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FOR CALIFORNIA'S RESIDENTIAL SECTOR

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December 1981

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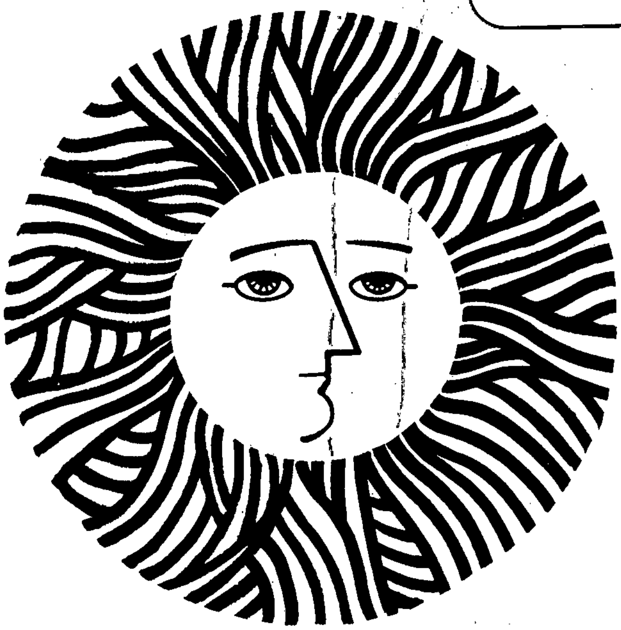

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SUPPLY CURVES OF CONSERVED ENERGY FOR CALIFORNIA'S RESIDENTIAL SECTOR

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ABSTRACT

A new method of presenting the potential for conservation is discussed. Supply curves of conserved energy provide a consistent accounting framework for assessing diverse conservation measures. They also permit simple comparison of conservation among themselves and with conventional energy supplies. The technique is applied to California's residential sector and illustrative policy conclusions are presented. Roughly 34% of the natural gas and 25% of the electricity used by the residential sector could be saved at costs of conserved energy below current marginal prices.

Figures and Tables

INTRODUCTION

In this paper, we discuss the technical potentials for conserving energy in California's residential sector. We have chosen to present these potentials as supply curves of conserved energy. In this way, one can grasp the magnitude and costs of various conservation measures relative to each other and to the cost of providing new energy supplies. We first briefly describe the supply curve of conserved energy technique. Next, we present the conservation supply curves for electricity and natural gas. Finally, we discuss the implications of the curves for setting energy conservation policies in California. The results presented here are based on work by Wright et al.[1] Details of the supply curve of conserved energy technique are discussed by Meier.[2]

THE COST OF CONSERVED ENERGY

Consumers do not demand energy itself but services of which energy is an input. They seek thermal comfort with the assistance of natural gas, and refrigeration with the assistance of electricity. Typically, there is some sort of intermediate device converting the energy to the useful service, such as a furnace or a refrigerator.

The efficiency at which these devices convert energy into useful services may vary widely. For example, air conditioners are now available with coefficients of performance (COP) ranging from 1.8 to 8.0.†
The service, a prescribed rate of heat removal, is the same for all models; only the electricity required to provide that service changes.

† See the Air Conditioning Conservation Supply Curve, p.11.

Generally, higher efficiency requires an additional investment to pay for better compressors, motors, heat exchangers, and controls.

There are several techniques to assess the economic trade-off between the additional investment and the lower energy operating costs. In this study, we used the "cost of conserved energy" technique. The cost of conserved energy formula transforms data on a conservation investment into a cost to save a unit of energy such as ¢/kWh and $/GJ. The capital recovery formula (presented in per cent per year) is used within the cost of conserved energy formula to annualize the investment as follows:

$$\text{cost of conserved energy (CCE)} = \left(\frac{I}{\Delta E}\right) \frac{d}{[1 - (1 + d)^{-n}]} ;$$

I is the investment, ΔE is the energy savings, n is the amortization period and d is the discount rate.† In our work, we assume a real discount rate, and a cost of conserved energy expressed in real (constant) dollars.

The cost of conserved energy provides a simple means of comparing investments of differing magnitude, lifetime or even discount rate. A conservation measure is economically attractive if its cost of conserved energy is less than the price of the energy that is saved. A sample calculation will now be given.

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† If payments are assumed to occur at the beginning of each period, an additional (1+d) will appear in the denominator. This lowers the cost of conserved energy.

Residential refrigerators with identical features are available with a wide range in electrical consumption. A national retailer offers the same 500 liter (17.5 ft^3), frost-free refrigerator in standard and high efficiency models. The high efficiency model costs $60 more but uses 400 kWh/year less electricity. The mean lifetime of refrigerators is about 20 years; however, the first owner will probably sell it sooner and, therefore, amortizes the efficiency investment over a shorter period, say 10 years.† If we take the consumer's nominal discount rate to be 20%, then his real discount rate (assuming 15% inflation) is 5%. The cost of conserved energy is then

$$CCE = \left[\frac{\$60}{400\ kWh}\right] \frac{0.05}{[1 - (1 + 0.05)^{-10}]} = 1.94\ ¢/kWh ,$$

which is much lower than current residential electricity prices in the United States. It is, therefore, an economically attractive measure. Moreover, the cost of conserved energy remains constant over the ten years, whereas the price of supplied electricity (even in real terms) will probably increase. By assuming a ten-year amortization period, the electricity saved by the purchase of the efficient refrigerator during the second half of its life is free, in the same manner as the electricity provided by a dam after the construction costs have been recovered.

The cost of conserved energy for each measure is calculated using incremental energy savings and cost. In many cases, a series of conser-

† We assume that the owner obtains no efficiency premium upon resale. Until permanent labeling of energy use begins, inefficient used refrigerators will appear identical to efficient ones.

vation measures can be applied to a single end use, such as space heating, lighting or refrigeration. For refrigerators (see Table 4), the sequence begins with "meet CEC standard" because any new refrigerator sold in California must use less electricity than the California Energy Commission (CEC) standard. Many models use considerably less electricity than the standard but cost somewhat more. Thus, the second measure in the sequence is "buy the most efficient available." The cost of this measure is the incremental cost beyond a comparable model just meeting the standard. Similarly, the energy savings would be those beyond the comparable model just meeting the standard. †

For retrofits, that is, improvements of existing homes, the cost is simply that of the retrofit and the energy savings are the avoided energy use. Difficulties arise when one measure saves energy in two end uses. Wall insulation, for example, reduces both space heating and cooling energy needs. In such cases, we apportioned the investment between two measures, that is, "wall insulation air conditioning savings" refers to the air conditioning portion of the investment, while "install R-11 in walls" refers to the space-heating portion. We divided the insulation cost between the two measures in fractions roughly equal to their respective primary energy savings.

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† There is a consumer cost associated with buying appliances that meet the standard. One could probably buy a non-complying refrigerator for less in Nevada. Since the consumer has no choice here, we assigned no cost to this measure. Assigning a cost to the measure will affect only that measure's cost of conserved energy; the subsequent measures in the sequence will not be affected.

In calculating the cost of conserved energy, we made several general assumptions. We assumed a consumer perspective for the inputs to the CCE calculation. The energy savings were those savings at the home meter and therefore ignore savings in transmission and distribution.† The market price was taken to be the cost of a measure. Wherever appropriate, we included labor costs, that is, we assumed that the consumer did not do the measure himself. We also assumed amortization periods shorter than the actual physical lifetimes of the investments. Finally, we assumed a 5% real consumer discount rate. As we shall see, these assumptions have a direct bearing on the choice of comparison energy prices.

Many of the estimates of energy savings rely on engineering calculations and manufacturers' specfications rather than measured results. Therefore one must ensure that the assumptions in the calculations conform to reality. We devoted considerable effort to reconciling engineering calculations to billed energy use. In addition, we sought to isolate the individual contributions to that use. This ensured that an already-applied conservation measure was not applied twice to the same unit. This is relatively simple for a single house but requires careful accounting when analyzing several million California homes.

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† 10% of the electric power generated is typically lost during transmission and distribution. Therefore, the energy savings measured at a house meter will reduce generation needs by an additional 10%. We have also ignored new energy consumption caused by greater investments in conservation materials and services. This increase would appear principally in the commercial and industrial sectors. Input-output analyses suggest that the increase would be no more than 10% of the total residential energy savings. (personal communication, E. Hirst, Oak Ridge National Laboratory, 11 Sept. 1981.)

The order in which conservation measures are performed will affect the energy savings attributed to each of them. For example, a water heater insulation blanket will save less energy when installed after a thermostat set-back due to the smaller temperature difference. Likewise, a thermostat set-back will save less when done after the tank has been insulated. However, the total energy savings, after completion of the entire sequence, will not change. To avoid potential double-counting, we estimated the energy savings for each measure by assuming that all measures with lower CCE in the sequence had already been implemented.

CALIFORNIA SUPPLY CURVES OF CONSERVED ENERGY

A supply curve of conserved energy can be constructed for a single unit by arranging the measures in order of increasing cost of conserved energy. Such a curve (a "micro supply curve of conserved energy") would appear as a series of rising steps, where the horizontal reach of each step represents annual energy savings of the measure while the height represents the cost of conserved energy. While micro-conservation supply curves are interesting, they can also be misleading. There is no indication whether the graph represents anything more than just that unit. In other words, one cannot know whether a case study is an average unit, whose conservation potential could be multiplied by a region's entire stock or a special case with no further applicability. The microeconomic and regional assumptions for each of the measures are discussed in detail by Wright et al.[1]

For policy purposes, regional supply curves of conserved energy are more useful than a micro-conservation supply curve. Such curves show the location of the important reserves, that is, which specific measures could save regionally significant amounts of energy. In addition, regional conservation supply curves permit the comparison of energy conservation with conventional energy supplies, both in size of reserves and costs.

We developed two types of regional supply curves of conserved energy, the single end use curve and the sectoral (or "grand") curve. In this section, we present end use curves for water heating and air conditioning as examples. We also present a gas and electric conservation supply curve for California's entire residential sector.

Regional conservation supply curves require additional information pertaining to the stocks of energy-consuming equipment and special assumptions about timing. The number of units eligible for each conservation measure must be estimated. If the measure can be implemented only when a unit is replaced, then information about turnover rates is also needed.

In this California study, we considered the conservation potential for only the existing stock of energy-using equipment. In other words, the number of units in the stock is considered constant, even though they may be gradually replaced with more efficient units over time. The impact of growth (i.e., the increase in stock) was ignored. We assumed a 10-year time horizon, that is, we allowed 10 years of implementation to occur and plotted the results. New, high-efficiency appliances were introduced at rates equal to their natural replacement rates.

To assess the economic reserves of conserved energy, one must compare the costs of conserved energy to the prices of the energy displaced. We assumed that real energy prices would remain constant over the 10-year time horizon. This admittedly simplistic assumption probably understates the reserves of conserved energy by assuming an unrealistically low comparison price. The comparison is complicated by the inverted rate structure faced by California's residential customers (the more used, the higher the rate), and significant variation in energy prices among the utilities.

THE GAS WATER HEATING CONSERVATION SUPPLY CURVE

The supply curve of conserved energy for gas water heating (Fig. 1) is somewhat unusual in that it begins with two measures having a zero cost of conserved energy, namely, setting back the thermostat of the water heater and doing more of the laundry in warm water (as opposed to hot water). We assumed that these measures were implemented in homes only when it caused no change in service. This means only a fraction of all California homes are eligible.†

The third measure, installing low-flow showerheads, saves large amounts of energy and is very cheap. Most showerheads can be changed

† Thus, only homes without dishwashers were eligible because dishwashers require 65 ^{o}C water because lower water temperature causes spotting on the glassware. Some homes need large amounts of hot water and therefore must maintain a high thermostat setting. In this way, there is enough hot water to permit the occupants to take three showers in rapid succession. These homes were also excluded. The second measure, switching to cold-water laundry, has similar exclusions. Greasy or especially dirty clothes may need to be cleaned in hot water; however, we estimated that 80% of the laundry could potentially be washed in cold or warm water without affecting quality.

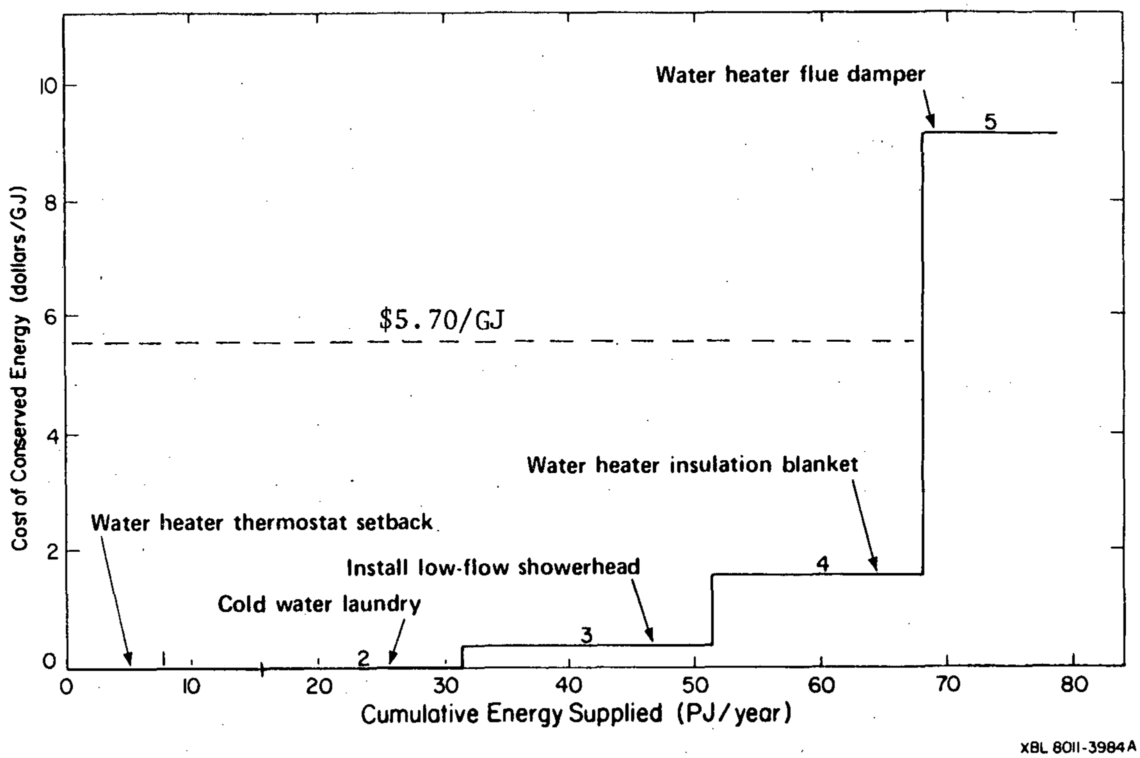

Fig. 1. A gas water heating conservation supply curve for California's residential sector. Each step corresponds to a conservation measure: the y-coordinate is the cost of conserved natural gas and the x-coordinate the cumulative energy saved. Total gas used for residential water heating in California in 1978 was 216 PJ. We list each of the measures in Table 1.

No. Measure	Cost of conserved energy ($/GJ)	Energy supplied per measure (PJ/year)	Cumulative energy supplied (PJ/year)
1. Water heater thermostat setback	0.0	15.5	16
2. Cold water laundry	0.0	16.5	32
3. Install low-flow showerhead	0.38	19.5	52
4. Water heater insulation blanket	1.61	17.0	69
5. Water heater flue damper	9.29	10.2	79

Table 1. Table to supplement the gas water heating conservation supply curve (Fig. 1). The conservation measures are listed in the order they appear on the curve. 1 GJ is approximately equal to 1 x 10^6 Btu (MBtu) and 1 PJ = 10^{15}J = .948 x 10^{12}Btu.

easily by homeowners; the roughly 10% that require a plumber to change the "gooseneck" have been excluded. Also, we estimated that 10% of the homeowners have already installed low-flow showerheads or flow restrictor devices. Obviously the savings in individual homes will vary widely; our results are an average for the state.

The fourth measure, insulation of the water heater with a blanket, demonstrates the anti-synergistic effect of conservation. To calculate the energy savings, we assumed that the thermostat setback had already been done; that is, the consumer did the cheaper measure first. If the setback were not done, however, the energy savings for the blanket would be greater and the cost of conserved energy less.† A similar situation applies to the fifth measure, installation of a flue damper, which saves more energy when the water is stored at higher temperatures. This is a general feature of supply curves of conserved energy: conservation measures implemented prior to their position shown in the sequence will save more energy and have lower costs of conserved energy.

At the end of the 10-year time horizon, roughly 37% of the gas used for water heating in 1978 could be saved. Residential customers in California pay roughly $4.00/GJ for natural gas; therefore, at current rates, only the first four measures are economic. Even at the tailblock rate (the highest rate) of $6.00/GJ, no further measures are economic.

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† Losses through the tank walls are proportional to conductivity and the temperature difference. A thermostat setback decreases the temperature difference; proportional savings from extra insulation will be the same, but the absolute savings will be smaller.

In the short time since we developed this curve (1980), we have identified additional conservation measures. Low-temperature dishwasher detergents are chemically possible to manufacture.[3] These would reduce hot water needs for some homes and enable more homes to set back the thermostat on the water heater. Water-conserving washing machines could further reduce the hot water needs of washing clothes. It is also possible to heat water with the waste heat from central air conditioning systems. The energy savings and cost of conserved energy for such a measure depends on the length of the air conditioning season as well as on the amount of hot water used during that period. That, in turn, depends on which measures have already been implemented.

Solar water heating measures could also be incorporated in the supply curve of conserved natural gas. The cost of conserved energy for a solar measure is very sensitive to the conservation measures already implemented because the energy savings depend on the initial energy use. A solar water heating measure would cost $6 - $10/GJ and appear in the sequence before the flue damper measure. Not every home has solar access nor would 100% of the heat be provided by the collectors, so California homes would still need some natural gas to heat water.

THE AIR CONDITIONING CONSERVATION SUPPLY CURVE

The supply curve of conserved electricity for air conditioning is shown in Fig. 2. The cumulative annual savings after the last measure amount to 29% of the estimated 3,500 GWh/year consumed by room and central air conditioners in California.

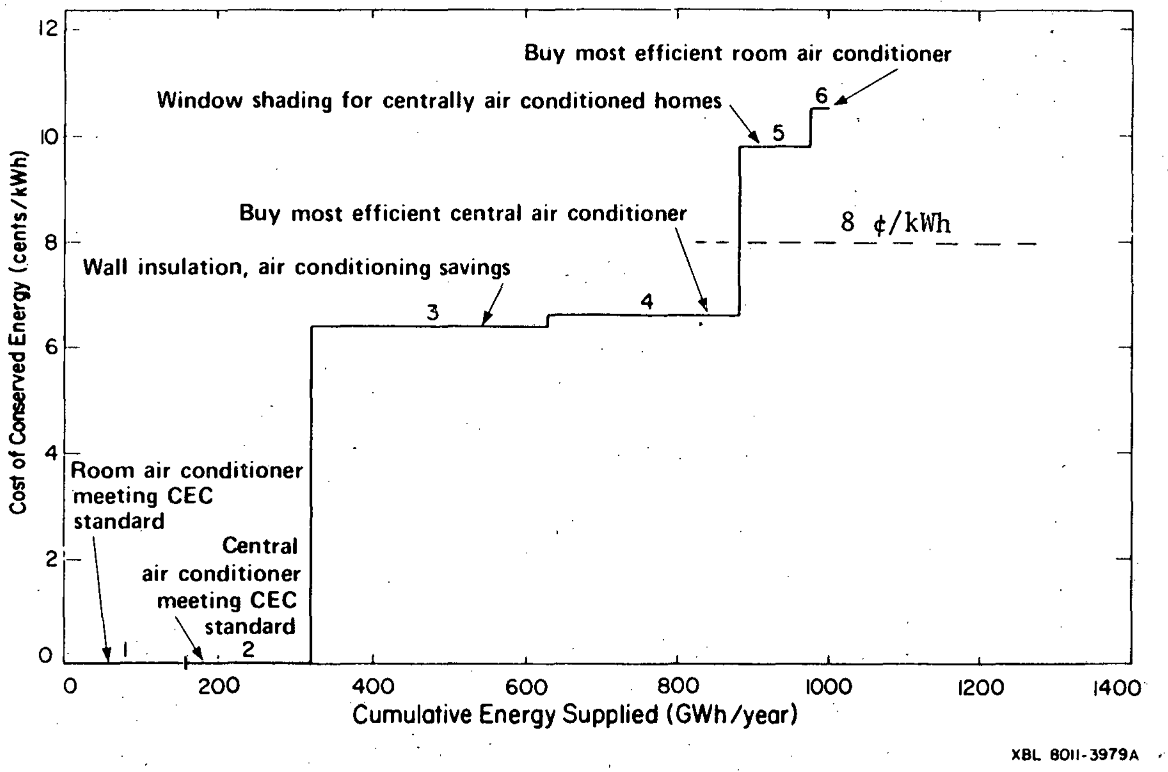

Fig. 2. An air conditioning conservation supply curve for California's residential sector. Each step corresponds to a conservation measure: the y-coordinate is the cost of conserved electricity and the x-coordinate the cumulative energy saved. Total electricity used for residential air conditioning in California in 1978 was 3,500 GWh. We list each of the measures in Table 2.

No.	Measure	Cost of conserved Energy (¢/kWh)	Energy supplied per measure (GWh/year)	Cumulative energy supplied (GWh/year)
1.	Room air conditioner meeting CEC standard	0.0	152.	152.
2.	Central air conditioner meeting CEC standard	0.0	168.	320.
3.	Wall insulation air conditioning savings	6.2	309.	629.
4.	Buy most efficient central air conditioner	6.4	252.	881.
5.	Window shading for centrally air conditioned homes	9.5	95.	975.
6.	Buy most efficient room air conditioner	10.2	24.	1,000.

Table 2. Table to supplement the air conditioning conservation supply curve (Fig. 2). The conservation measures are listed in the order they appear on the curve.

The simple turnover of the air conditioner stock, the first two measures, will result in a 9% reduction in electricity use due to the CEC performance standards. The savings from the third measure, wall insulation, were counted only for centrally air conditioned homes. (See below.) The cost of conserved energy is somewhat arbitrary since the cost of insulation was apportioned between the heating savings and the cooling savings. In some Central Valley regions, wall insulation will save Californians more air conditioning energy than space heating. We did not include energy savings from insulation for houses with room air conditioners. We suspect that occupants would cool more rooms rather than use the air conditioner less.

The fourth and sixth measures, buying the most efficient air conditioning unit available when the original one is retired, are relatively expensive. However, the maximum seasonal efficiency of new central air conditioners is rising rapidly. Units with a coefficient of performance exceeding 3.8 are now available, whereas the CEC standard is only 2.35, so substantial energy savings are still possible. The difference between the most efficient room air conditioners and the CEC standard is somewhat less. That, coupled with their relatively high price leads to a higher cost of conserved energy.

The fifth measure, window shading, shows the costs and electricity savings for shading one west-facing window in half of the centrally air conditioned homes. A great range of shading technologies is available; we chose one of moderate cost ($110), consisting of a reflective mylar film in a tight track. The electricity savings will depend directly on the efficiency of the air conditioner used to remove the heat. This measure will be least economic when used in conjunction with a high efficiency unit, which is the situation that we assumed. We ignored reduced summer conduction heat gains (which are small) or reduced winter conduction heat losses (which, on a resource energy basis, can equal 25% of the total cooling savings). Thus, the energy savings listed are certainly underestimates.

In spite of the relatively high costs of conserved energy for some of these measures, the high cost of summer electricity make many of them economic. Using 10 ¢/kWh as the comparison price, nearly one third of the electricity used by air conditioners could be conserved economically. On a hot summer day, residential air conditioners use almost a fifth of California's total electric load. Clearly, any substantial reduction in air conditioning electricity demands could have an enormous impact on the need for power plants.[4]

We have considered, but did not include, several other conservation measures. In dry climates, evaporative coolers can be (and often are) effectively used. With the COP near 10, they offer tremendous electricity savings. Many people complain that the moist cool air provided by evaporative coolers is unpleasant and, therefore, replacement of compression-type air conditioners may be a signifcant change in service. Just recently, however, an evaporative cooler, coupled to an air-to-air heat exchanger, has become available for residential applications. It provides cool, dry air with an effective COP of 8. Alternatively, a whole-house fan can provide adequate cooling when the outside temperature is only a few degrees above the desired indoor temperature. Thus, for parts of the summer, it could replace convential air conditioning with substantial energy savings. Again, we chose to exclude this measure because it appeared to be a signficant change in the amenity provided.

THE GRAND CONSERVATION SUPPLY CURVES

Figures 3 and 4 are grand gas and electric conservation supply curves. These curves summarize the potential for conservation in every major residential end use of energy in California. The two curves indicate that roughly 50% of the natural gas and 25% of the electricity used by the residential sector in 1978. However, by using the current residential energy prices as the cut-off point ($5.70/GJ and 8 ¢/kWh), the <u>economic</u> reserves of conserved energy represent roughly 34% of the natural gas and 22% of the electricity used by the residential sector in 1978. These estimates are based on a 10-year time horizon; substantially more electricity could be saved over a 20-year time horizon. Figure 5 shows how the breakdown in energy use would change if the entire economic potential were tapped.†

The conserved energy potential must be compared to natural gas and electricity supply facilities planned for the next decade. At least one major new natural gas facility is proposed. A liquified natural gas (LNG) terminal at Point Conception would distribute imported natural gas throughout California. The conserved energy corresponds to 60% of the

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† In addition, we assumed that the real price of energy would remain constant, so the appropriate comparison is with today's residential energy rates. Alternatively, one can assume that the real energy prices will not rise above today's tailblock (highest tier) rate. This implies that future energy prices will rise in real terms and is probably a more realistic assessment.

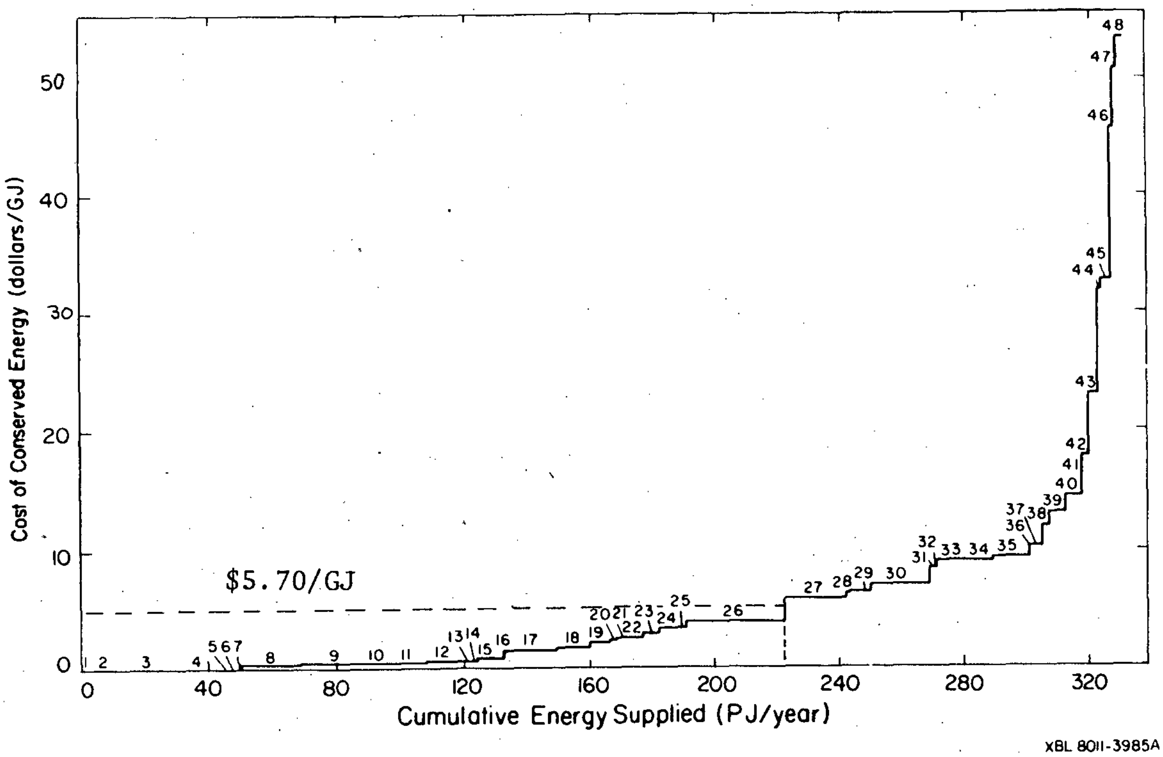

Fig. 3. The grand supply curve of conserved natural gas for California's residential sector. All residential natural gas end uses have been combined on this curve. Each step corresponds to a conservation measure: the y-coordinate is the cost of conserved natural gas and the x-coordinate the cumulative energy saved. We have listed these measures in Table 3. The cumulative energy saved after the final measure corresponds roughly to 50% of the total natural gas used in California's residential sector. California's residential sector consumed 646 PJ of natural gas in 1978.

No.	Conservation measure	Cost of conserved natural gas ($/GJ)	Energy supplied per measure (PJ/year)	Cumulative energy supplied (PJ/year)
1.	New dryer with spark ignition	0.0	1.5	2.
2.	New stove with spark ignition	0.0	10.3	12.
3.	Water heater thermostat setback	0.0	15.5	27.
4.	Switch to cold water laundry	0.0	16.5	44.
5.	Furnace pilot off in summer (MF)	0.0	1.4	45.
6.	Furnace pilot off in summer (S)	0.0	3.2	48.
7.	Furnace pilot off in summer (N)	0.0	1.1	50.
8.	Install low-flow showerhead	0.38	19.5	69.
9.	Night setback of 6°C (S)	0.47	19.5	88.
10.	Install pool cover (N)	0.47	8.1	97.
11.	Night setack of 6°C (N)	0.47	11.3	108.
12.	Install pool cover (S)	0.66	11.1	119.
13.	New furnace with spark ignition (S)	0.66	2.1	121.
14.	New furnace with spark ignition (N)	0.66	2.1	123.
15.	Night setback of of 6°C (MF)	0.95	7.2	130.
16.	New furnace with spark ignition (MF)	0.95	1.6	132.
17.	Water heater insulation blanket	1.61	17.0	149.
18.	Install R-19 in ceiling (N)	1.80	10.6	160.
19.	Seal attic bypasses (N)	2.27	6.5	166.
20.	Install R-19 in ceiling (MF)	2.46	2.2	168.
21.	Retrofit furnace spark ignitionS)	2.65	4.2	173.
22.	Retrofit furnace spark ignitionN)	2.65	4.2	177.
23.	Seal attic bypasses (S)	3.03	5.0	182.
24.	Install R-19 in ceiling (S)	3.51	5.4	187.
25.	Retrofit furnace spark ignition (MF)	3.51	2.7	190.
26.	Install R-11 in walls (N)	4.08	33.0	223.
27.	Install storm windows (N)	6.07	19.2	242.
28.	Seal attic bypasses (MF)	6.54	0.5	243.
29.	Install R-11 in walls (MF)	6.63	7.1	250.
30.	Install R-11 in walls (S)	7.20	18.9	269.
31.	Install fireplace damper (S)	8.63	0.7	269.
32.	Install fireplace damper (N)	8.63	0.7	270.
33.	Water heater flue damper	9.29	10.2	280.
34.	Caulking (N)	9.29	7.6	288.
35.	Install storm windows (S)	9.57	12.0	300.
36.	Pool heater tune-up (N)	10.52	0.2	300.
37.	Install storm windows (MF)	10.52	4.2	304.
38.	Buy most efficient gas dryer	12.3	1.6	307.
39.	Caulking (S)	13.46	5.3	311.
40.	Additional R-19 in ceiling (N)	14.88	5.1	316.
41.	Pool heater tune-up (S)	16.59	0.3	316.
42.	Caulking (MF)	18.39	1.9	318.
43.	Additional R-19 in ceiling (S)	23.79	3.2	322.
44.	Seal ducts (N)	32.80	1.6	323.
45.	Weatherstrip (N)	33.65	3.4	327.
46.	Seal ducts (S)	46.92	1.1	328.
47.	Weatherstrip (MF)	52.04	0.9	329.
48.	Weatherstrip (S)	54.69	2.1	331.

N = Northern California, S = Southern California, MF = Multifamily homes.

Table 3. Table to supplement the grand supply curve of conserved natural gas (Fig. 3). The conservation measures are listed in the order they appear on the curve.

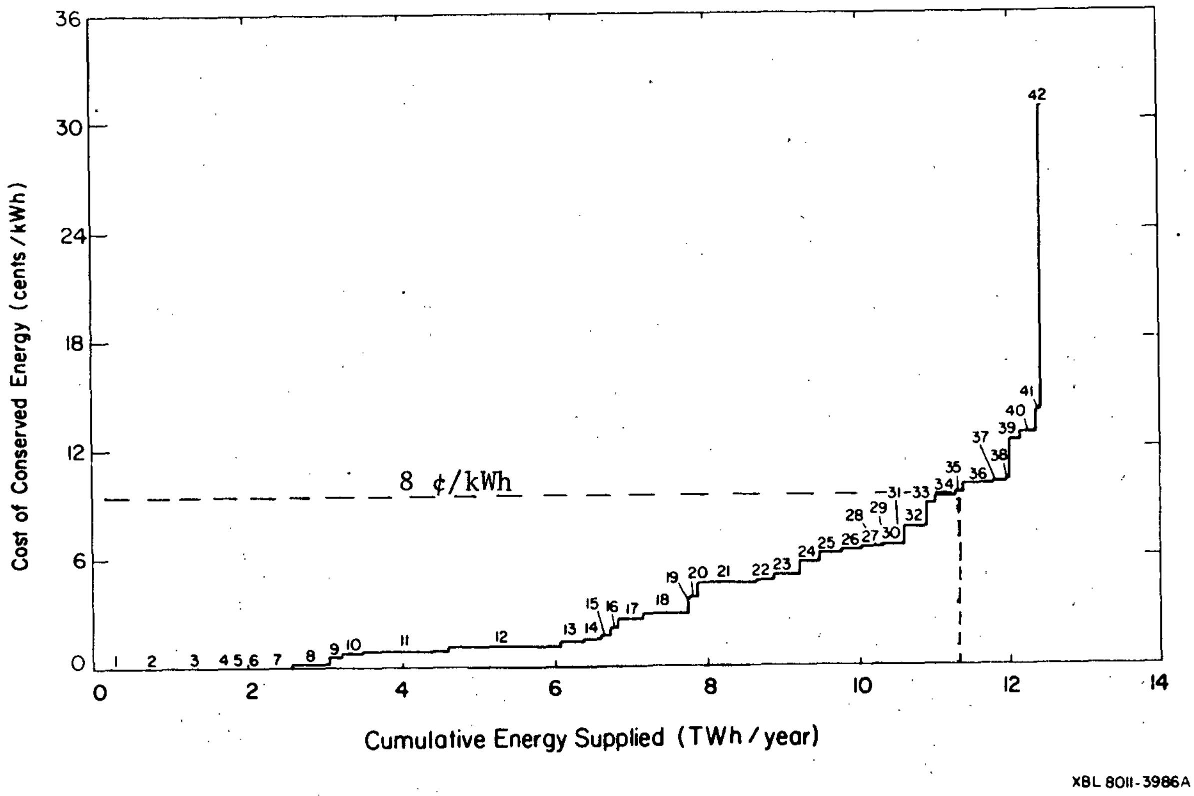

Fig. 4. The grand supply curve of conserved electricity for California's residential sector. All residential electrical end uses have been combined on this curve. Each step corresponds to a conservation measure: the y-coordinate is the cost of conserved electricity and the x-coordinate the cumulative energy saved. We have listed these measures in Table 4. The cumulative energy saved after the final measure corresponds to about 25% of the total electricity used in California's residential sector. This energy is roughly equivalent to the output of two standard 1000 MW power plants. California's residential sector consumed 49.6 TWh of electricity in 1978.

Measure	Cost of conserved energy (¢/kWh)	Energy supplied per measure (GWh/yr)	Cumulative energy supplied (TWh/yr)
1. Solid-state color TV	0.	599	0.6
2. Solid-state black-and-white TV	0.	322	0.9
3. CEC standard refrigerator	0.	728	1.6
4. CEC standard room air conditioner	0.	152	1.8
5. CEC standard central air conditioner	0.	168	2.0
6. Water heater thermostat setback	0.	186	2.2
7. Cold-water laundry	0.	407	2.6
8. Low-flow showerhead	0.2	497	3.1
9. Night setback of 10°F	0.6	153	3.2
10. Pool filter savings from cover	0.8	287	3.5
11. Buy most efficient refrigerator	0.9	1,092	4.6
12. Refrigerator package "A"	1.1	1,466	6.1
13. Buy most efficient freezer	1.4	306	6.4
14. Water heater insul. blanket	1.5	241	6.6
15. 3-Way bulb to high efficiency	1.7	111	6.7
16. Seal attic bypasses	2.1	93	6.8
17. Freezer package	2.6	328	7.1
18. Kitchen fluorescent	2.9	609	7.7
19. Install R-19 in ceiling	3.7	10	7.8
20. Divert elec. clothes dryer vent	3.8	105	7.9
21. Switch to gas clothes dryer	4.6	767	8.6
22. Exterior fluorescent conversion	4.7	239	8.9
23. 100 W bulb to fluorescent (high use light)	5.0	335	9.2
24. Storm windows	5.7	258	9.5
25. Wall insulation air conditioning savings	6.2	309	9.8
26. Buy most efficient central air conditioner	6.4	252	10.0
27. Manual refrigerator improvement	6.5	208	10.2
28. Buy most efficient electric dryer	6.5	62	10.3
29. Fireplace damper	6.5	13	10.3
30. 100 W bulb to fluorescent (medium use light)	6.6	290	10.6
31. Install R-11 in walls	7.4	9	10.6
32. 3-way bulb to fluorescent	7.6	305	10.9
33. Caulking	8.9	102	11.0
34. Switch to gas range	9.3	274	11.3
35. Window shading for centrally air conditioned homes	9.5	95	11.4
36. Refrigerator package "B"	10.0	406	11.8
37. 100 W bulb to fluorescent (low use light)	10.1	191	12.0
38. Buy most efficient room air conditioner	10.2	24	12.0
39. 75 W bulb to fluorescent	12.4	156	12.2
40. Weatherize apartments	12.8	204	12.4
41. Additional R-19 in ceiling	14.0	69	12.4
42. Weatherstrip	30.8	48	12.5

Table 4. Table to supplement the grand supply curve of conserved electricity (Fig. 4). The conservation measures are listed in the order they appear on the curve.

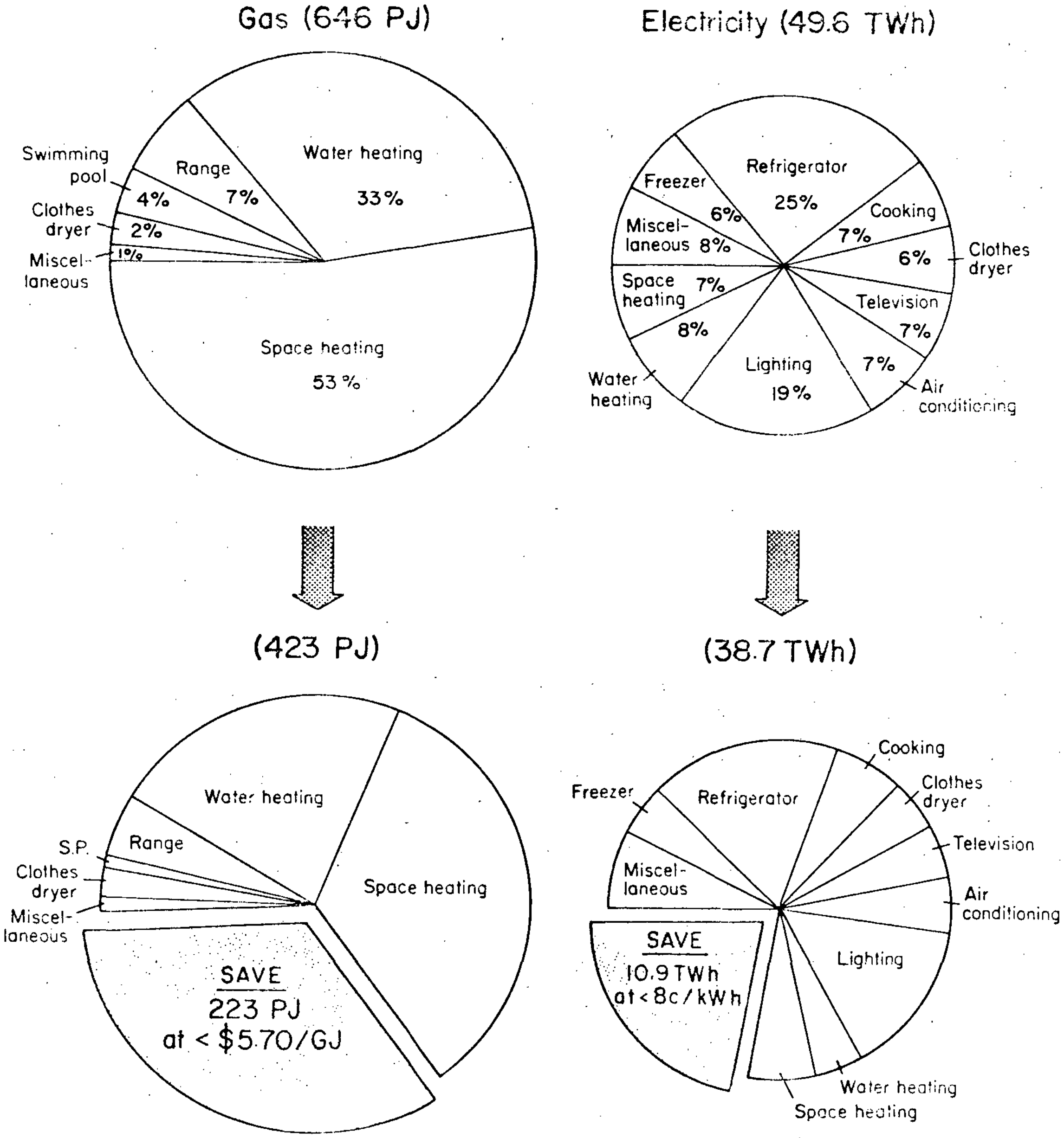

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Fig. 5. Residential energy consumption by end use in 1978 (above) and after ten years (below) assuming all economic conservation measures are implemented. The shaded area represents the potential savings. The areas of the pie graphs are proportional to the energy in primary (or resource) energy. Electricity was converted to primary energy assuming a 33% efficiency, 10,300 Btu/kWh.

terminal's anticipated maximum capacity. The consumer cost of that gas is expected to be roughly $7.00/GJ (in 1980 dollars).† The potential electricity savings correspond to the output of two conventionally sized power plants.‡

BEST CONSERVATION BUYS IN CALIFORNIA

Where are the major inexpensive reserves of conserved energy located? Within the electricity end uses, the measures with zero costs of conserved energy are principally a result of technological progress in televisions, CEC standards for refrigerators, and some hot water conservation measures. To exploit these potentials fully requires continuation of existing standards, and programs to educate consumers regarding hot water conservation. For the most part, however, we have considered only measures requiring a technological improvement rather than a change in patterns of behavior.§

Among the measures with low costs of conserved energy, more efficient refrigerators dominate: "buy most efficient". This suggests that refrigerator standards could be tightened considerably while still

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† E. Texeira, California Public Utilities Commission, personal communication, July 7 1980.

‡ Here, though, one must carefully distinguish between energy and capacity.[4]

§ For hot water conservation measures, voluntary labels on soaps and detergents would be an example of focused education. Many laundry detergents still suggest using as hot water as possible.

remaining economic for consumers.† Alternatively, utilities (if allowed to treat conservation investments like those for power plants) could offer consumers bonuses for the purchase of high efficiency appliances. From a utility perspective, efficient refrigerators are especially attractive conservation measures. The energy savings are reliable in the sense that they are not subject to consumer whim and there is little degradation in performance over time. Moreover, an inefficient refrigerator bought today will remain in use for the next 20 years.

The lighting measures (numbers 15, 18, 22, 23, 30, 32, 37, and 37) do not save large amounts of electricity. However, they may be tapped through innovative programs. For example, a scheme where each home receives one fluorescent fixture (the kind that screws into an existing socket) might result in rapid tapping of this potential.

Even the most expensive types of swimming pool covers (gas measures 10 and 12) will have very low costs of conserved energy, save substantial amounts of natural gas, and some electricity (measure 10) because of less filter pump operation. Pool covers could reduce the current natural gas used by pools by over 70%. This leaves little gas for solar heating to save.

Ceiling and wall insulation (gas measures 18, 20, 24, 26, 29 and 30) appear as relatively poor investments, in part, because of our lower assumed estimates of initial heating energy use. These are based on

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† The "Refrigerator Package" measures correspond to refrigerator improvements believed possible and economic by Arthur D. Little. Inc. Recent discussions with the Amana Corporation indicate that protoypes using less than the ADL estimates already exist, and should be marketed in a couple of years.

actual energy consumption data instead of heat loss calculations and already reflect existing thermostat set-backs and furnace turn-offs due to holiday travel or daytime vacancy of the homes. The conventional degree-day calculations do not include these effects and therefore overestimate potential energy savings.† Apart from the pilot light, all space heating conservation measures save less energy if the furnace is operated for fewer hours or at lower thermostat settings. This results in a higher cost of conserved energy. In addition, the average cost of conserved energy presented on the supply curve does not reflect the great variation in space heating use even among comparable homes.‡ A utility-sponsored insulation program, such as Pacific Gas and Electric Company's "Zero Interest Program"(ZIP),[5] might more profitably aim at the highest users first, resulting in a significantly lower CCE than indicated here.

POOR CONSERVATION BUYS

The last electricity measure, weatherstripping resistance-heated homes (measure 42), is very expensive and saves relatively small amounts of electricity. The small savings are due to our assumption that all earlier measures had been implemented. in this case, principally

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† The space heating energy use of a home in California is very sensitive to the thermostat setting because many of the heating days have average temperatures above 10°C. An example of this sensitivity is given in Leonard Wall, Tom Dey, Ashok Gadgil, Alan Lilly and Arthur Rosenfeld, "Conservation Options in Residential Energy Use: Studies Using the Computer Program Twozone," Lawrence Berkeley Laboratory Report No. 5271 (August 1977) Berkeley, CA 94720.

‡ In Berkeley, for example, it appeared that nearly a fifth of the homes operated their furnaces for only a few hours during January. See, Alan Meier, "Final Report of the Energy Conservation Inspection Service," Lawrence Berkeley Laboratory Rep. No. 10739 (March 1980), Berkeley, CA 94720.

thermostat set-backs. At the same time, we assumed contractor labor. Together, the high labor cost and the small energy savings, lead to a very high cost of conserved energy.

SOME CONCLUSIONS

The supply curves of conserved energy describe the potential for conserved energy, but give no indication of the likelihood that this potential will be realized. Nevertheless, the supply curves address two issues vital for energy policy. First, the curves show the importance of conservation relative to traditional energy supplies, both in magnitude and cost. This addresses the question, "Is it worth establishing conservation policies and programs similar to the those for traditional fuels?" Electricity growth per capita has ceased in California and only 1 - 2% overall growth rates are expected.Per capital natural gas use is actually declining (as measures shown on the supply curves are implemented by the consumers). [6] Yet the need to replace aging facilities, reduce oil and natural gas use and the desire to improve environmental quality all remain strong reasons to consider conservation.

Second, the curves rank conservation measures in a way that shows their relative significance. This permits comparison of diverse conservation measures and addresses the question "granted that energy conservation is important, towards what specific measures should the policies be directed?"

How large are the economic reserves of conserved energy? Estimates will change depending upon the perspective adopted. In this analysis, we adopted a consumer perspective, that is, consumer costs, consumer discount rates, and short amortization times. Therefore, the price comparison must be with consumer energy prices. In addition, we assumed that the real price of energy would remain constant, so the appropriate comparison is with today's residential energy rates.† Other perspectives are possible. A utility company perspective must include the cost of administering a conservation program and use the appropriate utility discount rate. In addition, the energy savings are slightly larger due to the avoided transmission and distribution losses. Finally, the cost of conserved energy must be compared to the utility's cost of avoided energy supplies.

Both the natural gas and electricity curves climb very sharply at the end, suggesting that the reserves of conserved energy are limited. This is deceptive. In fact, it reflects the fact that our society has never confronted such high energy prices, and therefore never devised economically appropriate conservation technologies. At the same time, we lacked the resources to include every conservation measure; there are many measures omitted, especially within the region of sharply climbing costs of conserved energy.

Some of the conservation potential described by the curves will be realized without (some might say, in spite of) government or institutional involvement. Nevertheless, the striking gap between the costs of conserved energy and current energy prices suggest that the response is at best sluggish. Supply curves of conserved energy do not tell us how

† Alternatively, one can assume that the real energy prices will not rise above today's tailblock (highest tier) rate. This implies that future energy prices will rise in real terms and is probably a more realistic assessment.

to close the gap, but they do show where to focus our efforts.

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