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Is China ready for its nuclear expansion?

Yun Zhou [a,b,*], Christhian Rengifo [c], Peipei Chen [d], Jonathan Hinze [c]

[a] Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, 79 John F. Kennedy Street, Cambridge, MA 02138, USA
[b] Center of International Security and Studies at Maryland, School of Public Policy, University of Maryland, 4113 Van Munching Hall, MD 20742, USA
[c] The Ux Consulting Company, LLC, 1501 Macy Drive, Roswell, GA 30076, USA
[d] Department of Nuclear, Plasma, and Radiological Engineering, 104 South Wright Street, Urbana, IL 61801, USA

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ABSTRACT

China's rapid pace of nuclear energy growth is unique, and its impact on the global nuclear market as both a customer and potential future supplier is already tremendous and will continue to expand. It is crucial to understand this energy policy development and its impact on various global areas. Unfortunately, there is relatively limited English-language information available about China's nuclear power industry and its current development. This paper aims to provide a comprehensive assessment of the Chinese nuclear energy program and policy, reviewing its past, present, likely future developments, as well as to consider potential challenges that deserve further attention. This paper will explore reasons that have caused the existing industry, describe China's nuclear bureaucracy and decision making process to understand how different stakeholders play a role in China's nuclear energy development. This study concludes that China's existing nuclear program and industry, in combination with its current stable economic and political environment, provides a sound foundation for the planned nuclear expansion. However, challenges which are crucial to the success of the nuclear expansion will need to be addressed.

1. Introduction

The term "nuclear renaissance" is widely used to articulate the growing interest expressed by countries around the world to develop and increase the use of nuclear power to meet energy demand and reduce carbon emissions. However, there is one country in which the term nuclear renaissance is a full blown reality, and that is China. Nowhere else in the world are there such aggressive plans for nuclear energy development. This study provides an overview of the status and future prospects of China's civilian nuclear energy program and is divided into three main parts. The first part explains the transition of China's nuclear energy program from a military-oriented program to one that aims to help China meet increasing energy demands and reduce carbon emissions. The second part identifies the main stakeholders in the planning and implementation of China's nuclear energy program, and explains key issues, such as nuclear energy licensing and financing. The final part identifies potential challenges to the implementation of the nuclear energy plan and forecasts the likely outcomes.

2. The evolution of China's nuclear energy policies

2.1. Nuclear weapon era: 1955–1978

Before China had a nuclear energy industry, it had a nuclear weapons program.[1] After successfully testing its first atomic bomb in 1964, China made remarkable progress in the weapons field, launching its first nuclear missile in 1966 and detonating its first hydrogen bomb in 1967. The weapons program developed a complete industrial nuclear science and technology infrastructure. This infrastructure serves as the foundation of China's nuclear energy industry today. Furthermore, the military-oriented nuclear system continues to strongly influence the present-day civilian program.

The Cultural Revolution, which lasted from 1966 to 1976, disrupted the country's strategic weapons program, yet China's nuclear-related weapons and technology programs continued. In December 1970, China launched its first nuclear submarine, indicating its ability to develop nuclear power systems for military and civilian uses. During the weapons era, commercial nuclear development was not a priority and the development of nuclear technologies followed the principle of "self-reliance first, foreign assistance remains as a supplement".

* Corresponding author at: Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, 79 John F. Kennedy Street, Cambridge, MA 02138, USA. Tel.: +1 917 293 2114; fax: +1 617 495 8963.
E-mail address: yun_zhou@hks.harvard.edu (Y. Zhou).

[1] For the history, see the "Contemporary China's Nuclear Industry" (1987), the China National Nuclear Corporation history page: www.cnnc.com.cn/cnnc-history/20year3.htm.

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2.2. A slow transition: 1978–2005

In 1978, Chinese leaders decided to transform the Chinese economy from a Soviet-style, centrally planned economy to a more market-driven system. China shifted its major financial resources from its military activities to its economic activities. Military industries were converted to state-owned and -managed enterprises and began importing and exporting goods. These enterprises also began maintaining their own profits and losses, acting in accordance with the principles of a market-oriented economy, and developing products and technologies for both military and civilian purposes.

As part of these reforms, the nuclear industry underwent major changes. In May 1982, China's leadership created the Ministry of Nuclear Industry (MNI) from the Second Ministry of Machine-Building. This change indicated a shift in policy from the principle of "military uses first" to "combining military and civilian uses". The MNI was subsequently reorganized and renamed the China National Nuclear Corporation (CNNC) in 1989.

The transition from a military to a civilian industry was not easy, and, for several reasons, it took many years for China's nuclear entities to adjust to the new reality. First, the facilities and equipment of the military-oriented nuclear industry could not be converted to civilian use quickly. Second, due to the relocation policy of the Cultural Revolution, military-related factories and research institutes were located inland, far from coastal transportation links and cities. Finally, the transition in management systems – from military to commercial – introduced many challenges. After years of being segregated from the civilian market, taking direct requests from the military and working with nearly unlimited funding, the whole industry – from top officials to frontline engineers – lacked the skills to survive in a competitive environment.

These organizational changes were preceded in 1981 by the first proposal to build a commercial nuclear power plant at Haiyang in the Zhejiang province; 11 years after Premier Zhou Enlai delivered a speech emphasizing the need to explore the peaceful use of nuclear energy. Though China initially emphasized self-reliance and domestic production as a principle of its nuclear energy program, it later embraced the principle of "from foreign technology transfers to domestic design and production". Chinese leadership believed that technology transfers would accelerate the acquisition of advanced reactor technologies and narrow the gap between China's indigenous nuclear technologies and leading technologies in the world. This principle has guided China in implementing its nuclear energy plans.

Despite China's relatively long interest in nuclear power, its civilian nuclear development was modest until 2005. Until then, China's efforts lacked a long-term strategic plan. China believed that its abundant coal resources were sufficient to meet its rising energy demands.[2] As such, its nuclear efforts were comprised of building a small nuclear fleet, obtaining nuclear technology capabilities, and maintaining professional teams of scientists and technicians as part of its nuclear weapons program. Nuclear energy was not integrated into China's overall strategic energy plan. In addition, China did not establish a powerful and professional authority to research, plan, and supervise its nuclear energy-related development activities. CNNC was ill-suited to coordinate nuclear-related activities, as it was a legacy from a centralized economy and an organization designed to oversee nuclear-related military and civilian production and activities. Without a firm commitment from top officials, civilian nuclear energy development had little chance for success.[3]

Nuclear energy development also lacked sufficient financial support. The construction of a nuclear reactor requires huge initial capital investment. In developed countries, governments have financially supported nuclear energy projects with major investment coming from private interests. In China, the nuclear energy program relied solely on government funding, which was notably absent in 1980 and 1990s. One exception was the Daya Bay project, which was built in 1987 by an economically prosperous local government and relied on revenues from selling electricity to Hong Kong as collateral for financial support.[4]

Inconsistencies in China's technology development strategy – and in the execution of that strategy – also hampered efforts. Due to the weak commitment of top officials and vague long-term planning, China struggled for years to determine which nuclear technologies to develop.[5] In addition, China failed to implement its goals of "combining technology transfers and technology purchases" and "combining localization and technology purchases of complete plants from overseas (Li and Ding, 2006)". When modernizing their economies, developing countries such as China often use existing technologies and experience accumulated by pioneering industrial countries to make them competitive in both national and foreign markets in a short time-frame. The industrialization of Japan in the 1970s and of Korea in the 1980s demonstrates the benefits of this strategy for a range of industries, including the nuclear industry. In contrast, China has developed its nuclear energy projects individually and discontinuously. For example, China's current nuclear fleet consists of different reactor designs imported from several countries such as France, Canada, and Russia.

Finally, China's nuclear program lacked political and economic incentives. During the Cold War, security concerns remained the top national priority. Only after China moved to a market-oriented system, the economy became the main force guiding all reform and development activities, including nuclear energy activities. After much internal debate in 1980 and 1990s, it decided to move ahead with the domestic development of pressurized-water reactor (PWR) technology. By the end of 2005, China had developed its own nuclear reactor designs—the CNP-300, CNP-600, CNP-1000, and CPR-1000. Including the units it has purchased from France (M310 3-loop PWR), Russia (AES 91), and Canada (CANDU 6), China now operates 12 reactors with a capacity of 9602 MWe net (see Table 1). As of late 2010, this represented a little less than 2 percent of China's total electricity production capacity.

2.3. A booming future: 2005 to present

In March 2006, China's State Council approved the "Medium- and Long-term Nuclear Power Development Plan" (2005–2020), which outlined its goal of increasing China's nuclear capacity to about 40 GWe by 2020. A 2007 white paper, "China's Energy Policy," listed nuclear energy as an indispensable energy source and suggested that the Chinese government should transform nuclear energy from a moderate development role (as outlined in the 10th Five-Year Plan) to an active development role as outlined in the 11th Five-Year Plan (State Council Information Office, 2007). Two years later, Chinese nuclear energy development shifted from a state of "active" to "aggressive" development (Zhang, 2009).

In recognition of the heightened emphasis on nuclear energy, in March 2008, China relocated the nuclear energy division of the State Administration of Science Technology and Industry for

[2] Personal communication with personnel from the Institute of Nuclear and New Energy Technology (INET) at Tsinghua University and CNNC, January 2008.

[3] Personal communication with personnel from INET at Tsinghua University and CNNC, January 2008.

[4] For the information of the Daya Bay project, see www.cgnpc.com.cn/n1093/n14643/n14974/671576.html.

[5] Personal communication with personnel from INET at Tsinghua University and CNNC, January 2008.

Table 1
China's operating nuclear reactors (as of September 2010).
Source: The Ux Consulting Company.

Plant	Location	Main owner	Reactor design	NSSS [a]	MWe gross	MWe net	Startup date
Qinshan I-1	Zhejiang	CNNC	CNP-300	CNNC	300	288	4/1994
Daya Bay 1	Guangdong	CGNPC	M310	Framatome	984	944	2/1994
Daya Bay 2	Guangdong	CGNPC	M310	Framatome	984	944	5/1994
Qinshan II-1	Zhejiang	CNNC	CNP-600	CNNC	650	610	4/2004
Qinshan II-2	Zhejiang	CNNC	CNP-600	CNNC	650	610	6/2004
Lingao 1	Guangdong	CGNPC	M310	Framatome	990	938	5/2004
Lingao 2	Guangdong	CGNPC	M310	Framatome	990	938	12/2004
Qinshan III-1	Zhejiang	CNNC	CANDU 6	AECL	728	665	12/2002
Qinshan III-2	Zhejiang	CNNC	CANDU 6	AECL	728	665	7/2003
Tianwan 1	Jiangsu	CNNC	AES-91	ASE	1060	1000	12/2004
Tianwan 2	Jiangsu	CNNC	AES-91	ASE	1060	1000	12/2005
Lingao 3	Guangdong	CGNPC	CPR-1000	CGNPC	1080	1000	09/2010
Total: 12				**Total**	**10,204**	**9602**	

[a] NSSS: Nuclear Steam Supply System.

Table 2
Nuclear reactors under construction in China (as of September 2010).
Source: UxC, 2010.

Plant	Location	Main owner	Reactor design	NSSS	MWe gross	MWe net	Constr. start	Estimated startup
Qinshan II-3	Zhejiang	CNNC	CNP-600	CNNC	650	610	3/2006	3/2011
Lingao 4	Guangdong	CGNPC	CPR-1000	AREVA	1086	1000	6/2006	6/2011
Qinshan II-4	Zhejiang	CNNC	CNP-600	CNNC	650	610	1/2007	1/2012
Hongyanhe 1	Liaoning	CGNPC	CPR-1000	CGNPC	1080	1000	8/2007	8/2012
Ningde 1	Fujian	CGNPC	CPR-1000	CGNPC	1080	1000	2/2008	2/2013
Hongyanhe 2	Liaoning	CGNPC	CPR-1000	CGNPC	1080	1000	4/2008	4/2013
Ningde 2	Fujian	CGNPC	CPR-1000	CGNPC	1080	1000	10/2008	10/2013
Yangjiang 1	Guangdong	CGNPC	CPR-1000	CGNPC	1080	1000	10/2008	10/2013
Fuqing 1	Fujian	CNNC	CPR-1000	CGNPC	1080	1000	11/2008	11/2013
Fangjiashan 1	Zhejiang	CNNC	CPR-1000	CGNPC	1080	1000	12/2008	12/2013
Hongyanhe 3	Liaoning	CGNPC	CPR-1000	CGNPC	1080	1000	3/2009	3/2014
Sanmen 1	Zhejiang	CNNC	AP1000	WH	1200	1117	4/2009	4/2014
Fuqing 2	Fujian	CNNC	CPR-1000	CGNPC	1080	1000	6/2009	6/2014
Yangjiang 2	Guangdong	CGNPC	CPR-1000	CGNPC	1080	1000	6/2009	6/2014
Fangjiashan 2	Zhejiang	CNNC	CPR-1000	CGNPC	1080	1000	7/2009	7/2014
Hongyanhe 4	Liaoning	CGNPC	CPR-1000	CGNPC	1080	1000	8/2009	8/2014
Haiyang 1	Shandong	CPIC	AP1000	WH	1200	1117	9/2009	9/2014
Taishan 1	Guangdong	CGNPC	EPR	AREVA	1700	1650	10/2009	10/2014
Sanmen 2	Zhejiang	CNNC	AP1000	WH	1200	1117	12/2009	12/2014
Ningde 3	Fujian	CGNPC	CPR-1000	CGNPC	1080	1000	1/2010	1/2015
Taishan 2	Guangdong	CGNPC	EPR	AREVA	1700	1650	04/2010	04/2015
Changjiang	Hainan	CNNC	CNP-600	CNNC	650	610	04/2010	04/2014
Haiyang 2	Shandong	CPIC	AP1000	WH	1200	1117	06/2010	06/2015
Fanchenggang	Guangxi	CGNPC	CPR-1000	CGNPC	1080	1000	07/2010	07/2015
Ningde 4	Fujian	CGNPC	CPR-1000	CGNPC	1080	1000	09/2010	09/2015
Total: 25				Total	**27,430**	**25,598**		

National Defense (SASTIND) (the former Commission of Science Technology and Industry for National Defense, or COSTIND) to the newly established National Energy Bureau (NEB), which is organized under the National Development Reform Commission (NDRC). China also reexamined its nuclear technology development route and took steps to standardize its complete nuclear energy design and manufacturing system in order to introduce economic efficiencies and improve safety. China's recent emphasis on economically oriented development will enhance this domestic capacity, for example, by allowing nuclear component manufacturers to compete with each other. These policy changes have paved the way for the current wave of reactor planning and construction. China is currently benefitting from Generation III technology transfer agreements and it expects that the transfer will allow its nuclear energy sector to become more self-sufficient as it applies the technology domestically and considers exporting its own designs. While 8 out of 12 of the currently operational nuclear units were based on foreign designs, 19 out of 25 units under construction (as of September, 2010) are of Chinese design (see Table 2).

The growth of nuclear energy's projected share of capacity is evidence of the success of these initiatives. In 2008, the NEB estimated that China's nuclear power capacity will rise to 5 percent of the total electricity share by 2020; this translates into a total of 60,000 MWe in operation by 2020. Therefore, as early as 2008, government and industry representatives estimated that China will exceed the 2006 target of 40 GWe installed capacity by 2020 (China Daily, 2008).

3. China's civilian nuclear program: stakeholders and key issues

China's civilian nuclear program consists of three main components: government organizations, the nuclear industry, and other research organizations. The government agencies play a major role in planning, approving, and licensing reactor projects in the country, and the other stakeholders play a major role in implementing China's nuclear energy plans.

Nuclear reactor planning, approval, and licensing are not easy tasks in any country, and this is particularly the case in China. The process involves many government organizations, each of which has multiple and – sometimes – overlapping, responsibilities. As a consequence, the interaction among these bodies is complex and difficult to understand. Only three Chinese enterprises, all of which are state-owned, are licensed to own and operate nuclear power plants: CNNC, the China Guangdong Nuclear Power Corporation (CGNPC), and China Power Investment Corporation (CPIC). In addition to this "nuclear troika," the State Nuclear Power Technology Company (SNPTC), which was created in 2004, oversees the selection of advanced PWR technology from overseas and implements technology transfers. SNPTC is currently collaborating with Westinghouse on the transfer of technology related to the AP1000 design, and it is also cooperating with the nuclear troika on plant construction, particularly with CNNC (due to CNNC's advanced research and development capabilities). In addition to its current responsibilities, SNPTC is a potential competitor to invest in nuclear power plants, to manufacture nuclear components, and to construct and design advanced plants.[6] In December 2009 SNPTC joined the Huaneng Nuclear Power Development Corporation to begin work in the CAP1400 reactor design (based on AP1000 technology). The first CAP 1400 is expected to begin operations in 2017.[7]

Other investors (e.g. energy companies, financial institutions, provincial governments, etc.) participate in nuclear reactor projects. Although these investors are not allowed to have majority shares in the projects, they are important components of China's nuclear energy development. China also has a significant and rapidly expanding construction and manufacturing base capable of contributing to power plant construction. A number of companies are fully specialized in nuclear plant construction and are capable of manufacturing nuclear and conventional island (non-nuclear related) components.

3.1. The Chinese nuclear bureaucracy

The State Council is the supreme committee that takes ownership of all Chinese policy decisions, including final decisions on the all-important five year plans that, among other matters, set guidelines for implementing nuclear energy projects. All government bodies fall under the authority of the State Council. The NDRC is best known as the agency responsible for drafting the five-year plans and is responsible for the selection of appropriate energy projects, including power plant construction projects.

The National Energy Commission (NEC) was created in March 2008 during a major reshuffling of the Chinese bureaucracy, and it was given the authority to lay out China's energy development strategy and oversee energy-related issues that had been previously distributed in several ministries. NEB conducts the daily work of the NEC and is under the authority of NDRC. Also, as a part of this restructuring, the COSTIND'S division for the peaceful use of nuclear energy became a part of the NEC. NEB formulates and implements energy development plans and industrial policies, promotes institutional reform in the energy sectors, and restructures the energy industry as needed.

The China Atomic Energy Agency (CAEA) is a key participant in the nuclear energy infrastructure and maintains regulatory authority, but it is not responsible for China's overall nuclear power development. CAEA is responsible for planning and managing nuclear-related research studies and projects. It sets policies and regulations for the use of nuclear technologies, such as nuclear fuel recycling technologies, and supervises nuclear material management and control. CAEA promotes all bilateral and multilateral cooperation between the Chinese nuclear industry and international organizations, including the International Atomic Energy Agency. The CAEA was formerly under the control of COSTIND and is now under the control of the newly established Ministry of Industry and Information Technology.

The National Nuclear Safety Administration (NNSA), which is responsible for developing relevant guidelines and regulations for nuclear safety and radioactive materials, is under the authority of the Ministry of Environmental Protection. NNSA also supervises reactors' operation and nuclear material management, drafts emergency response plans, and oversees nuclear facility safety and security. In practice, the NNSA is the key administrative body that licenses, regulates, and supervises nuclear power plant operation. Fig. 1 gives the organization chart of China's nuclear industry and agencies.

3.2. The nuclear troika

Of the three companies that are licensed to own and operate Chinese nuclear power plants, CNNC is the central operator because it not only owns nuclear plants, but also owns all Chinese nuclear construction companies and fuel cycle facilities. CNNC currently operates 7 plants and is the developer of the indigenous CNP-300, CNP-600, and CNP-1000 reactor designs. CNNC also owns the world's first AP1000 reactors, which are located at the Sanmen site in China's southeastern Zhejiang province.

CGNPC is the owner and primary investor for several current and planned plants and has a close relationship with France, dating back to the first Sino-French project, the Daya Bay nuclear power plant. Recently, CGNPC purchased two French-designed EPR reactor units and developed the CPR-1000, a 1 GWe PWR based on French technology. Furthermore, CGNPC has started to develop its own research and development institutes and construction subsidiaries in order to compete with CNNC. An important event for CGNPC, in the framework of the French–CGNPC cooperation, took place in December 2009 as CGNPC and AREVA signed agreements covering reactor design and the supply of nuclear fuel components.[8]

CPIC, the third member of the troika, is the largest state-owned nuclear power investment organization in terms of assets. However, it is solely an investor in these projects and does not have nuclear research and development, manufacturing, or construction subsidiaries. It is the major investor in the AP1000 reactor under construction in Haiyang and the CPR-1000 reactor under construction in Hongyanhe.

The three owners that make up the nuclear troika are competitors rather than collaborators and rarely exchange information on technologies, management, and operations.[9] The three are actively investing in coastal and inland nuclear projects, and compete aggressively for nuclear projects with local governments and to reserve potential nuclear power plant sites to ensure their future market share and profits. This competition is best exemplified by

[6] Personal communication with personnel from INET at Tsinghua University and CNNC, January 2008.

[7] Personal communication with personnel from Shanghai Nuclear Engineering Research & Design Institute, China Nuclear Eastern Engineering Company, January 2008.

[8] Areva press release, Areva signs agreements covering reactor design and the supply of nuclear components, December, 2009. Available at <http://www.areva.com/EN/news-8013/china-areva-signs-agreements-covering-reactor-design-and-the-supply-of-nuclear-components.html>.

[9] Personal communication with personnel from INET at Tsinghua University, China Institute of Atomic Energy (CIAE), and CNNC, January 2008.

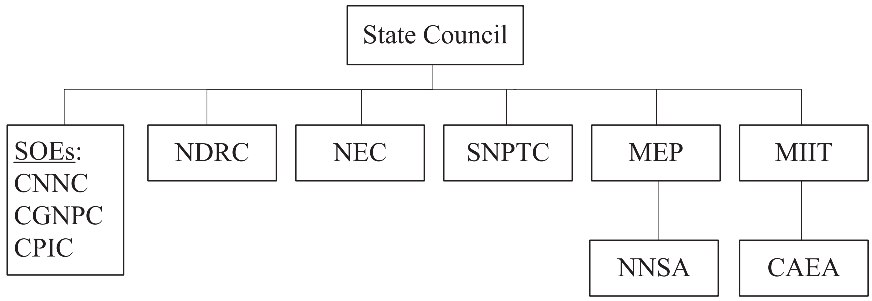

Fig. 1. The principle organizations involved in nuclear energy development in China. SOE: State-Owned Enterprises, CNNC: China National Nuclear Corporation, CGNPC: China Guangdong Nuclear Power Corporation, CPIC: China Power Investment Corporation, NDRC: National Development and Reform Commission, NEC: National Energy Commission, MEP: Ministry of Environmental Protection, MIIT: Ministry of Industry and Information Technology, SNPTC: State Nuclear Power Technology Corporation, NNSA: National Nuclear Safety Administration, CAEA: China Atomic Energy Authority.

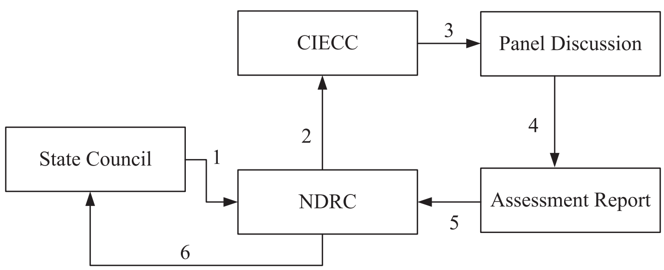

Fig. 2. China's nuclear policy decision making process.

the fact that they all are preparing for the construction of China's first nuclear power plant inland projects. All projects are based on AP1000 technology. CNNC is the owner of the Taohuajiang nuclear power plant project in the Hunan Province, CGNPC is the owner of the Xianning project in the Hubei Province, and CPIC is the operator of the Pengze project in the Jiangxi Province.

3.3. The decision-making process

Due to the lack of a lead nuclear energy development body, the NDRC typically relies on research institutes, such as Tsinghua University, and nuclear industrial units (mainly CNNC) to shape nuclear energy policies and to demonstrate their feasibility. The NDRC assigns projects based on an institute's expertise and qualifications. For example, in the past, the NDRC requested a proposal on PWR-related, strategic projects from CNNC. After CNNC submitted its proposal, the NDRC requested the China International Engineering Consulting Corporation (CIECC) to evaluate the proposal. CIECC organized a panel of academic and industry experts to discuss the proposal. The NDRC relied heavily on the panel's findings when it delivered its nuclear energy policy proposals to the State Council and other top officials who made the final policy decisions.[10] The flow chart in Fig. 2 illustrates the decision-making process.

China has identified a number of potential sites for new reactors, so understanding how projects are prioritized and sites are approved is crucial. In some instances, the central government is determined to move forward on a particular nuclear power plant project, due to economic, energy, and/or political rationales. However, provinces and local leaders can influence the NDRC and other central government officials when a project may be "on the fence." Recent decisions about where to site the first inland power plants demonstrate how some provinces, such as Hunan, Hubei, and Jiangxi, have been able to beat out the competition. Over time, nearly every Chinese province seems to be destined to have a nuclear power plant.

One large outstanding question is whether plant owners and other industry players can independently decide where to locate plants. Since these investors must now raise a majority of the financing for new plants, one would imagine that they would have a major say in which projects go forward. Yet it appears that the State Council, the NDRC, and other government entities heavily influence CNNC, CGNPC, and CPIC, and it would likely be very hard for the industry to disagree with government decisions on which plants to prioritize.

3.4. The licensing process

The three nuclear operators (CNNC, CGNPC, and CPIC) typically work with local governments to initiate nuclear projects. The regulations for licensing these projects are based on the 1986 rules, "Implementation of Regulations on the Safety Supervision and Management for Civilian Nuclear Installations of the People's Republic of China" (HAF 001).[11] A plant operator needs to obtain three permits from the NNSA before it is granted an operating license: the early-site permit, the construction permit, and the first fuel loading permit (Yu, 2006).

To obtain an early-site permit, an operator first needs to submit an early-site safety report and an environmental impact assessment to NNSA. The operator also needs to complete a preliminary feasibility study as a part of a project application to NDRC. Once the State Council approves the project and the NNSA issues the early-site permit, the operator can submit a preliminary safety assessment report, an environmental impact assessment report for the plant's construction phase, and a construction quality assurance outline to NNSA—all of which are necessary to obtain a construction permit (Yu, 2006).

An operator is required to apply for its first fuel loading permit at least 12 months before fuel is loaded into a reactor. To obtain the permit, an operator needs to submit a final safety assessment report, an environmental impact assessment report for the first loading phase, a construction progress report, a pre-service and in-service inspection outline, and a quality assurance outline for the testing phase. One year after it has loaded the first fuel into the reactor, an operator can apply for its final operation permit. Operation permits can be renewed every 10 years upon completion of an NNSA safety review (Yu, 2006).

3.5. Plant financing and subsidies

Despite the large cost of nuclear power plants, China's booming economy has helped to ensure enough capital investment for planned projects. The ongoing global finance crisis has affected

[10] Personal communication with personnel from NDRC, January 2008.

[11] HAF is an abbreviation from the Chinese for "nuclear safety regulations".

China, but it did not decrease Chinese investment in nuclear energy development. Instead, the government has increased the amount of financial aid available for the nuclear industry.

Since 1998, the Chinese government has supported nuclear power development with preferential tax policies. For instance, the Ministry of Finance and State Administration of Taxation waived the value-added tax for the Daya Bay nuclear power plant in 1998. This policy was expanded to the entire industry after China committed more broadly to long-term nuclear energy development. As part of this policy, nuclear power companies receive a 75 percent tax rebate a year during their first five years of reactor operation. The amount of the rebate decreases to 70 percent in the following five years and to 55 percent for the third five-year period (Order [2008] No. 38).The nuclear energy industry benefits from preferential tax policies in three additional areas:

- A waiver of tax on the import of nuclear energy equipment and raw materials that cannot be manufactured and produced domestically (Order [2007] No.11)
- Land-use tax rebates on land uses associated with nuclear power plants (Order [2007] No.124)
- Income tax rebates whereby nuclear energy companies are assessed a reduced, 15 percent income tax rate, and permitted a reduced tax base, and possible tax waivers (Order [2008] No. 38).

Government support, however, accounts for only part of plant financing. Plant operators are required to have more than a 50-percent financial stake in each project. In addition to operators, a range of stakeholders, including provincial governments, provincial and national utilities, and local investment companies, can invest in nuclear plants (to date, no private investors are involved in nuclear plant projects). For example, CNNC holds a 51 percent share in the Changjiang nuclear power plant project (Hainan Province), while the Huaneng Group holds the remaining 49 percent. Also, CNNC holds a 51 percent share of the Fuqing nuclear reactor project, while the China Huadian Fujian company holds a 39 percent share, and the Fujian Investment Company holds the remaining 10 percent.[12]

It is worth noting that Chinese companies are also looking to the international market to raise financial funds. In early 2010, China First Heavy Industries (CFHI) launched its first Initial Public Offering (IPO). Furthermore, it has been reported that CGNPC and SNPTC are also planning to launch IPOs in the next years. Finally, CNNC is planning to make major investments in nuclear energy projects (around $117 billion). As a part of this investment, is it planned that CNNC's subsidiary CNNC Nuclear Power Co. Ltd. will be publicly listed in 2011 (China Daily, 2010a; 2010b; People's Daily, 2010).

3.6. Nuclear liability

China is not party to any of the international legal instruments on liability for nuclear damage. Rather, the Chinese government has enacted domestic legislation that follows the main principles contained in international legal instruments. In 1986, the Chinese government issued a ''Reply to the Ministry of Nuclear Industry, The National Nuclear Safety Bureau and the State Council Atomic Energy Board in respect of Handling Nuclear Third Party Liability''. (Order [1986] No. 44) to govern liability-related issues for all non-military nuclear facilities in China. This Reply was later replaced (and supplemented) by the State Council's ''Reply to Questions on the Liabilities of Compensation for Damages Resulting from Nuclear Accidents'' (Order [2007] No. 64) in 2007. The main purpose of the 2007 Reply is to partially indemnify the nuclear industry against liability claims arising from nuclear accidents while still ensuring compensation coverage for the general public. The Order [2007] No. 64 establishes a no fault insurance-type system in which each reactor plant operator is obliged to contribute up to 300 million RMB in the event of an accident, and the government will pay up to 800 million RMB if monetary claims exceed 300 million RMB. In addition, the Reply implies that the government bears unlimited financial liability if severe damages were caused by accidents. In order to fulfill the potential liability, all nuclear plant operators are required to have adequate financial preparation (by either insurance or cash reserves) for full and prompt compensation to those affected by incidents. Although none of the Replies have the status of ''Law'' in the Chinese legal system, it is believed that the Chinese State Council and the Chinese industry consider the 1986 and 2007 Replies as legally binding. Also, it is expected that the State Council will provide more clarity concerning the legal status of the Replies in future legislation concerning nuclear energy development in the country (i.e. drafting of an Atomic Energy Law).

3.7. Domestic construction capabilities

Until recently, the China Nuclear Engineering and Construction Group (CNECG), which includes six major nuclear construction companies, was the only licensed nuclear reactor construction company in China and constructed all current 12 nuclear plants in operation. CNECG alone will be unable to implement China's medium- and long-term nuclear development goals by the year of 2020. To address this shortfall, China is permitting conventional thermal power construction industries to participate in the construction of nuclear power plant projects. These companies have contributed to the construction of non-nuclear related facilities e.g. balance of plant and peripherals, of past and ongoing projects, yet their participation was limited. This changed in late 2006, when NNSA issued 12 conventional thermal power construction and engineering companies a special license to install major nuclear components, such as reactor pressure vessels, and construct containment buildings (Yu and Li, 2008).

3.8. Manufacturing capability

China's civilian nuclear industry inherited manufacturing capabilities from the military nuclear reactor industry, which built propulsion reactors in submarines and successfully fabricated major components for 300 MWe commercial PWRs in the 1980s. In addition, Chinese manufacturers developed a 300 MWe steam turbine in the 1970s and built several 300 MWe steam turbine generators for hydro-electric and fossil-fuel power plants by the early 1980s. By the time construction started on the Qinshan phase I reactor in 1985, China was capable of manufacturing major components for the reactor and auxiliary system, such as the reactor vessel, primary loop pump and valves, steam generator, and steam turbine and generator. The 1991 export of a CNP-300 reactor to Pakistan (Chashma 1) confirmed China's confidence in its reactor technology and manufacturing capability.

The lack of government commitment and the vague policy towards nuclear power during the 1990s stalled research and development in nuclear technologies and also slowed down the development of China's nuclear power manufacturing capacity. Most key components in Chinese nuclear power plants constructed in the 1990s were imported from Western countries, though Chinese manufacturers provided some auxiliary systems and were given contracts for less important parts of key components.

[12] Personal communication with personnel from the Hainan Nuclear Reactor Project at CNNC, October 2009.

Table 3
China PWR (1 GWe and above) components manufacturing capability in 2009 and projections after 2010.

	SEC	CDEC	HPEC	CFHI	Total
Primary loop components except pump and valve	2.5 (4)	2 (4)	1.5 (3.5)	2	8 (13.5)
Primary loop pump	(6)	7	NA	NA	7 (13)
Control rod drive system	6	(4)	NA	NA	6 (10)
Reactor internal hardware	6	(4)	NA	NA	6 (10)
Steam turbine and generator	3 (4)	4 (6)	4	NA	10 (20)

Unit: set per year; For example: "2.5(4)" stands for 2.5 sets per year capability in 2009 and 4 sets per year capability after 2010.

Table 4
Some of the planned nuclear power projects in China.
Source: UxC, 2010.

Plant	Province	Main owner	Reactor design	Units planned	Total MWe (net)
Taohuajiang	Hunan	CNNC	AP1000	4 units	4468
Lufeng	Guangdong	CGNPC	CPR-1000	6 units	6000
Xianning	Hubei	CGNPC	AP1000	4 units	4468
Wuhu	Anhui	CGNPC	CPR-1000	4 units	4000
Jiyang	Anhui	CNNC	AP1000	4 units	4468
Jieyang	Guangdong	CGNPC	CPR-1000	6 units	6000
Pengze	Jiangxi	CPIC	AP1000	4 units	4468
Nanyang	Henan	CNNC	AP1000	6 units	6702

Foreign-backed nuclear reactor projects, especially those supported by France, had an ancillary effect: they helped China establish and strengthen its reactor manufacturing base to the point where today China is capable of constructing CPR-1000 reactors employing domestic capabilities and joint ventures. Further growth in China's nuclear manufacturing industry was triggered by the wave of new reactor projects announced by NDRC. The increased government commitment spurred rapid nuclear manufacturing development starting in 2003, as government-backed investment poured into major heavy industry manufacturers.

By 2009, the government had invested approximately 300 billion RMB in four key nuclear manufacturing companies: the Shanghai Electric Company (SEC), Dongfang Electric Corporation (DEC), the Harbin Power Equipment Company (HPEC), and CFHI. These companies are involved in manufacturing a range of nuclear reactor components, including pressure vessels, steam generators, pressurizers, core internals, and steam turbine generators. In addition, they have contributed to a range of reactor projects: the construction of CPR-1000 reactors; the implementation of technology transfer for AP1000 reactors; and participate in the EPR technology transfer process (Ma, 2009; Zhu, 2007).

The increased domestic demand has led to further investment and expansion. Table 3 compares manufacturing capabilities in 2009 with those projected for 2010 (Ma, 2009; Zhu, 2007). As investments accelerate, China may find itself with extra manufacturing capacity in some areas, such as pressure vessels, and steam turbines and generators, and it may decide to enter the international market for these goods.

4. China's nuclear expansion plans and challenges

4.1. Future nuclear expansion

China's rapid construction of nuclear power plants has led NDRC to reassess its official estimates of installed nuclear power capacity by 2020 (40 GWe) to possibly 70–80 GWe by 2020. In addition to those plants currently under construction, a range of provincial sites have been announced as candidates for future reactors (see Table 4 for a sample of future planned reactors). Both coastal and inland provinces plan to construct nuclear power plants in the next five to ten years, though, so far, all approved plant proposals are from coastal provinces. Although proposals from inland provinces will be considered in the State Council's "12th Five-year Plan" (2011–2015), several contracts for these new units have been already signed with Chinese and foreign companies. Overall, China's nuclear industry has identified more than 50 sites for nuclear plants, but it is not clear yet how many of them will be developed. Most provinces are currently evaluating sites and preparing preliminary feasibility studies for sites in their provinces.

Most nuclear power plants in China have a capacity to accommodate six 1 GWe reactor units. Generally, in the first phase of a plant's construction two units are built. For the next two or three decades, 1 GWe or larger PWRs will remain the reactor size of choice for Chinese operators, and designs are likely to vary and to be built with the support of both domestic and international suppliers.

In addition to choosing to build its domestically designed CPR-1000 reactor, China has also selected foreign designs as a part of its new wave of reactors. In December 2006, after a 22-month bid process, China offered Westinghouse $5 billion for the construction of four AP1000 reactor units. China chose the AP1000 design as a model type for three main reasons: first, it conformed with accumulated Chinese experience with PWR design, construction, and management; second, it conformed to international trends to move toward Generation III reactors; and third, the design is more cost effective sufficiently simple and has safety advantages.[13] In addition, CGNPC signed an $8 billion contract with AREVA to purchase two EPR reactor units in December 2007. News of the AREVA contract met a mixed reception domestically. Some Chinese experts viewed it as a favor to the French government to compensate for its loss of the previous bid process to Westinghouse, and to CGNPC, which has consistently used French technologies since the Daya Bay project. Some also argued that the decision ran counter to China's goal of standardizing reactor construction.[14] On the other hand, others believe that China's nuclear market is big enough to

[13] Personal communication with personnel from INET at Tsinghua University, CIAE, and CNNC, January 2008.

[14] Personal communication with personnel from INET at Tsinghua University, CIAE, and CNNC, January 2008.

support two types of Generation III designs and that the AREVA contract will not affect the standardization process. Indeed, it could lower the risk of relying completely on the AP1000 design.

An additional reactor design that will be deployed again in the country is Russia's VVER reactor. In September 2010, China and Russia agreed the construction of two additional VVER units in the Tianwan NPP where two VVERs are deployed. So far there are not additional plans to deploy this design anywhere else in the country.

Concerning Chinese technologies, CNNC has been pushing to build its CNP-1000 reactors, which is developed from AREVA M310 design. With years of review and several delays, NNSA finally issued a design certificate to CNP-1000 (renamed as CP-1000). However, at this stage, none of the planned reactor projects foresees the deployment of the CP-1000 design.

Moreover, several CPR1000 reactors are currently under construction, and this design will be built at other sites. However, the total number of CPR-1000 reactor units that will be deployed by 2020 is not clear, and the deployment of the AP1000 reactor at several inland and coastal sites might signal its status as a favored design.

Furthermore, based on the established technology transfer agreements with Westinghouse, China plans to develop its own Generation III technology and boost the AP1000 to 1400 MWe or larger (any designs below 1350 MWe would fall under Westinghouse's intellectual property rights).[15] If China succeeds in developing and deploying this design prior 2020, the country might reach and supersede its new targets for that year.

China is also working to develop a high-temperature gas-cooled reactor and an experimental fast neutron reactor, which are predominantly from German and Russian technologies and designs. However, at this point, it is not clear if the development of high-temperature gas-cooled reactors will build a solid foundation to enable gas-cooled reactor technology replace the large-scale PWRs. China participated in the international Generation IV Forum (GIF) in November 2007, but it did not commit to particular research on Generation IV reactor designs, except the high-temperature gas-cooled and super-critical-water reactors, the latter of which is considered as a continuation of PWR technology.

4.2. Current and potential challenges

China is not the first country to pursue an ambitious industrial expansion, such as it is planning for its nuclear energy industry. Its plan is ambitious, yet it is feasible. Whether it is able to achieve its lofty goals depends on whether it can effectively manage several aspects of the development process, such as bolstering its nuclear regulatory and safety enforcement regime, improving its safety culture, furthering its research and development capability, and expanding its workforce.

4.2.1. Need to strengthen nuclear safety and security culture

The public's top concern about nuclear energy since the 1986 Chernobyl accident has been nuclear safety, and the Chinese government's top priority as it expands nuclear energy capacity has been to maintain its relatively clean nuclear safety record. Since the first nuclear plant was connected to the Chinese electricity grid in 1991, China's nuclear power plants have operated without any major safety incidents. According to the 2008 NNSA annual report, no incident at an operational Chinese plant has risen to or above a level-one incident as classified by the IAEA (NNSA, 2008). In 1998, what nuclear safety officials described as a "welding problem" crippled the Qinshan I reactor for more than 12 months, yet the incident did not reach the severity of a level-two accident (BBC news, 1999).

The CAEA and NNSA regularly inspect nuclear power plants to ensure that operators follow regulations and laws. On-site safety personnel typically comply carefully and strictly with safety regulations and standards, and all employees and managers have a strong awareness of and comply with regulations and laws. Yet, plant staffs might not necessarily appreciate the necessity of these regulations and laws. They also might not understand why regulations and standards are set and enforced, and fail to proactively improve the system.[16] The planned nuclear expansion requires strong regulations in order to succeed and it also needs plant employees and managers to comply with regulations proactively, not reactively. This would effectively lower the already low number of accidents and reinforce the awareness that unsafe and insecure conditions are intolerable.

An additional concern that could impact plant safety is China's general poor construction quality, which has been a chronic problem in China. Poor planning, poor quality control, unqualified construction workers, corruption and bribes, and/or theft of materials may be to blame for widespread poor construction. As China's nuclear power program expands it could designate civilian nuclear development as local infrastructure projects, rather than projects requiring national priority. This could lead to construction quality becoming an even bigger challenge. Nuclear experts are optimistic that China will be able to provide quality construction capacity to build two to three 1-GWe reactors every year, a rate that will match the Medium- and Long-term Plan's goals. Furthermore, with more conventional construction companies, such as coal-fired power plants, beginning to work in nuclear area, compliance with the special safety needs and safety cultures of nuclear power plant construction is likely to become more difficult.[17] If China wants to award licenses to the construction companies that have typically worked on the conventional island of nuclear power plant projects, the NNSA must ensure that these companies meet nuclear safety standards.

4.2.2. Incomplete and weak nuclear regulatory systems

China has not issued a major law to govern the use of nuclear energy and related activities (something akin to Japan's Japanese Atomic Energy Basic Law). The one related statute is the Law on Prevention and Control of Radioactive Pollution, which was published by the Chinese State Environmental Protection Administration (SEPA) in 2003 and focuses on radioactive pollution and does not cover nuclear power safety and operation (SEPA is now known as MEP). Additionally, China's State Council has released three major regulations related to nuclear energy: one that outlines ways to ensure the safe supervision and management of civilian nuclear facilities (HAF 001, 1986); one that addresses nuclear material control (HAF 501, 1987);[18] and another that outlines emergency measures for accidents at nuclear power plants (HAF 002, 1993).[19] These regulations might seem relatively complete, yet most current regulations and rules were issued at least a decade ago and need to be updated to meet new requirements. Existing Chinese nuclear regulations, rules, and standards have been adopted from international regulations and technical standards, such as those drafted by the IAEA and regulatory authorities in France and the United States.

[15] Personal communication with personnel from Shanghai Nuclear Engineering Research & Design Institute, China Nuclear Eastern Engineering Company, January 2008.

[16] Personal communication with personnel from Qinshan Nuclear Power Plant, January 2008.

[17] Personal communication with personnel from the Nuclear Power Plant Division in NNSA, March 2010.

[18] HAF 501 is the regulations on Nuclear Materials Control of the People's Republic of China.

[19] HAF 002 is the regulations on Nuclear Accident Emergency Management at Nuclear Power Plants.

However, the regulatory and supervisory agency for civilian nuclear activities, NNSA, lacks independence and authority. First, NNSA is under the current MEP as a sub-division. Therefore, the NNSA is less powerful in China's public administrative hierarchy system, while large state-owned nuclear companies are directly under the authority of the State Council. This setting could significantly limit the independence and authority of the agency when it regulates the nuclear industry. Second, NNSA lacks its own research and development branch that would allow it to set up its own safety technical standards and assess conditions that are not covered by existing regulations and laws. For example, it does not have capabilities to verify the safety design of purchased reactor technologies.[20] Third, NNSA does not have enough staff to cope with the increasing demands of the rapid nuclear expansion. The agency has around 50 staff members, who manage 12 subdivisions, and around 100 staff members are assigned to 6 regional nuclear safety inspection offices (Chen and Li, 2007). The technical support center conducting technical analyses and inspections has currently around 200 staff member. With such a small nuclear safety workforce, NNSA will not be able to ensure the necessary regulatory enforcement of the expanding nuclear fleet. Although, recent proposals foresee to expand the NNSA workforce and its technical support center from the current 300–1600 in the next few years,[21] its number of permanent staff per GWe installed capacity ratio is still significantly lower than the level in other major nuclear power countries. If China reaches 70 GWe installed capacity by 2020, the number of permanent staff per GWe installed capacity is approximately 22.9 staff/GWe, only two thirds of the US Nuclear Regulatory Commission (NRC) level (38.6 staff/GWe in 2009) (NRC, 2009). With such a small nuclear safety workforce, it is doubtful whether the NNSA will be able to effectively ensure the necessary regulatory enforcement of nuclear safety for China's fast expanding nuclear fleet.

4.2.3. Inadequate nuclear workforce

Significant human resources will be needed to support the implementation of China's aggressive nuclear energy policy. As a part of its military-related nuclear program in the 1950s, China had a strong nuclear technology workforce made up of technocrats, engineers, designers, and researchers. Most of these workers had prestigious Western academic backgrounds, which supported progress on the Chinese nuclear weapons program. China built on this foundation in the 1960s, as many of China's major universities built nuclear science and engineering programs that trained students who helped design, construct, and manage China's early nuclear energy program. China's modest nuclear energy industry, however, could not sustain interest in the field. Low student demand forced many universities that had trained the initial nuclear workforce to cancel their nuclear engineering programs. Today, only a few Chinese universities have nuclear engineering programs, including Tsinghua University, Shanghai Jiaotong University, Harbin Institute of Technology, and XiAn Jiantong University.

In addition, these universities have struggled to keep in the field those students who joined with an interest in nuclear engineering. According to 2004 data, major nuclear engineering programs admit approximately 372 undergraduate students and 145 graduate students every year. However, only about 30 percent of these students remain in the field (Guo, 2004). Many students admitted to nuclear engineering programs end up switching their majors.

The Chinese nuclear industry is well aware of these problems and is attempting to ensure the training of the necessary workforce for future nuclear energy development.[22] Universities are pitching in by launching new nuclear engineering programs. Some of these programs matriculate junior students from other engineering majors and offer one-year professional training programs focused on nuclear science and engineering. These students are often offered work in nuclear power plants directly after they graduate. Nuclear power plants pay competitive wages and offer excellent benefits in order to keep talent, yet it remains to be seen whether personnel who undergo such a short training program will be able to maintain current quality standards. These recruitment programs do not address the need for high-level research and development personnel to work on core areas, such as nuclear reactor design.

If industry and university efforts fail, there is likely to be a severe imbalance between the supply and demand of capable personnel in China. A recent survey suggests that China will need 6000 nuclear engineering professionals to staff the nuclear expansion planned by 2020 (Li and Ding, 2006).

4.2.4. Lagging public participation

While public opinion in Western countries has generally had a chilling effect on the development of nuclear power, the Chinese public seems to accept and embrace nuclear technologies for several reasons (Liu et al., 2008). Nuclear power plant development, for instance, provides thousands of local jobs. Local Chinese governments have been scrambling to build nuclear power plants, in part, because they believe that nuclear power can significantly benefit the local economy, increase local tax income, and resolve persistent electricity shortfalls.

Yet, facilitating China's nuclear energy development plans will require a higher degree of sustained support among the general public. In the past, the Chinese public has not been an integral part of nuclear energy decision-making. This situation is changing, however. The MEP has released a tentative measure that outlines increased public involvement in the environmental impact assessment (EIA) process. As part of the measure, local governments are required to release EIA reports and allow public feedback before the construction of large-scale projects can commence. So far, this process has not been effective or efficient. The public review period is presently 10 days long—an insufficient time to understand an assessment of a nuclear energy project. Additionally, the public is generally not aware of how to participate in the consulting process. For example, according to the first national environmental protection and livelihood index released in 2006, 80 percent of respondents were unaware of the existence of China's free phone hotline for reporting environmental problems (Liu, 2006).

Recent debates about the Rushan nuclear power project in Shandong Province indicate that public awareness of the potential environmental impact of nuclear power is improving. Internet bloggers launched the debate by pointing out that the MEP had not issued an EIA for the Rushan project prior to the official announcement of the project.[23]A couple of national media networks picked up the news, which triggered an intensive local debate about the project. A nongovernmental organization, the Ocean Protection Commune (www.dahai.ngo.cn), is actively following the project, and several online demonstrations against the Rushan project are reported on its website. Nevertheless, public participation in nuclear energy policy making, project assessment and safety oversight is still

[20] Personal communication with personnel from the Nuclear Power Plant Division in NNSA, March 2010.

[21] Personal communication with personnel from the Nuclear Power Plant Division in NNSA, March 2010.

[22] "The Challenges and Countermeasures for Human Resources Development on Nuclear Power in the 21st Century" Presentation delivered by SNERDI at "International Conference on Opportunities and Challenges for Water Cooled Reactors in the 21st Century" Vienna, Austria. October 2009.

[23] Personal communication with personnel from the Nuclear Power Plant Division in NNSA, March 2010.

Table 5
A list of major nuclear energy research and engineering units in China.

Name	Location	Parent body	Major projects
Institute of Nuclear and New Energy Technology	Beijing	Tsinghua university	HTR-10 NHR-5 Partitioning and Transmutation of high level nuclear waste
School of Nuclear Science and Engineering	Shanghai	Shanghai Jiaotong University	Super critical water reactor (SCWR)
Nuclear Power Institute of China (NPIC)	Chengdu	CNNC	CNP600 CNP1000
China Institute of Atomic Energy	Beijing	CNNC	CEFR
Beijing Institute of Nuclear Engineering	Beijing	CNNC	CNP1000

limited in China. The government should expand the period of public review of EIAs, perform public hearings for major nuclear plant projects, and the regulatory bodies – MEP or NNSA – need to inform the public regularly of developments related to nuclear regulation, safety, and technology (e.g. hosting regular public meetings).

4.2.5. *Transparency in the policymaking process*

In the short run, China's closed-loop decision making process might have an advantage in terms of efficiency, especially as the industry is beginning to grow and the public's knowledge about nuclear energy is limited. The close relationship between the NDRC and important stakeholders (prestigious research and industrial units and the panel format for discussing important proposals) has effectively streamlined the policy and decision making process. Yet, public understanding of how the State Council and top-level officials assess the discussions and make decisions is still unclear.

Since nuclear energy development will involve hundreds of billions of RMB in investment from a range of parties (e.g. a government planning agents, regulatory authorities, vendors, utilities, manufactures, construction contractors, research institutes, etc.), the decision making process will need to become more transparent in order to ensure that all stakeholders' interests are met. Any discussion between top government agencies, the State Council, and/or NDRC should include all relevant parties and make space for a variety of opinions, studies, and proposals. Also, efforts should be made to avoid conflict of interests. For example, the current expert panel discussions organized by CIECC include experts that are involved in both the drafting process and the evaluation process of proposals for different projects. Involvement in both processes could cause conflict of interest.[24] NDRC could create a special entity to manage an expanded decision-making process.

4.2.6. *Insufficient research and development capabilities*

Because of its nuclear weapons work, China is one of only a few countries to have a complete set of indigenous nuclear industrial capabilities. Despite its modest nuclear energy development to date, China has designed its own 300-MWe and 600-MWe PWRs. The country has also invested on other next-generation nuclear technologies, such as the high-temperature gas-cooled reactor and the fast neutron reactor. China demonstrated its nuclear prowess in December 2000, when its first high-temperature gas-cooled test reactor (HTR-10) went critical at the Institute of Nuclear Energy Technology. A high-temperature gas-cooled demonstration reactor in the Shangdong Province is under construction, and a 25-MWe fast neutron reactor, which reached critical in July, 2010 (Xinhua news, 2010).

However, the development of the high-temperature and fast-neutron reactors relied primarily on the support of a few key research institutes and universities. Table 5 lists the main nuclear energy research and engineering units in China. China's main nuclear research bodies are typically assigned the nation's top nuclear engineering projects, which are typically guaranteed funding. For example, China's experimental fast neutron reactor has research funding through the former COSTIND and the Ministry of Science and technology (MOST). MOST and the State Council's National Natural Science Foundation of China are major investors in basic nuclear and applied research projects, typically called "vertical projects." Research projects funded by private and industrial units are typically called "horizontal projects." Industries often look to universities to supplement or substitute for their in-house research and development capacity, a trend that does not always work well for universities designed to carry out basic and applied research.

Scarcity of funding is an additional problem for researchers. Chinese energy R&D expenditures counted 6.4 percent of total R&D expenditures and 0.064 percent of GDP in 2000, yet these levels are still relatively small compared to other developed countries (Gao et al., 2004). In order to effectively address these shortfalls, China needs to adopt a new approach to international cooperation and should seek a more active role in the international science and technology community. It should not only focus on adopting the latest technologies, but also on harnessing new knowledge and working toward the nation's long-term social and economic development.

5. Conclusions

There is little doubt that China will meet its announced target of 40 GWe of nuclear power capacity by 2020. Indeed, this target will most probably now be reached by 2015. It is an open question whether China's nuclear capacity will grow above 70 GWe by 2020. It needs to be pointed out that success of the CAP-1400 project could bring China closer to a 70 GWe target sooner than expected. Regardless, any capacity that brings China closer to its official target should be seen as a sign of progress. China's approach to nuclear power development mimics somewhat the rapid expansion in other large nuclear power countries, such as the United States, France, Russia, and Japan. However, its pace of growth is rivaled only by that of the United States in the 1970s and 1980s, when an average of 4 or more new units per year were brought online during a 20-year period.

The availability of financial resources will be crucial for the implementation of China's nuclear energy plans. So far, there are no major signs that would indicate that China's nuclear energy program is facing financial constraints. Making use of the international financial market could serve as an additional tool to further support nuclear energy development in the country.

Safety oversight and an adequately trained nuclear workforce are two major challenges, which are crucial to the success of the

[24] Personal communication with personnel from NRDC and CNNC, March 2010.

nuclear expansion and need to be addressed in a timely manner. So far, the Chinese leadership seems to recognize the key importance of nuclear safety in implementing the nuclear energy program. Indeed, China is leading the global nuclear renaissance, and the country *must* ensure the safe operation of its nuclear plants. By doing so, China will help ensure the further expansion of nuclear energy worldwide. Clearly, a nuclear accident in China, or anywhere for that matter, could mean the end of the current worldwide expansion of nuclear energy.

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