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Choosing a standard reactor: International competition and domestic politics in Chinese nuclear policy

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ABSTRACT

China has ambitious plans to expand its nuclear power capacity. One of the policy goals that high-level policymakers have desired is to base the nuclear program on a standardized reactor design. However, this has not materialized so far. By examining its nuclear reactor choices for individual projects, we argue that China's policymaking process has been greatly influenced by international competition and domestic politics. Multiple international nuclear vendors are intent upon maintaining their respective niches in the expanding Chinese reactor market, and they have used various forms of economic and political pressure to achieve their objectives. On the other hand, China's policymaking process is fragmented and the shifting power balances among powerful domestic actors do not allow a fixed path to be followed. Further, because of the high costs and potential profits involved, nuclear reactor choices in China have been driven not just by technical considerations but also by foreign and trade policy objectives. All of these make it unlikely that China will standardize the reactor type it constructs in the near future.

1. Introduction

China plans a major expansion of nuclear power. In 2005, China's National Development and Reform Commission (NDRC) announced "The mid and long-term plan for nuclear power" which aims to install nuclear capacity of 40 GW by 2020 [1]. Subsequently much higher rates of growth have been projected. Though the recent accidents in Fukushima appear to have prompted a rethink and the pattern of nuclear growth might change, it seems fairly certain that China will continue with enlarging its nuclear power sector, and that its plans for nuclear power development will remain far more ambitious than any other country in the world.

To help achieve this expansion, the Chinese policymakers appear to have wanted to construct only reactors based on a standardized design. Some prominent policymakers have insisted not just on a standardized design, but standardization to a domestically developed one. For example, in 2002, Chinese President Hu Jintao argued: "[the] nuclear energy industry is a strategic industry and China needs to develop its own technology for its expansion. No money can buy the core technology. Developing indigenous design and technology is the only way for nuclear expansion" [2]. There are many arguments for why standardization is a good idea, especially faster construction and lower costs. But, these standardization plans have not materialized so far.

In academic literature, the term standardization is technically defined using the concentrations of each manufacturer's share in each subsystem of the reactor fleet [3]. As used by the nuclear industry, however, the concept of standardization simply refers to building reactors in series of the same design, with the exception of a limited number of site-specific differences [4]. More simply put, standardization is the attempt to reduce diversity of reactor types. Simultaneously constructing large numbers of AP-1000s and CPR-1000s, along with a few EPRs and VVERs, as China has been doing, would not constitute standardization according to this definition.[1] In this paper, we analyze why China has not been successful in standardizing its nuclear reactor choices.

We explore this question by looking at the history of China's nuclear policymaking and analyzing the role of different domestic and international actors in this process. This history shows that Chinese policymakers have had different opinions on the tradeoff between reliance on indigenous reactor technology and importing more advanced designs. These differences have been exacerbated

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[1] It would also constitute a lower level of standardization using measures involving concentrations of manufacturer shares.

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by the increasing number of domestic organizations that have become involved in the nuclear energy sector. At the same time, international competition for nuclear reactor orders has intensified, with newer vendors entering the market even as older, more established, vendors are yet to recoup the considerable sums they have spent on developing nuclear reactors of new designs. The competition has been even keener in the case of China, not just because of its large capacity projections, but also because it professed to want a standard reactor type on which it would expand nuclear generation in the country. Therefore, the Chinese market has had, at least rhetorically, a "winner takes all" character.

In practice, the Chinese market has proved big enough, domestic electricity generating organizations numerous enough, and decision making powers fragmented enough for a number of international nuclear vendors and a couple of domestic reactor designers, to carve out shares for themselves. Thus, it has become more and more difficult to agree on what the standard type of nuclear reactor should be. In contrast to the popular image of China as a state with a centralized and powerful decision making system, our study shows that the country struggles to implement stated policy calling for the standardization of nuclear reactor designs due to its fragmented bureaucracy. The effects of this fragmentation have been amplified by intense foreign competition.

2. Reactor type and standardization

As of December 2010, China had 13 operating nuclear reactors with a total generating (gross) capacity of 10,688 MW, with a further 26 reactors (total gross generating capacity of 28,603 MW) under construction [5]. Together they generated 76.8 TWh, out of a total of 4228 TWh generated in the country in 2010 from all sources of electricity.

The growth of nuclear power has been characterized by multiple reactor types. The different reactor types deployed so far are listed in Table 1. Table 1 shows that most of the reactors are various kinds of the Pressurized Water Reactor (PWR), with the exception of a couple of Pressurized Heavy Water Reactors (PHWR) from Canada.[2]

Table 2 shows the reactor designs that are currently under construction. Among the models to be deployed in proposed reactors are CNP-600, CPR-1000, AP-1000, CAP-1400, VVER-1000, VVER-1200, and EPR-1700 [6].[3] In addition to these LWRs, China is also constructing High Temperature Gas cooled reactors (HTR-PM) and a Fast Breeder based on the Russian BN-800 design. Within the category of LWRs, some designs that have so far not been operated anywhere in the world – the AP-1000 and the EPR-1700 – are under construction at the Sanmen and Haiyang, and the Taishan sites respectively.[4]

Even though the majority of the reactors that are being constructed or proposed to be constructed are PWRs, they are of multiple types, with specific design characteristics of their own. Broadly speaking, one can divide the reactors being constructed into two categories, those based on Generation II designs and those based on Generation III designs. The latter refers to the latest generation of reactors that was developed in the 1990s, following the Chernobyl accident, with more advanced safety features [7].[5] As Table 2 shows, the bulk of the reactors under construction are Generation II designs. Among Generation III reactors, once again, there are substantial differences. For example, the AP-1000 relies on passive methods to ensure safety of the reactor whereas the EPR-1700 relies on active systems.[6]

This wide variety of reactor designs under consideration is somewhat of a puzzle. There are good reasons to desire greater, if not complete, standardization. The U.S. Nuclear Energy Institute, an industrial forum, asserts: "Design standardization offers significant benefits… Standardization will reduce construction and operating cost, and lead to greater efficiencies and simplicity in nuclear plant operations, including safety, maintenance, training and spare-parts procurement… International experience demonstrates the benefits of standardization" [11]. The example of France is often quoted as offering evidence of the benefits of standardization. Specifically, it has been observed that standardization plays a large part in explaining why average construction costs in France are lower than in the United States [12].

The other chief benefit that accrues with deploying a standard design is safety. Chinese energy experts realize this and hence regard "reactor safety issue resulting from the diversity of nuclear technology" as one of the "main problems in nuclear power development in China" because "more work is required to ensure nuclear safety" [1, p. 4285]. With the deployment of a large number of reactors of identical design, there is a higher probability of early detection of any design flaw due to accumulation of experience [13].

Finally, one of China's interests is in the degree of technology transfer that international vendors are willing to provide. It has been suggested that "China's ultimate plan is to take over, by license from the vendors, the complete design, manufacturing, and construction of future nuclear plants" [14, p. 80]. From this perspective, it is again puzzling that China would import so many different types of reactors. This import diversity is therefore "a great challenge for the independent R&D of China's nuclear power industry" [1, p. 4285].

There are arguments against standardization as well. The chief argument is that if the whole reactor fleet, or even a substantial majority of it, uses only one design, the fleet is vulnerable to a common problem. Detection of a serious design error, for example, might require all reactors of the same design to be shut down for modification.

Though they are likely familiar with arguments against standardization, Chinese leaders seem to have found the idea of standardizing designs within China more appealing. In early 2000 it was reported that Beijing ordered the five leading Chinese nuclear

[2] The most widespread nuclear reactor type today is the Light Water Reactor (LWR), a water-cooled reactor which is also moderated by water. There are two categories of LWRs, Pressurized Water Reactors (PWR) and Boiling Water Reactors (BWR), each of which come in multiple varieties. The third most popular type of reactor is the Pressurized Heavy Water Reactor (PHWR). The latter reactors use heavy water to slow down neutrons released and to carry away the heat produced during fission.

[3] Some of these reactor designs are related, being simply larger capacity versions of another. This category includes the CNP-600 and the CPR-1000, the VVER-1000 and VVER-1200, and the AP-1000 and CAP-1400.

[4] Two EPR-1700 reactors are under construction in Finland and France.

[5] Some also talk about Generation III+ reactors. However, there is no clear distinction between Generation III and III+ designs [8]. There is also an ongoing international research effort to develop Generation IV nuclear energy systems, including both the reactors and their fuel cycle facilities. The aim is to provide significant improvements in economics, safety, sustainability, and proliferation resistance [9]. However, these are intended for commercial deployment only by 2020–2030.

[6] The idea motivating reactors that use passive safety features is that if safety were based on natural forces, such as convection and gravity, rather than on active systems and components like pumps and valves, then the risk of failure might be lower. This is, however, debated by others who feel that passive systems may not act sufficiently fast. For a comparison of the safety features of the AP-1000 and the EPR by nuclear engineers from China Nuclear Power Design, a subsidiary of China Guangdong Nuclear Power Holding Company (CGNPC), see Ref. [10]. The broader point is that the choice of different designs implies different safety and regulatory challenges.

Table 1
Reactor designs deployed in China.

Location	Type	Design	Gen.	Vendor/Designer	Operator	Construction	
						Start	End
Qinshan-1#1	PWR	CNP-300	Gen II	SNERDI (China)	CNNC	1985	1991
Qinshan-2#1	PWR	CNP-600	Gen II	SNERDI (China)	CNNC	1996	2001
Qinshan-2#2	PWR	CNP-600	Gen II	SNERDI (China)	CNNC	1997	2004
Qinshan-2#3	PWR	CNP-600	Gen II	SNERDI (China)	CNNC	1997	2004
Qinshan-3#1	PHWR	Candu-600	Gen II	AECL (Canada)	CNNC	1998	2002
Qinshan-3#2	PHWR	Candu-600	Gen II	AECL (Canada)	CNNC	1998	2003
Daya Bay #1	PWR	M310	Gen II	Framatome (France)	CGNPC	1987	1993
Daya Bay #2	PWR	M310	Gen II	Framatome (France)	CGNPC	1988	1994
Lingao-1	PWR	M310	Gen II	Framatome (France)	CGNPC	1997	2002
Lingao-2	PWR	M310	Gen II	Framatome (France)	CGNPC	1997	2002
Lingao-3	PWR	CPR-1000	Gen II	CGNPC (Framatome Indeginized)	CGNPC	2005	2010
Lingao-4	PWR	CPR-1000	Gen II	CGNPC (Framatome Indeginized)	CGNPC	2006	2011
Tianwan #1	PWR	VVER-1000	Gen III	Atomstroyexport (Russia)	CNNC	1999	2006
Tianwan #2	PWR	VVER-1000	Gen III	Atomstroyexport (Russia)	CNNC	2000	2007

Source: Power Reactor Information System Database, International Atomic Energy Agency.

organizations to pool their resources and collaborate on developing a standardized commercial power reactor [15]. In 2004, on the basis of interviews with several officials and executives involved in nuclear power in China, the *New York Times* reported that nearly everyone said that China wants a more standardized system [16]. The 11th Five-Year Plan for Nuclear Industry announced in August 2006 by the Commission of Science, Technology and Industry for National Defense expressed concern about the lack of a nuclear power standardization system [17].

However, as Tables 1 and 2 suggest, this has not happened in the past, nor does it seem to be happening in the list of proposed reactors. We argue below that two factors explain this puzzle: domestic organizations involved in China's nuclear power sector and the role of international nuclear vendors.

3. Domestic organizations involved in China's nuclear power sector

This section briefly describes the development of China's nuclear power industry through the history of the actors involved and the national policies for this sector. We divide this history into three phases, each with different foci and involvement of domestic organizations.

3.1. *The first phase*

China is a late entrant to nuclear power. Serious plans for nuclear power plant construction started only in 1982 even though it has had a nuclear weapons program since the 1950s, building its first plutonium production reactor between 1960 and 1967 [18].[7] In 1956 the Chinese government established the Third Ministry of Machine-Building (MMB), which became the agency responsible for building China's nuclear industry. Since then, China's nuclear power sector went through several reorganizations. In 1958, the Third MMB was incorporated into the Second MMB, and the Ministry of Nuclear Industry (MNI) was created in 1982 from the Second MMB. The 1982 change was an indication of the shift from a focus on military uses of nuclear power to a more mixed, civilian and military, orientation [20].

In 1988, MNI was reorganized, renamed the China National Nuclear Corporation (CNNC), and was given responsibility for both civilian and military nuclear activities. CNNC oversees more than 100 subsidiary enterprises and institutions, and sees itself as the "representative of the interests of the nuclear energy sector and the principal voice for the nuclear community in China" [2, p. 1201]. CNNC is not a government-administered body. Like other large-scaled state-owned enterprises – for example, Sinopec and PetroChina in the oil industry – its presidents and vice-presidents are appointed by the Premier of the State Council. CNNC has been the major actor in the nuclear power industry, and several of the reactors in China are operated by it or its subsidiaries [21]. In the case of the oil industry, its access to the top leadership has been identified as one of the key reasons for its success in influencing policymaking in China [22]. The similar structure of CNNC and its relationship to the political elite should allow it to successfully influence nuclear policymaking.

The formation of CNNC marks the consolidation of what we see as the first phase of Chinese nuclear reactor technology development. This phase saw the birth of the Chinese nuclear power industry culminating in 1993 with China commencing the construction of a 300 MW reactor in Chashma, Pakistan.[8] China built three reactors within the country in this first phase. These included Qinshan-I in Qinshan, Zhejian and two reactors in Daya Bay, Guangdong. The latter reactors were supplied by the French conglomerate, Framatome, and the French utility, Electricité de France (EDF), undertook project management [23].

During this phase, though institutionally there was only one main player, there were internal struggles on several issues. Yingzhong Lu, a former director of Tsinghua University's Institute for Techno-Economics and Energy Systems Analysis, and an important participant in Chinese energy policymaking during this period has argued that the reason for the slow development of nuclear power during this phase has been the "friction among the various authorities within a highly centralized economy" [24, p. 56].

One arena where these internal battles manifested themselves was in the choice of reactor type. According to Lu, choosing a reactor type has been a controversial issue all along with different institutions, each with "powerful bureaucratic background" promoting different types [24, pp. 57,58]. The struggle was most intense in the early years, when MNI and the ministries of Power Industry and of Machine-Building Industry had different ideas

[7] The nuclear weapons program did help; as the country became interested in nuclear power, several key administrators and some 2000 to 4000 engineers were transferred to the civilian side from the military side [19].

[8] China is currently constructing another reactor at the same site, and has agreed to construct two more reactors, probably at the same site. These remain China's only exports of nuclear power reactors.

Table 2
Reactor designs under construction in China.

Location	Type	Design	Gen.	Operator	Construction start
Qinshan-2#4	PWR	CNP-600	Gen II	CNNC	2007
Hongyanhe#1	PWR	CPR-1000	Gen II	CGNPC w/CPIC & Dalian	2007
Hongyanhe#2	PWR	CPR-1000	Gen II	CGNPC w/CPIC & Dalian	2008
Hongyanhe#3	PWR	CPR-1000	Gen II	CGNPC w/CPIC & Dalian	2009
Hongyanhe#4	PWR	CPR-1000	Gen II	CGNPC w/CPIC & Dalian	2009
Ningde #1	PWR	CPR-1000	Gen II	CGNPC w/Datang	2008
Ningde #2	PWR	CPR-1000	Gen II	CGNPC w/Datang	2008
Ningde #3	PWR	CPR-1000	Gen II	CGNPC w/Datang	2010
Ningde #4	PWR	CPR-1000	Gen II	CGNPC w/Datang	2010
Fuqing #1	PWR	CPR-1000	Gen II	CNNC	2008
Fuqing #2	PWR	CPR-1000	Gen II	CNNC	2009
Fuqing #3	PWR	CPR-1000	Gen II	CNNC	2010
Yangjiang #1	PWR	CPR-1000	Gen II	CGNPC	2008
Yangjiang #2	PWR	CPR-1000	Gen II	CGNPC	2009
Yangjiang #3	PWR	CPR-1000	Gen II	CGNPC	2010
Fangjiashan #1	PWR	CPR-1000	Gen II	CNNC	2008
Fangjiashan #2	PWR	CPR-1000	Gen II	CNNC	2009
Sanmen #1	PWR	AP-1000	Gen III	CNNC	2009
Sanmen #2	PWR	AP-1000	Gen III	CNNC	2009
Haiyang #1	PWR	AP-1000	Gen III	CPIC	2009
Haiyang #2	PWR	AP-1000	Gen III	CPIC	2010
Taishan #1	PWR	EPR-1700	Gen III	CGNPC	2009
Taishan #2	PWR	EPR-1700	Gen III	CGNPC	2010
Fangchenggang #1	PWR	CPR-1000	Gen II	CGNPC	2010
Fangchenggang #2	PWR	CPR-1000	Gen II	CGNPC	2010
Changjiang #1	PWR	CNP-600	Gen II	CNNC & Huaneng	2010
Changjiang #2	PWR	CNP-600	Gen II	CNNC & Huaneng	2010

Source: Power Reactor Information System Database, International Atomic Energy Agency

about the nuclear power reactor design [25]. The former was supportive of a PHWR, whereas the latter was interested in a PWR.[9]

The resolution of these differences was reached at a meeting convened by the State Science and Technology Commission and the State Planning Commission in early 1983 [24, p. 58]. At that meeting, those who supported PWRs won over those in favor of a PHWR after intense discussion. However, the PHWR was not to go away forever.

The second split was between those who wanted to import reactors and those favoring a domestic design. The former group argued that the "lead-time and financial resources for independently developing nuclear power technology to the commercialization stage would be formidable" and therefore importing "the most advanced Western nuclear power technology from abroad" was preferable. The latter group based its claim on the "successful experience in developing the atomic bomb and the nuclear submarine" and argued that "no technical obstacle actually existed if China decided to build its own power reactors based on its nuclear submarine technology" [24, p. 58]. Institutionally, the Second MMB favored developing an indigenous reactor while the Ministry of Electric Power argued for the import of a foreign-developed PWR [27].

The decision on what was to be the first Chinese reactor provides some glimpses of the struggle between these two factions. In 1978, Chinese negotiators started talks with Framatome [28, p. 183], the first public indication of which faction had the upper hand. But these negotiations were broken off after a few months. A couple of years later, it was the turn of the domestic faction. At the first congress of the Chinese Nuclear Society held in February 1980, an official from the Second MMB announced, "[if] foreign countries refuse to supply us with their technology, it is entirely possible for us to rely on our strength to design and build nuclear power stations" [29].

A media interview a few months later by Wang Ganchang, the President of the Chinese Society for Nuclear Research, is revealing. "China wants to 'rely on its own resources' in building nuclear power stations… [and] that was why the Peking government had broken off negotiations with foreign firms about deliveries of complete reactors" he stated [30]. But he was also clear about the limitations of an all-domestic strategy. While China was "able to produce a large part of the reactor installations… there were still problems in erecting reinforced concrete reactor buildings and in the design of the huge pumping plant. In this field China [had to depend] on foreign aid".

In October 1980, when French President Valerie d'Estaing visited China, the import faction managed to convince Chinese government officials to agree "in principle" to purchase two complete French nuclear reactors [28, p. 184]. These were to be the Daya Bay reactors, but the "in principle" agreement did not materialize fast enough for a French design to become China's first reactors. France had to wait for the possibility of a joint project with Hong Kong [27].

In 1982 MNI announced that an indigenous design (later designated CNP-300) was chosen for the first Chinese reactor [31]. This was to be Qinshan-I, with a net capacity of 279 MW operated by CNNC. However, even in this project, key pieces of equipment were provided by a number of foreign enterprises, especially the Mitsubishi Corporation [32]. MNI solicited company bids on the foreign components for which the State Council had allocated $100 million [33]. Many of these suppliers were also involved in other projects.

The main organization within China developed for the purpose of reactor design was the Shanghai Nuclear Engineering Research and Design Institute (SNERDI). SNERDI was established in 1970 and first named the 728 Institute [32]. In 1982, when the indigenously designed Qinshan-I was chosen as the first reactor, it was SNERDI

[9] This is corroborated in part by a 1980 interview to a Japanese newspaper by Cao Benxi from the Second Ministry of Machine-Building who mentioned that China was designing two kinds of reactors, a PWR and a heavy water reactor that was at that point in the middle of the designing stage [26]. There is a parallel here with early developments in France when the Commissariat à l'Energie Atomique (CEA) wanted to continue with gas cooled reactors whereas Electricité de France (EDF) was arguing in favor of importing PWRs from Westinghouse.

that undertook that task. In 1988 when CNNC was created, SNERDI became affiliated to CNNC. In May 2007, it was incorporated into the State Nuclear Power Technology Corporation (SNPTC).

3.2. The second phase

The second phase of nuclear power in China lasted from the mid 1990s until the mid 2000s. This phase was marked by an increase in the number of domestic players in the nuclear sector and somewhat erratic support, or lack thereof, for nuclear power at the level of the government's planning bureaucracy. These led to slow, somewhat confused, movement in nuclear policymaking and development in the country.

Evidence for confusion and ambiguity comes from the Five-Year plans of the period. In 1996, when the 9th Five-Year Plan was created, the government aimed to construct eight nuclear power units at four sites, totaling 7.4 GW of nuclear capacity. Zhao Renkai, the vice chairman of CNNC, was optimistic and forecasted in 1996 that China would reach 15–17 GW of installed nuclear capacity by 2010, 30–40 GW by 2020, and 150 GW by 2050 [34,35].

The 10th Five-Year Plan in 2001, on the other hand, was more ambivalent about nuclear power. This is illustrated by Premier Zhu Rongji's comment: "While making full use of existing power-generating capacity, we need to develop hydroelectric power and build large-scale thermal power plants near coal mines… and moderately develop nuclear power" [35]. Premier Zhu also curtailed CNNC's power and activities significantly, ordering it to slash the number of employees on its payroll and calling for it to be broken up and reorganized [36]. Other energy sector actors were clearly more powerful as compared to the nuclear energy utilities during this period.

Further, the number of institutional actors in the nuclear arena increased. One significant outcome of the construction of the Daya Bay reactors was the formation of a new Chinese utility to operate it: the China Guangdong Nuclear Power Holding Company (CGNPC).[10] CGNPC remains one of the three enterprises that are allowed to own and operate nuclear power plants in China, and its constitution represented the emergence of a second important institutional player in addition to CNNC. Indeed, in recent years, it may have outstripped CNNC in political influence and economic clout; in 2009, CGNPC, but not CNNC, made it to an elite list of "Chinese backbone corporations" [37, pp. 86–89]. Unlike CNNC, it appears to prefer French reactor technology rather than indigenous ones. Another new institutional actor created during this phase was the China Atomic Energy Agency (CAEA).[11]

Yet again, the variety of reactor types chosen for construction during this period offers a glimpse into the contested nature of policymaking during this phase. As shown in Table 1, construction of three CNP-600s, two CANDU-600s, two M310s, and two VVER-1000s commenced in the second phase. While the CNP-600s and the M310s are logical successors to the Qinshan-I and Daya Bay reactors, the VVER-1000s and especially the CANDU-600s do not fit the pattern established in the first phase.

[10] The origins of this entity go back to the 1979 formation of a special committee by the Guangdong Electric Power Company and the China Light and Power Company in Hong Kong, which was a result of the long history of economic, commercial, and technological exchanges between China's Guangdong Province and Hong Kong [23]. The special committee eventually set up the Guangdong Nuclear Power Joint Venture Company in 1985, which oversaw the construction of the Daya Bay reactors.

[11] Shortly after it was created, Yuming Xu, the vice chairman of CAEA, argued for achieving "localization and standardization in the nuclear power industry to cut down the cost and shorten the construction cycle for the sustainable development of nuclear power" [38].

3.3. The third phase

The third phase, which could be said to begin somewhere in the early to mid 2000s, marks the government's renewed and earnest interest in enlarging nuclear power. During this phase, nuclear energy became prominent in the development plans of the central government, with senior officials and policymakers emphasizing its importance. Some analysts date the start of this rapid development of the industry to 2003 when the Communist Party's National Congress revised the earlier guiding principle of "appropriate development of nuclear power" to "vigorous promotion of nuclear power" [39, pp. 967,968]. Others point to the March 2006 approval by the State Council of a "Medium and Long-term Nuclear Power Development Plan" (2005–2020), which outlined its goal of increasing China's nuclear capacity to about 40 GW by 2020, as the beginning of a new era in Chinese nuclear power [20]. Yet others date it to 2002 "when power shortages once again seriously affected economic growth" [2, p. 1199].

During this phase, as clearly stated in the 11th Five-Year Plan created in 2005, the focus was on adopting the most advanced technology with the aim of introducing Generation III reactors from other countries [2]. The phrase "combining self-reliance with foreign partnership" was dropped. There was a clear divergence from the policies agreed earlier, and CNNC criticized NDRC for this change (see 2 and Refs. [10,43] therein). The NDRC's "medium long-term development strategy" for nuclear power was to unify the nuclear power development technologies [40].

Institutionally, two important players were created. In 2005 the China Power Investment Corporation (CPIC) became the third entity, after CNNC and CGNPC, authorized to participate in nuclear energy activities [32]. In 2007, the State Council established the SNPTC authorizing it "to sign contracts with foreign parties to receive… 3rd generation [i.e., Generation III] nuclear power technology" [41]. The State Council provided sixty percent of the assets of the new corporation with ten percent each coming from CNNC, CGNPC, CPIC, and China Technology Import and Export Corporation.

Since then, CNNC, which used to be the sole government player, had to compete with CGNPC and SNPTC for influence [6,42]. There appears to have been conflict between CNNC and SNPTC since the very beginning. Early on, SNPTC took away SNERDI from CNNC [37, p. 152]. Like most players in the nuclear energy sector in China, SNPTC also wanted the country to focus on a standard reactor type. Since it was explicitly created to import third generation reactors, i.e., the AP-1000, that was its preferred design. As Yu Zhuoping, an SNPTC advisor, put it, "[in] principle, the absorbed, redeveloped AP-1000 technology from Westinghouse will be the dominant technology for China's future nuclear industry development" [43]. CNNC has favored designs developed indigenously, albeit based on French technology imported in the 1990s. These are all Generation II reactors.[12]

In 2007, SNPTC recommended to the central government that further work on CNNC's indigenous reactor design, the CNP-1000, be postponed until at least the beginning of the 12th Five-Year Plan, which covers the period 2011–15 [44]. The CNP-1000 had been under development since the early 1990s when CNNC started working with Westinghouse and Framatome to develop a successor to the CNP-300 and CNP-600 designs constructed at Qinshan. Its aim was to develop a 1000 MW reactor with full intellectual property rights. Under the 11th Five-Year Plan, CNNC planed to build two CNP-1000 plants at Fangjiashan, next to Qinshan.

[12] China has the legal right to sell such Generation II reactors to other countries, whereas it cannot, at least so far, sell Generation III reactors.

However, as a result of the 2007 SNPTC recommendation, further development of the CNP-1000 was reportedly put on hold [6]. When construction at Fangjiashan restarted in 2008, the reactor design had been changed to CPR-1000 rather than the planned CNP reactors [6]. The change was most likely the result of a struggle between CNNC and CGNPC under the influence of SNPTC.

The outlook for the CNP-1000 design, thus, seems to be somewhat bleak. Yet, CNNC is still constructing CNP-600 at Qinshan and Changjiang. It is also developing another design called the ACP-600 that is expected to be completed by 2013 [6]. After the Fukushima accidents, it was reported that Chinese entities were marketing the CNP-1000 in various countries such as South Africa, Argentina, and Saudi Arabia [45].

In 2007, again, it was decided that only CNNC, CGNPC, and CPIC could own and operate nuclear power plants; all other entities were to have only minority shares [6]. However, of late, interest in entering nuclear power as sole operators appears to be increasing. The four largest utilities – Huaneng, Datang, Guodian, and Huadian – have all acquired sizeable minority stakes in projects under construction, and have ambitious plans to move forward after establishing themselves as experienced nuclear players [46].

The managers of China's electricity sector have also played a part in promoting a diverse group of players since 2002 [47]. The primary focus of dealing with electricity shortages has been to delegate much of the task of adding capacity to provincial and local authorities [48, p. 77]. The "need for new infrastructure to match current growth rates [favored] continuing decentralization of policy decision making about the electricity portfolio" [48, p. 107]. There are also "large and growing regional disparities" [49, p. 439]. Further, the "frantic rush to invest in new capacity" has meant that the "central government (indeed government altogether) has lost control over the size and shape of the electricity industry" [48, p. 104].

All of these observations appear to be as true of the nuclear power sector as electricity generation in general. Different provinces have developed different outlooks toward nuclear power expansion. This has become particularly apparent in the aftermath of the March 2011 Fukushima accidents, when some provinces have maintained that they would continue expanding nuclear power, whereas other provinces have been more reluctant to do so [50]. Regional differences in energy demands and supply will also play a role in shaping nuclear policies of different provinces [51].

What this history suggests is that while there has been relatively steady commitment to a nuclear expansion, ideas about the nature of the expansion have been changing all along. The question of whether the expansion should be based on an indigenous design or an imported one seems to have been a major subject of debate. In each phase, actors and their political power has changed, as has the importance of foreign influence.

4. International competition

There has been another key set of players influencing the trajectory of nuclear power in China – international nuclear vendors. Nuclear power has historically been an arena of fierce competition among nuclear vendors [52,53]. China has been a particularly intense case because most of the nuclear expansion in the country has been over the last couple of decades, a period of near stagnation in nuclear capacity in other countries. Even in recent years, despite much hype about a nuclear revival, there has not been any significant actual growth in generating capacity around the world, especially in Western Europe or the United States [54,55]. China is among the few countries where nuclear power growth has been rapid and accelerating.

Since the Chinese market promises to be huge, it has been of great interest to nuclear vendors. This has been particularly the case with Generation III nuclear reactors, such as the EPR-1700 or the AP-1000. Though the development of Generation III reactors has taken decades costing billions of dollars, very few reactors of this generation have been actually constructed. Therefore, it has been suggested, "the vast Chinese nuclear power market attracts a lot of international gold diggers and becomes the international nuclear power giants' game scene" [1].

One indication of the high stakes involved in nuclear reactor deals is the involvement of very senior political leaders at various points in the negotiation, most visibly through the participation of heads of state in various agreements to purchase reactors. Thus, for example, the nuclear cooperation agreement with Canada was signed by Canadian Prime Minister Jean Chretien and Chinese Premier Li Peng in Beijing [56]. Likewise, the framework accord governing the construction of the first Russian VVER-1000s was signed by Prime Ministers Li Peng and Victor Chernomyrdin [57]. High-level leaders are involved in earlier stages too. As the *New York Times* reported in 2004: "In recent months, a procession of political leaders has pressed China to favor power plant designs and equipment from their home countries. They have included President Jacques Chirac of France; former Prime Minister Jean Chretien of Canada; Viktor Khristenko, who was named fuel and energy minister in Russia on Tuesday; and dozens of less prominent officials. President Bush even raised the virtues of American nuclear technology with the Chinese prime minister, Wen Jiabao" [16].

Different nuclear vendors have been enticing Chinese policymakers with different attractions.[13] These include reactors with different features, varying degrees of technology transfer, attractive financing arrangements, and other political benefits. Vendors have also linked purchase of their nuclear reactor designs to other related technology transfer. For example, Areva offered China a suite of fuel cycle technology options, including an offer to help set up a reprocessing industry in China, modeled on its own experience in France [59]. In turn, Russia offered to do the same, by "vowing to integrate Chinese labs into advanced fuel cycle R&D work now ongoing in Russian centers" [59]. Russia also offered fast breeder reactors, a technology Chinese leaders have been interested in.

Countries have used financing arrangements as bait, in particular the use of loans from Export Credit Agencies (ECA) instead of private lenders. ECA provide government-backed loans, guarantees, credits and insurance to private corporations from their home country to do business abroad, particularly in financially and politically risky ventures. These offer lower rates of interest compared to private lenders. Earliest to offer such a reactor at low payment was the second country to enter the Chinese nuclear market: Canada. For Qinshan-I and II, Canada's Export Development Corporation offered a loan of Cdn$1.5 billion plus US$ 0.35 billion [60].

China, too, has historically looked to other countries to further its nuclear power development. Its nuclear weapons program began in earnest only after it signed an agreement on nuclear cooperation with Russia in 1955 [24, p. 56]. In terms of civilian nuclear technology, the countries that have had the greatest influence on China are France and, in recent years, the United States.[14] Soon after it decided to expand its civilian nuclear energy

[13] An extreme illustration of how keen international competition is to get into the Chinese market is the dismissal and subsequent sentencing to life imprisonment of the general manager of CNNC for taking a bribe from Areva in relation to a sought after contract to build a project in southern China [58].

[14] China started negotiating with the United States for importing equipment in the 1980s and an inter-government agreement for nuclear cooperation was signed in July 1985 [28, p. 188]. However, due to concerns about export controls, the actual implementation had to wait till 1998.

program, China also signed several other bilateral agreements [61]. Of importance amongst these is Germany, with whom China signed a cooperation agreement in 1984 [62]. Germany was instrumental in helping China set up a research and development program into a different kind of reactor that is fueled by thousands of spheres of uranium operating at high temperatures – the HTR-PM.[15]

To better understand the role of international vendors in this milieu, we focus on two aspects of nuclear reactor imports – the competition to secure the contracts for the Sanmen and the Haiyang sites, and the role of PHWRs in the face of what seems to be China's overwhelming emphasis on PWRs.

4.1. The case of Sanmen and Haiyang

In September 2004, China put out tenders for two Generation III reactors to be installed in Sanmen and Yangjiang. SNPTC, directly under China's State Council, was in charge of technology selection [6]. More than 10 international nuclear vendors put in bids, with Areva and Westinghouse being shortlisted [1]. Areva's bid was backed by Coface, the French export credit agency while the Export Import Bank of the United States approved $5 billion in loan guarantees for the Westinghouse tender [63]. The decision on reactor type was delayed, and came under review at the highest political level rather than China's energy planning bureaucracy [64].

One reason for the delay was CNNC reportedly pushing for its indigenous reactor designs at both sites [6]. Eventually, in 2006, the Westinghouse bid to construct two AP-1000s was accepted. Areva's EPR lost out to Westinghouse's AP-1000 because Westinghouse was more open to the idea of transferring its technology to China [2].

Soon thereafter, early in 2007, the two units planned for Yangjiang were shifted to Haiyang. The following year, the government approved the largest nuclear project till that point, which is to involve the construction of six CPR-1000s [65]. Just eleven days later, after a ceremony to celebrate the start of work on these units, construction of two more CPR-1000s started in Fangjiashan [66]. Note that the chosen reactor designs were not the CNP-1000 that CNNC had designed, but something that CGNPC favored. At the same time, this is a Generation II reactor design.

Much political capital was invested by the United States in securing the contract for Westinghouse. Letters of support were provided by officials at the U.S. Departments of Commerce, Energy, and State as well as the U.S. ambassador to China [67]. The U.S. Commercial Service introduced Westinghouse officials to high-level Chinese decision makers. Westinghouse officials were included in an official trade mission led by the U.S. Secretary of Commerce. Another factor in favor of the choice of Westinghouse was intense U.S. pressure on China to reduce its trade balance with the United States [68].

Westinghouse had played an important part in getting the U.S. government to allow nuclear reactor sales to China in the mid 1990s. Around that period, U.S. nuclear vendors started becoming increasingly restive about not being allowed to sell reactors to China due to United States not having a nuclear agreement with the country.[16] Westinghouse teamed up with companies such as Bechtel, Asea Brown Boveri, and Stone & Webster Engineering in a lobbying and public relations campaign that stressed domestic job creation in the United States from reactor and other nuclear technology sales to China [69]. Michael Jordan, chairman and chief executive of Westinghouse, argued that continuation of nuclear sanctions would "result in the loss of tens of thousands of jobs across 28 states and the gradual elimination of the trained personnel base now supporting more than 100 U.S. nuclear power plants and the nuclear Navy". The lobbying was successful, in part because it fit well within the broader strategy of the Clinton administration, which focused on exports and was seeking for a way by which U.S. companies could beat the challenge from European, Canadian and Japanese competitors in Asia's energy sector.

Other countries have also pressured China to favor their nuclear vendors. Upon losing the Sanmen contract, the French government intervened strongly and was assured that France would not be shut out of the Chinese market [63]. In 2007, Chinese President Hu Jintao and French President Sarkozy presided over Areva signing what was reported to be the largest ever nuclear deal estimated at 8 billion Euros ($12 billion) for two EPRs to be constructed at Taishan [70]. Following on the Taishan contract, Areva is reportedly negotiating the sale of two more reactors to China.

The 2007 deal for the Taishan reactors was signed without any international bidding [63]. To obtain the contract, however, Areva had to offer an attractive financing package. Further, EDF took a 30 percent stake in the project, making it an investor for the first time in nuclear generation in China [71]. Areva also had to accede to the Chinese demand for technology transfer. In October 2008, Areva and CGNPC announced that they were establishing a joint venture for the development of an EPR and other PWR plants in China and abroad [6,72]. The joint venture will be "initially dedicated to CGNPC's projects in China," but will move on to support "joint projects abroad" [72].

These developments clearly suggest that Areva is likely to be a player in the Chinese nuclear market for a long time. They also provide evidence that one way by which international vendors establish themselves and stay on in the Chinese nuclear market is by developing a close relationship with a domestic actor (possibly more than one), and furthering it. Thus, in Areva's case, the relationship is with CGNPC; the bulk of CGNPC's operating reactors are based on French designs and the organization is said to have "an established preference for French technology" [73]. Vendors also compete in trying to fulfill, at least in part, Chinese demands. Areva was reportedly not willing to transfer its technology early on, but agreed eventually to do so.

At the same time, Areva has also furthered its relationship with other domestic actors, in particular, CNNC. In November 2007, Areva and CNNC signed a contract to "assess the feasibility of setting up a reprocessing plant for used fuel and a mixed-oxide (MOX) fuel fabrication plant in China, representing an investment of EUR 15 billion" [21, p. 2490].[17] The following year, CNNC was talking about a 800 ton/year reprocessing plant operated by Areva to begin operation in 2025, and presumably a matching MOX plant [75]. As though to keep Areva on its toes, CNNC surprisingly signed an agreement with the Belgian company, Belgonucleaire, and two other companies in October 2010 to build a pilot MOX fuel fabrication facility [76]. However, plans to build a large reprocessing plant with Areva are still alive.

Almost at the same time as Areva was signing its contract for the Taishan reactors, China also signed an agreement with the other vendor that had put in a bid for Sanmen: the Russian State Atomic Energy Corporation (Rosatom). This was to construct two more VVER-1000s at the same Tianwan (Lianyung) site. The following year, at the end of President Dmitry Medvedev's visit to China, the joint communiqué stated "The heads of state consider cooperation in nuclear power to be a priority area of economic cooperation, and

[15] In other countries, it is often called the Pebble Bed Modular Reactor.

[16] This is the 123 agreement, which refers to the section of the U.S. Atomic Energy Act.

[17] CNNC has already completed a pilot reprocessing plant [74].

express their satisfaction with the success that has been achieved in this sphere, and the readiness of the two countries to continue mutually beneficial cooperation" [77]. Medvedev was accompanied by the Rosatom's Sergei Kirienko.

China's import of Russian reactors was also influenced by foreign policy and diplomatic goals [37, pp. 56–58]. The sale of Tianwan I and II followed improved relations between the two countries, especially following U.S. intervention in the Taiwan crisis of 1996 and the signing of a "Joint Declaration on a Multipolar World and the Formation of a New International Order". By the mid 2000s, there was friction between the two countries over trade. The bulk of China's imports from Russia were natural resources, especially oil and gas. Buying the second set of Russian reactors was one way for Beijing to address this imbalance.

Just as France was offering reprocessing plants, Russia offered fast neutron reactors. In a June 2009 interview, Kirienko said about China, "the Chinese side has asked us to consider possibilities of constructing two fast neutron reactors. These reactors are similar to the one we're building near Yekaterinburg at Beloyarsk NPP site, it's BN-800 reactor" [78]. The agreement for the BN-800 was signed in October 2009 [6].

These recent reactor decisions and other contracts illustrate how multiple international nuclear vendors are intent upon maintaining their respective niches in the expanding Chinese reactor market, and how various technological, economic, political, and foreign policy interests also play a part in these vendors achieving their desired ends. These practices are likely to continue into the future.

4.2. The curious case of the PHWR

The processes of partnership between international vendors and domestic organizations may be at play in other, less prominent, cases too. Throughout its history, Chinese leaders have largely focused on PWRs. As discussed earlier, there was a faction within the Chinese nuclear establishment that was in favor of developing PHWRs, and they were outgunned in 1983 [24]. Future nuclear plans also seem to involve only PWRs. On the face of it, therefore, excluding PHWRs seems to be a choice made deliberately, most likely as a way of standardizing the reactor fleet. But this begs the question, why was a solitary set of twin PHWRs built at Qinshan? And, what does the decision to build the Qinshan PHWRs and follow on activities imply for the possibility of future PHWR construction in China?

One of the odd features of the agreement with Canada to purchase two PHWRs is that it was signed just as the first of the Daya Bay reactors started operating. In other words, though China had by then decided on constructing PWRs, successfully constructed two different kinds of PWRs (the indigenous design at Qinshan-I and the French designs at Daya Bay), it nevertheless went ahead and signed an agreement to import a new kind of reactor.

Financial considerations may offer a partial explanation. It has been reported that the French government and industry tried to convince China to use the Framatome design as standard for all reactors envisioned as part of the 9th Five-Year Plan of 1996 [79]. However, because of a lack of domestic capital, and France's inability to finance so many reactors, China turned to Atomic Energy of Canada Ltd. (AECL) and Russia's Atomenergoprojekt. Purchasing a reactor from neighboring Canada may also have been intended to send a message to the United States [37, p. 52]. Finally, those sections of the CNNC that had earlier pushed for importing PHWRs in preference to PWRs may have also pushed for PHWRs.

Again, the lure offered to Canada seems to have been the possibility of entering the Chinese reactor market in a big way. For example, when AECL and CNNC began negotiating sales of two CANDU-600 reactors, the AECL CANDU Vice President suggested that there was "the potential for up to 10 CANDU reactors" [56]. The following year it was reported that "Canadian nuclear industry and government officials have also been lobbying recently to have [the] CANDU reactor chosen as a second standard design for the growing Chinese power market" [80].

The bargaining process was not so smooth with some of the differences being over the price. Finally, however, the Qinshan-III reactors seem to have been built by Canada on schedule and under budget. As seen in Table 1, Qinshan-3#1 has had the shortest construction period among all nuclear reactors built in China. Speaking at the Canadian Nuclear Society Conference, one of the Canadian participants in the construction of the reactor stated "AECL and its Chinese partners will continue their long-term nuclear cooperation in China and will look for opportunities to work together internationally" [81].

But this has not happened at least so far. By the time the Qinshan-3 reactors were completed, i.e., in 2002 and 2003 respectively, the transition to the third phase had been mostly completed. This meant that the domestic political configuration had changed again, and the focus had shifted back to PWRs. AECL of Canada, however, had been preparing for such a possibility. Its hopes of following up its agreement with China in the 1990s with agreements with other countries (Turkey, for example) had been dashed. Country after country seemed to have decided to focus on PWRs and there were no takers whatsoever for AECL's new ACR (Advanced CANDU Reactor) design. One way that AECL has tried to reinvent itself is to offer the PHWR not as a competitor to PWRs, but as a synergistic complement to the PWR. This was through the so-called DUPIC cycle, which tries to reuse the spent fuel from PWRs to fuel PHWRs.[18] The basic idea behind this option had been realized much earlier, but it was converted into a selling point only in the 1990s. By the end of the decade, AECL officials were touting this feature of PHWRs (for example, Refs. [82,83]).

In 2001, AECL set up cooperative programs with Xi'an Jiaotong University and Tsinghua University to carry out in-depth studies of the use of spent PWR fuel in CANDU reactors in China [84, p. 26]. By 2003–04, researchers from Xi'an Jiaotong University had started publishing technical papers about the utilization of spent PWR fuel in PHWRs and "PWR/CANDU synergism" [85,86]. The argument made for using PHWRs in this fashion is the consequent reduction of uranium requirement per unit of energy generated and the lowered quantity of spent fuel to be disposed [85]. This feature has been praised by others as being "of great economical and practical significance to China" [39].

In September 2005, AECL signed a technology development agreement with CNNC which opened the possibility of it supplying further CANDU-6 reactors [6]. In 2008 work on CANDU fuel technologies passed to a CNNC entity: the Nuclear Power Institute of China (NPIC) and it signed an agreement with AECL to undertake research on advanced fuel cycle technologies. Later the same year, this expanded into a deal between AECL and the Third Qinshan Nuclear Power Company, China North Nuclear Fuel Corporation and NPIC [87]. According to the agreement, the partners would jointly develop DUPIC technology to be used in the CANDU reactors in China. The agreement explicitly states that the technology would not be implemented in Canada [88]. In March 2010, the first trials of this technology were started in Qinshan-3#1 [87].

[18] This is technically possible because PWRs use low enriched uranium with about 3–5 percent of uranium-235 as fuel whereas PHWRs can be operated with natural uranium containing 0.7 percent of uranium-235 as fuel. Depending upon initial enrichment and burnup, spent LWR fuel contains about 0.9 percent U-235 and 0.6 percent fissile plutonium [82]. Thus, there is more than enough fissile material to allow for reactor operations in a PHWR, which uses heavy water to achieve a better neutron economy.

The above history of PHWRs in China, and their ongoing reinvention as a technology that is complementary to the PWR shows how international vendors continue to try to find ways of bypassing the stated intent of standardizing reactor types. The modus operandi is similar to what we have seen in other cases, is to find one or more domestic organizations to partner with, and to find some technical argument to establish their uniqueness.[19] In the case of the PHWR, the current argument is that it would result in greater efficiency of uranium utilization, thereby playing into stated concerns by Chinese policymakers about limited domestic availability of uranium.

It is too early to say whether AECL's partnership with NPIC and other domestic players will result in the import of further PHWRs, but it is clearly a possibility. Whether that possibility materializes will depend on a number of factors: AECL's institutional power within Canada and the extent to which it is capable of inducing the Canadian government to intervene in China on its behalf; the contours of the China–Canada relationship; and the strength of those domestic institutions in China that are involved with PHWRs. Currently the AECL does not enjoy a strong institutional profile within Canada, as suggested by its privatization.

5. Conclusion

It is often stated that because China is not a multi-party democracy, the government can make and implement policies with ease. For example, in September 2009, in his column in the *New York Times*, Thomas Friedman stated, "One-party autocracy certainly has its drawbacks. But when it is led by a reasonably enlightened group of people, as China is today, it can also have great advantages. That one party can just impose the politically difficult but critically important policies needed to move a society forward in the 21st century. It is not an accident that China is committed to overtaking us in electric cars, solar power, energy efficiency, batteries, nuclear power and wind power" [90]. Likewise, a 2004 article in *Wired* magazine argues, "What's an energy-starved autocracy to do? Go nuclear" [91].

Our analysis suggests that Chinese nuclear policymaking does not fit this picture. Decision making has been far more fragmented and the divisions between the ideas of different policymakers are reflected in the diversity of reactor designs chosen for construction. This diversity does not appear to be a result of deliberate strategy. This inchoate choice of reactor designs is consistent with the picture suggested by the fragmented authoritarianism model proposed by Lieberthal and Oksenberg [92] that argues that decision making in China is pluralized and "disjointed, protracted, and incremental" (p. 22). Applied to the energy sector, they conclude that the "pursuit of particular missions by different bureaucracies have precluded the formation and implementation of a single, coherent national 'energy policy' and produce somewhat contradictory policies to deal with various dimensions of the energy issue" [92, p. 24]. Even though this picture is more than two decades old, it still rings true. Similar to Lieberthal and Oksenberg, we find that diverse actors take part in China's nuclear power development, and that this has affected decision making greatly.

The situation is somewhat analogous to the oil sector in China. The three main nationalized oil companies (NOC) have acted as a strong interest group, while competing intensely amongst themselves. Marketization and globalization "have heightened the divergence between corporate and national interests" and these developments have helped pluralize the policymaking process [22]. This has resulted in decision making becoming more contentious and protracted. The NOCs "regularly vie for markets and projects and hence rarely function as a coherent unit, leaving the government to devote more resources to managing their competition" [22]. This description can carry over, mutatis mutandis, to the nuclear sector, and the analogs of the NOCs are organizations like CNNC and SNPTC.

Our analysis of domestic determinants of nuclear policy in China has mainly focused on major organizations at the national level that participate in nuclear power generation and policymaking. As briefly mentioned earlier, local and provincial governments also play an evident role. The participation of these and other additional domestic players can, however, only reinforce our assessment of the fragmented nature of nuclear policymaking.

The second, and equally important, factor that we have identified as having a strong impact on Chinese nuclear policymaking is competition between international nuclear vendors. Because of the large amounts of capital and potential profits involved, many governments take a keen interest in their nuclear sectors, and therefore use various other forms of inducement and coercion to promote reactors designed by vendors from their country. We emphasize that the lack of standardization is a result of the interaction between these two factors. Separately, neither of these factors would have necessarily resulted in the persistence of multiple reactor designs, especially foreign designs.

Going into the future, plans for nuclear power in China have been in flux since the March 2011 accidents at Fukushima. One aspect of the debate has been about whether or not to continue constructing CPR-1000 reactors. Since these are also of Generation II designs just like the damaged Fukushima reactors, some, including the proponents of Generation III designs, have been calling for a stop in the manufacture of CPR-1000 designs. CNNC and its allies have been resisting this pressure.

There are, broadly speaking, two scenarios going forward. One is that construction of reactors with older Generation II designs will be stopped, sooner or later, and only more modern, Generation III designs, will be constructed. An alternative scenario is that construction of both Generation II and more modern reactor designs will continue apace, as has been the case so far. Which scenario will better describe China's future will depend on political forces, both domestic and international, and it is still too soon after Fukushima to predict how China's nuclear sector will evolve.

In both scenarios, however, our analysis suggests that the underlying factors that determine Chinese nuclear policy make it unlikely that China will adopt one standard reactor type, for example, the AP-1000, and deploy it in all its nuclear projects. There are many international nuclear vendors offering Generation III designs, including Atomic Energy of Canada Limited and Areva, and it is likely all of them will compete for the Chinese nuclear market, as has been the case in the past. The past also suggests that it is likely that more than one of these vendors will succeed in finding domestic organizations to partner them in adopting and constructing their reactor. China's nuclear development path will, in both scenarios, be characterized by diversity.

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[19] There is no dearth of domestic organizations to partner with. In 2002, the U.S. embassy in Beijing estimated that "about 300 enterprises are engaged in the development and production of nuclear technology in China" [89].

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