

Domestic Commercial Uranium Enrichment in the Republic of Korea: Investigating Institutional Gaps and Economic Feasibility

Changhyun Jo, Junhee Lim, Junseo Park, Hyeongtak Kang, Dongki Lee, Youho Lee*

Department of Nuclear Eng., Seoul National Univ., 1 Gwanak-ro Gwanak-gu, Seoul 08826, Republic of Korea

*Corresponding author: leeyouho@snu.ac.kr

***Keywords : Uranium enrichment, Fuel supply, 123 Agreement, Economic analysis**

1. Introduction

Nuclear power accounts for ~30% of energy production in the Republic of Korea (ROK), by leveraging the economic advantages of high energy density produced in UO₂ nuclear fuel. However, as the ROK relies entirely on foreign imports for uranium enrichment, its energy infrastructure remains highly vulnerable to geopolitical shifts and global supply chain disruptions. Particularly in light of escalating geopolitical tensions, such as the Russia-Ukraine war, diversifying the fuel supply chain and securing domestic nuclear fuel procurement capabilities have emerged as top priorities directly linked to national energy security.

Furthermore, the ROK has faced challenges in the international nuclear export market, particularly when competing for integrated package contracts that include fuel supply, due to its lack of indigenous enrichment capacity. The recently released ROK-U.S. Joint Fact Sheet noted U.S. support for the ROK's uranium enrichment activities, provided if they are consistent with the bilateral 123 agreement and subject to U.S. legal requirements. Therefore, it is essential to develop a sophisticated robust strategy to leverage this favorable diplomatic environment.

In this context, this study explores the current institutional gaps and the economic feasibility of achieving domestic uranium enrichment. First, we examine the bilateral 123 Agreement within the framework of the U.S. legal system and evaluate the diplomatic and legal feasibility by benchmarking the 1988 U.S.-Japan Agreement. Second, we investigate the practical challenges and mitigation strategies associated with introducing 'black-box' facilities. Lastly, a quantitative economic feasibility study is conducted to evaluate the potential cost advantages of domestic production compared to international imports.

2. Institutional gaps in the U.S.-ROK 123 Agreement

The legal system of the U.S. is organized into a hierarchical structure originating from the Constitution, which provides the binding legal authority to subordinate laws and regulations. Particularly, Congressional-Executive Agreements are legally authorized by statutes enacted by the Congress, deriving their authority from the Constitution. These agreements, including the bilateral 123 Agreement, not only signify the delegation of authority from Congress to the Executive

(Administration) but also represent international agreements led by the Executive under the oversight of the Congress.

The bilateral 123 Agreement stems from the Atomic Energy Act (AEA) and serves as the legal framework for nuclear cooperation between the U.S. and other nations. While specific terms vary from country to country based on U.S. national interests and geopolitical factors, nine non-proliferation criteria based on IAEA's Full-scope Safeguards act as common and essential prerequisites for any such agreement.

In 1988, Japan successfully concluded a long-term agreement on uranium enrichment for a period of 30 years. Unlike countries such as India, which already possessed indigenous enrichment facilities, the fact that Japan had never operated its own enrichment facility before then makes it a critical case for benchmarking. In addition to consistent diplomatic efforts and the economic significance Japan held within the U.S. nuclear export market, Japan established an Implementation Agreement that demonstrates how Japan could initiate indigenous domestic enrichment while complying with the existing AEA regulations (**Table 1**).

Table 1 Comparison of AEA Requirements and Japan's Solutions in the 1988 Implementing Agreement [1].

Category	AEA Requirement	Japan's Solution
Reprocessing	Case-by-case approval	Designated Facilities: Proved safety by limiting activities to specific, pre-approved plants/countries for 30 years.
Timely Warning	Physical detection time	Alliance Trust: Demonstrated that "Alliance Reliability" is as effective as physical time in detecting diversion.
Enrichment	Prior U.S. consent	Low-Risk Guarantee: Proved non-proliferation by capping enrichment at 20% (LEU) to ensure it remains non-weapons grade.

The revision of the Agreement heavily relies on the U.S. administration, as the procedure operates under the principle of tacit approval. To override a presidential decision, a two-thirds majority in Congress is required, veto the President's decision, an outcome that is hard to

occur. Considering the recent ROK-U.S. Joint Fact Sheet, the current U.S. administration has shown a favorable stance toward supporting the ROK's domestic enrichment activities. Furthermore the ROK's nuclear power plant construction capabilities align with U.S. national needs for building new power plants, resembling Japan's case in 1988. Just as Japan leveraged the "Golden Age" of the Reagan administration within a favorable environment, the most effective strategy for the ROK is to seize this "Golden Time" - where diplomatic and technical readiness of the ROK align with the U.S. national interests - well in advance of the agreement's expiration in 2035.

3. Case studies of 'black-box' facilities and mitigation strategies for associated challenges

A promising option to achieve domestic enrichment capability is introducing 'black-box' facilities from other countries, which operate while keep the major design, manufacture, and all associated technologies proprietary. This black-box approach has been adopted in various countries, such as the U.S., France, and China.

The primary issue associated with the introduction of black-box facilities is to prohibit the transfer of enrichment technology. To mitigate this issue, the U.S. and France established government-to-government agreements, such as the Washington Agreement and Cardiff Agreement which explicitly state that the core technology must remain classified and inaccessible to the recipient. To address the inevitable information asymmetry between the supplier and the host country, it is essential to establish a technology control and security plan that clearly defines the shareable and classified boundaries. By clarifying these scopes, the host country can protect its own operational rights and exercise technical sovereignty even within the constraints of a black-box arrangement.

Nevertheless, the host country encounters significant operational challenges that extend beyond mere facility management. While the core technology is provided as a black-box, the host remains responsible for the design and construction of auxiliary systems, such as UF₆ feed, product, and tail lines. Furthermore, the host must independently submit Safety Analysis Reports (SARs) covering all potential accident scenarios to regulatory authorities.

Additionally, while IAEA's safeguard inspections are mandatory, it could be technically difficult to obtain sufficient information due to the black-box concept, which keeps major technologies and areas concealed. This creates an information gap that complicates verification. Therefore, it is essential to integrate the IAEA's safeguards into the initial design phase prior to construction and operation through Safeguards-by-Design (SBD), as demonstrated by China's Tripartite Enrichment Project (TEP).

4. Economic feasibility of introducing domestic enrichment facilities

4.1. Cost components and levelized cost formulation

The economic evaluation on uranium enrichment facilities have conducted using a top-down, microeconomic cost engineering methodology proposed in [2]. The total annual cost of producing total annual SWU (TC) is decomposed into four contributions associated with capital (K), labor (L), electricity (E), and hardware (H).

$$TC = p_K K + p_L L + p_E E + p_H H \quad (1)$$

where K is the total capital investment cost, p_K is the annual capital charge rate, L is the number of employees, and p_L is annual salary of an employee, E is the electricity input, p_E is the price of electricity per unit energy, H is the amount of hardware consumed, and p_H is the price of hardware.

K is determined by adjusting the overnight cost (C) to account for the IDC (interest during construction) rate and contingency. Based on the reference projects in **Figure 1**, the overnight cost was estimated using the following correlation: $C = 1.07 \times 10^{-2} SWU^{0.72}$, where C in \$B and SWU in tSWU.

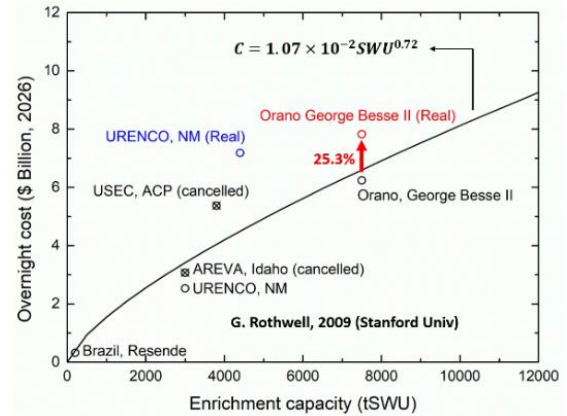


Figure 1 Correlation between overnight cost and enrichment capacity based on reference projects.

Furthermore, the levelized SWU cost (AC), which indicates the cost per unit SWU, is expressed as

$$AC = \frac{\sum_t [(p_{KH}K + p_L L_t + p_E E_t)(1+r)^{-t}]}{\sum_t [SWU_t(1+r)^{-t}]} \quad (2)$$

where $p_{KH}K$ denotes the capital and hardware cost, $p_L L_t$ and $p_E E_t$ correspond to the labor and electricity cost at the year t , respectively. The factor $(1+r)^{-t}$ accounts for the time value of money by discounting future costs and production to their present value. Thus, **Eq.(2)** represents the present value of the total costs normalized by the present value of total production.

4.2. Economic analysis of Centrus and ETC centrifuges

To analyze the economic impact of centrifuge design and plant capacity, three distinct scenarios based on construction in the U.S. were assumed. Case 1 represents construction by Centrus, while Case 2 represents construction by ETC with an identical enrichment capacity as Case 1 to isolate the effect of centrifuge design. Case 3 represents construction by ETC (GB-II) at a larger scale of 7000 tSWU/year to verify the impact of plant capacity (economies of scale).

As mentioned in **Sec. 4.1**, C for the ETC-based constructions (Case 2 and 3) was estimated using the correlation $C = 1.07 \times 10^{-2} SWU^{0.72}$. However, as Centrus is reported to require high construction costs than others [3], we utilized the data point of the USEC American Centrifuge Plant (ACP) projects as shown in **Figure 1**, with $\$1.41 \times 10^{-3} B/tSWU$, which is the predecessor of Centrus. To compute K , the IDC rate was assumed to be 2.85% with a 10% contingency to all cases.

The correlation for L proposed in [2] was directly utilized in this study: $L = 9.5 SWU^{0.44}$. P_L was assumed to be \$180k/person/year, E was set to 62 kWh/SWU [2], and p_E was fixed at \$120/MWh. Lastly, H was simplified under the assumption that it linearly increases with K , specifically $p_H H = 0.2K$. This results in $p_{KH} = p_K + 0.2$ for the calculation of **Eq.(2)**.

Table 2 Summary of assumptions and parameters for economic analysis for Centrus and ETC in the U.S..

Category	Case 1 (Centrus)	Case 2 (ETC - same capacity with Case 1)	Case 3 ETC (GB-II)
Firm	Centrus	ETC	ETC
Plant capacity	3800 tSWU/yr	3800 tSWU/yr	7000 tSWU/yr
Overnight Cost Correlation (C , SWU in tSWU)	$(\$1.41 \times 10^{-3} B) SWU$	$(\$1.07 \times 10^{-2} B) SWU^{-0.72}$	
Cost of Capital (r)	0.019		
Capital Charge Rate (p_K)	0.044		
IDC Rate	0.0285		
Contingency	0.1		
Operation Period	30 years		
Construction Period	3 years		

Annual Depreciation Rate	0.01
Number of employees (L)	$9.5 \cdot SWU^{0.44}$
Labor Cost (p_L)	\$180/person-yr
Electricity Consumption (E)	62 kWh/SWU
Electricity Price (p_E)	\$120/MWh
Material Cost per SWU (p_{HH})	20% of K

4.3 Economic analysis of deploying a Centrus black-box enrichment facility in the ROK

To quantitatively evaluate the economic impact of establishing domestic enrichment facilities compared to international imports, three distinct test scenarios were assumed (**Table 3**), where all types are fixed as a Centrus facility. Case 1, which is identical to Case 1 in **Sec. 4.2**, serves as a benchmark for comparing economic benefits between the U.S. and the ROK. Case 2 represents a standard ROK-based construction scenario, while Case 3 estimates the potential benefits under conditions of strong government policy support (i.e. Exemption of IDC rate and Contingency).

All modeling parameters for Case 1 are kept identical to **Sec 4.2**. While firm-specific factors remain unchanged, financial factors are adjusted based on the country of construction. The IDC rate was assumed to be 2.85% for the U.S. and 1.5% for the ROK, with a 10% contingency applied to both. P_L was assumed to be \$180k/person/year for the U.S. and \$120k/person/year for the ROK to reflect regional differences in average wages. For Case 3, both IDC rate and contingency are assumed to be exempted.

Table 3 Summary of assumptions and parameters for economic analysis for deployment in the ROK.

Category	Case 1 (U.S.)	Case 2 (ROK)	Case 3 (ROK w/ policy support)
Firm	Centrus	Centrus	Centrus
Plant capacity	3800 tSWU/year		

Overnight Cost Correlation (C, SWU in tSWU)	($\$1.41 \times 10^{-3}B$) SWU		
Cost of Capital (r)	0.019	0.01	0.01
Capital Charge Rate (p_K)	0.044	0.0387	0.0387
IDC Rate	0.0285	0.015	0
Contingency	0.1	0.1	0
Operation Period	30 years		
Construction Period	3 years		
Annual Depreciation Rate	0.01 (1%)		
Number of employees (L)	$9.5 \cdot SWU^{0.44}$		
Labor Cost (p_L)	\$180k /person/year	\$120k /person/year	\$120k /person/year
Electricity Consumption (E)	62 kWh/SWU		
Electricity Price (P_E)	\$120/MWh		
Material Cost per SWU ($p_H H$)	20% of K		

4.4. Economic analysis results

Table 4 summarizes the result of economic analysis of Centrus and ETC centrifuges based on the parameters detailed in **Sec. 4.2**. Centrus is expected to yield a higher levelized SWU cost (\$115.5/SWU) compared to both ETC scenarios (\$87.9/SWU for Case 2 and \$73.0/SWU for Case 3). This disparity primarily arises from the complex design of gas centrifuge, which results in higher overnight construction costs. Furthermore, a comparison between Case 2 and 3 confirms that increasing the plant capacity significantly reduces unit costs through economies of scale while utilizing identical technology.

Table 4 Summary of economic analysis result of Centrus and ETC centrifuges.

Category	Case 1 (Centrus)	Case 2 (ETC - same capacity with Case 1)	Case 3 ETC (GB-II)
Plant capacity	3,800 tSWU/year	3,800 tSWU/year	7000 tSWU/year
Overnight cost (C)	\$5370M	\$4044.2M	\$6278.5M
Total capital investment cost (K)	\$6060M	\$4563.8M	\$7085.3M
Capital/SWU ($p_K K/SWU$)	\$70.2/SWU	\$52.9/SWU	\$44.6/SWU
Number of employees (L)	500 persons	357 persons	467 persons
Annual salary (p_L)	\$180k/year	\$180k/year	\$180k/year
Labor/SWU ($p_L L/SWU$)	\$23.7/SWU	\$16.9/SWU	\$12/SWU
Electricity consumption (E/SWU)	62 kWh/SWU	62 kWh/SWU	62 kWh/SWU
Electricity price (p_E)	\$120/MWh	\$120/MWh	\$120/MWh
Electricity/SWU ($p_E E/SWU$)	\$7.4/SWU	\$7.4/SWU	\$7.4/SWU
Materials/SWU ($p_H H/SWU$)	\$14.1/SWU	\$10.6/SWU	\$9/SWU
Annual Total Cost (TC)	\$438.8M	\$334M	\$510.9M
Levelized SWU Cost (AC)	\$115.5/SWU	\$87.9/SWU	\$73.0/SWU

Table 5 presents the result of economic analysis of deploying a Centrus black-box enrichment facility in the ROK. The levelized SWU cost in the ROK (Case 2) was calculated as \$98.4/SWU, which is ~15% lower than the U.S. (Case 1). This primarily due to more favorable financial conditions, such as the lower cost of capital (r), and reduced labor cost (p_L). Notably, under a scenario of strong government policy support (Case 3) - where both

IDC and contingency are exempted – the levelized SWU cost further decreases to \$92.1/SWU.

Table 5 Summary of economic analysis result of deploying a Centrus black-box enrichment facility in the ROK.

Category	Case 1 (U.S.)	Case 2 (ROK)	Case 3 (ROK w/ policy support)
Plant capacity	3,800 tSWU/year	3,800 tSWU/year	7000 tSWU/year
Overnight cost (C)	\$5370M	\$5370M	\$5370M
Total capital investment cost (K)	\$6060M	\$5987.6M	\$5370M
Capital/SWU ($p_K K/SWU$)	\$70.2/SWU	\$61.1/SWU	\$54.8/SWU
Number of employees (L)	500 persons	500 persons	500 persons
Annual salary (p_L)	\$180k/year	\$120k/year	\$120k/year
Labor/SWU ($p_L L/SWU$)	\$23.7/SWU	\$15.8/SWU	\$15.8/SWU
Electricity consumption (E/SWU)	62kWh/SWU	62kWh/SWU	62kWh/SWU
Electricity price (p_E)	120	120	120
Electricity/SWU ($p_E E/SWU$)	\$120/MWh	\$120/MWh	\$120/MWh
Materials/SWU ($p_H H/SWU$)	\$7.4/SWU	\$7.4/SWU	\$7.4/SWU
Annual Total Cost (TC)	\$438.8M	\$374M	\$350M
Levelized SWU Cost (AC)	\$115.5/SWU	\$98.4/SWU	\$92.1/SWU

These results emphasize the importance of strategic selection of enrichment technology to maximize economic feasibility. Even when utilizing Centrus equipment, which is expected to carry above the market average, the resulting levelized SWU cost remains

significantly lower than the current long-term price of approximately \$170/SWU [4]. This confirms the economic justification for domestic enrichment facilities, a benefit that is further strengthened by proactive government support.

5. Conclusion

In this study, we evaluated the concept of domestic uranium enrichment in the Republic of Korea, focusing on institutional gaps and economic feasibility.

The deployment of foreign black-box technology in Korea is currently limited by identifiable institutional and regulatory gaps. Meaningful domestic adoption will require deliberate amendments to the existing legal architecture and oversight mechanisms.

Economic analysis indicates that domestic enrichment is highly viable. Under favorable policy support, the levelized SWU cost could potentially reach \$92.1/SWU. This is significantly lower than the current long-term import price of \$170/SWU confirming the economic justification for establishing domestic facilities.

Ultimately, the success of domestic enrichment depends on a combination of technical preparation and sustained diplomatic efforts to secure a favorable and stable regulatory environment.

Acknowledgement

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning(KETEP) and the Ministry of Climate, Energy & Environment(MCEE) of the Republic of Korea (No. RS-2025-02633904, Center for Advanced Nuclear Fuel Innovation).

REFERENCES

- [1] “B-230201 [Comments on Proposed U.S.-Japan Agreement],” U.S. Government Accountability Office (GAO), 1988.
- [2] G. ROTHWELL, “Market Power in Uranium Enrichment,” *Sci. Glob. Secur.*, vol. 17, no. 2–3, pp. 132–154, Oct. 2009, doi: 10.1080/08929880903423586.
- [3] A. Pavlov, “On the choice of technology for a new uranium enrichment plant,” *Nucl. Eng. Des.*, vol. 320, pp. 9–16, Aug. 2017, doi: 10.1016/j.nucengdes.2017.05.014.
- [4] Y. Lee, “Korea’s growing need for a stable supply of enriched uranium,” Korea On Point. Accessed: Feb. 22, 2026. [Online]. Available: https://koreaonpoint.org/articles/article_detail.php?idx=416