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N90-15838 APPENDIX B-1

Analysis of the Financial Factors Governing the Profitability of Lunar Helium-3

by

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INTRODUCTION

The need for new energy sources in the 21st Century has been established in the body of this report and the benefits of using the DHe3 fuel cycle are discussed in Appendix B2. Assuming that such an energy source can be brought on line by the year 2015, this appendix will address the following questions;

A.) What are the financial factors which can have the greatest leverage on the profitability of DHe3?

B.) Over what range can these financial factors be varied to keep the DHe3 option profitable?

C.) What ultimate effect could this energy source have on the price of electricity to US consumers?

We will not address the environmental features of this fuel cycle nor the procurement of the He3 fuel from the Moon as both of these topics have been covered elsewhere (1-6). Our sole purpose here is to concentrate on the financial aspects of this fuel.

1.) L. J. Wittenberg, J. F. Santarius, G. L. Kulcinski,"Lunar Source of He3 for Commercial Fusion Power", **Fusion Techn. ,10**, 167 (1986)

2.) G.L.Kulcinski, and H. H. Schmitt, " The Moon: An Abundant Source of Clean and Safe Fusion Fuel for the 21st Century", Published in the Proc. of the 11th Intern. Sci. Forum on Fueling the 21st Century, Sept. 6, 1987, Moscow, USSR

3.) G.L. Kulcinski, et. al., "The Commercial Potential of D-He3 Fusion Reactors", Proc. 12th Symp. on Fusion Engr., IEEE Cat. No. 87CH2507-2, 1987

4.) G.L. Kulcinski et. al., " Apollo- An Advanced Fuel Fusion Reactor for the 21st Century," **Fusion Techn., 15,** 1233(1989)

5.) J.P. Holdren et. al., "Exploring the Competitive Potential of Magnetic Fusion Energy" **Fusion Techn., 13**,7 (1989)

6.) I. N. Sviatoslavsky and M.Jacobs, " Mobile He3 Mining and Extraction System and its Benefits Toward Lunar Base Self-Sufficiency", To be Published.

Assumptions and Approach

The main assumptions made for this study are listed in the accompanying table. The acceptance that DHe3 plasmas can be effectively utilized to provide electricity on the Earth with sufficient environmental advantages so as to be aggressively pursued by the developed nations is taken as an initial starting point. It was also assumed that there is no question about the magnitude and distribution of He3 on the surface.

The basic figure of merit used here is the real rate of return on investment. The analysis has been confined to the U.S. only and covers the period from 1985-2050. All the calculations have been in 1988 dollars, i.e., inflation has not been included.

The results have been viewed from 3 different perspectives;

- From that of an electric utility which is interested in providing a reliable form of safe, clean, and economic electricity and views He3 as a fuel only,
- From that of a lunar developer whose main goal is to mine and sell a product (He3) at an attractive profit,
- From that of a vertically integrated energy company which owns both the 'mines' and the power plant.

Real Rate of Return Investment Method

Two complementary methods of analysis are used to assess the benefits of using lunar He3 in the DHe3 fuel cycle to provide some of the electricity needed in the United States for the first half of the 21st century. They are;

1.) Rate of return on incremental investment required,
and 2.) Reduction revenue requirements (total cost to customers) achieved.

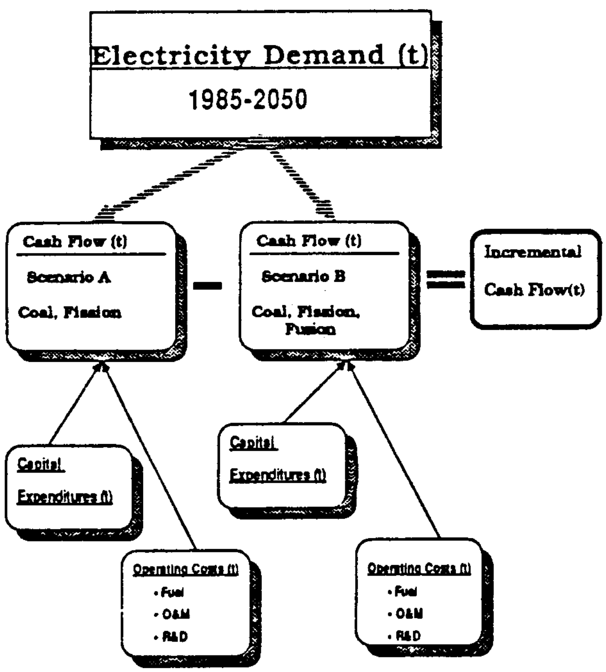
The first step in this type of calculation is to establish the future electrical demand(see accompanying diagram). Next, two scenarios to satisfy this demand are constructed. The first relies simply on coal and fission (it is assumed that in the 21st century oil and natural gas will not be used to any great extent to produce electricity in the U.S. and the contribution from hydro plants is ignored at this time for simplicity). The second scenario assumes that DHe3 fusion will start to contribute in the year 2015 will a penetration rate described in more detail later.

Once the amount of kWh's produced by each form of energy is calculated, the incremental investment and cash flows for each scenario can be determined. The difference in total cash flow between the two scenarios is then the incremental investment required. In method 1, it is the rate of return on the incremental investment that captures our interest. This rate of return measures the benefit to society from the increased capital investment in the fusion alternative.

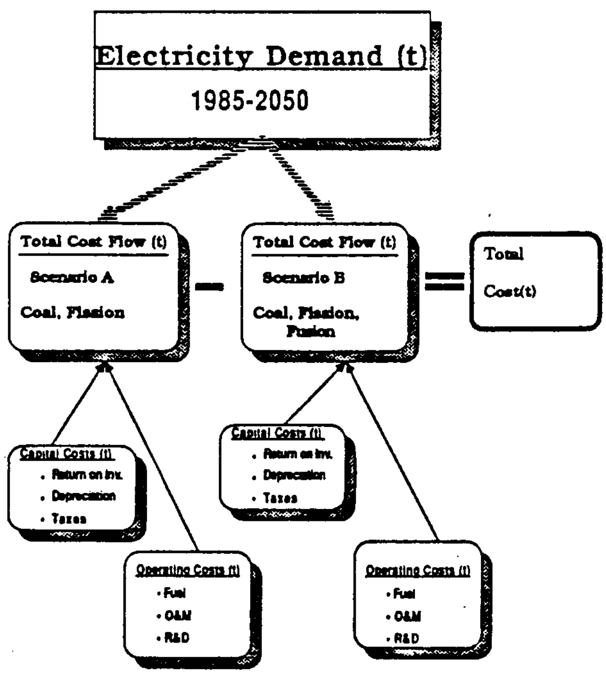
The calculation of the kWhr's produced by each form of energy can also be used to calculate the reduction in revenue required achieved through the use of DHe3. (Method 2). The revenue requirements (total annual costs of generating electricity)--which the ultimate consumer must bear-- consist of the costs of capital, taxes and the costs of operation. By adding the yearly costs of each, the total cost per kWh for each of the two alternatives can be calculated. The calculations are made using the same procedures used in rate cases for regulated utilities. The revenue requirement, or total cost, is the sum of depreciation, fuel costs, O&M costs, R&D costs, taxes, and return on investment.

The main financial assumptions, which are relevant only to method 2, are: (1) the financing mix consists of 50% debt and 50% equity; (2) the cost of debt is 10% and the cost of equity is 13%; (3) the effective corporate income tax is 30%. These assumptions, along with others on the parameters governing costs allow calculation of the rates(mills/kWh) consumers would be charged. This another way to measure the benefits to society.

It is important to note that both methods understate the RRR because we have arbitrarily cut off the calculation at the year 2050 even though much of the equipment and power plants still would produce electricity in the future.



Method 1
Rate of Return on
Incremental Investment



Method 2
Total Cost Reduction

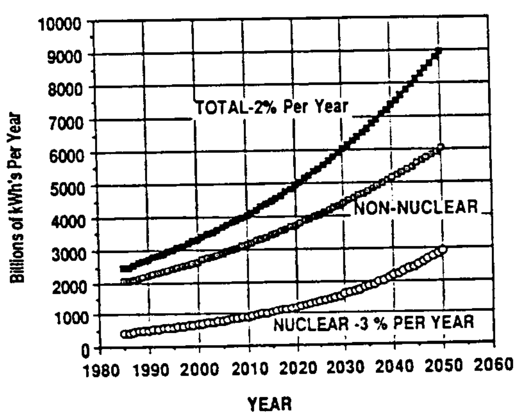
Projected Electricity Demand 1985-2050

It has been assumed that the U.S. growth rate in electricity demand over this period is 2% per year. While no one can really predict this number with any accuracy, it is less than 1/2 the growth rate of the 1970's and considerably lower than the current growth rate from 1985-1988 (3.2%). Most of the DOE and electric utility predictions fall in the 2 to 3% range and a recent Edison Electric Institute report concludes that the growth rate will be in the 2% range from now to 2020.

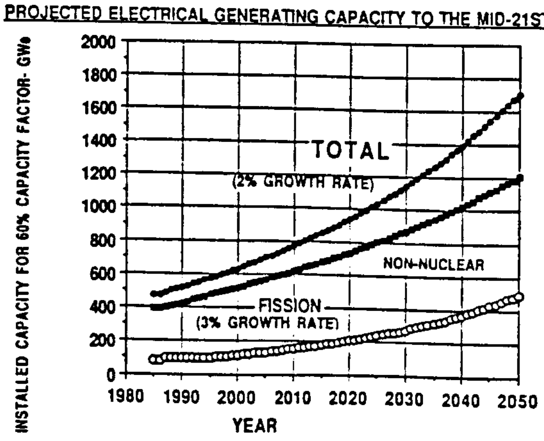
The result of a 2% annual increase in electrical demand is illustrated in the accompanying graphs, both for installed capacity and for the total kWh's generated. For the purposes of this study we have assumed that nuclear power grows at 3% per year after 1995 and that the difference between the 2% overall growth and the 3% nuclear growth (albeit on a smaller base) is made up by coal. This scenario envisions that the electrical energy consumed in the U.S. will rise from 2.5 trillion kWh's in 1985 to ≈ 9 trillion kWh's in 2050. Approximately 1/3 of that energy in the year 2050 would be provided by nuclear power.

The total installed capacity also rises from ≈ 500 GWe in 1990 (calculated on the basis of an average 60% capacity factor) to ≈1700 GWe in the year 2050. The installed nuclear capacity grows from ≈100 GWe in the mid 90's to ≈500 GWe by the year 2050.

Projected U.S. Electrical Power Generation



PROJECTED ELECTRICAL GENERATING CAPACITY TO THE MID-21ST CENTURY



Calculation of Electrical Generation Costs Without Fusion

The total cost for generating electricity in this case is the sum of coal and fission produced energy. Given the demand scenarios previously described, there are three main factors to consider; capital costs, fuel costs, and O&M costs. In addition, the true cost of the electricity should include the R&D required to keep the plants running competitively. All of these factors must be included in the total busbar cost(see accompanying flow diagram).

The current capital costs for coal plants in this study were assumed to be 1400 $/kWe and the corresponding value for fission plants is 2650 $/kWe. Both of these numbers come from recent DOE summaries of existing plants. It is recognized that some new facilities cost more and some cost less, but these averages seem to reasonable at this time.

Current fuel costs for coal plants average 33.13 $/ton which translates into 19 mills/kWh. Similarly, current fission reactor fuel costs are about 7 mills/kWh. The lower fission fuel costs are countered somewhat by its higher O&M costs. Presently fission O&M costs average 10 mills/kWh versus 4 for coal. In order to reflect environmental factors, we have allowed the fuel and O&M costs to escalate by 2 % per year. These environmental costs include mine and plant clean up, increased emission costs and increased waste management costs.

The current R&D costs are taken to be those funded by the Federal Government through DOE. These currently run 800 $M/y for both technologies and because of the concern over the environment, we have allowed 4% escalation in these costs.

Calculation of Electrical Generation Costs With Fusion

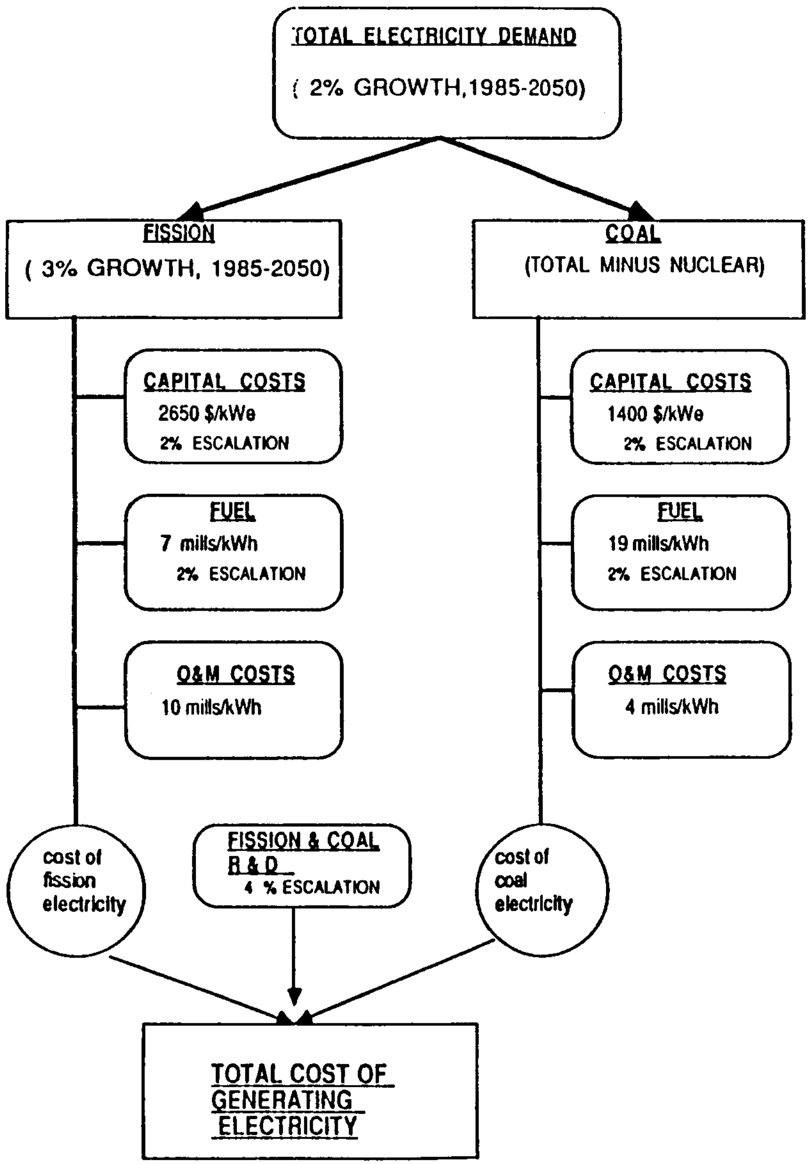
This calculational procedure is identical to that without fusion. The capital cost for a DHe3 fusion reactor was taken from the Apollo reactor study at the University of Wisconsin. The 1200 MWe facility was costed out at 2030 $/kWe and the O&M costs amounted to 5 mills/kWh. The fuel cost is the cost of operating the moon base including the transportation costs of materials taken to the moon and the cost of returning the fuel.

The current magnetic fusion R&D costs are ≈350 $M/y and it was assumed that these costs escalate at 4 %/y exclusive of inflation.

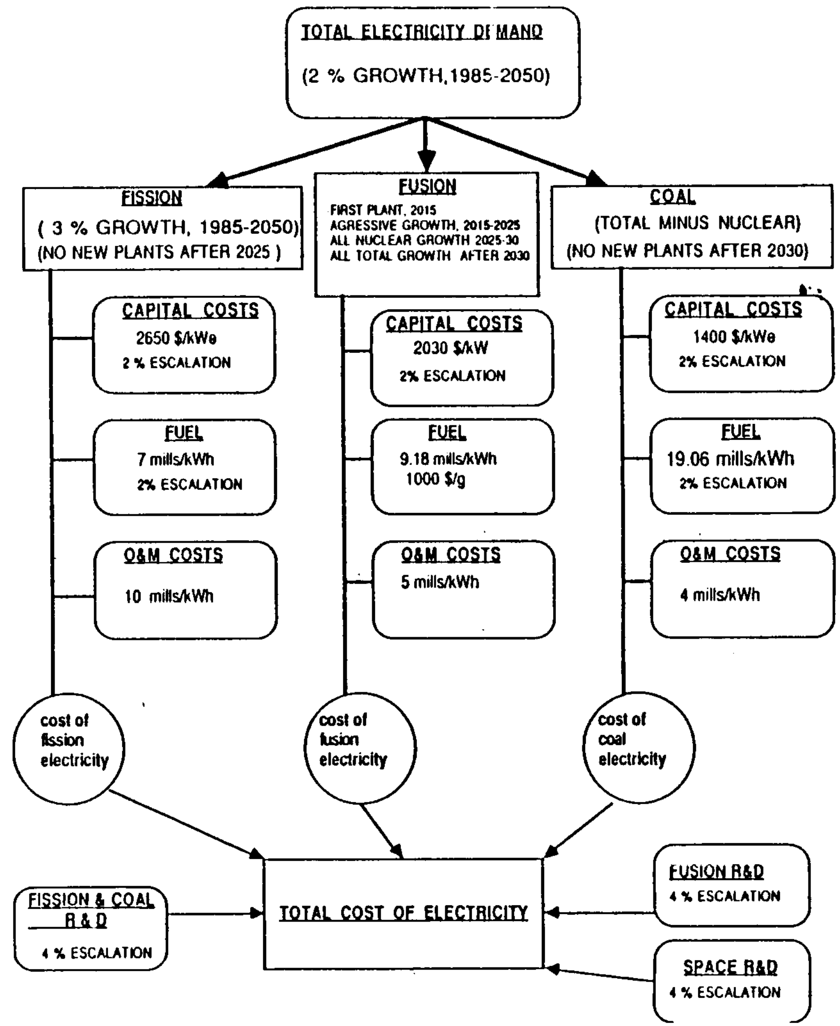
Finally, the R&D needed for Space research must be included. We only included R&D specific to He3 and assumed that heavy lift vehicles, a scientific base on the Moon as well as the basic research needed to return to the Moon for scientific reasons would be part of the national program. The specific He3 Space related research was assumed to start in 1991 at a 10 $M/y level, rapidly escalating to a 100 $M/y by the mid 1990's and thereafter growing at a real rate of 4%/y.

The rate of return analysis which follows will consider a return to the lunar company as well as to the utilities. This is accomplished by assuming a selling price for He3 from the Moon. The base case cost is 1000 $/g. This translates into a fuel cost of 9.18 mills/kWh. Varying this transfer price will merely shift profits between the lunar company and the utilities without affecting the return to society as a whole.

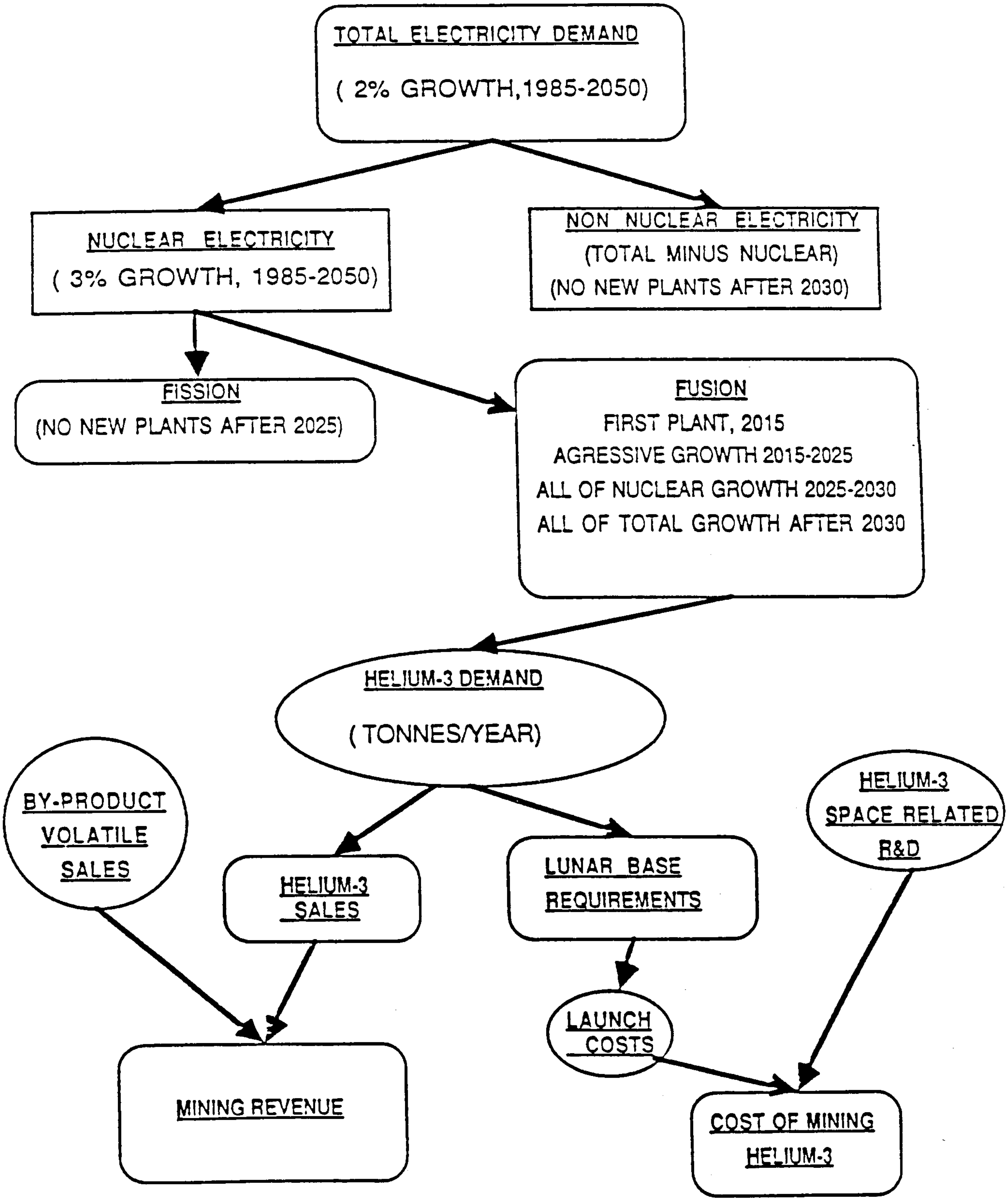
REFERENCE COST FOR ELECTRICITY GENERATION, 1985-2050



EFFECT OF DHe3 FUSION ON THE REFERENCE COST FOR ELECTRICITY GENERATION, 1985-2050



CALCULATION OF PROFITABILITY OF LUNAR He3 MINING

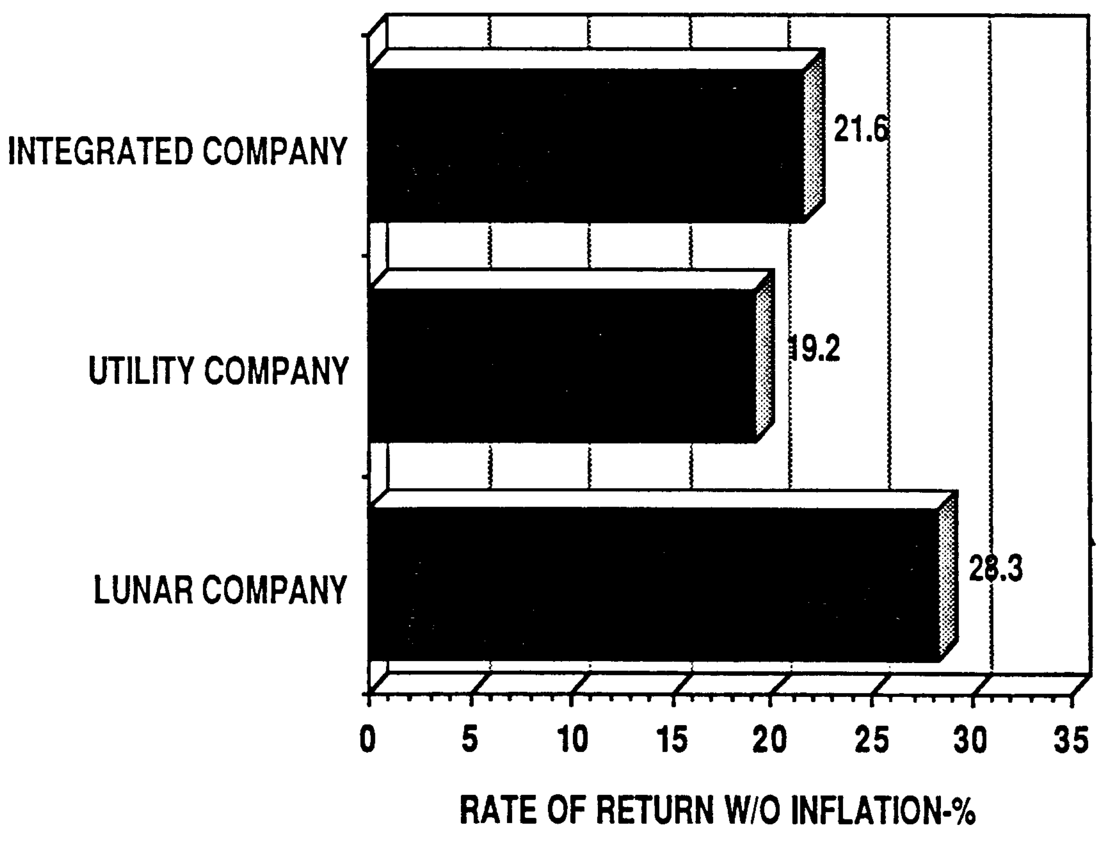


Base Case Profitability For DHe3 Fusion

Using the energy demand scenarios described earlier, along with the input information on coal, fission, fusion, space, and R&D cost, we have calculated the internal rate of return on the incremental investment in fusion. The accompanying graph shows that if the selling price of He3 is $1000/g, the Lunar Company could realize (before including inflation) a 28.3 % rate of return. The Utility Company could still obtain a 19.2% profit and if the Lunar and Utility Companies were owned by the same organization, the rate of return would be 21.6%. Obviously the 'financial center of gravity' is close to the Utility company.

The effect of inflation on the base case was examined next. It was found that if the inflation rates were on the order of 4%, the rate of return then approached ≈ 25% for both the Earth and Lunar based companies(see the accompanying graph).

PROFITABILITY OF He3 FUSION ENERGY IN THE 21ST CENTURY-BASE CASE



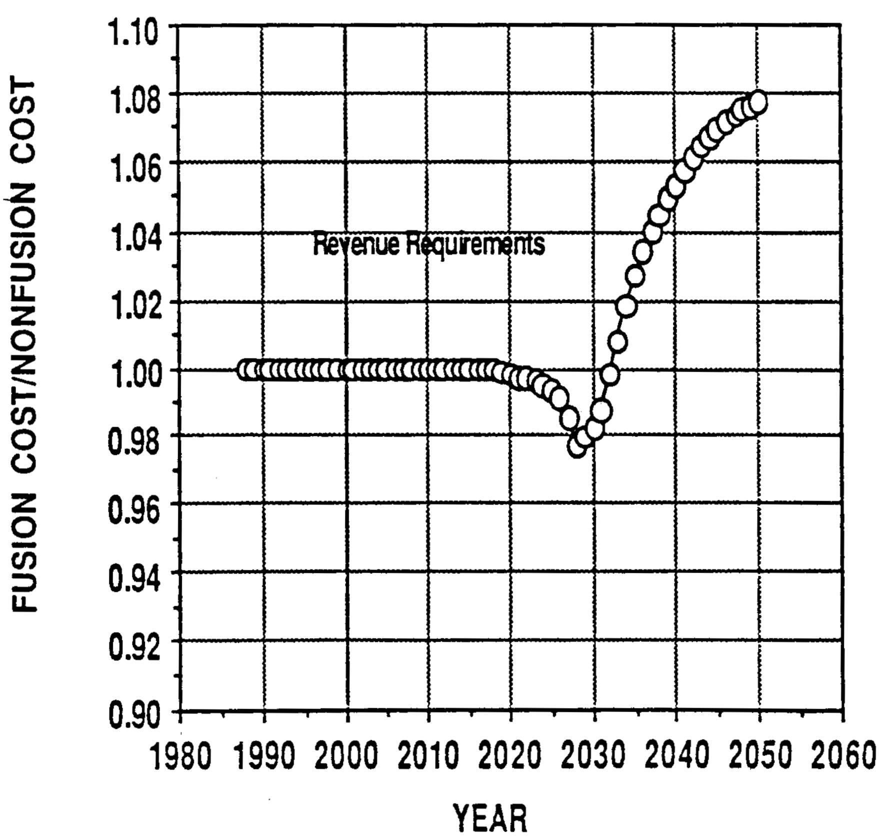
Annual Capital Cost Comparison

In order to develop a complete financial picture, we need to calculate the total cost of electricity to the consumer. Input to that calculation includes the capital costs and the operating costs, each of which we will calculate separately, then combine them into a final cost of electricity comparison. The analysis of this data is for the Vertically Integrated Company and includes all the costs to the ultimate customer and thus serves as a measure of the effect on society.

The annual capital costs plus taxes includes depreciation charges resulting from an assumed plant life of 40 years, return on investment, and income taxes. For each alternative it is assumed that capital requirements will be financed with 50% debt and 50% equity capital. The cost of equity is assumed to be 13% and the cost of debt is 10% for each alternative. Profits are assumed to be subject to a 30% income tax rate.

The ratio of the capital cost required for the two scenarios is plotted in the accompanying diagram for the Integrated Energy Company. From the year 2015 to ≈2025, the capital requirements are slightly less for the fusion case. After 2025, when fusion begins to replace large amounts of more expensive fission power , the ratio drops to 97% of the nonfusion case. However, when fusion begins to replace the less expensive coal plants after 2030, the ratio climbs to 108% of the base case.

ANNUAL CAPITAL COST COMPARISON



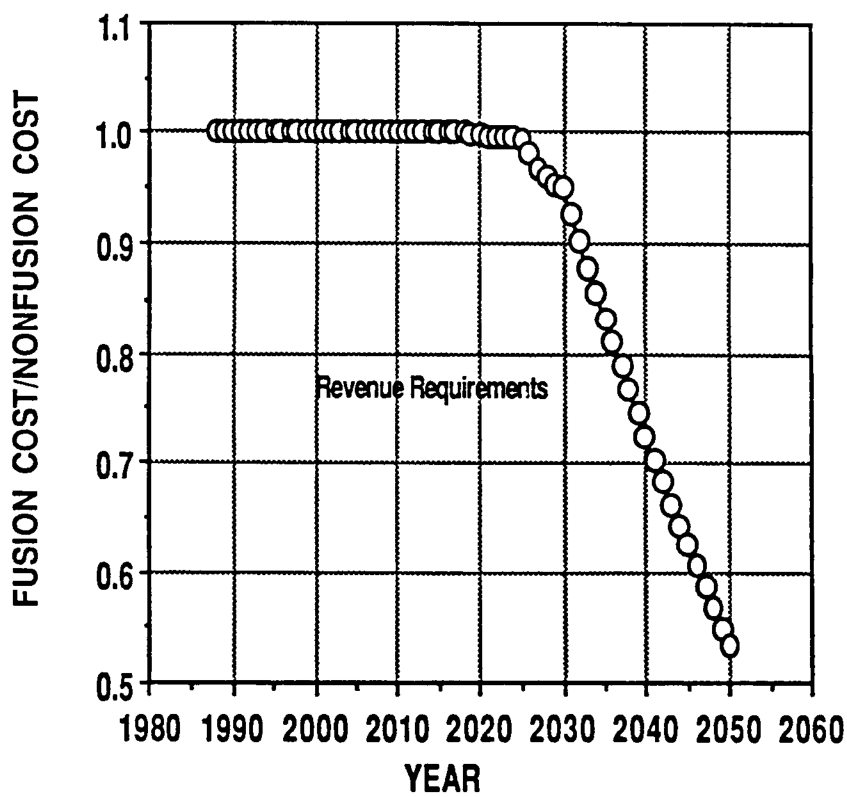
Annual Operating Cost Comparison

The analysis of lunar base costs suggests that there will be economies of scale present in the mining of He3. It is also obvious that the amount of He3 required in the fusion alternative will increase dramatically between the first installation of a fusion plant in 2015 and the 'end point' of the analysis in 2050. This increasing economy associated with He3 mining will cause the fuel costs for the fusion alternative to decline significantly towards the middle of the 21st century.

Non fusion fuel costs include escalation factors for fission and coal costs to represent the diseconomies associated with environmental and economic limitations of these methods of production.

The ratio of the operating cost required for the two scenarios is plotted in the accompanying diagram for the Integrated Energy Company. From the year 2015 to ≈2025, the operating cost requirements are slightly more for the fusion case because of the added R&D costs. After 2025, when fusion begins to replace large amounts of the more expensive fission operating costs , the ratio drops to 95% of the nonfusion case. However, when fusion begins to replace the much more expensive coal plant operating costs after 2030, the ratio drops rapidly to only ≈50% of the base case by 2050.

ANNUAL FUEL, O&M, R&D COST COMPARISON

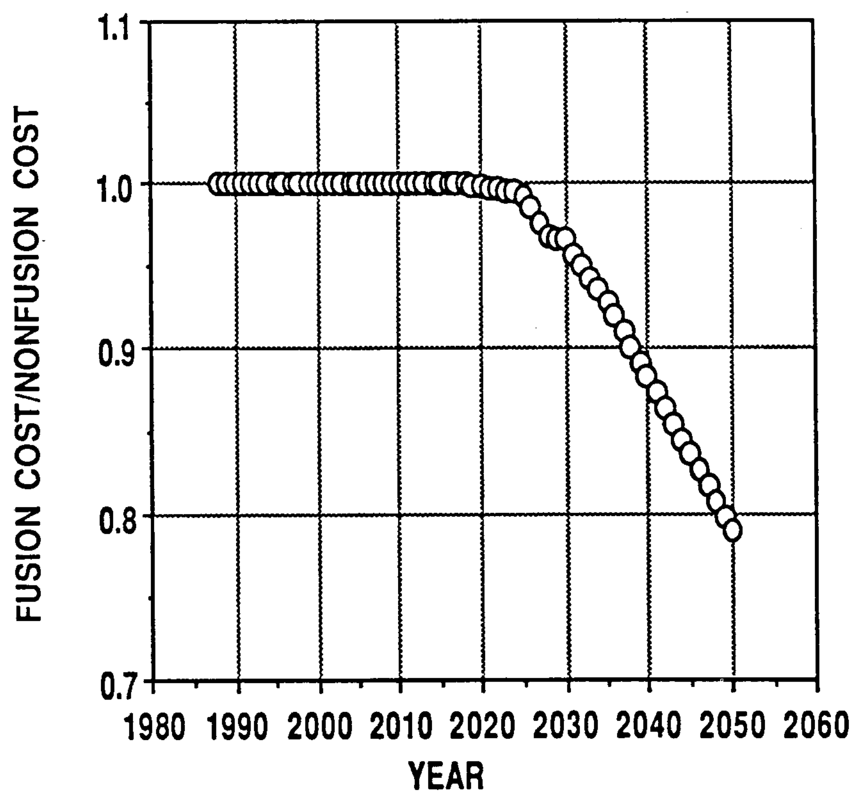


Effect of DHe3 Fusion on the Consumer Cost of Electricity

The previous two graphs are combined to calculate the effect of DHe3 on the costs which consumers pay for electricity.

The ratio of the cost per kWh from the fusion alternative to that from the nonfusion alternative is shown on the accompanying graph. The cost per kWh for the fusion case is slightly (1%) higher in the early years because of the added R&D for fusion and space. However, by the year 2020 the two costs are equal again and by 2025 the ratio starts to move rapidly in favor of the fusion case. By the year 2050 the composite cost of electricity has fallen to 80% of the nonfusion case.

RATIO OF ELECTRICITY COST, MILLS/kWh, FOR FUSION AND NONFUSION SCENARIOS



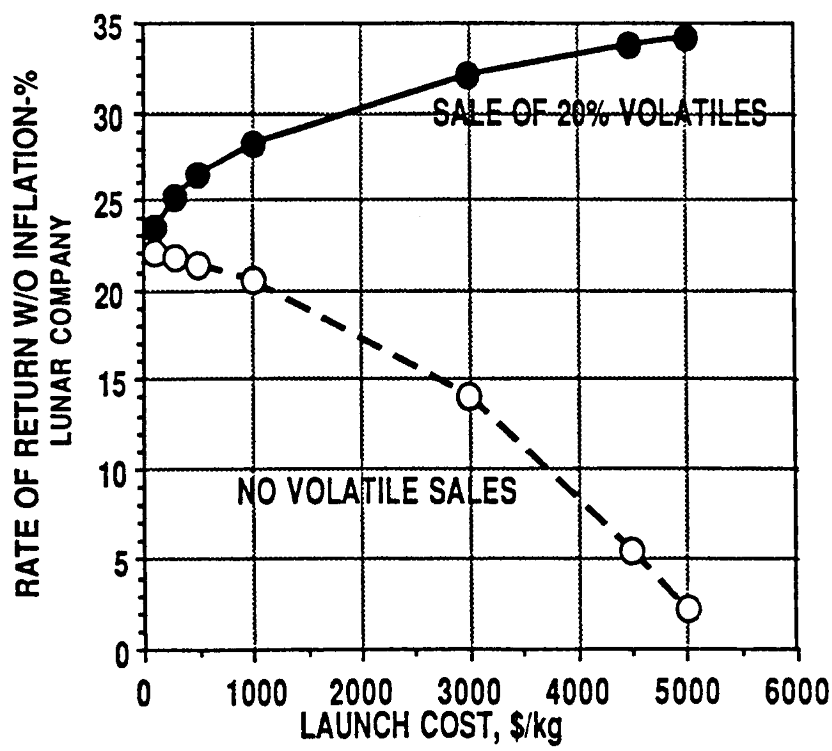
The Dependence of Helium-3 Profitability on the Cost of Launching Payloads to the Moon

One of the major costs for procuring Helium-3 is the cost of carrying the equipment and lunar base facilities to the Moon. This cost depends on both the amount of material needed from the Earth and the cost per kg of placing that mass on the Moon. Today it costs ≈$4000/kg to place material in low earth orbit (LOE). This number must be multiplied by 4 to 6 to place the same kg on the Moon, making current launch costs equal to ≈$15,000 to $25,000/kg. It is the stated goal of the U.S. Space Program to reduce the payload cost to LEO to ≈ $250/kg. This would imply that launch costs to the Moon might approach ≈$1000/kg of payload. We have chosen $1000/kg for our base case in this study but we have examined variations from $100 to $5000/kg.

A complicating feature of our present scenario is the treatment of the by-products from He3 mining such as water, hydrogen, nitrogen, etc. For this study we have assumed that 20% of the volatile by-products can be "sold", either to the scientific base, to a foreign country lunar base, to the Space Station, or to offset the cost of bringing these same volatiles to the Lunar Company base camp. The volatiles are assumed to be sold at 50% of the launch cost.

A wide variation in launch costs is shown in the lower graph which reveals that even if the launch costs were zero, the rate of return is no larger than ≈23% because of the R&D invested in Space Research. On the other hand, If the launch costs approach ≈$5000/kg, the Lunar Company becomes unprofitable if no credit is claimed for the excess water, hydrogen, nitrogen, etc. If the volatiles can be sold, then the higher the launch costs, the higher the profitability.

EFFECT OF LAUNCH COSTS ON THE PROFITABILITY OF DHe3 FUSION

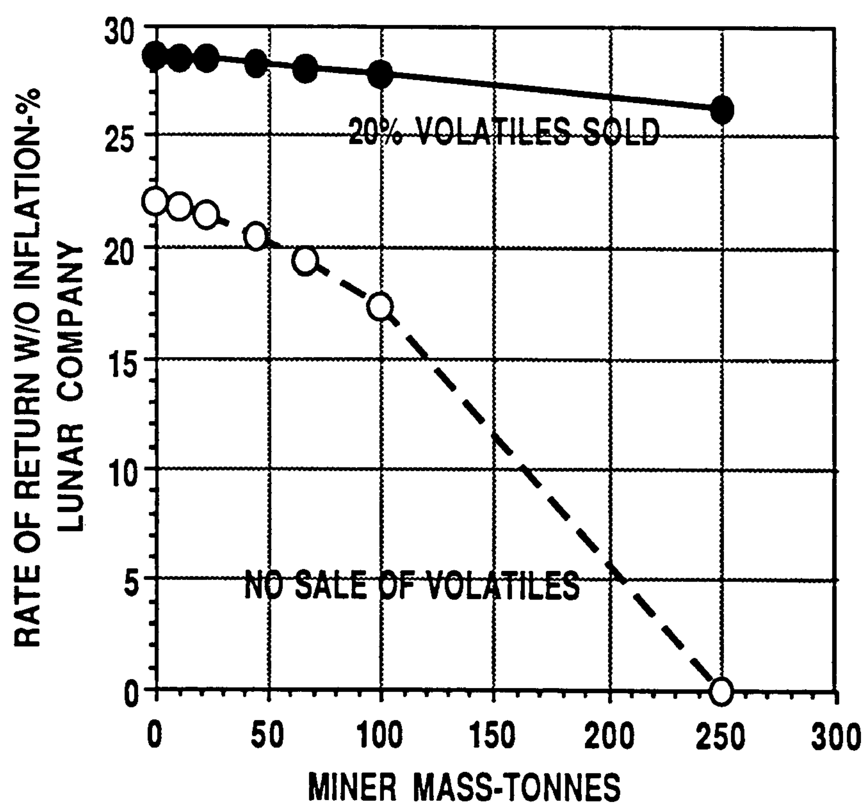


Effect of the Mass Launched to the Moon on the Profitability of DHe3 Fusion

Current designs for the mining of He3, its separation from other lunar volatiles, purification, and condensation show that the mass of one unit that will produce 33 kg of He3 per year is 43.6 tonnes. Furthermore, it is assumed that this equipment will last ≈ 20 years. Also required, along with the mining equipment, are the personnel, living habitat, and consumables for life support. This latter mass amount to 820 kg per person year. We have looked at a 50% variation on the base case launch mass of 43.6 tonne/unit, i.e., 66 and 22 tonnes per unit. The results are shown on the upper graph on the next page.

The results of rather large variations in the mass launched to the Moon show that there is only a small effect on the profitability of the Lunar Mining Company (≈ 1%) and essentially no effect on the overall profitability of the integrated Helium-3 system. In fact, it was found that the miner mass would have to be increased by more than a factor of 5 before the profitability would be threatened(see lower graph on the next page) for the case where no volatiles are sold. If some of the volatiles are sold, then the mining equipment mass can increase a factor of 10 over the base case without serious erosion of the profitability.

EFFECT OF MINER MASS ON PROFITABILITY OF DHe3 FUSION



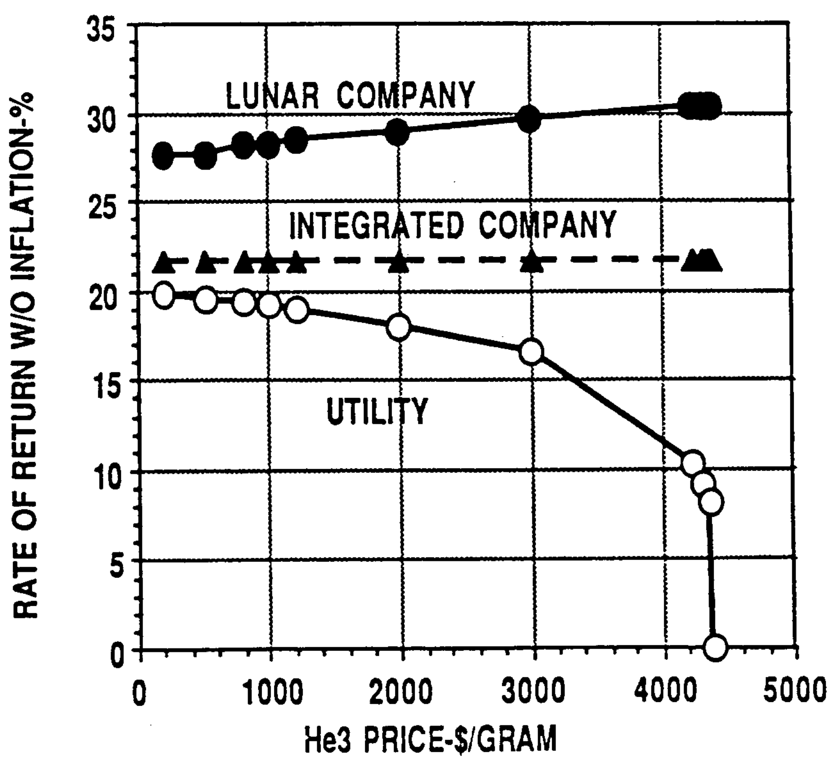
Effect of He3 Price on the Profitability of DHe3 Fusion

One of the most often asked questions in this analysis is "What is the allowable price of He3 to the Utility and the Lunar Mining Company?" Early analyses showed that He3 could cost as much as $1000-$2000/g and still allow DHe3 fusion to be economically competitive. As noted previously, we chose the base case value as $1000/g and tested the sensitivity to variations of plus or minus $200/g. It was found that $200/g variations resulted in less than 1% changes in the profitability of the Lunar Company and <1% in the profitability of the Utility Company. There was no change in the profitability of the Integrated Company since the price of He3 is merely an internal transfer with in the Integrated Company and does not effect the overall profitability

A wider variation in the Helium-3 price is included in the figure below. There are two important observations with respect to our strawman companies. On the low side, it appears that even at a He3 price of $500/gthere is an attractive (≈25%) return on investment in the Lunar Company. It is also shown that even if He-3 were free, the profitability of the Utility would not be more than 20 %.

On the high side, it was found that the He3 price needs to be below $4000/g to insure a 10% return on the Utility Company. At a price of $3000/g, the profitability of the Lunar Company will exceed 30%. The profitability of the Integrated Company is unaffected by the He3 price because it balances the profits of one company against the losses of another company.

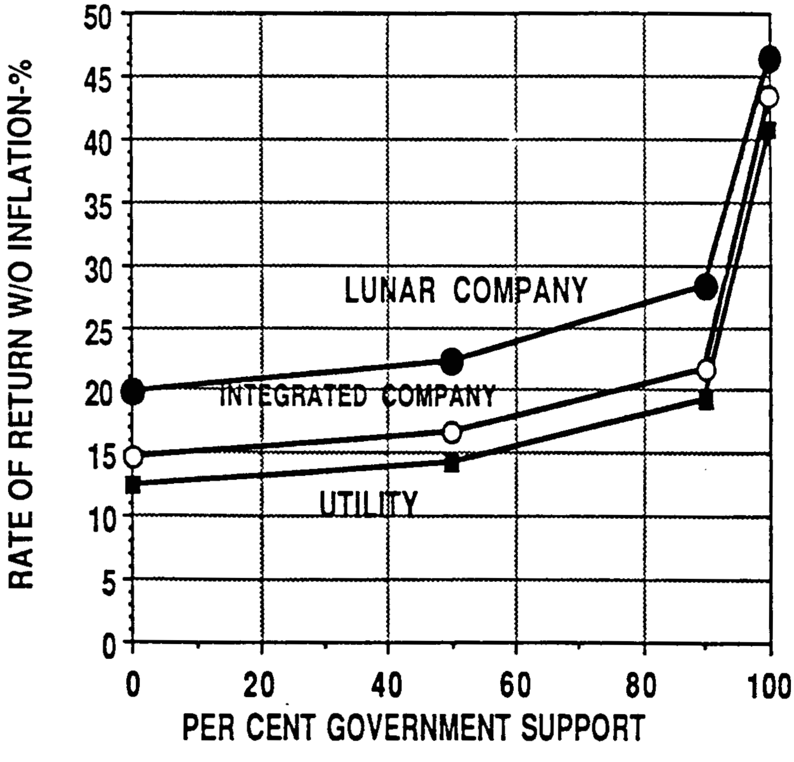
EFFECT OF HELIUM-3 PRICE ON THE PROFITABILITY OF DHe3 FUSION



Effect of Source of R&D Funding on the Profitability of DHe3 Fusion

The question of who provides the funds for needed coal, fission, fusion, and space R&D is important to the overall profitability of this analysis. The possibilities range from 100% governmental support to 100% private funding. This range is explored in the graph on the next page and it reveals that if all the R&D is funded by the government, the profitability soars to values of 40% or more. However,even if the R&D is supported solely by private industry, a very respectable rate of return of ≈15% is calculated. Perhaps a more likely case is for a 90-10 split between government and private industry. Under these circumstances, the profitability is in the 20-25% range.

EFFECT OF GOVERNMENT SUPPORT ON THE PROFITABILITY OF DHe3 FUSION



Conclusions

It is convenient to address the conclusions from this work with respect to each of the companies considered.

Utilities

- The Real Rate of Return (RRR) is quite attractive (i.e., >19%) for the base case even without escalation for inflation.
- For a given He3 price, the RRR is not very sensitive to ± 10 % variations in capital or non-fuel O&M costs for fission, fusion, or coal systems.
- The RRR is moderately sensitive to present fuel costs for coal and fission systems as well as to future escalation in those costs.
- The RRR is not as attractive for fusion if fission and/or coal capital costs are equal to or less than inflation.
- The RRR is quite sensitive to the level of government R&D support for fusion in the next 10-15 years.

Lunar Mining Company

- The Real Rate of Return (RRR) is extremely attractive (i.e.,>28%) for the base case even without escalation for inflation.
- If the volatile by-products are not considered as a revenue source, then the RRR is very sensitive to;

  Launch Costs (Should be < 3000 $/kg)
  Launch Mass (Should be < 150 tonnes /miner)
  He3 Selling Price (Should > 500$/g)

  The sale of even a small fraction of the volatiles (≈ 20%) removes the above restrictions and allows for a very profitable operation even at high launch costs, high miner masses, and low He3 prices.
- The RRR is sensitive to whether the Space R&D over the next 10-15 years is supported by the Federal Government or by Private Industry.

Integrated Energy Company (IEC)

- The Real Rate of Return (RRR) is quite attractive (i.e., > 21%) even without escalation for inflation.
- The RRR for the IEC is insensitive to the price and cost of He3 (at least within the scope of this study.
- The RRR is quit sensitive to the escalation in the capital costs and fuel prices of non-fusion energy sources.
- The RRR is quite sensitive to whether the space R&D is financed by the Federal government or by private sources.
- The revenue from the sale of even a small (≈20 %) amount of the lunar volatiles can be very beneficial to the profitability of the IEC