THE DEVELOPMENT STATUS OF CHINA'S URANIUM ENRICHMENT

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Abstract

China leads the world in term of nuclear power development pace and new reactor construction. To meet the expected rapid increase of enrichment requirements, since 2010 the China National Nuclear Corporation (CNNC) has expanded significantly its indigenous centrifuge enrichment capacity. However, China does not officially release information on its enrichment capacity. Based on satellite imagery, Chinese publications, and discussions with Chinese experts, this work will examine the current status of China's uranium-enrichment development and offer significant new estimates of the capacity of China's operating enrichment facilities.

The pace of Chinese nuclear-power development and new-reactor construction leads the world. The China National Nuclear Corporation (CNNC)—the sole player responsible for enrichment services in China—has said that it maintains a policy of "self-sufficiency" in the supply of enriched-uranium products needed to fuel its nuclear power plants.[1] To meet the expected rapid increase of enrichment requirements, since 2010 China has expanded significantly its indigenous enrichment capacity.

China does not officially release information on its enrichment capacity. Based on satellite imagery, Chinese publications, and discussions with Chinese experts, this author made in 2015 an estimate on China's enrichment capacity.[2] In the years since then, there have been a number of new significant developments. Several new centrifuge facilities have been recently commissioned. In 2020, China has a total estimated enrichment capacity of about 7.8 million SWU (separative work units), which represents an increase of about four times over its 2010 capacity (see Figure 1).

Moreover, since 2016 the CNNC has scaled back the enrichment expansion by suspending and postponing some already planned or under-construction projects, mainly due to China's slowing reactor growth. That trend will likely continue, at least for the coming few years. However, China's SWU capacities are expected to expand significantly to align well with the country's domestic and export reactor growth over next two decades.[3]

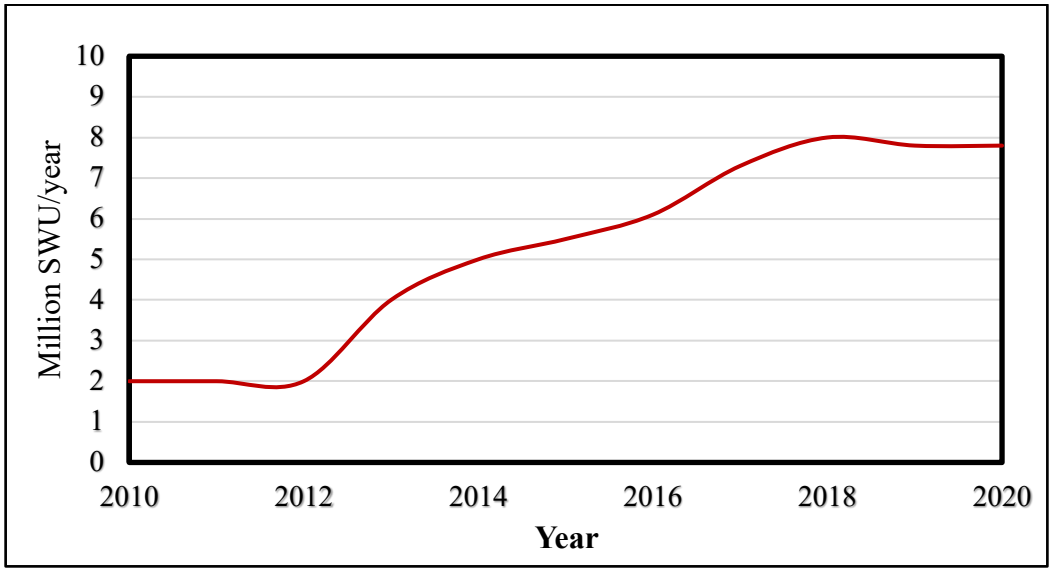

Figure 1: China's Uranium enrichment capacity (2010-2020)

The CNNC is operating three large CEPs at Lanzhou (Gansu province, Plant 504), at Hanzhong (Shaanxi province, Plant 405), and at Emeishan (Sichuan province, the Emeishan civilian facility of Plant 814) to produce LEU for civilian purposes. Plant 814 also operates a pilot CEP near Emeishan that likely serves non-weapon military uses, or dual use.

Lanzhou Uranium Enrichment Plant

China has produced HEU for weapons in two complexes: the Lanzhou gaseous-diffusion plant (GDP) (Plant 504) and the Heping GDP (Plant 814).[4] The Lanzhou GDP began operation in 1964 and ended HEU production in 1979. It has since shifted to making low-enriched uranium (LEU) for civilian power reactors and possibly for naval reactors. The plant was shut down in 2000 and demolished in 2017. Since the GDP was closed in 2000, the plant has operated its first centrifuge project, called Lanzhou Centrifuge Project 1 and alternately referred to as Russian-supplied Phase III, since July 2001. Since 2007, the Lanzhou plant has built three additional indigenous centrifuge projects (see Table 1).

The significant Lanzhou Centrifuge Project 4 has been in development at the Lanzhou plant since 2015. Based on the experience of demonstration Projects 2 and 3, this larger commercial project for a one-million SWUs-class production line was built according to principle of "one-time planning and step-by-step implementation via module."[5] The first module, with an estimated enrichment capacity of about 0.5 million SWU per year, was commissioned in 2015. The second module, with an estimated enrichment capacity of about 0.6 million SWU per year, was commissioned in 2016.

However, construction for the expected new CEP project has been suspended since late 2015. Based on satellite images, another main processing building containing pads for stack installation was under construction in late 2014 (see Figure 2-1), which will likely be used in a subsequent

project (e.g., Lanzhou Centrifuge Project 5)[6]. However, construction seems to have been suspended since late-2015. The stack-installation pads evince weathering corrosion in the 2020 image (see Figure 2-2). It is not clear when the project will be completed. In summary, by June 2020, the Lanzhou plant has a total estimated capacity of 2.6 million SWU/year, and has space ready to be used for expansion.

Table 1: Lanzhou Centrifuge Facilities

Project	Capacity	Projects	Status
Lanzhou CEP 1	0.5	Russia-supplied phase III, Russian centrifuges	Operation in July 2001.
Lanzhou CEP 2	0.5	Called Plant 504 Project 2, Demonstration Project 1, Domestic centrifuges	Operation in July 2010.
Lanzhou CEP 3	0.5	Called Plant 504 Project 3, Demonstration Project 2, Domestic centrifuges	Operation in December 2012.
Lanzhou CEP 4	1.1	Set up by Modular I (0.5 MSWU/year) and Modular II (0.6 MSWU/year)	Started construction in 2013. Modular 1 operational in 2015; Modular 2 operational in late 2016.
Lanzhou CEP 5	(1.4?)	Domestic centrifuges	In early 2015, pads for stack installation were under construction. It has been suspended since late 2015.

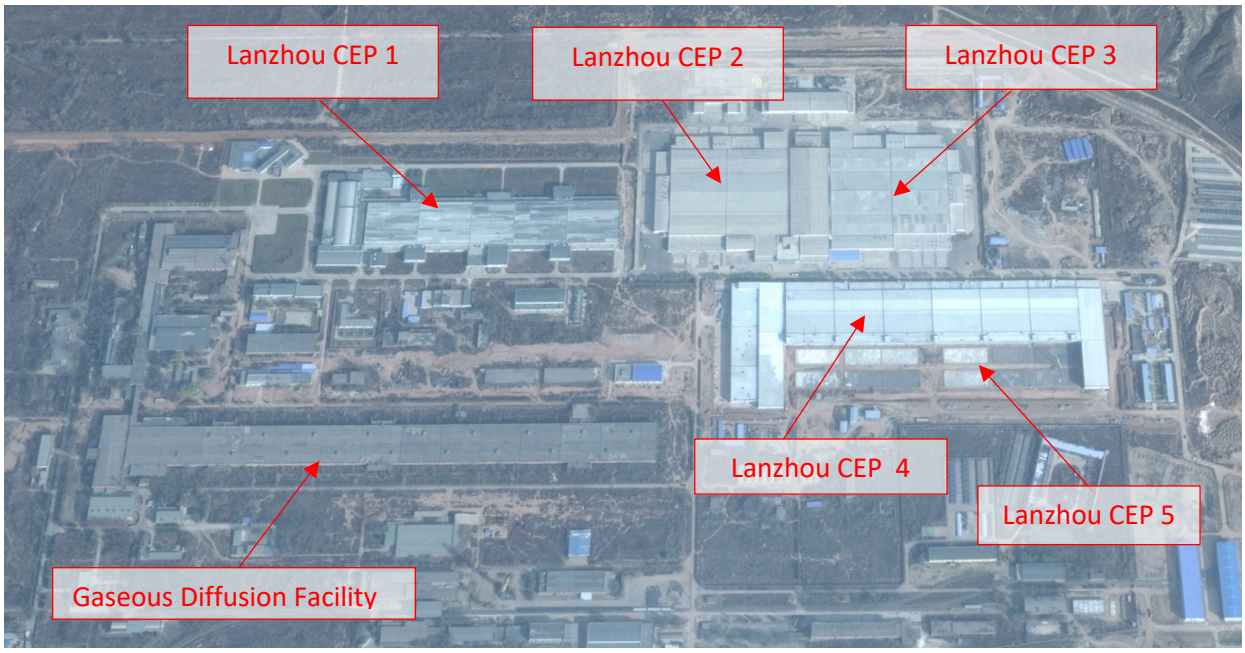

Figure 2-1: Lanzhou uranium enrichment plant. Satellite image from November 16, 2014 (Coordinates: 36^{0}08’53.30’’ N/103^{0}1’24.49’’ E). Credit: Maxar Technologies and Google Earth.

Figure 2-2: Comparison of construction activities of Lanzhou CEP5. (a) The left image over CEP5 (taken November 16, 2014) shows the main processing building with pads for stack installation was under construction, as evidenced by the cranes. (b) The right image (taken February 16, 2020) over the same site shows no construction activities. The same pads show weathering corrosion. Credit: Maxar Technologies and Google Earth.

Hanzhong Enrichment Plant

This plant has four centrifuge facilities, including three Russian-supplied centrifuge facilities built under phases I, II, and IV of the bilateral agreements, with a total enrichment capacity of 1.0 MSWU/year, and a much larger indigenous centrifuge facility referred to officially as the North Expansion Centrifuge Project (Hanzhong 4) that includes phase one and two. Currently, the Hanzhong plant has four CEP projects with a total enrichment capacity of around 2.71 million SWU/year (see Table 2).

In January 2012, the north expansion project received permission for construction.[7] It concludes two phases. Phase one began around 2014.[8] Based on the new information of Lanzhou Centrifuge Project 4, phase one has an estimated capacity of about 1 million SWU/year.[9]

Phase two, a large-scale commercial demonstration project with a new-generation centrifuge, started to run the first group of cascades in December 2017 and reached full operation in March 2018.[10] Most importantly, the second-phase project has employed firstly the second-generation indigenous centrifuges. It is estimated that the second phase has a design-enrichment module capacity of about 0.7 MWSU per year, a significant increase from an early module of about 0.5 MWSU per year. The second-generation centrifuges have been further improved by 1.5%. Thus, phase 2 has an estimated enrichment capacity of 0.71 MSWU per year.

Moreover, the Hanzhong plant has planned to build another centrifuge facility called “The New District” project, which began in 2015 and became operational before 2020 as planned. Given that the current site of the Hanzhong plant is very limited in terms of space, this new project is planned to be sited at a new location, though likely close to the current one. The new commercial centrifuge facility expects to have least one production line with two modules of second-generation centrifuges, which represents a capacity of about 1.4 MSWU per year. However, the

New District Project has not made significant progress since 2016. Like other projects at the Lanzhou plant and Plant 814, it seems to have been suspended.

Table 2: Hanzhong Centrifuge Facilities

Project	Capacity	Projects	Status
Hanzhong CEP 1	0.2	Russian-supplied phase I, Russian centrifuges	Operational in February 1997. IAEA Safeguards.
Hanzhong CEP 2	0.3	Russian-supplied phase II, Russian centrifuges	Operational in January 1999. IAEA Safeguards.
Hanzhong CEP 3	0.5	Russian-supplied phase IV, Russian centrifuges	Normal operation in 2013.
Hanzhong CEP 4-I	1	North Expansion Centrifuge Project phase I, Domestic centrifuges	Trials in 2013. Normal operation in March 2014.
Hanzhong CEP 4-II	0.71	North Expansion Centrifuge Project phase II, the first demonstration project with second-generation domestic centrifuges	Trials in 2017. Normal operation in 2018. The design capacity is about 0.7 million SWU/year. Later the centrifuge capacity increased 1.5%.
Hanzhong CEP 5	1.4?	New District Project (nearby current site)	Initiated in 2015. Operational before 2020 as planned. But no construction started, project significantly delayed.

Emeishan Enrichment Facilities of Plant 814

Plant 814 hosts enrichment facilities at three sites in Sichuan province. The Heping GDP in Jinkouhe of Leshan City started operation in 1970 and likely closed by 2019. Plant 814 is also operating a pilot CEP near Emeishan City. The larger commercial centrifuge facility (Emeishan CEP 1 and 2) of Plant 814 is located in the town of Shuangfu near Emeishan City, about 5.7 kilometer away from the pilot facility (see Table 3).

Based on satellite images, the Emeishan CEP 1 project may have gone into operation around 2013. New information concerning Lanzhou Project 4 suggests that this facility could have a capacity of around 1 million SWU per year.[11] Based on satellite images, Emeishan CEP 2 was in the early construction stage in 2014. This facility could have been commissioned around 2017. Emeishan CEP 2 is assumed to have a capacity of around 1.2 million SWU per year.[12]

In addition, the satellite images show that the space alongside the CEP 1 is perhaps being prepared for an additional CEP (Emeishan CEP 3). Satellite imagery taken in February 2015 shows some early construction activities including preparation for pad construction. But the images also show that construction has been suspended since at least February 2016.

Table 3: Plant 814 uranium enrichment facilities

Project	Capacity	Projects	Status
Emeishan CEP 1 of Plant 814	1.0	Domestic centrifuges	Project initiated in 2008. Operational around 2013.
Emeishan CEP 2 of Plant 814	1.2	Domestic centrifuges	Earlier construction stage in 2014. At stage of installment and adjustment in 2015. Operational around 2017.
Emeishan CEP 3 of Plant 814?	1.4?	Domestic centrifuges	A spare space nearby CEP 1 was at early construction stage in February 2015. But has been suspended since 2016.
Heping GDP (Plant 814)	0.23	Gaseous diffusion technology	Stopped HEU for weapons in 1987. Likely closed by 2019.
Emeishan pilot CEP of Plant 814	0.25	Pilot CEP project, Domestic centrifuges	Operational in 2007. Likely non-weapons military or dual uses.

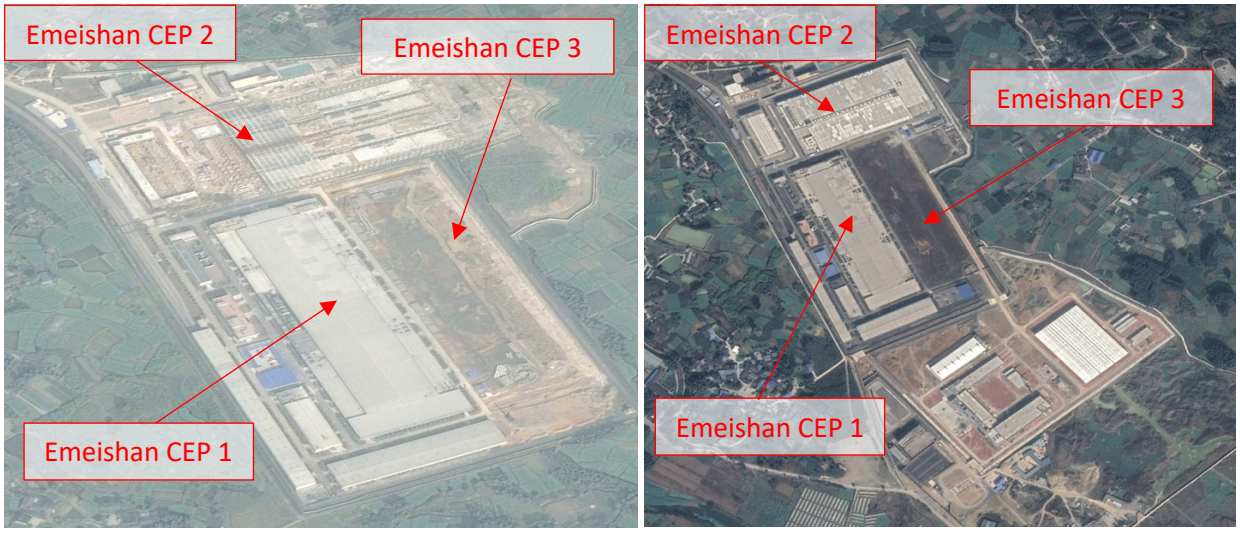

Figure 3: Commercial CEPs near Emeishan City (Coordinates: $29^0$40'38.33"N/$103^0$32'04.65" E)**.** (a) The left satellite image (taken February 16, 2015) shows the CEP 3 was in an early phase of construction. Note that building materials for pads were present. (b) The right satellite image (taken February 24, 2018) shows no construction activities or building materials, which must have been cleared. Credit: CNES/Airbus (Google Earth).

The Two Uranium-Processing Complexes

Besides the centrifuge facilities at Lanzhou, Hanzhong, and Emeishan, the CNNC also plans to build two larger uranium-processing complexes in Hebei (referred to as the "North Project") and Guangdong (referred to as the "South Project").[13] The CNNC wants to build each complex as a "one-stop" service center capable of performing uranium purification and conversion, uranium enrichment, and fuel fabrication, aiming to support China's "going global" nuclear power strategy.[14]

Until 2013, the CNNC had planned to build such a center in Heshan of Jiangmen in Guangdong Province. However, the Heshan project was cancelled in July 2013 after large-scale protests.[15] In 2014, the CNNC relocated the Heshan-type project on a similar scale to the Cangdong Economic Development Zone near Cangzhou City in Hebei Province. This uranium-processing complex, referred to as the "North Project," is solely owned by the CNNC and will cost around 40 billion yuan (~$6 billion). The CNNC planned to reach partial production capacity by 2018 and full capacity after 2020.[16] Site preparation started in 2015.[17]

Based on available Chinese sources and satellite images, the plant could have been sited about 43 kilometers east of Cangzhou City, as shown in Figure 4. The plant seemed to be at an early stage of construction, with fencing and a few auxiliary buildings, when satellite photos were taken on April 19, 2017. In an image taken in January 2018, another building had just been added. However, since then there has been no significant construction activity at the site. The project may have been suspended or significantly delayed like the other CEP projects mentioned above.

The CNNC and China General Nuclear Power Corporation (CGN) have also worked on a joint venture involving a uranium-processing complex referred to as the "South Project" that is to be located in Guangdong Province. It would be similar to the North Project in terms of production capacity and financial investment. In 2015, the Guangdong government announced it would speed up to start construction of the complex.[18] CNNC officials mentioned in March 2016 that the "South Project" was looking for a site.[19] However, since then this this project seems to have also been suspended. These delayed or suspended projects may be on hold until the release of the 14th Five Year Plan (2021-2025), which would be issued in 2021.

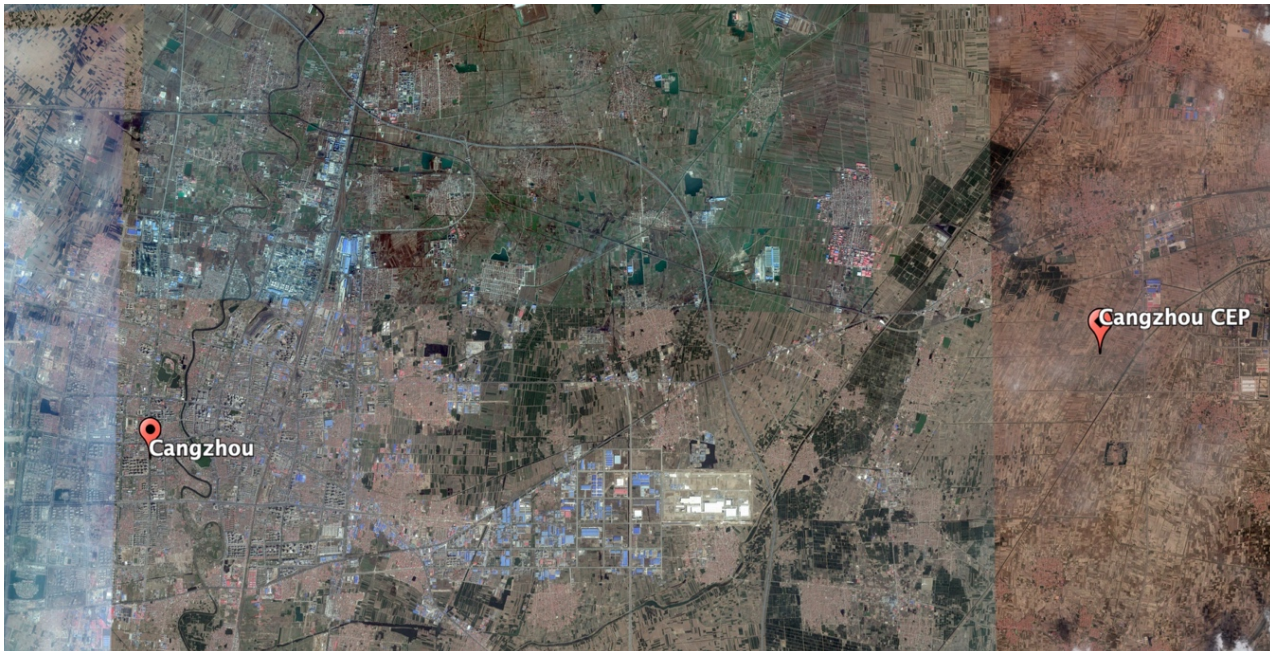

Figure 4-1: Cangzhou uranium-processing complex near Cangzhou City (Coordinates: 38°19'7.00"N/117° 5'6.11"E). Satellite image taken December 2016. Credit: Landsat/Copernicus (Google Earth). In April 2016, there was no visible construction activity at the site.

Figure 4-2: Cangzhou uranium-processing complex. a) The left satellite image (taken April 19, 2017) shows the site was in an early phase of construction. Note the fence and that a few auxiliary buildings had been constructed. (b) The right satellite image (taken January 30, 2018) shows very modest progress, namely the addition of one building. Credit: CNES/Airbus (Google Earth).

Conclusion

Estimates based on satellite imagery, Chinese publications, and discussions with Chinese experts suggest that by 2020, China has reached a total estimated enrichment capacity of about 7.8 million SWU per year, which is large enough to meet its reactors' demands of 7.5 million SWU annually.[20] Moreover, since 2016 the enrichment expansion has been scaled back through the suspension and postponement of certain projects that were either under construction or already planned, mainly due to slowing reactor growth. This trend may continue, at least in the coming few years. However, as shown in the past decade, China's SWU capacity is expected to increase significantly to match the country's domestic and export reactor growth over next two decades.

China's enrichment expansion in the future will depend on a number of factors, including the number of domestic reactors to be installed, the number China expects to export, and the share of international markets China plans to occupy.[21] The CNNC has announced that China is able to produce enough enriched-uranium products to feed its domestic and exported reactors. Considering the CNNC's plans, domestic centrifuge technology, centrifuge-production capacity, and space availability at each site, China will have enough capacity to meet its nuclear-power fuel requirement for the coming decade and beyond.

NOTES AND REFERENCES

[1] Li Guanxing, "Status and Future of China's Front-end of Nuclear Fuel Cycle, "China Nuclear Power 3, (2010), in Chinese.
[2] See more details in Hui Zhang, "China's Uranium Enrichment Capacity: Rapid Expansion to Meet Commercial Needs." Cambridge, Mass.: Report for Project on Managing the Atom, Belfer Center for Science and International Affairs, Harvard Kennedy School, August 20, 2015. http://belfercenter.ksg.harvard.edu/files/chinasuraniumenrichmenntcapacity.pdf; also, Hui Zhang, "China's Uranium Enrichment Complex," Science & Global Security, 23:3, 171-190, 2015.
[3] For more detail see: Hui Zhang, "China's Uranium Enrichment 2020-2040: Current Practices and Projected Capacities," Research paper for the Nonproliferation Policy Education Center, forthcoming.
[4] Hui Zhang, "China's Fissile Material Production and Stockpile," IPFM Research Report No. 17, 2018. Princeton, NJ: Princeton University, http://fissilematerials.org/library/rr17.pdf.
[5] CNNC, "Lanzhou Uranium Enrichment," China Nuclear Industry Daily, May 30, 2018. http://www.cnnc.com.cn/cnnc/300582/fczh/507027/index.html; "Wei Jinhui, senior technician of uranium enrichment: keeps improving and dances with "nuclear," China's Gabsu web news, April 23, 2015. http://gs.sina.cn/news/2018-04-23/detail-ifzqvvrz6734421.d.html.
[6] Once Project 5 resumes, it can be expected to use the second-generation centrifuge with two modules, each about 0.71 MSWU/year as discussed in Hanzhong's North Expansion Project Phase II case.
[7] China's National Nuclear Safety Administration (NNSA), "Annual Report 2012" (in Chinese).
[8] NNSA, "Annual Report 2014."
[9] Lanzhou Centrifuge Project 4, a commercial centrifuge facility of a level of 1 MSWU/year production line, generally consists of two modules, assuming 0.5 MSWU/year for a pre-2015 module and 0.6 MSWU/year for a post-2015 module. But the post-2017 module could be about 0.7 MSWU/year with second-generation centrifuge.

[10] CNNC, "China's large-scale commercial demonstration project of a new generation of uranium enrichment centrifuge has passed the project completion acceptance," CNNC news, November 20, 2018. http://www.cnnc.com.cn/cnnc/300555/300557/518709/index.html; Liu Caiyu, "New uranium enrichment centrifuges go commercial," Global Times, November 20, 2018. http://www.globaltimes.cn/content/1128247.shtml.

[11] The total footage of the presumed enrichment building is comparable to that of Lanzhou Project 4. The Emeishan CEP 1 could host two pre-2015 modules, each with 0.5 MSWU/year.

[12] Given that it became operational after the second Lanzhou Centrifuge Project 4 module but before the first use of the second-generation centrifuge in the Hanzhong plant, the Emeishan CEP 2 is likely using two modules, each with 0.6 MSWU/year.

[13] "CNNC stepped up deployment of nuclear fuel industrial park to help China's nuclear power 'go global,'" January 29, 2016, China Daily. http://www.chinadaily.com.cn/interface/yidian/1120781/2016-01-29/cd_23312141.html.

[14] Lin Chunting, "Coordinated with nuclear going out, CNNC plans to set up international nuclear fuel supply centers for 80 billion RMB," News, yicai.com (in Chinese), March 3, 2016. http://m.yicai.com/news/4757072.html.

[15] Liu Qingshan, "Waiting to Know the East Wind: Heshan Setback," China SOE, No. 4, (2014), pp. 28–29. Based on an interview with CNNC president Sun Qin. The China SOE (State Owned Enterprise) is run by the State Owned Assets Supervision and Administration Commission of the State Council.

[16] "Announcement on Environmental Impact Assessment of CNNC's Nuclear Fuel Industrial Park Construction Project," November 13, 2014. Cangzhou Government, http://www.cangzhou.gov.cn/zwbz/zwdt/gggq/301500.shtml.

[17] "Speeding up Nuclear Industrial Layout in Hebei," China Energy News (in Chinese), March 23, 2015. http://paper.people.com.cn/zgnyb/html/2015-03/23/content_1546832.htm.

[18] "CNNC restarts Guangdong Nuclear Fuel Industry Park project, Yicai Web News, July 20, 2015. https://www.yicai.com/news/4647348.html.

[19] Lin Chunting, "Coordinated with nuclear going out, CNNC plans to set up international nuclear fuel supply centers for 80 billion RMB," op.cit.

[20] To estimate SWU demand in 2020, a total nuclear capacity of around 50.3 GWe in 2020 was assumed by adding 4.6 GWe PWRs of new capacity to the total of 45.7 GWe in 2019, as we should include SWU for the new cores. From the total nuclear capacity of 50.3 GWe should be subtracted about 1.5 GWe of the two Candu reactors (which do not need SWU).

[21] Hui Zhang, "China's Uranium Enrichment 2020-2040: Current Practices and Projected Capacities," op cit.