Economics of Reprocessing and Recycling Nuclear Fuel[1]

Geoffrey Rothwell, Ph.D.
Department of Economics, Stanford University

Three alternative fuel cycles for managing Light Water Reactor (LWR) Spent Nuclear Fuel (SNF) have been identified:

Alternative (1): Once-through (open) uranium oxide (UOX) fuel cycle with temporary storage and final disposal in a geologic repository.

Alternative (2): Twice-through (partially closed), involving the reprocessing of SNF and recycling of MOX fuel in LWRs.

Alternative (3): (Fully) closed, involving the reprocessing of SNF and recycling of actinide (plutonium plus others)-bearing fuels in Fast Reactors.

After much debate, the U.S. selected Alternative (1) as the best option with the Congressional passage of the Nuclear Waste Policy Act of 1982, plus subsequent amendments.[2] However, for all three alternatives, a geologic repository is required for both new and legacy SNF and High Level Waste.

Thus, the first determination is not whether to store SNF and build a geologic repository, but rather how to determine what level of SNF reprocessing is most efficient, given U.S. resources and repository constraints.

If it is determined that reprocessing should begin as soon as possible to employ future repository capacity more efficiently, then Alternative (2) is the best option, because Alternative (3) Fast Reactors will not be available commercially for two to three decades.

1. From "Policy Review Panel on Spent Nuclear Reactor Fuel Reprocessing and Recycling," (2010), prepared through Johns Hopkins University, Paul H. Nitze School of Advanced International Studies, Global Energy and Environment Initiative.
2. Given that no repository site is under consideration, to facilitate interim storage, Congress should strike the following language in the *NWPA*: "Sec. 148 (d) Licensing conditions. Any license issued by the NRC for a Monitored Retrievable Storage facility under this section shall provide that – (1) *construction of such facility may not begin until the NRC has issued a license for the construction of a repository under section 115(d); (2) construction of such facility . . . shall be prohibited during such time as . . . construction of the repository ceases*; (3) the quantity of SNF or high-level radioactive waste (HLW) at the site of such facility at any one time may not exceed 10,000 MTHM *until a repository under this Act first accepts SNF or solidified HLW*; and (4) the quantity of SNF or HLW at the site of such facility at any one time may not exceed 15,000 MTHM." (emphasis added)

Questions?: rothwell@stanford.edu

If it is determined that repository capacity must be minimized, then Alternative (3) is the best option, because Alternative (2) cannot consume actinides as efficiently as Alternative (3). Employing all three alternatives is the least risky strategy, but some selection among alternatives must be done given budget constraints.

During the last decade, numerous economic and cost-engineering studies have attempted to estimate the life-cycle costs of these fuel cycle alternatives, e.g., the 2006 Boston Consulting Group (BCG) report for AREVA.[3] However, few of these studies identify the financial risks and uncertainties associated with either Alternative (2) or (3).

While the BCG report provides an analysis of one version of Alternative (2), i.e., the co-extraction of plutonium with uranium (COEX), the validity of the conclusion of the BCG study, namely, "Recycling shows comparable economics to an exclusive once through strategy," depends upon several crucial assumptions. Two of these crucial assumptions are

(1) that the weighted average cost of capital for an integrated reprocessing and MOX fuel fabrication plant is 3%, and

(2) that used MOX fuel is not placed in a geologic repository.

First, there is an implicit assumption that the U.S. government should pay all expenses for COEX reprocessing and MOX fuel fabrication facilities. BCG "shows cash flow requirements that could fit until 2030 within the current financing resources available for the once-thru strategy" (p. 12), where "Historically, expenditures for commercial nuclear waste management have been paid out of the federal Nuclear Waste Fund." (p. 29)

Because Congress is the trustee of the Nuclear Waste Fund, the $1/MWh tax on nuclear power goes into the U.S. General Fund, out of which Congress allocates monies for nuclear waste management. Hence, expenditures are disbursed from the General Fund, not from a separate "Nuclear Waste Fund." Therefore, the impact on the General Fund (including deficits) should be considered following Office of Management and Budget guidelines

BCG's assumption of a 3% discount rate can be derived from the economists' consensus that the "social discount rate" or "risk-free" rate is 3%. However, this is not the cost of capital for the U.S. government, a public-private partnership, or a private joint venture on a risky project. Either a risk premium should be included in the assumed cost of capital, or input probability distributions should be specified. Here, the BCG implicitly assumes that the U.S. government pays the entire risk premium, but BCG does not provide an estimate of how big that risk premium might be on this first-of-a-kind reprocessing and recycling project.

3. Boston Consulting Group (BCG). 2006. "Economic Assessment of Used Nuclear Fuel Management in the United States," prepared for AREVA (July).

Questions?: rothwell@stanford.edu

In the BCG analysis, the cost of capital varies between 2% and 4%. The analysis should have considered costs of capital up to 10%, as suggested by the Economic Modeling Working Group of the Generation IV International Forum.[4] At a minimum, these higher rates should be used in determining the Interest During Construction (i.e., financing charges during construction). At these higher costs of capital, it is unlikely that the costs of Alternatives (1) and (2) are so similar.

Second, concerning BCG's assumption that used MOX never will be placed in a repository, the report states,

> "Disposal of used MOX in a geologic repository is not considered a viable option, because it could increase recycling costs up to 40% by undermining any advantage gained on repository capacity, while also wasting material with a high energy content that could be used by future generations." (p. 36)

Instead, used MOX would be stored at the plant site until it could be reprocessed for Fast Reactor fuel. A complete economic analysis should include (1) the cost of this future reprocessing, and (2) the cost of similarly storing used UOX fuel without reprocessing. The BCG report, and future U.S. government financed reports on Alternative (2), should include these alternative reprocessing and storage scenarios, as well as an analysis of the project's impact on the U.S. federal budget, following Office of Management and Budget guidelines.

Regarding Alternative (3), the cost of Fast Reactors and their fuel is not now known. In many studies, there is an assumption of a 20% cost difference between LWRs and Fast Reactors. This ignores fast reactor first-of-a-kind costs, which could be twice as much as well known LWR costs. An Idaho National Laboratory report discusses this assumption:[5]

> "A commonly heard 'rule-of-thumb' is that the fast reactor will be 20% higher than a LWR on a per kilowatt of capital basis. Russian experience has shown this factor to be more like 60% . . . These cost comparisons are currently speculative. . ." (p. R2-9)

The crucial, and as yet unknown, parameters (aside from capital construction costs and the date of commercial availability) in calculating the cost of full recycle are (1) the burnup rate in future Fast Reactors, and (2) the cost of qualifying fuels of various actinide compositions as the actinides are burned completely, theoretically eliminating the need for more than one geologic repository. Given that the cost of MOX fuel fabrication has been rising due primarily to tighter health, safety, and environmental standards, the cost of fabricating Fast Reactor fuels in hot cells with varying actinide content could be very high.

4. Economic Modeling Working Group (EMWG). 2007. *Cost Estimating Guidelines for Generation IV Nuclear Energy Systems*. Generation IV International Forum (GIF).

5. INL (Idaho National Laboratory). 2009. *Advanced Fuel Cycle Cost Basis*. INL/EXT-07-12107.

Questions?: rothwell@stanford.edu

No existing deterministic cost study of full recycling is credible, because there has been no engineering demonstration of full recycling. Electricity from Fast Reactors likely will be more expensive than electricity from LWRs. This is because remote reprocessing and fabrication of recycled fuel as required by all technologies in Alternative (3) will be more expensive than reprocessing LWR SNF for MOX fabrication. It seems likely that full recycling in Fast Reactors in Alternative (3) could be the most expensive alternative, although it is not known how much more expensive it could be than other alternatives, or the degree to which the costs could be off-set by reduced uranium costs and waste disposal savings.

Proponents of Alternatives (2) and (3) assume that the government will pay a major portion of the costs. However, if Alternative (2) is not competitive at market costs of capital, and must rely on U.S. government funding, then Alternative (2) is not ready for U.S. commercial deployment. Bunn, Fetter, Holdren, and van der Zwaan[6] show that Alternative (2) may not be competitive in the U.S. until the price of uranium rises above its historic highs, or the cost of final disposal is shown to be much greater than the estimated cost of completing the Yucca Mountain repository.[7] Until a repository is constructed, the cost of interim SNF storage is low enough that the U.S. government has time to solve the SNF problem scientifically, technically, economically, and equitably.[8]

Given this, the most effective action that the U.S. government could undertake is defining, identifying, and siting at least one geologic repository, which will be required under Alternatives (1), (2), and (3).

The decision whether to reprocess can be made after identifying a geologic repository of a particular capacity, so that the reprocessing technology that best optimizes that space can be selected. Hence, the identification of a geologic repository should be made soon so that the optimal SNF management strategy can be determined.

Finally, the Savannah River Site MOX facility, which is currently under construction by Shaw AREVA MOX Services, should provide important insights as to whether MOX fuel is commercially viable in the U.S. (without additional subsidies). If it is commercially viable, the U.S. Congress should review its decision not to invest in commercial aqueous reprocessing technology.

6. Bunn, M, Fetter, S., Holdren, J.P., and van der Zwaan, Bob. 2003. *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel*. Project on Managing the Atom, Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, Cambridge, MA.

7. OCRWM (U.S. Department of Energy, Office of Civilian Radioactive Waste Management). 2008. *Analysis of the Total System Life Cycle Cost of Civilian Radioactive Waste Management Program*. (DOE/RW-0533). Washington, DC.

8. Rothwell, G.S. 2010. “Scale Economies in Monitored Retrievable Storage,” Pacific Northwest National Laboratory Working Paper, Richland, WA (April).

Questions?: rothwell@stanford.edu