APPENDIX D

EXACT COMPUTATION OF PRESENT WORTH UNIT HEAT RATE CHARGE
(RESULTS EXTRACTED FROM APPENDIX C)

YEAR	MAX. LOAD 800,000 kW	75% LOAD 600,000 kW	50% LOAD 400,000 kW	25% LOAD 200,000 kW
		($$10^6$ per Btu/kWh)		
1	20.506	10.571	7.329	0.401
2	20.696	10.669	7.397	0.405
3.	43.800	5.376	5.885	0.0
4	44.337	5.442	5.957	0.0
5	44.743	5.492	6.011	0.0
6	43.852	5.382	5.892	0.0
7	43.008	5.279	5.778	0.0
8	42.210	5.181	5.671	0.0
9	41.422	5.085	5.566	0.0
10	40.646	4.989	5.461	0.0
11	28.583	12.279	4.301	0.186
12	28.010	12.033	4.215	0.182
13	27.525	11.823	4.141	0.179
14	27.002	11.599	4.063	0.176
15	26.537	11.400	3.993	0.173
16	26.041	11.187	3.918	0.169
17	25.570	10.984	3.847	0.166
18	25.056	10.763	3.770	0.163
19	24.618	10.575	3.704	0.160
20	24.175	10.385	3.637	0.157
21	15.826	12.238	2.977	1.548
22	15.528	12.007	2.921	1.519
23	15.272	11.810	2.873	1.494
24	14.951	11.561	2.812	1.462
25	14.671	11.345	2.760	1.435
26	14.270	11.035	2.684	1.396
27	13.871	10.726	2.609	1.357
28	13.485	10.428	2.537	1.319
29	13.106	10.135	2.465	1.282
30	12.753	9.861	2.399	1.247
31	8.263	5.322	2.331	1.212
32	8.038	5.177	2.268	1.179
33	7.820	5.036	2.206	1.147
34	7.606	4.899	2.145	1.115
35	7.399	4.765	2.087	1.085
	831.196	312.839	138.610	22.314

Present Worth Differential Net Heat Rate Charges:

$$\text{100\% Load: } \frac{831.196 \times 10^6}{8860}$$

$$= \$93{,}814/1 \text{ Btu/kWh } (\$88{,}918/1 \text{ kJ/kWh})$$

$$\text{75\% Load: } \frac{312.839 \times 10^6}{9135}$$

$$= \$34{,}246/1 \text{ Btu/kWh } (\$32{,}459/1 \text{ kJ/kWh})$$

$$\text{50\% Load: } \frac{138.610 \times 10^6}{10{,}000}$$

$$= \$13{,}861/1 \text{ Btu/kWh } (\$13{,}138/1 \text{ kJ/kWh})$$

$$\text{25\% Load: } \frac{22.314 \times 10^6}{10{,}400}$$

$$= \$2145/1 \text{ Btu/kWh } (\$2033/1 \text{ kJ/kWh})$$

Present Worth Differential Net Heat Rate Charge

$$= \$93{,}814 + 34{,}246 + \$13{,}861 + \$2145$$

$$= \$144{,}066/1 \text{ Btu/kWh } (\$136{,}548/1 \text{ kJ/kWh})$$

Weighted Heat Rate

$$= \frac{\$1304.960 \times 10^6}{144{,}066} = 9{,}058 \text{ Btu/kWh } (9557 \text{ kJ/kWh})$$

Levelized Unit Fuel Cost

$$\frac{\$123.49 \times 10^6}{4835.52 \times 10^6} = \$0.02554/\text{kWh}$$

or 25.54 mills/kWh

Levelized Fuel Price

$$= \frac{\$0.02554}{9058} = \$2.8196/10^6 \text{ Btu } (\$2.6725/10^6 \text{ kJ})$$

DISCUSSION

R. M. Wainwright[2]

The authors are to be congratulated on their promotion of the "Present Worth of Future Revenue Requirements" as the most appropriate method for economic selection of engineering alternatives. Why the utility industry has taken so long to adopt this methodology is somewhat of a mystery. Even more mysterious is why the "Capitalized Cost Method," referred to by the authors in their opening paragraphs, was ever used at all. Most engineering economists define "Capitalized Costs" as the present worth of perpetual renewals. But this was not what was usually meant by the "Capitalized Cost Method," which indiscriminately divided *all* annual charges by a factor, usually the fixed charge rate, to arrive at some number. This number was, in general, neither a valid present worth nor a true capital investment. If this dubious process ever arrived at a correct economic selection, it was because the user knew how to avoid the pitfalls. On the other hand, the "Discounted Cash Flow Method" is sound; it just has no particular advantage for utility-type problems over the PWRR method advocated by the authors.

I should like to point out that the levelizing process is a product of interest rate calculations and is technically applicable only to sums of money, not to capacity factors, kilowatt-hours, heat rates or other non-monetary quantities. More correctly, most of these "levelized" numbers are, in fact, combinations of factors lifted from a mathematical equation which is correctly calculating dollar amounts. To

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use these factors out of context may invite errors, as the authors pointed out. This point should be emphasized.

The 1.733 factor used by the authors, I have called the PWCF (present worth conversion factor), as it converts a capital investment to the PW of its annual fixed charges. Another factor which has proved useful is the PWSF (present worth summation factor), which can be defined as

$$\mathrm{PWSF} = \sum_{k=1}^{N} \left(\frac{1 + \frac{ESC}{100}}{1 + \frac{MAR}{100}} \right)^{k}$$

This factor multiplies an amount, such as an estimated O&M cost at $t = 0$, to arrive at the PW of N periods of such costs under a per period escalation rate of ESC percent; MAR percent being the basic cost of money. If, in addition, there are other cost variations per period, these may be handled easily by a computer program. Such programs can account for load schedule changes, plant efficiency changes at various load levels, and the like. With the ready access to computers and small programmable calculators, such as the HP-97, there seems to be no good reason for settling for approximation methods when exact methods can be used as easily.

The authors' examples, as they noted, were computed using sinking-fund type depreciation annuities. in practice, retirement dispersion should be considered. Use of retirement dispersion methods will usually add about 1 percent to the fixed charge rates as used by the authors for 35-year life items. Also, the levelized income tax formula, as given by the authors, may need to be revised in practice to account for investment tax credit and the type of accounting practiced by the utility. Such tax formulas are available in the authors' reference [1], and elsewhere in the literature.

D. A. McCutchan[3]

The authors have produced a valuable paper, since it is explicit and practically oriented. One improvement occurs to this discusser, offered in the spirit of the rigorous approach taken by the authors. Better ways of present-worthing fuel costs are available than are shown in Example 1. There the authors combine mid-year fuel costs with end-of-year present worth factors using a year-by-year calculation. The result can be shown to be slightly in error relative to a more exact calculation in which fuel costs are calculated monthly or continuously. The calculation is easy if there are only a few periods with distinct escalation rates.

To illustrate the continuous calculation method, we must first de-escalate the stated fuel cost from an assumed July 1 date to the start of the year, obtaining 1.144 $\$/10^6$ Btu. Calling this C, the PW of the first five years' fuel at a constant consumption rate of 10^6 Btu/yr is obtained from the formula

$$\mathrm{PW} = \frac{C\left(\frac{1+g}{1+r}\right)^{n}}{\ln\left(\frac{1+g}{1+r}\right)}$$

with $n = 5$, fuel escalation rate $g = 0.10$, and annual return $r = 0.09$, giving 5.853 dollars. For the next 20 year period, $C = 1.843$ $\$/10^6$ Btu, $n = 20$, and $g = 0.07$, giving a PW at end of year five of 30.7986 dollars. This must be discounted at nine percent/year for five years, giving a PW of 20.017 dollars at January 1, 1981. The final ten years contribute an additional PW of 7.216 dollars for a total of 33.086 dollars, a result about six percent higher than the authors' answer. The result of a month-by-month calculation is nearly the same, viz. 33.029 dollars.

R. S. Sproule[4]

Study of this paper has clarified for the discusser, as it will for many engineers, the concept of "present worth," which in the past has been confusing because of frequent misuse of the expression. Even the authors are guilty in places of using the term "present worth" when they mean "present worth of revenue requirements." If you can buy a power plant today for 550 million dollars, its present worth is 550 million dollars, but the authors point out that the "present worth of revenue requirements of invested capital" may be 953 million dollars. This explains why so many contradictory numbers appear in discussions of possible solutions to the energy crisis—in the technical press as well as in the popular press. This discusser recently read that solar generation without storage could have economic value at costs below about 700.00 dollars, "1986 investment-dollar capital equivalent of total lifetime capital and operation and maintenance costs". The man in the street, and some of those in the lobby, would probably deduce from that statement that there will be a market in 1986 for solar generation if it can be built for somewhat under 700 dollars/kilowatt. However, someone who has read the authors' paper will realize that the above statement means that there might be a market if the constructed cost can be kept below 400 dollars/kilowatt.

It might help to avoid this type of confusion if economists would use the initials 'PWRR" instead of shortening "present worth of revenue requirements" to "present worth." Then the man in the street would at least know that he did not understand.

Any comparison between energy-saving investment, such as an investment in larger pipe sizes, and the alternative higher total fuel costs is sensitive to assumptions on fuel cost escalation. The same remark applies to arriving at the correct economic decision between conventional fuel burning plants and capital intensive plants with low fuel costs, such as the CANDU reactor, or with zero fuel costs, such as hydro, solar, or windmills.

As an example, if coal prices at the authors' 800 MW plant are assumed to escalate at 8 percent from the sixth to 35th year, instead at 7 percent from the sixth to 25th, and at 6 percent from year 26, the picture is as follows:

PWRR for 35 year life, $\$10^6$

	Coal Escalation at:	
	10, 7 & 6 percent	10 and 8 percent
PWRR of Capital Investment	953	953
PW of Fuel Expenses	1306	1475
PW of O & M Expenses	145	145
TOTAL P.W.R.R.	2404	2573

Thus, the 1 and 2 percent change in the assumption on fuel price escalation has made 7 percent difference in the PWRR of the steam plant.

Every consideration of capital expenditure to save fossil fuel will be found to be sensitive to assumptions on long term fuel costs. Have the authors any believable guidelines on escalation on various types of fuel, even 25 years out, and even as a multiplier of the average rate of inflation of all costs of living?

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Doan L. Phung[5]

The authors are to be congratulated for an excellent treatment of power system economics. The quality of the paper is consistent with the authors' reputation for succinctness in presenting solutions to problems frequently encountered by practicing engineers.

As cautioned repeatedly by the authors, the reader should not take the numbers and assumptions in the examples literally. Every circumstance has its own data which are sometimes quantifiable, sometimes not; but which must be considered thoroughly in the decision-making process. Indeed, one should be enlightened to realize that "discounted cash flow" and "present worth of revenue requirement" analyses, however impressive their tables of manipulated data, are based on some economic perception of the value of money which may be valid at the time of evaluation but not at a later date. Premises such as "life-cycle analysis," "35-year life span," "y dollars of interim replacement," etc., are all deterministic assumptions for things that are conditional in nature. This is why cautious managers would also consider 10-year—20-year levelization besides life-cycle, and would exert a conservative influence in order to minimize the effects of the unforeseeable. The authors, therefore, have very appropriately emphasized that economic evaluation is only one aspect in the process of selecting engineering alternatives. I would like to add further that the economic evaluation methodology as presented is only *one* way of ranking economic alternatives.

The practice of using the weighted cost of capital (R) as the discount rate for present worth calculations is entrenched but not well established. Its use appears to hinge on the following assumption: "All capital is to be retained in the project (or power company) until the end of project life so that each year a return of R must be paid out and a sinking-fund depreciation d_{SF} must be invested into a fund earning R percent per year (tax free); at the end of project life, that sinking fund will grow to the face amount of investment (in then-current dollars), and is returned to the investors for the so-called recovery of their original capital." This assumption appears unrealistic when 1) depreciation charges are used to retire obligations, 2) interest earning is taxable, and 3) in an inflationary economy, the recovery of investment in then-current dollars would not suffice for equipment replacement.

The debate between Jeynes and Bary [15][6] in the late 1950s centers around the use of discount rates. Bary [16] argued that a discount rate of $x = R - tDb$ must be used instead of R because debt interest is tax deductible. Although Jeynes won more audience in the utility industry because R is rather simple to understand, Bary's arguments are more rigorous. Thus, when x is used as the effective discount rate, the fixed capital charge rate (FCR) can be expressed as [17]:

$$\mathrm{FCR} = \frac{1}{1-t}\,\mathrm{CRF}_x - \frac{t}{1-t}\,\bar{d}_x + \pi \tag{1}$$

where CRF_x is the capital recovery factor based on discount rate x, $\bar{d}_x$ is the levelized depreciation charge, and π is the ad-valorem tax, insurance, and all other capital-related administrative expenses.

Using the above expression and the capitalization data assumed by Leung and Durning, the FCR is 15.8 percent if tax depreciation is straight-line, 18 percent if tax depreciation is sinking-fund, and 15.2 percent if tax depreciation is sum-of-the-years-digits. This practical information, along with investment tax credit, is important to the planning manager, especially when large sums of capital investment are involved.

Another area also deserves attention, although it is not clear that solution is forthcoming. The practice of present-valuing of future fuel and O&M expenditures for trade-off comparison with capital investment is shaky at best and wrong at worst. This is because the future is full of uncertainties which render values attached to future expenditures arguable. While both R and x are based on somewhat known capital and tax commitments and can therefore be relied upon as discount rates for capital-servicing cash streams, their use as discount rates for future out-of-pocket expenditures is debatable. One can argue that the money used to pay for these expenditures is capitalized in the same manner as investments, but in reality the following happens: 1) fuel adjustment is allowed, 2) operating costs are tax deductible, and 3) utilities can borrow short-term money to pay for operating costs. I would argue that the discount rate for future operating expenses must be different from the discount rate for capital-servicing purposes. (Note that Kenneth Arrow uses one rate for cost calculations, another for benefit calculations [18].) Worse still, the discount rate for operating expenses may differ from case to case, depending on the particular conditions. This is why intelligent judgment is still needed in this era of computerization.

For those who cherish a shorter (and possibly more elegant) way of handling Example 1, I would argue that the long Appendix C is unnecessary. Furthermore, the use of "weighted heat rate" of 9068.1 Btu/kWh in Table I.4 for 35 years is suspect, although the error is small. As the heat rate is directly related to the amount of fuel used, and therefore its cost, the use of a weighted value does modify the cash flow stream (albeit slightly in this case). One can find the heat rate HR_i in the year i exactly as follows:

$$\mathrm{HR}_i = \frac{\sum_j \mathrm{HR}_{i,j} \mathrm{L}_{i,j} \mathrm{W}_{i,j}}{\sum_j \mathrm{L}_{i,j} \mathrm{W}_{i,j}} \tag{2}$$

where index i indicates the year, index j indicates the number of load levels (j = 1 to 5 in Table 1.2), $\mathrm{L}_{i,j}$ indicates the load (100 percent, 75 percent, 50 percent, 25 percent, and 0 percent for j = 1, 2, 3, 4, 5 for all i), and $\mathrm{W}_{i,j}$ is the percentage of the time the plant is at a specified load level (e.g., 30 percent for i = 1, j = 1).

Note that the denominator of (2) is precisely the "plant capacity factor" as calculated in Table 1.2. The results of (2) for the yearly heat rate are as follows:

First 2 years	9146	Btu/kWh
Next 8 years	8996	Btu/kWh
Next 10 years	9037	Btu/kWh
Next 10 years	9122	Btu/kWh
Next 5 years	9190	Btu/kWh

By replacing the fourth column of Table 1.4 with the above values, one arrives at 1305.0 × 10^6 dollars for the present worth of life-time fuel expenses. This approach is as rigorous as Appendix C but requires much less time or computerization.

Additional References

15 Letter from Constantine W. Bary to Paul H. Jeynes, dated June 21, 1963, (made available from Paul H. Jeynes).

16 Bary, Constantine W., and Brown, W. T., "Some New Mathematical Aspects of Fixed Charges," Paper 57-152, AIEE Winter General Meeting, New York, January 21–25, 1957.

17 Phung, Doan L., "Guidelines for Cost Analysis of Energy Production—Regulated Utility Industry," Institute for Energy Analysis, Oak Ridge Associated Universities, July, 1977.

18 Arrow, Kenneth J., "The Rate of Discount on Public Investments with Imperfect Capital Markets," Notes prepared for the RFF/EPRI Workshop on Social Rate of Discount, *Resources for the Future*, Washington, D.C., March 3–4, 1977.

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[5] Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tennesee.

[6] Numbers in brackets designate Additional References at end of discussion.

H. I. Bowers[6]

This is an excellent paper which should be very useful to both the uninitiated and those experienced in engineering economic analysis. The explicit examples are especially helpful. A shortcoming of the levelized fixed charge rate approach is that it does not give a picture of the year-by-year cash flow requirements over the life of a project, which can be an important factor when comparing proposed projects having high initial costs and low operating costs with alternatives having lower initial costs and higher operating costs, e.g., nuclear versus coal-fired power plants. This discusser uses the present worth of revenue requirements method but prefers to tabulate systematically the minimum revenue requirements for each year of plant life and then to carry out the present worth and leveilizing computations. The components of each year's revenue requirements usually are categorized as (1) return on preferred stock investment, (2) return on common stock investment, (3) bond interest, (4) book depreciation (return of investment), (5) federal income tax, (6) state income tax, (7) and valorem taxes, (8) insurance expense, (9) administrative and general (miscellaneous) expense, (10) nonfuel operation and maintenance expense, and (11) fuel expense. Items (1) through (9) are those included by the authors in the levelized fixed charge rate. The sum of the above items (1) through (11) for each year is the minimum revenue requirement for each year. This annual cash flow table can be presented in either constant dollars or in year-by-year inflated or escalated dollars and is an additional source of information for use by management in making investment decisions. It can be a deciding factor in cash-short situations. The present worth and levelizing calculations can be carried out in a manner fully consistent with the authors' approach and will result in identical levelized costs.

The authors correctly point out that the sum of the rate of return and the sinking fund annuity is the capital recovery factor. It might be helpful also to point out that the capital recovery factor is the annualized, or levelized, equivalent of any schedule of book depreciation plus its associated return on investment over the life of the plant, whereas the income tax component of levelized fixed charge rate will vary depending on the schedule of depreciation used for tax purposes.

The authors' responses to the following questions are solicited.

1. As indicated in Appendix A, the authors have used straightline depreciation for both book use and income tax pruposes. Is it desirable to take into account investment tax credits and accelerated depreciation in engineering economic analyses, and what are their effects on the fixed charge rate?
2. Would it be desirable to allow for inflation or escalation of some components of the fixed charge rate, e.g., ad valorem tax, insurance expense, and administrative and general expense?

Authors' Closure

The authors are sincerely grateful to the discussers for their valuable comments on this paper. Furthermore, the authors believe that the discussions form a most important adjunct to the paper. In fact, one may find that some of the questions raised by one discusser were readily answered by another discusser of this paper. Users of the principles put forth in the paper would profit by making a careful review of the discussions, for they provide some very pertinent clarifications and amplifications of the materials presented in this paper.

Mr. Wainwright's introduction of a new term PWCF (present worth conversion factor) has a great deal of merit, and should satisfy Mr. Sproule's desire for better clarification of the terminology.

Mr. Bowers's question on the effect of using different depreciation factors was also discussed by Dr. Phung. When the resultant tax rate (T) is reduced by the inclusion of the investment credit, the annual fixed charges rate will decrease. As the annual fixed charges rate is reduced, a higher capital cost option becomes more attractive. A previous paper (8) discussed this facet in detail. Using a different discount rate for computing present worth fuel expenses, rather than the same rate as the return rate, has not been practiced within the power industry mainly because of the fact that in past decades, long-term fuel contracts were obtainable. Faced with uncertainty in future fuel pricing, using a different discount rate either higher or lower than the return rate to compute present worth life-time fuel expenses would not alter the degree of uncertainty. Using a lower discount rate would increase the present worth fuel expenses, resulting in greater incentive for adding capital expenditures for fuel economy. Conversely, using higher discount rate than the rate of return would de-emphasize the impact of fuel expenses, and a poorer thermal efficiency option would prevail. In this regard, the authors could only recommend once again a sensitivity analysis by testing the results using different discount rates. Fortunately, rate of return, depreciation, discount rate, escalation rate, etc., and the resultant annual fixed charges rate all have a relatively narrow range and narrow upper and lower limits. In the authors' experience, the rankings of the competing alternative often remain unchanged if the upper and lower limits of those factors used in testing are not unreasonably wide.

In closing, the authors should make a stronger impression in the paper in that the PWRR method presented is best suited for determining the economic choice rather than for computing the profitability of the competing alternatives.

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