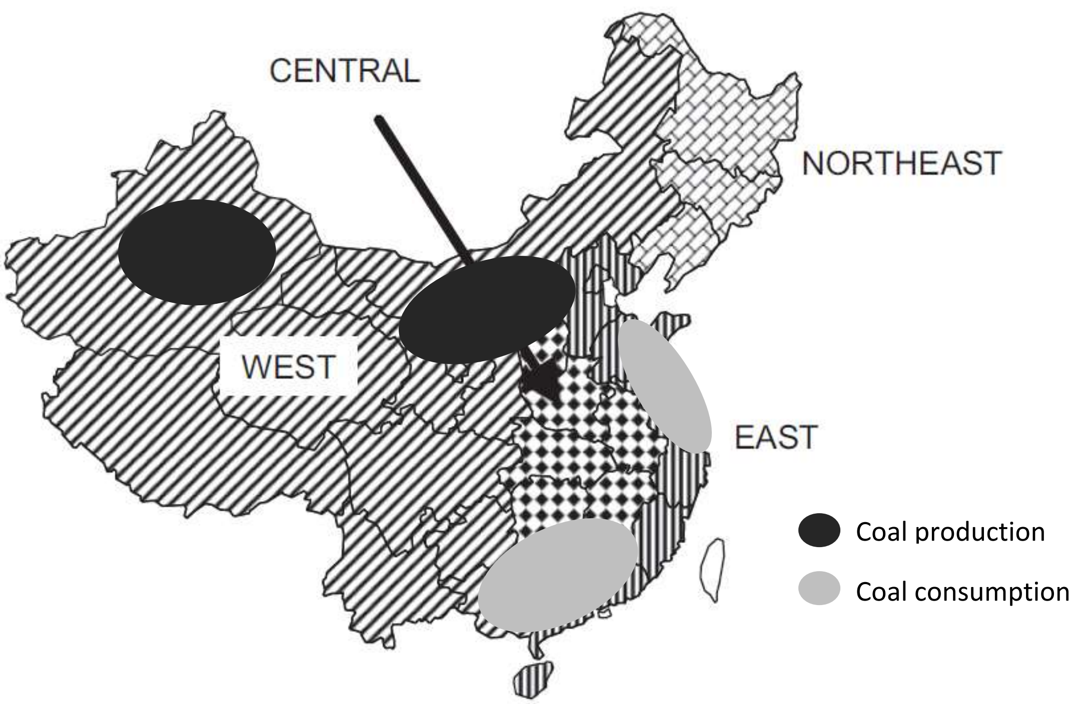
Data source: BP (2011)

2.2.2 Western development

The government's decision to put huge financial resources into coal liquefaction projects is also aligned with Beijing's interest to balance astronomic growth in the eastern part of the country by shifting more development west—a perennial goal also called "Western Development" or "the Great Leap West" (see figure 2). Under the leadership of Deng Xiaoping, China began to reform its economy in 1978 by changing from a planned economy to a market economy. The coastal regions of eastern China benefited greatly from these reforms, and their economies quickly raced ahead. Western China, however, severely lagged behind. As of the end of 2000 when the program was first initiated, for example, this region contained about 71 percent of mainland China's surface areas but only 27 percent of its population and 17.1 percent of its total economic output (NBSC, 2001). Today, the GDP number slightly increases up to 18.5 percent (NBSC, 2010).

Despite a lower level of economic development, western China is rich in natural resources. Inner Mongolia alone, for example, has nearly one quarter of China's total approved coal reserves (NBSC, 2010) and according to the most recent published number Xinjiang's coal resources are predicted to amount to 2.19 trillion tons, accounting for 40 percent of the country's estimated overall reserve volume (China Daily, 2011). The development of coal liquefaction industry in western China serves well the aim of "Western Development": to increase the economic situation of the western provinces mainly through capital investment and development of natural resources.

Figure 2: Map of China, the four regions of China



Note: The provinces (including autonomous regions and municipalities) of China are grouped into four regions as shown in figure based on their geographical locations. West China refers to Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang.

2.2.3 Coal transport bottleneck

Beijing also promoted liquefaction as a means of developing coal resources where they are rich, which would help the country address its perennial coal transport capacity bottlenecks. Most of China‘s coal resources are located in northern and western China including Shanxi, Shaanxi, Inner Mongolia, and Xinjiang, while most of coal consumption occurs in heavily industrial eastern and southern China such as Shanghai, Zhejiang, Guangdong, and Fujian (see Figure 2). Moving coal around the country utilizes a large and growing share of domestic transport capacity. From 2000 to 2009, for example, lengths of railways in operation in China grew only 2.5 percent annually, lower than the 7.6 percent of the annual growth rate of coal freight carried by national rail, and much lower than the 10.0 percent of annual coal production growth rate over the same period (NBSC, 2000 to 2010). These bottlenecks have proved persistent. As of 2009, the rail networks, as the dominant model of coal transport in China, transported more than 1.3 billion metric tons of coal, accounting for nearly 50 percent of the total railway transport capacity (NBSC, 2010). Indeed, one factor contributing to the recent rise in coal prices is stress from the transport system (Zhou, 2010 and Rui et al, 2010).

3. Beijing’s reversal: central and local CTL policies since 2006

All three drivers for pre-2006 policy are still present. All three point to rising interest by policy makers—especially in Beijing where the country’s interests are most broadly evaluated—to expand development of CTL. Since 2006, however, Beijing’s attitude on coal liquefaction has changed from extreme enthusiasm into more tepid support. As notable examples, the country’s central planner, the NDRC, has since then issued four regulation notices to cool down the development crazy. This section introduces the puzzle, the policy shift since 2006, and the next section explains in details the shift.

The pivot in this policy was a warning—issued at the highest level by Premier Wen Jiabao—focused on the risks of blindly rushing into the commercialization of CTL projects. Shortly after Premier Jiabao’s warning during his visit on Shenhua’s DCL plant, the NDRC issued its first regulation notice on the coal chemical industry on July 7, 2006 (Li, 2008). The notice urged for the "healthy development" of the CTL industry and required local governments not to approve any CTL project with an annual fuel output below three million tonnes. This threshold was designed, in part, to prevent the emergence of a small and fragmented CTL industry—one that would be less economically profitable and politically harder for Beijing to control when compared with an industry dominated by large, centrally administered firms such as Shenhua. This policy would also deter provinces that wanted to create CTL industries of their own—but with coal firms too small to be competitive—from acting outside Beijing's authority. The NDRC stated that CTL technologies were still not ready for widespread deployment and should be promoted nationally only after successful demonstration. NDRC's 2006 regulation also temporally suspend reviews and authorizations for any new projects to give the planning agency time to regain control over the CTL industry.

Despite these announcements from the central government the construction frenzy, however, showed no signs of abating.

Since then, the NDRC issued three more project suspension notices (see Table 1). In August 2008 the NDRC ordered a stop at all coal liquefaction projects except two involving Shenhua Group (the direct coal liquefaction plant in Inner Mongolia and the indirect one in Ningxia Hui Autonomous Region). Most recently in early 2011, the NDRC issued another circular banning any coal liquefaction plant with an annual fuel output below one million tonnes and also requiring that coal supply be prioritized for residential use and power generation—uses where the country's coal shortages were most visible and harmful to the broader economy. NDRC's 2011 order also banned the allocation of land and bank loans to those coal chemical projects which did not meet industrial policies and regulations.

These orders help slow the CTL industry. Suspended projects included a Shenhua/Sasol joint venture in Shaanxi, Yunnan Xinfeng Coal Chemical Group in Yunnan Xunxun, Shandong Energy Group in Xinjiang Yili, and China Pingmei Shenma Group in Henan Pingdingshan.

As of July 2011, there are eight active coal liquefaction demonstration projects in China—three that are operational and five others that are in various stages of planning, a process that is more onerous in light of NDRC's efforts to slow the industry—with a total annual oil capacity of 38.2 million tonnes and an estimated total investment of 380 billion RMB Yuan (about US$58 billion) (see Table 2). Major Chinese enterprises that have been involved in coal liquefaction projects include Shenhua Group, Inner Mongolia Yitai Group (Yitai Group), Shanxi Luan Group (Luan Group), and Yankuang Group.

Table 2: Major coal liquefaction projects in operation or under planned

Affiliation	Type	Capacity (million tonnes/year)	Location	Construction time	Operation time
Shenhua	DCL	1 (5[a])	Inner Mongolia	2004	2008
Yitai	ICL	0.16 (0.48[a])	Inner Mongolia	2006	2008
Luan	ICL	0.16 (0.48[a])	Shanxi	2006	2009
Yankuang	ICL	1 (5[a])	Shaanxi	Under plan	-
Shenhua-Ning/Sasol	ICL	3.2 (6 [a])	Ningxia	Under plan	-
Shenhua	DCL & ICL	3	Xinjiang	Under plan	-
Chongqing Yufu	ICL	5	Guizhou	Under plan	-

[a] Number in parentheses: planned expansion capacity in near future.

Source: Wang and Gao (2009); Xie (2011); Zhen and Cai (2011); Ruan (2011); Chen (2011) and Tan et al. (2011).

The effects of these new policy orders are revealed by looking at several of the large CTL projects that were in operation or planning at the time that the policy reversals began in 2006. Shenhua's direct coal liquefaction project in Inner Mongolia, for example, is one of the three projects officially approved by NDRC in Beijing. It started its construction in 2004 and accomplished its first trial operation at the end of 2008. The project produced 216,000 tons of refined oil products in the first quarter of 2011, which brought more than 100 million RMB Yuan (US$15.4 million) in profits, and in 2010 it operated for 5,000 hours and produced 450,000 tons of oil products (Zhen and Cai, 2011). The other two approved projects include Luan's ICL project in Shanxi and Yitai's ICL project in Inner Mongolia. They accomplished their first trial operation in 2008 and 2009, respectively, and both have achieved a long period of stabilized operation (Chen, 2011).

Shenhua's indirect coal liquefaction project in Ningxia, a joint venture with Sasol, however, is still waiting for final NDRC approval, although it has obtained initial environment approval by the Ministry of Environmental Protection (MEP) (Ruan, 2011). At the end of 2010, Shenhua Group announced its new plan on both direct and indirect coal liquefaction plants in Xinjiang Uyghur Autonomous Region, a region having 40 percent of China's total coal reserves (Tan et al., 2011). The move is to establish the biggest coal liquefaction base in China with an estimated annual fuel output of three million tonnes (Tan et al., 2011). Shenhua's another indirect coal liquefaction project with Shell in Shaanxi, however, was already suspended in 2009 after Beijing issued multiple projection suspension warnings (Wang and Gao, 2009).

Another notable ICL project by Yankuang in Shaanxi is also waiting for the approval from the NDRC after it was approved by the MEP in 2009 (Ruan, 2011). In addition, Guizhou province is planning to build an indirect coal liquefaction project with an annual oil capacity of 5 million tonnes with a total investment of 75 billion RMB Yuan (about US$12 billion) (Xie, 2011).

4. Explaining China's CTL policy shift since 2006

The policy shift since 2006 is a result of Beijing's efforts to balance multiple drivers—not just traditional concerns of energy security but also three new emerging forces. First, water is increasingly scarce in China. Except for Guizhou in southwest China, all other coal-rich regions in China are now subject to some degree of water scarcity and pollution. (The high emissions of carbon dioxide, widely discussed in western countries, do not figure so prominently in China.) Second, the consolidation of the coal industry in near term and shortages in coal supply will make coal more expensive and thus possibly less attractive as a feedstock for CTL (especially CTL processes that use fuel inefficiently). Last, perhaps what Beijing worries the most is pressure from local governments to develop local industries regardless of Beijing's interests—what we will call a "development craze." Indeed, some local governments have been highly motivated and entrepreneurial in pushing the CTL industry—despite the business risks associated with volatile oil prices and huge capital investment requirements, uncertainty about availability of essential natural resources, and likely pollution. These local governments have pushed the technology despite active efforts by Beijing to do the opposite.

4.1 Increasing water scarcity and other environmental concerns

Water scarcity in China, notably in northern China, is pressing. The problem has attracted extensive worldwide attention and been covered by major media outlets such as Economist, CNN, Routers, and the New York Times (Economist, 2009; CNN, 2010; Harrison, 2010; Wong, 2011). China's water scarcity is reflected not only in quantity, which is well-monitored, but also water quality where monitoring systems and governance mechanisms are much more immature (Rong, 2011). This scarcity is not just a reflection of China's geography (dry north and wet south in general) but also a series of mismatches among population, agriculture, industrial outputs, and natural resources. For example, almost all coal-rich regions in China are subject to some degree of water scarcity (see Table 3). Shanxi

Province, as a notable example, enjoys about one third of China's total proved coal reserves, but has only 0.4 percent of the country's freshwater resources and its per-capita freshwater resource is merely 251 cubic meters per person, less than one seventh of the national average and one thirtieth of the world average (NBSC, 2010).

Table 3: Freshwater resources in China's top five coal-rich provinces, 2009

	Coal reserve (billion ton)	Total water resources (billion m^3)	Per-capita water resources (m^3)
Shanxi	105.6 (33%)	8.6 (0.4%)	251
Inner Mongolia	77.3 (24%)	37.8 (1.6%)	1,546
Shaanxi	26.9 (8%)	41.7 (1.7%)	1,106
Guizhou	12.8 (4%)	91.0 (3.8%)	2,398
Xinjiang	14.8 (5%)	75.4 (3.1%)	3,517
Five provinces total	***237.3 (74%)***	***254.5 (10.5%)***	***1,633***
National Total	***319.0 (100%)***	***2,418.0 (100%)***	***1,816***

Data source: NBSC (2010)

The coal-water mismatch has important implication for coal liquefaction since it is considered being highly water intensive (Mielke, et al., 2010). According to industrial data disclosed, each ton of synthetic oil output needs 8-9 tons of freshwater in DCL and 12-14 tons in ICL (Zhang, et al, 2009). The water demand for a coal liquefaction plant with five-million-ton annual fuel capacity would range from 40 to 90 million tons. This would inevitably exacerbate the problems of water availability and quality in China's coal-rich but water-stressed regions such as Shanxi (see Table 3). In addition to tightening its CTL policies, in fact Beijing has announced its strict regulation on any project with high water consumption and being constructed in water-stressed areas and is drafting water consumption quotas for certain water-intensive industries or sectors (Zhang, 2011).

Besides water quantity, Beijing also has concerns on the impact of coal liquefaction on water quality. According to data disclosed by the liquefaction industry, each ton of synthetic oil output generates roughly 0.15 tons of wastewater in DCL (Lei and Zhang, 2009). The discharge amount is comparable to the petroleum industry but more difficult to process and recycle and therefore has the potential to pollute a natural water body nearby if not properly managed.

Carbon emission is another constraint that might influence development of coal liquefaction. It is estimated that each ton of synthetic oil output generates roughly 3.3 and 1.5 tons of CO_2 in DCL and ICL, respectively, about ten times higher than the petroleum industry (Lei and Zhang, 2009). With a target of reducing carbon intensity by 17 percent in country's current five year Plan (2010 – 2015) and likely more stringent targets in future plans, Beijing has to reconsider the option of further scale up coal liquefaction, at least when carbon capture and storage (CCS) is still considered highly economically unviable (the problem of who will pay for CCS) (Wilson, et al., 2011).

4.2 Consolidation of the coal industry and shortages in coal supply

Unreliable, inefficient and unsafe coal production has inspired an effort, led by Beijing, to restructure the coal industry, mainly through closure of smaller mines and establishment of larger, well-managed state coal corporations. On the one hand, the consolidation over the short term is yielding higher prices for coal (which disadvantages coal-intensive technologies such as CTL); but, on the other hand, it is essential for the development of the industry, which is both capital and technology intensive. The consolidation helps grow the potential players and over the longer term these large coal champions may raise China's ability to deploy CTL at scale.

During the 11th Five-Year Plan (2006-2010), for example, the country closed down about 9,000 small mines and eliminated 450 million tons of production on average annually (China Daily, 2011), although the country's total annual coal production has increased 42 percent during the same period (IEA, 2011). The shares of total production of China's four largest and eight largest coal companies among the national total have increased from 10 and 14 percent in 2000 to nearly 21 and 29 percent in 2009, respectively (China Coal Industry Association, 2002-2011). These numbers, however, are still quite low compared to those of western countries. The numbers for the U.S. top four and top eight coal companies, for example, are 48 and 62 percent in the same year, respectively (EIA, 2010). To further improve efficiency and safety at the mines and concentrate coal resources, Beijing believes that more consolidation is needed for China's coal industry and therefore announced in the current five year plan, a new target of reducing the number of coal companies from the existing 11,000 to 4,000 by 2015 and keeping only six to eight coal groups (Hu, 2011).

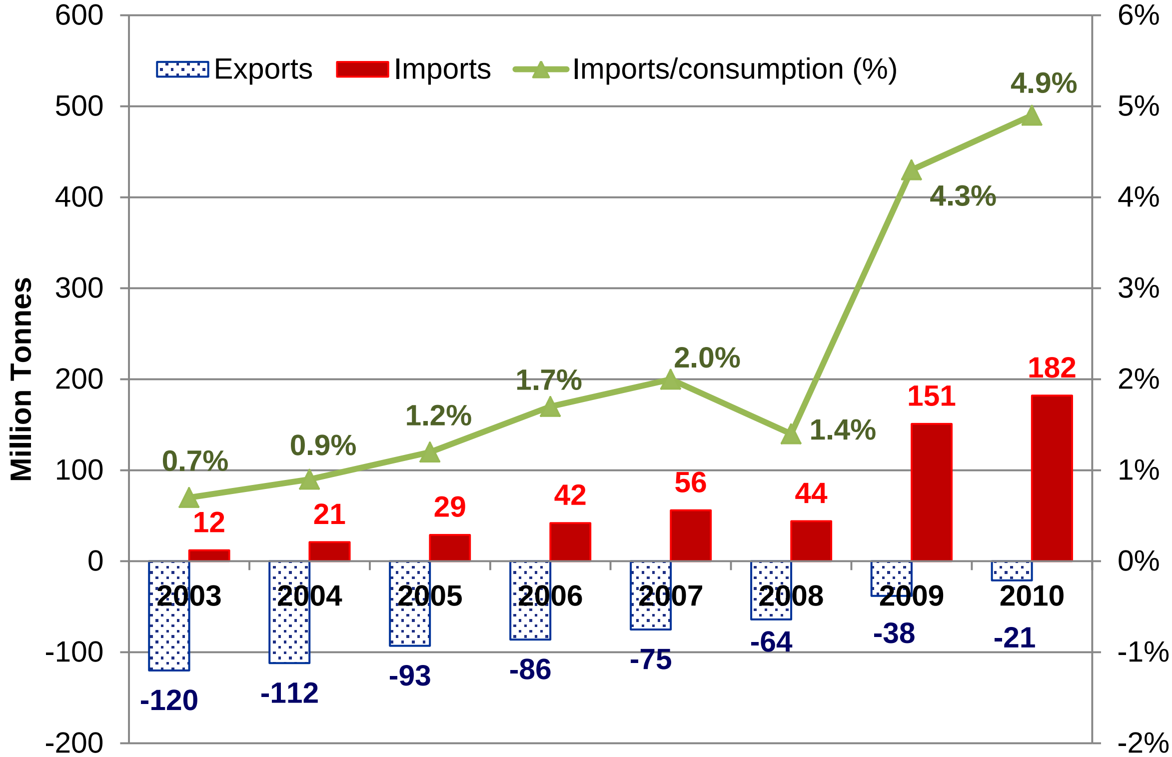
Today, the consolidation process is largely complete in Shanxi and now moving to other coal producing provinces including Henan, Shaanxi, Shandong, Guizhou, and Inner Mongolia (Hook, 2011). It is believed that policymakers in Beijing are cautious about the further scale up of coal liquefaction before the government-driven consolidation is accomplished, which may take at least five years.

However, the consolidation of the coal industry is temporarily contributing to rising coal imports and prices (Leo, 2008; Rudolf, 2010). All of these make the coal-intensive CTL industry less viable economically. Indeed, all of the factors we discuss in this paper interact with the fundamental economics of CTL. Couch (2008) reviews the economics of coal liquefaction, which depends heavily on oil and coal prices. According to the World Energy Outlook (2006) review, at a steam coal price of about $45 per ton (real international steam coal prices in 2006 and broadly comparable with long term contracted coal prices today), oil prices would have to be well over $50 per barrel for CTL to be competitive. Today, coal prices have more than doubled. According Shenhua's most recent (2011) analysis, its DCL is economically profitable with a crude oil price of $85 per barrel (Zheng and Cai, 2011). At current coal and oil prices the economics of CTL are favorable (though not overwhelming), but liquefaction involves many risks—from coal and especially oil markets, as well as CTL technology itself—that are not fully included in these studies.

Outside the liquefaction industry demand for coal in China continues to increase dramatically, largely driven by the thermal power industry which currently accounts for more than half of the demand. Over the past decade, annual final consumption of coal has increased 2.6 percent averagely, while the consumption of thermal coal has increased more than 9 percent (IEA, 2011). The country's supply shortages are not caused by a simple gap between supply and demand (Morse and He, 2010) but multiple complicated factors, including the restructuring of the industry by closing small coal mines that are unsafe, polluting, or wasteful, a distribution mismatch between where the coal is produced and where the coal is needed (see Figure 2), inadequate domestic supplies of higher-grade coal, and price gaps between non-thermal coal priced by market and thermal coal priced by government.

Supply problems have led to burgeoning imports and shrinking exports (see Figure 3). China has been a net coal exporter until recently (importing some coal but exporting just as much or more). But in 2009 China for the first time became a net coal importer, changing from the world's second largest coal exporter in 2003 to the world's second largest coal importer in 2009 and 2010. In 2010 China imported 165 million metric tons of coal, accounting for more than one fifth of all globally traded coal.

Figure 3: China's export/import of coal, 2003-2010



Source: 2003 to 2009 data from EIA (2010a) and 2010 data from China Customs Statistics Information Centre (2011)

Prices have risen sharply. State-controlled contract prices for thermal coal have been experiencing double digits increasing rates, rising from 137 Yuan/ton (US$17/t) in 2002 (Pan and Zhang, 2003) to currently 537 Yuan/ton ($83/t) (Xinhua, 2011). Average prices of commercial coal have soared even more, rising from 168 Yuan/ton ($20/t) in 2002 (Pan and Zhang, 2003) to currently 837 Yuan/ton (US$129) (Xinhua, 2011). Domestic coal prices have recently been higher than international ones, averagely 60 Yuan/ton higher (Pan and Wang, 2010).

These reforms in the coal industry, along with higher prices that are both cause and consequence of these new policies, are likely to have two contrasting effects on CTL. One effect, evident especially in the short term, is Beijing's reconsideration of its industrial policies to promote coal liquefaction, since coal is no longer seen as so abundant and cheap.

On the other hand, the consolidation of the coal industry may improve the prospects for coal liquefaction over the long term. Consolidation has led to larger firms with the economies of scale (and the incentive) to back the technology and to secure large coal resources essential to CTL. There are currently several super state-owned coal mining giants in China with

Shenhua Group as a notable example (see Table 4). Under the big consolidation context their market shares are expected to further increase in near future. Shenhua Group is the largest coal company in China and the largest coal supplier in the world, accounting for more than 10 percent of China's total coal production and nearly 5 percent of the world's total. Indeed, Shenhua Group has also been the epicenter of most innovation, for example, the development of a zero water discharge technology and CO_2 sequestration in its Ordos DCL plant (Bai and Stanway, 2010).

Table 4: Annual coal production of China's top eight coal companies, 2009

Rank	Coal Company	Production (million metric tons)	Market share (%)	Revenues (billion RMB)
1	China Shenhua	328	11.0%	161.2
2	China National Coal	125	4.2%	70.2
3	Shanxi Coking Coal	81	2.7%	77.5
4	Shanxi Datong	75	2.5%	42.5
5	Shaanxi Coal & Chemical	71	2.4%	32.1
6	Anhui Huainan Mining	67	2.3%	35.2
7	Henan Coal & Chemical	57	1.9%	104.1
8	Shanxi Lu'an	55	1.8%	49.9
	Total top eight	**859**	**28.9%**	**572.7**

Data source: China Coal Industry Association (2011)

Shenhua's leading position in China's coal industry enables it being a leading industrial promoter of coal liquefaction (alongside South Africa's Sasol) worldwide. The company was founded in 1995 under the auspices of the State Council and with Beijing's aim to build large, modern coal companies to consolidate the coal industry. As a stated-own enterprise of "China Characteristics," Shenhua Group enjoys a combination of uniquely favorable conditions which any other company may not easily clone, which at least partially explains why Shenhua leads coal liquefaction in China. First, it was granted the largest quantity of coal reserves ever granted by China's central government to a company. The total recoverable reserves of its Shenfu Dongshen coalfield are as much as 223 billion tonnes, accounting for more than one fifth of China's national total (Nolan, 2004). Second, the company was granted the largest ever CTL loans from the government. The central government, through the State

Development Bank, granted Shenhua Group preferential lower interest-rate loans of more than US$9.2 billion from 1985 to 2005 (Rui et al., 2010). The company was also granted by the central "Coal Replacing Oil Fund" of 11 billion RMB Yuan (US$1.3 billion)—a signal that the central government sees Shenhua as the main firm for the national development of coal liquefaction. Third, the central government granted Shenhua Group a dedicated railway to transport its coal from its Shenfu Dongshen Coalfield to the dedicated Huanghua port. Finally, water demand for Shenhua's DCL project in Ordos, Inner Mongolia, is also guaranteed with supports from both the central and the city government.

4.3 Development craze from local governments

Coal liquefaction policies reflect how the politics has been played between the central and local authorities. In the standard view of most western outsiders, China's one-party system gives Beijing the absolute authority to impose its will throughout China. However, this image of single leader or core groups of leaders responsible for or in command of all aspects of Chinese society is no longer fit (Bergsten et al., 2009). The fact is that, today, China is a state being centralized in its ideals but fragmented in practice (Landry, 2008). Policy making in China, for example, in the energy sector, is more like a battleground of negotiation among different power actors with conflicting interests (Cunningham, 2010), of which notable actors are local governments. As an old Chinese proverb saying, the mountains are high and the emperor is far way. When you look into the future, it is local governments that play the most important role in issues like environmental policies, intellectual property rights, and consumer/product safety. This is also the case that applies to coal liquefaction, where the central only wants a very few CTL demonstration projects until they are successful and can be commercialized at a large-scale but locals just cannot wait to jump into the industry which could bring about much needed jobs and GDP growth.

It was reported that ten Chinese provinces or autonomous regions, including Inner Mongolia, Xinjiang, Shanxi, Shaanxi, Guizhou, Ningxia, Yunnan, Shandong, Henan and Heilongjiang, are all planning or once planned CTL projects (Ren, 2009). It was estimated that by the end of 2007 taking all existing and planned CTL projects into account, China will have an annual CTL capacity of 16 million tonnes with investment planned at 120 billion RMB Yuan (US$18 billion) (China Daily, 2008a).

Because of local development craze, the NDRC centralized approval of these projects and pulled the brakes on dozens of projects. Table 2 lists three projects in operation and five under serious plan or consideration, while most were aborted during feasibility studies or even pre-feasibility studies. Several coal liquefaction projects in Yunnan Province, for example, were aborted because of the NDRC's tightened policies. Just as Shenhua Group, Yunnan Xianfeng Coal Industry Company was initially chosen as one of the three candidates to host a coal liquefaction demonstration project. The planned project had an annual fuel capacity of one million tonne with investment more than 10 billion RMB Yuan. Its pre-feasibility study was passed in 2004, but was called off by the NDRC in 2008, along with the other CTL projects in Yunnan (Tan, 2010).

The motivation behind local government officials' development craze is straightforward: they have been racing to boost regional GDP growth by putting huge investments in capital- and energy-intensive industries, since their career prospect is primarily tied to GDP growth under the current system. Over the past 20 years, China has enjoyed an annual average GDP growth of nearly 10 percent.

5. Ordos City: a vignette of coal liquefaction policies at the local level

The city of Ordos in Inner Mongolia, the host of both Shenhua's DCL project and Yitai's ICL project, provides a good illustration of how coal liquefaction policies have been played at the local level. Lying in the southwest of Inner Mongolia, Ordos is abundant with resources, among which the most well-known are sheep, coal, natural gas, and rare earth. For example, Ordos has 149.6 billion tons of proved coal reserves, accounting for about one-sixth of the national total. Besides its huge amount, Ordos's coal enjoys the advantages of low ash, low sulfur, low phosphorus and high heat output, thus was recognized as "clean coal" (City Government of Ordos, 2011).

Thanks to the exploitation of the region's rich natural resources, Ordos has achieved the fastest GDP growth rate in China. Statistics show that the GDP of Ordos soared from RMB 15 billion or US$1.94 billion in 2000 to RMB 264.3 billion or US$40.6 billion in 2010, averagely increasing 33 percent annually. With a thin population of less than 1.9 million, the city's 2010 GDP per capita is RMB 136,000 or US$20,800 (Ordos Bureau of Statistics, 2011), only after Macau, Hong Kong, and Karamay inXinjiang and higher than Beijing or Shanghai.

As many other cities in western China, however, Ordos has insufficient water resources to meet its rising water demand, which is largely driven by coal-related industries such as thermal power and coal chemical. Nearly 70 percent of water in Ordos is from groundwater, a share significantly higher than the national average. But the city's average exploration rate of groundwater already exceeded 60 percent (Ordos Water Bureau, 2009). Groundwater has been overexploited for years in some areas of the city, which causes serious ground subsidence (Gao et al. 2004).

The city government of Ordos has been highly "entrepreneurial" in attracting industries. To meet the water demand from the boosting industry sector, for example, the city government has been proactively pushing water transfer from agriculture to industry. During the first phase of water transfer pilot program from 2005 to 2007, the city accomplished a total water transfer of 130 million cubic meters and secured an investment up to 690 million RMB Yuan on upgrading irrigation infrastructure. The second phase of the water transfer program was launched in 2009 with a total water transfer of 100 million cubic meters and an industrial investment of 1.42 billion RMB Yuan (MWR, 2009).

Ordos built from scratch an entirely new city, called Kangbashi, of up to one million people, with the purpose of keeping the coal wealth closer to home and also partially dealing with the increasing scarcity of water. The new town is 25 kilometers from the old town, Dongsheng District, but close to rivers – the old town is chronically short of water – and to another a mining town, Yulin. The new city, however, is largely empty of people and thus called the "ghost city" of China (Chan, 2009; Batson, 2010).

Perhaps the most controversial incentive provided by the city government is so called "Black Gold" policy: attracting industries with coal reserves. In accordance with the provisions of Inner Mongolia Autonomous Region, for each new additional two- billion-RMB Yuan investment investors could receive 0.1 billion metric tons of coal up to one billion. The "Black Gold" policy makes Ordos stand up among all local cities in the race of fighting for the auto industry. Without any advantage such as human capital, transport, and supplementary industries but coal reserves (money), the city has attracted Chinese auto makers including Huatai, Chery, and Hebei Zhongxing (Fan, 2010). A notable example is Chery, China's seventh-largest auto-maker, which with its partners would jointly pump RMB 20 billion RMB Yuan or about US$3 billion into Ordos before 2015. It was reported that the Ordos government offered multiple incentives to set up a shop in the city, among which was the reported sale of a coal field, containing estimated reserves of 1.66 billion tons, to Chery at well below market price (Chen, 2010).

Thanks to the heavy lobbying of former mayor of Ordos, Mr. Xing Yunzhang, Ordos hosted Shenhua's DCL project, which was funded in part by China's "Coal Replacing Oil Fund" of 11 billion RMB Yuan (US$1.3 billion). Ever since Mayor Xing heard of the possibility of demonstrating coal liquefaction projects in 1996 he actively lobbied Shenhua and undertook a variety of other efforts to promote Ordos coal such as sending samples to U.S. laboratory analysis to show their suitability for liquefaction (Zhong, 2004). After Shenhua's DCL project was secured, the city government has supported it heavily. For example, the Ordos government decided to construct an airport to improve the local infrastructure, shortening the distance from the plant to the airport to 20 kilometers and the new airport was put into use in 2007. With the approval from Beijing, the city government guarantees all water usage for the project. All water is from groundwater although the city' groundwater is already overexploited.

6. Concluding remarks

China has emerged as a leader in coal liquefaction. The standard view is that China's leadership reflects the country's abundant coal resources coupled with Beijing's severe concerns about energy security. We have offered a history of Chinese coal liquefaction policy which suggests that the actual driving forces are more complicated. Since 2006 those complications have been in full display as Beijing has tried to cool the CTL industry—even as the country becomes even more dependent on imported oil—while local officials have pursued an opposite strategy. Our analysis suggests four conclusions.

First, Beijing's enthusiasm for coal liquefaction has depended on Beijing's perception of the security of the country's oil supply. R&D on synthetic oil began in the 1950s when oil embargo was initiated by western countries but suspended this research soon after the discovery of Daqing Field in 1959. It resumed R&D support in later 1970s as the government responded to dramatic rises in international oil prices seen following the oil crises of 1973 and 1979. Since the middle 1990s the central government has redoubled its support for this industry as the country became a net oil importer in 1993. Beyond these concerns of energy security there have been other two important drivers for coal liquefaction – one is the central government's conscious plan to shift more development west ("the Great Leap West"); the other is the need to build infrastructure to move energy, notably coal, from where it is rich in supply to where demand is greatest.

Second, Beijing's support for coal liquefaction has been erratic and fragmented. Since 2006, even as China has become more dependent on imported oil and most aware of insecurities in the world oil market, Beijing's support for liquefaction has waned. This policy shift is a result of Beijing's efforts to balance multiple forces. In addition to traditional concerns of energy security the country must contend with three other factors that influence liquefaction policy in different ways: first, water is increasingly scare in China; second, the consolidation of the coal industry over the short term will make coal more expensive and thus possibly less attractive as a feedstock for CTL; last is the pressure from local governments.

Third, as in many other areas of policy today in China, the actual pace and location of investment in liquefaction depends on local governments that push for projects even as Chinese central planners (NDRC) struggle to oversee coordinated development of the industry. Indeed, some local governments have been highly motivated and entrepreneurial in pouring investments into the CTL industry— which could bring about much needed jobs and GDP growth —despite the business risks associated with volatile oil prices and huge capital investment requirements, uncertainty about availability of essential natural resources, and likely pollution. We have illustrated these pressures in the city of Ordos in Inner Mongolia—host of China's biggest synthetic oil project.

Fourth, the liquefaction industry depends on the structure of the country's coal industry—in particular the industry's dominant enterprise, Shenhua Group, which has built the world's largest direct coal to liquid plant in Ordos. Over the short term consolidation may bring about pressure on future coal supply and prices, which will thus make coal possibly less attractive as a feedstock for CTL. Over the longer term, consolidation and other elements of restructuring is yielding coal enterprises that are more capable financially and technologically, which could increase the prospects for successful commercial-scale liquefaction.

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