ORAU/IEA-80-8(M)
Research Memorandum

MASTER

COST COMPARISON OF ENERGY PROJECTS: DISCOUNTED CASH FLOW AND REVENUE REQUIREMENT METHODS

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May 1980

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Research memorandums document substantive work in progress and receive internal review.

This report is based on work performed under contract number DE-AC05-76OR00033 between the U.S. Department of Energy, Office of Policy and Evaluation, and Oak Ridge Associated Universities.

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ABSTRACT

Both the discounted cash flow (DCF) and the revenue requirement (RR) methods are frequently used in the cost analysis of energy projects. Each is uniquely needed in special circumstances, but in the early stages of most ventures, the RR method appears to be more useful. This paper provides simple formulations for the two methods and some special cases of interest to costing practices. Both formulations are applicable to either free or regulated enterprises and in constant or inflated dollars. It is stressed that the interpretation of cost results depends on the selection of cash-flow streams and/or the intent of revenue requirements. Several numerical examples are given.

INTRODUCTION

The economic comparison of dissimilar projects using seemingly dissimilar methods of comparison has always baffled engineers and managers. The following simplistic examples focus on the problems.

Table 1 shows the estimated investment, revenue, and cost streams of two projects: Project A lasts five years, while Project B lasts six years. Which project is economically more attractive?

Table 2 shows the possibilities for Projects C and D. These projects differ in almost all aspects: tax rates on profit, ad valorem charges, capitalization, useful life cycles, and operating costs. Which project is economically more attractive? And finally, how can one compare Projects A and B to Projects C and D?

Cost comparisons like these examples are met daily by planners. Particularly in energy-related projects, technologies are so numerous and diverse in characteristics that their comparison can be overwhelming. The practicing cost engineer will immediately recognize that a good way to compare Projects A and B is to calculate their internal rates of return. The project that has the higher rate (Project B) will be more attractive. The discounted cash flow (DCF) method has been used because all relevant cash-flow streams are given and there is no pattern in each stream.

A good way to compare Projects C and D is to calculate the minimum unit cost of production. The project that leads to a lower cost of each unit product (Project D) is more attractive. The revenue requirement (RR) method has been used in this case.

TABLE 1: EXAMPLE OF PROJECT COMPARISON USING THE DISCOUNTED CASH FLOW METHOD

Year i	Investment I_i (\$)	Operating Costs O_i (\$)	Income Tax T_i (\$)	Ad Valorem Charges Π_i (\$)	Gross Revenue R_i (\$)
Project A					
0	1,000,000	0	0	0	0
1	0	350,000	40,000	15,000	600,000
2	0	350,000	50,000	20,000	700,000
3	0	400,000	60,000	20,000	800,000
4	0	450,000	60,000	25,000	850,000
5	0	500,000	60,000	25,000	850,000
Project B					
0	1,500,000	0	0	0	0
1	0	500,000	60,000	40,000	900,000
2	0	550,000	80,000	40,000	1,000,000
3	0	550,000	80,000	45,000	1,110,000
4	0	600,000	90,000	45,000	1,200,000
5	0	650,000	90,000	50,000	1,300,000
6	0	750,000	80,000	50,000	1,300,000

TABLE 2: EXAMPLE OF PROJECT COMPARISON USING THE REVENUE REQUIREMENT METHOD

	Project C	Project D
Service life (years)	5	6
Annual production (MMBtu/yr)	300,000	500,000
Beginning of life investment ($)	1,000,000	1,500,000
Salvage value	none	none
Depreciation*	SYD over 5 years	SL over 6 years
Capitalization		
Bond fraction	0.5	0.6
Bond rate	10%	10%
Stock fraction	0.5	0.4
Stock rate	18%	20%
Effective income tax rate	0.50	0.48
Ad valorem tax rate	0.02	0.03
Operating cost estimated at beginning of life ($/yr)	300,000	500,000
Operating cost escalation rate (%/yr)	12	12

* SYD = sum-of-the-years'-digits schedule
SL = straight line schedule

It will be apparent from this paper that cross-comparisons of projects in the two groups are also possible. In these cases, several indices of merit could be used together with additional assumptions to render a comparison of "apples and oranges" marginally acceptable.[1-3]

OVERVIEW OF THE DCF AND RR METHODS

Both the discounted cash flow (DCF) and revenue requirement (RR) methods are based on two fundamental principles: (1) money has a time value--a dollar today being more valuable that a dollar many years from now--and (2) a venture is solvent when receipts and disbursements balance out--the balancing process being defined as the equality of the present worths of net cash inflows and net cash outflows. The difference between the methods is in the manner they are used or in the quantity they are supposed to compute.

The DCF method starts out with all known cash flows (such as in a completed project), then attempts to look for the discount rate r that allows the inflow and outflow streams to be equivalent. Such a resultant rate r is also called the DCF rate and is interpreted as the opportunity cost of capital invested in the venture. A direct comparison of such a rate with the owner's criteria and/or experience will help determine whether the project is financially desirable. In general, the alternative that yields a higher r is the more attractive of the two viable options.

The RR method starts out at the opposite end. It assumes the owner's exact expectation of return on his capital and then proceeds to compute the minimum revenue he must obtain by selling the products. This minimum revenue should be enough to cover all of the owner's operating costs, all taxes, his return requirement, and the recovery of his capital. The resultant minimum revenue can then be converted to the minimum (or "bare-bones") sale price of the product. A judgment can next be made to see whether the minimum price can survive the marketplace. Or, when two options are available, the alternative that leads to a lower "bare-bones" price of product is the financially more attractive alternative, assuming that all other factors such as time frame, quality, and quantity of the product are similar.

In recent years, the economic analysis of energy technologies has assumed an important role in both government and private circles.[1,2] Both the DCF and RR methods are frequently invoked, not only in their traditional roles as means to compare similar or compatible alternatives, but also in an absolute manner. In this new role, the methods would give misleading results unless the limitations input data are well understood.

In the sections below, formulations for the DCF and RR methods are provided in forms that are immediately applicable to comparing various projects. Special cases of these formulations are also discussed to point out subtleties of some basic elements, such as the (internal) rates of return in the DCF case and the pricing schedules in the RR case. Numerical examples are given to illustrate applications of the formulations. Some basic assumptions in these formulations are as follows:

1. In both the DCF and RR methods, the project is assumed isolated from the rest of the activities of the firm. It enjoys privileges such as fast tax write-offs and investment tax credit but otherwise has its own capitalization.
2. In the DCF formulation, the internal rate of return is the opportunity cost of money and can be solved either before-tax or after-tax.
3. For the RR formulation, salvage value is zero. Tax life can be different from service life. Tax depreciation charges are used to retire bonds and stocks at a fixed proportion. All cash flows are accounted at the end of the year. Charges for the use of money (whether equity or debt) are also paid at the end of each year.

THE DISCOUNTED CASH FLOW METHOD

Formulation

The DCF method is also called the internal rate-of-return method, the receipts-versus-disbursements method, the investor's rate-of-return method, and the profitability-index method.[4,5] "Cash flow"* is defined as the movement of money, either into the project (revenues) or out of the project (disbursements). The following cash flows are characteristic of a project. (Symbols used in this paper are listed in Table 3.)

Disbursements (cash outflows)

Beginning-of-project investment, I_o, and subsequent year investment, I_i (i = 1, M)

*In colloquial business terminology, "cash flow" is frequently understood as the net cash inflow (e.g., "Company X has cash flow problems").

Annual operating costs, including start-up cost, fuel, and operations and maintenance, O_i (i = 0, M)

Annual income tax, T_i (i = 1, M)

Annual ad valorem expenses, Π_i (i = 1, M)

Receipts (cash inflows)

Revenue as a result of product sale, R_i (i = 1, M)

End-of-life salvage value, assumed negligible here for simplicity (if not zero, it can be identified as $-I_M$)

The basic objective of the DCF method is to find a discount rate (DCF rate or internal rate of return) such that the present worth of all cash outflows is equal to the present worth of all cash inflows. In mathematical terms, this statement is equivalent to finding r in the following equality:

$$\sum_i \frac{R_i}{(1+r)^i} = \sum_i \frac{I_i}{(1+r)^i} + \sum_i \frac{O_i+\Pi_i}{(1+r)^i} + \sum_i \frac{T_i}{(1+r)^i} \tag{1}$$

(All summations over time are for i between 0 and M. Some cash flow data can be zero, e.g., $T_o = 0$.)

Example 1: By trial-and-error calculations, Project A of Table 1 is found to yield a DCF rate of return of 11.06%, while Project B is found to yield 14.94%. These are the after-tax rates of return on the investment. They can be compared with the weighted after-tax costs of money available to the firm. If the larger capital investment of Project B can be raised, this project is definitely more attractive because it not only yields a higher rate of return, but also yields that rate for a longer time.

TABLE 3: TERMINOLOGY

C = unit cost of product (or bare bones sale price)(dollars/units)

$\overline{C}$ = levelized unit cost of product

$\overline{C}_{BT}$ = levelized unit cost of product, using r_{BT} as discount rate

$\overline{C}_x$ = levelized unit cost of product, using x as discount rate

$\overline{C}_r$ = levelized unit cost of product, using r as discount rate

CRF(r,M) = capital recovery factor for rate r in M periods:

$$CRF(r,M) = \frac{r}{1-(1+r)^{-M}}$$

D = depreciation charge

D^B = book depreciation charge

D^T = tax depreciation charge

E = amount of energy (product) produced annually

$\overline{\phi}$ = levelized annual capital charge rate, or fixed-charge rate

I = capital investment

M = life cycle of the project (in years)

O = operating costs (fuel and operations and maintenance)

$PWRR_r$ = present worth of revenue requirement, using r as discount rate

$PWRR_x$ = present worth of revenue requirement, using x as discount rate

$PWRR_{BT}$ = present worth of revenue requirement, using r_{BT} as discount rate

Π = ad valorem charges

R = gross annual revenue (dollars)

R^K = annual revenue needed to cover capital-related costs

$\overline{R}$ = levelized gross annual revenue

TABLE 3: TERMINOLOGY (continued)

T	=	income taxes
V_i	=	unrecovered value of the investment in the beginning of year i (a return on which must be paid at the end of year i)
Z_I	=	present worth factor to be multiplied with beginning-of-life investment to obtain $PWRRI_x$
Z_{op}	=	operating cost factor to be multiplied with beginning-of-life estimated operating cost to obtain levelized annual operating costs
i	=	time index, using end-of-year convention except for book value when beginning of year is implied; thus, I_o is the original investment, and V_1 is the book value as of the beginning of year 1
d	=	depreciation rate (with proper subscript)
$\bar{d}$	=	levelized depreciation rate
f_b	=	fraction of capital that is debt (bond)
f_s	=	fraction of capital that is equity (stock); $f_s = 1 - f_b$
r	=	nominal after-tax rate of return on capital; this quantity is the resultant rate from the basic DCF formulation
r_{BT}	=	before-tax rate of return on capital; this quantity is used as the before-tax discount rate when the T stream is not included in the DCF formulation
r_{HM}	=	home mortgage cost of money
r_b	=	required rate of return on bond (interest rate of debt)
r_s	=	minimum required rate of return to stock (equity)
τ	=	effective income tax rate
u	=	inflation rate (u is for "up"); when used as subscript, it indicates that the quantity under consideration is in an inflationary environment
x	=	effective after-tax rate of return; this quantity is the basic discount rate for present worth calculations in the RR formulation
y	=	escalation rate; it could be the inflation rate, u; it could also be the cost of money, x

There are, however, several difficulties in the application of the DCF formulation. The first of these arises from the fact that the solution for r requires several trial-and-error computations. Sometimes a solution does not exist (when the unrecovered capital investment at a particular time is negative, meaning that there is no investment at that time). Sometimes several solutions are possible (when the net cash flow, $R_i-O_i-\Pi_i-T_i$, changes signs several times during the life of the project).

The second type of difficulty arises from the requirement that data on all of the cash-flow streams be in hand at the outset. This is only possible when the entire history of the project is known, such as for a venture already completed. When a project is only beginning or planned, it is rather pretentious to list precise values of I_i, O_i, Π_i, T_i for every year. Predicting the R_i stream is difficult enough.

The third difficulty with Equation 1 is the tax cash-flow stream T_i, which is not an independent stream. When R_i, I_i, O_i, and Π_i are known, the stream T_i is determined by

$$T_i = \tau(R_i - O_i - \Pi_i - D_i^T - r_b f_b V_i), \tag{2}$$

where D_i^T is the depreciation charge for tax purposes, V_i is the unrecovered investment at the beginning of year i, f_b is the fraction of debt in the investment, and r_b is the debt interest rate. D_i^T can be determined when the depreciation schedule is known (for example, straight-line schedule, sum-of-the-years'-digits schedule).

Substituting Equation 2 into Equation 1, one has an alternative expression for the DCF formulation:

$$\sum_i \frac{R_i}{(1+r)^i} = \frac{1}{1-\tau} \sum_i \frac{I_i}{(1+r)^i} + \sum_i \frac{O_i+\Pi_i}{(1+r)^i} - \frac{\tau}{1-\tau} \sum_i \frac{D_i^T+r_b f_b V_i}{(1+r)^i} \tag{3}$$

Equation 3 highlights the fact that, unless the project is already concluded, the tax stream T_i is dependent not only on R_i, O_i, and Π_i, but also on the depreciation schedule and the interest payment on the debt portion of the unrecovered capital V_i. The stream V_i can be simply determined when book and tax depreciation are the same and when $I_i = 0$ for $i \neq 0$; otherwise it is not readily available.

Special Cases

It is interesting to note some special cases of Equation 1.

1. Rate of Return on Equity (After-Tax)

Because the resultant DCF rate r in Equation 1 is the weighted after-tax rate of return on investment, it can be used to find the rate of return on the equity portion of that investment. If the investment consists of equity with a fraction f_s, and the rest is borrowed at an interest rate r_b, then the after-tax rate of return on that equity portion is r_s where

$$r_s = \frac{r - r_b\,(1-f_s)}{f_s} \, . \tag{4}$$

Example 2: In Example 1, if $f_s = 0.5$ and $r_b = 12\%$, the after-tax rate of return on equity is 10.12% and 17.88% for Project A and Project B, respectively. To the owner, Project B appears definitely more attractive than Project A.

2. Home Mortgage Loan

The home mortgage loan, an institution touching the life of most Americans, is based on a special case of the DCF formulation in Equation 1. There an amount I_o is borrowed at time $i = 0$, and a level payment of $\bar{R}$ is due at the end of each period up to M. If no operating and ad valorem costs are charged, then Equation 1 takes on the form

$$\sum_i^M \frac{\bar{R}}{(1+r_{HM})^i} = I_o$$

or

$$\bar{R} = I_o \text{ CRF } (r_{HM}, M), \tag{5}$$

where r_{HM} is the interest rate on the home mortgage loan, and CRF (r_{HM}, M) $= [r_{HM}]/[1-(1+r_{HM})^{-M}]$ is the capital recovery factor for interest r_{HM} over M periods.

Example 3: A $50,000 home mortgage is to be paid in 30 years (360 months) at an interest rate of 10% per year (0.8333% per month). The monthly payment is computed from Equation 5 to be $438.79.

3. Revenue for Investment and Income Tax Coverage

Equation 1 can also be written as

$$\sum_i \frac{R_i^K}{(1+r)^i} = \sum_i \frac{I_i}{(1+r)^i} + \sum_i \frac{T_i}{(1+r)^i} \tag{6a}$$

where R_i^K is defined as

$$R_i^K \equiv R_i - (O_i + \Pi_i). \tag{6b}$$

The resultant DCF rate in this case is still r and is the nominal (weighted) after-tax cost of money. In this case R_i^K is the revenue stream which pays for the investment and for income taxes related to that investment.

Example 4: R_i^K for Project A in Table 1 is \$235,000, \$330,000, \$380,000, \$375,000, and \$325,000 for i = 1, 2, 3, 4, and 5, respectively. For Project B, R_i^K is \$360,000, \$410,000, \$515,000, \$555,000, \$600,000, and \$500,000 for i = 1, 2, 3, 4, 5, and 6, respectively. Using these values in Equation 6 with I_i and T_i streams from Table 1, one still has r = 11.06% for Project A and r = 14.94% for Project B.

4. Before-Tax Rate of Return

Equation 6 can further be rewritten in two ways:

$$\sum_i \frac{R_i^K - T_i}{(1+r)^i} = \sum_i \frac{I_i}{(1+r)^i}\ , \tag{7}$$

or, substituting the before-tax rate of return for capital r_{BT} (clarified below),

$$\sum_i \frac{R_i^K}{(1+r_{BT})^i} = \sum_i \frac{I_i}{(1+r_{BT})^i}\ . \tag{8}$$

Equation 7 states that "the present worth of net revenues (after taxes and all operating expenses) is equivalent to the present worth of all investments, when the discount rate is r."

Since R_i^K is the revenue before tax payments, r_{BT} must be larger than or equal to r, and Equation 8 conveys the statement, "the present worth of revenues before-tax payments is equivalent to the present worth of all investments when the discount rate is r_{BT}." In this case, r_{BT} is the "before-tax" rate of return on investment.[7-10]

Example 5: Using R_i^K streams as determined in Example 4, the before-tax rate of return for Project A is 18.12% and for Project B is 21.45%.

THE REVENUE REQUIREMENT METHOD

Intent of the RR Method

The RR method is also called the "minimum revenue requirement method" because its purpose is to determine the minimum revenue that can cover all costs, including a minimum acceptable (or allowed) return on capital investment.[4] This method assumes that the cost of money is known (e.g., stock rate, stock fraction, bond rate, bond fraction, taxes) and that the revenue stream R_i and/or its present worth is to be determined. The knowledge of R_i for every year i will lead to the determination of the bare-bones sale price of the product if the quantity of production, E_i, is also known. These bare-bones sale prices are subsequently compared with the prices in the marketplace to see whether the venture is economically feasible. Therefore, if two similar projects are to be compared, the one that yields a lower bare-bones project sale price is the more attractive project.

Figure 1 illustrates the intent of the RR method. The minimum revenue requirement R_i in the year i should be enough to cover all costs, which include operating costs, ad valorem charges, recovery of capital (through depreciation charge), return on the outstanding capital tied up in the project, and income taxes. Using the symbols listed in Table 3,* this statement is expressed as

$$R_i = O_i + \Pi_i + D_i^B + rV_i + T_i \ , \qquad (9)$$

where r is the after-tax cost of capital (or allowed rate of return) determined by

$$r = r_b f_b + r_s(1-f_b). \qquad (10)$$

Formulation

The purpose of the RR formulation is to collapse Equation 9 into one value that can represent the attractiveness of the project. The present worth of revenue requirement (PWRR) is a convenient value obtained by computing the present value, for each year i, of the right-hand side of Equation 9 and then adding the results for all years. Any

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*Note that R_i and r are deliberately used to carry the same meaning as those quantities in the DCF formulation with the exception that R_i is here determined from r (and other quantities) while in Equation 1, r is determined from R_i (and other quantities).

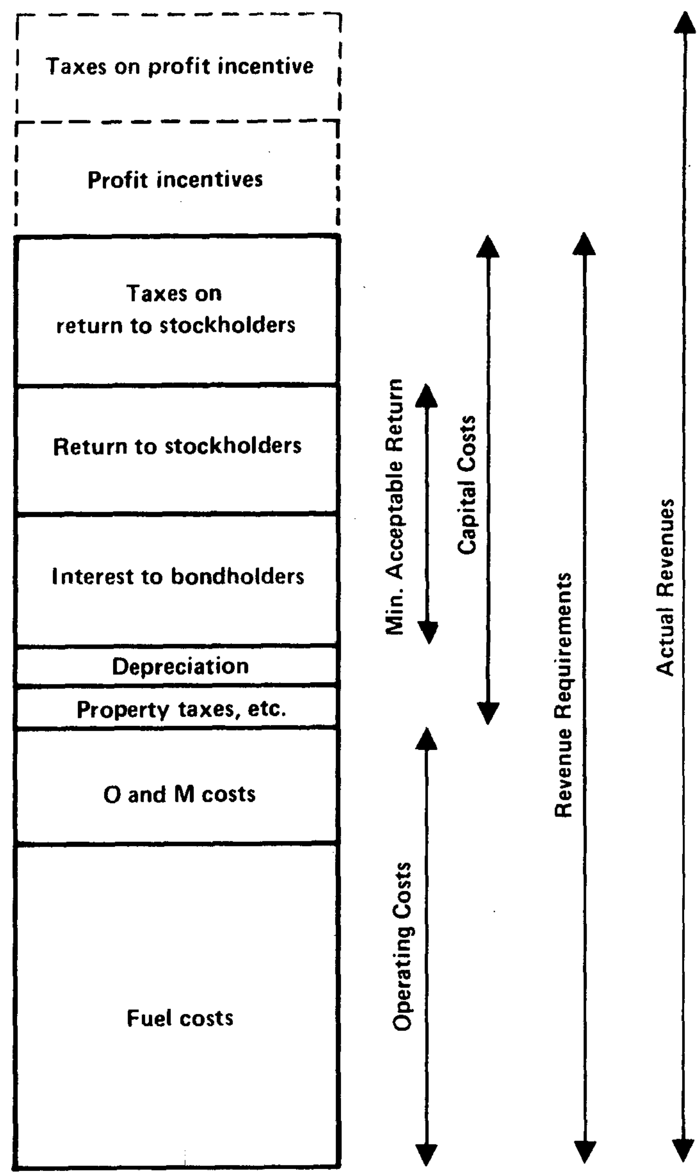

FIGURE 1: INTENT OF REVENUE REQUIREMENT METHOD

discount rate can be used in the present value calculations without disturbing the definitional nature of Equation 9, provided that the PWRR is qualified by that discount rate (e.g., $PWRR_r$, $PWRR_x$).

As a first choice, the after-tax cost of money r appears to be a good discount rate because it is known by virtue of Equation 10. One has, in this case,

$$PWRR_r = \sum_{i=0}^{M} \frac{R_i}{(1+r)^i} = \sum_{i}^{M} \frac{O_i + \Pi_i + D_i^B + rV_i + T_i}{(1+r)^i} . \tag{11}$$

In Equation 11 and hereafter, the summation over i is effected from i = 0 to i = M unless otherwise indicated. When i = 0, many quantities can be zero (e.g., $T_o = 0$, $\Pi_o = 0$, and $D_o = 0$).

Can one evaluate $PWRR_r$ readily? The answer is no, because the tax payment T_i and the book value V_i are functions of depreciation and of other quantities as well. These functions are

$$T_i = \tau(R_i - O_i - \Pi_i - D_i^T - r_b f_b V_i) \tag{12}$$

and

$$V_i = \sum_{j=0}^{i-1} (I_j - D_j^B). \tag{13}$$

Substituting Equations 12 and 13 into Equation 9 gives

$$(1-\tau)R_i = (1-\tau)(O_i+\Pi_i) + (r-\tau r_b f_b) \sum_{j=0}^{i-1} (I_j-D_j^B) + D_i^B - \tau D_i^T. \tag{14}$$

Let $x = r - \tau r_b f_b = (1-\tau)r_b f_b + r_s f_s$ and divide both sides of Equation 14 by $(1+x)^i$ and sum over i's:

$$\sum_i \frac{R_i}{(1+x)^i} = \sum_i \frac{O_i+\Pi_i}{(1+x)^i} + \frac{1}{1-\tau} \sum_i \frac{D_i^B-\tau D_i^T}{(1+x)^i} + \frac{1}{1-\tau} \sum_i \frac{x \sum_o^{i-1} (I_j-D_j^B)}{(1+x)^i} \tag{15}$$

A systematic evaluation of the double summation in Equation 15 has been provided in Reference 2. In this evaluation, the book depreciation term D_i^B disappears, and the result is

$$\sum_i \frac{R_i}{(1+x)^i} = \sum_i \frac{O_i+\Pi_i}{(1+x)^i} + \frac{1}{1-\tau} \sum_i \frac{I_i}{(1+x)^i} - \frac{\tau}{1-\tau} \sum_i \frac{D_i^T}{(1+x)^i} \tag{16}$$

where

$$x = (1-\tau)\, r_b f_b + r_s f_s = r - \tau r_b f_b . \tag{17}$$

When i = 0, some quantities, namely T_i, Π_i, and D_i are zero.

Equation 16 is an interesting result because it can be readily evaluated on the basis of the following quantities, which are normally known at the start of the project:

- Operating costs, O_i, which must be carefully studied when two projects of different technologies are compared.

  Ad valorem taxes, Π_i, which are normally assumed to be a rate π (about 1 to 5%) multiplied by the beginning-of-life investment (I_o).

- Capital investments, I_i, which usually consist of an original investment I_o and possibly some "deferred" investments. For capital intensive energy projects, deferred investments are usually very small compared to I_o.
- Tax depreciation, D_i^T, which can be readily determined if a tax schedule is chosen (e.g., straight-line or sum-of-years'-digits). Usually depreciation is also specified by a levelized depreciation rate, $\overline{d}$, multiplied by the original investment I_o.
- Effective income-tax rate τ. When there is a state or local income tax (of rate τ_L) in addition to the federal tax (of rate τ_F), the effective tax rate is

$$\tau = \tau_L + (1-\tau_L)\tau_F. \qquad (18)$$

- Required rates of return: on bond (debt), r_b; on stock (equity), r_s.
- Bond fraction, f_b, and stock fraction, f_s.

The well-defined discount rate x in Equations 16 and 17 can be called the effective after-tax cost of money. It is "effective" because, although the project must pay out rate r for the use of capital, the $\tau r_b f_b$ portion of it can be deducted from income tax. Controversy over its use has recently been put to rest by rigorous proofs by various authors.[3,11-13]

Example 6: In Table 1, Project C has the (nominal) weighted after-tax cost of money r = (0.5)(10%) + (0.5)(18%) = 14% and the effective after-tax cost of money x = (0.5)(0.5)(10%) + (0.5)(18%) = 11.5%. Project D has r = (0.6)(10%) + (0.5)(20%) = 14% and x = (0.52)(0.6)(10%) + (0.4)(2%) = 11.12%.

Special Cases

Similar to the DCF formulation, there are special cases of the RR formulation that are frequently encountered.

1. Present Worth of Revenues Required to Cover Costs Associated with Capital

Equation 16 has two components: revenues to cover operating costs (fuel and operations and maintenance), and revenues to cover costs associated with capital. It can be written as follows:

$$PWRR_x = PWRRO_x + PWRRI_x ,$$

where

$$PWRRO_x = \sum_i \frac{O_i}{(1+x)^i} \tag{19}$$

and

$$PWRRI_x = \frac{1}{1-\tau} \sum_i \frac{I_i}{(1+x)^i} - \frac{\tau}{1-\tau} \sum_i \frac{D_i^T}{(1+x)^i} + \sum_i \frac{\Pi_i}{(1+x)^i} . \tag{20}$$

Let I_o be the beginning-of-life investment, $I_i << I_o$ for $i > 0$, $D_i = \bar{d}I_o$, and $\Pi_i = \pi I_o$ for all i's, then Equation 20 becomes

$$PWRRI_x = I_o Z_I, \quad (21a)$$

where Z_I is defined as

$$Z_I = \frac{1}{1-\tau} - \frac{\tau}{1-\tau} \frac{\overline{d}}{CRF(x,M)} + \frac{\pi}{CRF(x,M)}, \quad (21b)$$

and where CRF(x,M) is the capital recovery factor of rate x over M periods

$$CRF(x,M) = \frac{x}{1-(1+x)^{-M}} \quad (21c)$$

In Equation 21, Z_I is the present worth factor which, when multiplied by I_o, gives the present worth of revenues required to cover all costs associated with capital. These costs include returns on the use of capital, recovery of capital, income taxes, and ad valorem charges.

Table 4 shows some typical values for Z_I, which may cover most energy projects of practical interest. These projects have life spans of 10 to 30 years; they have effective after-tax cost of money between 8 percent and 14 percent per year, levelized depreciation rates between 5 percent and 11 percent per year, ad valorem charge rates around 2 percent per year, and income tax rates around 50 percent.

2. <u>Levelized Annual Capital Charge Rate</u>

Equation 21a can further be written

TABLE 4: TYPICAL VALUES

Levelized Fixed Charge Rate ($\overline{\phi}$) and Present Worth of Revenue Requirements to Cover Capital (Z_I)

Effective After-Tax Discount Rate (x)	Levelized Annual Fixed Charge ($\overline{\phi}$) 10-year	20-year	30-year	Present Worth of RR Related to Capital (Z_I) 10-year	20-year	30-year
8%/year	0.207	0.162	0.153	1.39	1.59	1.72
10%/year	0.231	0.191	0.185	1.42	1.62	1.75
12%/year	0.257	0.221	0.219	1.45	1.65	1.77
14%/year	0.284	0.253	0.255	1.48	1.68	1.79

In this table, τ is assumed to be 0.5; $\pi = 0.02$; and $\overline{d}$ is taken from Table 5 using a sum-of-the-years'-digits (SYD) schedule.

$$PWRRI_x = \Sigma \frac{I_o \overline{\phi}}{(1+x)^i} = \frac{I_o \overline{\phi}}{CRF(x,M)} \qquad (22a)$$

where

$$\overline{\phi} = \frac{CRF(x,M)}{1-\tau} - \frac{\tau}{1-\tau} \overline{d} + \pi \qquad (22b)$$

The term $\overline{\phi}$ is often used in the utility industry and is called the levelized annual capital charge rate or simply fixed charge rate. It is the fixed rate to be multiplied by the beginning-of-life investment to obtain the level annual revenue required to cover all costs associated with capital. Note that Equations 21 and 22 assumed that all investments after the beginning of life are negligible.

Some typical values for $\overline{\phi}$ are also shown in Table 4. It is noted that the higher x is, the higher $\overline{\phi}$ and Z_I are. For an income tax rate τ around 50 percent, Z_I is smaller than 2, even though $\overline{\phi}$ may be as high as 30 percent per year (for porjects with short life cycles).

3. Levelized Depreciation Charge Rate

The computation of Equations 19, 21, and 22 is simple only if D_i^T is known. The U.S. Internal Revenue Service allows companies to select one of several depreciation schedules. The knowledge of the allowed depreciation rate d_i, in the year i, will allow the computation of D_i^T in the case with only one beginning-of-life investment:

$$D_i^T = d_i \, I_o \qquad (23)$$

When the effective after-tax cost of money x is known, the levelized depreciation rate $\overline{d}$ is defined as follows:

$$\overline{d} = CRF(x,M) \sum_i \frac{d_i}{(1+x)} \qquad (24)$$

The expressions for $\overline{d}$ for three depreciation schedules are given below.[14]

Straight-line (SL) depreciation over M years:

$$\overline{d}_{SL} = \frac{1}{M} \qquad (25)$$

Sum-of-the-years'-digits (SYD) depreciation over M years:

$$\overline{d}_{SYD} = \frac{2[M \cdot CRF(x,M) - 1]}{M(M+1)\ x} \qquad (26)$$

Sinking fund (SF) depreciation over M years:

$$\overline{d}_{SF} = M\ c_{SF}^2\ (1+x)^{M-1}\ , \qquad (27)$$

where c_{SF} is the sinking fund factor determined by

$$c_{SF} = \frac{x}{(1+x)^M - 1}\ .$$

Table 5 lists some typical values of $\overline{d}$ for these three schedules.

TABLE 5: SOME TYPICAL VALUES FOR LEVELIZED DEPRECIATION RATES

Effective After-Tax Rate and Service Life	$\bar{d}_{SL}$	$\bar{d}_{SYD}$	$\bar{d}_{SF}$
x = 8%			
M = 10 year	0.1000	0.1114	0.0953
M = 20 years	0.0500	0.0617	0.0412
M = 30 years	0.0333	0.0448	0.0218
x = 10%			
M = 10 years	0.1000	0.1141	0.0928
M = 20 years	0.0500	0.0642	0.0373
M = 30 years	0.0333	0.0469	0.0176
x = 12%			
M = 10 years	0.1000	0.1166	0.0900
M = 20 years	0.0500	0.0666	0.0332
M = 30 years	0.0333	0.0488	0.0138
x = 14%			
M = 10 years	0.1000	0.1191	0.0870
M = 20 years	0.0500	0.0687	0.0291
M = 30 years	0.0333	0.0504	0.0105

4. Present Worth and Levelized Value of Operating Costs

When the annual operating cost is estimated at time zero to be O_o (but not incurred at that time) and is further thought to escalate every year with a rate y, then Equation 26 becomes

$$PWRRO_x = \sum_i \frac{O_o(1+y)^i}{(1+x)^i} = \frac{O_o}{CRF(\gamma,M)} , \tag{28}$$

$$\gamma \equiv \frac{x-y}{1+y} \tag{29}$$

The levelized value of annual operating costs is defined as the level value to be charged every year and results in the same $PWRRO_x$; thus,

$$\sum_i \frac{\bar{O}}{(1+x)^i} = PWRRO_x \tag{30}$$

or, combining Equations 29 and 30,

$$\bar{O} = O_o \frac{CRF(x,M)}{CRF(\gamma,M)} = Z_{op} O_o \tag{31}$$

Equation 31 indicates that the levelized value of annual operating cost is the cost estimated at the start of operation multiplied by a factor $Z_{op} = CRF(x,M)/CRF(\gamma,M)$. We observe the following cases:

When $y = 0$ (no escalation), $Z_{op} = 1$, $\bar{O} = O_o$.

When $y < 0$ (operating costs decrease every year), $Z_{op} < 1$, $\bar{O} < O_o$.

When $y > 0$ (there is an escalation every year), $Z_{op} > 1$, $\bar{O} > O_o$.

Example 7: The above developments for the RR methodology allow the comparison of Projects C and D in Table 1.

Project C

Example 6 gives x = 11.5%; CRF (11.5%, 5) = 0.27398.
Equation 26 gives $\bar{d}_{SYD} = 0.21444$.
Equation 22 gives $\bar{\phi} = 0.35352$.
Equation 21 gives $Z_I = 1.29$.
Equation 29 gives $\gamma = -0.446\%$ and $CRF(\gamma,M) = 0.19733$.
Equation 31 gives $Z_{op} = 1.3884$ and $\bar{O}$ = \$416,531.91.
The level annual revenue requirement is $\bar{\phi}I_o + \bar{O}$ = \$770,051.91.
The level bare-bones product price is $(\bar{\phi}I_o + \bar{O})/\bar{E}$ = \$2.567/MMBtu.

Project D

Example 6 gives x = 11.12%; CRF (11.27%, 6) = 0.23774.
Equation 25 gives $\bar{d}_{SL} = 0.16667$.
Equation 22 gives $\bar{\phi} = 0.33335$.
Equation 21 gives $Z_I = 1.40$.
Equation 29 gives $\gamma = 1.018\%$, $CRF(\gamma,M) = 0.17266$.
Equation 31 gives $Z_{op} = 1.377$ and $\bar{O}$ = 688,478.18.
The level annual revenue requirement is $\bar{\phi}I + \bar{O}$ = \$1,188,503.18.
The bare-bones product price is $(\bar{\phi}I + \bar{O})/\bar{E}$ = \$2.377/MMBtu.

Project D is slightly more attractive than Project C. Note, however, that the service life of D is six years and that of C is five years. Should the result be \$2.377/MMBtu for Project C and \$2.567/MMBtu for Project D, the conclusion is not so obvious because of the difference in the levelization period. A projection of price to a base year, to be discussed in Example 10, will allow a better comparison.

RELATIONSHIP BETWEEN THE DCF AND RR FORMULATIONS

At this point, one should reiterate that the DCF method is applied to a complete set of cash-flow streams in order to compute a discount rate that allows the appropriate cash-flow streams to balance out. Depending on the streams selected, the resultant discount rate is interpreted as the before-tax or the after-tax internal rate of return on the investment.

The RR method, on the other hand, is applied at the planning stage of a project during which only some technical and economic conditions, but not complete cash-flow streams, are known. It includes the cost of capital and the recovery of capital as revenue requirements and computes the bare-bones sale price of the product. For most energy projects, because not all relevant cash-flow streams are known with confidence over the 20- to 40-year life cycles, the RR method should be used to determine their attractiveness.

It is then obvious that the DCF and the RR methods apply in two different circumstances. There should be no confusion as to which method should be applied when the data on projects to be compared are known. Such simplistic statements, however, have very little meaning in practice. Today there are thousands of companies favoring the DCF method and thousands of others favoring the RR method.[6,17,19] The results of their evaluation of a given energy technology seldom agree, mostly because of different assumptions and different interpretations of basic cost parameters. An example of this divergence can be seen by comparing the American Gas Association and the Bureau of Mines methods for assessing the cost of synthetic fuel.[19,20]

In order to reconcile the results of different methods, they must be consistent and convertible from one to the other, both algebraically and numerically.

Algebraically, let us assume that the project has the revenue stream R_i, investment stream I_i, operating stream O_i, ad valorem charge stream Π_i, and depreciation stream D_i^T. All of these streams are intricately related to the capitalization of the project (tax rate τ, bond rate r_b, bond fraction f_b, stock rate r_s, stock fraction $1-f_b$). The DCF method requires that the nominal (weighted) after-tax internal rate of return r be found such that

$$\sum_i \frac{R_i}{(1+r)^i} = \sum_i \frac{I_i}{(1+r)^i} + \sum_i \frac{O_i+\Pi_i}{(1+r)^i} + \sum_i \frac{T_i}{(1+r)^i} \quad , \qquad (1)$$

and when r is found, it is also related to r_b, r_s, f_b, and f_s by the relationship

$$r = r_b f_b + r_s f_s \ . \qquad (4)$$

The RR method requires that a bare-bones levelized price of product, $\overline{C}$, be found such that

$$\frac{\bar{C}\,E}{CRF(x,M)} = \sum_i \frac{R_i}{(1+x)^i} = \frac{1}{1-\tau}\sum_i \frac{I_i}{(1+x)^i} + \sum_i \frac{O_i+\Pi_i}{(1+x)^i} - \frac{\tau}{1-\tau}\sum_i \frac{D_i^T}{(1+x)^i}, \quad (16)$$

where

$$x = (1-\tau)\ r_b f_b + r_s f_s$$

and

$$R_i = O_i + \Pi_i + D_i^B + rV_i + T_i\ . \quad (17)$$

The equivalence and consistency between the two methods is established when one can show that Equation 1 leads to Equation 17 for the <u>same project</u>. Vice versa, one can also show that the R_i stream as determined from Equation 9 would satisfy Equation 16 and also Equation 1. The algebra of the former proof is provided in Reference 12 where Equation 1 is first transformed to Equation 3, then the values of V_i in Equation 3 is determined on the basis of I_i and D_i.

The proof of the reverse problem can be highlighted by the following example.

<u>Example 8</u>: In 1980, an energy venture needs a million dollars (1980 dollars) of investment and is expected to produce 250,000 MMBtu annually. After five years, the venture closes down with no salvage value. Other estimated conditions are as follows:

	In Constant 1980 Dollars	With 5% Inflation
Investment tax credit	None	None
Effective income tax rate (%)	50	50
Debt fraction (f_b)	0.5	0.5
Debt interest rate (r_b)	3%/year	8.15%/year
Equity return requirement (r_s)	8%/year	13.4%/year
Depreciation schedule	straight-line	straight-line
Operating and ad valorem charge ($/yr)	330,000 (i=1, 5)	$330{,}000\ (1.05)^i$ (i=1, 5)

Table 6 shows the streams D_i, V_i, T_i, $O_i + \Pi_i$, and R_i as determined by the RR formulation. Both the constant 1980 dollar case and the inflationary case are considered. Table 7 shows that the relevant cash flow streams R_i, I_i, $O_i + \Pi_i$, and T_i as determined in Table 6 do satisfy the DCF Equation 1. It has further been shown in Reference 15 that the DCF Equation 8 (which uses r_{BT} as discount rate) and the RR Equation 16 (which uses x as discount rate) are also satisfied when appropriate cash-flow streams are used.

CONSTANT-DOLLAR AND INFLATED DOLLAR APPLICATIONS

There is nothing in the formulations of Equation 1 and Equation 16 that specifies the use of constant dollars or inflated dollars. The formulations imply, however, two important points:

1. When constant dollars are used, all quantities must be in constant dollars. Specifically, the resultant DCF rate r in Equation 1 and the input x in Equation 16 must be rates compatible with the condition that no inflation is expected. These rates are about

TABLE 6: YEAR-BY-YEAR DETERMINATION OF CASH FLOWS BASED ON THE REVENUE REQUIREMENT CONDITION

Table 6a: Constant-Dollar Case

Year	I_i	D_i	V_i	$r_b f_b V_i$	$r_s f_s V_i$	T_i	$D_i + rV_i + T_i$	$O_i + \Pi_i$	R_i	C_i
0	1,000,000	0	0	0	0	0	0	0	0	--
1	0	200,000	1,000,000	15,000	40,000	40,000	295,000	330,000	625,000	2.500
2	0	200,000	800,000	12,000	32,000	32,000	276,000	330,000	606,000	2.424
3	0	200,000	600,000	9,000	24,000	24,000	257,000	330,000	587,000	2.348
4	0	200,000	400,000	6,000	16,000	16,000	238,000	330,000	568,000	2.272
5	0	200,000	200,000	3,000	8,000	8,000	219,000	330,000	549,000	2.196

Table 6b: Inflated-Dollar Case

Year	I_i	D_i	V_i	$r_b f_b V_i$	$r_s f_s V_i$	T_i	$D_i + rV_i + T_i$	$O_i + \Pi_i$	R_i	C_i
0	1,000,000	0	0	0	0	0	0	0	0	--
1	0	200,000	1,000,000	40,750	67,000	67,000	374,750	346,500	721,250	2.885
2	0	200,000	800,000	32,600	53,600	53,600	339,600	363,825	703,625	2.814
3	0	200,000	600,000	24,450	40,200	40,200	304,850	382,016	686,866	2.747
4	0	200,000	400,000	16,300	26,800	26,800	269,900	401,117	671,017	2.684
5	0	200,000	200,000	8,150	13,400	13,400	234,950	421,173	656,123	2.624

3 percent to 4 percent for debt and 8 percent to 12 percent for equity. Similarly, when inflated dollars are used, all quantities must reflect inflation. A good way of inspecting the consistency of data is to look at some cash-flow streams. For example, the O_i stream in Table 1 obviously shows some effects of inflation whereas the D_i and the $O_i + \Pi_i$ streams in Table 7a do not.

2. The present worth of cash-flow streams is measured in the dollar of the year 0 (the "present").

It is important to examine the relationship between constant-dollar and inflated-dollar analyses of the same project. Let all quantities have a subscript c when they are measured in constant dollars and a subscript u (for "up") when they are measured in inflated dollars, then Equations 1 and 16 can be written as follows:

<u>DCF Formulation</u>

Constant dollars

$$PWRR_{r_c} = \frac{\bar{C}_{r_c} E}{CRF(r_c, M)} = \sum_i \frac{R_{ci}}{(1+r_c)^i} = \sum_i \frac{I_{ci}}{(1+r_c)^i} + \sum_i \frac{O_{ci}+\Pi_{ci}}{(1+r_c)^i} + \sum_i \frac{T_{ci}}{(1+r_c)^i} \quad (32a)$$

Inflated dollars

$$PWRR_{r_u} = \frac{\bar{C}_{r_u} E}{CRF(r_u, M)} = \sum_i \frac{R_{ui}}{(1+r_u)^i} = \sum_i \frac{I_{ui}}{(1+r_u)^i} + \sum_i \frac{O_{ui}+\Pi_{ui}}{(1+r_u)^i} + \sum_i \frac{T_{ui}}{(1+r_u)^i} \quad (32b)$$

TABLE 7: DEMONSTRATION THAT THE APPROPRIATE RR-DETERMINED CASH FLOWS SATISFY THE DCF CONDITION,

$$r = r_b f_b + r_s f_s$$

Table 7a: Constant-Dollar Case, r = 5.5%

Year	Cash Inflow R_i	Cash Outflow Including Tax I_i	$O_i + \Pi_i$	T_i
0	0	1,000,000	0	0
1	625,000	0	330,000	40,000
2	606,000	0	330,000	32,000
3	587,000	0	330,000	24,000
4	568,000	0	330,000	16,000
5	549,000	0	330,000	8,000
Present Worth at r = 5.5%	2,515,334.32 =	1,000,000 +	1,409,193.88 +	106,140.44

Table 7b: Inflated-Dollar Case, r = 10.775%

Year	Cash Inflow R_i	Cash Outflow Including Tax I_i	$O_i + \Pi_i$	T_i
0	0	1,000,000	0	0
1	721,250	0	346,500	67,000
2	703,425	0	363,825	53,500
3	686,866	0	382,016	40,200
4	671,017	0	401,117	26,800
5	656,123	0	421,173	13,400
Present Worth at r = 10.775%	2,568,598.11 =	1,000,000 +	1,409,193.88 +	159,485.90

(within 0.003%)

RR Formulation

Constant dollars

$$PWRR_{x_c} = \frac{\bar{C}_{x_c} E}{CRF(x_c,M)} = \sum_i \frac{R_{ci}}{(1+x_c)^i} = \sum_i \frac{O_{ci}+\Pi_{ci}}{(1+x_c)^i} + \frac{1}{1-\tau} \sum_i \frac{I_{ci}}{(1+x_c)^i} - \frac{\tau}{1-\tau} \sum_i \frac{D^T_{ci}}{(1+x_c)^i} \quad (33a)$$

Inflated dollars

$$PWRR_{x_u} = \frac{\bar{C}_{x_u} E}{CRF(x_u,M)} = \sum_i \frac{R_{ui}}{(1+x_u)^i} = \sum_i \frac{O_{ui}+\Pi_{ui}}{(1+x_u)^i} + \frac{1}{1-\tau} \sum_i \frac{I_{ui}}{(1+x_u)^i} - \frac{\tau}{1-\tau} \sum_i \frac{D^T_{ui}}{(1+x_u)^i} \quad (33b)$$

In the ideal situation when inflation is assumed to be known exactly over the entire project cycle, cash flows and costs of money track inflation simply by the following relations:

$$I_{ui} = I_{ci}\ (1+u)^i \quad (34a)$$

$$O_{ui} = O_{ci}\ (1+u)^i \quad (34b)$$

$$\Pi_{ui} = \Pi_{ci}\ (1+u)^i \quad (34c)$$

$$T_{ui} = T_{ci}\ (1+u)^i \quad (34d)$$

$$R_{ui} = R_{ci}\ (1+u)^i \quad (34e)$$

$$1+r_u = (1+r_c)(1+u) \quad (34f)$$

Thus, in the ideal case when Equation 34 holds, $PWRR_{r_c}$ and $PWRR_{r_u}$ in Equation 32 are identical. This result satisfies common sense because the present worth of the project must be the same quantity no matter what mode of analysis is used. In this case, the relationship between the unit costs $\overline{C}_{r_c}$ and $\overline{C}_{r_u}$ is

$$\overline{C}_{r_u} = \overline{C}_{r_c} \frac{CRF(r_u,M)}{CRF(r_c,M)} \quad . \tag{35}$$

It has also been shown numerically that $\overline{C}_{r_c}$ should be the same as $\overline{C}_{x_c}$, while $\overline{C}_{r_u}$ should be the same as $\overline{C}_{x_u}$.[12,15,16] In other words, in constant dollars, the levelized unit cost of products must be the same whether the DCF or RR methods are used. Similarly, in inflated dollars, the levelized unit cost of products is the same irrespective of the method of analysis. In addition, the inflated levelized unit cost is related to the constant-dollars levelized unit cost by Equation 35.

In reality, however, one is faced with nonlinear interactions between inflation and cash streams as well as costs of money. Furthermore, depreciation has not been allowed by the Internal Revenue Service to track inflation in order to provide funds for equipment replacement. These factors are under current debate in various forums and are not within the scope of this paper.[6,21,22]

REGULATED AND FREE ENTERPRISES

Just as in the discussion of the effect of inflation, no distinction was made between free enterprises and regulated industries in the formulation of Equation 1 and Equation 16.

A free enterprise has the aim of furthering the interests of its owner, and profit is commonly the foremost of his interests. It is "free" because it is operated at his will and risk. Although the proliferation of regulations has more and more reduced the degrees of freedom under which a private industry must operate, several options still remain open to it. For example, there is as yet no law placing a ceiling on profits, or dictating which among several operational paths must be taken, or restricting the appointment or election of corporate officers or directors.

In order to survive and to turn a profit in the competitive marketplace, a free enterprise must study the marketplace well, minimize costs, and make wise commitments. In the context of this paper, a free enterprise would study the market behavior of the R_i and O_i streams and would not commit itself to a project with low r's and long M's.

On the other hand, a regulated enterprise is created with the aim of serving the public. It is often accorded a monopoly privilege and a guaranteed profit on the investment. In order to control excesses, the law also establishes a ceiling on the profits of the firm as well as the requirement that the firm provide adequate service to the public. In the context of this paper, the regulated firm knows reasonably well its cost of money r, its planning horizon M, and can afford to place lesser importance on the ability to predict the operating cost stream O_i as well as the revenue stream R_i.

With the above distinction, it is clear that both the DCF and the RR methods can be usefully employed to compare alternatives for both free enterprises and regulated firms.

Example 9: Example 2 shows that the after-tax rate of return on equity is 10.12% for Project A and 17.88% for Project B (Table 1). A free enterprise would not undertake Project A but would have a look at other factors involving Project B. A regulated industry, whose cost of money is at about 10% for debt and 15% for equity, would realize that Project A may be acceptable, but Project B would provide more room for contingencies (such as sudden increases in the cost of equipment).

Example 10: A synfuel plant producing some 50,000 barrels per day cost \$1.0 billion in 1980. The plant would operate 330 days per year for 20 years. Fuel and operation and maintenance (O&M) costs are estimated at \$8 per barrel in 1979 and escalate at 10% per year. Determine the levelized production cost per barrel for (Option a) a free enterprise with 100% equity which requires a hurdle rate of 15%, and (Option b) for a regulated enterprise with a 50% loan guaranteed at 9% per year and 50% equity at 15% per year minimum required rate of return. Use $\tau = 0.5$, $\pi = 0.02$, and the SYD depreciation schedule. Assuming that the market cost of imported oil is \$20 per barrel and increases at 10% per year, determine the attractiveness of such a synfuel program.

First, it is observed that the analysis in this example is carried out in an inflationary environment.

Option a

Equation 17 gives $x = r = 15\%/\text{year}$.

Equation 21(c) gives $CRF(x,20) = 0.15976$.

Equation 26 gives $\overline{d}_{SYD} = 0.06969$.

Equation 22(b) gives $\overline{\phi} = 0.26983$.

The levelized capital charge per barrel of production is

$$\overline{C}_{Ia} = \overline{\phi} I_o/E = (0.26983)(1.0 \times 10^9)/(50{,}000)(330) = \$16.35/\text{bbl}.$$

The levelized operating charge per barrel is

$$\overline{C}_{Oa} = CRF(x,20)\ \Sigma \frac{8(1.1)^i}{(1+x)^i} = \$16.56/bbl.$$

The levelized product cost for this option is, therefore,

$$\overline{C}_a = \overline{C}_{Ia} + \overline{C}_{Oa} = \$32.91/bbl \quad (1980\text{-}2000).$$

Option b

Equation 17 gives x = (1-0.5)(0.5)(0.09) + (0.5)(0.15) = 0.0975.

Equation 21(c) gives CRF(x,20) = 0.11546.

Equation 26 gives $\overline{d}_{SYD} = 0.06394$.

Equation 22(b) gives $\overline{\phi} = 0.18698$.

The levelized capital charge per barrel of production is

$$\overline{C}_{Ib} = \overline{\phi} I_o/E = (0.18698)(1.0 \times 10^9)/(50{,}000)(330) = \$11.33/bbl.$$

The levelized operating charge per barrel is

$$\overline{C}_{Ob} = CRF(x,20)\ \Sigma \frac{8(1.1)^i}{(1+x)^i} = \$18.92/bbl.$$

The levelized production cost for this option is, therefore,

$$\overline{C}_b = \overline{C}_{Ib} + \overline{C}_{Ob} = \$30.25/bbl \quad (1980\text{-}2000).$$

Comparison to Imported Oil Cost

Two approaches can be used to compare the above results to the market cost of imported cost, such as oil imported from the Organizations of Petroleum Exporting Countries (OPEC). The first approach involves the transformation of the market oil cost in 1980 ($20 per barrel, 10% per year escalation) to a levelized value using either x = 15% for Option a or x = 9.75% for Option b. Thus,

$$\overline{C}_{OPEC,15\%} = CRF(15\%,20)\ \sum_i \frac{20(1.1)^i}{(1.15)^i} = \$41.40/bbl \quad (1979\text{-}1999),$$

and

$$\overline{C}_{OPEC,9.75\%} = CRF(9.75\%,20)\ \sum_i \frac{20(1.1)^i}{(1.0975)^i} = \$47.30/bbl \quad (1979\text{-}1999).$$

In this synfuel program, both Options a and b are more attractive than oil import, with Option b being even more attractive than Option a.

The second approach for determining the attractiveness of Options a and b is to project their levelized cost of production to the base year 1980. Let the pricing be such that it starts out in 1980 at C(1980) and increases at 10% per year thereafter; then one has

$$\text{Option a:}\quad C_a(1980) = \bar{C}_a \frac{CRF(\gamma,M)}{CRF(x,M)} = 15.90\ \$(1980)/\text{bbl},$$

where $x = 15\%$ and $\gamma = \frac{1.15}{1.1} - 1 = 4.545\%$; and

$$\text{Option b:}\quad C_b(1980) = \bar{C}_b \frac{CRF(\gamma,M)}{CRF(x,M)} = 12.79\ \$(1980)/\text{bbl},$$

where $x = 9.75\%$ and $\gamma = \frac{1.0975}{1.1} - 1 = -0.227\%$.

$C_a(1980)$ and $C_b(1980)$ show that both options are more attractive than the 1980 price of imported oil ($20/bbl). Option b is, of course, more attractive and less risky to the investor than Option a.

Although Option a is attractive, a free enterprise may still hesitate to engage in the venture for the following reasons: (i) the rate of 15% per year may not be attractive enough to attract an amount of capital at the level of $1 billion; (ii) the planning horizon of 20 years appears to be too long; (iii) there may be unforeseen problems with the synfuel technology; (iv) the fuel and operating costs must be further ascertained; and (v) with a large production capability, OPEC can undermine the synfuel venture by artificially lowering the price of oil. These uncertainties and others are bases for the industry to seek government guarantees.

Figure 2 illustrates the values of $\overline{C}_a$, $\overline{C}_b$, $C_a(1980)$, $C_b(1980)$, $\overline{C}_{OPEC,15\%}$, $\overline{C}_{OPEC,9.75\%}$.

CONCLUSION

An attempt has been made to provide a unified view of cost comparisons among energy projects. The following four aspects of the cost comparison have been considered:

- When and how are the DCF and the RR methods to be used?
- How can dissimilar technologies be compared?
- Are there differences between cost analyses for free enterprises and regulated firms?
- How does inflation affect the analyses?

Among important points made in this paper are the following:

1. The DCF formulation can be transformed with the RR formulation and vice versa.
2. The DCF resultant rate r has several meanings depending on what kinds of cash flows are included. A proper solution of cash flows and a proper understanding of the resultant DCF rate are most important in the DCF analysis.
3. For analysis of perspective energy projects, the RR method provides a simple formula to determine their attractiveness. This formula (Equation 16) relies on known quantities such as the tax rate, the cost of money, and the depreciation schedule. Unless there are specific reasons to list detailed cash flows for a DCF analysis, such listing is cumbersome and does not lead to better perspectives.

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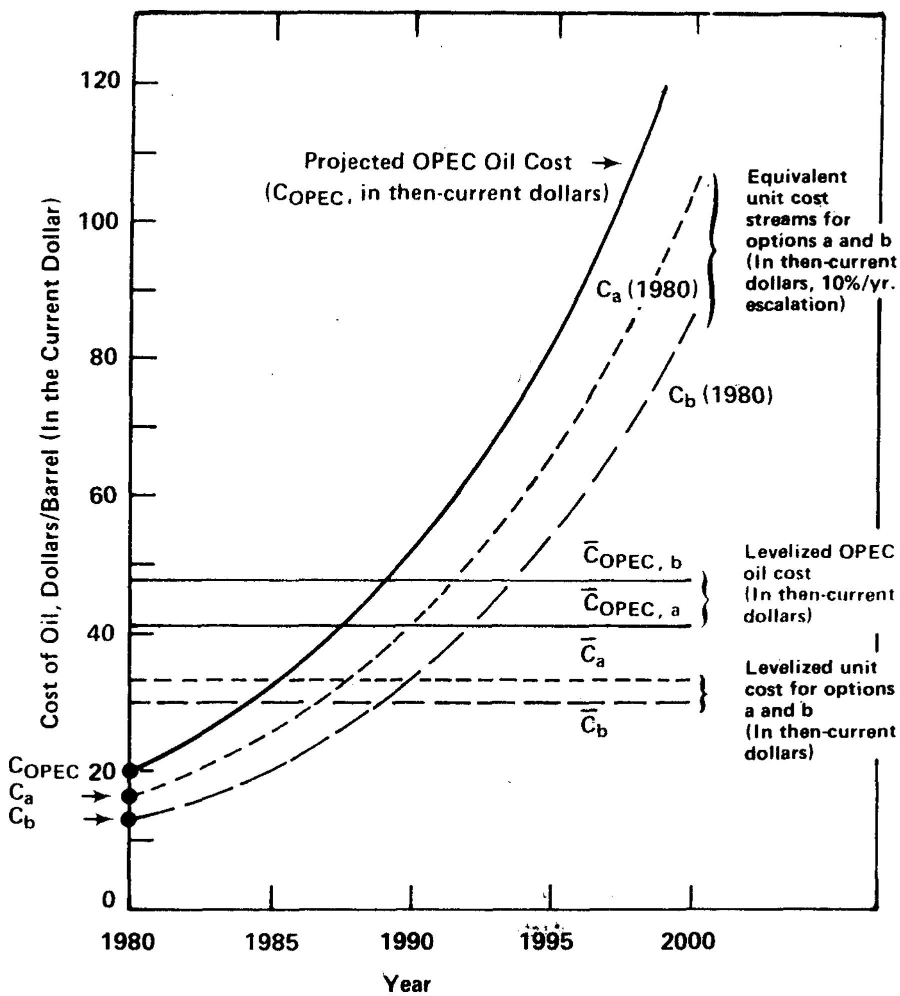

FIGURE 2: COST ANALYSIS FOR THE SYNFUEL PROGRAM

Options a and b have levelized unit cost at $\bar{C}_a$ and $\bar{C}_b$, which are lower than OPEC levelized unit cost $\bar{C}_{OPEC,a}$ and $\bar{C}_{OPEC,b}$ (all in then-current dollars per barrel). Converted to an increasing pricing schedule (at 10% per year), the equivalent 1980 unit cost of Option a is C_a(1980) and of Option b is C_b(1980). Both are lower than the price of OPEC oil in 1980.

4. A good way of comparing dissimilar energy projects is to determine the bare-bones production cost for each unit of product. Other factors (e.g., technology maturity, social acceptability, time frame, feasibility of capital formation) must be put into perspective before a ranking can be made.
5. The DCF and RR formulations are applicable to both free and regulated firms. The parameters in the formulations (such as the cost of money) must reflect conditions of these firms.
6. The DCF and RR formulations are applicable in both constant-dollar and inflated-dollar analyses. In the ideal case, cost streams in the two modes are related by a simple rate of inflation, and the results are related in a simple manner. In reality, the results can only be converted to each other within some margin of error, chiefly because of nonlinear relationships between cash-flow streams and inflation. The margin of error usually does not modify the ranking of alternatives.

REFERENCES

1. Eli Ezzati, ed. (1977). "Economic Analysis of Advanced Energy Technologies," Proceedings of Engineering Economic Analysis Workshop, MITRE Tech. Report 7611, The Mitre Corporation, McLean, Virginia.

2. U.S. Energy Research and Development Administration Division of Solar Energy (1976). "Solar Water and Space Heating," DSE-2322-1, Washington, D.C.

3. C. W. Bary and W. T. Brown (1957). "Some New Mathematical Aspects of Fixed Charges," Trans. Amer. Inst. Elect. Eng. 76, Pt. 3:230-249.

4. Paul H. Jeynes (1968). Profitability and Economic Choice, Iowa State University Press, Ames, Iowa.

5. Paul E. DeGarmo (1969). Engineering Economy, 4th ed., MacMillan Company, Toronto.

6. "Corporate Finance: The Cash-Flow Takeover Formula," Business Week (December 19, 1978):86-87.

7. U.S. Bureau of Mines, Process Evaluation Group (1975). "Basic Estimated Capital Investment and Operating Costs for Underground Bituminous Coal Mines," Information Circular 8689, Morgantown, West Virginia.

8. U.S. Bureau of Mines, Process Evaluation Group (1976). "Basic Estimated Capital Investment and Operating Costs for Coal Strip Mines," Information Circular 8703 (revision of IC 8661), Morgantown, West Virginia.

9. U.S. Bureau of Mines, Process Evaluation Group (1976). "Economic Analysis of Westinghouse Low-BTU Gasification--Combined Cycle Power Generating System Producing 134.1 MW," ERDA 76-49, Morgantown, West Virginia.

10. Doan L. Phung (1977). "Bureau of Mines Methodology in Cost Analysis--A Tentative Critique and Correction" (unpublished paper) Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tennessee.

11. D. R. Vondy (1965). "Basis and Certain Features of the Discount Technique," Appendix F in M. W. Rosenthal et al., A Comparative Evaluation of Advanced Converters, ORNL-3686, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

12. Doan L. Phung (1978). "The Discounted Cash Flow (DCF) and Revenue Requirement (RR) Methodologies in Energy Cost Analysis," ORAU/IEA-78-18(R), Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tennessee.

13. J. B. Oso (1978). "The Proper Role of the Tax-Adjusted Cost of Capital in Present Value Studies," The Engineering Economist 24, no. 1 (Fall):1-12.

14. Doan L. Phung and H. Rohm (1978). "Cost Analysis in Energy Conservation--A General Formulation," in Proceedings of the 1978 National Conference on Technology for Energy Conservation, pp. 193-205, Albuquerque, New Mexico.

15. Doan L. Phung (1979). "Selection of Discount Rates in Energy Cost Analysis Using Discounted Cash Flow (DCF) and Revenue Requirement (RR) Methodologies," Energy Systems and Policy 3, no. 2:145-169.

16. R. Michael Harnett and Doan L. Phung (1979). "Three Modes of Energy Cost Analysis: Then-Current, Base-Year, and Perpetual-Constant Dollar," Energy Systems and Policy 2, no. 4:61-72.

17. J. W. Doane et al. (1976). "The Cost of Energy from Utility-Owned Solar Electric Systems," JPL 5040-29, ERDA/JPL-1012-7613, Jet Propulsion Laboratory, Pasadena, California.

18. National Bureau of Standards (1976). "Federal Funding of Civilian R&D," NBS-GCR-ETIP 76-03, Washington, D.C.

19. Robert Skamser (1976). "Coal Gasification Commercial Concepts--Gas Cost Guidelines," Report FE-1235-1, prepared for U.S. ERDA, C. F. Braun and Co., Alhambra, California. Also in Roger Detman, ed., "Factored Estimates for Western Coal Commercial Concepts," Report FE-2240-5, prepared for U.S. ERDA, C. F. Braun and Co., Alhambra, California.

20. Sidney Katell and Leulla White (1976). "Clean Fuels from Coal are Expensive," Hydrocarbon Processing (July).

21. R. N. Anthony (1976). "A Case for Historical Costs," Harvard Business Review (November/December).

22. T. D. Flynn (1977). "Why We Should Account for Inflation," Harvard Business Review (September/October).