A USERS MANUAL FOR BICYCLE III:
A COMPUTER CODE FOR CALCULATING LEVELIZED LIFE-CYCLE COSTS

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ABSTRACT

This report describes the BICYCLE III spreadsheet computer code. BICYCLE calculates levelized life-cycle costs for plants that produce electricity. Included here are derivations of the equations used by BICYCLE and input instructions for the Excel™ spreadsheet.

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I. INTRODUCTION

BICYCLE III is a computer code designed to calculate levelized life-cycle costs of electric power generation plants. In addition to total levelized life-cycle costs, the code gives a detailed breakdown of the various life-cycle components that make up the total cost. The code also gives yearly cash flows in current dollars during each year of the plant's lifetime.

Life-cycle costs are calculated using two basic methods that reflect two modes of debt capital repayment. One method assumes that the ratio of outstanding debt capital to outstanding equity capital remains constant. The other method assumes that the debt capital repayment schedule is fixed in advance and that all expenses other than the initial capital investment come from equity capital.

This report presents derivations of levelized life-cycle costs for both methods. This report also includes input instructions for the spreadsheet.

II. METHOD

The costs of producing electricity from a particular plant normally vary during the lifetime of the plant. For example, fuel and labor costs may increase significantly with time, while other components may decrease. The trouble with production costs that vary with time is that it is difficult to compare these costs for competing technologies because there are several numbers to compare. For example, a product from one plant may be more expensive than the product from another plant during one part of its lifetime and less expensive during another part. Therefore, it may be very hard to determine which plant produces the least expensive product over its total lifetime. As a result, levelized (constant) life-cycle costs are usually used for comparing production costs because each technology is characterized by a single number.

The underlying principle in computing levelized life-cycle costs is that the income over the lifetime of a project must equal the expenses associated with the project. The income is derived from the revenue received from the sale of the product – in this case, electricity. The expenses include the recovery of the investment, return on the investment, fuel costs, operating and maintenance costs, taxes, and any other expenses related to the project.

Two basic methods of calculating levelized life-cycle costs reflect two methods of debt capital repayment. They are (1) the proportional case and (2) the fixed-payment case. For the proportional case, the debt capital and the equity capital are paid off in a constant ratio. Therefore, throughout the lifetime of the project, the ratio of outstanding debt to outstanding equity is constant. For the fixed-payment case, the entire schedule of debt repayment is fixed in advance.

Therefore, any expenses that occur after the start of the project come from equity capital or from revenues.

Projects that are part of an overall corporate financial structure are better represented by the proportional case, which assumes that all funds come from a pool of capital where the ratio of debt to equity is held constant. Single projects that have their own independent debt structure are better represented by the fixed-payment case. Derivations of the expression for levelized life-cycle costs for each method are given below.

A. Derivation of Life-Cycle Costs Using Proportional Debt Repayment

In any year k of a project, a balance sheet can be tabulated. The amount available to reduce the outstanding capital investment in year k is equal to the revenue received in year k minus the expenses in year k. The terms are defined in Table I.

TABLE I. Definition of Terms

Nonannual Quantities		Annual Quantities	
Term	Definition	Term	Definition
e	Equity fraction	I_k	Total investment outstanding at start of year k
i_e	Cost of equity		
b	Debt fraction	I^e_k	Total equity investment outstanding at start of year k
i_b	Cost of dept		
i	Cost of money $= ei_c + bi_b$	R_k	Revenue received at end of year k
		E_k	Quantity of product produced in year k
i'	Tax adjusted cost of money $= i - tbi_b$	oam_k	Operation and maintenance costs for year k
		$fuel_k$	Fuel cost for year k
L	Levelized life-cycle cost	tot_k	Total operating costs for year k
g	Gross revenue tax rate	rev_k	Gross revenue taxes for year k
t	Income tax rate	dep_k	Depreciation on capital for year k
S	Net salvage value	bin_k	Bond interest for year k
K	Project lifetime	A_k	Additional capital investment at end of year k
		cap_k	Annualized capital investment in year k
		bp_k	Bond principal payment for year k

1. Balance Sheet for Year k.

Amount towards reduction of investment in year k = revenue in year k - total operating costs for year k - return on debt and equity for year k - (income + gross revenue taxes for year k)

$$= (R_k - tot_k - i \times I_k) - (\text{income + gross revenue taxes for year k}) .$$

Gross revenue taxes for year k = gross revenue tax rate x revenue in year k

$$= g \times R_k .$$

$$\text{Income taxes for} = \text{income tax rate} \times \left(\text{revenue in year k} - \text{deductible expenses year k} \right)$$

$$= t(R_k - tot_k - dep_k - bin_k - g \times R_k)$$
$$= t(R_k - tot_k - dep_k - b \times i_b \times I_k - g \times R_k)$$

Therefore,

amount towards reduction of investment in year k $= R_k\,(1 - g) - tot_k - i \text{ x } I_k - t[R_k(1 - g) - tot_k - dep_k - b \text{ x } i_b \text{ x } I_k\,]$

$$= R_k(1 - g)(1 - t) - tot_k\,(1 - t) + t(dep_k\,) + I_k(t \text{ x } b \text{ x } i_b - i)$$

Investment outstanding at end of year k $= I_{k+1}$

= investment outstanding at beginning of year k − amount towards reduction of investment in year k + additional investment at end of year k

$$I_{k+1} = I_k - [R_k(l - g)(l - t) - tot_k\,(1 - t) + t \text{ x } dep_k + I_k(t \text{ x } b \text{ x } i_b - i)] + A_k$$
$$= I_k(l + i - t \text{ x } b \text{ x } i_b\,) - [R_k(l - g)(l - t) - tot_k\,(1 - t) + t \text{ x } dep_k\,] + A_k$$

Let

$i' = i - t \text{ x } b \text{ x } i_b$.

Then,

$$I_{k+1} = I_k(l + i') - [R_k(l - g)(l - t) - tot_k\,(1 - t) + t \text{ x } dep_k - A_k] \ .$$

2. Balance Sheet for Year 1.

$$I_2 = I_1(1 + i') - [R_1(1 - g)(1 - t) - tot_1(1 - t) + t \text{ x } dep_1 - A_l] \ .$$

3. Balance Sheet for Year 2.

$$I_3 = I_2(1 + i') - [R_2(1 - g)(1 - t) - tot_2(1 - t) + t \text{ x } dep_2 - A_2]$$
$$= I_1\,(1 + i')^2$$
$$- (1 + i')\,[R_1(l - g)(1 - t) - tot_1\,(1 - t) + t \text{ x } dep_1 - A_1]$$
$$- [R_2(1 - g)(l - t) - tot_2\,(1 - t) + t \text{ x } dep_2 - A_2] \ .$$

4. Balance Sheet for Year 3.

$$I_4 = I_3(1 + i') - [R_3(1 - g)(l - t) - tot_3\,(1 - t) + t \text{ x } dep_3 - A_3]$$
$$= I_1(1 + i')^3$$
$$- (1 + i')^2\,[R_1(1 - g)(1 - t) - tot_l\,(1 - t) + t \text{ x } dep_1 - A_1]$$
$$- (1 + i')\,[R_2(1 - g)(l - t) - tot_2\,(1 - t) + t \text{ x } dep_2 - A_2]$$
$$- [R_3(1 - g)(1 - t) - tot_3\,(1 - t) + t \text{ x } dep_3 - A_3] \ .$$

5. Balance Sheet for Year K. Because the capital investment is fully recovered at the end of the project (except for the salvage value)

$$
\begin{aligned}
I_{K+1} &= S \\
&= I_K(1 + i')\,[R_K(1 - g)(1 - t) - tot_K\,(1 - t) + t \times dep_K - A_K] \\
&= I_1(1 + i')^K \\
&\quad - (1 + i')^{K-1}[R_1(1 - g)(1 - t) - tot_1\,(1 - t) + t \times dep_1 - A_1] \\
&\quad - (1 + i')^{K-2}[R_2(1 - g)(1 - t) - tot_2\,(1 - t) + t \times dep_2 - A_2] \\
&\quad - \ldots - [R_K(1 - g)(1 - t) - tot_K\,(1 - t) + t \times dep_K - A_K] \quad .
\end{aligned} \tag{1}
$$

Dividing Eq. (1) by $(1 + i')^K$ and rearranging yields

$$
I_1 - \frac{S}{(1+i')^K} = \sum_{k=1}^{k} \frac{R_k(1-g)(1-t) - tot_k(1-t) + t \times dep_k - A_k}{(1+i')^k}
$$

or

$$
\sum_{k=1}^{K} \frac{R_k}{(1+i')^k} = \frac{I_1 - \dfrac{S}{(1+i')^K}}{(1-g)(1-t)} + \sum_{k=1}^{K} \frac{tot_k(1-t) - t \times dep_k + A_k}{(1-g)(1-t)(1+i')^k} \tag{2}
$$

Equation (2) is merely a restatement that the revenues over the lifetime of the project (the left side of the equation) must equal the expenses over the lifetime of the project (the right side of the equation). The revenue in year k is equal to the quantity of product produced in that year, E_k, times the price of the product. The levelized life-cycle cost L is defined as follows.

$$
L = \frac{\displaystyle\sum_{k=1}^{K} \frac{R_k}{(1+i')^k}}{\displaystyle\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}} \quad . \tag{3}
$$

When Eqs. (2) and (3) are combined, we get

$$
L = \frac{I_1 - \dfrac{S}{(1+i')^k} + \displaystyle\sum_{k=1}^{K} \frac{tot_k(1-t) + t \times dep_k + A_k}{(1+i')^k}}{(1-g)(1-t)\displaystyle\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}} \quad . \tag{4}
$$

If we use the algebraic identity,

$$
\sum_{n=1}^{N} r^n = \frac{r(1-r^N)}{1-r} \text{ , then}
$$

$$
\sum_{k=1}^{K} \frac{1}{(1+i)^k} = \frac{(1+i)^K - 1}{i(1+i)^K} \quad .
$$

Making use of this identity, the capital investment can be represented as a uniform annual payment over the lifetime K.

$$\text{cap}_k = \left[I_1 - \frac{S}{(1-i')^K} + \sum_{k=1}^{K} \frac{A_k}{(1+i')^k} \right] \frac{i'(1+i')^K}{(1+i')^K - 1} \tag{5}$$

When Eq. (5) is substituted in the expression for L [Eq. (4)],

$$L = \frac{\displaystyle\sum_{k=1}^{K} \frac{\text{cap}_k + \text{tot}_k (1-t) - t \text{ x } \text{dep}_k}{(1+i')^k}}{\displaystyle(1-g)(1-t)\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}} \tag{6}$$

If the components included in tot_k are substituted in Eq. (6),

$$L = \frac{\displaystyle\sum_{k=1}^{K} \frac{\text{cap}_k + (\text{oam}_k + \text{fuel}_k)(1-t) - t \text{ x } \text{dep}_k}{(1+i')^k}}{\displaystyle(1-g)(1-t)\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}}$$

It is frequently convenient to express the levelized life-cycle cost as a function of each of the following components.

$$L = \left.\frac{\displaystyle\sum_{k=1}^{K} \frac{\text{cap}_k + (t/1-t)(\text{cap}_k - \text{dep}_k)}{(1+i')^k}}{\displaystyle\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}}\right\} \text{capital plus income taxes}$$

$$+ \left.\frac{\displaystyle\sum_{k=1}^{K} \frac{\text{oam}_k}{(1+i')^k}}{\displaystyle\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}}\right\} \text{operation and maintenance charges}$$

$$+ \left.\frac{\displaystyle\sum_{k=1}^{K} \frac{\text{fuel}_k}{(1+i')^k}}{\displaystyle\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}}\right\} \text{fuel costs}$$

$$+ \left.\frac{\displaystyle\frac{g}{1-g}\sum_{k=1}^{K} \frac{\text{cap}_k + (\text{oam}_k + \text{fuel}_k)(1-t) - t \text{ x } \text{dep}_k}{(1+i')^k}}{\displaystyle(1-t)\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}}\right\} \text{gross revenue taxes .}$$

B. Derivation of Life-Cycle Costs Using Fixed Payment for Debt Retirement

The derivation for levelized life-cycle costs when the debt repayment schedule is known in advance is similar to the proportional debt retirement case. A key difference is that the calculation of the amount towards the reduction of investment in any given year is for the equity investment only. This is because, by definition, the reduction of the debt investment is already known.

1. Balance Sheet for Year k.

Amount towards reduction of equity investment in year k = revenue in year k - total operating costs for year k - equity return on investment for year k - bond interest for year k - bond principal payment for year k - (income + gross revenue taxes for year k)

$$= (R_k - tot_k - i_e \text{ x } I^e_k - bin_k - bp_k) \text{ - (income + gross revenue taxes for year k).}$$

Gross revenue taxes for year k $= g \text{ x } R_k$

Income taxes for year k $= t(R_k - tot_k - dep_k - bin_k - g \text{ x } R_k)$

Therefore,

amount towards reduction of equity investment in year k $= R_k(1 - g) - tot_k - i_e \text{ x } I^e_k - bin_k - bp_k - t[R_k(1 - g) - tot_k - dep_k - bin_k]$

$$= R_k(1 - g)(1 - t) - tot_k (1 - t) - i_e \text{ x } I^e_k - bin_k - bp_k + t(dep_k + bin_k)$$

Equity investment outstanding at end of year k $= I^e_{k+1}$

= equity investment outstanding at beginning of year k - amount towards reduction of investment in year k + additional equity investment at end of year k .

$$I^e_{k+1} = I^e_k - [R_k(1 - g)(l - t) - tot_k(1 - t) - i_e \text{ x } I^e_k - bin_k - bp_k + t(dep_k + bin_k)] + A_k$$
$$= I^e_k (l + i_e) - [R_k(1 - g)(1 - t) - tot_k (1 - t) - bin_k - bp_k + t(dep_k + bin_k) - A_k]$$

2. Balance Sheet for Year 1.

$$I^e_2 = I^e_1 (1 + i_e) - [R_1(1 - g)(l - t) - tot_1(1 - t) - bin_1 - bp_1 + t(dep_1 + bin_1) - A_1] \ .$$

3. Balance Sheet for Year 2.

$$I^e_3 = I^e_2 (1 + i_e) - [R_2(1 - g)(l - t) - tot_2(1 - t) - bin_2 - bp_2 + t(dep_2 + bin_2) - A_2]$$
$$= I^e_1 (l + i_e)^2$$
$$- (1 + i_e)[R_1(l - g)(l - t) - tot_1(1 - t) - bin_1 - bp_1 + t(dep_1 + bin_1) - A_1]$$
$$- [R_2(1 - g)(l - t) - tot_2(1 - t) - bin_2 - bp_2 + t(dep_2 + bin_2) - A_2]$$

4. Balance Sheet for Year K.

$I^e_{K+1} = S$

$= I^e_K\ (1+ i_e) - [R_K(I - g)(l - t) - tot_K(1 - t) - bin_K - bP_K + t(dep_K + bin_K) - A_K]$

$$
\begin{aligned}
&= I^e_1\ (1 + i_e)^K \\
&\quad - (1 + i_e)^{K-1} [R_1(l - g)(l - t) - tot_1(1 - t) - bin_1 - bp_1 + t(dep_1 + bin_1) - A_1] \\
&\quad - (1 + i_e)^{K-2} [R_2(1 - g)(1 - t) - tot_2(1 - t) - bin_2 - bp_2 + t(dep_2 + bin_2) - A_2] \\
&\quad - .... - [R_K(1 - g)(1 - t) - tot_K(1 - t) - bin_K - bp_K + t(dep_K + bin_K) - A_K] \quad . \qquad (7)
\end{aligned}
$$

Dividing Eq. (7) by $(1 + i_e)^K$ and rearranging yields

$$I^e_1 - \frac{S}{(1+i_e)^k} = \sum_{k=1}^{K} \frac{R_k(1-g)(1-t) - tot_k(1-t) - bin_k - bp_k + t(dep_k + bin_k) - A_k}{(1+i_e)^k}$$

or

$$\sum_{k=1}^{K} \frac{R_k}{(1+i_e)^k} = \frac{I^e_1 - \frac{S}{(1+i_e)^K}}{(1-g)(1-t)} + \sum_{k=1}^{K} \frac{tot_k(1-t) + bin_k + bp_k - t(dep_k + bin_k) + A_k}{(1-g)(1+i_e)^k} \qquad (8)$$

Solving Eq. (8) for the levelized life-cycle cost L yields

$$L = \frac{I^e_1 - \frac{S}{(1+i_e)K} \sum_{k=1}^{K} \frac{tot_k(1-t) + bin_k + bp_k - t(dep_k + bin_k) + A_k}{(1+i_e)^k}}{(1-g)(1-t) \sum_{k=1}^{K} \frac{E_k}{(1+i_e)^k}}$$

If the capital investment is represented as a uniform annual payment over the lifetime K,

$$cap_k = \left[I^e_1 - \frac{S}{(1+i_e)^K} + \sum_{k=1}^{K} \frac{A_k}{(1+i_e)^k} \right] \ x \ \frac{i_e(1+i_e)^K}{(1+i_e)^K - 1}$$

then the levelized life-cycle cost can be written as

$$L = \frac{\sum_{k=1}^{K} \frac{cap_k + tot_k(1-t) + bin_k + bp_k - t(dep_k + bin_k)}{(1+i_e)^k}}{(1-g)(1-t) \sum_{k=1}^{K} \frac{E_k}{(1+i_e)^k}} \ .$$

The capital plus income tax component of the levelized life-cycle cost can be written as

$$\frac{\sum_{k=1}^{K} \frac{cap_k + bin_k + bp_k + (t/1-t)(cap_k + bp_k - dep_k)}{(1+i_e)^k}}{\sum_{k=1}^{K} \frac{E_k}{(1+i_e)^k}} \ .$$

The expressions for the other components of the levelized life-cycle cost are identical to the expression derived for the proportional case with two important exceptions. First, the discount rate used for the fixed-repayment case is i_e, the return rate on equity. The discount rate used for the proportional case was the weighted cost of money adjusted to take into account the fact that interest on debt is tax deductible. Second, the gross revenue tax expression for the fixed-repayment case is modified to include factors for bond interest and principal payments.

C. Life-Cycle Components

This section is intended to provide additional details regarding the calculation of life-cycle components in BICYCLE.

1. Operation and Maintenance Costs. For this version of BICYCLE, the fixed costs are included with the operation and maintenance costs. The operation and maintenance costs will consist of two types—fixed and variable. Fixed costs are independent of the capacity factor and include such things as property insurance, property taxes, and other fixed costs. The variable cost are of two types. The first type is costs that are proportional to the capacity factor, such as for fuel used to operate the plant. The other type includes one time charges such as expensed capital replacements. As discussed in the input instructions, the user must input these costs for each year. These costs are in inflated (current year) dollars.

2. Fuel Costs. Fuel costs are defined in BICYCLE as the net cost of the raw material that produces the product. For example, fuel costs for a coal generating plant would be the cost of coal. Fuel costs of any coal required by the plant would be included in operation and maintenance costs. These costs are also in current year dollars.

3. Income Taxes. The expression for the calculation of income taxes for year k, shown in Section II, is

(income tax rate) x (revenue in year k - deductible expense in year k)

Depending on the relative magnitude and time dependence of the revenues and expenses, there may be cases where revenues minus deductible expenses could be negative during some years of a project's lifetime. As a result, there may be cases where the income taxes are negative during some years. In fact, there may be some years when the reduction of the capital investment is negative, which means that the total outstanding capital has increased in these years. Of course, the total capital must still equal zero at the end of the project's lifetime (including the salvage value credit).

4. Depreciation Allowance. Two methods of calculating depreciation allowance are included in BICYCLE—straight-line depreciation and sum-of-digits depreciation. The expression for the depreciation allowance dep_k for each method is given below.

$$dep_k = \frac{I_1}{K} + f_l A_k \quad \Big\} \quad \text{straight-line depreciation}$$

$$dep_k = \frac{I_1}{\sum_{k'=1}^{K} k'}(K+1-k) + f_d A_k \quad \Big\} \quad \text{sum-of-digits depreciation,}$$

where
I_1 = initial capital investment ($),
K = project lifetime (years).

The terms $f_l A_k$ and $f_d A_k$ are for depreciation of any capital added after the start of the project. This is only for funds that must be capitalized as opposed to being expensed. Most projects will not have any A's. If capital is added in year k, the added depreciation begins in year k+1, since the capital is assumed to be added at the end of the year. The formulas for these terms are:

$f_l A_k = 0$ for $k <= k_1$

$$= \frac{A_{k_1}}{K - k_1} \quad \text{for } k_1 < k <= k_2$$

$$= \frac{A_{k_2}}{K - k_2} \quad \text{for } k_2 < k <= k_n$$

$$= \frac{A_{k_n}}{K - k_n} \quad \text{for } k > k_n$$

k_1 = the year that the first additional capital, A_{k_1} is added to the project
k_2 = the year that a second addition to capital, A_{k_2} is added to the project
k_n = the last year that has additional capital, A_{k_n}
The term, $f_d A_k$, for the sum-of-the-digits method, is calculated in the same way as the straight line method except that the term 1/(K - k) in the denominator is replaced by the term

$$\frac{(K - k_n) + 1 - (k - k_n)}{\sum_{k'=1}^{K-k_n} k'} = \frac{K + 1 - k}{\sum_{k'=1}^{K-k_n} k'} \quad \text{for } k_n < k <= k_{n+1}$$ where k_n is any year that capital is added.

D. Treatment of Inflation

A common error in economic analyses is to improperly mix inflated and deflated parameters. For example, inflated money costs are used with deflated expenses, or vice versa. The general form for the levelized life-cycle cost equation is

$$L = \frac{\sum_{k=1}^{K} \frac{C_k}{(1+j)^k}}{\sum_{k=1}^{K} \frac{E_k}{(1+j)^k}} \qquad (9)$$

where
- C_k = expenditures in year k,
- E_k = quantity of product produced in year k,
- j = discount rate, and
- K = project lifetime.

If the expenditures and the interest rate are both inflated parameters, then L is the inflated levelized lifecycle cost. The trouble with such a parameter is that it is difficult to have a "feel" for such a value because it is not in today's dollars. One solution, the use of deflated parameters for both expenditures and the interest rate, gives levelized costs that are in constant dollars. However, income tax effects will result in errors if inflation really does occur.

A more satisfactory solution is to use the following expression.

$$\text{income} = \sum_{k=1}^{K} \frac{E_k L_{in}}{(1 + j_{in})^k}$$

$$= \sum_{k=1}^{K} \frac{E_k L_{de} (1+z)^k}{(1 + j_{in})^k}$$

where

L_{in} = inflated levelized cost,
L_{de} = deflated levelized cost,
j_{in} = inflated discount rate, and
z = inflation rate.

Solving this equation for L_{de}

$$L_{de} = \frac{L_{in} \sum_{k=1}^{K} \frac{E_k}{(1+j_{in})^k}}{\sum_{k=1}^{K} \frac{E_k (1+z)^k}{(1+j_{in})^k}} \tag{10}$$

By substituting Eq. (9) into Eq. (10), where inflated parameters are used in Eq. (9), we get

$$L_{de} = \frac{\sum_{k=1}^{K} \frac{C_k^{in}}{(1+j_{in})^k}}{\sum_{k=1}^{K} \frac{E_k (1+z)^k}{(1+j_{in})^k}} \tag{11}$$

The denominator of Eq. (11) is frequently written as

$$\sum_{k=1}^{K} \frac{E_k}{(1+j_{de})^k}$$

where j_{de} is the deflated discount rate. The expression for j_{de} is given by

$$j_{de} = \frac{(1+j_{in})}{(1+z)} - 1$$

Although this approach gives levelized life-cycle costs in constant dollars (referred to as "price year" dollars), it also takes into account the impact of inflation on income taxes. BICYCLE calculates levelized life-cycle costs in both constant and current, or inflated, dollars.

E. Simplified Solution for Special Case

There is a special simpified case (no summation signs) for computing levelized life-cycle costs that can be used when certain assumptions are made. Even when all the assumptions are not met, this equation can be used for “back of the envelope” estimates. The assumptions that must be made are:

(1) revenue tax = 0,
(2) straight line depreciation is used,
(3) the product output is the same for each year,
(4) no capital is added after the start of the project, ie., all A_k’s = 0, and
(5) the expenses are the same for each year, ie. all oam_k’s are equal and all $fuel_k$’s are equal,

Since the O & M and fuel costs are assumed constant, this simplified levelized life-cycle cost is really an approximation of the deflated levelized life-cycle cost L_{de}. Therefore, the salvage value used in this case should be deflated.

$S_{de} = S/(1 + z)^K$

With these assumptions, the levelized life-cycle cost for the proportional case is

$$L_{de} = \frac{\displaystyle\sum_{k=1}^{K} \frac{cap_k + (oam_k + fuel_k)(1-t) - t \text{ x } dep_k}{(1+i')^k}}{(1-t)\displaystyle\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}}$$

where $cap_k = \left[I_1 - \frac{S_{de}}{(1-i')^K} \right] \frac{i'(1+i')^K}{(1+i')^K - 1}$

$$L_{de} = \frac{\displaystyle\sum_{k=1}^{K} \frac{cap_k}{(1+i')^k}}{(1-t)E_k \displaystyle\sum_{k=1}^{K} \frac{1}{(1+i')^k}} + \frac{oam_k + fuel_k - t/(1-t) \text{ x } dep_k}{E_k} \text{ x } \frac{\displaystyle\sum_{k=1}^{K} \frac{1}{(1+i')^k}}{\displaystyle\sum_{k=1}^{K} \frac{1}{(1+i')^k}}$$

$$= \frac{I_1 - S_{de}/(1+i')^K}{(1-t)E_k \displaystyle\sum_{k=1}^{K} \frac{1}{(1+i')^k}} + \frac{oam_k + fuel_k - t/(1-t) \text{ x } dep_k}{E_k} .$$

Since $\displaystyle\sum_{k=1}^{K} \frac{1}{(1+i)^k} = \frac{(1+i)^K - 1}{i(1+i)^K}$,

$$L_{de} = \frac{i' \text{ x } (I_1 + S_{de}/(1+i')^K)}{(1-t)(1-1/(1+i')^K)E_k} + \frac{oam_k + fuel_k - t/(1-t) \text{ x } dep_k}{E_k} .$$

Using the same assumptions for the fixed debt payment case,

$$L_{de} = \frac{\displaystyle\sum_{k=1}^{K} \frac{cap_k + tot_k(1-t) + bin_k + bp_k - t(dep_k + bin_k)}{(1+i_e)^k}}{(1-t)\displaystyle\sum_{k=1}^{K} \frac{E_k}{(1+i_e)^k}} .$$

where, for this case

$$cap_k = \left[I_1^e - \frac{S_{de}}{(1+i_e)^K} \right] \text{ x } \frac{i_e(1+i_e)^K}{(1+i_e)^K - 1}$$

The sum $bin_k + bp_k$ is a constant, $bin_k + bp_k = b \text{ x } i_b \text{ x } I_1 \text{ x } (1 + 1/((1+i_b)^K - 1))$

The term, bin_k is not constant but can be derived.

$$\sum_{k=1}^{K} \frac{bin_k}{(1+i_e)^k} = \frac{i_b \text{ x } b \text{ x } I_1}{(1+i_b)^K - 1} \left[\frac{(1+i_b)^K}{(1+i_e)^K} \text{ x } \frac{\left((1+i_e)^K - 1\right)}{i_e} - \frac{1 - \frac{(1+i_b)^K}{(1+i_e)^K}}{i_e - i_b} \right]$$

Therefore, for the constant debt payment case.

$$L_{de} = \frac{I_1 - S_{de}/(1+i_e)^K}{(1-t)E_k}\left[\frac{i_e(1-b)}{1-1/\left(1+i_e\right)^K} + \frac{bi_b}{1-1/\left(1+i_b\right)^K}\left(1-t+t\left(\frac{1/\left(1+i_b\right)^K - 1/\left(1+i_e\right)^K}{\left(1-i_b/i_e\right)\left(1-1/\left(1+i_e\right)^K\right)}\right)\right)\right]$$

$$+\ \frac{oam_k + fuel_k - t/(1-t)\ \text{x}\ dep_k}{E_k}$$

To get an approximation of the inflated life-cycle cost, L_{in}, the inverse of Equation 10 can be used. Starting with Equation 10,

$$L_{de} = \frac{L_{in}\sum_{k=1}^{K}\frac{E_k}{(1+j_{in})^k}}{\sum_{k=1}^{K}\frac{E_k(1+z)^k}{(1+j_{in})^k}}$$, the value of L_{in} can be derived by rearranging to get

$$L_{in} = L_{de}\ \text{x}\ \frac{\sum_{k=1}^{K}\frac{(1+z)^K}{(1+j_{in})^K}}{\sum_{k=1}^{K}\frac{1}{(1+j_{in})^K}} = L_{de}\ \frac{1+z}{1-z/j_{in}}\left[\frac{1-\frac{(1+z)^K}{(1+j_{in})^K}}{1-1/(1+j_{in})^K}\right].$$

III. INPUT INSTRUCTIONS

Table II is a copy of the time independent section and the first few years of the time-dependent section of the input sheet from a sample case. The total length of the time-dependent section will depend on the Excel[TM] plant lifetime.

Table II. Sample Input

CLEAN COAL LEVELIZED COST ESTIMATOR

Time-Independent Data	
Investment in bonds (fraction)	0.6
Nominal interest rate, bonds (fraction/yr.)	0.04
Nominal rate of return, equity (fraction/yr.)	0.1
Inflation rate (fraction/yr.)	0.03
Depreciation: 0=str. line; 1=sum of digit	0
Debt repayment: 0=proportional; 1=constant	1
Income tax rate (fraction)	0.5
Plant lifetime (Years)	30
Initial capital cost (K$)	1200
Salvage value (K$)	24
Gross revenue tax (fraction)	0.03

Time- Dependent Data					
Year	*Depreciation (K$/yr.)*	*O&M cost (K$/yr.)*	*Fuel cost (K$/yr.)*	*Output (mWh/yr.)*	*Added cap invest. (K$)*
1	38.06	50	100	5000	0
2	38.06	50	100	5000	0
3	38.06	50	100	5000	0

A. Time Independent Data

The top section of Table II is for input of time-independent data. Each of these constants will be described in this section.

1. Investment in Bonds. This number is the fraction of the initial capital investment that is obtained by issuing bonds. For the proportional method, any capital added after start-up (ie., any A_k's), will also be divided proportionately between equity and bonds by the ratio of this fraction. For the fixed debt repayment method, this fraction is used only for the initial capital and any capital added after start-up increases only the equity investment portion.

2. Nominal Interest Rate, Bonds. This is the interest rate or coupon rate of the bonds used to help finance the project with no correction for inflation. It is input as a fraction per year. It is assumed that these bonds will all mature at the end of the project lifetime Yearly payments are made to both principal and interest with the fraction depending on whether the proportional or fixed debt repayment method is used.

3. Nominal rate of Return, Equity. This is similar to the bond interest rate, but is the payment to the equity portion of the investment with no correction for inflation. It is input as a fraction per year. Yearly payments are made to equity just as they are to debt with a fraction used to pay back the equity capital and a fraction used for return on equity. The fraction will depend on whether the proportional or the fixed debt repayment method is used.

4. Inflation rate. This the estimated average inflation rate over the lifetime of the project, input as a fraction per year. Although, inflation will vary over the lifetime of the project, this analysis assumes a constant inflation rate for the total lifetime. This term is used to estimate the deflated levelized life-cycle cost.

5. Depreciation. This input is either a 0 or a 1. If it is a 0, the code uses straight line depreciation to calculate the depreciation over the plant lifetime. The initial capital will be depreciated uniformly over the plant lifetime. Any capital that is added after start-up will be depreciated uniformly over the lifetime remaining from the time of the addition of the capital. In other words, if capital is added in Year 5 of a 30 year lifetime plant, then that capital is depreciated over Years 6 through 30.

If this input is a 1, the code uses the sum-of-the-year-digits method of depreciation over the plant lifetime. The depreciation is treated the same way as straight line except that instead of constant yearly values, the values decrease over the lifetime.

Future depreciation values are fixed at the time of added capital, independent of any inflation assumptions. This is because depreciation schedules are usually chosen because of income tax considerations and the assets are depreciated as fast as the tax code allows.

6. Debt Repayment. This input is either a 0 or a 1 reflecting two methods of debt repayment. Input a 0 for the proportional method and a 1 for the fixed debt repayment method. For the proportional case, the debt capital and equity capital are paid off in a constant ratio. Therfore, throughout the lifetime of the project, the ratio of outstanding debt to outstanding equity is constant. For the fixed payment case, the entire debt schedule is fixed in advanced. Therefore, any expenses that occur after the start of the project come from equity capital.

7. Income Tax Rate. This is the average income tax rate, input as a fraction, that the project pays on net earnings.

8. Plant Lifetime. This is the assumed lifetime of the plant in years. This number is used by the code to fill in the first column of time-dependent data with the appropriate year. For this version of the code, this number is used for the length of time for capital repayment (both debt and equity) and the length of time for depreciation. In future versions, these lifetimes will be decoupled.

9. Initial Capital Cost. This is the initial capital investment in the plant in thousands of dollars. If the plant is constructed over a number of years, the initial capital cost includes the capital outlays over those years plus the interest during construction. The expression for initial capital cost in this case is

$$I_1 = \sum_{n=1}^{N} G_n (1+i)^{N-n}$$

where
G_n = capital cost outlay in year n of construction,
i = interest rate during construction, and
N = number of years for capital construction.

10. Salvage Value. This is the estimated salvage value of the plant at shut-down in thousands of dollars. It is in inflated year of shut-down dollars. It should be the net salvage value, subtracting any decommissioning costs if the plant is actually shut-down. If the plant continues to operate, the salvage value should be the market value of the plant at shut-down minus any taxes that would be paid if it were sold, since the assests have been fully depreciated. If inflation were very high and the plant still had several years of useful life left, the salvage value could actually be more than the total depreciation.

11. Gross Revenue Tax. This is the tax rate as a fraction of any taxes paid on the total revenues. An example would be a state sales tax on electrical output.

B. Time Independent Data.

The bottom section of Table II is for input of time independent data. The costs (credits) in these columns are assumed to occur at the end of each year. Each of the columns will be described in this section.

1. Year of operation. The column is filled in by the code based on the plant lifetime input.

2. Depreciation. This column is also filled in by the code based on the number (0 or 1) that was input for depreciation as described above. Of course, the user could change these values, but the formulas in the cells would be lost. If these numbers are changed, the total depreciation must equal the total added capital. The numbers in this column will make a step increase in any year after capital is added, reflecting the additional depreciation of this added capital.

3. O & M Cost. The O & M costs are all the non-fuel expenses in thousands of dollars. As described in Section IIC, the fixed costs are included with the operation and maintenance costs. The operation and maintenance costs will consist of two types—fixed and variable. Fixed costs are independent of the capacity factor and include such things as property insurance, property taxes, and other fixed costs. Variable costs are of two types. One type are costs that are proportional to the capacity factor, such as fuel costs used to operate the plant. The other type are one time costs such as expensed capital replacements. All costs are in inflated (current year) dollars. For example, if future costs must be estimated, and it is assumed that the actual constant dollar value of O & M in Year 2 is the same as in Year 1, then with an inflation rate of 3%, the value in Year 2 should be input as 1.03 times the value in Year 1.

4. Fuel Costs. This is the cost of the coal used to generate electricity in thousands of dollars. It is in inflated current year dollars just like the O & M costs. It should only include the cost of fuel used to generate electricity. Any fuel used to run the plant or for auxillary equipment should be included in the variable O & M costs.

5. Output. This column is for the yearly electrical output of the plant in megawatt-hours/year. It should be the actual output for each year which means that it should include the effects of capacity factor and any down times during the year.

6. Added Capital Investment. This column is for any capital that is added after plant start-up in thousands of dollars. It should be in inflated (current year) dollars. It should only be for funds that are capitalized. Any capital funds that can be expensed should be included in O & M costs. Normally there would be few if any additions to capital after plant start-up.

IV. OUTPUT RESULTS

Table III is a copy of the top section of the ouput sheet from a sample case, showing the cost of money and the levelized life-cycle cost, and the first few years of the cash flow section.

Table III. Sample Output

COST OF MONEY (yearly rate)	
Nominal rate	0.064
Tax adj. nominal rate	0.052
Real rate	0.03301
Tax adj. real rate	0.02135

LEVELIZED LIFE-CYCLE COSTS	Current ($/kWh)	Constant ($/kWh)
Capital	0.0185	0.0138
O&M	0.0100	0.00744
Fuel	0.0200	0.01488
Income tax	0.0062	0.0046
Gross revenue tax	0.0017	0.0013
Total	0.0564	0.0420

YEARLY CASH FLOWS

Year	Revenue (K$)	Interest on debt (K$)	Return on eq. (K$)	Income tax (K$)	O&M costs (K$)	Fuel costs (K$)	Tot cap reduction (K$)	Tot cap at end of year (K$)	Outst. equity (K$)	Outst debt (K$)	Gross rev tax (K$)
1	282.06	28.80	48.00	28.37	50.00	100.00	18.43	1181.57	474.41	707.16	8.46
2	282.06	28.29	47.44	28.63	50.00	100.00	19.25	1162.32	468.51	693.81	8.46
3	282.06	27.75	46.85	28.90	50.00	100.00	20.10	1142.22	462.30	679.93	8.46

A. Cost of Money.

The cost of money table gives the values of "i" used in the code. The nominal yearly rate, $i=i_e(1-b)+i_b b$ is the weighted average value of the cost of equity and the cost of debt. The tax adjusted nominal rate, $i' = i - t b i_b$, accounts for the fact that interest on debt is tax deductible. The real yearly rates are the nominal rates adjusted for inflation. The tax adjusted real rate is equal to $((1+i')/(1+z))-1$.

B. Levelized Life-cyle Costs.

Both inflated (current dollar case) and deflated (constant dollar case) levelized life-cycle costs are computed. The equations defining these variables are derived in the methods section. Only the current life-cycle cost case is used for the cash flow calculations in the bottom section of the table.

C. Yearly Cash Flows.

This table shows the cash flow for each year. In addition, to showing the cash flow of revenue and expenses, it shows the current equity, debt, and total capital oustanding at the end of each year. Note that at the end of the last year, the outstanding capital must equal the salvage value.