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ABSTRACT

This paper describes a simplified methodology to compare supply and demand-side resources. The *screening curve approach* supplements with load shape information the data contained in a supply curve of conserved energy. In addition, a screening curve contains information on competing supply technologies, such as annualized capital costs, variable costs, and cost per delivered kWh. The information in the screening curve allows policymakers to promptly and conveniently compare the relevant parameters affecting supply and demand-side investment decisions.

While many sophisticated computer models have evolved to account for the load shape impacts of energy efficiency investments, this sophistication has, by and large, not trickled down to spreadsheet-level or "back-of-the-envelope" analyses. Our methodology allows a simple summary of load shape characteristics based on the output of the more complicated models. It offers many advantages, principal of which is clarity in analyzing supply and demand-side investment choices.

This paper first describes how supply-side screening curves have been used in the past, and develops the conceptual tools needed to apply integrated supply/demand screening curves in the least-cost utility planning process. It then presents examples of supply and demand-side technologies and plots them on a representative screening curve.

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INTRODUCTION

This paper describes a simplified methodology to compare supply and demand-side resources. The *screening curve approach* supplements with load shape information the data contained in a supply curve of conserved energy. In addition, a screening curve contains information on competing supply technologies, such as annualized capital costs, variable costs, and cost per delivered kWh. The information in the screening curve allows policymakers to promptly and conveniently compare the relevant parameters affecting supply and demand-side investment decisions.

While many sophisticated computer models have evolved to account for the load shape impacts of energy efficiency investments, this sophistication has, by and large, not trickled down to spreadsheet-level or back-of-the-envelope analyses. Our methodology allows a simple summary of load shape characteristics based on the output of the more complicated models. It offers many advantages, principal of which is clarity in analyzing supply and demand-side investment choices.

This paper illustrates the uses of screening curves in the least-cost utility planning process. The first section explores the conventional uses of screening curves for presenting information on supply technologies. The second section develops the concepts needed to plot demand-side technologies on a screening curve. The third section uses detailed examples of supply and demand-side technologies from the appendices to create a representative supply/demand screening curve.

SCREENING CURVES FOR SUPPLY TECHNOLOGIES

In the past, utility planners used a tool called a "screening curve" for preliminary analysis of the cost of new supply options. This curve was obtained from a set of plots for supply options, with each plot showing the capacity factor[1] on the x-axis and annual power plant cost (fuel plus capital) per installed kW on the y-axis. A typical screening curve for supply options is shown in Figure 1. The y-intercept is the annualized capital cost of the power plant, and the slope

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[1] The capacity factor (range 0 to 1) is defined as the number of kWh generated by a power plant in some time period, divided by the number of kWh that would be generated if the plant operated at rated capacity for that time period. In India and Britain this term is called plant load factor.

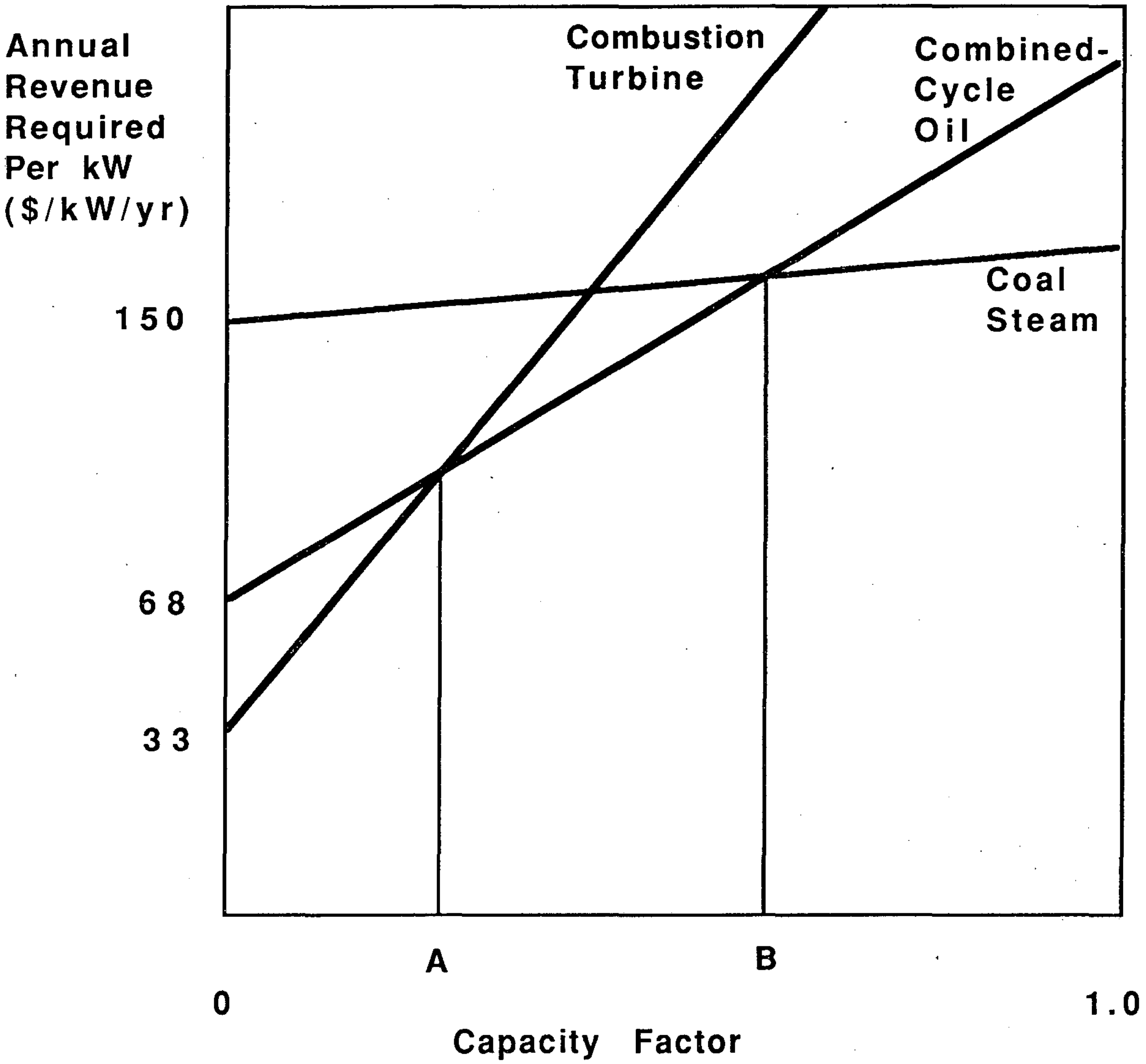

Figure 1: Conventional Screening Curve: Such a graph contains information on both capital and operating costs of power plants. The lines plotted here are also used in Figure 3.

of the cost curve for each option represents the variable cost of operating the plant. In this figure, we see that combustion turbines are the cheapest solution at low capacity factor (0 to A), but the high operating costs of these plants soon make them more expensive when operated at a capacity factor greater than A. High capital cost baseload plants are only economic when operated at capacity factors greater than B.

A power purchase from other utilities or from independent power producers may also be included on a screening curve. The annual fixed cost of the contract is the same as the annualized capital cost of a power plant, while the per kWh cost is analogous to the variable cost of the plant.

The screening curve establishes the envelope within which a supply option will be economic, and reduces the number of options to analyze. Thus, if the projected cost curves of three new supply technologies fell well below the envelope, these options would be worthy of further analysis. This tool, while admittedly a crude one, serves to "screen out" options that cannot possibly be economic. Such screening tools were especially important in the days before the advent of abundant and inexpensive computing power, but they can still be useful as a simple summary of the essential characteristics of supply technologies.

A limitation of this approach is that it is a single year "snapshot", based on certain fuel price assumptions. The curves may be based on current fuel prices or on some levelized estimate of future prices.[2] A levelization procedure may also be used to compensate for projected power plant cost escalation.

CHARACTERISTICS OF ENERGY-EFFICIENCY INVESTMENTS

This section lays the conceptual groundwork for integrating supply and demand side resources on a screening curve. It first presents two of the most widely used measures of conservation's cost effectiveness and describes their advantages. It then describes the *conservation load factor* and its uses.

Evaluating Conservation's Cost

When evaluating energy-efficiency technologies, analysts typically calculate the Cost of Conserved Energy (CCE, in $/kWh) and the Cost of Avoided Peak Power (CAPP, in $/kW) (Meier et al. 1983). Both CCE and CAPP are used in supply curves of conserved energy and avoided peak power, ranked in order of increasing CCE and CAPP. Creating these curves typically involves detailed calculations for dozens or hundreds of conservation options. Figure 2 shows a representative supply curve of conserved energy from the Michigan Electricity Options Study (Krause et al. 1987).

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[2] Levelization is a kind of present-value average of expected prices over some future period. For more details, see EPRI 1987, pp.2.8-2.12.

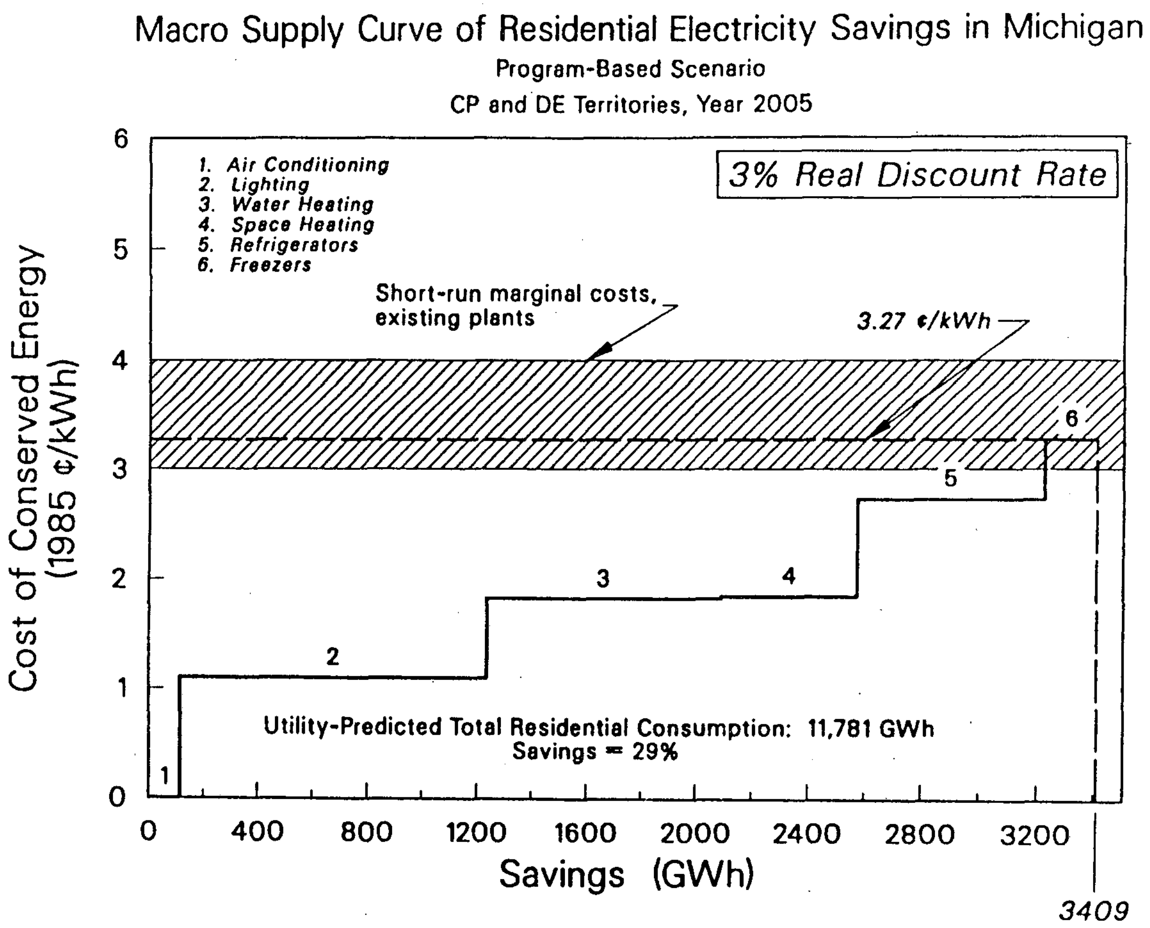

Figure 2: Supply Curve of Conserved Electricity for Michigan's Residential Sector
Source: Krause et al 1987.

CCE and CAPP are useful because they allow ostensibly consistent comparisons between characteristics of energy conservation and energy supply technologies. The procedure for calculating both quantities involves annualizing the total cost of the conservation technology, and dividing by the number of kWh saved or peak demand (kW) avoided. CCE is analogous to the busbar cost of a power plant (adjusted to represent the cost per *delivered* kWh), while CAPP may be compared to the capital cost of the plant per delivered kW.

However, it is arbitrary to allocate all of the costs of conservation technologies to peak power savings; this approach reflects a fundamental problem in using CAPP for all but load management technologies. Busbar cost is widely used because it summarizes information about capital costs, fuel costs, and operation of the power plant. CCE is a more useful measure than CAPP in part because its analogue, busbar cost, is more inclusive and general than the corresponding measure of power plant capital cost per installed kW.

Introduction to the Conservation Load Factor

This section introduces a new concept, called the conservation load factor or CLF. Once the CLF is determined through simulation or measurement, it allows straightforward calculation of the peak demand avoided from a given amount of energy savings, as well as the *value of conserved energy*, which can be compared to the CCE. This formulation can be useful in back-of-the-envelope or spreadsheet analyses of conservation measures. The CLF is analogous to the capacity factor, which allows demand and supply-side resources to be plotted side by side on a screening curve, as shown in the next section.

The CLF is defined as:

$$\mathrm{CLF} = \frac{\textbf{Average Annual Load } \textbf{\textit{Savings}}}{\textbf{Peak Load } \textbf{\textit{Savings}}} \qquad (1)$$

where average annual load savings is the conservation measure's expected kWh savings divided by 8760 hours, and the peak load savings (i.e., savings at the time of utility peak demand) is based on measured data or on the output of an hourly simulation model.[3] The peak load savings are a function of the utility's load profile, the diversity and shape of end-use loads, and the coincidence of energy savings with peak demand.

Previous analysis indicates that the CLF of efficiency measures for U.S. refrigerators is approximately 0.86, while for U.S. air conditioners it averages 0.15 but may range from 0.08 to 0.28, depending on climate (US DOE 1988). A conservation technology that saves a constant amount of power on a continuous basis has a CLF of 1.0.

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[3] If peak demand savings equal zero then the CLF is undefined.

Although the CLF usually ranges from 0 to 1.0, in principle it may exceed one, if a conservation measure saves energy principally in off-peak periods (e.g., variable-speed compressors for air conditioners). The screening curve's abscissa may be extended to account for such measures, even though power plant capacity factors cannot exceed 1.0. A better solution is to plot only those conservation measures with a CLF between 0 and 1 (which are by far the majority) and include the CLFs for *all* measures in a table that summarizes the essential characteristics of each measure.

The CLF is analogous to both the utility load factor[4] and the power plant capacity factor, and it is related to the more commonly used diversified load factor (DLF). The DLF is calculated as the ratio of the average load of a group of appliances to the measured peak demand of the same set of appliances. If the peak demand is averaged over the hours when the utility needs capacity, the peak load *savings* from a conservation measure can be calculated using the diversified load factors for efficient and inefficient appliances.[5]

The demand savings used to calculate the CLF should be the *coincident* demand savings, since only at time of system peak do energy savings displace capacity. The utility will operate dispatchable supply options with low first costs and high operating costs (such as gas turbines) during those few hours when capacity is needed. Coincidence with peak demand is therefore implicit for these technologies. The CLF must be based on coincident peak demand savings to allow direct comparison to power plant capacity factors.

It would be most accurate to use a loss-of-load probability (LOLP)[6] weighted average (over the hours of significant LOLP) of measured or calculated peak demand savings in Equation 1, although in practice cruder approximations are often used.[7] To illustrate how LOLP may be used and to show how this definition of peak load savings can account for seasonal variations, consider a hypothetical utility with LOLP split evenly between two peak hours, one of which is in the summer and one of which is in the winter. This situation reflects that of a utility with sharply peaked summer and winter demands of about the same magnitude. Table 1 shows Central Air Conditioner

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[4] Defined as $\frac{\text{Average Class Load}}{\text{Highest Hourly Class Load}}$.

[5] The DLF may be different for the efficient appliances because the conservation measure may change the shape of the appliance load curve.

[6] LOLP is defined as the probability, in any hour, of the load exceeding the available generating capacity. It is a highly non-linear function that tends to be concentrated in the 100 to 500 highest hours of load. For more details, see Kahn 1988, pp.81-86.

[7] One such approximation is to average the load savings over the 200 highest residential or commercial hourly loads; another is to average the savings over the hours of noon-6pm in the summer. Many other approximations can be used to account for both diversity and coincidence, all of which are imperfect. They can be improved in accuracy through an iterative process of measurement and simulation.

TABLE 1: WEIGHTING PEAK DEMAND SAVINGS BY LOLP

	*LOLP**	*CAC Load Savings*	*Refrigerator Load Savings*
Summer Peak Hour	0.5	381 W	86 W
Winter Peak Hour	0.5	0 W	86 W
LOLP-Weighted Peak Load Savings		190 W	86 W
Average Load Savings		57 W	74 W
CLF (Split Peak)		0.30	0.86
CLF (Summer Peak Only)		0.15	0.86

Energy savings are from Table 3.

*LOLP = Loss of Load Probability, which is the probability of load exceeding available capacity. We have followed custom and normalized LOLP to 1.0. In this example, LOLP is split evenly between two peak hours, one in summer and one in winter.

(CAC) and Refrigerator wattage savings in each of the two peak hours (based on Table 3). It also shows CLFs calculated for the split peak case and for another case where only the summer peak load savings count. Refrigerators, which reduce demand in both summer and winter, contribute the same amount of peak load savings all year round, leading to a CLF in both cases of 0.86.[8] CAC savings, which are concentrated in the summer, are substantially affected by weighting over summer and winter LOLP. The effect is to reduce the capacity value of CAC savings in a utility with split peaks. In this case, CACs save only half as much capacity per unit of energy savings as if the savings occurred in a utility with only a summer peak.

Multiplying both numerator and denominator in Equation 1 by 8760 hours gives:

$$\text{CLF} = \frac{\text{Annual Energy Savings (kWh)}}{\text{Peak Load Savings (kW)*8760 hours}} \qquad (2)$$

Once the CLF is determined through measurement or calculation of energy and peak demand savings, this equation gives the number of kWh of energy savings to avoid 1 kW of peak demand:

$$\text{CLF*8760 hours} = \frac{\text{Annual Energy Savings}}{\text{Peak Load Savings}} = \frac{\text{kWh}}{\text{kW}} \qquad (3)$$

Equation 3 may be used to calculate the *value* of capacity (kW) saved ($/kWh), given information on the cost per kW of the appropriate proxy power plant (US DOE 1988). For example, suppose the annualized cost of a combustion turbine proxy is $33/kW/yr (adjusted for reserve margin and system losses--see Table 2), and the CLF of a conservation measure for an air conditioner is 0.15. Because 1314 kWh (0.15x8760) of energy savings results in 1 kW of peak demand savings, each kWh saved with this efficiency measure is worth 2.5¢ (=$33/1314 kWh). A conservation measure with a low CLF will have a high capacity value per kWh, as we expect.

The capacity value can be added to the fuel cost avoided by each kWh (i.e., the short-run marginal cost) to get a *value of conserved energy* ($/kWh) that can be compared directly to the CCE. A demand-side measure is economic if the value of conserved energy is larger than the CCE.

Once the CLF is determined, equation 3 can be used to calculate the amount of peak demand savings from a given amount of energy savings.

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[8] Many studies indicate that refrigerator load savings may vary substantially by season. We ignore this effect for simplicity.

TABLE 2: SUPPLY TECHNOLOGIES			
PARAMETER	CT GAS	COMBINED CYCLE OIL	BASELOAD COAL
FIXED COSTS			
Lifetime (Years)	30	30	40
CRF	0.073	0.073	0.067
Capital Cost ($/kW)	348	618	1421
Annualized Capital Cost ($/kW/yr)	25.58	45.38	95.66
Fixed O&M ($/kW/yr)	0.506	8.315	22.585
Sum of Fixed Costs ($/kW/yr)	*26.08*	*53.69*	*118.25*
T&D + Reserve Margin Adjustment	1.272	1.272	1.272
ADJUSTED FIXED COSTS ($/KW/YR)	*33.18*	*68.30*	*150.41*
VARIABLE COSTS			
Incremental O&M (¢/kWh)	0.48	0.21	0.56
Heat Rate (Btus/kWh)	13900	8440	9660
Fuel Price ($/MMBtu)	3.04	3.58	1.67
Fuel Cost (¢/kWh)	4.2	3.0	1.6
Sum of Variable Costs (¢/kWh)	*4.7*	*3.2*	*2.2*
T&D Adjustment	1.06	1.06	1.06
ADJUSTED VARIABLE COSTS (¢/KWH)	*5.0*	*3.4*	*2.3*
DELIVERED COST @ 100% CAP.FACTOR (¢/KWH)	*5.4*	*4.2*	*4.0*

ASSUMPTIONS

T&D Losses	1.06
Reserve Margin	1.2
Real Discount Rate	6.1%

All Costs in 1988 $

Source: EPRI 1986

TABLE 3: CONSERVATION TECHNOLOGIES

PARAMETER	REFRIG-ERATOR	CAC	COMPACT FLOURESCENT LOW USE	COMPACT FLOURESCENT HIGH USE	ELECT. BALLAST LOW USE	ELECT. BALLAST HIGH USE
Usage (hours/yr)	*	*	2000	8760	2700	8760
Lifetime (hours)	*	*	7500	9000	45000	45000
Lifetime (years)	20	15	3.75	1.03	16.67	5.14
Capital Recovery Factor	0.088	0.104	0.306	1.034	0.097	0.233
Incremental Capital Cost ($)	95	380	15	15	12	12
Annualized Capital Cost ($/yr)	8.35	39.38	4.60	15.50	1.17	2.79
Additional Maintenance Cost ($/yr)	0	0	0	0	0	0
Other Costs Avoided ($/yr)	0	0	1.33	5.84	0	0
Total Annualized Cost ($/yr)	8.35	39.38	3.26	9.66	1.17	2.79
Annual Energy Savings (kWh/yr)	650	500	90	394	89	289
CCE (¢/KWH)	*1.3*	*7.9*	*3.6*	*2.5*	*1.3*	*1.0*
Peak Load Savings (W)	86	381	45	45	33	33
Average Load Savings (W)	74	57	10	45	10	33
CLF	*0.86*	*0.15*	*0.23*	*1.00*	*0.31*	*1.00*
ANNUAL COST PER KW SAVED ($/KW/YR)	*96.78*	*103.50*	*73.02*	*214.73*	*35.57*	*84.58*

ASSUMPTIONS *All costs in 1988 $* Real Discount Rate 6.1%

*Refrigerators and CACs are cycling appliances for which lifetime is not simply related to hourly usage.

Sources: Krause et al. 1987, Turiel 1987, Rosenfeld et al 1988, Gordon et. al 1988, and Geller et al 1987.

Equation 3 also suggests that a close relationship exists between the CLF and the power plant capacity factor. For a baseload plant, one kW that generates 5700 kWh has a capacity factor of 0.65, while a conservation measure that saves 5700 kWh and reduces peak demand by 1 kW has a conservation load factor of 0.65.

INTEGRATING SUPPLY AND DEMAND TECHNOLOGIES

Capacity factors and CLFs may be used to plot conservation options on a screening curve, as shown in Figure 3. All conservation options are represented by points (squares, triangles, circles, diamonds), all supply options by solid lines. The y-coordinate of the point representing a conservation measure is the annualized additional capital and maintenance cost[9] of the conservation measure per kWh saved (which has nothing to do with the operating cost of the appliance). The x-coordinate equals the CLF or the capacity factor.

The three new conventional supply options shown in Figure 3 produce a representative screening curve, which may be seen as the upper limit to cost-effective conservation resources. A conservation measure is then attractive if its point falls below the boundary for the corresponding electricity supply technology. The dotted lines starting from the origin (lines of constant $/kWh) represent the short-run marginal cost (SRMC) of energy from existing generating plants, with zero capital costs (the plants are already purchased).[10] These lines also represent the cost of conserved energy or cost per delivered kWh for demand and supply options falling on that line.

A conservation measure with a CLF close to zero saves a larger amount of peak demand than a measure with a CLF close to 1, and thus has a larger capacity value per kWh. The screening curve shows that even measures with relatively high CCEs (such as central air conditioner efficiency improvements) may still be economic if the energy savings is concentrated in peak hours (i.e., the CLF is close to zero). The screening curve accurately portrays the tradeoff between high CCE and low CLF.

The particular characteristics of each technology are not as important for our purposes, since we care more about the method for plotting them. We discuss these characteristics below. Appendix A contains technical details

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[9] Designers of an integrated screening curve must decide which cost perspective they wish to illustrate (e.g., utility or societal). In this paper, we adopt the societal perspective, but avoid the added complication of estimating the externalities associated with electricity production. The subtleties of defining these perspectives have been addressed in Krause et. al 1988.

[10] Using one number to represent the marginal costs over the entire year is a crude approximation, but it is entirely in the spirit of the screening curve approach.

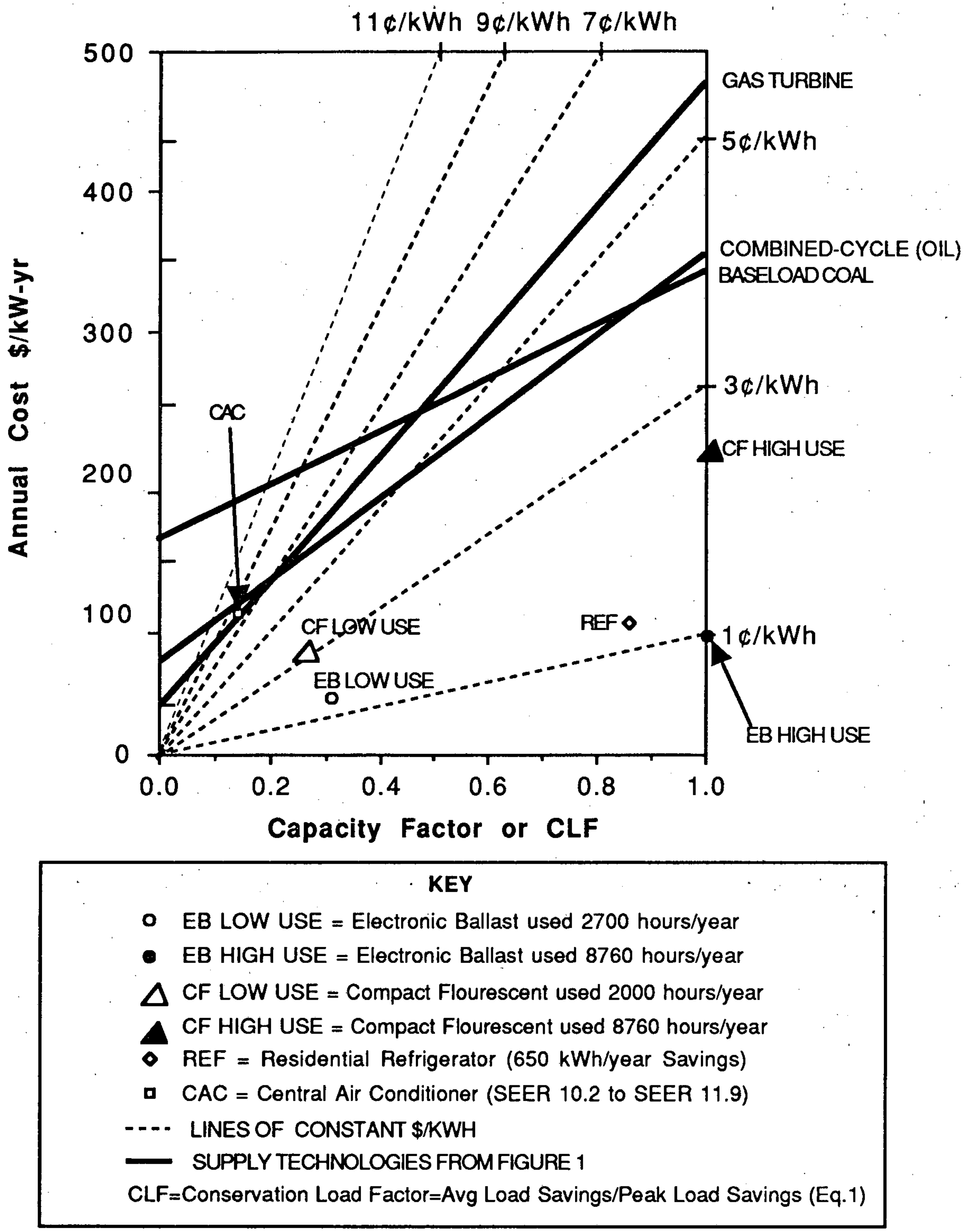

Figure 3: Integrated Screening Curve: This graph shows both supply and demand-side technologies on a comparable basis.

about the supply technologies shown in Figure 3, while Appendix B contains similar information for efficiency technologies.

Supply Options

This section presents some of the assumptions (shown in Table 2) used to calculate the characteristics of supply options shown in Figure 3.[11] In all cases, we used a 6.1 percent real discount rate, a T&D loss factor of 6 percent, and a reserve margin of 20 percent. We adjusted all costs to 1988 dollars using the consumer price index. We took data for the three conventional fossil fuel technologies from the 1986 EPRI Technical Assessment Guide (EPRI 1986). We used levelized, base-case natural gas, oil and coal price forecasts, calculated using fuel price forecasts for the period 1988-2000 from the U.S. Department of Energy (US DOE 1989).

Two of the following three parameters need to be specified to plot a supply technology on Figure 3: total annual variable cost (as a function of capacity factor), annualized fixed cost, and/or busbar cost for continuous operation.[12] The variable cost may be matched to the slope of the appropriate SRMC line emanating from the origin. The annualized fixed cost may be plotted for a point at zero capacity factor (on the y-axis), while the busbar cost for continuous operation may be plotted for a point at capacity factor equals one (using the appropriate SRMC lines).[13]

Efficiency Options

Table 3 shows two types of efficiency options: devices that have an accepted useful lifetime, and those whose lifetime varies in a simple way with annual usage. The first category (group A) includes refrigerators and central air conditioners, while the second (group B) contains compact flourescent light bulbs and electronic ballasts.[14] Each category of devices requires slightly different treatment.

In some sense, device lifetime always depends on usage. However, when this relationship is complicated or unpredictable (as for cycling

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[11] Future analyses will include estimates of the avoidable transmission and distribution system costs associated with delivery of electricity from power plants. Such costs are difficult to calculate but may be substantial.

[12] All these costs must be adjusted to account for transmission and distribution losses; in addition, annualized fixed costs must be adjusted to account for reserve margin needed to preserve adequate reliability. Thus they are costs per *delivered* kW or per *delivered* kWh.

[13] While thermal power plants never operate 8760 hours/year, plotting the point for capacity factor=100% is a convenient way to establish the slope of the line.

[14] A ballast controls the flow of current to flourescent lights. The electronic ballast is a solid-state version of the more common core-coil electromagnetic ballast.

appliances, such as refrigerators and air conditioners) it is often convenient to choose a single lifetime. It is a simple matter in this case to calculate the capital recovery factor and annualize the conservation investment. If lifetime depends in a simple way upon usage, then the appropriate capital recovery factor will need to be calculated based upon the lifetime implied by certain usage assumptions. In addition, the CLF may also depend in a complicated way upon usage assumptions and utility system characteristics.

For completeness, we have included a row for maintenance costs in the conservation worksheet, though we have not used it for these examples. This row should include only those additional maintenance costs that an efficient appliance would incur over and above those needed for an inefficient appliance. This term may be negative, such as for compact flourescent bulbs in commercial applications, where the avoided maintenance costs more than pay for the additional capital costs. Our examples of compact flourescents are for residential applications, so we ignore this cost savings. Other costs avoided include, for example, the incandescent bulbs replaced by longer-lived compact flourescents.

UTILITY INVESTMENT DECISIONS

When analyzing a utility's least-cost plan, regulators and other analysts can use a supply curve of conserved energy to estimate the *amount* of energy savings available, and can use a screening curve to compare the costs and load shape characteristics of efficiency to those of competing supply technologies. Once the screening curve is created, analysts can quickly determine which efficiency measures have CCEs below the delivered cost of electricity generation for peaking and baseload resources. Efficiency measures can be combined in "packages" that save the same amount of energy as the comparable power plant would generate, thus facilitating comparisons.

CONCLUSIONS

Screening curves supplement the information contained in supply curves of conserved energy. They incorporate and summarize CCE and load shape characteristics for conservation investments, and cost per delivered kWh and capacity factors for supply technologies. They are a new and useful tool for conducting least-cost utility planning analyses.

APPENDIX A: TECHNICAL NOTES FOR SUPPLY OPTIONS

A. Conventional Combustion Turbine (CT)

This plant represents an average of the characteristics of conventional 75 MW combustion turbines (CTs) powered by natural gas, distillate, or residual fuels. We used a lifetime of 30 years, a capital cost of $348/kW, fixed operations and maintenance (O&M) costs of $0.506/kW-yr, incremental O&M costs of $0.048/kWh, and a heat rate of 13,900 Btus/kWh (EPRI 1986 p.B-83). The line representing the CT has the steepest slope of all three powerplant technologies, showing the high variable costs characteristic of a peaking power plant.

B. Intermediate Combined-Cycle Oil

This plant represents an average of the characteristics of conventional 225 MW combined-cycle turbines powered by natural gas, distillate, or residual fuels. We used oil prices and assumed a lifetime of 30 years, a capital cost of $618/kW, fixed O&M costs of $8.312/kW-yr, incremental O&M costs of $0.021/kWh, and a heat rate of 8440 Btus/kWh (EPRI 1986 p.B-79).

C. Baseload Coal Steam

This plant is a 1000 MW (2-500 MW units), supercritical, bituminous coal plant with scrubbers. We used a lifetime of 40 years, a capital cost of $1421/kW, fixed O&M costs of $22.59/kW-yr, incremental O&M costs of $0.056/kWh, and a heat rate of 9660 Btus/kWh (EPRI 1986 p.B-33). The line representing the coal plant has the flattest slope of all three powerplant technologies, showing the low variable costs characteristic of a baseload power plant.

APPENDIX B: TECHNICAL NOTES FOR EFFICIENCY OPTIONS

A.1. Refrigerator (REF)

The refrigerator example is taken from the MEOS study (Krause et al. 1987). The additional capital cost for the more efficient appliance ($95) is offset by energy savings of 650 kWh/yr. The annual cost per kW saved is about $97/kW-yr. The CLF is 0.86 (US DOE 1988).

A.2. Central Air Conditioner (CAC)

The CAC example is taken from cost-efficiency curves used for the U.S. DOE's appliance efficiency standards impact analysis (Turiel 1987). This example involves improving the efficiency of an average U.S. CAC (rated < 39kBtus/hr) from the approximate level of the 1990 NAECA efficiency standard (Seasonal Energy Efficiency Ratio [SEER]=10.2) to SEER 11.9. The lifetime of the CAC is about 15 years, the incremental capital cost is $380, the annual energy savings total 500 kWh/yr, and the CLF is 0.15. The CCE for CACs is a substantial 7.9¢/kWh, but cooling energy savings are concentrated at peak times. The annualized cost for CAC energy savings is slightly more than the cost of a conventional combustion turbine for meeting peak load.

B.1. Compact Flourescent Light Bulb (CF)

The compact flourescent used in this example emits light equivalent to that of a 60 W incandescent, while using only 15 W. It retails for about $15/bulb. We have included in Other Costs Avoided the annual costs of incandescent light bulbs replaced by the flourescent, assuming that standard bulbs cost $0.50/bulb and last 750 hours.

We show two cases: one in which the bulb is burned 2000 hours/year, and one in which the bulb is burned continuously (8760 hours/year). In the second case, we assumed a lifetime of 9000 hours, while in the first case used 7500 hours to account for reduced lifetime from on-off switching. We calculated the CLF for the first case by assuming that 1/2 the hours the bulb burns are peak hours, and that these are the only peak hours. The peak savings in these hours is 45 W. The average load savings is equal to 45 W x 2000 hours/8760 hours or 10.3 W. The CLF for the high usage case is equal to 1.0, since the energy and demand savings accrue in every hour of the year.

B.2. Electronic Ballast (EB)

We include a high and low usage case for electronic ballasts as well. The high usage case is the same as for the compact flourescent (continuous use), while the low usage case corresponds to a typical commercial office building schedule (2700 hours of weekday and Saturday operation) (Rosenfeld et al. 1988). The savings are calculated comparing a standard core-coil ballast to a typical electronic ballast controlling two 40 W flourescent tubes. The ballast lifetime of 45,000 hours is about the average of current estimates, as is the assumed 33 W savings.[15] For an additional $12/ballast, the user can save approximately 89 kWh/year per ballast in the low case, resulting in a CCE of 1.3¢/kWh. In the high case, the user can save 289 kWh/year, at a CCE of 1.0¢/kWh.

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[15] The ballast lifetime estimate is taken from Gordon et al. 1988; The wattage savings estimate is adopted from Geller et al. 1987. The savings is calculated by dividing the Geller et al. estimate of average savings of 133 kWh by 4000 hours.

REFERENCES

EPRI, Electric Power Research Institute. 1986. *TAG-Technical Assessment Guide: Vol. 1: Electricity Supply-1986*. EPRI. EPRI P-4463-SR. December 1986.

EPRI, Electric Power Research Institute. 1987. *TAG-Technical Assessment Guide: Vol. 3: Fundamentals and Methods, Supply-1986*. EPRI. EPRI P-4463-SR. May 1987.

Geller, Howard, Jeff P. Harris, Mark D. Levine and Arthur H. Rosenfeld. 1987. "The Role of Federal Research and Development in Advancing Energy Efficiency: A $50 Billion Contribution to the U.S. Economy." In *Annual Review of Energy 1987*. Edited by J. M. Hollander. Palo Alto, CA: Annual Reviews, Inc. p. 357.

Gordon, Frederick M., Marjorie McRae and Michael Rufo. 1988. "Use of Commercial Energy Efficiency Measure Service Life Estimates in Program and Resource Planning." In *Proceedings of the 1988 ACEEE Summer Study on Energy Efficiency in Buildings.* Asilomar, CA: American Council for an Energy Efficient Economy. p. 3.

Kahn, Edward. 1988. *Electric Utility Planning and Regulation*. Washington, DC: American Council for an Energy Efficient Economy.

Krause, Florentin and Joseph Eto. 1988. *Least-Cost Utility Planning: A Handbook for Public Utility Commissioners (v.2): The Demand Side: Conceptual and Methodological Issues*. National Association of Regulatory Utility Commissioners, Washington, DC. December 1988.

Krause, Florentin, Arthur H. Rosenfeld, Mark D. Levine and et al. 1987. *Analysis of Michigan's Demand-Side Electric Resources in the Residential Sector (Prepared for the Michigan Electricity Options Study).* Lawrence Berkeley Laboratory. Report # LBL-23025. May 1987.

Meier, Alan, Jan Wright and Arthur H. Rosenfeld. 1983. *Supplying Energy Through Greater Efficiency*. Berkeley, CA: University of California Press.

Rosenfeld, Arthur and Jonathan Koomey. 1988. *Promoting Efficiency Investments in New Buildings: A New Policy to Improve Building Efficiency, Reduce Pollution, and Avoid Power Plant Construction.* Testimony Before the Public Service Commission of Wisconsin. August 4, 1988.

Turiel, Isaac. 1987. *Memo to Barry Berlin, U.S. DOE: Cost, and Price Versus Efficiency Curves for Residential Appliances*. Lawrence Berkeley Laboratory, Appliance Standards Project. January 22, 1987.

US DOE, U.S. Department of Energy. 1988. *Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators, Furnaces, and Television Sets*. U.S. Department of Energy, Assistant Secretary, Conservation and Renewable Energy, Building Equipment Division. DOE/CE-0239. November 1988.

US DOE, U.S. Department of Energy. 1989. *Annual Energy Outlook: Long-Term Projections 1989*. Energy Information Administration. DOE/EIA-0383(89).

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