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Financing Strategies for a Nuclear Fuel Cycle Facility

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FINANCING STRATEGIES FOR A NUCLEAR FUEL CYCLE FACILITY

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ABSTRACT

To help meet the nation's energy needs, recycling of partially used nuclear fuel is required to close the nuclear fuel cycle, but implementing this step will require considerable investment. This report evaluates financing scenarios for integrating recycling facilities into the nuclear fuel cycle. A range of options from fully government owned to fully private owned were evaluated using DPL (Decision Programming Language 6.0), which can systematically optimize outcomes based on user-defined criteria (e.g., lowest life-cycle cost, lowest unit cost).

This evaluation concludes that the lowest unit costs and lifetime costs are found for a fully government-owned financing strategy, due to government forgiveness of debt as sunk costs. However, this does not mean that the facilities should necessarily be constructed and operated by the government. The costs for hybrid combinations of public and private (commercial) financed options can compete under some circumstances with the costs of the government option. This analysis shows that commercial operations have potential to be economical, but there is presently no incentive for private industry involvement. The Nuclear Waste Policy Act (NWPA) currently establishes government ownership of partially used commercial nuclear fuel. In addition, the recently announced Global Nuclear Energy Partnership (GNEP) suggests fuels from several countries will be recycled in the United States as part of an international governmental agreement; this also assumes government ownership.

Overwhelmingly, uncertainty in annual facility capacity led to the greatest variations in unit costs necessary for recovery of operating and capital expenditures; the ability to determine annual capacity will be a driving factor in setting unit costs. For private ventures, the costs of capital, especially equity interest rates, dominate the balance sheet; and the annual operating costs, forgiveness of debt, and overnight costs dominate the costs computed for the government case. The uncertainty in operations, leading to lower than optimal processing rates (or annual plant throughput), is the most detrimental issue to achieving low unit costs. Conversely, lowering debt interest rates and the required return on investments can reduce costs for private industry.

INTRODUCTION

With the current heightened concern for air pollutants and natural resources conservation, a new focus has been established on searching for advanced future energy options. One option under consideration is the resurgence of nuclear power with a new, closed fuel cycle. Research in this area is being conducted within the framework of the Department of Energy's advanced fuel cycle initiative (AFCI). "A mission of the AFCI program is to develop technologies that concurrently will meet the need for an economic and sustained nuclear option while satisfying requirements for a controlled, proliferation-resistant nuclear material management system" [1].

Initial work on the economics of the private sector versus regulated nuclear fuel cycle facilities was completed by Braun in 2005 and was reported in the *2005 Advanced Fuel Cycle Cost Basis, Appendix D* [2]. Building on this work, a dynamic model was created using Decision Programming Language (DPL) Version 6.0 Professional. Scenarios were run to determine which factors were most influential in determining benefits and costs, and then evaluated to develop a realistic range of values. With this range, both discrete value and Monte Carlo simulations were run, and the scenarios evaluated. This report discusses the merits of various scenarios and attempts to understand the cost implications from facility ownership options: government, private, and combinations of government/private.

BACKGROUND

When a recycle facility is constructed to support a future fuel cycle, the facility will represent a first-of-a-kind (FOAK) plant. There is little directly applicable research on the ownership options for such a facility. Initial work performed by the National Research Council evaluated recycling facility ownership options for a private company, a utility consortium, and the government [3]. The National Research Council determined that "A pure, private venture to design, build, own, and operate such a complex, without government financial guarantees, appears unrealistic." Further, they conclude, "At a minimum, it would appear that some new type of government risk/cost sharing, far more extensive than on past projects/programs, would be necessary to attract utility participation." Similarly, Bunn argued before Congress, "Since facilities required for reprocessing and transmutation would not be economically attractive for private industry to build, the U.S. government would either have to build and operate these facilities itself, give private industry large subsidies to do so, or impose onerous regulations requiring private industry to do so with its own funds" [4].

A comparative analysis of a generic fuel cycle facility was conducted by Braun [2] for the AFCI Economic Benefits activity, analyzing the unit costs for recycling under various ownership options with an ultimate conclusion that government ownership led to lowest costs, especially if the government were willing to forgive debt. Braun also explored qualitative differences in financing options, such as the national social benefit of such a facility and government legal obligations to the utilities as related to partially used fuel disposition. In addition, there has been some comparative economic analysis done on public and private facilities in the past; however, most of these are not wholly representative in this case, as the bulk of these analyses are based on the electric generating industry power plants and carry assumptions not applicable here. There is historical evidence of private industry having lower operating costs compared to similar government facilities [5]. Further, Shleifer [6] finds that private ownership can lead to direct incentives for innovation not present in contractual arrangements typical of government facilities. Blank [7] analyzed the differences between government ownership and regulation, "If quality is readily observable, the government can regulate private providers to assure [sic] standards are met. But when standards are difficult to observe or when the recipient is not the agent who makes decisions, government ownership may be preferable." Assumptions for differences in the operation of regulated and unregulated facilities are based on previous studies; Taggert [8] showed that regulation in utilities led to less risky behavior with firms having greater access to debt financing.

None of these studies addressed the sort of complexity present when dealing with controlled material (nuclear fuel) or firms that do not have to compete for continued contracts. In the case of recycling nuclear fuel, only one customer (the government) will control all the input material to the facility and most of the output products; this one customer relationship was also not explored in the literature.

APPROACH

This analysis is designed to meet the needs of the AFCI program. To that end, we have considered the required capacities and processes stated in the AFCI Report to Congress [1]. The AFCI program is considering advancements to the established PUREX process, such as UREX+ and pyroprocessing as recycling technology options. The specific designs and methods for separation in a future fuel recycle facility have not yet been determined. There are limited cost data available on new recycle facility costs that would be applicable to a United States facility construction application. The AFCI program has compiled historical reports and studies on recycling and has determined that there are very large cost uncertainty ranges for these facilities.

The current plan does not anticipate large numbers of recycle facilities being built, so the relative advantages coming from next-of-a-kind or eventually (Nth-of-a-kind or NOAK) facilities are ignored, and the financing options are only considered for the FOAK facility. Subsequent facilities, if built, will likely have similar financing considerations as the first.

This model follows the conclusions drawn from previous studies. For comparison, this model could easily be extended to include the modeling of other related facilities, such as those intended for fuel fabrication or combined (integrated) recycling and refabrication. The ownership structure for facilities in mature industries is not in doubt, but similar analyses may be necessary for new processes that accompany or complement the intention to recycle partially used nuclear fuel.

The model was set up for comparing: (a) a totally government-constructed-and-operated facility, (b) a government-constructed facility sold to a private sector corporation with a portion of initial investment forgiven, (c) a private-sector regulated facility, and (d) a private-sector unregulated facility. This type of economic model could be extended and easily modified to accommodate all facilities to be considered (e.g., separations, fabrication, and storage).

Assumptions

The major baseline financial assumptions underlying this analysis are provided in Tables 1 and 2. These assumptions are consistent with existing technology reported in the open literature, and the initial basis used in AFCI studies on the economics of the private sector versus regulated nuclear fuel cycle facilities [2]. All the computations carried out here relate to a hypothetical facility and do not represent any specific plant design or cost data.

Considerations

Originally, return on investment (ROI) in the model was a calculated variable from other inputs, but this setup did not allow direct comparison of government and private facilities. From these financial assumptions, the ROI to private investors becomes fixed in the model at the required ROI (as shown in Table 2). This may not be the real-world scenario, as investors may demand a higher ROI (or receive a lower one) than suggested here, depending on the degree of perceived risk and risk mitigation measures contemplated. Also, private companies may choose to allocate capital expenses differently among debt and equity portions. There are some tax advantages to maximizing debt; however, there has not been the tendency of corporations to simply maximize debt, because there are other advantages to having equity financing [9].

To meet the needs of a new generation of nuclear power plants, it is expected that the first commercial-scale recycling facility would be commercialized by the year 2025, with a capacity of 2,500 to 3,000 MT/yr and a design life of 40 years [1]. Further, AFCI is also considering 3,000-MT/yr facilities with a lifetime of 60 years. These possibilities are not modeled here as they suggest significant deviations from the currently available data on other existing recycle facilities and estimates of future scenarios. The existing technology (PUREX) is used at both La Hague (two plants with 800-MT/yr capacity each) and THORP (1,200 MT/yr). This analysis uses the 800 MT/yr as a baseline capacity for comparison. We do investigate the implications from increasing this capacity to those under consideration by the AFCI program in one scenario.

TABLE 1. ANALYSIS MAJOR BASELINE ASSUMPTIONS

	Baseline values used in all four cases
Total capital charges (TCIC)	$8.0 billion
Annual operating costs (O&M)	$396 million/year
Annual capacity	800,000 kgHM/year
Lifetime	30 years

TABLE 2. FINANCIAL ASSUMPTIONS USED IN THE MODEL

	Government Constructed & Operated	Government Constructed & Sell Private	Regulated Private	Unregulated Private
Debt portion (%)	100.0	40	50	30
Debt interest rate (%/yr)	4.0	4.8	4.8	9.0
Equity portion (%)	0	60	50	70
Required return on investment (%/yr)	N/A	10.5	8.5	16.0
Insurance (%/yr)	2.0	2.0	2.0	2.0
Federal taxes (%/yr)	N/A	33.0	33.0	33.0
State and local taxes (%/yr) (average)	N/A	5.0	5.0	5.0
Forgiveness of Plant Investment (%)	100%	62.5%[a]	N/A	N/A

a. Of the debt, 62.5% is considered forgiven by the government. The private owner then distributes capital portions over only the 37.5% of the initial capital investment made by the government. This figure is simply an assumption used for comparison; the actual forgiveness percentage will be chosen by legislation.

While we are considering optimizing a fuel recycle facility, definitive studies have not been done showing that this is the only path forward. We have not modeled other used fuel treatment options. The reader should be mindful that recycling costs need to be compared against other fuel processing and technology costs, and with competing energy source costs when determining energy strategies. Consideration should also be made of the fact that the current legal framework establishes government ownership of used nuclear fuel [11]. We should also consider the fact that costs will be recovered from citizens of some classification, ratepayers for private financing and taxpayers for government financing. Depending on the political environment, support may be greater for a public/private partnership like the government-to-private partnership case modeled here, since the costs are distributed among taxpayers and ratepayers.

SETTING UP THE MODEL

The model (Figure 1) was created using spreadsheets and Decision Programming Language DPL 6.0 with a strategy table to allow for adjustment of some values to support the four modeled cases. This model is quite simple to allow for wide applicability and generalization.

The model shows the various financing and assumed inputs as well as calculations for our analysis. The large yellow rectangle is the "strategy table" where our decisions (smaller rectangles) are selected based on choices made to model the case; the decisions are selected to match our assumptions in Table 2.

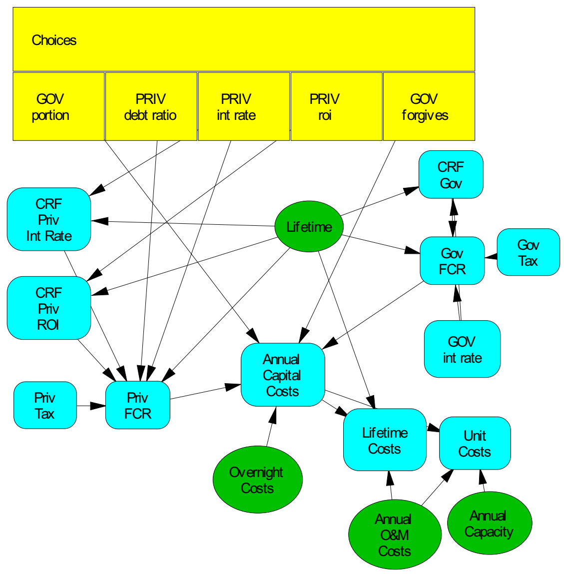

FIG. 1. DPL 6.0 MODEL OF FINANCING STRATEGIES

The financing calculations are the most important aspect of our model. The model uses our input assumption values to calculate a Fixed Charge Rate (FCR) through the following calculations.

$$CRF = \frac{(Rate)}{1-(1+Rate)^{-Lifetime}}$$

$$FCRgov = \frac{CRF_{gov} - (\frac{tax}{Lifetime}) - (IntRate * tax)}{(1-tax)} \qquad (1)$$

$$FCRpriv = \frac{(EquityFract) * CRF_{equity} + (DebtFract) * CRF_{debt} - (\frac{tax}{Lifetime}) - (DebtFract * IntRate * tax)}{(1-tax)}$$

TABLE 3. CALCULATED FCR AND NOMINAL UNIT COSTS

	Government Constructed & Operated	Government Constructed & Sell Private	Regulated Private	Unregulated Private
FCR (for case)	0.51186	0.13196	0.106399	0.211545
Resulting Unit Cost ($/kgHM)	495	990	1559	2610

The Annual Capital Charges are the sum of annual capital costs incurred by the government or private sector, depending on the case. Annual charges for each are simply the Overnight Costs multiplied by the calculated FCR. The calculated FCR and unit costs with nominal input values are shown in Table 3.

The unit cost is determined by ensuring that all annual costs are met with the proceeds from the annual throughput. Further research will have to investigate what the actual asking cost will have to be to ensure that enough is made off the actual throughput to cover costs incurred.

$$UnitCost = \frac{AnnualCapitalCosts + AnnualO\ \&\ MCosts}{AnnualCapacity} \quad (2)$$

In DPL, the sensitivity of each variable is determined by creating a tornado diagram. The variables for the baseline government constructed and operated option were run over a range of potential values (+/- 50% of nominal value except where the range is 0 to 1) as noted on the value tornado diagram in Figure 2. On the diagram, each bar shows the end values as "end of range/expected unit cost with this value." Only those variables that had a significant effect on the value of the estimated unit costs were included in this analysis.

The green ovals in Figure 1 are showing values for which uncertainty has been assigned. Uncertainty has been added to the model by assigning values in the forms of normal curves with a mean at the nominal value and a standard deviation of 10%. This results in 99.73% of possible input values falling into the range of three standard deviations on either side of the nominal value. One exception to the normal curve is lifetime. The lifetime could vary substantially from the 30-year assumption, so the uncertainty in lifetime is modeled by a uniform probability from 20 to 50 years. Also, the amount of debt incurred by the government, which is forgiven, is assumed to be 100%, except in the case where it is modeled that the government does not forgive (or sink) debt.

The way the DPL program runs through the scenarios is depicted by the decision tree in Figure 3. The decision tree shows the flow through the model to determine the outcomes. The model will run through each of the four financing options with 1 million cases; each case will go through the decision tree, so we actually run 4 million cases each time we do an analysis on this model. The case will stop at each continuous chance node, where the model will "roll the dice" (Monte Carlo simulation) to determine a value for that parameter, then the model will continue until the desired value for comparison is reached. In this case, the objective function is unit costs, which is evaluated and then compared across the financing scenarios.

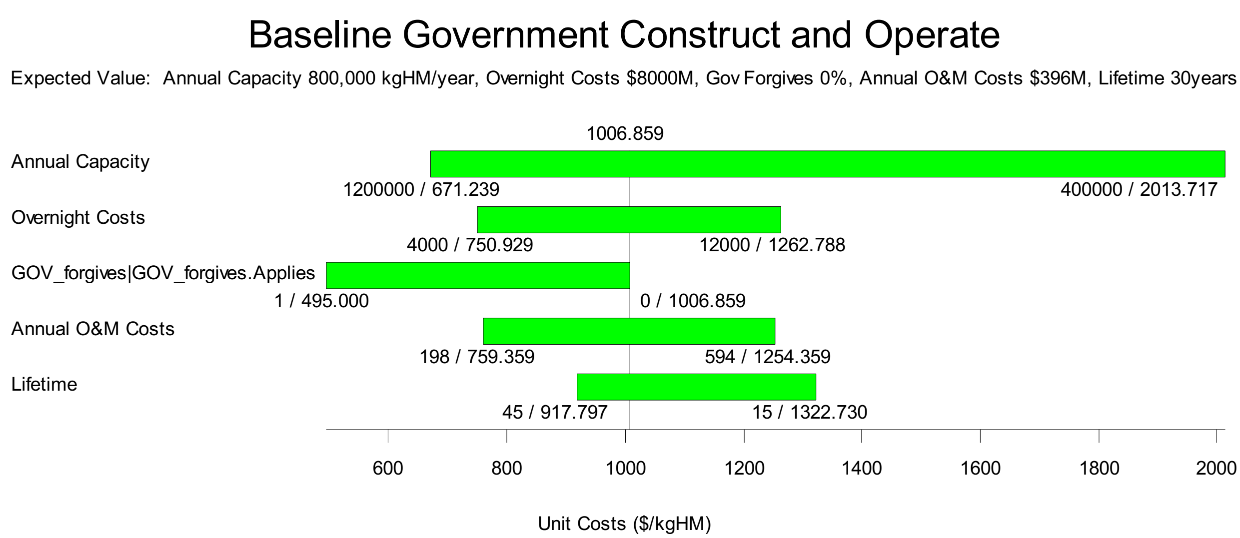

FIG. 2. TORNADO DIAGRAM SHOWING THE EFFECT OF UNCERTAINTY ON UNIT COST FOR THE GOV. CASE

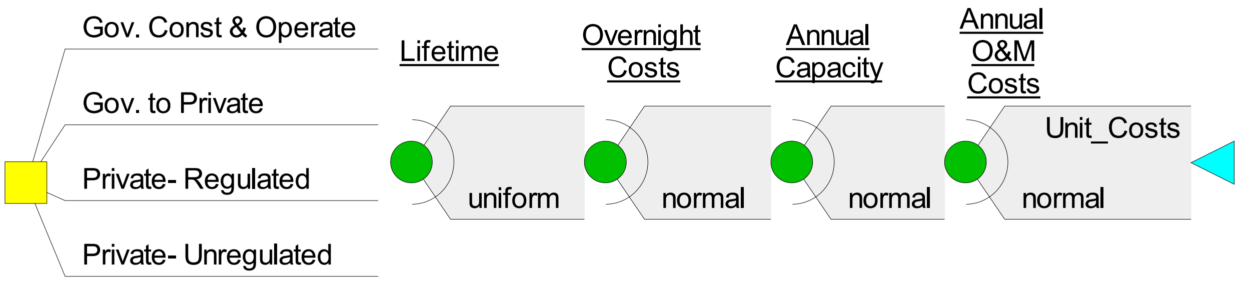

FIG. 3. DECISION TREE FOR RUNNING A SCENARIO IN DPL

RESULTS

With this setup, the model was run to see the range of unit costs and the relationship between the financing strategies. For clarification, these simulations are all run under the assumptions documented in the previous section, except where explicitly noted. From Figure 4, we can see that there is a large distribution of costs from the low mean of nearly $500/kgHM to around $2600/kgHM.

The government ownership option provides the lowest estimated unit cost distribution. By decreasing the level of government involvement, the options become progressively more expensive. The regulated option is more attractive than private ownership, even though none of the debt is forgiven. The private (unregulated) option is clearly the most expensive option.

Figure 5 shows a broad and overlapping range of estimated lifetime cumulative costs across the options (representing 20 to 50 years of operation). All costs are considered recovered, as the unit costs are determined by the facility costs. The government option results in the lowest costs primarily due to the writing-off of the debt of $8 billion, and the government-to-private option is the next least cost, as 62.5% of the initial investment is forgiven and not recovered from the sales of services.

The results from the nominal scenario lead us to investigate various policy scenarios. For each scenario, the simulations will be run again to estimate unit and lifetime costs. These scenarios help to gain a greater appreciation of the possibilities to determine the best financing option.

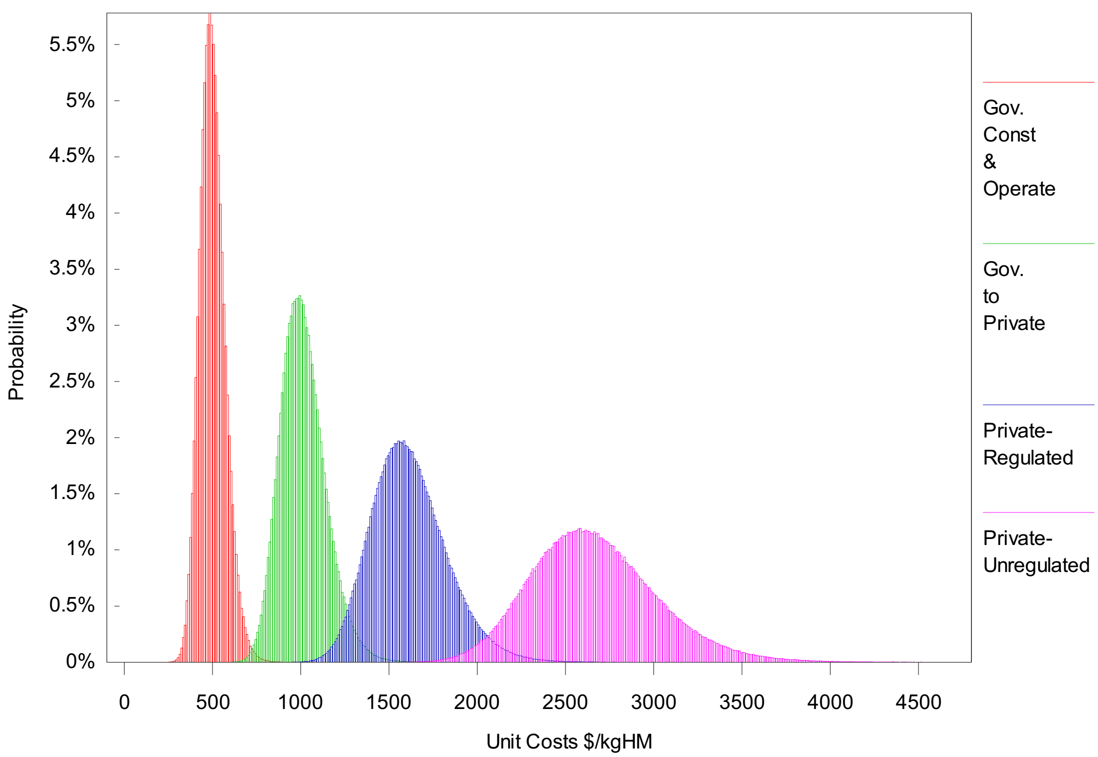

FIG. 4. NOMINAL SCENARIO ESTIMATED UNIT COSTS

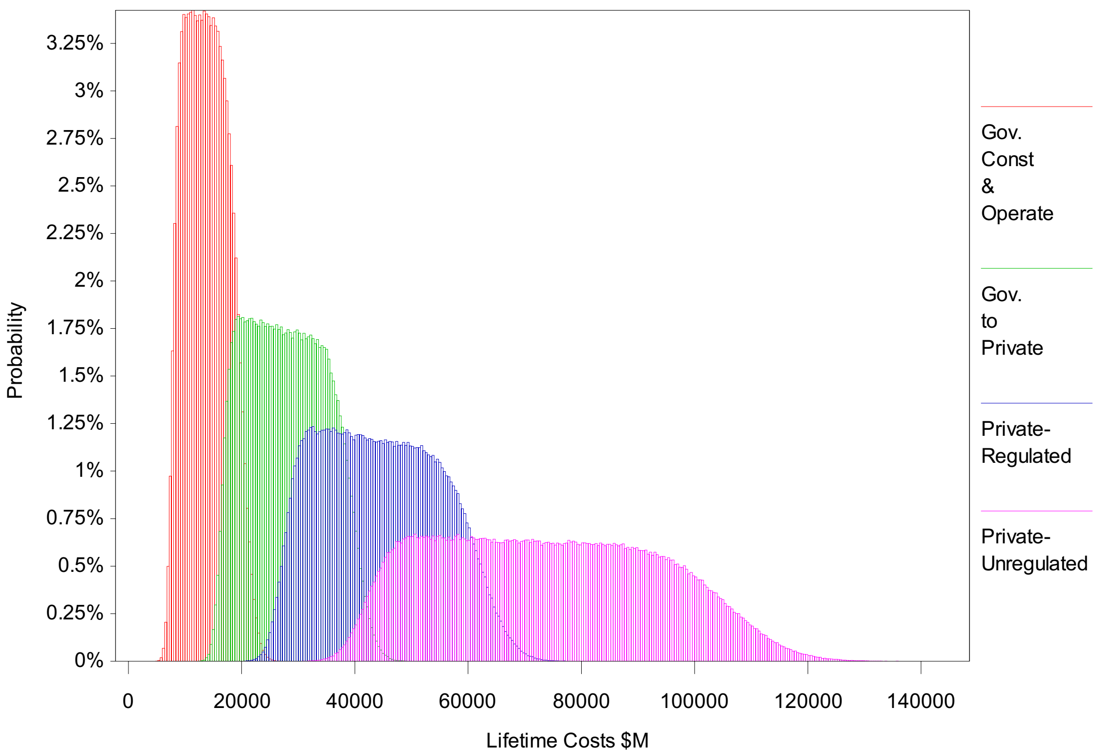

FIG. 5. NOMINAL SCENARIO ESTIMATED LIFETIME COSTS

1. What if the government doesn't forgive or write off the plant construction debt?

The public is more likely to support a project that will minimize government-sunk money. Historically, it has been the practice of the U.S. Government to write-off its own debt when building facilities that are used for the public good. Politically, the term *public good* varies in definition by users; so, what is considered a public good for some may be a waste to others. For these reasons, we consider cases that minimize government-sunk money by repaying the debt over the facility's lifetime.

In this simulation, only the wholly owned government option is changed, to reflect the possibility that the government could choose to not forgive the debt. When debt is not forgiven, the government ownership cost advantage is significantly diminished over the course of the lifetime of the facility, as shown in Figures 6 and 7. In this case, the government is assumed to still forgive 62.5% of the debt when transferred to the private sector, which results in reduced costs to the taxpayers. This change results in the government-to-private option becoming slightly less expensive than the wholly owned government option.

2. What if problems cause annual capacity to be less than nominal?

For this question, the scenario runs with the annual capacity at 30 to 70% (240,000 to 560,000 kgHM/yr) of the nominal design capacity of 800,000 kgHM/yr as a uniform distribution of probability. The recycling facility may run at lower than the nominal design capacity due to being a first-of-a-kind facility. Lowering the annual plant capacity leads to higher unit costs, as should be expected (Figure 8). The tornado diagram (Figure 2) showed expected increase in costs for lower capacity. What might not have been expected is the shape of the new probability distribution graphs. The ranges are much broader, compared to the nominal values, and there is more uncertainty associated with the higher costs in the ranges. An interesting result of this analysis is the asymmetric distribution of the cost curve when the capacity is reduced. The left side of the distribution corresponds to the 70% value (560,000 kgHM/yr) of the capacity reduction and the 30% (240,000 kgHM/yr) value results in the long distribution tail to the right. The asymmetric cost distribution pattern is derived from the ratio of the fixed (capital recovery) costs to the variable (production) costs for this case. It is unnecessary to include a lifetime cost curve since the costs each year are recovered based on capacity; the curve will be identical to the nominal case.

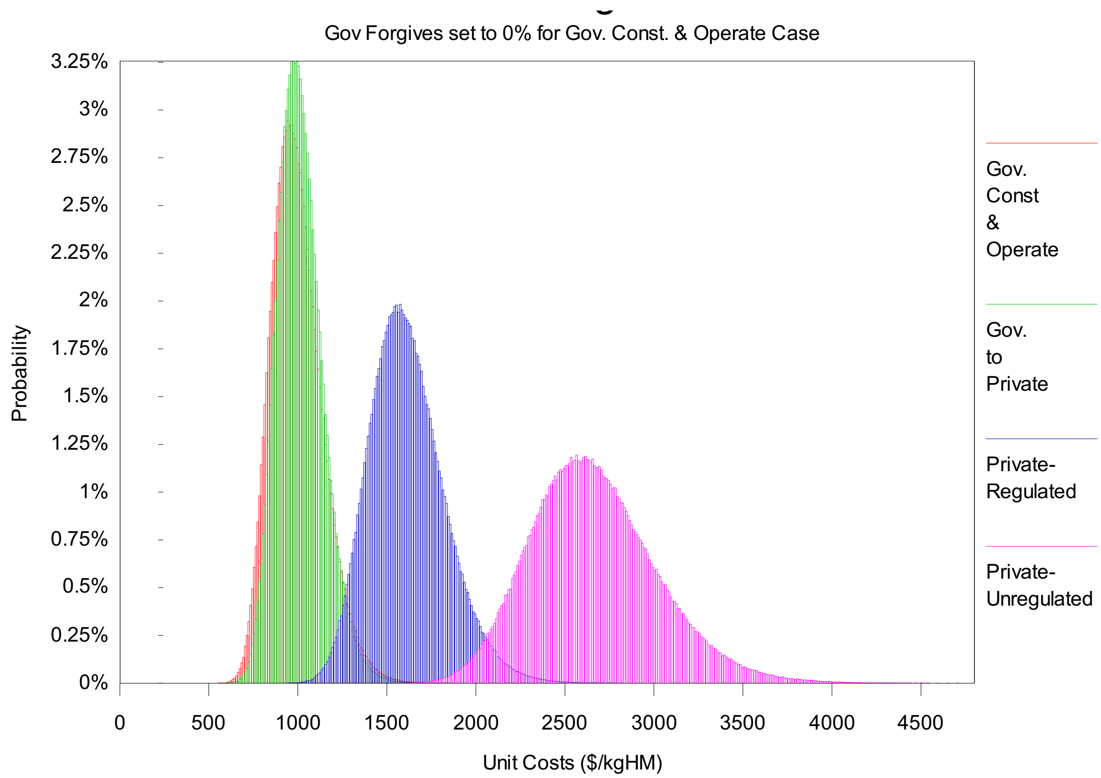

FIG. 6. ESTIMATED UNIT COSTS IF THE GOVERNMENT DIDN'T FORGIVE ITS OWN DEBT

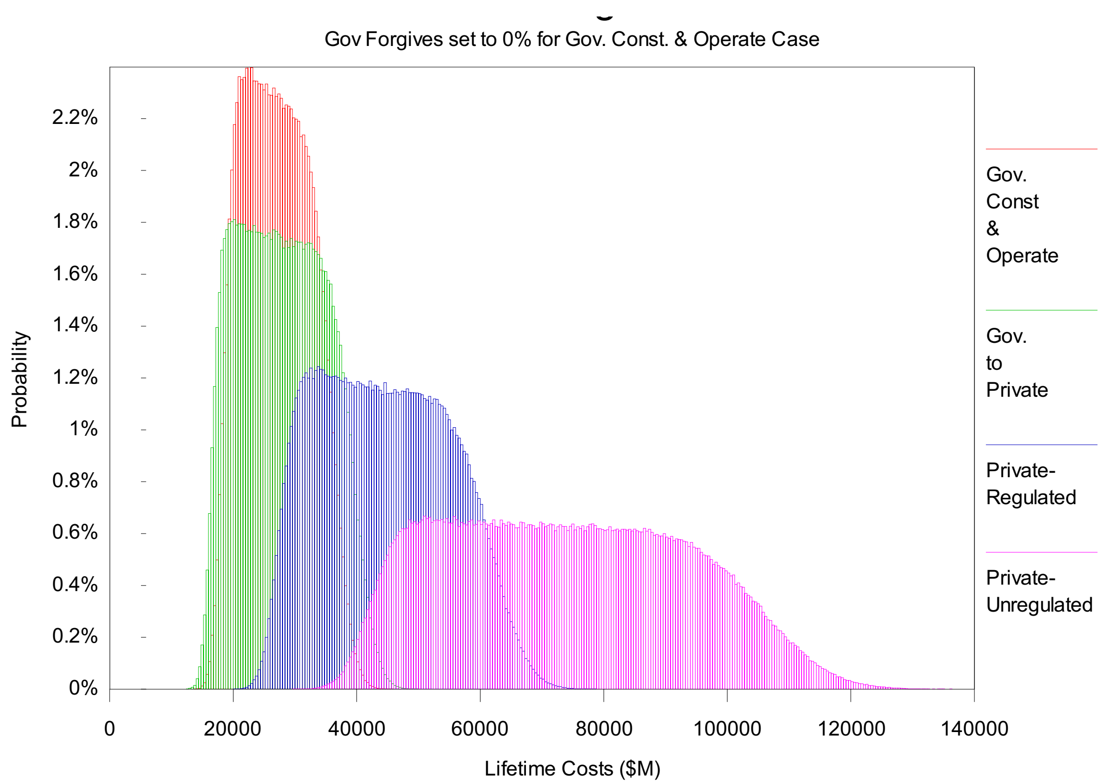

FIG. 7. ESTIMATED LIFETIME COSTS IF THE GOVERNMENT DID NOT FORGIVE ITS OWN DEBT

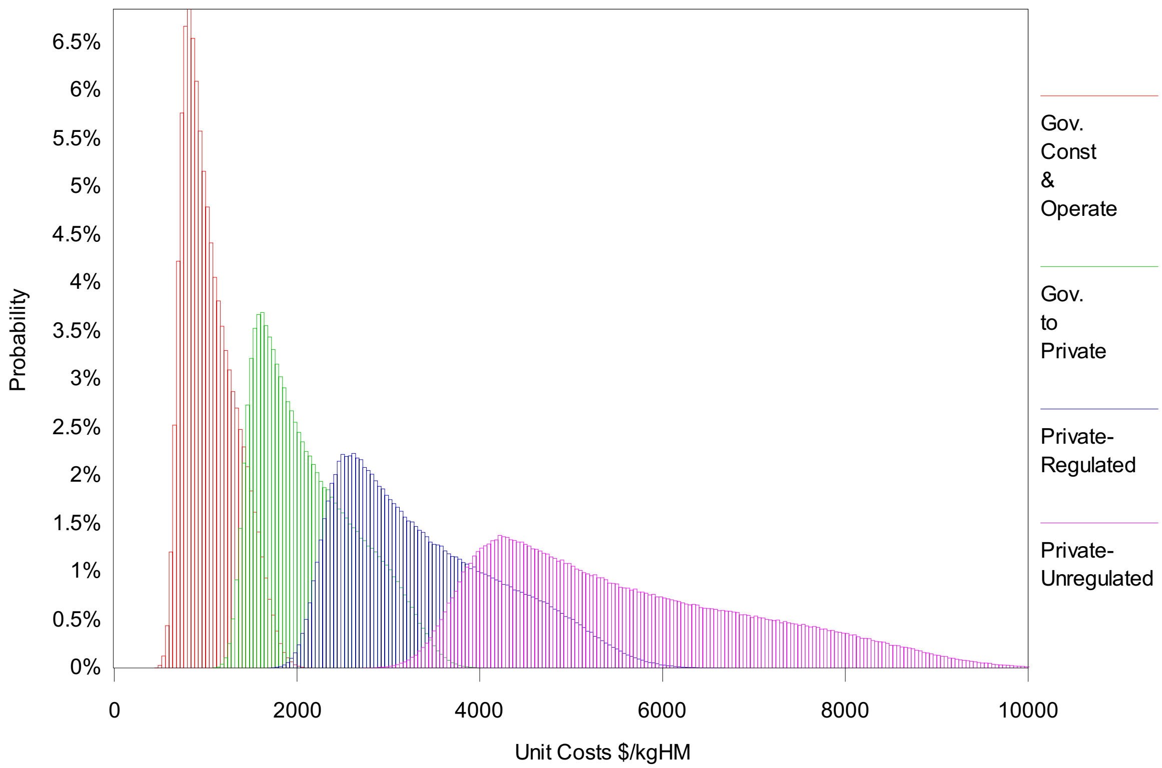

FIG. 8. ESTIMATED UNIT COSTS FOR THE LESS THAN NOMINAL CAPACITY CASE

3. What if there are significant economies of scale and a larger plant is built?

This is an important question considering that the current fleet of reactors produces more than 800 MTHM of used fuel per year and the country is considering recycling fuel from other nation's nuclear programs as well. For this case, a 2,500-MTHM facility was simulated assuming that it could be built and operated for the same costs assumed for our nominal 800-MTHM plant. Note here that there is no agreement in the literature as to the scalability of such plants [11, 12]. From Figure 9, we can see that increasing capacity has an expected outcome related to unit costs, but the increase is less important than the decrease as modeled in the previous scenario. The tornado diagram (Figure 2) shows that for the base case, the effect of a 50% decrease in capacity had a greater effect than a 50% increase. Again, the unit costs are based on the capacity to ensure their coverage, so the lifetime costs will be the same as in the nominal case.

4. What if guaranteed contracts or government incentives are in place leading to lower investment risk?

To run a simulation of lower risk, the debt interest rate and required return on investment were lowered for private investing to 6 and 10%, respectively (values lower than nominal). We assume that lowering the risk will bring private ownership closer to the results from regulated ownership. Simulating lower risk is consistent with many proposed legislation ideas to reduce risks for capital intensive energy industry components. Such approach has been written into the Energy Policy Act of 2005 [13]. At the moment, recycle facilities are not considered in the legislation, but it is possible that the incentives put into place for energy producing facilities in the EPACT 2005 might in future legislation be applied to other types of facilities that support the U.S. energy infrastructure.

The reduced risk to the private sector scenario, shown in Figure 10, leads to the private option having improved certainty and lower unit costs. This is demonstrated by the narrower cost distributions. The government-to-private option also has slight improvements in certainty and costs because of the reduction of 0.5% of the ROI for the equity financing received.

The lifetime cost result in Figure 11 is similar to the unit cost result in Figure 10, with the unregulated case shifting noticeably to lower values and the government-to-private cost distributions moving slightly to the left (decreasing costs). The differences in their shift are due to the original assumptions which already benefited the government-to-private option with a debt interest rate of 4.8% and equity ROI of 10.5%. Therefore, the government-to-private scenario only gains 0.5% ROI rate reduction on the equity portion of its 32.5% of investment to be recovered, which results in a very small change in the resulting cost. However, the private-unregulated ownership option benefits by the reduction of the debt interest rate from 9 to 6% and equity ROI rate from 16 to 10%.

5. How does a government subsidy compare with the reduced risk scenario?

Economists often argue the merits of subsidies versus taxes. In this scenario, we are looking for the unit cost results assuming a significant ($2 billion) subsidy was applied to new recycle plant construction. This effectively lowers the overnight costs from $8 billion to $6 billion for the private cases. Figures 12 and 13 show that the unregulated case appears to benefit more from the subsidy while the regulated case appears to benefit less than it did from reduced risk (lower interest rates) as seen in comparison with Figures 10 and 11; the government-to-private case shows less certainty in the subsidy scenario than in the reduced risk scenario.

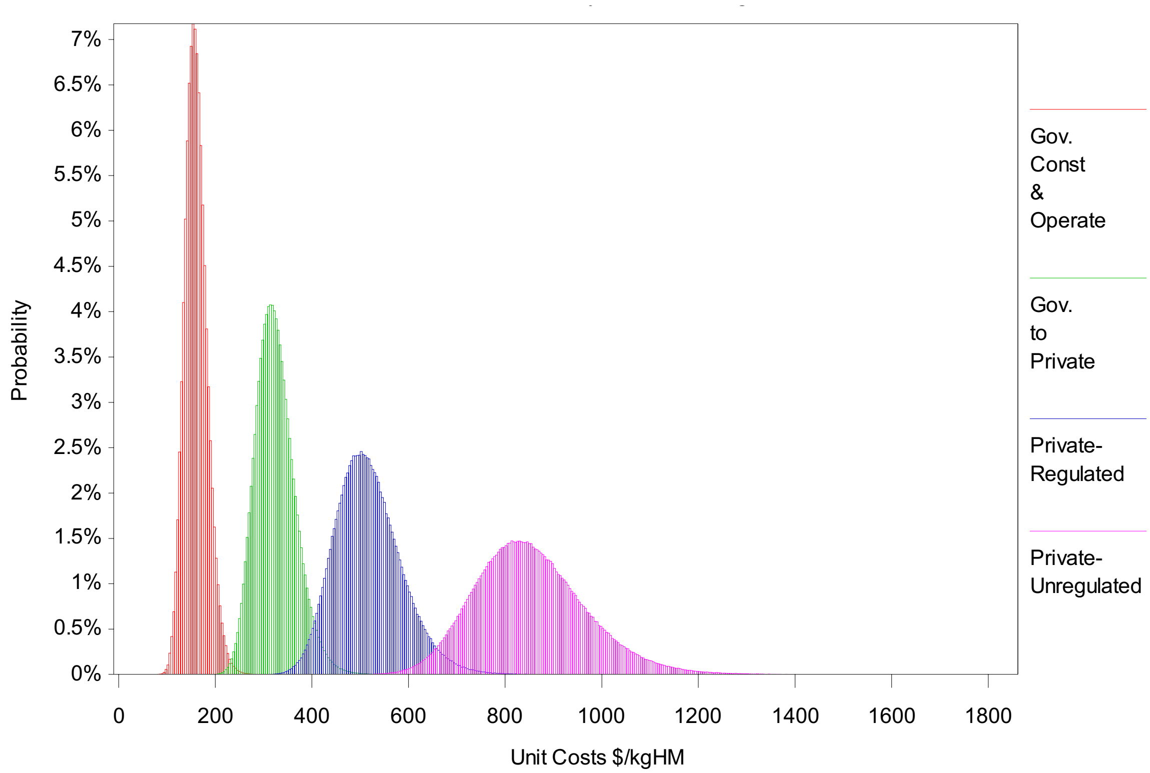

FIG. 9. ESTIMATED UNIT COSTS FOR SIGNIFICANT ECONOMIES OF SCALE

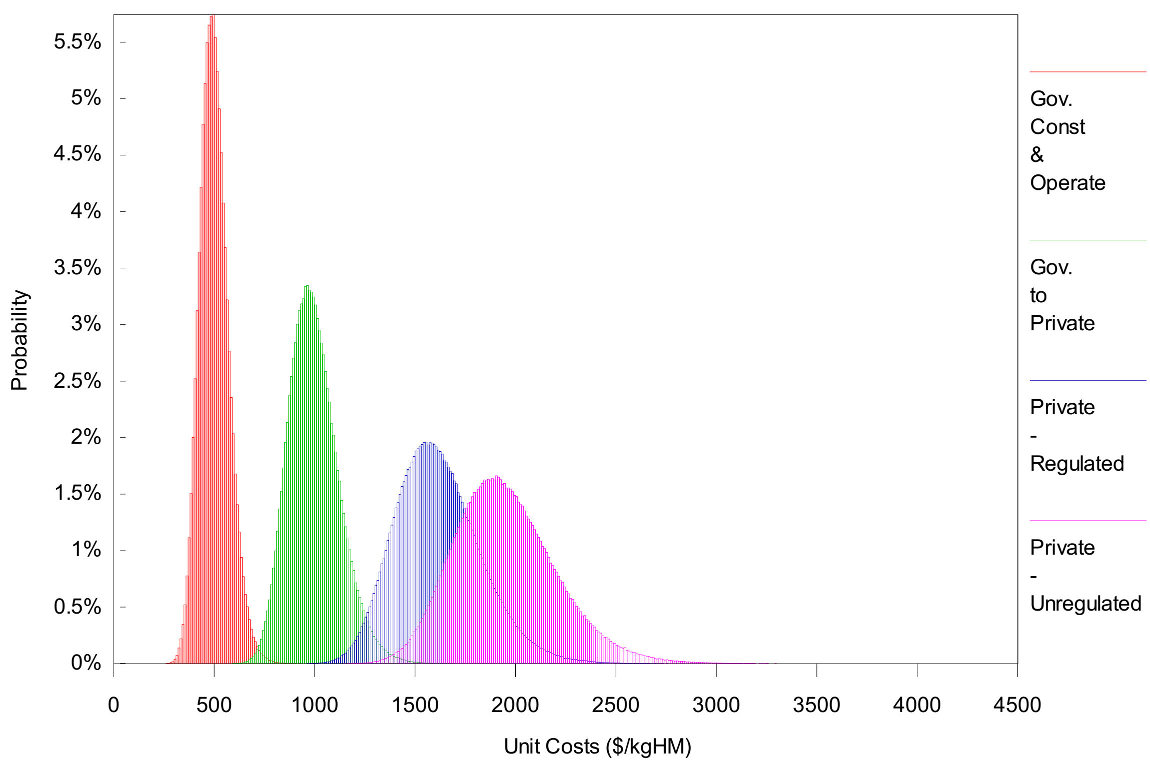

FIG. 10. ESTIMATED UNIT COSTS FOR THE LOWER RISK SCENARIO

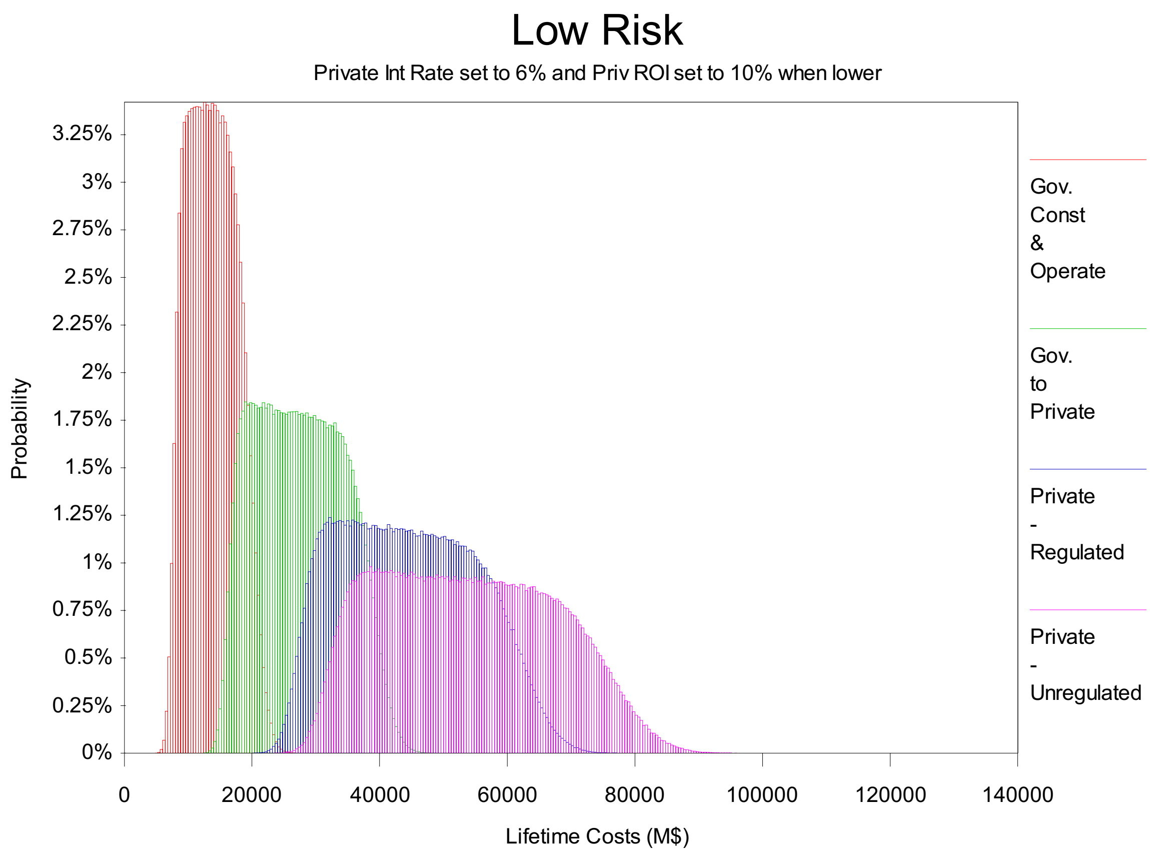

FIG. 11. ESTIMATED LIFETIME COSTS FOR THE LOWER RISK SCENARIO

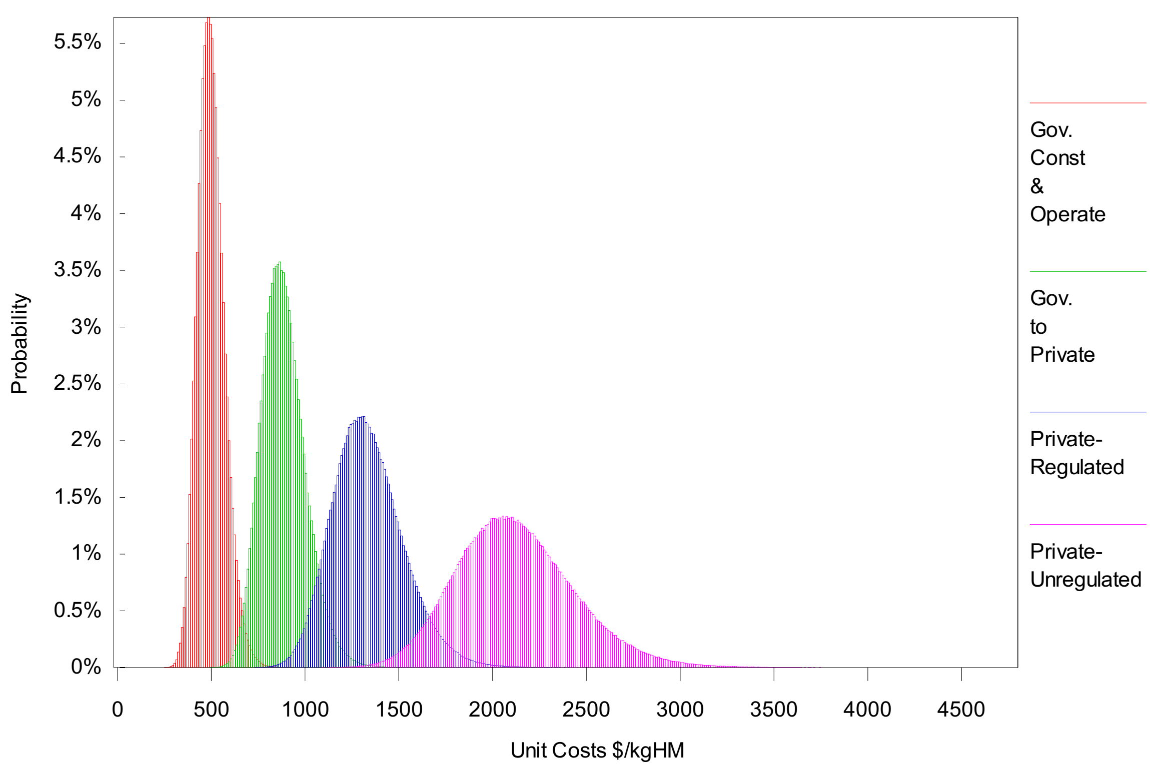

FIG. 12. ESTIMATED UNIT COSTS IN THE SUBSIDY SCENARIO

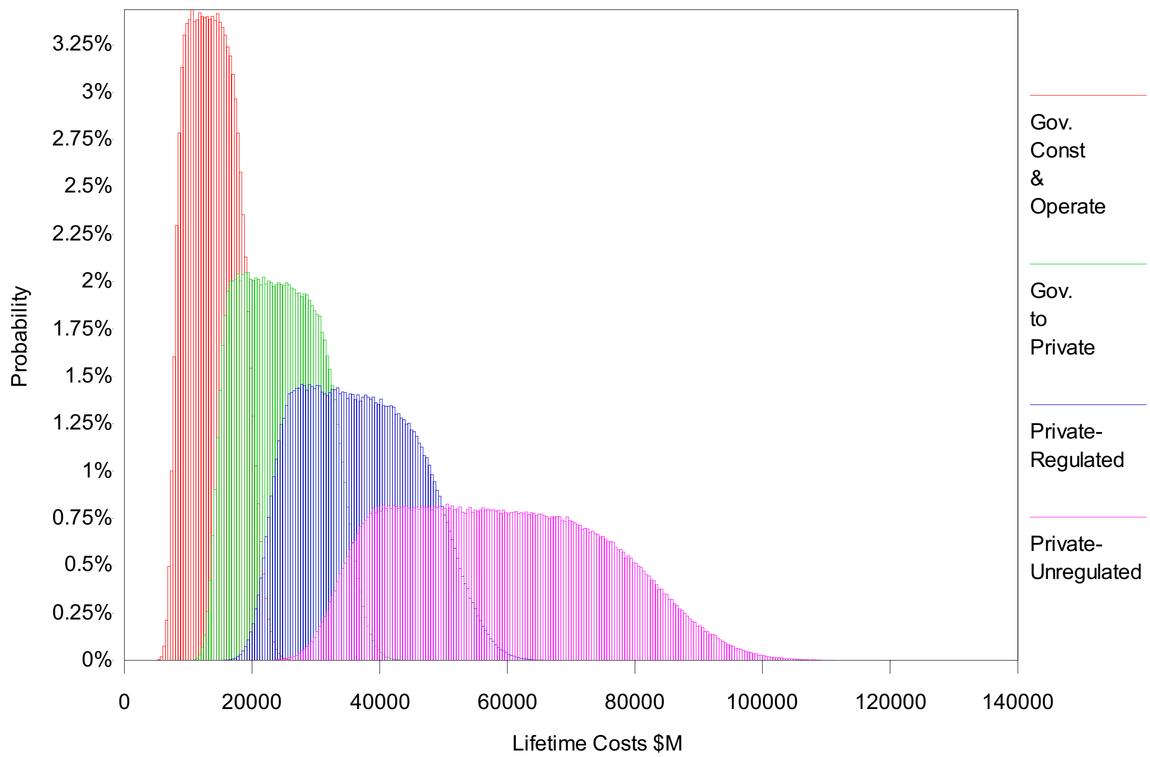

FIG. 13. ESTIMATED LIFETIME COSTS FOR SUBSIDY SCENARIO

CONCLUSION

The most consistent result from our studies of the costs of fuel recycle facilities is that government ownership generally leads to lowest costs. However, this does not mean that the facilities should necessarily be constructed and operated by the government. Through this analysis we found that the costs of the government–to-private and the private (regulated) ownership options were not greatly different than the fully government owned option. This analysis indicates that commercial operations have potential to be economical, but there is presently no incentive for private industry involvement, since the current legal framework establishes government ownership of partially used fuel [10].

We have come to similar conclusions regarding the significance of cost variables as does the AFCI 2005 study prepared by Shropshire. In the government ownership option; annual O&M costs, forgiveness of debt, and overnight costs are the most significant cost contributors. In the regulated and private ownership cases, initial capital costs will be most significant. Further, we have established that uncertainty in variables has a greater effect on the private ownership option than the others.

Uncertainty in operation, leading to lower annual capacity, is the most detrimental scenario economically. Determining the facilities throughput will be a driving factor in setting unit costs. There is a significant penalty for operating at less than capacity, as shown by the 30 to 70% nominal annual capacity simulation. With appreciable economies for full-capacity facility operation, the facility should be designed for maximum throughput and availability to support the needs of the nuclear power plant fleet. If high annual plant capacities (approaching 3,000 MT/yr) are achievable within the same range of capital and operation cost parameters as modeled, then unit costs less than $500/kgHM could be obtained. These capacities could result from significant economies of scale (specifically capital cost versus capacity), arising from the construction design and facility operations designed for optimal economic throughput. The construction of parallel recycle lines all feeding from a centralized facility might allow such economies of scale to be achieved.

Mitigating risks, thereby lowering debt interest rates and required return on investments, led to the most promising result for private-unregulated industry initiative. A subsidy showed benefits to the private-regulated industry ownership/operations model. Most of the contributors to costs for the private ownership ventures are found in the interest on debt and equity for the initial capital investment. Any mechanism causing the capital investment and the related returns rates to decrease will lead to a more attractive situation for private ownership.

Further research should investigate the year by year costs of changing conditions on the financial parameters. Significant work still must be done on the scalability of these facilities and the comparison of constructing multiple facilities of varying sizes. Political research must also be undertaken to determine the conditions under which legislation could be passed to encourage private investment if that is desired.

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