On China's Nuclear Fuel Cycle

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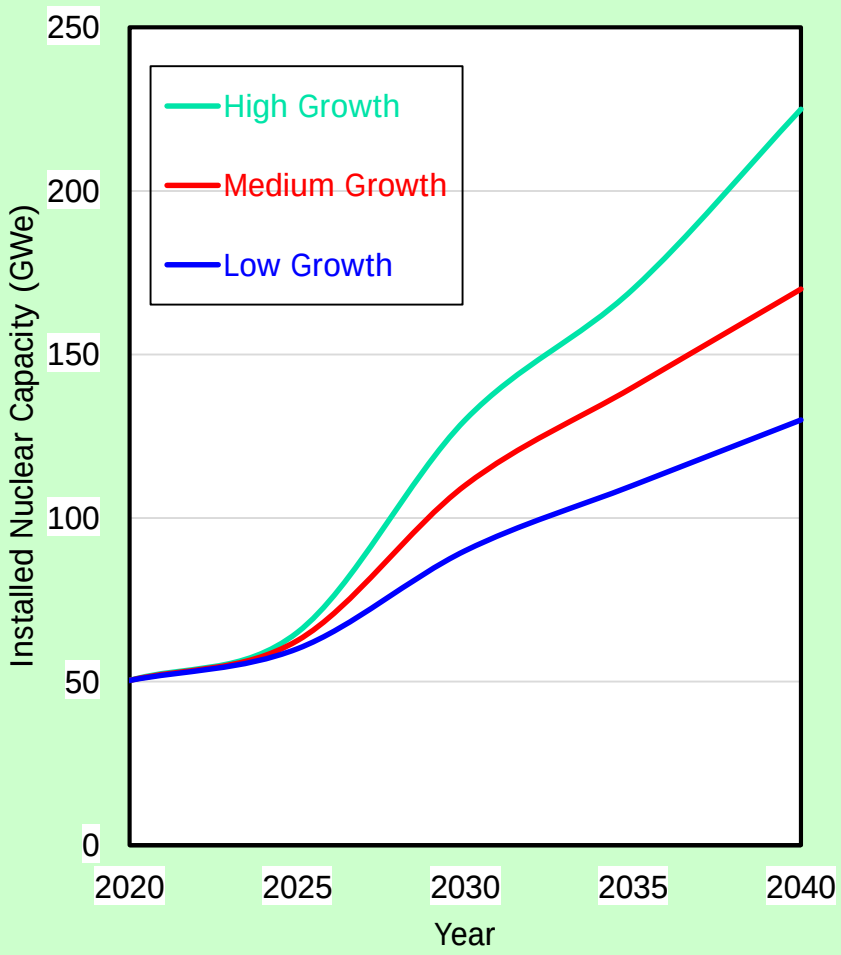
China's nuclear power development

-- As of Nov 2021, 51 reactors in operation (49.6 GWe) , 18 reactors under construction (17.3 GWe)

-- The new 14th Five-year Plan (March 2021 issued) reaffirms: 70 GWe in operation by 2025 .

-- Some recommend that China install a nuclear power capacity about 120 GWe by 2030; about 200 GWe by 2040.

-- Within a few decades, China is expected to operate more nuclear power plants than any other country in the world.



Projected domestic reactors: based on Chinese sources, assuming from 50 GWe (2020) to 130—225 GWe (2040).

China's Commercial Reactor Technologies

Most current and new commercial reactors are PWRs

- CNP-300 / CNP-600
- CPR-1000 (M310+)
- Hualon One (HPR-1000)
- VVER-1000/1200
- AP1000 / CAP1400
- EPR

Localization effort has promoted domestic supply chain

- 8-10 reactor sets per year capability, localization about 88%
- The engineering construction ability over 30 reactors at the same time
- Hualong One is Chinese localized advanced Generation III design
- CAP1400 is enhanced version of Westinghouse AP1000

--Larger PWRs is still the main stream in the near future

--Other priority: FBR, HTR, SMR

Source: CNNC

China's high-temperature gas-cooled reactor development

The prototype HTR-10

- Tsinghua University's INET
- 10 MWe
- construction start: 1995
- criticality in 2000; reached full power in 2003.

The demonstration 210 MWe HTR-PM 200

- capacity: 2x105 MWe
- construction start: December 4,2012.
- location: Shidaowan, Rongcheng, Shandong
- *The twin reactors achieved criticality on Sept.12 & Nov.11, 2021 respectively.*

HTR-PM 600

- based on HTR-PM 200 modules
- plans to build commercial 600 MWe HTR-PM 600

Small Modular PWRs

CNNC:

- *July 2021 CNNC started construction the first land-based SMR, 125 MWe PWR-- Linglong One (ACP100) at Changjiang NPP, Hainan*
- More ACP100 planed.
- CNNC also planning to build floating nuclear power plants (based on ACP100S).

CGN:

- CGN developing its small modular PWR designs: ACPR100 (140 MWe) and the offshore ACPR50S(60 MWe).

SPIC:

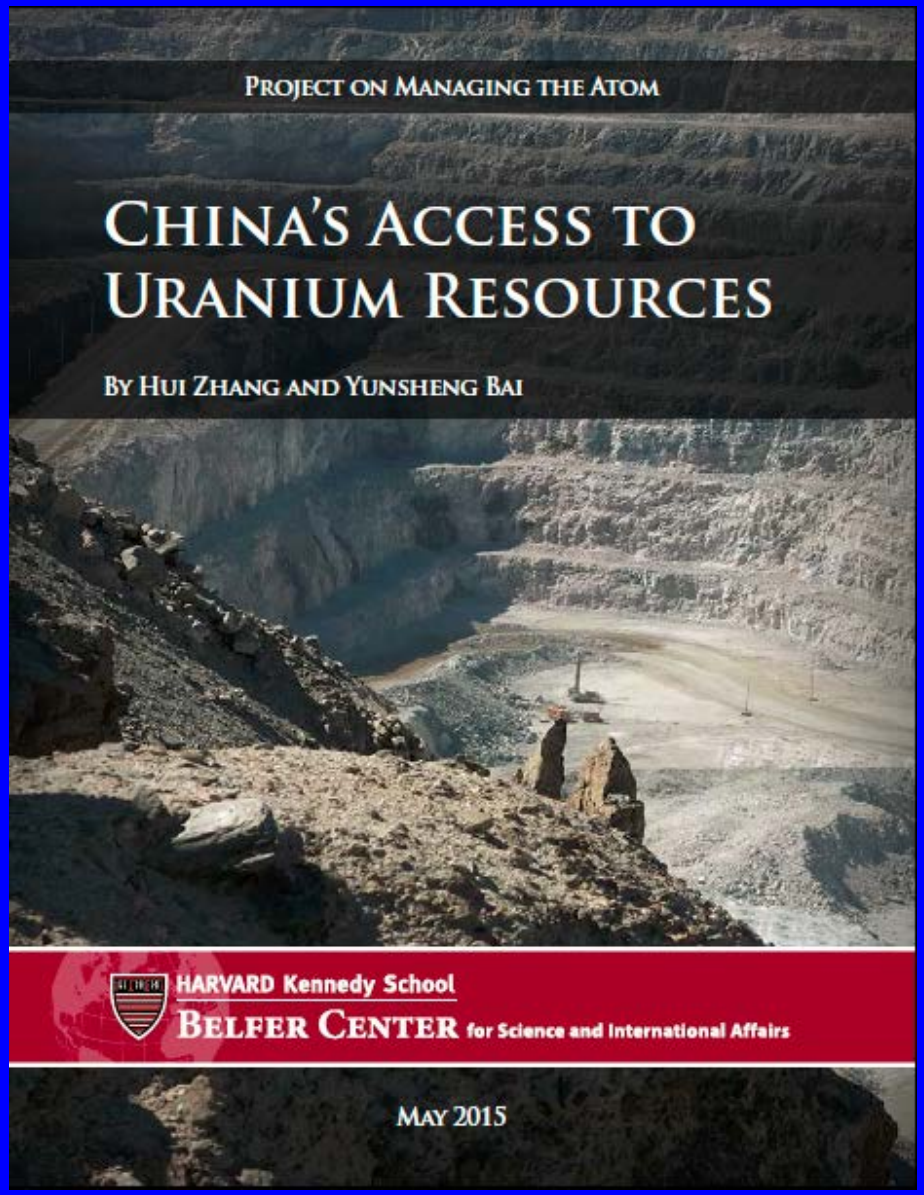
- SPIC developing CAP200 and CAP 50 SMR designs based on CAP1000.

China's Uranium Supply

-- Since mid-2000s, pursuing "Three One-Thirds" rule—one third from domestic supply, one third from mining abroad, and another third from direct international trade.

Should China's Uranium Resources Constrain Its Nuclear Power Development?

--Our study concludes that uranium supply enough for 2050, even under the most ambitious scenarios.

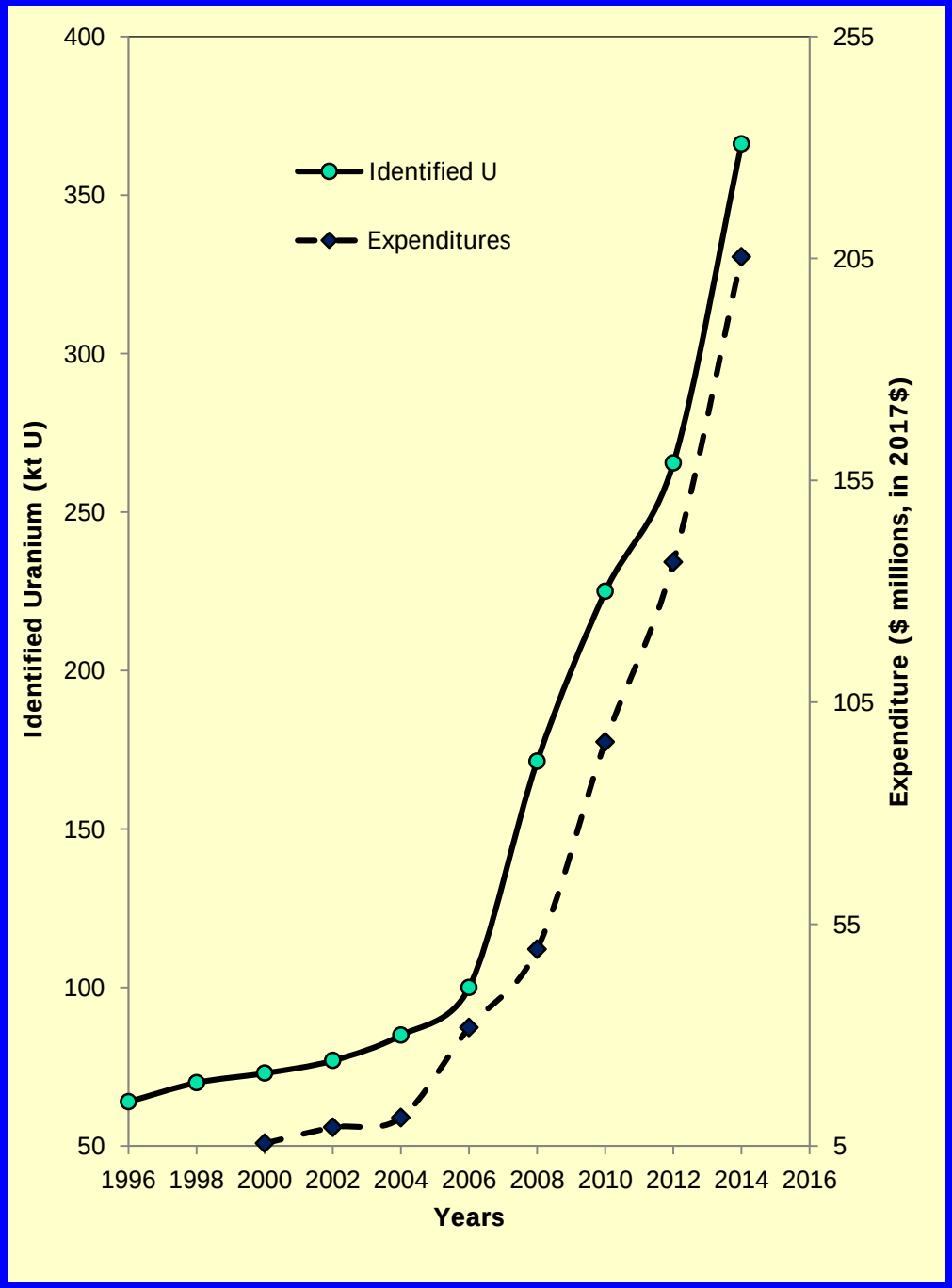


Hui Zhang and Yunsheng Bai, "China's Access to Uranium Resources." Managing the Atom Project, Belfer Center, May 26, 2015.
https://www.belfercenter.org/sites/default/files/files/publication/chinasaccesstoruraniumresources.pdf

China's identified uranium resources increased rapidly as exploration expenditures increased from 2004.

China's uranium potential:

Based on uranium metallogeny, new models, and exploration data from the past several decades, recent predictions ---over 2 million tons potential uranium resources.



China's Uranium Conversion

- China maintains a policy of "self-sufficiency" in the supply of conversion, enrichment, and fabrication services to meet the requirements of its nuclear power plan.
- CNNC is the major player for China's nuclear fuel cycle
- 2020 demanded conversion capacity about 9000 tU; expected to be about 12000 tU in 2025.

Uranium conversion capacity

- Plant 404 at Jiuquan of Gansu province--current capacity: 9000 tU/year
- Plant 272 at Hengyang of Hunan province--Current capacity about 3000tU/year.
- CNNC also planned two uranium processing complexes (each about 10000 tU/year) (suspending?)
- The current conversion capacity 12000 tU/year (expandable to 18000 tU/year) large enough to meet the requirement of China's nuclear power plan by 2025.
- As more reactors built , China can easily expand its uranium conversion capacity as needed

China's Enrichment Capacity

Military origins of Chinese enrichment

-- Lanzhou GDP: 1964-1979 HEU production for weapons; 1980-2000 LEU for power reactor. Since 2001 shut down –" Sealed and under maintenance" ; demolition in 2017.

-- Heping GDP (Plant 814 at Jinkouhe): 1970-1987 HEU production for weapons; Since 1987 operation for non-weapons military or dual uses. Closed around 2019.

The emergence of civilian enrichment in China

-- Deepened its "shift from military to civilian" during the late 1980s---importing Russian technology and then localizing it.

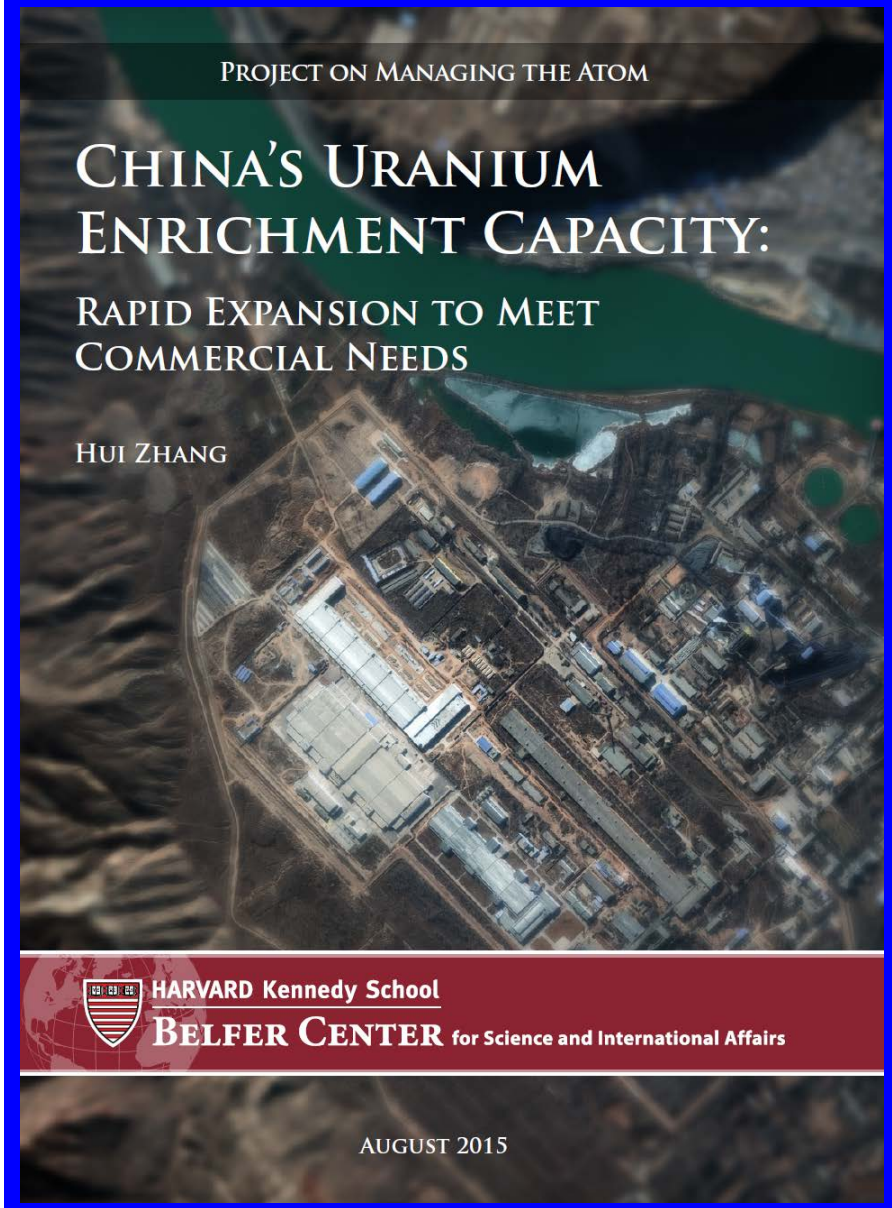
-- Built Russian-supplied centrifuges at Hanzhong and Lanzhou plants in four phases for a total capacity of 1.5 million SWU/year.

The indigenization of Chinese centrifuges

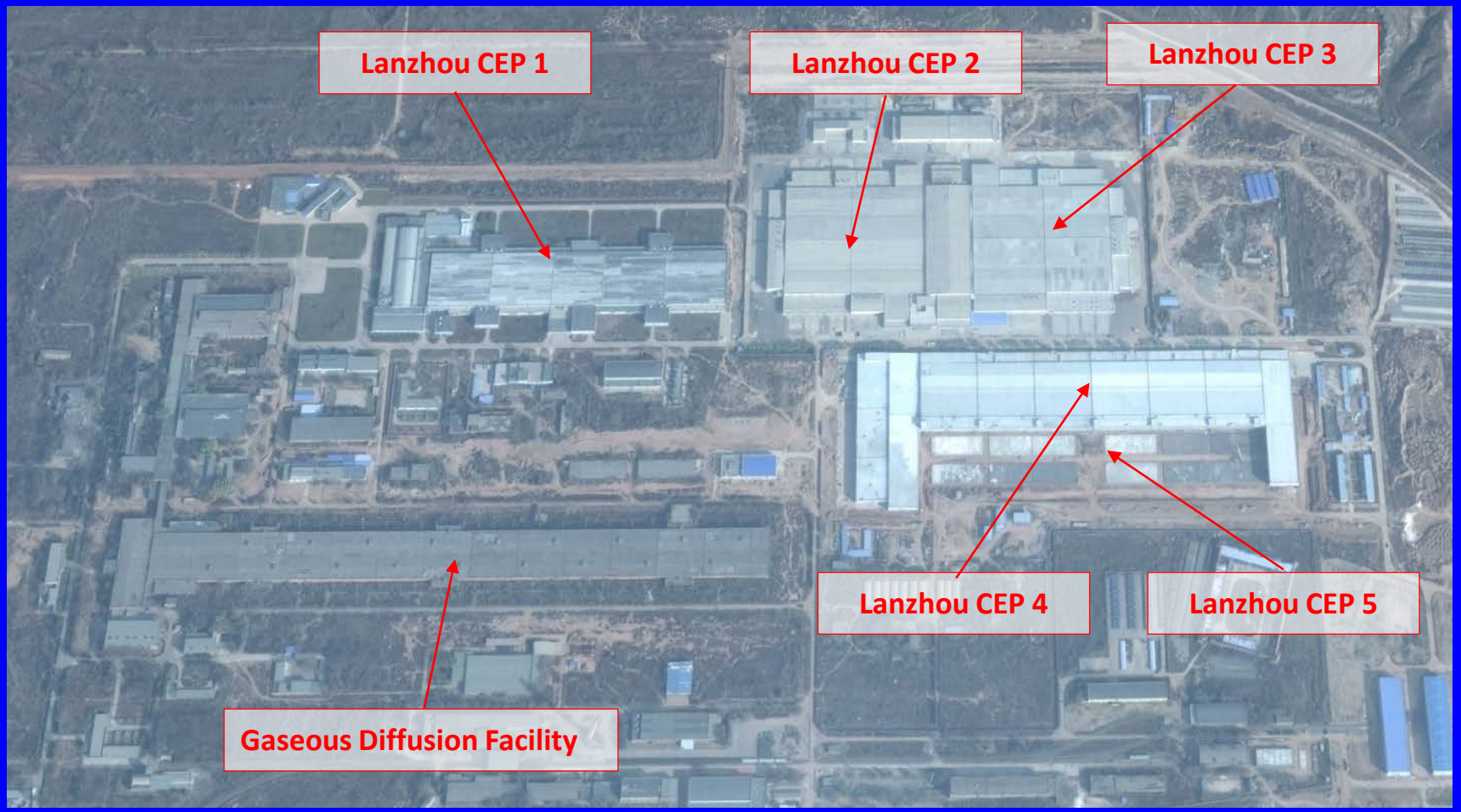
-- Built a pilot facility in 2007 near Emeishan city

-- 2010 operation of a demonstration CEP at Lanzhou plant (0.5 MSWU/yr)

--Since then, built several commercial facilities at Lanzhou, Hanzhong and Emeishan.



Lanzhou Uranium Enrichment Plant



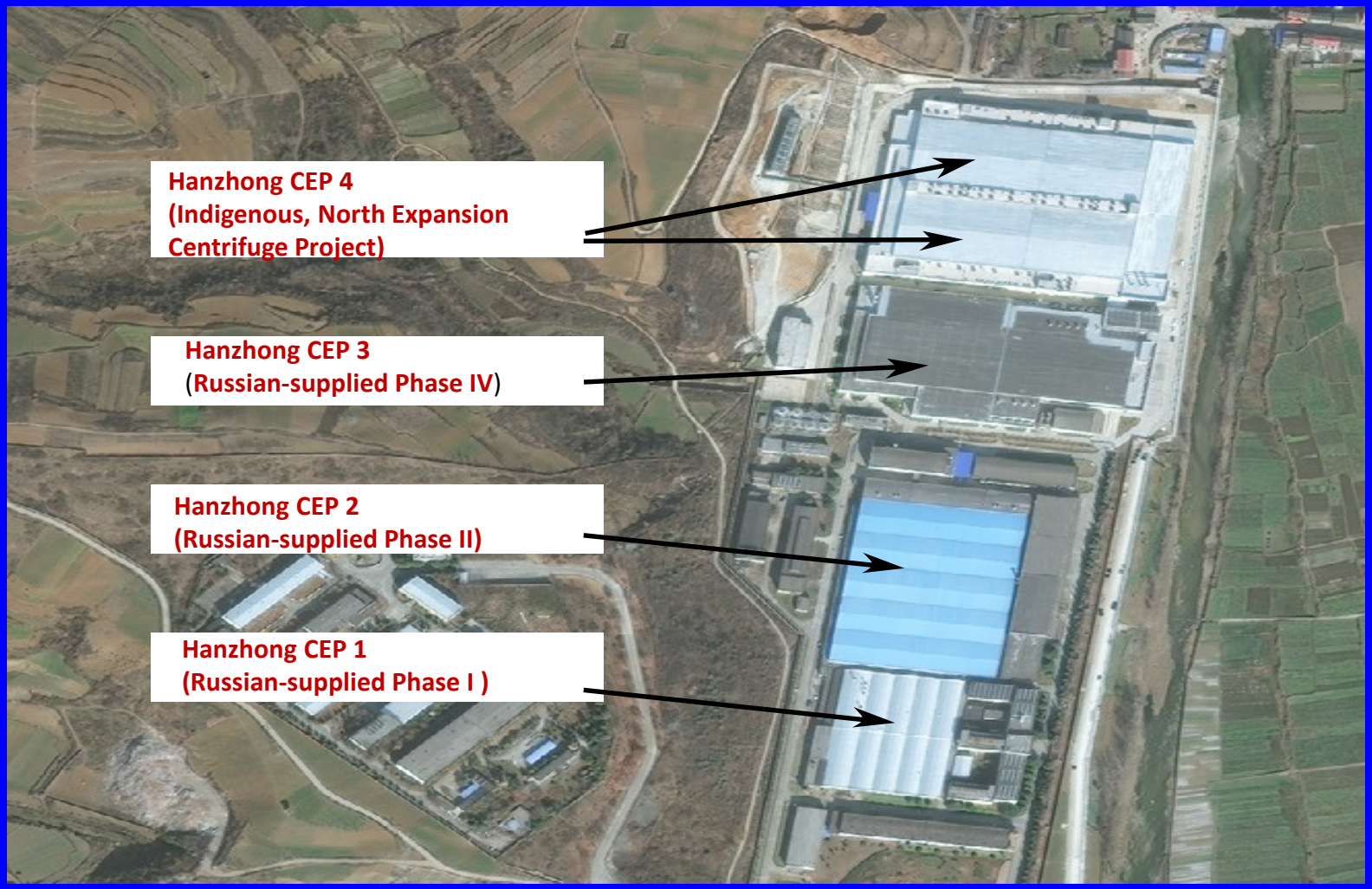
Lanzhou uranium enrichment plant. Satellite image from November 16, 2014 (Coordinates: 36008'53.30'' N/10301'24.49'' E). Credit: Maxar Technologies and Google Earth.

Lanzhou centrifuges facilities (by Nov 2021)

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	(1-2)	Domestic centrifuges	In early 2015, pads for stack installation were under construction. It has been suspended since late 2015.

➢By Nov.2021, the Lanzhou plant has a total estimated capacity of 2.6 million SWU/year, and has space ready for expansion.

Hanzhong Uranium Enrichment Plant (Plant405)



Satellite image from January 27, 2013
Coordinates: 33°15'47.70" N/107°25'52.74" E. Source: DigitalGlobe.

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	0.7	North Expansion Centrifuge Project phase I, Domestic centrifuges	Trials in 2013. Normal operation in March 2014.
Hanzhong CEP 4-II	0.91	North Expansion Centrifuge Project phase II, the first demonstration project with second-generation domestic centrifuges	Trials in 2017. Normal operation in 2018.
Hanzhong CEP 5	1-2	New District Project	Initiated in 2015. Operational before 2020 as planned. But no construction started, project significantly delayed.

---Currently, a total enrichment capacity of around 2.61 million SWU/year

---The second-generation domestic centrifuges first used in North Expansion Centrifuge Project phase II

---The New District Project (Hanzhong CEP 5) –delayed.

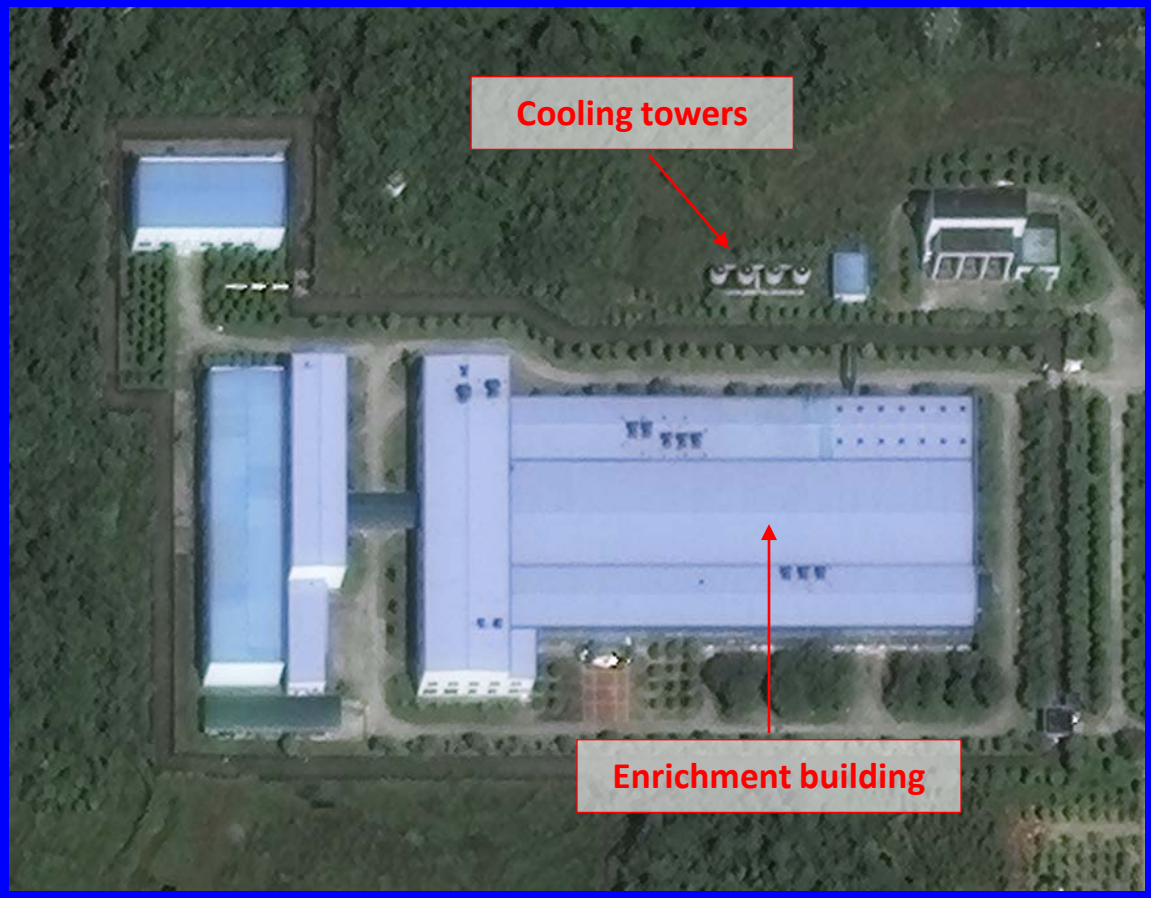
Plant 814 : Dual/military CEP near Emeishan

--A CEP pilot plant of Plant 814

--Completed around 2007

--Estimated capacity around 0.25 million SWU/year.

--Dual/military CEP? E.g. Isolated, secured location, etc.



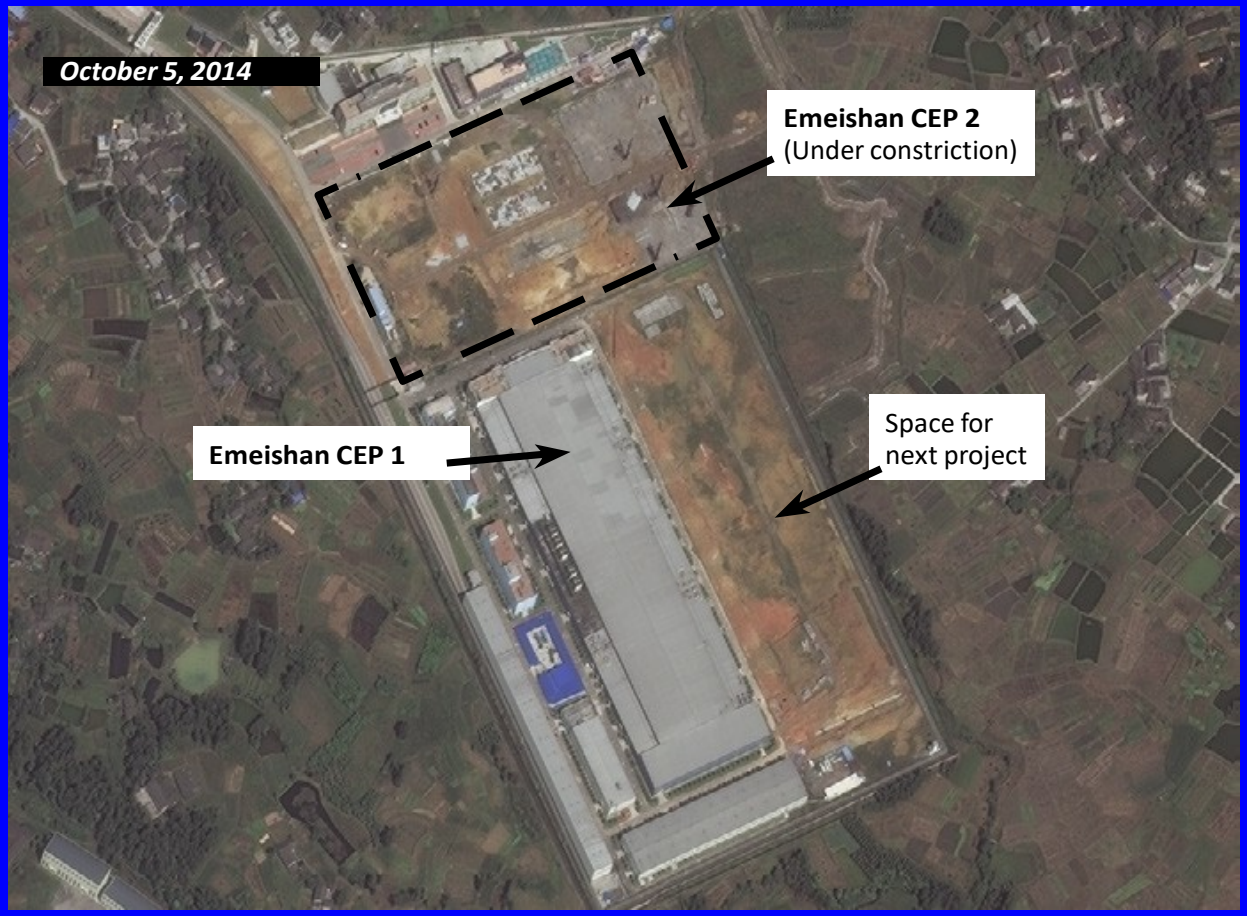
Label A: Enrichment building; B: Cooling towers.

Plant 814 : Commercial CEPs near Emeishan city

--CEP1: local government planned to start the project in 2008
--Construction around 2011, and operation around 2013

--CEP2: construction in 2014; operation around 2017.

--CEP 3? spare space nearby CEP1 for another project



Satellite image from October 5, 2014 (Coordinates: 29°40'38.33'' N/103°32'04.65'' E). The image shows CEP2 under construction. Source: DigitalGlobe

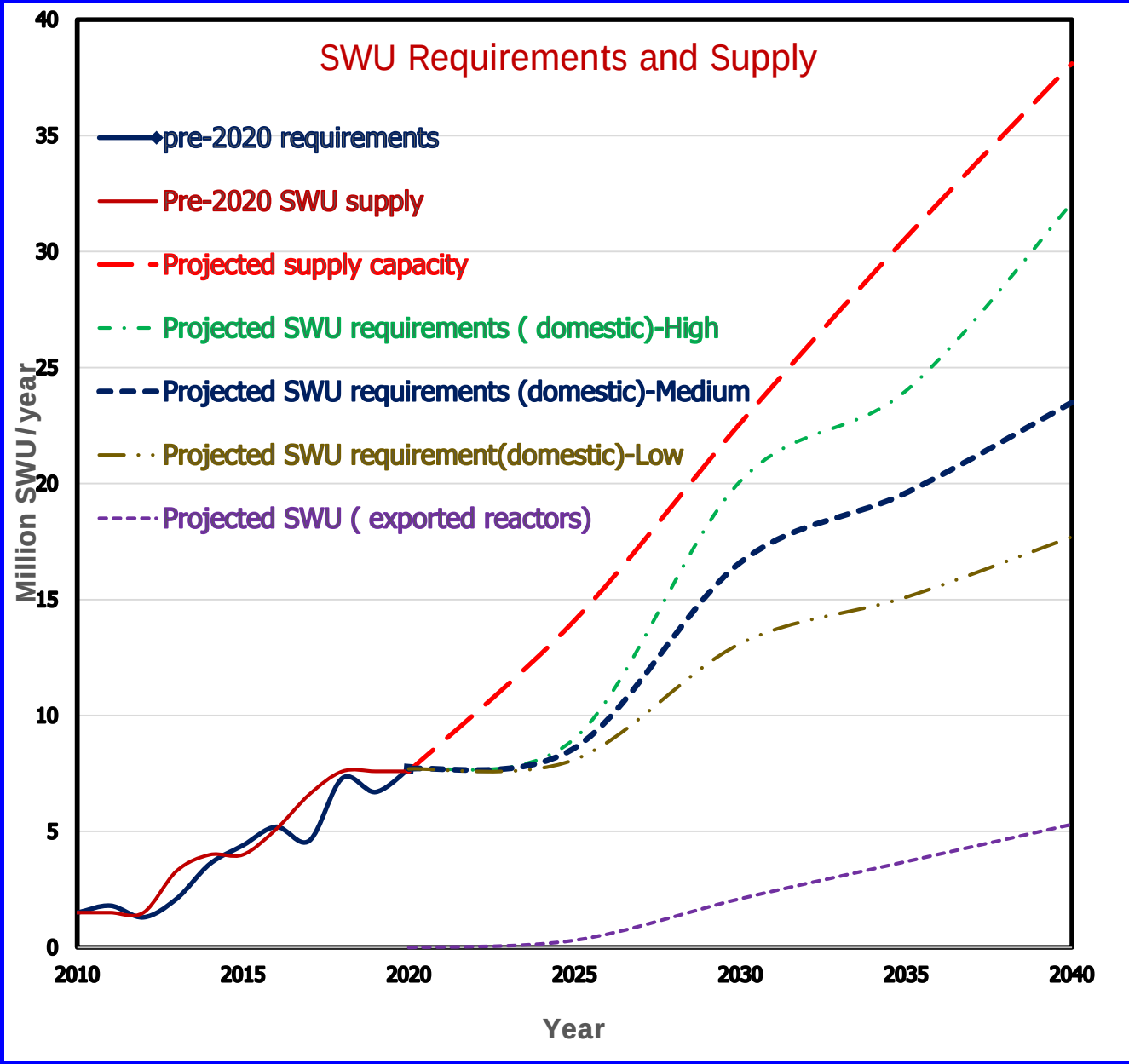
Plant 814 uranium enrichment facilities

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?	1-2	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.

China's uranium enrichment :

--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 .

---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.



Hui Zhang, "China's uranium enrichment and plutonium recycling 2020-2040: current practices and projected capacities," in Henry D. Sokolski,ed., *China's Civil Nuclear Sector: Plowshares to Swords?* Nonproliferation Policy Education Center, Occasional Paper 2102, March 2021.

China's Back-End Programs

In the mid 1980s, China selected a closed fuel cycle strategy to reprocess spent fuel and has recently speed up development of this strategy.

Motivations

---Full use of uranium resources; Reducing cost of mining, milling and enrichment uranium
---Provide MOX fuel ; Development of FBR;
---Energy security concerns;
---Reduce the waste repository volume
---minimizing radioactive toxicity, disposal of radwast safely;
---Reducing the burden of spent fuel at reactor pools

The reprocessing pilot plant

--Capacity: 50 tHM/year; Jiuquan nuclear complex, Gansu;
--Project approved July 1986; construction commenced July 1997;
--Successful hot test Dec 21, 2010, operating about 10 days, producing 13.8kg Pu. Later: 25.4 kg
--problem: MUF ; high waste volume,
--Capital cost : about 3.2 billion RMB in 2014; several times more than earlier estimates.
--Long delay: from projected approval to hot test =14 year, then operating only 10 days.
--till 2017-2019, separated a total 50 tHM SF.

Two 200 tHM/yr demonstration reprocessing plants

---In July 2015 the CNNC started construction of the first demonstration reprocessing plant in Jinta, Gansu Province--a planned capacity of 200 tHM/yr, to be commissioned in 2025

---Also building a MoX demonstration plant (about 20 t/yr) at the site

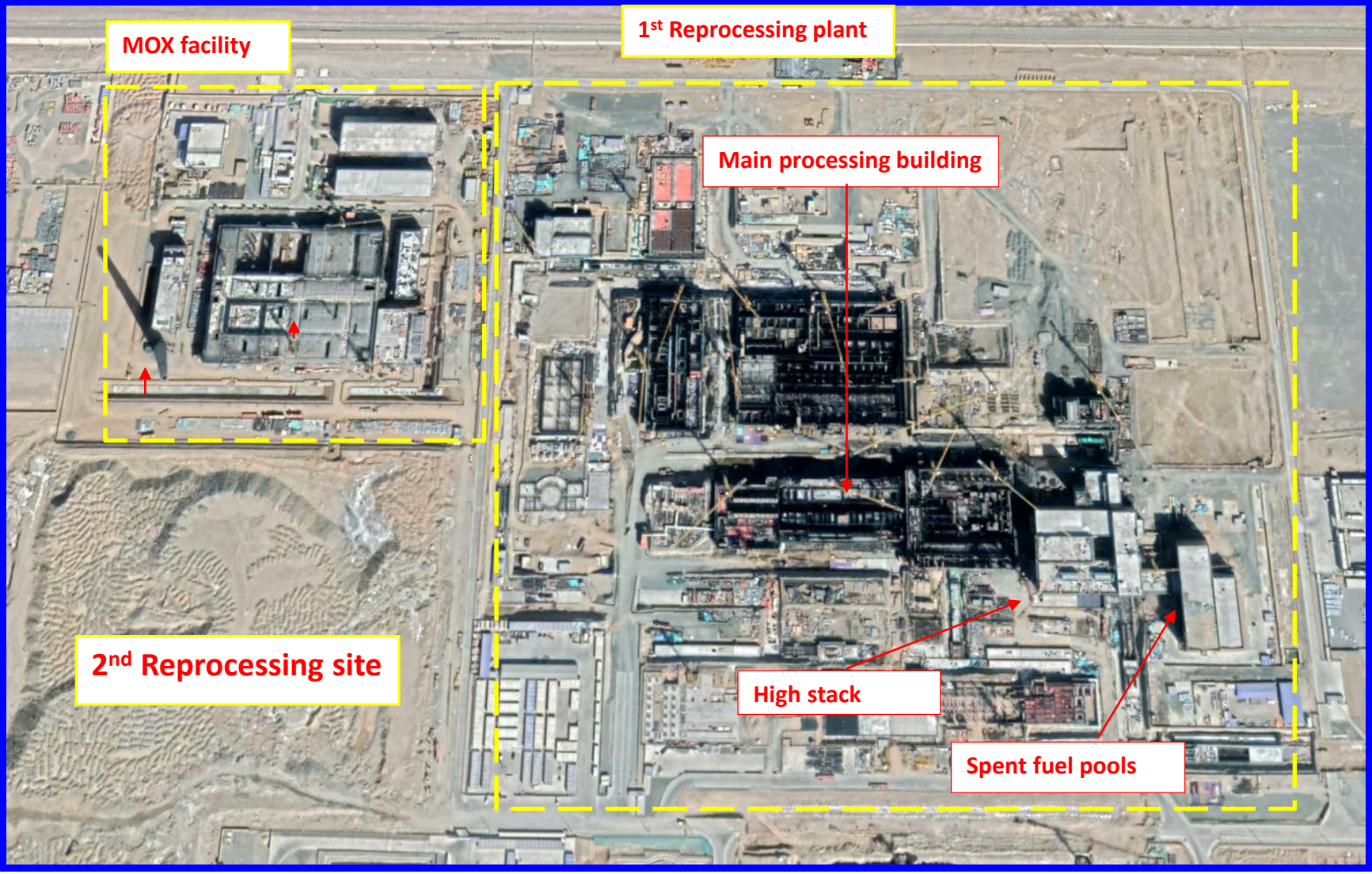
---In late 2020, the second 200 tHM/yr plant started construction (operational around 2030)

---Based on available information and satellite imagery, the location of the demonstration reprocessing and mixed-oxide facilities are identified .

---In December 2019, the CNNC issued a tender for equipment purchase of the reprocessing plant.--- the 1st plant could complete its civil engineering stage and enter the equipment-installation stage in 2020.

--- In 2019, the company started to order equipment for the demonstration MOX facility and opened a bidding period between August 29 and September 3, 2019 for a package of chemical analysis equipment.

---The intensifying construction and bidding activities show that the first reprocessing and mixed-oxide fuel facilities could complete the civil engineering stage and enter the equipment-installation stage in 2020, expected to be operational by 2025



The demonstration reprocessing and MOX facilities under construction at Jinta, Gansu. Satellite image from March 12, 2020 (Coordinates: 40°19'29.74"N 98°30'53.30"E). Credit: Maxar Technologies and Google Earth.

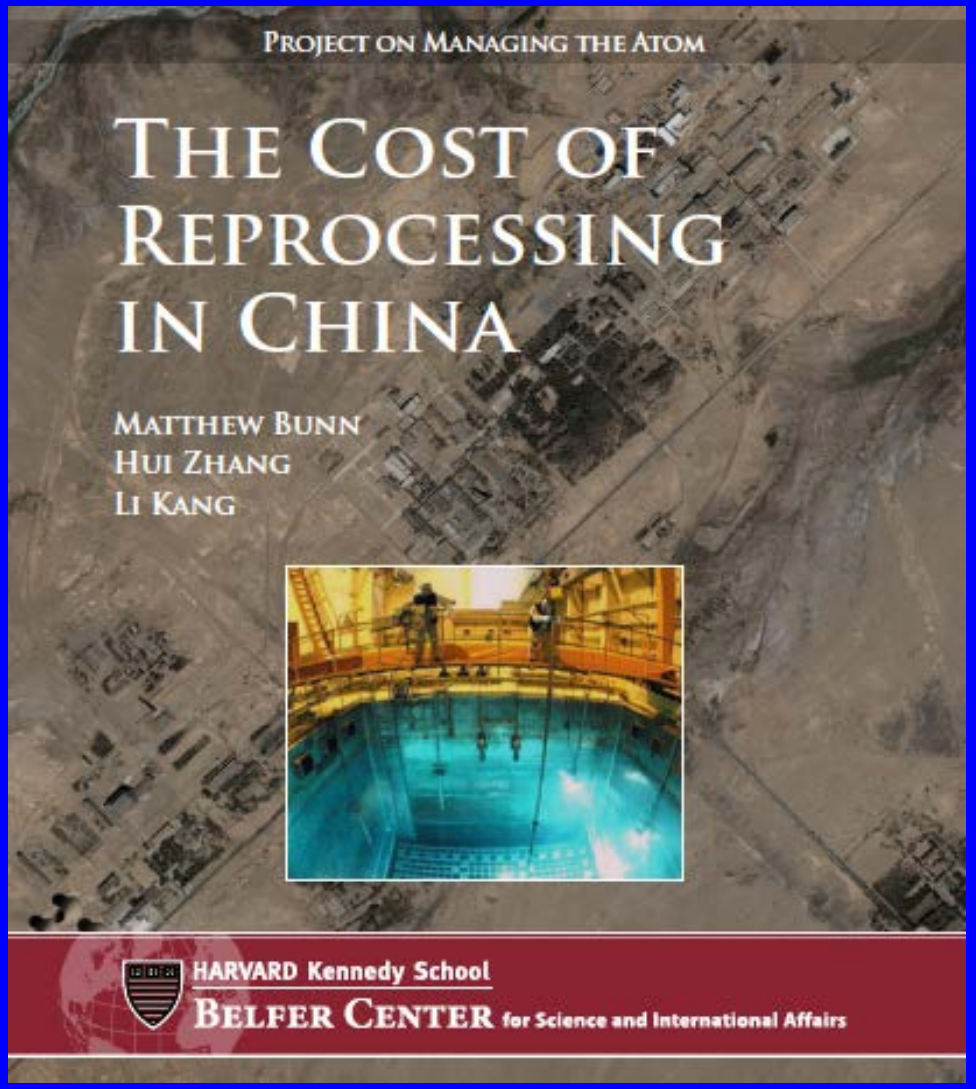
800 tHM/yr reprocessing plant

--Since 2007 negotiation with Orano/AREVA – disputes over price, conditions

--Finished first stage (technical) and entered second stage (business) since 2015

--Lianyungang, Jiangsu: protest in August 2016, since then suspending! Now still need to finalize siting issue.

--CNNC planned to start construction around 2020 and operation around 2030. But no site selected in 2021.



Matthew, Hui Zhang, and Li Kang. "The Cost of Reprocessing in China." Managing the Atom Project, Belfer Center, January 2016.

Cost for reprocessing & dry cask storage: high and low estimates

Plant	Capital Cost	Operating Cost	40-year Cost	40-year Storage Cost
200 tHM/yr, Low	$3.3 B	$200 M	$11.3 B	$1.7 B
200 tHM/yr, High	$5.9 B	$360 M	$20.1 B	$1.7B
800 tHM/yr, Low	$8.3 B	$500 M	$28.4 B	$6.7 B
800 tHM/yr High	$21 B	$1.6 B	$83.4 B	$6.7 B

(Source: Bunn, Zhang, and Li, "The Cost of Reprocessing in China," table 5.1, p.55. This table is an update by inflating the 2014 figures to 2017 figures.)

Even without financing costs :

---Even low estimate for 800 tHM/yr plant operated at full capacity throughout 40-year life--save over $21 B by dry casks for that period.

--About $10 B savings for low estimate of 200 tHM/yr plant

CFR-600 demonstration fast reactors

The first CFR-600

-- design power: 600 MWe
--location: Xiapu, Fujian province
--FCD in Dec 2017
--Jan 2020, ended civil engineering and entered the stage of installment.

--plans operation in 2023.
--The initial core and the first 7yrs replacements fueled by HEU from Russa, then MOX.

The second CFR-600

-- The same design as the first and to be co-located;
--Share some auxiliary facilities with the first one;
--FCD in Dec 2020; commissioned around 2026.

Credit: Maxar Technologies and Google Earth.

CFR-1000 (1000-1200 MWe)

-- Planned: to make the final decision in 2020 whether to proceed. But not yet

--Planned to finish the concept and preliminary designs by 2024 and 2028, respectively.

--Planned to start construction in 2028, and start operation in Dec 2034.

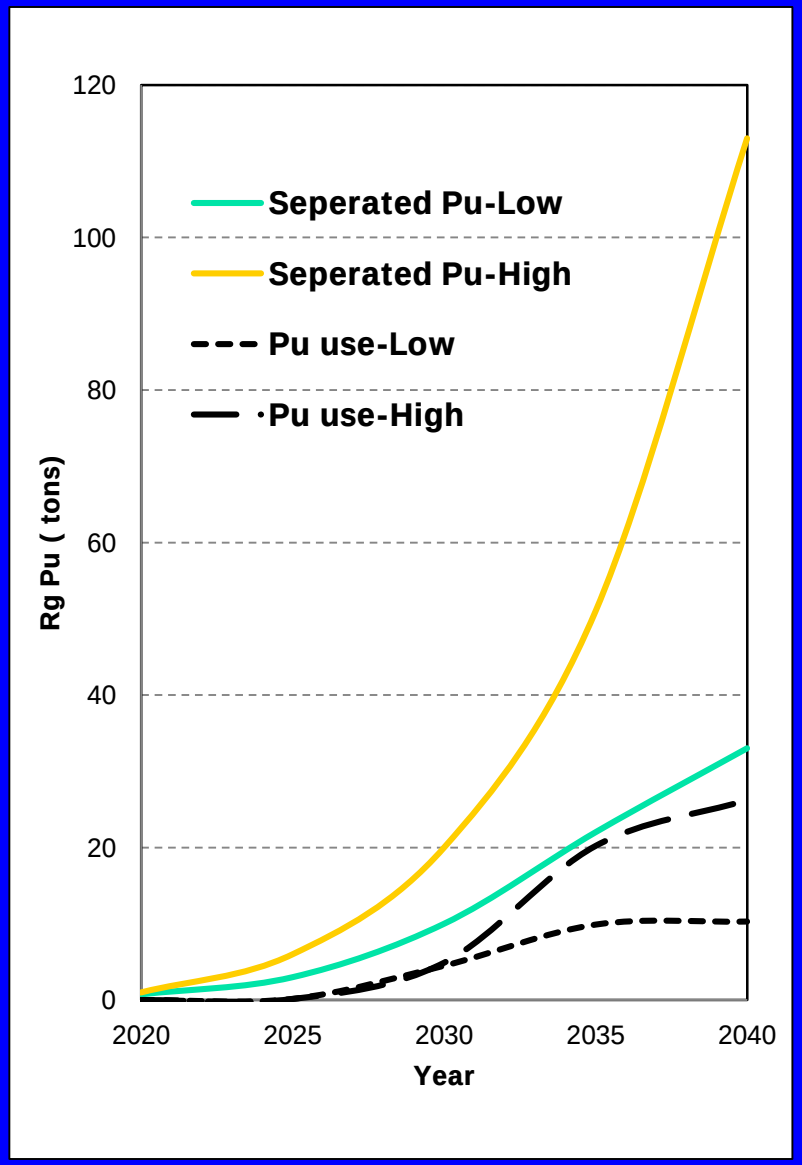
A 800 tons/year reprocessing needed?

---Even for the low case of Pu separation (no 800 tons/yr reprocessing, and the pilot plant and two 200t/yr plants run at half capacity) is large enough for even the high case of pu uses for FBRs (CEFR, two CFR-600 reactors and one CFR 1000 run at full capacity)

---Thus, no need of a 800 tons/yr reprocessing plant in the near future.

---Most likely, China would have a large stock of Rg Pu as Japan and France have.

Cumulative PWR plutonium used by Fast Reactors (tons)(2020-2040)



Postponing China's reprocessing?

- Our study shows that China's reprocessing and plutonium recycle is much more costly than LWR once-through cycle.
- Enough U for many decades, even under the most ambitious scenarios. To secure long-term uranium supplies for its fast-growing nuclear power industry, China should continue maintaining its one-third policy: domestic uranium, international market, overseas mining.
- Should postpone the large reprocessing plant, and take an interim storage approach, which offers a safe, flexible ,and cost-effective near term approach to spent fuel management.
- The postponing approach will give China a substantial opportunity to carefully develop a long-term policy for the nuclear fuel cycle.

Discussions:

- Rg Pu used in FBRs could produce Wg Pu in the "blanket":e. g. CFR600:around 0.2 tons WgPu/yr; CFR1000: around 0.4 tons WgPu/yr. Given China's small stock of military plutonium (around 2.9 tons), it could be doubled easily.
- To reduce international concerns, China needs to keep its plutonium recycling programs more transparent.

THANK YOU!

Q&A