Innovation in China's Energy Sector

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Abstract

The performance of China's national system of innovation has improved since reforms began in 1978, but reform impact by sector is not well characterized. This case study identifies factors affecting patterns of technological innovation and adoption in eight industries in China's energy sector (coal, oil and non-conventional hydrocarbons, natural gas, nuclear power, electric power, renewable sources, automobiles, and motor systems). Innovation performance is strongest in industries that have experienced institutional transformation and growing market competition, whereas in industries where the pre-reform legacy of central control, weak intellectual property protection, and low levels of corporate R&D persists, innovation is lagging. Government initiatives to mitigate urban air pollution by strengthening environmental regulations and reduce dependence on imported oil by funding alternatives are also influencing innovation patterns. Based on current performance of the innovation system and examples of collaboration in the energy sector, China's ability to be a productive partner in international collaborative R&D efforts depends on the participation of local developers, domestic policy support for collaboration, and the strength of China's own R&D enterprise.

I. Introduction

Building a strong national system of innovation is a major challenge for any emerging economy. Upgrading innovative capacity offers a nation the chance to gain a foothold in global markets by establishing an engine for economic growth. In the energy sector, adoption of the latest technologies favors the efficient generation of energy to fuel growth, while also helping to reduce dirty emissions, improve workplace safety, and spare scarce water and land resources.

Energy sector innovation is particularly important in China, which has grown at an official annual average of 9.4 percent from 1978-2002.[1] Reconciling aspirations for continued economic growth with environmental concerns has been a persistent challenge for China's top leaders. In many sectors, policies designed to encourage innovation form a critical part of the country's long term development strategy. This paper offers an overview of China's national innovation system and describes how its strengths and weaknesses affect technology investment decisions in each of eight energy-related industries. Six are involved in energy production (coal, oil and non-conventional hydrocarbons, nuclear power, natural gas, renewable sources, and electric power generation) and two account for a large percentage of energy use (automobiles and motor systems). Examples from each industry illustrate the strengths and weaknesses of the overall innovation system and aid in the evaluation of international partnership strategies aimed at supporting continued innovation.

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[1] Based on figures taken directly or calculated from *China Statistical Yearbook*. Lin, Justin Yifu. 26. Feb. 2004. "Is China's Growth Real and Sustainable?" China Center for Economic Research. Working Paper E2004003. www.ccer.edu.cn.

China's capacity for innovation has made impressive strides since the beginning of its broad-based nationwide economic reform program in 1978, and in some exceptional cases is approaching the global frontier.[2] Targeted funding initiatives have yielded some impressive projects, and government efforts to bridge the gap between research and industry by forcing the former into the market have resulted in a surge in applied research. However, industrial R&D still remains weak, particularly in state-owned enterprises, and in many sectors, technology investments are at least partially determined and financed by the government. Despite limited successes, the establishment of a relatively autonomous, highly productive industrial R&D enterprise is far from complete.

Overall, innovation in China's energy sector seems to be influenced by the pre-reform institutional legacy, degree of market competition, relative technology costs, global energy prices, and government interventions in the form of incentives or regulations. These influences arise from general strengths and weaknesses of China's national innovation system, and vary in importance by industry and sometimes even by technology. For example, investment in coal liquefaction may be driven by government concern over foreign oil dependence and rising oil prices, while in the case of cleaner coal preparation technologies, the availability of inexpensive domestic substitutes may drive producer adoption decisions. This paper examines in detail the factors driving technological innovation and adoption, and draws several lessons for international collaborative efforts to promote the diffusion of clean energy technologies.

II. China's National System of Innovation: An Overview

China is no stranger to innovation. Over thousands of years, China has at times led the world in science and technology development, pioneering strategically important inventions such as the compass, paper, and gunpowder. Over the last few centuries, innovation in China lagged in comparison to its acceleration in Western Europe and North America in the wake of the industrial revolution. This imbalance led China's leadership to experiment with policies to induce similar industrial transitions inside its own borders. Institutional reforms over the last 25 years have in part been aimed at establishing a national system of innovation that matches research to production needs and in the long term secures China a position at the global technological frontier.

Bridging the Research-Production Gap: China's S&T Reforms

In the late 1970s, China's reformers faced formidable obstacles. After the People's Republic of China was established in 1949, the government adopted the Soviet central planning model of defining separate research and production units under the leadership of each industrial ministry. Some basic research was also carried out in the Chinese Academy of Sciences, which was isolated from the industrial sectors altogether; very little research was done in universities.[3] During the Cultural Revolution (1966-76),

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[2] For an overview of China's research scientific achievements in recent and historical perspective, see Lu Yongxiang. (2001) "Construction of Chinese national S&T innovation system and latest advancements in science and technology in China." *Current Science*, 81 (8), 930-935.

[3] *A Decade of Reform: Science and Technology Policy in China.* IDRC Canada, www.idrc.ca, 1997, Ch. 4.

universities were dispersed to the countryside, researchers and professors were downgraded to the lowest classes, and industry limped along with little to no infusion of fresh ideas. Despite the isolated achievements of a few focused initiatives, such as the synthesis of insulin, the 1970 satellite launch, and the detonation of the hydrogen bomb, the national system of innovation languished and proved ill-equipped to support ambitious state growth targets.

Mao's death and the end of the Cultural Revolution prompted a sober look at the systematic shortcomings of China's innovation system. Led by Deng Xiaoping, the government embarked on a broad reform program that included rehabilitation of academics, limited ownership and market reforms in China's state-owned enterprises (SOEs), and strong emphasis on science and technology development. Both the 1978 National Science Conference and the Sixth to Eighth Five Year Plans (1981-1995) included commitments to revitalizing science and technology as economic drivers. To modernize capital stock and seed domestic innovation, the government spent an estimated U.S. $40-70 billion on imported technology purchases between 1979 and 1993.[4] Despite poor or redundant technology choices, this effort did result in the widespread upgrading of product quality, savings in energy use, and productivity gains.[5] China also sent many students overseas for further study and upgraded its own laboratory facilities with the help of World Bank loans.

By the mid-1980s, slow progress led government officials to embrace more comprehensive institutional and market-based reforms. The 1985 "Decision on Reform of the S&T Management System" included weaning research institutes from government funding and providing them with more management autonomy to foster relationships with enterprises based on market supply and demand.[6] The survival of research institutes depended increasingly on their ability to meet the needs of industry, while stronger market competition led industries to seek the latest technologies that would confer a competitive advantage. The government also began to provide competitive grants to researchers to focus on industrial problems, the most prominent of which was the "863" Program (so named because it was launched in March of 1986), which awarded competitive grants for applied research in several key sectors, including energy, aerospace, and biotechnology.

Radical departure from the old system at least sensitized many institutions to their bottom lines and at most induced drastic overhauls of mission and identity. Research institutes facing tight budgets have struggled to redefine themselves as universities, consultancies, businesses or basic research facilities, and some still fill the roles of all four. Some research institutes were completely restructured into enterprises or became the in-house R&D department of their industrial counterpart, while others engaged in a mixture of consulting activities, enterprise spin-offs, or basic research. Decisions and outcomes varied widely by location and industry, but overall responsiveness of institutes to economic realities increased. Though the number of spin-offs was high (CAS spun off

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[4] Suttmeier, R. and C. Cao. (1999) "China Faces the New Industrial Revolution." *Asian Perspective.* Vol. 23, No. 3, 4. / *A Decade of Reform: Science and Technology Policy in China.* IDRC Canada, www.idrc.ca, 1997.

[5] Suttmeier, 4.

[6] Liu X. and S. White. (2001) "Comparing innovation systems: A framework and application to China's transitional context." *Research Policy*, 30:1092.

more than 900 enterprises during the reform period), the number failed attempts was also significant (60-70 percent), placing an added burden on parent institutions and the social welfare system, which did often did not allow failed companies to declare bankruptcy and disband.[7] Yet some spin-off attempts were highly successful and helped to seed China's rapidly developing high technology industries, such as biotech and information technology.[8]

The reforms also targeted state-owned enterprises with the goal of increasing their responsiveness to international and domestic competition by reducing state ownership, increasing R&D spending and technology acquisition, and encouraging formation of domestic or international joint ventures.[9] SOEs that had for years passively accepted government-mandated technology investment decisions had seriously weak or nonexistent R&D departments. Despite growing doubts that the state would cover their financial losses, SOEs were slow to streamline redundant labor forces, which were often 30-40 percent larger than needed, or stop impractical technology investments.[10] Meanwhile, many of the most capable technical personnel left SOEs for other institutions or new technology enterprises that offered increased freedom and opportunities.[11] As reforms progressed, many SOEs found that they lacked the financial resources to invest in R&D, in part due to corresponding weaknesses in the financial sector. Yet there are some signs that R&D in SOEs is growing more responsive to production needs. According to a study by Wei Li at Duke University, an estimated 73 percent of SOE output growth from 1980-1989 was attributed to growth in total factor productivity (TFP), and 87 percent of TFP growth was attributed to improved technology investment incentives, intensified market competition, and improved factor allocation.[12] However, TFP growth in large SOEs still lagged behind the growth of the more entrepreneurial township and village enterprises (TVEs), collectively-owned enterprises, foreign joint ventures, and private enterprises.[13]

The university system also experienced considerable restructuring during the reforms. In 1998, many research institutes were decoupled from industrial ministries, given full-fledged university status, and oversight was reassigned to the Ministry of Education. Suddenly, formerly technical institutes were charged with a broader mission of training and basic research, with faculty status determined by student throughput and academic publications in internationally recognized journals. Widespread budget cuts

[7] *A Decade of Reform: Science and Technology Policy in China.* IDRC Canada, www.idrc.ca, 1997, Ch. 2.
[8] Examples of success stories include the Lenovo Group (Institute of Computing Technology at the Chinese Academy of Sciences), Tsinghua Tongfang (Tsinghua University), and to a lesser extent Peking Weiming Bioway Biotech Group (Peking University) and Biocentury (Biotechnology Research Institute at the Chinese Academy of Agricultural Sciences). See Xie, Wei and Stephen White. (2004) "Sequential Learning in a Chinese Spin-off: The Case of Lenovo Group Limited," *R&D Management*. 24 (4), 407-422. and Keeley James. (2003) "The Biotech Developmental State? Investigating the Chinese Gene Revolution." Institute for Development Studies Working Paper 207.
[9] An overview of these strategies can be found in *A Decade of Reform: Science and Technology Policy in China.* IDRC Canada, www.idrc.ca, 1997, Ch. 8.
[10] Ibid, Ch. 8.
[11] *A Decade of Reform: Science and Technology Policy in China.* IDRC Canada, www.idrc.ca, 1997, Ch. 8.
[12] Wei Li. (1997) "Impact of Economic Reform on the Performance of Chinese SOEs, 1980-1989," Journal of Political Economy, No. 5(5), 1080
[13] Zheng et al. (2000) "Efficiency, Technical Progress, and Best Practice in Chinese State Enterprises, 1980-1994." Working Papers in Economics, No. 30. Goeteborg University, 2.

around the same time left many universities with difficulties in making ends meet. Many began to raise tuition and began to market their services and inventions. Both traditional comprehensive universities and those derived from research institutes began to spin-off enterprises, creating a rich class of new high technology businesses. On the other hand, in the more traditional industries, such as mining and petrochemicals, universities and research institutes grew more entrepreneurial through a different model in which the former performed contracted R&D activities for the latter. Often partnerships were dictated by former institutional ties carried over from the association of production and research units under the same ministerial leadership; outside of these historical links, novel horizontal partnerships were otherwise slow to form.[14]

In addition to extensive purchases of foreign technology, the government encouraged overseas firms to invest in China and set up manufacturing bases, the success of which is reflected in high levels of foreign direct investment (FDI) and a growing number of joint ventures. Often China's large market size gives regulators considerable leverage to secure full transfer of a new technology as a condition for allowing market access, though this has changed in some industries since WTO accession. Chinese-made versions of imported technologies are often developed quickly and in some cases are up to eight times cheaper than their foreign counterparts, which may carry heavy royalty payments and technical fees. Although in many cases the quality and technical support associated with foreign imported technology is superior, price is often the deciding factor for local firms lacking an established financial position and fighting to survive in competitive industries.

Despite cutbacks in direct state control since the reforms, the government still frequently intervenes in the market by setting environmental regulations, creating incentives for investment, or allowing preferential funding arrangements to promote some industries or technologies. The recent introduction of stricter emissions standards for coal-fired power plants and a renewed commitment to enforcement has encouraged plant owners in some areas to shop around for the most affordable technologies that enable them to comply.[15] The technology recommendations of regulatory agencies and design firms are still swayed by government targets for certain types of energy use. For example, China is aiming for 15 percent of its energy to be supplied by renewable sources by the year 2020, and providing significant incentives to generation companies that choose to invest. In cases where companies relying on conventional technologies attempt to create barriers to entry by innovative developers (as in the case of strong transportation interests opposing development of ethanol or methanol based fuels incompatible with their current product lines), the government is further expected to step in and resolve these disputes.[16] However, its ability to uphold these targets and effectively arbitrate disputes in practice remains the subject of ongoing inquiry.

Reform Impact on Today's Innovation Performance

[14] Conversation with Deputy Director of Overseas Oil and Gas Engineering Center, China University of Petroleum, Jan. 2006.
[15] Conversations at Tsinghua-BP Clean Energy Center, Jan. 2006.
[16] Yi, Bian. "Nation Needs Renewable Energy Resources," *China Daily*. 30. Sept. 2005.

China's reform program did not teach the cat to catch mice overnight,[17] but it has begun to address major shortcomings in the national system of innovation. The strengths of China's innovation system today include an increasingly well-trained pool of talent, a domestic capacity for producing low cost and quality manufactured goods, and incentives that support a wealth of new technology enterprises that have carved out unique niches in the transforming economy.

However, systematic weaknesses remain. Universities are still among China's strongest centers of homegrown innovation, but many are overstretched financially and find themselves serving both industry and academia. Industries, particularly SOEs, often look to universities and their affiliated companies to supplement or substitute for their in-house R&D, often in a redundant fashion.[18] This is not always the best fit for a university or research institute, which tends to favor autonomy in its research activities and stakes its reputation on academic publications. The universities that are most successful in marketing new technologies are the ones that have the funding, connections, technology transfer offices, and personnel to channel promising technologies from labs to market. Leading universities such as Tsinghua University have explicit restrictions on the payments professors can receive for external consulting activities and running businesses, helping to underscore its commitment to educational and research quality.[19] However, Tsinghua University is a rare exception in a university system where professors commonly supplement their income by consulting or running a side business, while maintaining their academic title as a fallback in case business goes bust.[20]

Reliance on universities and research institutes for R&D capacity is not always favorable for enterprises, either. Since the reforms began in 1980, enterprises with initial low R&D investment have gradually outsourced much of their remaining in-house R&D, while their technologically stronger counterparts (often university spin-offs or commercially-oriented derivatives of research institutes) have invested heavily in knowledge creation.[21] This specialization according to comparative advantage was necessary for survival in the wake of market-based reforms, but has not remedied a generally weak absorptive capacity—or the technological know-how needed to assimilate new technologies—in many industries. Only the largest SOEs appear to have the resources to invest in the development of an in-house R&D department, but both in-house and outsourced R&D is often redundant and uncoordinated.[22]

Solving this problem has been a chronic challenge. Even after strong incentives for research institutes to merge with their production counterparts were introduced in the early 1980s, actual mergers were limited and only succeeded in a few specific cases, as

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[17] A reference to a Deng Xiaoping's statement on state of the Chinese economy at a CCP meeting in 1962 that "It doesn't matter whether it's a black cat or a white cat, as long as it can catch mice, it's a good cat," which has since been widely quoted.

[18] Based on conversations with representatives of a major U.S. oil company and Tsinghua-BP Clean Energy Research Center, Tsinghua University Department of Thermal Engineering, Jan. 2006.

[19] Conversation at the Tsinghua-BP Clean Energy Center, Tsinghua University Deparment of Thermal Engineering, Jan. 2006.

[20] Conversations with faculty at China Agricultural University, China Petroleum University, and China University of Mining and Technology, Sept. 2005 – Jan. 2006.

[21] Motohashi et al. (2005) "China's Innovation System Reform and Growing Industry and Science Linkages." Discussion Paper 05-E-011, 8.

[22] Conversations at the China University of Mining and Technology and the China University of Petroleum, Beijing, China, Jan. 2006.

most research institutes did not want to surrender their newfound autonomy.[23] Yet contacts with research institutes and universities remain a must for enterprises, as the former provide a window into the global technology market by attracting visiting scholars and links with developers overseas, allowing enterprises to keep abreast of the latest developments.[24] Often advances at universities and research institutes are transferred to enterprises for a small service fee that hardly reflects the millions of yuan the government invested in original development.[25] Research institutes and universities are also natural partners for enterprises given that together with their parent ministry, they belonged to the same "family" under the pre-reform system. Indeed, many students in these universities go on to assume leading roles in industry, further strengthening ties. These ties are likely to continue to remain important, as they remain a source of inexpensive homegrown technology and personnel for industry as well as a portal to the international research community.

Government policies to increase R&D expenditures have met with mixed success. China's R&D to GDP ratio rose from 0.6 to 1.3 percent between 1996 and 2003, and the enterprise share of R&D spending has grown from less than 30 percent to approximately 60 percent.[26] Though some have been quick to assume this translates into a corresponding leap in R&D performance, the rise in corporate R&D spending may primarily reflect the reclassification of research institutes as enterprises and the emergence of spin offs, particularly at the end of the 1990s, with little change in innovation performance per se.[27] Instead, as institutes grow more market oriented, inventiveness shows signs of lagging, as shown in a general decline in the publication (-2.9 percent) and patent performance (-9.5 percent) in research institutes since 1990.[28] This may be due to the increasingly commercial orientation and historically weak IP protection, which leaves little assurance of returns on original or fundamental research.

Perhaps the most important point to keep in mind is that many institutions are still adapting to the reforming system. The last 25 years have seen significant improvisation in the wake of an alphanumerical soup of policy reforms, suggesting that government departments are vying for a stake just as much as universities, research institutes, and enterprises in shaping the technological growth trajectory in today's China. It is against this backdrop that the story of innovation in China's energy sector has unfolded. The general patterns mentioned above have stronger influence in some energy industries than in others, and their differential importance will be explored in the remainder of this paper.

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[23] Gu, Shulin. *China's Industrial Technology: Market Reform and Organizational Change.* Routledge, UK, 1999, 31.

[24] Conversations with several CNPC (PetroChina) representatives at the China-U.S. Relations Conference Research Roundtable on Non-conventional Hydrocarbons, 16. Nov. 2005.

[25] Conversations at the China University of Mining and Technology, Jan. 2006.

[26] Jefferson, Gary and Jian, Gao. "Science and Technology Takeoff in Theoretical and Empirical Perspective," Working Paper, 30. Apr. 2005, http://people.brandeis.edu/~jefferso. / Kong, Xinxin. (2003) "Corporate R&D in China: The Role of Research Institutes," Working Paper No. 179, Graduate School of the Chinese Academy of Social Sciences Institute of Industrial Economics, 8-9.

[27] Kong, Xinxin. (2003) "Corporate R&D in China: The Role of Research Institutes," Working Paper No. 179, Graduate School of the Chinese Academy of Social Sciences Institute of Industrial Economics, 8-9. / Conversation with Dr. Pete Suttmeier, Professor, University of Oregon, Feb. 2006.

[28] Huang et al., "The Transition of Chinese S&T Institutes Since the 1980s: Policy, Performance, and Implication," Prepared for Conference: The Dynamics of Industry and Organization: Organizations, Networks, and Systems, 01. June 2005, 29-30.

III. China's Energy Sector: An Overview

China derives most of its energy from coal and petroleum resources, although natural gas, nuclear power, and renewable sources (particularly hydropower) account for non-trivial and growing percentages of the energy mix. Coal is by far China's most abundant domestic resource, while oil reserves are very limited. Concerns about growing reliance on foreign oil and urban air pollution have prompted emphasis on energy efficiency and diversification of energy sources in government energy policy. This is reflected in ambitious growth targets for nuclear power and renewable energy and increased support for alternative liquid fuels generated by direct and indirect processes of coal liquefaction. Chinese oil companies are also purchasing rights to develop oilfields abroad and shoring up domestic reserves to insulate against growing uncertainties in international oil markets. Natural gas, hydropower, and nuclear energy are also expected to account for a growing proportion of the energy mix, primarily to counter the universal smog problem in cities.

During the reforms, the responsibility for China's energy policy was reshuffled several times. In the late 1970s, national energy policy focused on ensuring supply to fuel economic growth, and responsibility resided with various industrial ministries (Ministry of Petroleum, Ministry of Coal, and so on), which set production targets under the guidance of the State Planning Commission and State Economic and Trade Commission. As the top planning office, the SPC was charged with setting energy prices and approving investments. Production units subordinate to corresponding industrial ministries were responsible for implementing production targets, while research institutes tackled problems identified by the ministries.

Massive restructuring of the energy industry began in 1997, as many industrial ministries were dismantled completely and replaced by state-owned enterprises to attract greater domestic and international investment and increase competition.[29] Energy policy functions of each ministry were reassigned in 1998 to departments under the State Development Planning Commission (SDPC, formerly the State Planning Commission or SPC since 1952), SETC, and Ministry of Land and Resources. In 2003, following the leadership transition, the SDPC was dissolved and replaced by the National Development and Reform Commission (NDRC), under which energy policy functions were consolidated in a new Energy Bureau. The bureau was established to eliminate confusion under the earlier system and improve sector-wide coordination. However, a persistent low profile within the government, lack of staff support, and an inability to set energy prices have limited the Energy Bureau's ability to coordinate national energy policy, new strategies have been pursued. Recently, the NRDC appointed 15 experts representing the Ministry of Finance, the State Electric Power Regulatory Commission, and the State Council's Legislative Affairs Office to develop a law that lays out China's long term national energy strategy.[30]

Several regulatory agencies were also set up in the late 1990s to act as industry watchdogs and represent environmental interests. The State Environmental Protection

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[29] Andrews-Speed, Phillip. "China's Energy Woes: Running on Empty." *Far Eastern Economic Review.* June 2005.
[30] "Law Drafted to Regulate Energy Sector," 27. Jan. 2006, www.chinadaily.com.cn.

Administration, created in 1998, is responsible for adopting regulations for environmental protection, though these have suffered from chronically weak enforcement. This is expected to improve with the establishment of regional centers to strengthen local oversight.[31] The State Electricity Regulatory Commission (SERC) and the State-owned Asset Supervision and Administration Commission (SASAC) were also introduced to strengthen the oversight of enterprise management. A discussion of the SERC follows later in the section on electric power.

As a result of reforms, government control over energy investment decisions in all but a few industries has greatly decreased since the reforms began. This decrease has rendered the government less able to control investment and output levels in the energy industries, and overall investment in these industries has increased. However, the government has maintained control over domestic energy tariffs and pump prices, though in some cases is now slowly allowing them to reflect the market value. Although price-setting policies have helped protect consumers from price hikes, price-setting has reduced the extent to which consumer decisions reflect the actual costs of production. Attempts to encourage competition in China's energy producing and consuming industries have met with varying degrees of success, and the levels of competition vary significantly by industry. Detailed discussion is reserved for the case studies to follow.

Today, China's national energy strategy focuses primarily on increasing efficiency, reducing reliance on foreign oil, and cleaning up the air. During the 1980s and 1990s, a decline in energy intensity was observed based on national statistics, but the extent of this trend has been called into question and has unequivocally reversed in recent years.[32] Air pollution also remains a major problem in most of China's major cities. Several laws, such as the 2004 limits on emissions for coal power plants and 2005 Renewable Energy Law have been passed. China's energy planners are also keen to reduce reliance on oil, much of which is expected to be imported to meet increases in demand. If China's economy continues to grow as expected, achieving these goals will in large part depend on the ability of industries to develop and adopt the latest technologies.

IV. China's Energy Sector: Analysis by Industry

A. Coal

China is expected to rely on its large domestic coal reserves (11 percent of the global total) to supply the bulk of its energy needs for at least the next several decades. Coal currently supplies approximately 65 percent of China's energy needs, and while its overall contribution to China's energy mix is projected to fall, coal demand will increase significantly in absolute terms.[33] The location of China's coal resources, concentrated mostly in the northeast and central north, only partially overlap with the most intensive energy consuming regions. Technologies that minimize the invasiveness of extraction

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[31] Conversation with a Senior Economist, State Environmental Protection Administration, Feb. 2006.

[32] Fisher-Vanden, K., G. Jefferson, H. Liu, and Q. Tao, 2004 "What is Driving China's Decline in Energy Intensity." Resource and Energy Economics, 26, 77-97. / Zhang, Zhongxiang. (2003) "Why Did the Energy Intensity Fall in China's Industrial Sector in the 1990s? The Relative Importance of Structural Change and Intensity Change," *Energy Economics* 25(6), 625-638.

[33] China Country Analysis Brief. U.S. Department of Energy, August 2005, 8.

techniques, dirty emissions, and safety hazards will be essential to offset these adverse effects as demand grows.

China's coal production is supplied by 778 large state-owned mines (57 percent), 1,200 medium-sized state-owned mines (15 percent), and 23,400 village or township mines (28 percent).[34] Nearly all mines are underground (as opposed to open cast), and operations and have long been plagued by poor safety records and chronically low recovery rates. The coal industry is undergoing major restructuring, including the consolidation of many companies into several large firms to improve control over production and compensate for production decreases following the closure of many small mines for safety reasons. Even with the consolidation, the coal sector is still comprised of many suppliers, which can be classified as small local mining operations and large state-owned mining enterprises or groups.

Several organizations strongly influence technology investment decisions in the coal sector by setting or implementing environmental or design regulations, or allocating funds for technology investment. The China National Coal Association advises the NDRC on clean coal technologies. Design Research Institutes draft plans for large plants, but technologies are typically chosen by plant managers and in the case of major investments may require prior government approval.

Patterns of innovation in China's coal industry vary across different stages of the production chain. Ninety percent of extraction technologies used in China—which are aimed mostly at boosting recovery rates in China's underground mines from less than 50 percent at present to government targets of 75 percent—are produced domestically, while the remainder originates overseas.[35] Over the past two decades, billions of dollars in foreign technology purchases have helped to seed indigenous R&D programs, but foreign industry representatives have claimed that domestic technology lags behind the international frontier by 10-15 years with respect to mining efficiency, safety, and environmental protection standards. The government tends to recommend purchases of indigenous technology although WTO commitments prohibit outright incentives. China's largest coal mining companies, such as the Shenhua Group and the Yankuang Coal Mining Group, which have strong financial positions and some in-house R&D, are able to afford extensive foreign technology purchases.[36] Foreign investment in mining operations is encouraged to improve safety and management practices, and as of the end of 2004, two U.S. companies had entered into joint venture partnerships to develop one underground and one opencast mine. Underground gasification—or the underground burning of coal to produce gases that can be purified and channeled to power electricity generators—is also being explored at China's University of Mining and Technology as a low cost way of increasing recovery, improving safety, and reducing pollution by filtering out most of the particulate and sulfur content. Developed through initial contacts in the late 1970s between U.S. researchers from Lawrence Livermore National Lab, Cornell University and Chinese researchers at the China University of Mining and Technology,[37] this technology has not been successfully demonstrated on a commercial

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[34] "Coal Mining Equipment Market in China," U.S. Commercial Service, U.S. Department of Commerce, www.buyusainfo.net.
[35] *Ibid.*
[36] *Ibid.*
[37] Conversation at China University of Mining and Technology, Jan. 2006.

scale in China, although it has been implemented in several mines in the United States.[38] Developing UCG in China has been one main focus of the UK-China Cleaner Coal Technology Transfer and Export Promotion Program, which has established a collaboration with CUMT's Gasification Research Center.[39]

Coal preparation technologies, such as washing, that reduce sulfur content in emissions are also widely applied in China. The technology is often manufactured domestically, and although perceived to be inferior to imported technologies, homegrown versions can often be more than 8-10 times cheaper and are therefore often preferred. Plant design decisions are usually made by design research institutes in collaboration with local partners such as universities or other research institutes, and these connections often facilitate the adoption of locally developed R&D in line with government standards.[40] In many cases, government support is channeled to "small innovation projects" to develop improved dry cleaning technologies for mines in arid regions or solve other specific localized problems.[41]

China also plans to invest aggressively in coal liquefaction technologies. According to *China Oil News*, the NDRC has committed $15 billion in state funds to invest in coal-to-liquids plants over the next five to ten years that could produce up to 16 million tons of oil products.[42] Even if this projection proves overly optimistic, investment is expected to be significant. The first approved project is being carried out by the Shenhua Group, which is the leading investor in a state of the art liquefaction research center in Shanghai and a world's largest liquefaction plant in Inner Mongolia.[43] The technology was licensed by a U.S. company Hydrocarbon Technologies Inc. (HTI), a subsidiary of Headwaters Technology Innovation Group, with the assistance of the U.S. Department of Energy after investors compared several German, U.S., and Japanese technologies on the basis of product yield and price.[44] Coal from Inner Mongolia had already been tested on the HTI technology at the U.S. Department of Energy, and these early ties may have further influenced the investment decision. Investment in liquefaction technology is aimed at reducing reliance on foreign oil, and fits conveniently with government goals to create jobs and develop the infrastructure of China's western regions. Energy planners assert that liquefaction is financially workable as long as oil stays above

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[38] Based on conversations with a research director at the China University of Mining and Technology, Jan. 2006. For more information on underground gasification technology and the extent of application see Underground Coal Gasificiation, UCG Engineering Ltd. at www.coal-ucg.com.

[39] Creedy, DP and K Gardner. "Clean Energy from Underground Coal Gasification in China," Prepared for UK Department of Trade and Industry, Report No. COAL R250, Feb. 2004, 3.

[40] "Review of the Coal Preparation Sector in China," Cleaner Coal Technology Program, U.K. Department of Trade and Industry, Project Summary 324, March 2002, 3.

[41] *Ibid*, 4.

[42] "Coal Liquefaction to Get Major Investment," *China Oil News*, oilnews.com.cn, 10. Feb. 2006.

[43] Investment in the liquefaction plant itself is estimated to be US $3.3 billion. Shenhua's current and planned liquefaction projects are expected to be financed by at least US $20 billion from domestic banks. Collaborations with West Virginia University are expected to conduct ongoing impact assessments of the Inner Mongolia liquefaction project. "Coal Industry Investment: Outlook to 2030," Workshop Summary from the *World Coal Institute*, www.iea.oeg, 4. / "2005/2006 Special Research Assignment Awards: Joint Research Between the U.S. and China," West Virginia University Regional Research Institute, www.rri.wvu.edu.

[44] Pelham, Jack. "Ultra-clean Fuels from Coal Liquefaction: China About to Launch Big Projects." *Diesel Fuel News,* 22. July 2002.

$23/barrel, although the process is not particularly efficient (15 tons of coal are needed to produce 5 tons of oil) and does not contribute to reductions in CO_2 emissions.[45] This project is the first to be approved by the government and the approval of two additional liquefaction plants depends on the results of the Shenhua project.[46] Other projects in the pipeline include a Shenhua-led collaboration with South Africa's Sasol to develop indirect coal liquefaction technology, and Shenhua and the Ningxia Industry Group, Co. have partnered with Royal Dutch/Shell to explore options for future liquefaction plants.[47] Inside China, coal-to-ethanol and coal-to-methanol methods are the subject of both technical and policy research at Tsinghua University and other institutes. Researchers at the Tsinghua-BP Clean Energy Center are currently exploring the feasibility of a "syngas city" funded by the municipal government of Zaozhuang in Shandong Province.[48]

Coal combustion or conversion technologies for power plants and industrial boilers that increase the efficiency of coal consumption form a critical share of the latest round of technology investments. New power plants built in 2004 mostly used either sub-critical technology, with which contractors, manufacturers, and plant owners have over 20 years or more of experience, or supercritical technology, which relies mostly on imported technologies and expertise.[49] As contracts for the next round of plants are in the negotiating stages, many are struggling with the decision of whether or not to adopt the more expensive and less mature integrated gasification combined cycle (IGCC) technology (350 yuan/MWh) or deploy next generation ultra-supercritical (USC) technology (280 yuan/MWh).[50] IGCC has the added advantage of easy adaptation for hydrogen or carbon capture.[51] Moving to IGCC technology will depend primarily on the success of demonstration projects as well as potential financial incentives (such as lower equity investment requirements for plants adopting IGCC).[52] IGCC technology may be heavily resisted by the automobile industry, which has expressed opposition to making product lines compatible with methanol-based fuels, which if plants are engineered appropriately, could be a potential by-product of the IGCC process. Developers also expect resistance from state-owned electric power companies, which prefer the lower costs associated with USC and have more political clout than coal companies in determining technology investment decisions. After nearly ten years of negotiations, construction has not yet started on the first IGCC plant, a 400 MWe demonstration facility at Yantai in Shandong Province.[53] Other coal conversion technologies are also

[45] Article on China Liquefaction Plans on China's Clean Coal Research page, get web address (in Chinese). / Conversation with Director, Tsinghua-BP Clean Energy Research Center, Jan. 2006.
[46] Tian, Mai. "First coal liquefaction centre set up in Shanghai," *China Daily*, 12. Mar. 2004.
[47] Cromberge, Peter. "Energy-hungry China turns to South African scientists for coal-to-liquids expertise," www.miningweekly.com.za, 14. Oct. 2005. / Fu, Chenghao, "Groups to Cooperate on CTL Technology," *Shanghai Daily*, 01. Mar. 2006.
[48] Aldhous, Peter. "China's Burning Ambition," *Nature*, Vol. 435, 30. June 2005, 1153-4.
[49] Li, Wenhua and Guodong Sun. Report of the Joint Workshop on the Cooperation in Clean Coal Technologies between the United States and China, Hangzhou, China, 2004.
[50] *Ibid.*
[51] "Advanced Power Generation Technologies: Integrated Gasification Combined Cycle (IGCC)," www.coal21.com.
[52] *Ibid.* and conversation with Research Fellow at Belfour Center for Science, Technology, and International Affairs, Feb. 2006.
[53] Negotiations for the Yantai plant have been underway since 1996, starting with early U.S. interest in developing IGCC projects in China, but its umbrella program was not approved in Congress. China

being developed, such as above ground gasification mostly used to fuel fertilizer chemical plants.[54] As domestic versions are often designed for a small scale uses and have low efficiency, the technology originates mostly from international petrochemical companies.[55]

Overall, institutional legacy still appears to influence the path of cleaner coal technology development. Outsourcing research activities appears to remain the norm. For example, China University of Mining and Technology's gasification research center provides contracted research services to PetroChina on gasification technologies for use in deep coal seams, while relying on government grants to support a broader research program and gasification test lab. The university further collaborates to field test its technology at several sites that belong to the Xinwen Mining Group (Shandong Coal Mining Group), and that company can access the technology for only a small service fee.[56] The China Coal Research Institute, another major center of R&D and policy support for the coal industry, is a frequent partner in international collaborations. Research institutes and universities also tend to maintain international ties on behalf of coal producers, acting as an intermediary in the introduction of new technologies. The Institute of Coal Chemistry, Chinese Academy of Sciences, in Taiyuan City, Shanxi Province is also a major center of research on clean coal technologies, which has set up several joint research projects with large coal mining companies to transfer its technologies.

One exception to the general pattern of institute-based research is the case of the Shenhua Group, which has recently committed resources to develop its own world class coal liquefaction R&D center. However, the basic technology in this case originated overseas, and it is unclear to what extent Shenhua will invest in its own basic research on the technology as opposed to making incremental changes to adapt it to Chinese conditions. However, given that coal liquefaction technology has a limited track record and has been rejected outright in other markets (at least as long as oil prices remained low), much of the R&D to support the plant's current and future development will likely take place in China. Shenhua's investments are also likely to occur in parallel with research at universities and research institutes that are developing liquefaction technologies in their own labs.

Cost is also an important determinant of technology investment decisions, particularly for smaller mining companies that have low cash reserves and are less

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organized an IGCC working group and starting from the mid-1990s funded IGCC-related R&D under the "863" Program. The State Power Corporation was designated responsible for managing investment and construction and plans were approved in 1999. The process of negotiations has been slow, and construction has begun only after 10 years of negotiations. The project is expected to incorporate carbon capture and storage technology as part of the U.S. Department of Energy FutureGen project, though this is still in the early stages.

[54] OECD Paper, 20.

[55] Dongfang Boiler Works is a leading domestic boiler design and manufacturing company. Watson et al. "International Perspectives on Clean Coal Technology Transfer to China," Final Report to the Working Group on Trade and the Environment, August 2000, 10. Major suppliers of coal gasification technology include ChevronTexaco and Shell. "Press Release: ChevronTexaco Worldwide Power and Gasification and China Petroleum and Chemical Corporation (Sinopec) Announce Agreement on Technology License," www.chevron.com, 18. Oct. 2002. / "Shell: Coal Gasification," *News Guangdong*, www.newsgd.com, 08. Nov. 2005.

[56] Conversation with a research director at the China University for Mining and Technology, Jan. 2006

insulated against cutthroat market competition. In the absence of strong environmental regulations, producers appear to shun more expensive, cleaner technologies unless the benefits of adoption outweigh the costs. When plants must comply with environmental regulations, the lowest cost version that will allow compliance is likely to be adopted. Therefore, domestic technologies may quickly replace imports after a market for cleaner coal product is created. As of 2000, the penalty for polluting (and the chance of getting caught) was not high enough to spur investment in more costly cleaner technologies,[57] but the latest round of emissions limits passed in 2004 are stricter and enforcement has reportedly improved. The removal of government price caps has further allowed prices of coal to rise in response to demand, and if prices remain high, companies may soon be in a better position to fund larger purchases and perhaps even the original development of new technologies.

B. Oil and Non-conventional Hydrocarbons (NCH)

Technology development in China's oil and NCH industry is focused on increasing the production of newly acquired and existing reserves and enabling the development of marginal reserves. In spite of attempts to diversify China's energy mix, a massive rise in oil demand is expected as increases in individual and industrial transportation needs accompany economic growth. China's demand for crude surpassed Japan in 2004, reaching 6.5 million barrels per day (bbl/d), making China the world's second largest consumer, and is projected increase to 14.2 million bbl/d by 2025 (with an expected 10.9 million bbl/d in net imports).[58] In response, China's national oil companies are increasingly securing overseas concessions and developing technologies for the extraction of harder to reach reserves, such as coal bed methane, heavy oil, and tar sands. Technologies for extracting harder-to-reach fuel sources and increasing production in conventional fields will therefore be important as rising prices make riskier exploration and production projects financially attractive.

China's onshore petroleum industry is dominated by two vertically-integrated, regionally-focused firms, China National Petroleum Corporation (CNPC) in north and west and China Petrochemical Corporation (Sinopec) in the south. Prior to the 1997 reforms, CNPC had been mainly focused on exploration and production and Sinopec on refining and distribution, and these emphases are still evident in current operational strengths. China National Offshore Oil Corporation (CNOOC) focuses on offshore exploration and production and accounts for 10 percent of China's domestic crude oil production. The State Energy Administration, established in 2003, is charged with regulatory oversight. Petroleum universities, the successors of pre-reform industrial research institutes, also play an important role by training future employees, providing specialized technology services, and supporting fundamental research.

China's petroleum industry has some distinct features when it comes to technology adoption and original development. Chinese university and industry representatives often claim that imported technologies are not suited to "Chinese conditions" and therefore require considerable adaptation. This stems from two factors: 1) China's reservoirs are generally smaller and higher development costs have historically

[57] Watson et al., 15.
[58] China Country Analysis Brief, U.S. Department of Energy, Aug. 2005, www.eia.doe.gov.

deterred exploration by international oil companies, plus many common imported technologies designed for large, high-pay reservoirs may be unsuitable, and 2) China's steady supply of inexpensive skilled labor makes cost-effective the application of labor-intensive technologies that are rejected elsewhere. As a result, technologies in use in China are often based on earlier versions of internationally accepted technologies that were replaced in other parts of the world by labor-saving technologies. In general, Chinese researchers have been very entrepreneurial in perusing the literature and gaining experience with various foreign technologies, but have difficulty adapting them to meet specialized production needs.[59] However, when Chinese enterprises do enter into joint ventures for upstream development, often the foreign partner provides the technology, particularly when developing very difficult reservoirs for which no domestic technology is available. As oil prices rise, such opportunities have attracted increasing interest from major international oil companies. In such cases, Chinese partners sometimes demand full transfer of technology on a scale more comprehensive than that envisioned by their overseas counterparts, sometimes causing tensions in these collaborative efforts.[60]

Eliminating internal duplication of R&D efforts also remains a major challenge for China's national oil companies. CNOOC, CNPC and Sinopec enjoy a stable and strong position as a result of their monopoly within the Chinese market and strong ties to the government. The advantage of this system is that significant funding is available for R&D (PetroChina, CNPC's listed arm, is the most profitable company in Asia). All three companies maintain a large in-house R&D operation as well as ties to research institutes turned universities that further supply consulting or other research services. However, disadvantages include considerable duplication of efforts, both because historical ties preclude cutting support for universities and low labor costs do not make trimming a necessity. By contrast, most international oil companies choose either to follow a model of either maintaining a large corporate R&D department (as in the case of ExxonMobil) or contracting R&D capacity to a number of universities and research consortia (as in the case of BP). Chinese national oil companies seem to maintain both systems with little coordination between them.[61]

In addition to duplication and a general lack of coordination between external and internal R&D, the R&D departments in China's petroleum industries sometimes have difficulty adapting a particular technology to production needs. Often national oil companies have few or no personnel with cross-disciplinary experience. Because companies can afford to hire an abundance of engineers with extremely specialized knowledge (and the educational system provides an steady supply), managers often overlook the importance of creating positions for people who can collect, synthesize, and adapt specialized knowledge to specific production problems. Further, since scholars are traditionally accorded great respect and distance in Chinese culture, there is little constructive dialog between R&D personnel and field technical staff. Indeed, field staff can be frustrated by researchers' impractical solutions but must nevertheless attempt to apply them out of respect.[62]

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[59] Conversation with a representative of major U.S. oil company, Jan. 2006.
[60] Conversations with Former Head of the Science and Technology Research Unit, Univ. of Sussex and a representative of a major U.S. oil company, Jan. 2006.
[61] Conversation with a representative of a major U.S. oil company, Jan. 2006.
[62] *Ibid.*

Though government maintains a strong role in industry leadership, environmental regulations do not seem to have a strong influence on which technologies are adopted in the oil and NCH industry. Part of the reason is that technical standards are still being developed to reflect international norms, and enforcement can be a challenge.[63] Foreign joint ventures often employ imported technology that complies with environmental standards more stringent than China's domestic requirements.[64]

Relative costs are a major part of the reason why state-owned enterprises often rely on homegrown technologies rather than imports. Given cheap manufacturing capacity and an abundance of labor, the major oil and NCH producers in China face a very different cost scenario than their foreign counterparts, making labor-intensive technologies a more financially attractive option. For example, instead of employing less invasive well-drilling techniques typically used internationally, national oil companies drilled a staggering 30,000 wells in Daqing oil field to achieve similar recovery levels, an endeavor uneconomic for companies facing higher labor and equipment costs. Many technologies used are older models that were initially introduced from overseas, either through technology transfer agreements or corporate gifts, and have formed the basis for a similar set of domestically produced technologies adapted to meet specific conditions of China's reservoirs and equipment markets.

The case of China's petroleum industry reinforces the observation that in industries where reforms have progressed more slowly, R&D performance is also relatively low. Without the pressure of diminishing profit margins or a scarcity of personnel to adapt research to meet production needs, national oil companies face few incentives to streamline R&D departments and cut or reduce historical ties with universities in ways that would radically disrupt employment contracts and existing networks. In the long run, as rising oil prices and supply reductions focus attention on non-conventional reserves, China is likely to continue to rely on imported technologies through joint ventures to overcome associated technical challenges in the absence of institutional arrangements that encourage domestic innovation.

C. Nuclear Power

Nuclear power factors strongly into the government's energy development plans, especially for the energy hungry southeastern provinces far from coal reserves. Although nuclear power on the mainland is at present fairly limited (now 2 percent of China's energy mix), government energy planners plan to expand capacity to 40 GWe by 2020 and encourage additional investment in the years beyond. The latest investment round (to 2020) will rely on a combination of imported and domestically developed conventional pressurized water reactor technology, but beyond that, promising homegrown efforts to develop cutting edge high pressure gas cooled (HPGC) reactor technology are poised to offer a competitive alternative. Critical factors that will influence the next generation of adoption decisions include the relative prices of plant component parts, a competitive market for nuclear power, and continued government support for its development.

[63] Chinese Petroleum Standardization Technical Committee sets technical standards for the petroleum industry.
[64] Conversation with Vice President, Kerr-McGee China, Feb. 2006.

China began developing nuclear power in the mid-1980s. The first plants included one at Hong Kong's Daya Bay designed by Framatome with turbines supplied by GE, while one at Qinshan (south of Shanghai) employed technology that was almost entirely indigenously designed based on earlier imported models. Two later plants relied on similar Framatome or indigenous designs, though one employed CANDU technology developed by Atomic Energy of Canada. Plants currently under construction in Jiangsu are being constructed under a cooperation agreement between China and Russia using a Russian design, Finnish safety features, and Siemens instrumentation and control systems. When these plants are operational in 2006, the country's total capacity will reach 8350 MWe.[65]

As part of plans to quintuple this capacity by 2020, China's National Nuclear Corporation (CNNC) has applied to construct eight new large reactors, all of which will employ a mixture of foreign and domestic advanced second to third generation technology. Following the lifting of restrictions on American bids for nuclear power plants in China, U.S. company Westinghouse has been favored to win the bid for the plant, a deal that may attract less criticism in the U.S. now that its parent company has sold Westinghouse to Japan's Toshiba Corporation.[66] CNNC hopes to use the final plant design to develop its own version of the technology, which could prepare it for a greater role in the next round of expansion after 2020.[67]

However, domestic technology may alter the playing field prior to the post-2020 expansion, opening the way for new fourth generation technology to take hold. Currently, fourth generation technology is still under development. Tsinghua's Institute for Nuclear Engineering Technology (INET) developed a 10 MWe HPG pebble-bed test reactor funded by the "863" Program. Justification for the project focused on the need to improve efficiency and safety over conventional reactor designs. Pebble-bed reactor technology—so-named for the spherical packing of fuel—had originally been developed in Germany, but shelved in the wake of widespread rejection following the Chernobyl and Three Mile Island accidents. Building on the German platform with the help of Siemens and Interatom, China has developed its own pebble-bed reactor designs. The pebble bed model was chosen over a block reactor alternative because research on the former had been underway for 20 years, and China's domestic manufacturers already had experience making the component parts. South Africa is the only other country where the technology is under development, also based on the German model. The success of the pilot in China was followed by the formation of Chinergy, a 50/50 joint venture between Tsinghua University's Holding Company and China's State Nuclear Power Corporation, which attracted investment from a consortium led by the Huaneng Energy Group to build a 200 MWe pilot reactor in Shandong Province. Research has also been underway since the mid-1960s to develop a fast neutron reactor with Russian support and a 65 MWt pilot near Beijing is scheduled to be completed by 2008. These new forms of technology are expected to be important by mid-century, particularly as component parts become cheaper and the technology is further proven.

At present, nuclear power technology choices are heavily influenced by several organizations. All feasibility studies for new plants are reviewed by the China Atomic

[65] "Nuclear Power in China," World Nuclear Association, www.worldnuclear.org, Feb. 2006.
[66] Conversation with Director, Tsinghua-BP Clean Energy Center, Feb. 2006.
[67] Zu, Boru. "Foreign Energy Giants Bid for Nuke Contracts," *China Daily*, 12. Sept. 2004.

Energy Authority before submission for final approval by the NDRC. The National Nuclear Safety Administration acts as a licensing and regulatory body that is responsible for ensuring that new projects comply with international safety regulations. The State Nuclear Power Technology Corporation takes charge of technology selection for new plant bids from overseas, in line with the advice of China's State Council. For example, it is at this stage that decisions to favor designs with domestically produced components may be taken. The China National Nuclear Corporation and its several provincial counterparts (Guangdong is particularly important) are the major state-owned enterprises responsible for in-country R&D, engineering design, mining, enrichment, fuel fabrication, reprocessing, and waste disposal. CNNC is also heavily involved in organizing construction and equipment bids for new plants, and tends to champion local designs in the decision-making process. The China Power Investment Corporation is the largest state-owned nuclear power investment and operating organization.

Given that nuclear power plants incur hefty initial fixed costs and raise particular safety concerns, the state has taken a strong facilitative and regulatory role in the decision process. Decisions are based on the plant suitability (e.g. size, capacity) for a particular area, the maturity of the technology, and opportunities to minimize costs of component parts, often through domestic suppliers. Though at present designs still originate overseas, as fourth generation technologies are proven, opportunities for their developers, such as the dually Tsinghua University-CNNC invested Chinergy, are likely to grow. Indeed, since China's government funded initial pilots for the pebble-bed reactor at INET, it is likely that if associated costs continue to decrease and the second pilot is successful, it may become the preferred model. Even the United States is very interested in China's homegrown fourth generation nuclear technology, and could employ it in a proposed revitalized nuclear program.

D. Natural Gas

Despite China's long experience with natural gas, which was first burned under shallow pans of seawater 2,500 years ago to collect salt, natural gas production and consumption in China has remained quite limited. Until very recently, domestically-produced natural gas was used almost exclusively to fuel chemical and fertilizer plants close to its origins, which were primarily concentrated in the Western part of the country. In 2003, only 10 percent of natural gas recovered domestically was piped to residences or used for electricity generation.[68] Although estimates of domestic reserves have increased 15-fold since 1982, the market remains immature—in China the oil to natural gas use ratio is 1/0.1 compared with 1:0.7 in most developed countries.[69]

Based on government plans, this situation is expected to change dramatically. China's energy planners have favored natural gas as a cleaner alternative to coal for supplying energy to Beijing and Shanghai. Many Beijing households are already heavily reliant on gas produced in the Ordos Basin. To transport western gas to the prosperous

[68] Yamaguchi, Kaoru and Keii Cho. "Natural Gas in China," Report for the Institute of Energy Economics of Japan, Aug. 2003, 1.

[69] "China becoming a major natural gas nation," chinanews.com.cn, Sept. 5, 2005. / Li, Yugeng and Li, Jianmin. "Gas Industry Development Energetically in China [sic]," China Development Gateway, chinagate.com.cn.

east, a 4,000 km pipeline connecting the Tarim Basin in Xinjiang with Shanghai was completed in 2004 (led by CNPC). As demand is expected to eventually outstrip domestic supply, China has announced plans to build a series of LNG terminals along the eastern seaboard.

The three main players in the natural gas industry are the same as for oil and NCHs: CNPC (PetroChina), Sinopec, and CNOOC, which account for 90 percent of the market. PetroChina in particular invested heavily in the west to east pipeline and is perhaps the most active in developing land reserves of coal bed methane and other marginal natural gas reserves. At all stages of the production pipeline, foreign involvement has been important. Upstream partnerships with foreign gas producers provide access to technologies needed to develop marginal reserves that the Chinese do not have or are not cost-effective to develop domestically, while allowing domestic producers to spread the risk of exploring ever more marginal fields. At the downstream stages, partnerships with foreign technology suppliers are critical to gain access to the most efficient and reliable technologies, as the equipment market for natural gas production equipment and components is said to be 10-15 years behind in China. The NDRC remains the main government body controlling decisions for the natural gas sector, and decides pricing policies and approves foreign investment and partnerships.

Patterns of technology adoption in China's natural gas industry are characterized primarily by reliance on foreign suppliers. Though some components may be manufactured in China, nearly all companies rely on foreign technology. For instance, in a partnership between Royal Dutch Shell and PetroChina for exploration of the Changbei Gas Field in Ordos Basin, Shell is expected to supply most of the advanced technology.[70] Equipment used in the construction of China's West-to-East pipeline is a mixture of domestic and foreign, though most routine components are produced by Chinese manufacturers while advanced control and pressurization equipment originates abroad. In the construction of natural gas generation plants, the turbines (mostly supplied by GE) and control equipment also come from foreign suppliers. Most new construction incorporates the latest proprietary technologies imported from abroad, though older versions are often licensed to manufacturers in China. For LNG importation, most of the advanced equipment for the LNG terminals is expected to be supplied from abroad, at least for the near term future.

Several factors may explain the reliance primarily on imported technologies. First, the natural gas market in China remains relatively immature and is characterized by weak competition. The government is still strongly involved, which makes foreign investments more risky since the market is subject to highly unpredictable political decisions. Special investment policies are often enforced by the government, for example, allowing foreign companies to hold shares in upstream projects while funding downstream network construction. Given the close government ties and virtual domestic oligopoly of China's "Big Three," these companies may not feel strong cost pressures when making their technology investment decisions. Furthermore, these companies have access to preferential government loans, and often can often reshuffle funds among departments, allowing them to afford large technology purchases they otherwise could not.

Rising global prices for natural gas have important consequences for China's natural gas market. For electricity generation—which will account for at least half of

[70] "PetroChina, Shell Seal Gas Project," *China Daily*, 18. May, 2005.

natural gas use in China—gas power plants are more expensive to supply and operate than coal power plants, and are often deployed after older, less expensive, and more polluting coal burning facilities. Government incentives could have a critical role in subsidizing or otherwise creating incentives for the operation of natural gas plants; without them, current patterns of low usage may continue. The commercial and residential markets, on the other hand, benefit from artificially low gas retail prices, which are controlled by the provincial commodity price bureau, and demand for natural gas in these markets is expected to remain strong.[71]

Environmental regulations may be a crucial driver of increased reliance on natural gas for power generation. At present, given rising natural gas costs, it is likely that coal (with its abundant domestic reserves) will remain a more secure and inexpensive option. Since natural gas supplies are eventually expected to come increasingly from overseas or neighboring Russian gas fields, Chinese users will be subject to global market prices—and the priorities of other governments—which energy planners may find unacceptable. However, if the State Environmental Protection Administration is able to enforce new emissions limits for coal fired power plants, and costs of using cleaner coal technologies are internalized in operating costs, natural gas may become a more competitive option. Shanghai has gone one step further by banning the construction of new coal-fired power plants inside the city limits to further encourage alternatives; however this ban was reversed amid concern over the availability of a steady and affordable supply of natural gas.

Overall, domestic R&D capacity as well as adoption of domestically manufactured technologies for natural gas exploration, production, and electricity generation remains low. Although large corporate R&D departments and universities have some programs related to natural gas, most are focused on identifying reserves and less on developing technologies. This seems to be the result of a market limited to a relatively small number of large domestic suppliers still heavily subject to state control. However, if the domestic supply-demand gap increases to the point where imports become necessary, subsidized pricing may be unsustainable. At that point, widespread adoption of natural gas is likely to depend on its cost compared with coal. Factoring in transportation costs may also produce sharp disparities in relative costs among regions. In the meantime, these sizeable efforts are likely to result in considerable imports of advanced foreign technologies. Although parts may be manufactured in China through joint ventures, the designs and most sophisticated propriety components are likely to originate abroad.

E. Electric Power

China's electric power industry supplies the country's large and rapidly growing generation needs. Energy shortages in recent years have prompted a rapid expansion of capacity—total installed capacity reached 440 GW by the end of 2004 and 60-70 GW were expected to be added in 2005.[72] Currently, coal-fired power plants followed by hydropower stations supply the bulk of China's electric power, though renewable sources

[71] Miramoto, A., and Ishiguro, C. "Price and Demand for LNG in China: Consistency Between LNG and Pipeline Gas in a Fast-Growing Market," Oxford Institute for Energy Studies, Jan. 2006, 10.
[72] "China's Electric Power Sector to Reach Growth Limit," 05. May 2005, *Asia Times*, www.atimes.com.

and nuclear power are expected to play important roles in the future. Encouraging diversification to reduce urban air pollution is a major goal of state planners. Although reforms to encourage competition may lead companies to focus on technologies with a price advantage, concerns about power shortages have placed a premium on adopting reliable technologies even if they are dirtier or less efficient.

China's electric power industry has experienced major reforms since the mid-1980s. Prior to the reforms, competition in China's electric power industry was severely limited as the State Power Monopoly bought supplies only from its own plants. In 1986 as part of the government's broader reform agenda, efforts to attract greater investment by opening the sector to non-state investors were introduced and proved very successful, raising over $20 billion per year. Reforms went another step forward in 1997 by creating the State Electric Power Corporation from the former production arm of the Ministry of Electric Power, which in 2002 was parsed into five generating companies (each less than 20% of market share), two grid administration companies, and several consulting companies to further encourage improvements in management and allocation efficiency by fostering competition.[73]

In March 2003, a regulatory body, the State Electricity Regulatory Commission was created under the State Council to supervise and regulate competition in the industry.[74] As the first government-sponsored regulatory agency in the primary industry sector, the SERC is charged with issuing licenses to operators, monitoring operations, and holding operators accountable for violations of pricing and competition rules, as well as setting up an electricity supply trading market. Although intended as a major step towards allowing more competition and independence among various players in the power sector, the role of the SERC remained unclear for two years and was often overshadowed by the powerful NDRC. New guidelines issued in 2005 helped to clarify the situation, but allocated the key task of approving power investments to the NDRC instead of the SERC as originally envisioned, and electricity tariffs are to be jointly decided by the NDRC and SERC.[75] The need to retain government control until the power shortages can be resolved is the reason given for the failure to delegate greater responsibility to the SERC, which has rendered the organization weak and ineffective.[76]

Due to ambitious plans to expand China's generation and grid capacity, the government is expected to invest US $2 trillion in China's electric power industry from 2001-2030, an equivalent annual expenditure of US $60 billion per year.[77] As a result, demand for technology will be massive as plants are expanded and retrofitted to meet growing capacity needs. Use of local technologies for plant construction and grid expansion is encouraged, and where foreign technology must be used, full transfer is often part of the deal.[78]

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[73] "China: Power Generation," U.S. Commercial Service, U.S. Department of Commerce, www.buyusa.gov.

[74] "Regulator Sets Target for China's Power Sector Reform," *People's Daily*, 26. Mar. 2003.

[75] Yu Qin. China Business Law Bulletins: Water, Energy, and Petrochemicals. "Strengthening the State Electricity Regulatory Commission." April 2005. www.chinalawandpractice.com.

[76] Metha, Aashish. "Establishing the National Electricity Regulatory Commission," Technical Assistance Completion Report, Asia Development Bank, 31. August 2005.

[77] Integrated Resource Planning in the Context of China's Electricity Situation. Paper by the Regulatory Assistance Project for the China Development Forum, June 2005, 2.

[78] *Ibid*, 2.

The introduction of greater competition into the electric power industry means that plant construction decisions, as well as decisions to bring plants online, are heavily influenced by costs. While in some cases this may favor the adoption of cost or energy-saving technologies, it may also favor cheaper proven technologies that may be older and more polluting. For example, now that plant dispatch proceeds according to the lowest bids, coal-fired plants would trump cleaner but pricier natural gas generation. Such procedures may also result in old, more polluting plants remaining online for as long as possible to maximize the return on sunk costs and take advantage of cheaper technology. Several pilot programs have tested strategies to remedy the problem, for instance, by evaluating bids on the basis of costs after subtracting out any additional costs associated with adoption of cleaner technologies. However, critics of these programs point out that the correction is not enough to encourage cleaner technology investment and focuses too narrowly on coal plants.[79]

The strengthening of environmental regulations and perhaps also the role of the SERC could help to remedy the problem. SEPA's most recent emissions control standards for new coal fired power plants, if strictly enforced, will require many plants to adopt cleaner technologies. Although SEPA's presence in the provinces has increased in recent years, implementation of SEPA regulations has been historically weak. Coal-fired power plants have found it more financially attractive to pay fines rather than operate technology that spares the air. One encouraging step has been a shift from input-based regulations (caps on pollution per unit of fuel input) to output-based regulations (caps on pollution per kWh produced), which provides plant owners flexibility to seek the most energy saving technologies irrespective of fuel source.

Electricity tariff policies also seem to heavily influence technology investments in China's power industry. Policy has traditionally focused on ensuring the affordability of electricity to all. In 2004 and 2005, the government raised electricity tariffs three times to more closely reflect market prices while preventing sharp price increases during power shortages. However, in the absence of other incentives, power generation companies have shown a preference for cheaper proven technologies, which has discouraged innovation in the industry.

Since cost is a key factor in technology investment decisions, selection of foreign versus domestic technology and type of energy source is determined by price comparisons of component parts, though quality is also important. Many internationally recognized technology suppliers have formed joint ventures with Chinese companies to lower overall costs and make their bids attractive to plant owners and state energy planners, who also tend to favor domestically produced technologies. Most of the turbine designs used in the majority of Chinese plants still come from abroad, although Chinese manufacturers are beginning to gain a foothold in the market. However, international companies such as Alstom and GE have an established reputation in terms of products and service, and therefore tend to dominate.

Although reforms have moved the electric power industry far closer to a competitive, independently regulated model than ever before, fully realizing these goals is still a ways off. Given that the NDRC still desires to maintain strong control over tariff and investment policies at least as long as power shortages continue, the profile and

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[79] The SERC During the 11th Five Year Plan: Building an Effective Regulatory Framework." Paper by the Regulatory Assistance Project for the World Bank and the Energy Foundation, Dec. 2004.

duties of the SERC will remain very limited. For policy advisors interested in institutional reforms that favor cleaner technology adoption, it is more appropriate to directly approach the energy policy arm of the NDRC. From the technology side, many international suppliers have gained firm footing and established partnerships with local companies in China, leading to a broad availability of the latest technologies. Still, relative costs, tariff levels, and state-mandated environmental incentives or penalties are likely to determine the extent to which these technologies are adopted.

F. Renewable Sources

Although at present renewable energy accounts for only three percent of China's energy use, this share is expected to grow. The renewable energy law that took effect on January 1, 2006, is aimed at boosting the overall contribution of renewable energy to an ambitious 15 percent by 2020. Since China is thought to have an abundance of potential wind, hydro, and solar energy, the government has embraced them as logical alternatives to reliance on foreign oil or dirtier sources such as coal. Drivers of technological change in the solar and wind industries remain similar, and in many ways constitute an important success story in China's overall efforts to encourage innovation. Hydro and geothermal energy development, and to some extent biomass energy as well, have also benefited less from local sources of technology, but the pace of innovation appears to be slower.

Research on photovoltaic (PV) solar cell technologies first seriously appeared on China's research agenda following the start of reforms. The work was concentrated primarily in government research institutes and even as the number of production factories grew, the industry remained nearly a decade behind the world standard through most of the 80s and early 90s. Meanwhile, the number of solar systems sellers gradually increased to include private enterprises in addition to the government research institutes and SOEs. By the mid-1990s, suppliers and sellers operated in a fairly competitive market, with some suppliers exporting nearly 90 percent of their products.[80] However, R&D investment still depended heavily on domestic as well as multi- and bilateral loan and grant funding, as after start-up costs few companies had funding left to invest in the latest technologies. Markets for the necessary raw materials and supporting technologies (such as DC lamps) were also not well developed.

The situation has recently changed, as a few superstars have entered the domestic market in recent years, requiring domestic competitors and suppliers to match quality and price or lose out. The brightest rising star is Suntech, founded by an Australian-trained Chinese engineer who returned to China with several of the latest patented advances and started his own PV solar cell production business. Suntech increased its capacity 12-fold in three years and developed technologies that compete favorably with leading global brands.[81] It enjoys year-on-year growth of 163 percent, and was recently listed on the New York Stock Exchange.[82] The company has constructed a leading global R&D facility that is working on second and third generation technologies, and has increased

[80] Tang, Yuankai. "Solar Power Shines," *Beijing Review*, 02. March 2006.
[81] Liu, Yingling, "Brain Gain in China's Solar Cell Sector," Worldwatch Institute's Chinawatch Environmental News Service, www.worldwatch.org, 22. Dec. 2005.
[82] *Ibid.*

sun capture efficiency to 16-17.8 percent, in line with global standards.[83] Meanwhile, while the number of domestic PV manufacturers has doubled between 1998 and 2004, most subsist on far smaller sales volumes and older versions of the technology.

Suntech benefited early on from direct government support for its founding and R&D efforts, as well as from a large supply of cheap labor and a sizeable and growing global market for its products. It maintains high profit margins in part because production costs in China are low and concerns about copying by competitors has so far not impeded success. Demand for Suntech's products is projected to grow further if government pledges to raise significant funds for renewable energy investment are realized, creating opportunities for domestic firms. [84] Beijing has plans to build a "solar street" and Shanghai aspires to cover 100,000 roofs with solar panels by 2007,[85] and price is likely to dictate that much of the technology is supplied by domestic firms.

Wind power is also gaining ground with help from targeted government initiatives, such as the allocation of "wind concessions" to attract investment. Jiangsu province recently announced plans to expand its Rudong County Wind Farm to become the world's largest, suggesting government incentives to encourage investment are working, though whether or not the wind park will be financially sustainable remains unclear. Investors in wind power are a mixture of domestic and foreign, with the domestic producers still generally lagging behind in terms of production capacity, but offer a cost advantage.[86] Wind power is becoming more attractive overall as costs have decreased at an annual rate of 15 percent, partially in response to technological advances made in recent years, and costs are expected to fall even faster as more Chinese producers enter the market. Spanish power company Endesa and China's Huaneng Group recently announced a deal under the Kyoto Protocol's Clean Development Mechanism that would allow Endesa to gain emissions credits by building a wind power generation facility, and most of the technology is expected to be supplied by domestic manufacturers.[87]

China is estimated to have the largest potential for hydropower energy production in the world, and expanding hydropower has long been a major goal of Chinese energy producers, as witnessed in gigantic projects such as the Three Gorges Dam.[88] China's energy planners have announced targets to expand hydropower's contribution to energy production for 2002 levels of 84 GW to 125 GW in 2010, supplying 25 percent of the nation's electricity. [89] Technology choices are made by plant designers and often influenced by government technology standards. Most of the technology for large projects originates overseas in the U.S. and UK. However, China has been a prolific manufacturer of small hydropower plants since pre-reform electrification projects

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[83] *Ibid.*

[84] A senior official at the Beijing Renewable Energy Conference, Nov. 7-8, 2005, said that the government had pledged to raise $180 billion for investment in renewable energy sources, which was reported in *Xinhuanet* and other publications, "China to raise $180 billion for renewable energy projects," 07. Nov. 2005, *Xinhua Online* (ChinaView), www.chinaview.cn.

[85] Liu, Yingling, "Shanghai to Embark on 100,000 Solar Roofs Initiative," Worldwatch Institute's Chinawatch Environmental News Service, www.worldwatch.org, 10. Nov. 2005.

[86] Liu, Yingling. "Jiangsu to Build World's Largest Wind Farm," Worldwatch Institute's Chinawatch Environmental News Service, www.worldwatch.org, 31. Oct. 2005.

[87] Liu, Yingling. "Chinese Power Giant to Sell Carbon Dioxide under CDM Contract," Worldwatch Institute's Chinawatch Environmental News Service, www.worldwatch.org, 23. Jan. 2006.

[88] GTZ China Renewable Energy Study, 11.

[89] *Ibid*, 13.

encouraged the construction of small dams. The industry now exports homegrown models worldwide, but the basic designs have not changed much and have drawn criticism for poor quality.[90]

Using biomass to generate energy has been embraced primarily in the agricultural sector, and is subsidized by the government at 0.25 RMB below the cost of equivalent desulfurized coal-generated on-grid power.[91] Research and pilot projects in this area are carried out primarily through agricultural university collaborations, some with international partners, such as the partnership between China Agricultural University and Cornell University to build a fully energy self-sufficient industrial cattle farm complex relying to some extent on domestic technology.[92] Geothermal energy is also likewise being undertaken on a limited scale. Technologies for geothermal pilot projects are still mostly imported and funded by grants such as a U.S. Trade and Development Agency program to support U.S.-based Jacwill Services Incorporated to collaborate with Beijing Jike New Technology Development Company in conducting feasibility studies for heating and cooling applications.[93]

Overall, renewable energy's greatest domestic achievements in terms of innovation lie in the solar and wind power sectors. In both cases, cost advantage, plans for rapid expansion, and provisions for including domestic suppliers seem to be an important driver of investment, as Chinese producers can undercut foreign counterparts while supplying a sophisticated product. This local innovation is encouraged by stronger recognition of intellectual property (IP) rights and the rapid pace of technological change globally that leaves low-tech copycat competitors behind. Yet despite the fact that exceptional cases reflect the highest global standards, many domestic wind and solar equipment providers still do not operate at the frontier and lack the capital to invest in R&D. Other forms of renewable energy still rely almost exclusively on foreign technology, either as a result of aid agreements, limited market potential, or the highly specialized nature of the projects.

G. Automobiles

After twenty years of virtual absence and then a slow start in the early reform era, China's automotive industry has taken off only in the past ten years. Driven by economic growth and dreams of car ownership, demand for vehicles is expected to increase further, from 18.01 million in 2001 to 40 million in 2010 and 75 million in 2020.[94] This has inspired concerns over rising reliance on foreign oil and increased emissions that will compound China's severe urban smog problem. As a result, cleaner automotive technology is gaining the attention of energy planners. Despite historical weaknesses in

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[90] *Ibid*, 12.

[91] Li, Zijiun. "China's Renewable Energy Law Takes Effect; Pricing and Fee-Sharing Rules Issued," Worldwatch Institute's Chinawatch Environmental News Service, www.worldwatch.org, 18. Jan. 2006.

[92] Conversation with the President of China Agricultural University, Aug. 2005.

[93] "Energy Efficiency and Renewable Energy Technology Development in China: Geothermal Energy Production and Use," National Renewable Energy Laboratory Website, International Programs, www.nrel.gov.

[94] Mao, Zongqiang. "Hydrogen Energy – For Transportation Sector In China," Work Sponsored by the China National Hydrogen Project, Prepared for the International Hydrogen Energy Congress and Exhibition, 13.-15. July 2005, 3.

innovation capacity, there are signs that Chinese manufacturers and joint venture partnerships are succeeding in the development of cutting edge motor vehicle technologies that could have broad applications in China's nascent but rapidly growing market.

Following the development of the first automobiles in the United States, China began very limited imports, but no foreign auto makers invested directly on the mainland. This left little foundation when, after 1949, China launched its ambitious industrialization program and welcomed transfer of automotive technology from the Soviet Union. When relations with the U.S.S.R. turned frosty in 1960, the tiny industry all but disappeared for the following two decades. In 1963, 11 cars were produced in the whole country.[95] The industry was revived in the early years of the reforms, and in 1984, the government established a policy to encourage JV formation and license technology from overseas to jump start production according to modern standards. To create a market, the government allowed private citizens to purchase cars. However, 1984 industry regulations did not require transfer of know-how along with technology, and China's many small automotive manufacturers, which lacked R&D departments and capital, were hardly in a position to assimilate it.[96]

In 1994, China's policy emphasized consolidation of the automotive industry to mirror the U.S. or European situations, restricted foreign involvement to favor domestic producers, and required JVs to contract at least 40 percent of parts production to domestic suppliers. This last requirement had the effect of creating a strong components manufacturing industry (that even began to export products), but innovation in vehicle technologies remained very weak. Nevertheless, rising demand led the domestic automobile industry to grow at 18 percent per year through the 1990s, a rate that has since accelerated to around 60 percent.[97] Yet until the last few years, most automotive technology originated abroad and was frequently outdated in its country of origin. In negotiations leading up to WTO entry in 2001, China agreed to drop its protectionist stance and in May 2004, reinforced its commitment to encouraging a competitive market, strengthening domestic R&D, and promoting itself as a major global automotive manufacturer. Today, the automotive industry is a mainstay of economic stability, providing jobs and ensuring demand for raw materials and manufactured parts.

Only since the late 1990s has China's automotive industry begun to reap the benefits of homegrown innovation. Government programs such as the "863" Program and others provide targeted funding to develop cleaner, more energy efficient automotive technology. These efforts began to pay off by the late 1990s, and have yielded several impressive advances in the area of hybrid technologies and fuel cells. Some of China's most promising breakthroughs are in the area of hydraulic and electric hybrid vehicle technology. The Chargeboard Electric Vehicle Company Ltd. was the first company to develop an energy efficient braking retrofit for diesel buses that reduces fuel consumption by 30 percent and thereby cuts emissions by 20 to 70 percent.[98] The government plans to

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[95] Gallagher, K.S., "Innovation and Learning in the Chinese Automobile Industry Through Technology Transfer," Paper given at Globalics Conference, Beijing, China: 18. October 2004, 7.
[96] *Ibid*, 22.
[97] *Ibid*, 1.
[98] "New Buses Could Help Beijing Cut Fuel Intake." *People's Daily Online*, www.english.people.com.cn, January 3, 2006.

provide preferential support for the technology, which is completely Chinese-owned IP, to introduce it initially into a select group of Beijing's bus fleet. Electric hybrids are also expected to be launched in China's market soon, as a GM-Shanghai Automotive Industry Corporation partnership prepares to launch a hybrid bus, and Toyota proceeds with plans to roll out its Prius.

Research to develop fuel cell technology is also very strong. In 1999, Beijing Fuyuan New Technology Development Corporation along with Tsinghua Automotive Engineering Department has been the first to develop a fuel cell powered vehicle prototype in China. Shenli-Beijing LN Power Sources Technology Ltd. has also developed fuel cell technology and has showcased several hydrogen powered test vehicles.[99] Indeed, government funding here is relatively strong, with 380 million RMB allocated to fuel cell research during the Tenth Five Year Plan, with much of the funding dispensed to universities, research institutes, or new technology industries. Shanghai and Wuhan also have research groups working on fuel cell passenger cars. GM-SAIC and DaimlerChrysler are also developing fuel cell technology for the Chinese market.

Patterns of innovation in China's automotive industry have been influenced by several main factors. Unlike most industries in the developed world, China's automotive industry started from zero in the early 1980s and had to compete with overseas industries that had just experienced major growth and rapid technological advances over the previous decades. The fact that the market is characterized by a large number of small automakers means that individual firms cannot capitalize on economies of scale, or fund extensive in-house research departments. It wasn't until after 1994 when GM-SAIC set up the Pan-Asian Technical Automotive Center in Shanghai that companies began to develop in-house R&D, and even then, the GM-SAIC partnership remained unique among its competitors. Indeed, most research remained housed in research institutes and in a few cases, universities, reminiscent of the pre-reform situation.

Competition in the automotive sector is driving investment in technologies that are cheaper and more sophisticated, as well as boosting responsiveness to customer needs. Unlike other sectors (such as oil and NCH) where a few state-owned companies dominate, the automotive sector is increasingly characterized by competition for a stake in a rapidly growing market. Reductions in the number car purchases resulting from rising pump prices overseas have increasingly led many major automakers to substitute cheaply manufactured parts from China. Whether or not an increased demand for Chinese-made parts stimulates innovation will depend largely on customer willingness to pay a premium for fuel efficiency and better features. Therefore, following WTO entry and exposure to full international competition, China's automotive sector may shrink as expected but suppliers and private high technology development companies are well positioned to survive and may even grow more inventive to undercut competitors.

Environmental regulations are also expected to play an important role in technology choices, and in particular may restrain JVs from introducing technology that no longer meets environmental standards or has been otherwise phased out in its country of origin. Furthermore, environmental regulations or financial incentives that favor the purchase of vehicles that employ cleaner technologies could help to hasten the introduction of hybrid or fuel cell powered vehicles.

[99] Mao et al., 3.

Costs will certainly be a factor in decisions to adopt new technologies. Although it is likely that advanced proprietary technologies will continue to be imported for certain JV projects, it is equally likely that China's developers will take full advantage of the manufacturing opportunities available. This may make certain technologies, such as electric cars, more cost effective over the long run, perhaps even in comparison to other countries, if domestic innovators can partner effectively with local manufacturers. The initial success of China's developers in demonstrating electric technology that is far ahead of the U.S. industry when it was abandoned in the 1980s has attracted the attention of U.S. firms and importation of the first products—mostly scooters—has recently begun.

H. Motor Systems

Motor systems are integral to the operation of industrial enterprises and consume over half of the electricity produced in China. China is a major producer and user of motor systems components, most of which are less efficient than those produced overseas. In general, China's electric motors are 2-4 percent less efficient than those used in the U.S. or Canada.[100] Optimizing efficiency of 50 percent of China's electric motors would result in an estimated 20 percent in reduction in electricity consumption in the sector and 5 percent nationwide.[101] Annual savings from such improvements would approach U.S. $4 billion and result in declines in CO_2 emissions by 25 million metric tons.[102] However, innovation in the motor systems industry remains hindered by artificially low electricity prices that discourage increases in efficiency awareness and investment. This section focuses on innovation in pump and fan designs in particular, which together account for 40 percent of the electricity consumption of motor systems.[103]

The pumps and fans markets in China have an abundance of suppliers that face stiff competition both domestically and internationally. Chinese manufacturers can be divided into four categories based on product quality, size, and overall quality of service: high class, medium class 1, medium class 2, and low class.[104] High class and medium class 1 manufacturers typically produce efficient models and are subject to standards testing, while medium class 2 and low class manufacturers are not. However, many high and medium class 1 manufacturers have started to reserve their high quality products for export, as they can compete favorably with counterparts abroad where manufacturing costs are higher. After WTO entry, Chinese manufacturers have been able to increasingly sell high quality products in overseas markets, but domestic demand for these products remains low. The NDRC, which sets electricity prices, indirectly has perhaps the greatest control over innovation in this market, since adoption of advanced technologies depends on the extent manufacturers will gain from efficiency improvements.

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[100] Steven Nadel, Wang Wanxing, Peter Liu, Aimee McKane. "The China Motor Systems Energy Conservation Program," Report by Lawrence Berkeley National Laboratory, Industrial Partnerships Department, 1.

[101] Adam Hinge, Steven Nadel, Dai Yande, Zhang Jin Lan, and Sun Chunxuan. "Chinese Market for Electric Motors and Motor Speed Controls," Report by American Council for an Energy Efficient Economy, 1997. / *Ibid*, 1.

[102] Nadel et al., 2.

[103] "Study of Pumps and Fans Market in China," Prepared by CERF/IIC Asia for Lawrence Berkeley National Laboratory and ACEEE, Dec. 2002, 5.

[104] *Ibid,* 19.

A number of reform era developments have helped to encourage the development and uptake of more efficient products. Awareness of the importance of efficiency is slowly increasing, and some universities, research institutes, and design institutes have begun to conduct research or feasibility studies on ways to adapt technologies to maximize efficiency gains. The creation of standards organizations has provided a mechanism for certifying products. The 1998 Energy Conservation Law and the founding of centers (such as the Chinese Mechanical Industry Energy Saving Center) and other consulting organizations are helping to raise awareness of the benefits of adopting more efficient technologies, though observers point out that national policies to promote efficiency are still not well developed or coordinated.[105]

According to a study conducted in 2000, of all pumps and fans installed in China, fewer than 30 percent equal or exceed the average European efficiency standard.[106] Innovation in the domestic market remains weak—most specialized, highly efficient fans and pumps are purchased from overseas (often for customized plants built by foreign companies), while high quality versions produced domestically are destined primarily for export. Also exported are low quality fans that compete favorably in overseas markets, mostly in Southeast Asia and several other developing countries. Most low quality fans, however, are purchased in China's domestic market, and are often particularly attractive for agricultural users or small manufacturing operations trying to minimize their costs. Original technology development is further discouraged by the rapid appearance of copycat models, which often employ cheaper materials to hasten market introduction.[107] According to the same study, manufacturers rarely considered pump efficiency when formulating their competitive strategies. Interviews with sales representatives revealed that customers did not care about product efficiency, and several were completely unfamiliar with the concept.[108]

The pre-reform policy of maintaining artificially low electricity prices to stimulate industrial investment and ensure affordability for residential users has also discouraged investment in energy efficient technology. Cutthroat competition in the manufacturing sector means that few companies have resources to front for energy saving technologies despite potential cost savings, and obtaining financing through loans or other means requires precious time and expense. Under these circumstances, suppliers face few incentives to invest in R&D in the absence of domestic market demand, allowing the low pre-reform levels of industrial R&D to persist. An exception can be made for those companies developing technologies for export. Shenyang Blower Works, a state-owned enterprise that collaborated with a CAS institute and six Chinese universities to develop an advanced computer-integrated manufacturing system, the sales of which helped earn Shenyang Blower Works a position among the top 10 manufacturers in its field worldwide. However, despite the company's success in technology development—which is attributed to its entrepreneurial strategy in the wake of reforms—as of the late 1990s it

[105] Conversation with leader of GTZ project to advise local governments on how to improve incentives for the construction of energy efficient buildings, GTZ Beijing Office, April 2006.
[106] *Ibid*, 6.
[107] *Ibid*, 14.
[108] *Ibid*, 25.

still depended on overseas suppliers of advanced parts and is not representative of the industry in China more generally.[109]

Market competition among manufacturers of fans and pumps for the domestic market further squeezes R&D budgets, which are directed toward cost savings, not energy saving innovations in the absence of widespread domestic demand. Innovative activities are directed at reducing overall costs to consumers, though would-be innovators often have to contend with copycat technologies shortly after a new product is released.

Environmental regulations and other state interventions are playing an increasingly important role in creating demand for energy efficient products. The Chinese Mechanical Industry Energy Saving Center makes technology recommendations and pushes for efficiency improvements. The main intervention likely to affect industrial technology adoption decisions will be China's Medium and Long Term Energy Conservation Plan, which is divided into two phases, 2006-2010 and 2010-2020. The plan envisions a series of incentives for industries to adopt energy saving technologies, both to mitigate risks of future power shortages and reduce overall energy consumption, and may be critical to encouraging further gains in the efficiency of motor systems.

V. Conclusions

Factors Affecting Innovation

The strengths and weaknesses of China's national system of innovation help to explain patterns of technological change in China's energy sector. While patterns of both technological innovation and adoption can be largely explained by the same set of factors, their influences are distinct and described briefly in Table 1. Reforms since 1978 have played a major role in enabling China's emerging innovators, but the penetration and effectiveness of reforms has varied across industries, with corresponding discrepancies in innovation performance.

Government industrial policy, both in general and R&D policy in particular, plays an important role in creating conditions in which technological innovation can thrive. Prior to the 1978 reforms, the separation of research and production activities resulted in universally low levels of innovation. When the Soviet model was gradually abandoned in the early 1980s, formerly isolated research units grew more commercially oriented as spin-offs, transformed enterprises, or service providers. Equally important to the success of this transformation was the ability of production units to absorb new technologies effectively. The process has further benefited from a strengthening of incentives outside of R&D policy, such as an overall transition from government to market-based control, as well as greater transparency, reduced corruption, and the strengthening of intellectual property rights. However, this process is far from complete.

Innovation is strongest in industries that have been able to take advantage of incentives created by post-1978 S&T reforms, including targeted public R&D funding, management reorientation, and spin offs or novel partnership opportunities. Technologies as diverse as Tsinghua's high pressure gas-cooled reactor, Suntech's solar cells, and the Chargeboard Electric Vehicle Company's diesel bus retrofit are all products of this new class of enterprises that have emerged since the reforms began. For these enterprises, IP

[109] Oldham et al., Ch. 8.

protection is critical to preserve incentives for continued innovation, particularly in industries where competition is cutthroat and copying is widespread. On the other hand, in traditional enterprises where R&D capacity has been historically weak, research is often carried out by a large number of specialists and often spills over to include research institutes or universities, as in the case of China's large petrochemical or mining companies. Companies may not feel pressure to cut personnel due to welfare concerns and low labor costs, while a steady supply of educated manpower may reduce the need to adopt or develop labor-saving technologies. It is in these industries—oil and NCHs, electric power, and natural gas are key examples—that innovation remains low and reliance on foreign technology for cutting edge applications is likely to persist.

In the energy sector, the government's twin priorities of reducing urban pollution and dependence on foreign oil have directly influenced the national R&D agenda. Funds allocated through the "863" Program and others have aimed at developing liquid fuel alternatives and other cleaner, safer energy technologies, including direct and indirect liquefaction, a fourth generation nuclear reactor, cleaner vehicles, and improved wind and solar power technology. In addition to influencing government research priorities, high global oil prices also directly impact the economic incentives for innovation, for example, as reductions in car sales lead the automotive industry to substitute cheaper parts, often from manufacturers in China. This trend may not necessarily spur innovation in clean energy technologies, however, unless consumers are willing to pay a premium (at least initially) for highly efficient vehicles. High petroleum prices and government energy priorities have also encouraged China's major petroleum companies to pursue international partnerships for further developing overseas technology and expertise to exploit more marginal reserves of coal bed methane and oil shale. Environmental regulations have only recently been more stringently enforced, and were not observed to have any strong effects on original technology development.

Factors Affecting Adoption

When examining patterns of technology adoption, several trends can be attributed to the pre-reform institutional legacy. Historically low corporate R&D capacity has led many industries rely on imported or older, more labor-intensive technologies. Weak intellectual property protection persists, and has led overseas developers to introduce older versions of technologies, as in the case of auto parts or natural gas turbines, or not enter the market at all. Low energy tariffs are designed to protect consumers, but discourage efficiency improvements. Government intervention remains strong, though incentives and recommendations have largely replaced mandatory directives.

Market competition, technology costs, and environmental regulations go hand in hand in determining patterns of technology adoption. Enterprises in competitive industries operating on tight budgets generally spend more on marketing than R&D, and often face difficulty obtaining loans, which discourages risky or slow payback investments. Less competitive industries (such as oil and NCHs or nuclear) or larger companies in competitive industries are able to afford riskier, longer term investments, often with government support. A preference for cheaper alternatives often means that domestic technologies are preferred when available, sometimes even if the quality is lower compared to imports—though notably in the power sector this is not the case, as quality and reliability are seen as crucial to maintaining a stable supply. For the oil and NCH, natural gas, and larger mining enterprises, low competition and the relative reliability of internal bureaucracy funding sources makes riskier technology purchases more possible, particularly with supportive state intervention. In competitive industries, strengthening environmental regulations may help to overcome high price deterrents to cleaner or safer technology adoption by setting minimal standards for compliance. The effectiveness of this approach is hindered by weak enforcement, which is in part due to the fact that local environmental protection bureaus belong to the local governments, which control their staff and budgets, instead of answering directly to the national-level SEPA, which sets regulations.

Fixed gas and electricity tariffs also stifle demand for costlier, cleaner or more efficient technologies. Though energy planners are eager to encourage sharp rises in the percentage of China's electricity supplied by natural gas, nuclear power, and renewable sources, power producers are expected to rely on cheaper coal unless alternatives are attractively priced. In regulating supply and demand, transmission companies tend to purchase energy from the cheapest supplier given that they must charge fixed prices to consumers. The rising world prices for natural gas imports and higher costs of renewable energy generation therefore discourage investment in these sources. Disproportionately low prices for gas sold directly to industrial and residential users also discourage investments in both natural gas and the accompanying transportation and infrastructure requirements. Indeed, the costs of transporting fuels to end user locations are significant and must be spread among upstream suppliers, power producers, and transmission companies, raising the cost of supplying distant locations. The financial attractiveness of a particular energy source thus depends in part on the location of the end-user market.

The weaknesses in China's own innovation system have further prevented new technologies from spreading more widely in China. The need for local "absorptive" capacity, or the know-how and experience needed to fully integrate the technology into existing processes, is well-documented and accounts for limited diffusion of efficiency-enhancing technologies, particularly in the pumps and fans and automotive industries. Absorptive capacity is critical for enterprises that acquire technologies from external sources, such as universities and research institutes. However, enterprises must possess a baseline level of knowledge and experience to take advantage of such transfers.

Lessons for International Cooperation

A number of bilateral and multilateral cooperation efforts have attempted to introduce clean energy technologies into the Chinese market. Rationale for these efforts ranges from helping home country producers gain a foothold in overseas markets to mitigating environmental impact, and is often some combination of both. Based on observations of China's national innovation system, whether or not transferred technologies are widely applied or further developed depends on several factors. This final section assesses the effectiveness of several international cooperation efforts by drawing on the patterns of innovation observed in China's energy sector.

Picking the right in-country partner and involving local suppliers is essential to the success of collaborative efforts to promote widespread diffusion of clean energy technologies. This is no easy task in China, where the centers of innovation have shifted substantially over the last twenty years in response to reforms. R&D has moved out of the pre-reform structures through spin-offs, reclassification as enterprises, or outsourced industrial R&D, with patterns varying by industry. In industries where corporate R&D is weak or outsourced, suppliers and institutes or university partners may be better points of contact for deploying technologies. For example, a U.K. study that evaluates clean coal technology transfer initiatives describes a Japanese effort to transfer clean coal technologies initiated by the Ministry of International Trade and Industry (MITI) under the Green Aid Plan, US $338 million was spent on carrying out plant demonstration projects.[110] Equipment was provided by Japanese suppliers, but few follow up orders were received, largely because the technologies were too expensive and not tailored to needs of the Chinese market.[111] The JETRO (Japanese External Trade Organization) defended excluding suppliers on the grounds that design institutes, and not manufacturers, housed the expertise needed to assimilate the technologies, and Japanese partnerships with the former were sufficient to orchestrate the transfer. However, design institutes often rely on stock designs that do not easily accommodate unfamiliar technology. Japanese companies also hesitated to transfer technologies due to concerns that low-cost competitors would rapidly emerge. In practice, however, local design needs and the high cost of imported products ultimately limited diffusion, and as a result, Chinese manufacturers were included in the GAP in 1999. Primary contacts between MITI and the Chinese State Development Planning Commission (precursor to the NDRC) also limited communication between Japanese equipment suppliers and Chinese users. Indeed, many Japanese industry representatives suggested that direct partnerships with Chinese users were the preferred and most successful path of market entry, but that the GAP was helpful for establishing and maintaining these partnerships.[112]

The success of international collaborative efforts also depends on complimentary policies outside of R&D to foster incentives for innovation and international collaboration among China's R&D centers. For example, the fact that governments are allowed to hold retail prices for natural gas artificially low has reduced incentives for increased fuel purchases and infrastructure investment. Policies that allow retail prices to rise or subsidize the operation of natural gas plants would favor adoption of this cleaner source. The same is true for cleaner coal technologies that are more expensive to operate than their dirtier counterparts, as the former will be brought online first and, due to concerns about the instability of supply, existing proven technologies may be preferred over newer, cleaner ones. Despite the best of intentions, international collaborative efforts to promote cleaner fuel sources or technologies will run aground if they do not consider existing incentives for and constraints to their adoption in China's market.

Another important complimentary policy is the enforcement of intellectual property rights. For example, when U.S. company Combustion Engineering licensed its coal-fired boiler technology to Ministry of Electric Power, its IP was subsequently widely disseminated, leaving no recourse for recovery of licensing revenues.[113] This experience

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[110] Demonstration projects included "energy savings projects, cleaner coal projects, and electric power desulfurization projects." The following discussion is based on a report by Watson, Jim, Xue, Liu, Oldham, Geoffrey, MacKerron, Gordon, Thomas, Steve, (2000) "International Perspectives on Clean Coal Technology Transfer to China," Report to Working Group on Trade and the Environment, CCICED, 38-46.
[111] *Ibid.*
[112] *Ibid.*
[113] Watson et al., 22.

led its competitor, Mitsubishi-Babcock, to work directly with individual component manufacturers through its wholly-owned local trading company. Although perhaps inconsistent with bilateral programs focused on promoting exports, this model has proven successful in several cases. In another case, the Ministry of Machine Industry was eager to secure a country-wide license for highly efficient boiler technology as part of a World Bank Global Environment Fund (GEF) project, a prospect which—along with several technical concerns—discouraged many potential suppliers from participating.[114] However, there are signs that China's intellectual property protection is growing stronger, as the government clarifies legal requirements for seeking recourse. If these trends are any indication, intellectual property may not be as strong a barrier to foreign technology transfer in the future. Other complimentary reforms, such as improved transparency and reduced corruption, are also important to create favorable conditions for international collaborative efforts.

China's government and local partners must also be open and willing to support technology diffusion efforts. Though this may seem obvious, many partnerships aimed at introducing imported technology into the Chinese market have foundered because local economic incentives for adoption were low and diffusion strategies one-sided. In cases where price is a deciding factor, involvement of local suppliers in China may be critical if end users are ultimately going to be willing to purchase the technology, though this may undermine the originator's goal of developing its own export markets. Both Japan's GAP and the UK's Cleaner Coal Technology Transfer and Export Promotion Program initially emphasized the role of external suppliers, and local partners have only played a limited role in shaping the agenda, as most of the arrangements are made between governments, with suppliers involved only later. It is therefore important that collaboration is preceded by an assessment of willingness or need to adopt a particular technology.

Perhaps most importantly, the success of international collaborative efforts depends on the innovation performance of China's own enterprises. Although enterprises in many industries are eager to gain access to international partners and expertise, they may not be prepared to absorb the technologies for a variety of reasons. Where the historical legacy of low performing R&D persists—for example, in oil and NCHs, electric power, large mining enterprises, natural gas, and motor systems—imported technologies may diffuse more slowly. If the overseas partner provides all technology and expertise with minimal participation of its local counterpart, the technology may not be readily available (either for licensed use or development purposes) to other potential users, limiting its effectiveness in mitigating the environmental impact of energy production or use on a large scale. In cases of immature or cutting edge technologies, the existence of local capacity is critical to convince China's energy planners that a technology can be successfully implemented, maintained, and even replicated after international partners have withdrawn. In the case of China's IGCC power plant project, for example, government investments in local training and capacity building occurred simultaneously with feasibility studies and financing negotiations for the plant. After ten years, the fact that engineers in China now have significant expertise in component technologies has given local partners an important stake in its construction even as international financial support remains uncertain.

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[114] Watson et al., 55. For more information on the program, see "China GEF Energy Conservation II," World Bank Project Description, PID10757, 14. Sept. 2001.

China's present energy policy priorities are focused on shifting away from reliance on foreign oil and reducing sulfur and particulate emissions through use of cleaner and more efficient technologies for energy production and use. Commitments to reducing carbon emissions are not yet in place, but may play an important role in the future. So far, partnership strategies have not focused extensively on carbon mitigation strategies, with the exception of EU and U.S. efforts to support carbon capture technologies, both of which are still in the early stages. If technologies to reduce carbon emissions are prioritized in the future, the patterns of innovation in China's energy industries—particularly the most carbon-intensive—will affect how widely these technologies are adopted. This paper has identified several important categories of factors—pre-reform legacy, market competition, global energy prices, technology costs, and environmental regulations—that will likely have the greatest influence on observed patterns of technology adoption and original development in China over the next several decades, when large amounts of new capital stock will be acquired. The success of international collaborative efforts will depend on the involvement and support of local partners, favorable domestic R&D and other complimentary polices, and the innovation performance of China's own R&D centers.

References

A Decade of Reform: Science and Technology Policy in China. IDRC Canada, www.idrc.ca, 1997.

Adam Hinge, Steven Nadel, Dai Yande, Zhang Jin Lan, and Sun Chunxuan. "Chinese Market for Electric Motors and Motor Speed Controls," Report by American Council for an Energy Efficient Economy, 1997.

Advanced Power Generation Technologies: Integrated Gasification Combined Cycle (IGCC)," www.coal21.com.

Aldhous, Peter. "China's Burning Ambition," *Nature*, Vol. 435, 30. June 2005.

Andrews-Speed, Phillip. "China's Energy Woes: Running on Empty." *Far Eastern Economic Review*, June 2005.

"China and EU Sign Clean Energy Partnership," Updated 07. Mar. 2006. *EurActiv*, Sustainable Development, 05. Sept. 2006.

"China becoming a major natural gas nation," *China News*, chinanews.com.cn, Sept. 5, 2005.

China Country Analysis Brief. U.S. Department of Energy, August 2005.

"China GEF Energy Conservation II," World Bank Project Description, PID10757, 14. Sept. 2001.

China Liquefaction Plans on China's Clean Coal Research page, www.ccri.com.cn.

"China: Power Generation," U.S. Commercial Service, U.S. Department of Commerce, www.buyusa.gov.

"China's Electric Power Sector to Reach Growth Limit," 05. May 2005, Asia Times, www.atimes.com.

"Coal Industry Investment: Outlook to 2030," Workshop Summary from the World Coal Institute, www.iea.oeg.

"Coal Liquefaction to Get Major Investment," *China Oil News*, oilnews.com.cn, 10. Feb. 2006.

"Coal Mining Equipment Market in China," U.S. Commercial Service, U.S. Department of Commerce, www.buyusainfo.net.

Conversation with a Professor of Economics at Rutgers, Feb. 2006.

Conversation with a representative of a major U.S. oil company, Jan. 2006.

Conversation with Director, Tsinghua-BP Clean Energy Center, Feb. 2006.

Conversation with a research director at China University of Mining and Technology, Jan. 2006.

Conversation with Former Head of the Science and Technology Research Unit, Univ. of Sussex, Jan. 2006.

Conversation with Senior Economist, Chinese State Environmental Protection Administration, Feb. 2006.

Conversation with a representative of a major U.S. oil services company, Beijing, China, Feb. 2006.

Conversation with the Deputy Director of Overseas Oil and Gas Engineering Center, China University of Petroleum, Jan. 2006.

Conversations with faculty at China Agricultural University, China Petroleum University, and China University of Mining and Technology, Sept. 2005 – Jan. 2006.

Conversations with several CNPC (PetroChina) representatives at the China-U.S. Relations Conference Research Roundtable on Non-conventional Hydrocarbons, 16. Nov. 2005.

Conversation with a Representative of China National Center for Biotechnology Development regarding EU-China joint research funding programs, Feb. 2006.

"Deng Xiaoping," Microsoft Encyclopedia Encarta Online, referenced on March 1, 2006. www.encarta.msn.com

"Energy Efficiency and Renewable Energy Technology Development in China: Geothermal Energy Production and Use," National Renewable Energy Laboratory Website, International Programs, www.nrel.gov.

Fisher-Vanden, K., G. Jefferson, H. Liu, and Q. Tao, 2004 "What is Driving China's Decline in Energy Intensity." *Resource and Energy Economics*.

Gallagher, K.S., "Innovation and Learning in the Chinese Automobile Industry Through Technology Transfer," Paper given at Globalics Conference, Beijing, China: 18. October 2004.

Gallagher, K.S., "Innovation and Learning in the Chinese Automobile Industry Through Technology Transfer," Paper given at Globalics Conference, Beijing, China: 18. October 2004.

Gu, Shulin. China's Industrial Technology: Market Reform and Organizational Change. Routledge, UK, 1999.

Hu et al. A Great Wall of Patents: What is behind China's recent patent explosion?" Working Paper, people.brandies.edu/~jefferso, 20. Dec. 2005.

Huang et al. (2004) "Organization, Program, and Structure: An Analysis of the Chinese Innovation Policy Framework." *R&D Management*, 34 (4).

Integrated Resource Planning in the Context of China's Electricity Situation. Paper by the Regulatory Assistance Project for the China Development Forum, June 2005.

Jefferson, Gary and Jian, Gao. "Science and Technology Takeoff in Theoretical and Empirical Perspective," Working Paper, 30. Apr. 2005, http://people.brandeis.edu/~jefferso.

Keeley James. (2003) "The Biotech Developmental State? Investigating the Chinese Gene Revolution." Institute for Development Studies Working Paper 207.

Kong, Xinxin. (2003) "Corporate R&D in China: The Role of Research Institutes," Working Paper No. 179, Graduate School of the Chinese Academy of Social Sciences Institute of Industrial Economics.

"Law Drafted to Regulate Energy Sector," 27. Jan. 2006, *China Daily*, www.chinadaily.com.cn.

Li, Wenhua and Guodong Sun. Report of the Joint Workshop on the Cooperation in Clean Coal Technologies between the United States and China, Hangzhou, China, 2004.

Li, Zijiun. "China's Renewable Energy Law Takes Effect; Pricing and Fee-Sharing Rules Issued," Worldwatch Institute's Chinawatch Environmental News Service, www.worldwatch.org, 18. Jan. 2006.

Lin, Justin Yifu. 26. Feb. 2004. "Is China's Growth Real and Sustainable?" China Center for Economic Research. Working Paper E2004003. www.ccer.edu.cn.

Liu X. and S. White. (2001) "Comparing innovation systems: A framework and application to China's transitional context." *Research Policy*, 30:1092.

Liu, Yingling, "Brain Gain in China's Solar Cell Sector," Worldwatch Institute's Chinawatch Environmental News Service, www.worldwatch.org, 22. Dec. 2005.

Liu, Yingling, "Shanghai to Embark on 100,000 Solar Roofs Initiative," Worldwatch Institute's Chinawatch Environmental News Service, www.worldwatch.org, 10. Nov. 2005.

Liu, Yingling. "Chinese Power Giant to Sell Carbon Dioxide under CDM Contract," Worldwatch Institute's Chinawatch Environmental News Service, www.worldwatch.org, 23. Jan. 2006.

Liu, Yingling. "Jiangsu to Build World's Largest Wind Farm," Worldwatch Institute's Chinawatch Environmental News Service, www.worldwatch.org, 31. Oct. 2005.

Lu Yongxiang. (2001) "Construction of Chinese national S&T innovation system and latest advancements in science and technology in China." *Current Science*, 81 (8).

Mao, Zongqiang. "Hydrogen Energy – For Transportation Sector In China," Work Sponsored by the China National Hydrogen Project, Prepared for the International Hydrogen Energy Congress and Exhibition, 13.-15. July 2005.

Metha, Aashish. "Establishing the National Electricity Regulatory Commission," Technical Assistance Completion Report, Asia Development Bank, 31. August 2005.

Miramoto, A., and Ishiguro, C. "Price and Demand for LNG in China: Consistency Between LNG and Pipeline Gas in a Fast-Growing Market," Oxford Institute for Energy Studies, Jan. 2006, 10.

Motohashi et al. (2005) "China's Innovation System Reform and Growing Industry and Science Linkages." Discussion Paper 05-E-011.

"New Buses Could Help Beijing Cut Fuel Intake." *People's Daily Online*, www.english.people.com.cn, 03. Jan. 2006.

"Nuclear Power in China," World Nuclear Association, www.worldnuclear.org, Feb. 2006.

Pelham, Jack. "Ultra-clean Fuels from Coal Liquefaction: China About to Launch Big Projects." *Diesel Fuel News*, 22. July 2002.

"PetroChina, Shell Seal Gas Project," China Daily, 18. May, 2005.
Press Release: ChevronTexaco Worldwide Power and Gasification and China Petroleum and Chemical Corporation (Sinopec) Announce Agreement on Technology License," www.chevron.com, 18. Oct. 2002.

"Regulator Sets Target for China's Power Sector Reform," People's Daily, 26. Mar. 2003.
Review of the Coal Preparation Sector in China," Cleaner Coal Technology Program, U.K. Department of Trade and Industry, Project Summary 324, March 2002.

"Shell: Coal Gasification," *News Guangdong*, www.newsgd.com, 08. Nov. 2005.

Steven Nadel, Wang Wanxing, Peter Liu, Aimee McKane. "The China Motor Systems Energy Conservation Program," Report by Lawrence Berkeley National Laboratory, Industrial Partnerships Department.

"Study of Pumps and Fans Market in China," Prepared by CERF/IIC Asia for Lawrence Berkeley National Laboratory and ACEEE, Dec. 2002.

Suttmeier, R. and C. Cao. (1999) "China Faces the New Industrial Revolution." *Asian Perspective*, Vol. 23, No. 3.

Tang, Yuankai. "Solar Power Shines," *Beijing Review*, 02. March 2006.

"The China Motor Systems Energy Conservation Program: Establishing the Foundation for Systems Energy Efficiency," (2002) Report by representatives from Lawrence Berkeley National Laboratory, CECIC, UNIDO, ACEEE.

"The SERC During the 11th Five Year Plan: Building an Effective Regulatory Framework." Paper by the Regulatory Assistance Project for the World Bank and the Energy Foundation, Dec. 2004.

Tian, Mai. "First coal liquefaction centre set up in Shanghai," China Daily, 12. Mar. 2004.
Underground Coal Gasificiation, UCG Engineering Ltd. at www.coal-ucg.com.

Wei Li, "Impact of Economic Reform on the Performance of Chinese SOEs," 1980-1989. www.chinalawandpractice.com.

Xie, Wei and Stephen White. (2004) "Sequential Learning in a Chinese Spin-off: The Case of Lenovo Group Limited," *R&D Management*. 24 (4).

Yamaguchi, Kaoru and Keii Cho. "Natural Gas in China," Report for the Institute of Energy Economics of Japan, Aug. 2003.

Yi, Bian. "Nation Needs Renewable Energy Resources," *China Daily*. 30. Sept. 2005.

Yu Qin. China Business Law Bulletins: Water, Energy, and Petrochemicals.

Yugeng and Li, Jianmin. "Gas Industry Development Energetically in China [sic]," *China Development Gateway*, chinagate.com.cn.

Zhang, Zhongxiang. (2003) "Why Did the Energy Intensity Fall in China's Industrial Sector in the 1990s? The Relative Importance of Structural Change and Intensity Change," *Energy Economics* 25(6).

Zheng et al. (2000) "Efficiency, Technical Progress, and Best Practice in Chinese State Enterprises, 1980-1994." Working Papers in Economics, No. 30. Goeteborg University.

Zu, Boru. "Foreign Energy Giants Bid for Nuke Contracts," *China Daily*, 12. Sept. 2004.

Innovation in China's Energy Sector
By Valerie J. Karplus

Table 1. Explaining Patterns of Innovation in China's Energy Sector

Category	**Specific Factors**	**Influence on Technology Adoption**	**Influence on Technology Development**	**Lessons for International Cooperation**
Pre-reform Legacy	Weak corporate R&D	Favors adoption of imported technologies or compensation with greater manpower	Low absorption capacity for imported technologies Corporate R&D often supplemented by universities or research and design institutes	Need to transfer know-how along with technology Partnerships should focus on centers of outsourced innovation and suppliers in addition to corporate R&D
	IP protection	Threat of rapid copying may lead to introduction of outdated technologies; but enforcement may be improving	Reduced transfer of technology if protection is weak	Important to consider local market competition and price pressures when making technology transfer choices
	Low energy tariffs	Low energy tariffs discourage technology upgrades	Low demand for upgrades may reduce development incentives	Efficiency gains from transferred technologies will be undervalued
	Government intervention	Preferential financing arrangements for key sectors or projects	Research grants awarded to projects consistent with national priorities	Government can still strongly influence technology investment decisions
Market Competition	Low R&D budgets	Technology choices often based on price	R&D often weak in smaller enterprises	Clean energy alternatives must be priced competitively
	Price pressure	Focus on short term rapid payback technology investments	R&D directed toward technologies that reduce costs	Technologies with incremental benefits may be most successful
Global Energy Prices	Government desires reduced dependence on foreign oil	Large investments such as coal liquefaction plants become attractive	R&D focused on developing alternatives to oil	Technologies rejected elsewhere may be attractive options in China
	Demand for oil intensive products declines	Car manufacturers choose suppliers based on price rather than quality	Low demand may discourage development of high end products	Overseas orders for cheap parts will grow, depends on demand abroad
	Growing interest in marginal petroleum resources	Demand for technologies that aid marginal resource recovery	Large SOEs focus on developing or adapting technologies for marginal reserves	Increased demand for technology through partnerships with international oil companies
Technology Costs	Costs and licensing fees	Domestic suppliers have an advantage	Domestic R&D weak due to low recovery of costs of IP creation	Important to transfer know-how to domestic suppliers
	Low labor costs	Manpower can compensate for technology in some cases	Corporate R&D large, redundant in non-competitive sectors	Some labor-saving technologies developed abroad not cost competitive
Environmental Regulations	Incentives: tax breaks, subsidies	Improves competitiveness of clean energy technologies	Encourages investment in pilot projects, domestic R&D	Projects that capitalize on existing incentives will be more successful
	Penalties: fines, closure threats	Encourages implementation of cleaner technologies, depends on enforcement	Higher demand for clean energy technologies encourages domestic R&D, but efforts must be rewarded	Enforcement of environmental regulations key for long term adoption of clean energy technologies