China's Nuclear Export Ambitions in Context

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Global demand for nuclear energy is rising, despite slow growth in wealthy countries. Over thirty countries are pursuing their first nuclear power projects, and the IAEA predicts global capacity will need to double by 2050 to meet climate targets.[1] Historically, the US has been the largest producer of nuclear energy and the dominant exporter of nuclear reactors and fuel. But in the last two decades, China has been rapidly growing its domestic fleet of reactors, and is predicted to surpass the US as the world's largest producer of nuclear energy by 2030. China has ambitions to also become a leader in the global nuclear export market, but their success is far from guaranteed, as Western countries are shifting focus to new, so-called "advanced nuclear" technologies that offer many benefits over traditional nuclear power.

Most countries start their commercial nuclear power programs by importing the technology from one of the existing vendor countries. Even in China, the nuclear power sector initially relied upon a suite of imported designs from France, Canada, Russia, and the U.S. But there has been a major effort to localize the supply chain and develop indigenous reactor technology. In 2014, 80% of components and equipment for Chinese nuclear reactors was manufactured in China.

Today, the capital costs of nuclear power plants in China are about half of what they are in the U.S. and Europe.[2] While low labor costs and cheap financing from the state help to bring costs down for Chinese projects, the most important factor is reduced component costs through economies of scale across the industry and design standardization. They can benefit from such economies of scale because they are building so many reactors in succession.

China is now hoping to capitalize on this domestic success to export their technology globally. As part of their Belt and Road initiative, they are pursuing a broad strategy of influence through nuclear consisting of three components: 1) marketing its domestic Hualong reactor for export, 2) investing in existing nuclear projects abroad, such as Hinkley C in the UK, and 3) partnering with Canada and the U.S. to develop advanced reactor concepts. In 2019, the Chinese government launched Made in China 2025, an industrial policy aimed at growing market share in high-tech manufacturing,[3] and President Xi Jinping considers nuclear power to be an important contributor towards this goal.[4] In 2019, a senior Chinese official stated that they could build up to 30 nuclear reactors in Belt and Road countries.[5]

Of course, China is not the first country to have nuclear export ambitions; nine countries have exported commercial reactors including Canada, West Germany, France, the UK, Russia, Sweden, and the U.S. Yet each of these countries had different motivations and strategies for their nuclear exports.

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[1] IAEA. *Energy, Electricity and Nuclear Power Estimates for the Period up to 2050*. (2021) https://www.iaea.org/publications/15028/energy-electricity-and-nuclear-power-estimates-for-the-period-up-to-2050

[2] 1. IEA, NEA & OECD Nuclear Energy Agency. Projected Costs of Generating Electricity 2010. *Atomic Energy* 118 Suppl, (OECD Publishing, 2010).

[3] James McBride and Andrew Chatzky. "Is 'Made in China 2025' a Threat to Global Trade?" *Council on Foreign Relations*. May 13, 2019 https://www.cfr.org/backgrounder/made-china-2025-threat-global-trade

[4] Shunsuke Tabeta. "China's first homegrown reactor ready to take on Western players." *Nikkei Asia.* November 28, 2020 https://asia.nikkei.com/Business/Energy/China-s-first-homegrown-reactor-ready-to-take-on-Western-players

[5] Reuters Staff. "China could build 30 'Belt and Road' nuclear reactors by 2030: official." *Reuters* June 19, 2019 https://www.reuters.com/article/us-china-nuclearpower/china-could-build-30-belt-and-road-nuclear-reactors-by-2030-official-idUSKCN1TL0HZ

The UK exported two small reactors: one to Italy in 1958 and one to Japan in 1961, likely motivated by post-war rebuilding efforts. Sweden exported two large reactors to its neighbor, Finland, in the late 1970s, likely motivated by expanding their domestic industry. Germany -specifically the West German companies Siemens and Kraftwerk Union (KWU) - only exported seven reactors, but they were the dominant exporter to South America, with two large reactors exported to Argentina and two to Brazil (although the second was mothballed). Germany also signed an agreement to export enrichment and plutonium reprocessing technology to Brazil, despite loud objections from the U.S. on security and proliferation grounds.[6]

Canada and France's nuclear export industries were similarly motivated by a desire to expand their domestic industries. France was also a significant exporter of nuclear fuel, enrichment and reprocessing technology. Canada had an explicit goal of aiding the economic development of low-income countries. Complimenting this, their CANDU reactor was valued by nuclear newcomer countries for its use of natural, or unenriched, uranium. Canada exported to Argentina, China, India, South Korea, Pakistan, and Romania. Whereas French exports were concentrated in Europe and China, with additional projects in South Korea and South Africa.

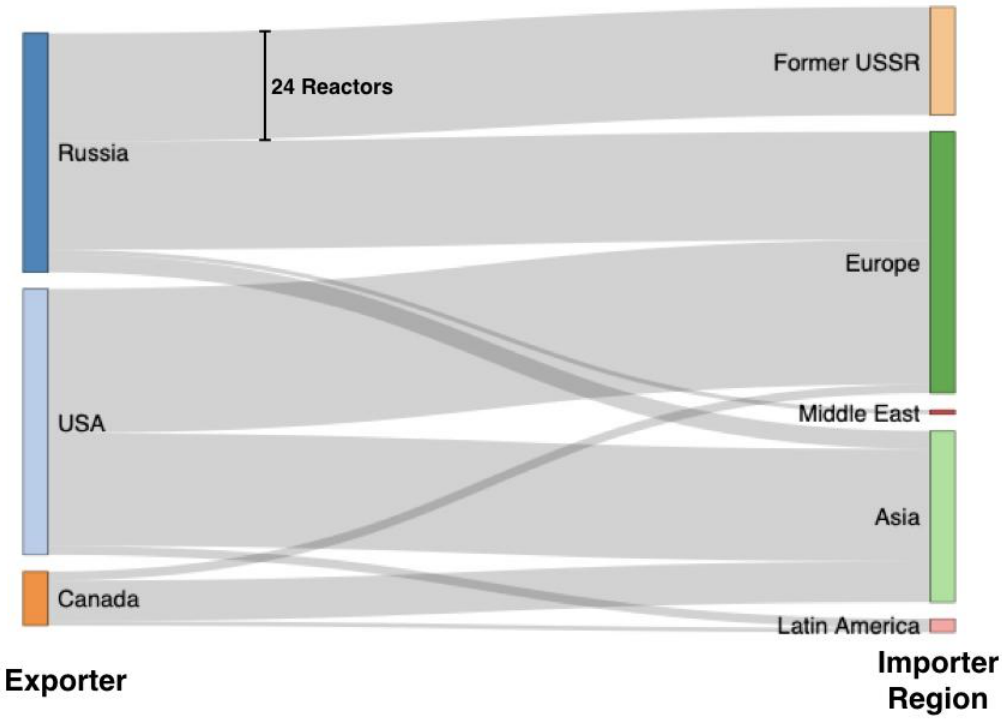

Figure 1. Geographical flow of commercial reactor exports from the top three exporters to the region of import. Width of the gray bar represents the number of reactors exported. Image credit: Lovering (2020)[7]

The U.S. and Russia (formerly as part of the U.S.S.R.) both began nuclear power programs soon after World War II and quickly moved towards exports as a tool of soft power and diplomacy. In Figure 1, the geographical extent of exports from the U.S. and Russia is shown. While Russia's exports tended to go to neighbors in the Soviet Union, Eastern Europe, or China, the U.S. exported to countries across Europe, Asia, and Latin America. The U.S. also exported a

[6] Victor Zaborsky. "The Brazilian Export Control System." *The Nonproliferation Review.* Summer 2003. https://www.nonproliferation.org/wp-content/uploads/npr/102zabor.pdf

[7] Lovering, J. R., Abdulla, A. & Morgan, G. Expert assessments of strategies to enhance global nuclear security. *Energy Policy* 139, (2020).

significant number of research and experimental reactors around the world. Unlike the U.S., Russia has continued to dominate the global nuclear market, becoming the main supplier for nuclear newcomer countries like Egypt, Turkey, and Bangladesh in recent years. Russian nuclear export agreements are well-known for their generous complimentary services, such as project financing, fuel supply, and workforce development programs.

China has been interested in exports from the very beginning of its commercial nuclear industry.

Finally, South Korea is the latest country to enter the nuclear export market, with four 1.4GW reactors under construction in the United Arab Emirates, the country's first nuclear power plant. South Korea is looking to take advantage of their successful domestic industry and grow their manufacturing capacity. In 2010, South Korea set a goal of exporting 80 nuclear reactors by 2030.[8] They will likely fall far short of this goal, especially as the country adopted a nuclear phase-out policy in 2017. Yet South Korea has continued to invest in strategic supply chain agreements. For example, Doosan Heavy Industries & Construction has invested close to $100 million in the American SMR developer NuScale; Doosan will manufacture many of NuScale's reactor components in South Korea. The two companies also have agreements to partner on hydrogen production and desalination technologies.[9]

Although Japan had the third largest nuclear power fleet before the 2011 Fukushima accident, the country was never actively involved in commercial exports. However, they did have a significant nuclear research and development program - they are still the largest spender on nuclear R&D annually - and Japanese companies became part-owners of other dominant nuclear vendors like Westinghouse (bought by Toshiba in 2006) and GE Hitachi Nuclear, an alliance between GE's nuclear division and Hitachi that was created in 2007.

Record of Chinese Nuclear Exports To Date

China has been interested in exports from the very beginning of its commercial nuclear industry. While China's first commercial reactor started generating electricity in 1991, they broke ground on their first export project in Pakistan in 1993. Since then, China has built four of these 300MW CNP reactors in Pakistan, and two 1,100MW Hualong One (or ACP-1000) reactors that came online in 2021 and February 2022.

The state-owned firm China General Nuclear did have an agreement in Romania to build the third and fourth reactors at Cernavoda Nuclear Power Plant, but that agreement was canceled in 2020 and a new agreement was signed with the U.S. to help build the reactors. Reasons for the cancellation were not entirely clear, but there was concern that as U.S.-China relations cooled during the Trump Administration, a partnership with a NATO ally was seen as preferable and more sustainable than with China.

Similarly in the U.K., China has been involved as an investor or developer in several projects, with China General Nuclear Power Group having a 33% share of Hinkley Point C and a 20% share of Sizewell C. However, in September of

[8] *World Nuclear News*. "South Korea seeks to boost reactor exports." 13 January 2010. https://www.world-nuclear-news.org/NP-South_Korea_seeks_to_boost_reactor_exports-1301104.html#:~:text=South%20Korea%20aims%20to%20export,share%20of%20the%20global%20market

[9] *World Nuclear News*. "Doosan makes additional investment in NuScale" 20 July 2021. https://www.world-nuclear-news.org/Articles/Doosan-makes-additional-investment-in-NuScale

2021, the U.K. government announced they were trying to force a sale of CGN's share in Sizewell C, to remove Chinese influence.[10] In June of 2022, the government moved forward with this plan, buying an option to take CGN's stake in the Sizewell project.[11]

While China had been in the running for a nuclear tender in the Czech Republic, in early 2021, the government excluded them from formal document sharing, effectively blocking them from participating in the tender. The Czech ministry of industry and trade said that China (and Russia) were "not invited."[12]

In more positive news for China, in February of 2022, China National Nuclear Corporation signed an agreement with Argentina to construct two of its Hualong units near the capital, Buenos Aires.[13] But just two months later, Argentina is requesting that China also finance the entire project, which may put the project at risk of cancellation.[14]

China has operating research reactors in Ghana, Iran, Nigeria, Pakistan, and Syria. China also collaborated with the U.S. to convert the Ghanian reactor from high-enriched uranium to low-enriched uranium in 2017, aiding security and non-proliferation goals. There is also an agreement for a planned research reactor in Thailand.

Since 2000, China has signed over 50 Nuclear Cooperation Agreements - bilateral trade agreements for nuclear technology, fuel, or services - with over 20 countries.[15] However, China is far from the dominant player in these nuclear bilateral trade agreements. An analysis by Jewell et al. (2019) found that China was a partner in only 6% of concrete technological agreements, compared with 30% for Russia, 23% for France, 20% for Japan, 17% for the U.S., and 10% for South Korea.[16]

Across Africa, China has been very active in a diverse array of infrastructure investments, and this includes nuclear. Namibia's largest Uranium mine is owned and operated by China General Nuclear—almost all of the Uranium is exported to China. Namibia has received a proposal from China General Nuclear to build its first nuclear power plant. The Kenya Nuclear Electricity Board (KNEB) has signed some agreements with a few nuclear developers: one in 2015 with China General Nuclear Power (CGN). In Sudan, A framework agreement with China National Nuclear Corporation was signed in 2016 to create a 10-year nuclear cooperation roadmap and to develop either one or two 600 MW reactors.

[10] https://www.reuters.com/world/uk/uk-weighs-sale-nuclear-plant-stake-institutional-investors-ft-2021-09-29/
https://www.nytimes.com/2021/08/02/business/great-britain-china-nuclear-power.html
[11] Alex Lawson. "UK buys option to take 20% stake in Sizewell C nuclear power plant." June 14th, 2022. https://www.theguardian.com/environment/2022/jun/14/uk-buys-option-to-take-20-stake-in-sizewell-c-nuclear-power-plant
[12] America Hernandez. "Czech nuclear tender competition dodges Russian and Chinese bids." *Politico*. June 24, 2021 https://www.politico.eu/article/czech-nuclear-tender-competition-dodges-russian-and-chinese-bids/
[13] *World Nuclear News*. "China and Argentina sign nuclear project deal." 02 February 2022 https://www.world-nuclear-news.org/Articles/China-and-Argentina-sign-nuclear-project-deal
[14] Eliana Raszewski. "Argentina wants China to fully fund $8.3 bln nuclear plant amid cash shortfall." *Reuters*. April 5, 2022. https://www.reuters.com/business/energy/argentina-wants-china-fully-fund-83-bln-nuclear-plant-amid-cash-shortfall-2022-04-05/
[15] Countries include: Algeria, Argentina, Australia, Belarus, Egypt, the European Union, France, Japan, Jordan, Kenya, Korea, Pakistan, Romania, Russia, Saudi Arabia, South Africa, Taiwan, Thailand, Turkey, the U.S., and the UK.
[16] Jewell, J., Vetier, M. & Garcia-Cabrera, D. The international technological nuclear cooperation landscape: A new dataset and network analysis. *Energy Policy* 128, 838–852 (2019).

Beyond Commercial LWR Exports

While China is well-known as the world leader in new reactors under construction, these are almost all traditional, large-scale light-water reactor technology. Yet, China also has several advanced nuclear designs under development. For example, there are two state-owned enterprises working on water-cooled small modular reactors. In December of 2021, the first of a pair of 200MW modular high-temperature gas-cooled reactors started generating electricity. At the Shanghai Institute of Applied Physics (SINAP), a 2MW experimental molten salt reactor was supposed to finish construction and begin experiments in the fall of 2021,[17] although it does not yet appear to be operational in 2022.[18]

However, it is difficult to compare China's progress on advanced nuclear technologies to efforts in the West, as there is much less transparency in China, where technology development occurs mainly at national laboratories or state-owned enterprises. We do know that China has been investing significantly in clean energy in recent years. From 2010-2019, China was the world's largest investor in renewable energy, spending close to $800 billion or almost double what the U.S. spent over that same time period. Presumably for security reasons, China is less open to sharing its investment figures for nuclear projects (in China there is less of a sharp division between military and civilian applications of R&D).

For countries in the Organisation for Economic Co-operation and Development (OECD), annual investments in R&D are reported and broken out by specific technology. In 2020, the top 10 countries spent about $2.5 billion total on nuclear fission (excluding fusion) research, development, and demonstration (RD&D), with the top two, Japan and the U.S. each spending around $700 million annually.[19] China is not a member of the OECD and does not make its annual spending on nuclear R&D publically available, but we can get some estimates from individual projects. For example, we know they committed roughly $500 million in 2011 to their molten salt reactor program, but over how many years is unclear.[20] In 2017, the Chinese government announced a $3.3 billion commitment to the Chinese Academy of Sciences to build a molten salt reactor demonstration in Wuwei in Gansu province.[21] Again, it is unclear how many years this funding is spread over.

There is no doubt that China's domestic nuclear industry has been successful: with 16 reactors currently under construction, they will soon surpass France to be the world's second largest generator of nuclear energy. However, their export ambitions have moved slower than experts would have anticipated ten years ago. Much like Russia, reports from U.S. universities, think tanks, and government agencies warned of the growing influence of China in the global nuclear market, citing dozens of MOUs and bilateral trade agreements. But similar to Russia, many of those agreements have stalled as importing countries re-evaluate the risks of forming a long-term relationship with authoritarian regimes.

China also has significant competition in the advanced nuclear market, and not just from Russia. There are over 60 companies in the U.S. developing advanced reactor designs. And while China may be farther along in first

[17] Smriti Mallapaty. "China prepares to test thorium-fuelled nuclear reactor." *Nature*. September 9th, 2021. https://www.nature.com/articles/d41586-021-02459-w
[18] IAEA. Research Reactor Database. https://nucleus.iaea.org/rrdb/#/home
[19] OECD IEA. "IEA Energy Technology RD&D Statistics: RD&D Budget." http://dx.doi.org/10.1787/data-00488-en
[20] Smriti Mallapaty. "China prepares to test thorium-fuelled nuclear reactor." *Nature.* September 9, 2021 https://www.nature.com/articles/d41586-021-02459-w
[21] Brian Wang. "China spending US$3.3 billion on molten salt nuclear reactors for faster aircraft carriers and in flying drones." *Next Big Future.* December 6, 2017. https://www.nextbigfuture.com/2017/12/china-spending-us3-3-billion-on-molten-salt-nuclear-reactors-for-faster-aircraft-carriers-and-in-flying-drones.html

demonstrations, the fact that U.S. developers are generally private companies competing for investments and government support, may give them an advantage over state-owned ventures in China. Around the world, new nuclear designs are trending towards smaller concepts, with many aiming for factory fabrication. As the global nuclear market moves away from large infrastructure projects, toward modular factory fabrication, many energy pundits assume that a manufacturing powerhouse like China (or Japan or Korea) would be at a significant advantage. But the reality of nuclear energy may be more complicated. Similar to nuclear energy, China has been slow to make headwinds into the global market for other large, complicated technologies like widebody aircraft or automobiles. While China's share of exports in these markets is growing, it is mainly to emerging markets, where cost is the main factor for consideration. For a technology like nuclear, where safety concerns loom large, nuclear newcomer countries may prefer to partner with a vendor that comes with a more trusted reputation, even if the technology is more expensive. Ironically, the fact that China's new nuclear designs are coming from state-supported firms in China may actually hinder their competitiveness, as potential customer countries view the lack of transparency with suspicion.

How Has the Russian War Against Ukraine Shifted the Conversation

When Russia launched its attack on Ukraine in February of 2022, the reliability of the EU's energy system was immediately thrown into doubt. It was well-known that the EU was dependent on imports of fossil fuels from Russia: importing 40% of its natural gas and 24% of its oil from Russia. But the EU, and the rest of the world, is also heavily dependent on Russian nuclear exports, particularly uranium fuel. Russia has close to half of the global capacity to enrich uranium for nuclear fuel. In the U.S., the nuclear industry lobbied successfully to exclude uranium from sanctions on Russian energy imports.

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Many countries started looking for alternatives for Russia across the nuclear supply chain, and many countries that were considering importing nuclear technologies from Russia are now reconsidering. Such a disruption to the market might have opened an opportunity for China to grow its market share. However, as President Xi Jinping has given tacit approval for Russia's invasion, more countries are becoming increasingly wary of dependence on anti-democratic countries as suppliers of key materials, whether for nuclear power, renewables, or electric vehicles.

One pathway China could take to mitigate such concerns is to partner with companies in other democratic nuclear vendor countries, such as France or the U.S. Indeed, China has partnered with the U.S. on many nuclear issues historically, from refueling Ghanain reactors with LEU, to developing molten salt reactor technology with Oak Ridge National Laboratory. In 2017, U.S. company TerraPower - chaired by Bill Gates - signed an agreement to build a demonstration of their advanced reactor design in China, and collaborate on technological development. However, the project was canceled in 2019, when the Trump administration put new restrictions on technology agreements with China. Still, Chinese companies could invest in foreign nuclear companies and position themselves as reliable suppliers

based on the success of their domestic industry. But it is currently unclear whether they would be as successful as Japan or South Korea have been in this regard, especially as more scrutiny is placed on governing institutions.

Jessica Lovering is the co-founder and Executive Director of the Good Energy Collective, a new organization working on progressive nuclear policy. She completed her PhD in Engineering and Public Policy at Carnegie Mellon University. Her dissertation focused on how commercial nuclear trade affects international security standards and how very small nuclear reactors could be deployed at the community level. She is a Fellow with the Energy for Growth Hub, looking at how advanced nuclear can be deployed in sub-Saharan Africa. She was formerly the Director of the Energy Program at the Breakthrough Institute, a pioneering research institute changing how people think about energy and the environment. Her work at Breakthrough sought policies to spur innovation in nuclear power technologies to drive down costs and accelerate deployment as part of a solution to climate change and economic development. She has a bachelor's degree in Astrophysics from University of California Berkeley and a Master's degree in Energy Policy from the University of Colorado.