International Gasification Technology Flow: From Developed Countries to China

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ABSTRACT

With its burgeoning energy consumption and emissions of greenhouse gases (GHGs), China is central to addressing the problem of climate change. As the world leader in GHG emissions for years, China is under tremendous international pressure in the fight against climate change.

Focusing on China's coal-to-chemicals industries—a major user of coal and significant contributor to GHG and other emissions in China—this paper seeks to explain how national policies have affected the deployment of coal gasification in China. In particular, the paper will exam the strategic response of innovative firms use in order to set a strong foothold in the Chinese emerging market: how are these firms balancing the crucial need to grow/retain the market share in the face of increased of competition from homegrown technology firms while also protecting their intellectual property right due to the weak IP regime in China.

Introduction

Policies for technological change – i.e., transmission, diffusion and innovation – in low carbon technologies (LCTs) take the central stage on curbing GHG emissions. The massive emissions reductions that nearly all models deem necessary to limit climate change can only be achieved by applying LCT such as wind, solar, energy-efficient appliances and clean coal technologies. However, high cost of LCTs hinders its widespread adoption. Therefore, national policies and technology innovation are essential to make the cost of LCTs come down.

China, as a developing country with a coal dominated energy structure, the development of clean coal technology is essential for them to address energy shortage and emission problem. Especially for China with a weak IP regime, the implication of national policies can help China absorb and re-innovate foreign advanced clean coal technologies effectively.

The data and information for this paper were mainly collected from interviews with experts from Chinese and U.S. companies, relevant government reports, and other Internet sources. First, I present the current state of energy consumption and the development status of related industries that are applying gasification technologies in China. I then present related policies and pilot projects for the development of gasification technology and analyze how these affect the Chinese gasification market. I analyze factors that have promoted a change in the mode of partnership between foreign firms and Chinese firms (from licensing contracts to joint ventures), and how joint ventures are enabling gasification technology transfer currently. Finally, I argue how the underlying conditions create drivers that promote gasification technology transfer despite China's weak IP regime.

Background

Energy Consumption and Emission Condition

China has experienced unprecedented rapid economic growth during the last thirty years, with annual gross domestic product (GDP) growing at an average rate of 10 percent from 1980 to 2010 (National Bureau Statistic, 1981-2011a). China became the world's largest emitter of energy-related carbon dioxide (CO_2) in 2007 and the world's largest energy consumer in 2009 (IEA, 2011). These trends are projected to accelerate over the next several decades. It is widely recognized that China's coal-dominated energy structure and its rapid industrialization process are the main reasons that China has become such an aggressive carbon emitter, as well as energy consumer.

China possesses abundant coal resources and is one of the few countries in which coal serves as the primary energy resource. Therefore, "abundant coal and scarce oil and gas" sums up the country's fundamental realities. Coal comprises approximately 70 percent of China's energy consumption portfolio, and has been the mainstay of its energy mix for decades. At the same time, it is the primary raw material for China's industrial chemicals, which has a significant influence on the chemical industry. Also China's energy consumption was dominated by the industrial sector, accounting for around 70 percent of total energy use. This industry-dominated energy consumption in China is very different from the energy consumption patterns found in many other industrialized countries. As with energy use, China's industrial sector is the largest emitter among the end-use sectors, being responsible for about 72 percent of the total energy-related CO_2 emissions.

Therefore, the widespread adoption of clean coal technology in China will be crucial for China in charting a clean coal path. Gasification, the technology that can transform coal, coke, and other fossil fuel into syngas, is used widely in the traditional coal-based chemicals industry (ammonia, methanol, etc.), the modern coal-based chemicals industry (substitute fuels such as gasoline, ultra-clean diesel fuel, jet fuel, naphtha, and synthetic oils; coal to olefin; SNG, etc.), and in clean coal power generation. Because of its potential impact on industry and the energy system, gasification is considered a foundational technology for China (GTC, 2013).

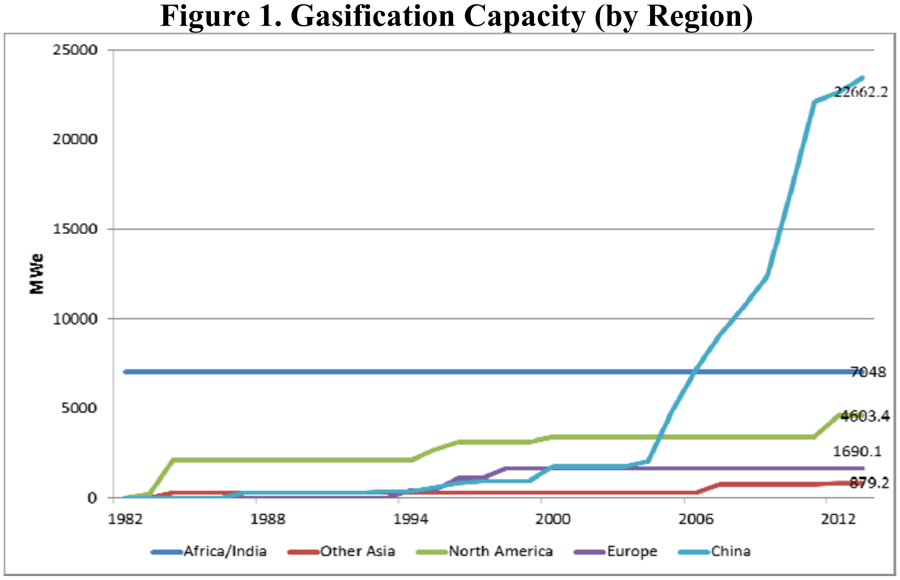
Current Status of Traditional Chemical Industry and New Chemical Industry

Traditional coal-based chemical industry that used gasification process accounts for 28% of the whole chemical industry, which is one of the most energy-intensive industries in China. At the same time, gasification process is the most energy-intensive process that consumes 60% of the energy through the whole production line. In recent years, traditional coal chemical industries represent an explosive growth. (Shell, 2007). However, the development of the traditional coal chemical industry also created some problems, particularly the tendency toward surplus production. Driven by higher petroleum prices, the industry has sought to develop oil alternatives such as coal-based methanol, leading to overcapacity in some products. For example, according to statistics from the National Development and Reform Committee (NDRC), in 2009 there was a 30 Mt methanol output capacity while the market demand was only 1.7 Mt (Li 2009). Moreover, most of the traditional coal-based chemical enterprises have adopted outdated technology with lower efficiency and lower raw-material utilization rates along with higher production costs and higher emission levels. Therefore, the potential of reducing energy consumption and emissions in this industry could be enormous (Wang, 2010).

Unlike the traditional coal chemical industry, China's modern chemical industry is still in the early development stage. It highlights the possibilities of clean coal utilization by using advanced coal gasification technology. With its focus on developing advanced gasification technology, the modern coal chemical industry represents a rapidly developing trend towards cleaner energy generation. Three Coal to Liquid (CTL)[1] pilot projects and two coal-based olefin pilot projects have been launched recently, although these require additional operational experience and expertise before they can expand to full-scale operations and further expansion (Asiachem 2012). At the same time, the SNG industry is steadily advancing in China. Four pilot projects have been approved by the NDRC and now are under construction. By 2015, the SNG industry expects to produce 15.1 billion cubic meters of natural gas (Asiachem, 2011).

For the past ten years, the deployment of gasification capacity in China explored extensively. (Figure 1)(Rai, Heguy 2011) However, the gasification portfolio of technologies deployed so far suffers from a lower technology capabilities that lag far behind advanced nations (GTC 2012). China has taken steps to modernize its gasification technology over the last few years, and now employs several advanced gasification technologies—such as Shell's and Siemens' GSP gasifier and GE's entrained bed gasifier—in some of its plants (Shell 2007). However, most of the installed gasification capacity in China remains outdated and inefficient. Replacing outdated gasification capacity with advanced and significantly more efficient technologies is key to maintaining an adequate balance between economic, energy security, and environmental concerns in China.

Figure 1. Gasification Capacity (by Region)



Source: Rai, Heguy 2011

[1] Two basic paths are employed in converting coal to motor fuels via gasification, which generally called coal to liquid. The first is the Fischer-Tropsch (FT) method in which syngas undergoes an additional chemical reaction to convert it to a liquid petroleum product. In the second process, called Methanol to Gasoline (MTG), syngas is first converted to methanol (a commercially used process) and then to gasoline by reacting the methanol over catalysts (GTC 2013).

Policies and Investment

Policy and Investment for Coal-Chemical Industries

Over the last few years, China has made significant progress in both gasification technology advancements and increased deployment of advanced gasification technology. With technology development by and stiff competition from domestic technology suppliers, the stronghold of foreign coal gasification technologies (CGT) in the Chinese market is being increasingly dismantled. Part of the driver for such dynamic technology supply conditions is an aggressive national energy saving and emissions reduction objective

China adopted an ambitious energy saving and emission reduction policy in the 11th Five Year Plan (FYP) (2006–2010). The central government put energy consumption per unit of GDP reduction and emissions reduction per unit of GDP as binding goals in the national development plan[2] (NDRC, 2013). In addition, implementation of economic policies, such as a preferential tax treatment, energy subsidies, tiered electricity pricing, and the establishment of an accountability and energy consumption supervising system, are all part of the coordinated effort in helping China meet these binding goals.

Further, in order to achieve these targets the Chinese government has carried out a series of projects. Due to China's unique energy consumption pattern, most energy conservation projects are focused on the industrial sector. Since the coal gasification industry plays a significant role in China's energy system, gasification technology modernization projects are major components of these projects. The Chinese government has invested significant resources in these projects, and the scale of these projects is growing (NDRC, 2012).

In order to conserve energy through improving energy efficiency, *Energy Conservation Project* and *Enterprises Energy Saving Action* are the major projects organized by the central government and CGT modernization is part of the projects. During the 11th FYP, changes to CGT mainly focused on large ammonia enterprises. Coal-water slurry gasification technology and dry pulverized coal technology were promoted through this process while the scale of CGT modernization efforts in the 12th FYP is even larger than that of the 11th FYP. For one thing, modernization targets no longer only focus on large ammonia enterprises. Medium-sized enterprises also have the chance to be supported by the government in CGT modernization projects. The total investment in the project is roughly 10 Billion RMB, which could result in energy savings of 2.5 Mtce each year (Taylor, 2012., NDRC,2006).

During 12th FYP, the Ministry of Industrial and Information Technology (MIIT) also organized a large-scale technology modernization project specific to traditional coal-based chemical industries called *The Promotion of Advanced Gasification Technology Plan* (MIIT 2012). This project sought to save energy and reduce emissions in 19 large and medium coal-to-ammonia and coal-to-methanol enterprises by replacing 7.8 Mt production capacity using coal-water slurry gasification technology and dry coal powder gasification technology. Meanwhile, approximately 1.7 Mtce can be saved each year by implementing this project (MIIT, 2012). The government, energy-intensive enterprises, and financial institutions financed the project in equal parts at a total cost of 10 billion RMB. Additionally, all 19 of the enterprises involved in this project can apply for an energy-savings subsidy when their energy saving is verified.

[2] The energy consumption reduction per unit GDP during 11th FYP and 12th FYP are 20% and 16% respectively, while 17% CO_2 emission reduction per unit GDP for 12th FYP.

The growth has been so rapid that it has become crucial for the Chinese government to promote technology modernization projects to achieve greater energy efficiency in coal technologies, while simultaneously promulgating policies to regulate the development of the overheated coal chemical industries. The NDRC issued a *Notice on Strengthening of Coal Chemical Industry Projects to Promote the Healthy Development of the Industry and Several Suggestions for Restraining the Expansion of Excessive Production Capacity Industries* Separately (NDRC 2013). These official documents clearly state that surplus production exists in the coal chemical industry and that some enterprises tend to blindly plan and construct projects without weighing the costs to natural resources and the environment. The NDRC's Notice indicates that these industries, and investment departments at all levels are not eligible to approve any projects before accomplishing the National Development Plan for Coal Liquefaction and Gasification (NDRC 2011). Meanwhile, the central government has issued a series of policies designed to better balance the industry and environmental concerns. These policies include increasing the barrier of entry for industries both from the technology aspect and capacity aspect, as well as strengthening environmental regulation (State Council, 2010).

Based on the overcapacity conditions in traditional coal chemical industries, the government is being careful in its development of the modern coal chemical industry. However, because of the advantages of coal gasification technologies, the government also strongly encourages the development of the modern coal chemical industry, even though it has set forth a series of restrictions for the development of modern coal chemical industry. Since these industries are in the early phases of development, key technological breakthroughs, the implementation of demonstration projects will largely determine the trajectory of this emerging industry as well as the deployment of gasification technology in this industry. To guide the development of the related sectors, the central government has issued two reports, *Development Planning for New Coal-based Chemical Industries in the Medium Term and Long Term* (MIIT, 2012) and *Planning for Demonstration in Deep Coal Processing Industry* (MIIT, 2013) during the 11th FYP. These two documents set forth a future plan (see Table 1 and Table 2) to establish development goals for the modern coal chemical industries from 2006 through 2020. Initially the Chinese government encouraged capital investment for modern coal chemical projects, but then struggled to rein it in when the flood of new capacity exceeded demand. Consequently, the NDRC centralized approval powers for increasing the modern coal chemical project's production capacity (NDRC 2011). According to the new rules, a coal-based olefin plant must at least have a 500 kt/y capacity, while a 1 Mt/year limit is set for coal-to-methanol and coal-to-liquid projects. For SNG projects, the capacity must be at least 2bn cubic meters/year, while a coal to glycol plant must at least have a 200 kt/y capacity (State Council 2010).

Table 1. Future Planning for New Coal Chemical Industries

Planning	Coal to Oil			Coal to DME			Coal to Olefin		
Time	2010	2015	2020	2010	2015	2020	2010	2015	2020
Production(Mt)	150	1000	3000	500	1200	2000	140	500	800
Percentage to total production	n/a	4%	10%	n/a	n/a	n/a	3%	9%	11%

Source: Development Planning for Emerging Coal-based Chemical Industry on Medium Term and Long Term

Table 2. Future Planning for New Coal Chemical Project Scale

Project	Coal to Oil	SNG	Coal to Olefin	Coal to Glycol
2015	100~180 (Mt)	1.3~20 (Bm^3)	60~100 (Mt)	200~300 (Kt)

Source: Planning of Demonstration in Deep Coal Processing Industry

Policy and Investment for Gasification R&D

National R&D plans for Gasification Technology

The level of resources a country is able to devote to research and development (R&D) has a direct impact on its capacity of innovate. In general, despite significant increases over the 2000s, China's aggregate R&D efforts are not yet at the level of the developed economies. Since the openness and reform policies of 1977, however, China has recognized the importance of R&D capabilities and as such, has initiated several national R&D programs. Two of the largest national R&D programs in China are the National High Technology Research and Development Plan (the 863 Plan), which focuses on stimulating the development of advanced technologies in a wide range of fields, and the National Basic Research Program (the 973 Program), which focuses on fundamental cutting-edge technological research. Since CGT plays such an important role in China's energy system, it has gained strong support from Chinese government and now China possessed of several CGTs with independent IP right. Among them, Coal-Water Slurry Gasification Technology with Opposed Multi-Burner (OMB) developed by Eastern China University of Science and Technology (ECUST) is the most prominent one. Several demonstrations projects have also been funded as part of the large national programs. These industrial demonstration projects are different from the ones carried out by the NDRC. The aim of these projects is testing newly developed technology on different scales and integrating the technologies. Among these, the Tianjin IGCC demonstration project is the largest and it will be discussed later.

National R&D Plans for IGCC

In support of the 863 National R&D plan during the 11th FYP, Huaneng, one of the biggest power generation companies in China, formed a Joint Venture (JV) with Datang, Shenhua, and several other nationally owned energy companies and initiated the Green Coal Power Generation Project in 2006. This project is aimed at constructing an integrated gasification combined cycle (IGCC) plant in Tianjin in order to demonstrate and promote clean coal technologies in China.[3] The 10-year project has three stages. The first stage (2006–2011) is building a 265 MW IGCC plant, which has been completed. The second stage (2012–2014) focuses on power system modification and technological integration. The final stage (2014–2016) is project expansion. The Tianjin IGCC project uses the two-stage gasification technology designed by Huaneng cooperation. The satisfactory performance of CGT in this project indicates that China has the technological capability in coal gasification to support this kind of large-scale

[3] IGCC is a combination of three separate technologies: (1) gasification, (2) combined cycle power generation, and (3) carbon storage and sequestration. The third component, CCS, is not necessarily an integral component of IGCC projects.

power projects, although the commercialization of IGCC in China still has a long way to go. Even though at present the high cost of IGCC impedes its commercialization, its higher energy efficiency and lower emission levels still make IGCC one of the most promising markets for advanced CGTs (CHG 2012).

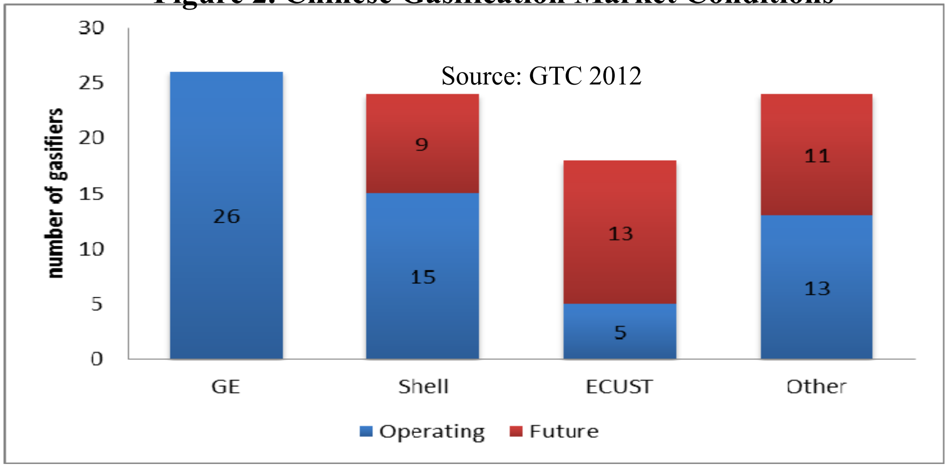
Overall, the development of CGT is critical for China to achieve its goals under its energy conservation and technology development policies. These aggressive, yet essential, energy policies are cultivating a marketplace for CGT. Even though the surplus capacity conditions in the traditional coal chemical industries may reduce market demand initially, the CGT modernization projects and the development of the modern coal chemical industries suggest that China will remain a promising market for this technology in the future, especially for large-scale, advanced CGT. At the same time, China's R&D policies have given strong support to the development of CGT. As discussed above, Chinese enterprises now also own intellectual property (IP) rights in some coal gasification technologies. Moreover, other technology R&D programs in the modern coal chemical industries such as SNG and CTL actually promote the deployment of CGTs in these industries. Because CGT is the pillar technology, it is really the downstream technologies that are needed for CGT to be utilized. Moreover, the Chinese government encourages the deployment of domestic CGTs through technology innovation projects and demonstration projects, thus, helping to promote the commercialization of domestic CGTs. This also has the effect of reducing the dominance of foreign CGTs in the Chinese marketplace. Yet, the huge potential market in China is luring additional foreign firms into the Chinese market, making the market for CGTs even more competitive. Consequently, CGT firms, especially foreign firms, are innovating and employing new business strategies to maintain and grow their market share. I discuss this next.

Partnership Analysis

Several CGTs with independent IP rights have been deployed in China. Among them, Shell, GE, and ECUST have the biggest market share (see Figure 2). The OMB technology from ECUST is rapidly increasing market share in China after its successful implementation of industrial demonstration project in 2005 (GTC 2012). Meanwhile, two other gasification technologies—U-gas from Synthesis Energy System (SES) and GSP from Siemens—are relatively new in China, but they also are very competitive in the of technical parameter aspect. Domestic CGTs—such as multi-component slurry gasification (MCSG), two-staged gasification from the Xi'an Thermal Power Research Institute (TPRI), and HT-L pulverized coal gasification from the China Aerospace Science and Technology Co.—have just finished industrial demonstration projects and are commencing the commercialization process (CCCI, 2013). Overall, foreign firms and domestic firms share the Chinese market roughly equally.

However, the rapid development of domestic CGTs has raised concerns over IP rights. Some analysts argue that IP infringements now exist in several domestic CGTs (Ren, 2013). Indeed, China's weak IP regime has long been a stumbling block in the technology transfer process (Rai, 2012). The rapid expansion of domestic CGTs, and the decline in foreign CGTs' market share have exacerbated concerns over China's weak IP regime. In order to continue their strong foothold in the large Chinese market, how foreign enterprises respond to this situation and what business strategies they use will not only affect gasification technology transfer but also the degree of technology innovation in China in general.

Figure 2. Chinese Gasification Market Conditions



Technology Transfer through Licensing: Falling Out of Favor?

CGTs are a very complex set of technologies, involving advanced equipment (hardware) as well as extremely intricate process and control techniques. As such, it is far from straightforward to put imported gasification technology to effective use without sufficient and ongoing interaction with technology providers. In the 1980s, IP licensing was the dominant partnership model between domestic firms and foreign firms. To gain access to advanced technology, many Chinese enterprises purchased technology licenses from foreign technology suppliers. After obtaining these licenses, however, there was insufficient interaction between the two sides either to effectively implement the CGT or to facilitate knowledge transfer associated with the technologies. With the licensed technologies, implementation of imported gasifiers created a host of mechanical problems. Shell's CGT is cited as a typical example of this problem. Even though Shell comprises a large portion of the CGT market and the technology now has become long-term operationally stable, China experienced serious difficulties in implementing Shell's advanced CGT. Since the first technology-licensing contract was signed in 2001, more than ten Shell gasifiers have been imported into China, and most of them were imported through a technology licensing-contract. (Zheng, 2008) However, shutting down, testing, and repairing was quite common for Shell's CGT in the early years; very few of these gasifiers operated successfully, leading to erratic production cycles. The typical one-day output value of an ammonia project in China could be up to millions of RMB. Therefore, the erratic operation of Shell's CGT resulted in huge losses for Chinese firms, even if the production was halted for just a day (Chen, 2013). Indeed, there have been reports of an increase in mechanical problems since the first start-up of Shell's gasifier, and that the repair processes have lasted several days or even up to a week, which seriously affected the enterprises' production levels. In addition, coal chemical project inherently are very capital intensive. Financing these projects is further complicated with foreign CGTs (such as Shell's CGT), because the main equipment deployed in these projects, namely the gasifier and the exhaust boiler, need to be imported. For example, the licensing fee for just one Shell gasifer could be as high as 50 million RMB, while the total cost of a project involving Shell gasification technology is roughly 1 to 2 billion RMB (Chen 2013). Thus, firms that purchased Shell's CGT faced high up-front capital costs (involving foreign exchange) and low returns because of frequent downtime associated with the operational difficulties (Zheng, 2008). The reported poor performance of Shell's CGT disappointed many

Chinese firms, and created a chilling effect on the importation of Shell's technology from 2009 to 2011. This three-year gap not only halted business between Shell and Chinese firms, it also impeded the CGT transfer process more generally for a variety of reasons. First, each CGT project needed to be specifically designed and optimized based on the specific coal quality associated with the project. There is no generic CGT that can handle every type of coal (and this is especially true for China, which has a low average coal quality). Second, a lack of communication between Shell and their Chinese customers impeded successful implementation of the technology. While Shell's CGT can indeed be adapted to a variety of coal types, their system still requires specific data on coal properties and other operational characteristics to properly customize its technology (Chen 2013). Once designed, Shell's CGT further required extensive testing and adjustment after the system was installed. Yet, as Bo (2009) reported, many Chinese enterprises simply imported Shell's CGT due to its good reputation without sufficiently communicating with Shell to ensure successful implementation of their CGT system. This reportedly naive utilization not only reduced syngas production but could also damage the expensive gasification equipment. A third reason for the difficulties with some of the early CGT imports is the Chinese firms' lack of experience and knowledge in operating these systems. According to my interviews, operating experience plays a significant role in the gasification process. When the first Shell CGT was imported into Chinese factory, the workers knew nothing about the massive, new equipment. They reportedly embarked on a lengthy process to uncover a way to make this CGT work well. Some Chinese firms even tried to hire foreign technicians to help them gain the knowledge and experience to operate the equipment, but high salary demands by these foreign technicians impeded this learning process (Chen, 2013). In short, the process of learning to operate CGTs successfully is a much longer and more complex process than most Chinese firms realized. To make this process easier, shorter, and effective, sufficient interaction between the technology supplier and the technology user is essential. Clearly, the simple procurement of advanced technology is not enough to promote CGT transfer, even with some basic technology service. Indeed, complaining about CGTs technology after-sale service has been quite common among Chinese firms (Ren 2013). Further, Chinese firms have been required to report back to and reportedly seek approval of the technology supplier for all adjustments/modifications to the licensed technology. While presumably IP concerns guided these requirements, the process usually took a long time for foreign firms to approve such adjustments, which in turn seems to have seriously affected the operating efficiency of some of the CGT projects (Ren, 2013).

Although these negative experiences with foreign-licensed CGT resulted in operational losses, both domestic and foreign firms have learned valuable lessons from them. One major outcome of these experiences seems to be that Chinese firms have arrived at the conclusion that licensing CGTs is not an effective form of partnership for CGT transfer. Domestic firms seem to have realized that in order to have this kind of complex, imported technology work in China, it is essential for them to have more interaction with the technology supplier.

Expectedly, foreign CGT suppliers have had to reposition their technology and business strategies in response to these developments. Many of these firms are focused on what type of business strategy they should use, how to reduce their operational costs, and how to grow market share without suffering from IP infringement when considering how to continue operating, and hopefully expanding, in China's CGT market. As I discuss below, foreign CGT firms that are adept at working together with Chinese firms, and especially with state owned enterprises (SOE), are more likely to get a strong foothold in the Chinese market.

Joint Ventures: An Emerging Business Strategy in the CGT Space

Given the challenges of simply licensing foreign technology, many Chinese firms have pursued a new model of cooperation to obtain or develop CGTs: joint ventures (JV). Even though technology licensing in gasification field is still the dominant partnership mode (Rai 2012), the number of CGT JVs has grown rapidly in recent years. Between 2009 and 2012, five new JVs were formed, whereas before 2008 the total number of such JVs was only three. This model of cooperation is not limited to large international companies such as Shell and GE; recently, several small and medium-sized companies like US-SES and US-Zero Emission Energy Plant Ltd. also have entered the Chinese market through joint ventures with their new gasification technologies. Moreover, foreign companies have entered into other forms of cooperation contracts, such as joint-study agreements and memoranda of understanding (MOU) in recent years. Indeed, some of the recent JVs were formed after the MOUs; so it is likely that the number of JVs in the Chinese gasification market may keep increasing. Although it is premature to say that JVs will be the dominant model for CGT development in China in the future, there is a clear trend that favors JVs as a conduit for continued technological development in the Chinese gasification field.

The JV model incentivizes both partners to contribute their resources and expertise to the venture, which promotes the technology transfer process. With its aggressive energy saving and emissions reduction goals, the Chinese government is eager to see that progress towards achieving these goals is accelerated through international business partnerships and has encouraged Chinese enterprises to operate through JVs and benefit from advanced foreign technologies (Rai 2012).

A key benefit of JVs for both Chinese and foreign partners is technological innovation. Since innovation is critical for the partnering firms to maintain and grow their market share in the highly competitive Chinese market, it is essential for both partners not only to be able to sell their current gasification technologies but also to improve their technologies to stay ahead in the competition. Notably, as regards R&D and innovation, Chinese firms today are significantly different from a couple of decades ago. Some Chinese firms have strong R&D capabilities: many have their own R&D teams, technology laboratories and have built close relationships with academic institutions. So these leading Chinese firms actually are very capable of co-developing new technology with foreign firms. In view of the fact that localization of CGTs to optimize for local coal characteristics is critically important for operational stability, it appears logical for foreign technology providers to work in collaboration with capable domestic firms to co-develop CGTs moving forward (Ren, 2013).

There are other drivers for foreign firms to form JVs with Chinese partners. First, market access: Ren (2013) indicated that China had been the biggest gasification market since 2005. Thus, it is impossible, or at least very hard, for any CGT enterprise to give up such a huge market. However, the increasingly competitive nature of the market means it is not as easy as in previous years for foreign firms to make large profits. Foreign companies that lack knowledge of the complex and quickly evolving Chinese market conditions are certainly at a disadvantage. Therefore, it is necessary for foreign firms to have a Chinese partner(s) that can help them in devising business strategies, building business relationships, and dealing with the unique problems that may present themselves in the Chinese market. In another words, foreign firms need a Chinese partner to help them navigate the market as well as the underlying policy and regulatory environment (Chen, 2013). Partnering with SOEs appears to be a particularly effective way for foreign firms to manage the complexities of the business environment in China. Chinese SOEs tend to have a wider range of customers and trading partner relationships, and often they have huge syngas demands for their own use; thus, working with SOEs could give foreign firms a guaranteed selling channel. At least, SOEs can help them manage their sales channels.

The second reason foreign firms are motivated to enter into JV's with Chinese firms is cost reduction. Due to rapid economic growth, Chinese firms, especially large energy-related SOEs, generally have superior capital strength; so these domestic firms are financially capable of engaging in large capital-intensive coal chemical projects, which foreign firms could likely not sustain alone. Moreover, technology equipment localization through a JV is a good way to reduce project costs. Chinese engineering companies in recent years have developed rapidly, especially in the areas of manufacturing and engineering. (Ren 2013) Even though some of their core technology components still need to be imported from foreign countries, Chinese engineering companies are able to finish an engineering project at less cost and in a shorter time period compared to foreign companies (Chen, 2013; Ren, 2013). In addition, localized manufacturing benefits from relatively lower-cost labor and favorable import tax treatment, which further decrease operational expenses. Thus, having a Chinese partner makes it easier for foreign firms operate efficiently in China.

The third reason for foreign firms to enter into JVs with Chinese firms is to get a better handle on government policies and preferences (Fang, 2013). Since all CGT innovation and demonstration projects as well as the associated regulatory requirements are organized by the central government, the Chinese government perhaps plays a more important role in the development of CGTs than Chinese firms themselves. Therefore, building a trustworthy relationship with the Chinese government, which can partly happen through SOE partner(s), is important in the Chinese market. This relationship can also help ensure that a foreign firm's technology IP is sufficiently protected. SOEs themselves are not likely to be involved in IP infringement issues due to their direct association with the government and also the need to maintain and enhance good reputation not just in China but globally. Further, a JV with a SOE means that a foreign firm's profit also benefits that SOE *and* the Chinese government directly, which in principle would drive both the SOE and the government to help ensure the protection of foreign CGT IP in such JVs. Although China has strengthened its IP system in recent years, it needs to enact additional reforms in order to catch up to IP regimes in developed countries. Foreign firms, therefore, often partner with SOEs in order to increase their IP protection (Rai et al., 2013). Broadly speaking, under current business environment in China JVs are perhaps the best way for foreign firms to achieve profitability in the Chinese gasification market, while also maintaining a grip on the technology development itself.

Summary

To achieve operational stability, dependable performance, and optimized production, CGTs need to be adapted to local operational conditions, especially to local coal characteristics. Foreign CGT firms and domestic project developers/operators who overlooked this critical need in their licensing contracts have run into operational difficulties and revenue losses, ultimately resulting in higher barriers for these CGTs in penetrating further in the Chinese market. Overall, the experience with licensing CGTs in China appears to have been fraught with difficulties, resulting in mistrust between the technology suppliers and their domestic customers. More recently, though, JVs have emerged as the preferred model for deploying CGTs, which continue to have strong demand in the Chinese market. Better and deeper communication and knowledge transfer, capital access, joint technology development, IP protection, and market navigation are the key factors that make the JV model more attractive to both foreign and domestic firms under current Chinese business environment.

Conclusion and Discussion

China's current economic development landscape and its coal-dominated energy structure have proven to be a fertile ground for the necessary conditions for the widespread adoption of CGT. China's aggressive energy conservation and emissions reduction goals coupled with its technologically-lagging gasification technology infrastructure have motivated the Chinese government to incentivize and invest in modernization programs for coal chemical industries, and to trigger innovation in its gasification technology sector. Although some Chinese regulatory policies may hinder development of CGTs in the short term due to the overcapacity that has developed in some traditional coal chemical industries, CGTs remain a major, long-term market opportunity for China for several key reasons. First, the central government has employed a series of technology modernization programs that are creating new markets for the deployment of advanced CGTs. Second, the aggressive development plan of modern coal chemical industries, such as SNG and coal-to-liquids, have made these industries a growing market for CGTs. Despite the limited number of these kinds of new projects that have been approved at this stage, China's ambitious development plan for these industries actually creates a huge market space for CGTs. Avoiding overheating and stabilizing the development of modern coal chemical industries appear to be the main reason why the central government maintains strict control over these industries currently. Similarly, China's R&D programs have paved the way to advance the country's gasification technologies. Chinese enterprises are developing their own CGTs and some of those technologies have become leaders in the domestic market. Although IP concerns are one of the issues within the gasification market that may impede Chinese technology from moving into foreign markets quickly, China, as a technology provider, is becoming more and more active in domestic and as well as global markets. Taken together, these factors have influenced the rapid growth of China's CGT market. Increasingly it is becoming clear that for a foreign firm to maintain or gain a strong foothold in the Chinese CGT market, they must seek a domestic partner. Joint ventures have emerged as a preferred model for these types of foreign/domestic partnerships because they allow firms to combine resources to compete effectively in the Chinese CGT market.

JVs appear to provide benefits to all parties under the current business environment in China. In most JV structures, foreign firms provide advanced gasification technology while the Chinese firms provide capital and other business resources such as operations, sales, and marketing expertise. Firms engaged in the JV experience increased interaction and cooperation, which in turn effectively promotes technology transfer and change in China, a key government objective in the energy sector. For foreign firms partnering with domestic firms, especially large SOEs, provides an effective way to develop a stream of project, while also improving the odds of protecting their IP. Further, several JVs seem poised to co-develop new technologies in the future. Even now, most of the JVs act as technology agents in this market, and as their cooperation deepens, it is reasonable to believe technology development will become a more important part of their business plans.

Overall, although China's weak IP regime is recognized as a hindrance to technology transfer, the underlying market and technology supply conditions in China are enabling gasification technology transfer from firms in developed countries to China. Moving forward, as the CGT technology frontier shifts further from the developed countries to China in response to China's huge demand for gasification technology and an enabling policy environment, it may be expected that China will become the leading gasification technology innovator in the future.

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