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Viewpoint

A comparison of the nuclear options for greenhouse gas mitigation in China and in the United States

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A R T I C L E I N F O

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A B S T R A C T

China is quickly building up its nuclear power capacity while the hailed nuclear renaissance in the United States has been largely stagnant. The political and industrial structures explain the divergent paths. This paper draws lessons from the French experiences in deploying nuclear power and uses the lessons in comparing Chinese and U.S. policies. An authoritative political system and state-owned utility industry allow China to emulate the French approaches such as government-backed financing and broad-scale deployment with standardized design. The democratic political system and fragmented utility industry, and the laissez-faire ideology in the United States, on the other hand, are unfavorable to a nuclear renaissance. The prospect of a nuclear revival in the United States remains highly uncertain.

As China builds up its nuclear industry, it will be able to reduce carbon emissions without a carbon price through a national plan to deploy low-carbon nuclear electricity, while the United States cannot implement a climate policy without a carbon price. American politicians should stop using China's lack of carbon cap as an excuse for postponing the legislation of a carbon price.

1. Introduction

In the early 2000s, many in the United States were expecting a revival of nuclear power. The hailed nuclear renaissance in the United States, however, proceeded very slowly, if at all. China, on the other hand, is quickly moving forward to scale up its nuclear power deployment. The recent diverge between the Chinese and the U.S. nuclear power development mirrors the historical divide between the France and the United States in the 1980s.

As shown in Fig. 1, the U.S. nuclear reactor market collapsed in 1974–1975. Overburdened by cost overruns, construction delays, and faced with lowered electricity demand outlook, the U.S. utilities canceled over a hundred of previously ordered nuclear reactors in the late 1970s and throughout the 1980s (Bupp and Derian, 1978; Campbell, 1988). Although the Three-Mile-Island (TMI) accident is commonly misperceived as the main cause of the collapse of the U.S. nuclear market, the perception is not true. TMI cannot account for the collapse because the accident happened in 1979, which was several years after the collapse. The main causes for the collapse of nuclear industry in the United States were economic and institutional factors.

In 1974, the French government decided to greatly buildup its nuclear power capacity. Unlike the United States, France has a national utility, Electricité de France, in charge of power supply for the entire country. The French nuclear power program was led by technocratic elites and funded with government-allocated capitals (Campbell, 1986; Schneider, 2008; Kidd, 2009; Sovacool and Valentine, 2010). France adopted the U.S. pressurized water reactor (PWR) design in its national plan and eventually built 58 reactors with a standardized design (Jasper, 1990). A single responsible authority and one standard design allowed the best practice to be replicated. Thanks to economies of scale and technological learning, French nuclear power turned out to be significantly cheaper than its U.S. counterparts (Valenti, 1991). A French nuclear power plant cost roughly the same as the cheapest American plant or half the cost of the average American plant (Jasper, 1990). In the United States, the fragmented utility industry and the lack of standardization prevented economies of scale and deterred technological learning. The best-practice costs in the United States were as good as the French ones, but the average was by far worse.

Other factors also contributed to achieving the French nuclear power buildup (Collingridge, 1984; Campbell, 1986; Lester and McCabe, 1993; Schneider, 2008; Sovacool and Valentine, 2010). The EDF enjoys state-backed finance, which the U.S. utilities typically lack. A nuclear power project is a tremendous financial undertaking. State-backing enables EDF to shoulder the financial risk. In addition to standard reactor design, national planning also has the advantage of site consolidation. A typical French nuclear power site accommodates four reactors, compared to typically

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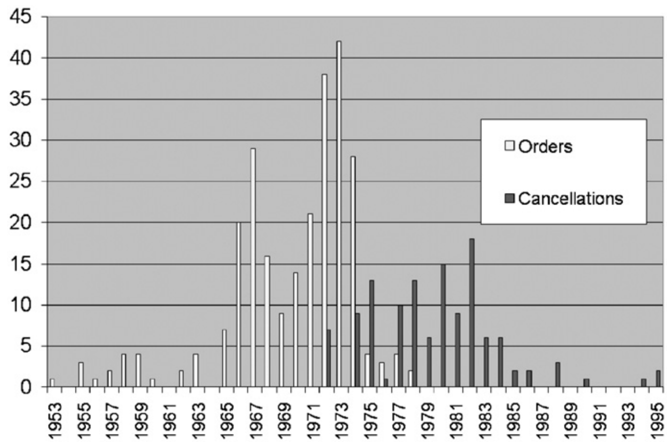

Fig. 1. Orders and cancellations of civilian nuclear reactors in the United States.

two reactors per site in the United States. More reactors per site contribute to lower costs in permitting and site preparation. A typical U.S. utility company serves a much smaller area than France. It is more difficult to achieve the economies of scale in the United States. To summarize, the French secrets in building up a nuclear-dominant electricity system include centralized planning, state-backed finance, standardized design and site consolidation. Government and industry structure largely explained the divergence between the French nuclear power buildup and the U.S. collapse in the past. A similar divergence exists today between China and the United States.

2. Nuclear buildup in China

China did not have any civilian nuclear power until 1994. China's first nuclear power plant (Daya Bay 1&2) adopted the French PWR design. Meanwhile, China also built a reactor with indigenous PWR (CNP300) design. Combining the experiences from the indigenous CNP300 and technology transfer from France, China developed semi-indigenous PWR (CPR1000) reactors. During the 1990s, standardization was not a high priority in China's nuclear power policy. In addition to the indigenous CNP/CPR reactors and the French reactors, China also built two reactors with Canadian pressurized heavy water design (PHWR or CANDU) and two with the Russian PWR (VVER) design. In the early 2000s, Chinese technocrats called for standardization. There was a debate over the choice between the semi-indigenous CPR1000 and the more advanced AP1000 designs (Xu, 2008; Lu, 2009). The National Development and Reform Commission (NDRC) eventually chose AP1000 as the official standard for the future nuclear buildup. Critics of this choice argued that AP1000 lacks proven construction record, and China would be the first to try building one. CPR1000, on the other hand, has a track record of construction experiences. Large-scale deployment of an untried design is risky. Therefore, China has to postpone its nuclear power deployment until its first (also the world's first) four AP1000 reactors are completed. However, faced with increasing international pressure to reduce greenhouse gas (GHG) emissions, China cannot wait until the AP1000 design is fully proven to deploy nuclear power. Therefore, China is not abandoning its CPR1000 design in the near term. It is currently building 16–20 CPR1000 reactors. AP1000 remains the official choice for the long term. More than 50 AP1000 reactors have been proposed.

The Chinese government established the State Nuclear Power Technology Corporation (SNPTC) to be responsible for the technology transfer and indigenization of AP1000. SNPTC is also charged with the development of CAP1400 design, which would be an indigenized and enlarged version of AP1000. If the first four AP1000 reactors perform satisfactorily, China could scale up the AP1000 deployment in the mid-term and follow up with CAP1400 reactors in the long term. The Chinese nuclear power program is on a path to become the biggest nuclear power deployment in human history. Some Chinese researchers are concerned with the potential high costs of AP1000 and argue for wider deployment of CPR1000, which already has a satisfactory cost record (Table 1; NDRC, 2008; Pan, 2009; Zhou et al., 2009). Due to such concerns, the CPR1000 design has continued to be deployed and developed in the near term.

The NDRC is the authority in charge of approving nuclear projects and administratively set the wholesale generation price (RAP, 2008). A nuclear power plant sells electricity at a price that is determined according to the levelized cost plus allowed return of this particular plant (Liu, 2009; Li, 2009). Such pricing scheme guarantees profitability for every nuclear power plant. Therefore, Chinese nuclear utilities do not need a carbon price to be profitable. The state-owned corporations will build as many nuclear power plants as the NDRC instruct/allow them to.

China National Nuclear Corporation (CNNC) is the owner of the first two AP1000 reactors currently under construction at the Sanmen site. China Guangdong Nuclear Power Holding Company (CGNPC) owns the CPR1000 design and operates most of the existing plants with French PWR and the CPR1000 designs. It is also the primary owner of most CPR1000 projects currently under construction. Before 2006, only these two specialized nuclear power companies (i.e. CNNC and CGNPC) were authorized to build and operate nuclear power plants in China. In 2006, one of the conventional power corporations, China Power Investment Corporation, broke the duopoly and obtained the license to become the primary owner of the nuclear power station at Haiyang site with two AP1000 units (Pan, 2009). Other state-owned conventional power companies have also expressed interests in entering the nuclear business. The NDRC has so far been cautious about further opening the market.

China's nuclear power development and deployment are nationally planned (Sovacool and Valentine, 2010). The state-owned banking system provides state-backed finance for nuclear projects. The administratively set tariffs guarantee profit. National planners dictate technology choice to insure standardization. Rapid demand growth allows large-scale deployment. A typical Chinese nuclear power plant site is designed to accommodate 8 reactors or more. Unlike the national monopoly in France, China's nuclear power industry is a state-owned oligopoly. Each of the two major designs (CPR1000 and AP1000) will be repeated at least in tens of projects.

Other features of the Chinese government also help to reduce costs of nuclear power. The Chinese constitution disallows private land ownership, which greatly eases the difficulty in siting. Legal challenges to nuclear projects, like those in the United States, are impossible in China, where the communist leadership openly rejects the very idea of judicial independence.

Table 1
Costs of nuclear plants in China.

CPR1000			AP1000		
Project	Cost/kW	Completion	Project	Estimated cost/kW	Expected completion
Lingao #1	$1800	2002	Sanmen #1, Haiyang #1	$1938	2013–2014
Lingao #2	$1550	2010	Sanmen #2, Haiyang #2	$1680	2014–2015

The Chinese government considers its economic plans equivalent to law. For example, in the eleventh five-year plan (2005–2010), China blacklisted 50 gigawatts (GW) of small and old coal-fired power plants and ordered them demolished. This target was achieved ahead of schedule in 2009. The NDRC decided in early 2010 that it would phase out another 10 GW of coal-fired capacities by the end of 2010, and once again achieved the target ahead of schedule in July (SERC, 2010; Wang, 2010). The Chinese national plan is far more forceful than the government plans in western democracies. For example, the Chinese government has been ordering its coal, electricity, steel, rare earth and other energy-intensive industries to consolidate as a means of improving energy efficiency. Government agencies in western democracies hardly ever enjoy such authority.

According to its Nuclear Power Mid-to-Long-term Plan (2005–2020), China plans to install 40 GW of nuclear power by 2020 (NDRC, 2007a). In 2010 China raised its 2020 nuclear power target to over 80 GW, which would account for about five percent of the projected 2020 total power generation capacity in China. The target appears reasonable and achievable. By 2020, China would have established a full-fledged nuclear manufacturing industry. It certainly intends to continue utilizing its nuclear manufacturing capacity after 2020 and further deploy more nuclear power. Nuclear power can only be justified with sufficient demand. In the late 1970s and 1980s, many proposed U.S. reactors were canceled due to less-than-expected demand growth. The problem is less likely in China. China is still a developing country with low per capita power consumption. The room for future demand growth is plenty. According to the International Energy Agency's projection, Chinese demand for electricity is expected to grow dramatically in the coming decades (Fig. 2; IEA, 2010). The rapid growing power demand justifies large-scale deployment of nuclear power. Furthermore, the Chinese government has an aggressive program in retiring old (>20 years) coal-fired power plants. The aggressive retirement program could potentially make room for future nuclear power deployment.

According to the current plan, nuclear power would account for the second largest share in China's low-carbon electricity resources by 2020. According to its Renewable Energy Mid-to-Long-term Plan, China plans to expand, by 2020, its hydropower capacity to 300 GW, wind power 30 GW, biomass power 5.5 GW and solar 1.8 GW (NDRC, 2007b). After 2020, further development of hydropower will likely be constrained by site availability, and nuclear power may become the primary driver in China's path to further lower carbon emissions in the power sector. According to the existing plan, China would have acquired sufficient experiences in building advanced nuclear reactors by 2020 and be ready to deploy them in even larger scale.

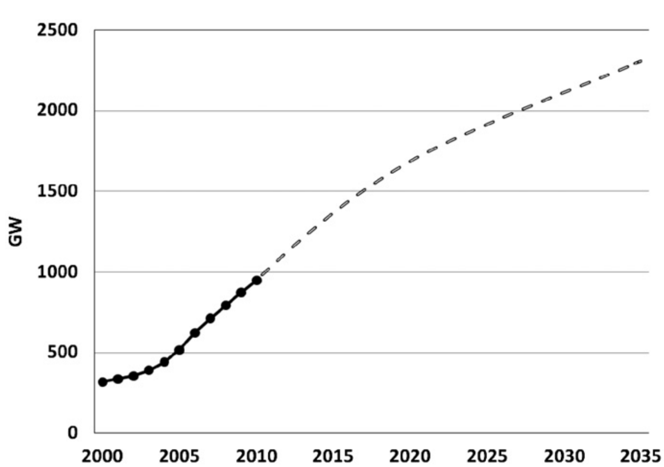

Fig. 2. China's power capacity growth projection.

3. Touted nuclear renaissance in the United States

Unlike France and China, the United States has a highly fragmented electric utility industry, which is composed of three federal agencies, over seventy investor-owned power companies and numerous municipal and rural power cooperative organizations. Although the United States as a whole is the world's biggest economy, each individual entity in the U.S. utility industry is typically by far smaller than their French or Chinese counterparts. The largest power company in the United States, Exelon, has a market capitalization that is less than one third of EDF's scale[1]. Lew Hay, chairman and CEO of FPL, was quoted, that a nuclear power project "is a huge bet for any CEO to take to his or her board" (NEI, 2007). The financial undertaking of a nuclear power project is prohibitive for most of the U.S. utilities, but not for the state-backed utilities in France and China.

From the 1960s to the 1980s, there was hardly any standardization in nuclear reactor designs in the United States. The consequences were constant cost overruns and construction delays, which in turn led to heavy financial losses and sometimes bankruptcies. Since then, the U.S. Nuclear Regulatory Commission has worked on standardization. The U.S. approach of standardization focuses on pre-certifications for designs and a laissez-faire policy toward industrial structure and the number of designs. This approach resulted in many competing pre-certified designs. As on March 2010, the proposed 26 reactors followed five different designs. Although each of the "standardized" designs is pre-certified, the variety of designs defeats the idea of standardization. Although the nuclear operators have been through some consolidation in the past decades, the industry is still fragmented. The proposed new nuclear projects are divided among 20 owners. Each owner will only build one or two reactors. The fragmented ownership will likely hinder two means of cost reduction: learning-by-doing and site consolidation. When a project owner has only one of two chances of trying, it is very difficult to accumulate experiences. Site consolidation is nearly impossible in the United States. A nuclear power project cannot place more than two reactors at the same site if the project contains only one or two reactors. The United States is a developed economy with slow growth in electricity demand. The U.S. government lacks an effective means of retiring old power capacities. Furthermore, the small demand growth is divided among a huge number of utilities. It is far less likely in the United States than in China that a utility can have sufficient new demand to justify large-scale deployment of nuclear power. The aforementioned conditions in the United States are unfavorable in reaching the economy of scale and technological learning.

The U.S. government does provide financial support for nuclear power. The Energy Policy Act of 2005 authorizes cost-overrun support, a production tax credit during the first eight years of operation for the first 6 GW of capacity and loan guarantees for new nuclear plants. While these financial incentives are significant, they are not comparable to directly government-backed finance in China and France.

The constraints on the U.S. nuclear power are embedded in its industrial and political structures (Table 2). The U.S. politics is unlikely to let the government dictate technology choice. The laissez-faire ideology and legal tradition of respecting private

[1] As of May 27, 2010. http://www.bloomberg.com/apps/quote?ticker=EXC%3AUS and http://www.bloomberg.com/apps/quote?ticker=EDF%3AFP.

Table 2
Comparison of French, U.S. and Chinese context of nuclear power development.

Country	France	United States	China
Utility industry structure	State-owned monopoly	Highly fragmented	State-owned oligopoly
Nuclear project finance	State-backed	Limited loan guarantee + tax credit	State-backed
Standardization	One design	Five pre-certified designs	CPR1000 for near-term deployment AP1000/CAP1400 for mid- to long-term scale up
Site consolidation	4 reactors per site	2 reactors per site	8 reactors per site

property make it very unlikely for the U.S. government to nationalize or consolidate the utility industry. The fragmented ownership and multiple standards will likely keep the cost high. High costs discourage large-scale deployment. Without a forceful national program, U.S. nuclear project will likely continue to suffer lack of scale. Unlike the Chinese government, the U.S. government cannot guarantee profitability for nuclear power projects. The U.S. federalist political system has prohibited a nationally unified electricity regulatory regime. In the conventionally regulated parts of the United States, the tariffs are determined by state commissions, and in the restructured parts they are determined by the competitive electricity market. Nuclear power projects will likely remain very risky investments in the United States. It is possible that a few new reactors may be built in the United States, but the overall industrial and political structures are unlikely to change in the foreseeable future.

4. Implications of Chinese and U.S. nuclear divergence

Within ten years, China may reach the tipping point to start de-carbonizing its electricity system. The United States, without the nuclear option, would face significantly higher costs in GHG mitigation. Up to now, many politicians in the United States have argued against committing itself to a binding GHG target without similar commitment from China. Such arguments overlook the fundamental differences in the political and industrial structures between China and the United States.

The U.S. energy sector is largely privately owned. U.S. utilities are unlikely to undertake high-risk large-scale low-carbon ventures without perceived high financial returns. Imposing a high price on carbon emissions is necessary to provide a path to profitability for low-carbon technologies in the United States. The lack of political will to impose a high carbon price does not only hinder nuclear renaissance, but also the development of other large-scale low-carbon technologies such as coal-fired power with carbon capture and storage (CCS). The U.S. climate policy primarily focuses on supporting the research and development of technologies (Stephens, 2009). Without a carbon price, no amount of research and development could make capturing carbon cheaper than not capturing it. Unlike the Chinese government's nuclear power and renewable energy plans, which are implemented without a carbon price, the U.S. government plans and roadmaps of CCS and nuclear power will remain empty promises until a carbon price is legislated.

Unlike the United States, China could move toward a low-carbon electricity system without a carbon price. The Chinese government owns most of the Chinese energy sector, and the Chinese national energy policymakers enjoy far greater authority than their U.S. counterparts. In the not-so-distant future, if China decides to de-carbonize its electricity with nuclear power, the United States would not be able to match China's pace in reducing GHG emissions. If the U.S. policymakers continue to postpone the imposition of a carbon price, it may someday find itself unable to catch up with China in the global efforts of containing climate change.

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