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PENNIES A DAY —
FINANCING EARLY DEPLOYMENT
OF PHOTOVOLTAIC UTILITY APPLICATIONS
THROUGH A USER SUBSIDY

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I. Introduction and Summary

The photovoltaic conversion of solar energy offers a potentially important source of electric energy that does not depend upon non-renewable fuels and which is expected to have only minor environmental effects in comparison with conventional power plants. Photovoltaic power systems are also favorably viewed by the public which may greatly alleviate licensing problems frequently encountered by proposed utility generating facilities.

However, the cost of photovoltaic electricity is expected to remain higher than that of conventionally-generated power for a number of years. In particular, photovoltaic plants are unlikely to be economically competitive with newly constructed coal-fired plants in most locations until about the year 2000. This conclusion is reached even if it is assumed that coal prices increase relatively rapidly and that all of the objectives of the Department of Energy (DOE) Photovoltaic Program with respect to array cost (price)¹ reductions are achieved on schedule. (One of the major goals of the Photovoltaic Program is to reduce the present costs of flat plate arrays which is about \$11,000/kW_{pk}² to \$500/kW_{pk} in 1986, \$300/kW_{pk} in 1990 and \$100/kW_{pk} in 2000.)³ The competitive position of photovoltaic plants with respect to oil-fired generation is somewhat better, but only if the price of oil continues to rise rapidly.

¹ In this report, the word cost is to be interpreted from the point of view of a utility company. The cost of an array to a utility is equivalent to the price charged by the seller. When the cost of electricity is referred to, on the other hand, it is the cost to the utility of generating the electricity that is meant.

² \$/kW_{pk} is the photovoltaic array purchase cost per unit power generated at maximum solar insolation, which is usually assumed to be 1 kW per square meter of array. Photovoltaic system cost, which includes the cost of system design and engineering, as well as the cost of electrical storage, arrays, power conditioning, wiring, and installation, is currently 2-3 times the cost of arrays.

³ All cost figures in this report are referred to 1975 dollars.

Such calculations indicate that the benefits of photovoltaic generation are unlikely to be soon realized unless the photovoltaic alternative is supported, as other energy technologies have been, by some sort of economic subsidy.

This report describes the results of a preliminary investigation of one way of providing the required subsidy: simply allowing the utility company to recover the additional cost of photovoltaic generation through increases in charges to customers. As will be seen, a very substantial early penetration of photovoltaic generation capacity into the generation mix of a utility system could be financed by quite modest increases in the annual electric bills of consumers.

The analysis procedure used assumes a photovoltaic plant deployment rate and computes the total additional cost of electricity generation that would result from the deployment of the photovoltaic plants rather than of equivalent fossil-fuel plants. This additional annual cost is then apportioned, on a per kWh basis, among all utility customers, and the impact on the average residential customer's electric bill is determined.

Two deployment scenarios were considered:

- (1) A national deployment in which 500 MW_{pk} of photovoltaic capacity goes on line in 1986 and the annual deployment rate thereafter increases exponentially with time, reaching 50 GW_{pk}/year in the year 2000. (Such a deployment rate would require that virtually all of the arrays that would be

produced in the 1986-2000 period, if DOE goals are met, would be used in the postulated photovoltaic power plants.) Approximately 4.4% of the electrical energy generated in the U.S. in 2000 would be provided by photovoltaic systems if this scenario were implemented.

- (2) A Southern California deployment in which the first photovoltaic power plants go on line in 1986 and the annual deployment rate, as before, subsequently rises exponentially with time. In this case, it is assumed that the total photovoltaic capacity reaches a magnitude, in 2000, that is enough to provide 10% of the electrical energy generated in that year in a hypothetical large utility system.

It was found that relatively small increases in annual electric bills would be enough to pay the extra costs resulting from the deployment of photovoltaic plants in accordance with either of these scenarios. For the national deployment scenario, even if the escalation of coal prices is no faster than general inflation, the average residential customer's share of the cost of deploying photovoltaic plants instead of intermediate-load coal-fired plants would never rise above \$25 per year over the 1986-2000 period. The average annual subsidy from residential customers over this period would be only about \$8. Even lower annual subsidies would allow existing oil-fired plants to be replaced by photovoltaic plants in accordance with the postulated deployment schedules.

In addition, calculations based on assuming that all photovoltaic systems deployed have a fixed array cost indicate that such a subsidy could permit early use of photovoltaic systems in central station applications even if the cost of arrays does not decrease as rapidly as expected. The subsidy may therefore also be considered as a form of insurance against possible delays in achieving very low cost arrays and photovoltaic systems. For example, a maximum increase of about 10% in annual electric bills would be enough to permit photovoltaic systems with \$500/kW_{pk} arrays to be substituted for new coal plants in accordance with the national deployment scenario over the entire 1986-2000 period even if the cost of coal increases no faster than the annual inflation rate. In Southern California, a 10% increase in annual electric bills would permit photovoltaic systems with \$1000/kW_{pk} arrays to replace existing oil plants over the 1986-1996 time period at the rate prescribed in the Southern California scenario if the cost of oil increases at the annual inflation rate. In addition, if the cost of oil is assumed to increase 3% per year in real terms, a maximum annual subsidy of \$12 would result in a situation where arrays costing less than \$800/kW_{pk} would never be required where photovoltaic plants replace existing oil plants. If the Southern California scenario were implemented, 70% of the oil-fired plants in operation in this region in 1976 could be replaced by year 2000 by photovoltaic plants.

In view of the relatively small impact on individual customers, the potential for significant early penetration of utility markets, the need to conserve fossil fuels and the desire to maintain and improve environmental conditions, such a subsidy for photovoltaic systems appears to be a highly attractive approach to alleviate national energy problems. It is therefore

recommended that serious consideration be given to this approach in the National Photovoltaic Program and to the interaction with other parts of the program, particularly technology development, research and development, market analysis, and commercialization.

The following sections of this report discuss these results in greater detail.

II. The Situation Without Subsidy

A number of analyses have indicated that very low array prices, in the \$100-300/kW_{pk} range, may be required if photovoltaic systems are to be economically competitive with fossil-fuel plants in central station (utility) applications (Refs. 1-6). Some typical results of such an analysis are presented in Figure 1, where the levelized busbar cost¹ of electrical generation is shown for several different types of power plants, all serving intermediate loads (plant capacity factor = 0.4)². The upward slanting lines represent the cost of energy from 100 MW flat-plate photovoltaic plants, as a function of the cost of the arrays, for two different locations: Sterling, VA (near Washington, D.C.) and Inyokern, CA. For the purposes of this study, the performance of a photovoltaic plant at Sterling has been taken as representative of the average performance over the continental U.S. The busbar costs of electricity indicated in the graph were calculated in accordance with the standard EPRI/ERDA revenue methodology (Ref. 7), with the fixed charge rate set at 15% (corresponding to an after-tax discount rate of about 8%). A 30 year plant life was assumed. The levelized operation and maintenance costs were assumed to be 3 mills/kWh.

The horizontal lines in Fig. 1 represent the cost of energy from two different types of fossil fuel generating stations: newly-constructed coal-fired plants and existing (older) oil-fired plants. The busbar cost of energy

1. The levelized busbar cost is the annual cost of capital and operations per kilowatt-hour of electricity generated.
2. The plant capacity factor is the ratio of the electrical energy delivered over a year to the total electrical energy the plant would have delivered if operated at rated power over an entire year. A plant capacity factor of .4 is typical of "intermediate load" plants which, in most utilities augment baseload power during daylight hours. Intermediate load operation appears to be the most appropriate use of solar plants in central station applications.

Figure 1. Levelized Busbar Energy Generation Cost vs Array Cost

from the coal plants was calculated by the same procedure as was used for the photovoltaic plants, except that the levelized annual cost of fuel was added. In the case of the oil-fired plants, however, it was assumed that the capital cost had already been amortized, so that the cost of generation includes only the cost of fuel and the other operation and maintenance costs. (In both the coal-fired and oil-fired cases, the levelized operation and maintenance costs, exclusive of fuel, were again set at 3 mills/kWh). New oil plants to serve intermediate loads were not considered in the analysis because it is expected that the increasing scarcity of oil will preclude the construction of such plants in the post-1986 period.

The calculated busbar costs of fossil-fuel-generated electricity in the graph are based on the assumption that the average 1976 cost of coal for electric power plants (in 1975 dollars) is $\$0.80/10^6$ Btu and that the corresponding price of oil is $\$2.50/10^6$ Btu. Two different assumptions about future changes in fuel price are represented:

- (1) The price of fossil fuel (coal or oil) will increase at the general inflation rate (no price escalation in real terms). Since plants that become operational over the 1986-2000 time period are being considered, this means that the cost of fossil fuel is assumed to increase at the inflation rate over the 1976-2030 time period. This assumption is likely to represent a lower bound on the expected future cost of fossil fuel.
- (2) The cost of fossil fuel will increase at an annual rate of 3% in addition to the general inflation rate from 1976 to 2030. Under this assumption, the 1976 cost of fossil fuel will double by year 2000. This 3% (in real terms) escalation rate is likely to represent an upper bound on the future cost of fossil fuel.

Figure 1 shows that, with no escalation (above general inflation) in the cost of fossil fuel, array prices well under \$100/kW_{pk} would be required even at Inyokern in order for photovoltaic plants to be economically competitive with new coal plants or with existing oil plants. With 3% annual fuel escalation, array prices of \$100-200/kW_{pk} would be required in the year 2000 in order to compete with new coal plants, but much higher array prices would permit replacement of existing oil-fired plants by photovoltaic plants.

Figures 2 and 3 show the levelized busbar energy cost as a function of the first year of plant operation for the coal and oil plants represented in Figure 1. Also shown is the expected decrease in photovoltaic plant energy generation cost if DOE array price reduction objectives are achieved as scheduled. Even if it is assumed that the cost of fossil fuel increases at 3% annually in real terms, photovoltaic plants would not be competitive with coal plants at Sterling until the turn of the century, but could begin to replace existing oil plants as early as 1988. At Inyokern, under this fuel cost assumption, photovoltaic plants are not likely to become competitive with new coal plants until after 1996, but could begin replacing oil plants by 1987.

It thus appears that, except in the Southwest, photovoltaic systems are unlikely to be competitive with coal fired plants in central station applications until about the year 2000, even if all array cost reduction objectives are achieved and the price of coal increases relatively rapidly over the next 54 years. It may be economic, however, to replace existing oil plants in most locations in the United States with photovoltaic plants by the late 1980's if the price of oil continues to increase at an annual rate significantly greater than the general inflation rate.

Figure 2. Levelized Busbar Energy Generation Costs, 1986-2000

Figure 3. Levelized Busbar Energy Generation Costs, 1986-2000.

III. The Effect of Subsidy Provided by Increases in Annual Electrical Bills

A. Analytical Approach

The competitive disadvantage of photovoltaic systems would, of course, be removed if a subsidy were provided to cover the difference in energy generation costs between photovoltaic and fossil fuel plants. Among the different ways of providing such a subsidy, of particular interest is the concept of doing so through increases in user electric bills. Such increases have been used in the past to subsidize the purchase and installation of experimental power plants as well as to defray the increased cost of fossil fuels.

Assume that each year, beginning in 1986, a utility purchases and installs a specified number of photovoltaic plants instead of equivalent lower-cost fossil fuel plants. If the additional cost of the photovoltaic choice is passed on to consumers, the annual subsidy or increase in an individual customer's electric bill in some year after 1986 (in 1975 dollars) can be shown to be equal to

$$([\overline{\Delta BC} \cdot E_{pv}]_{1986} + [\overline{\Delta BC} \cdot E_{pv}]_{1987} + \dots + [\overline{\Delta BC} \cdot E_{pv}]_i) \cdot \left(\frac{E_c}{E_u} \right)_i$$

where $\overline{\Delta BC}$ is the difference between the levelized busbar cost of electrical

energy generation by photovoltaic plants installed in a given year and the cost of generating the same energy in fossil fuel plants (either new coal plants or existing oil plants) (1975 dollars/kWh)

E_{pv} is the annual electrical energy generated by photovoltaic plants installed in a given year (kWh)

E_c is the amount of electricity used annually by a customer in a given year (kWh)

E_u is the annual electrical energy generated by the utility
in a given year (kWh)

$\overline{ABC} \cdot E_{pv}$ is the annual subsidy required for photovoltaic
plants installed in a given year (1975 dollars)

For example, suppose a single 100 MW rated photovoltaic plant with \$500/kW_{pk} arrays is put into operation by 1986 in Inyokern instead of a coal plant. If the price of coal increases no more rapidly than the annual inflation rate, Figure 1 shows that the difference in levelized busbar cost is about 65 mills/kWh in 1986. The photovoltaic plant generates 3.5×10^8 kWh per year (100 MW rated plant with 0.4 capacity factor). The annual subsidy is therefore \$22.7 million ($3.5 \times 10^8 \times 65$ mills/kWh). Of this amount, about 25-30% would be paid by residential customers, and the rest primarily by commercial and industrial customers. If the plant is part of a Southern California utility network that generates 122×10^9 kWh in 1986 and if a typical residential customer uses about 11,000 kWh a year, the incremental cost or subsidy per residential customer in 1986 is about \$2.07 ($\$22.7 \times 10^6 \times 11,000 / 122 \times 10^9$). If no additional photovoltaic plants are installed, and the ratio of typical residential energy use to utility electrical energy generation remains constant, the incremental cost per residential user remains \$2.07 each year from 1986 through 2016 (30 year plant life assumed). However, most projections indicate that the ratio of residential electrical energy use to utility energy generation will decrease in the future (References 8 and 9). Therefore, it is likely that the annual subsidy per residential customer will be less than \$2.07 during the life of the plant.

If an identical photovoltaic plant, at the same array price (\$500/kW_{pk}), were also installed in 1987, and the utility electrical energy generation and

residential customer usage remained unchanged, the incremental annual cost per residential customer for this plant would also be \$2.07 and the total increase in a typical residential electric bill in 1987 for both plants would be 2 (2.07) or \$4.14.

If it is assumed that the price of coal increases annually at a rate of 3% in real terms, the 1986 incremental cost per residential customer would be \$1.66 ($\overline{\Delta BC}$ is now 52 mills/kWh). The incremental cost of another identical photovoltaic plant added in 1987, however, would be about \$1.62, since the cost of electricity from the coal plant increases by about 1 mill/kWh in the one-year interval, reducing $\overline{\Delta BC}$ to 51 mills/kWh. The total annual increase in a typical residential electric bill in 1987 to support both photovoltaic plants would thus be \$1.66 plus \$1.62 or \$3.28.

If the electrical energy generation cost of photovoltaic plants decreases as a result of the expected reductions in array costs, and the cost of coal increases at the general inflation rate, the 1986 incremental cost per residential customer is again \$2.07 (\$500/kW_{pk} arrays assumed in 1986) but the incremental cost of adding another 100 MW rated plant in 1987 is \$1.85 since array prices are expected to decrease in the interval. (Fig. 3 illustrates this case.) The total increase in a typical residential electric bill for the two photovoltaic plants would be \$2.07 plus \$1.85 or \$3.92.

In general, it can be seen that the annual subsidy or increase in electric bills is a function of a number of parameters: the expected future cost of fossil fuels, photovoltaic plant energy generation costs, the amount of electrical energy generated by photovoltaic plants, the total electrical energy generated by a utility, the rate of purchase or deployment of photovoltaic systems, the date when such purchases are begun, and the amount of electrical energy used by individual customers.

Of particular interest is the fact that if the fraction of electrical energy generated by photovoltaic plants is small, then even large differences in busbar energy cost can be subsidized by relatively small increases in user electric bills. Since both these conditions are likely to be characteristic of photovoltaic systems in central station applications for many years, the concept of user subsidy becomes highly attractive.

B. Results

The potential effects on photovoltaic system deployment and array cost requirements of providing an annual subsidy for photovoltaic systems through increases in electric bills has been investigated for two scenarios.

1. National Deployment Scenario

The first scenario assumes that all Photovoltaic Program annual production goals are achieved for the period 1986-2000 and that all systems produced during that time period are used for intermediate load central station applications (capacity factor = 0.4). This means that 500 MW_{pk} of photovoltaic arrays for central station systems would be installed in 1986 and 50 GW_{pk} (50,000 MW_{pk}) would be installed in year 2000. The plants are assumed to be distributed over the continental U.S. in such a way that the performance at Sterling can be taken as representative of the entire distribution.

If it is assumed that systems are put into operation in the same year the arrays are sold, and that system installation increases exponentially from 1986 to year 2000, photovoltaic systems would provide about 4.4% of the U.S. electrical energy generating capacity in 2000 and about .08% in 1986. (In this scenario, it is assumed that the annual electrical energy generation of the United States increases from 33×10^{11} kWh per year in 1986 to 60×10^{11} kWh per year in 2000 and that the typical

residential annual demand increases from 11,400 kWh to 15,600 kWh over the same time period. These assumptions are based on the estimates provided in Reference 8.)

For this deployment scenario, Figures 4 and 5 show the subsidy required per residential customer over the 1986-2000 time period if reductions in photovoltaic array costs are achieved as scheduled ($\$500/\text{kW}_{\text{pk}}$ in 1986, $\$300/\text{kW}_{\text{pk}}$ in 1990, and $\$100/\text{kW}_{\text{pk}}$ in 2000). These figures show the annual subsidy required both when the cost of fossil fuel does not escalate in real terms and when it increases at 3% above the annual inflation rate. In Figure 4 it is assumed that photovoltaic plants have been purchased instead of coal plants, while Figure 5 shows the subsidy required to replace existing oil plants. The fraction of annual U.S. electric consumption that is provided by photovoltaic plants under this deployment scenario is indicated by the dashed curves in Figures 4 and 5.

Note that the subsidy in any year covers the incremental cost for all photovoltaic plants installed through that year. For example, the \$6 annual subsidy per residential customer shown in Figure 4 for 1994 pays for the difference in annual generation cost between photovoltaic and new coal plants for all photovoltaic plants installed through 1994. Figure 4 shows that a maximum annual subsidy per residential customer of less than \$25 would permit the installation, at the assumed deployment rate, of photovoltaic plants instead of equivalent coal-fired plants over the 1986-2000 time period even if the price of coal increases only as rapidly as the annual inflation rate. The average increase in residential electric bills over this time period would be only \$8. If the price of coal escalates at 3% per year in real terms, the maximum annual subsidy per residential user would be only \$7. Figure 5 shows that even smaller annual subsidies would be needed to replace existing oil plants with photovoltaic plants.

Figure 4. Annual Subsidy Required Per Residential Customer

Figure 5. Annual Subsidy Required Per Residential Customer

Also of interest is the subsidy required for a given array cost, if this cost remains unchanged over the 1986-2000 time period (i. e. if the electrical energy generation cost of photovoltaic plants remains constant over this time period instead of decreasing as a result of expected reductions in array costs). The relationship between the (fixed) array price and the required annual subsidy per residential customer is shown in Figures 6-9. These figures show the subsidy required each year after 1986 for the assumed rate of photovoltaic plant deployment for a selected value of array cost. For example (see Figure 6), if a $\$500/\text{kW}_{\text{pk}}$ array cost is assumed (i. e. all the photovoltaic systems deployed over the 1986-2000 time period had $\$500/\text{kW}_{\text{pk}}$ arrays), the annual subsidy per residential customer that is required in order to allow photovoltaic plants to substitute for new coal plants, in the case where the annual increase in the price of coal equals the inflation rate, would be slightly less than \$3 in 1990, about \$10 in 1994 and \$67 in year 2000. The maximum annual subsidy of \$67 is about equal to a 10% increase in annual residential electric bills. The increase in annual subsidy with time is due primarily to the increasing fraction of electrical energy that is provided by photovoltaic plants. This fraction is shown on the right hand scales of Figures 4 and 5.

As noted previously, the annual subsidy in any year covers the difference in energy cost between photovoltaic and equivalent fossil fuel plants for all photovoltaic plants deployed between 1986 and that year. For example (see again Figure 6), for $\$1000/\text{kW}_{\text{pk}}$ arrays, the \$20 per year increase in residential bills in 1994 would cover the energy cost difference for all photovoltaic systems installed between 1986 and 1994. If no additional photovoltaic systems were installed after 1994, and residential electricity use and the amount of electrical energy generated in the United States

Figure 6. Annual Subsidy Per Residential Customer

Figure 7. Annual Subsidy Per Residential Customer

Figure 8. Annual Subsidy Per Residential Customer

Figure 9. Annual Subsidy Per Residential Customer

remained constant, the annual residential subsidy would remain at \$20 until year 2016 and then decrease as the financing of photovoltaic plants installed between 1986-1994 was completed. If residential electricity use remained constant, but U.S. electrical energy generation increased after 1994 and no additional photovoltaic plants were deployed, the annual subsidy per residential customer would decrease each year after 1994 in proportion to the relative increase in energy generation until 2016 and would decrease even more rapidly after that date. For example, if U.S. electrical energy generation increased at 5% per year after 1994, the annual subsidy per residential customer for photovoltaic plants with \$1000/kW_{pk} arrays installed between 1986 and 1994 would be \$20 in 1994, \$19 in 1995, \$18.05 in 1996, and by 2015, only \$6.81. In 2016 the subsidy would drop to \$6.08 as a result of the combined effect of increased U.S. energy generation and the completion of payments for plants installed in 1986. The subsidy would of course become zero in 2024 when the financing of the last photovoltaic plants was completed.

The curves in Figures 6-9 can also be interpreted in another way that provides additional insight. Consider, for example, Figure 7, illustrating a situation where photovoltaic power plants are installed in place of new coal plants and where the coal price is assumed to increase at 3% per year in real terms. The curves in the figure show that a maximum annual subsidy of only \$10 per residential customer (with a lesser average) is sufficient to subsidize installation, at the assumed deployment rate, of a) photovoltaic plants with \$1000/kW arrays over the period between 1986 and 1992, b) plants with \$500/kW_{pk} arrays over the 1986-1994 period, or c) plants with arrays costing about \$180/kW_{pk} over the entire period 1986-2000. If the subsidy were allowed to reach a maximum of \$30/year, photovoltaic plants with arrays costing more than \$300/kW_{pk} could be deployed at the assumed rate over the full 1986-2000 period.

The effect of increasing photovoltaic energy production in raising the required annual subsidy for fixed array price is partially counteracted in the cases illustrated in Figures 7 and 9 by the assumed escalation in the cost of fuel. The increase in fuel cost reduces the difference in leveled busbar energy cost between photovoltaic and fossil-fuel plants. As a result of the combined effect of increasing fossil fuel prices and increasing photovoltaic energy production, some of the curves in Figures 7 and 9 display maxima. For the case illustrated in Fig. 9, photovoltaic plants with $\$600/\text{kW}_{\text{pk}}$ arrays could be substituted for existing oil plants at the assumed rate without ever requiring an annual subsidy per residential customer of more than about \$8. Conversely, an \$8 maximum subsidy would allow implementation of the assumed deployment scenario with photovoltaic systems having array costs of $\$600/\text{kW}_{\text{pk}}$.

In general, Figures 6-9 show that relatively small increases in residential bills to subsidize photovoltaic systems could make photovoltaic systems a viable alternative to fossil fuel systems in central station applications in many locations in the United States over the 1986-2000 time period even if the cost of arrays does not decrease as rapidly as expected.

2. Southern California Deployment

In the second scenario, it is assumed that photovoltaic central stations provide 10% of the annual electrical energy generated by a hypothetical Southern California utility in year 2000. It is further assumed that the first photovoltaic plants go on line in 1986, that in 1986 they provide 1% of the energy they provide in year 2000, and that the deployment rate increases exponentially over the 1986-2000 period. Performance of a photovoltaic plant at Inyokern is used to represent the performance of all the plants in the system. The electrical energy generated by the utility is assumed to

increase from 1.22×10^{11} kWh in 1986 to 2.38×10^{11} kWh in 2000 and the average residential use of electricity to increase from 10,850 kWh in 1986 to 15,400 kWh in 2000. These assumptions on utility energy generation and electricity use are based on planning estimates provided in Reference 9.

The annual subsidy required per residential customer if all reductions in photovoltaic arrays costs are achieved as scheduled ($\$500/\text{kW}_{\text{pk}}$ in 1986, $\$300/\text{kW}_{\text{pk}}$ in 1990 and $\$100/\text{kW}_{\text{pk}}$ in 2000) is displayed in Fig. 10. This figure shows that a maximum annual subsidy of less than \$20 (which occurs in year 2000) would permit photovoltaic plants to replace existing oil-fired plants over the 1986-2000 time period, even if the real price of oil is assumed to remain constant over the 1976-2030 time period. Photovoltaic plants could substitute for new coal plants under the same conditions with a maximum annual subsidy per residential customer of \$35. In addition, if the price of coal is assumed to escalate at a real annual rate of 3% (above general inflation), a maximum annual subsidy per residential customer of less than \$6 would be enough to allow installation, at the assumed deployment rate, of photovoltaic plants instead of new coal plants over the 1986-2000 time period. By 1999, this annual subsidy would be zero. (For 3% annual coal cost escalation, photovoltaic plants located at Inyokern would provide cheaper electricity by 1995 than new coal plants. The larger number of these photovoltaic plants installed over the 1995-2000 time period would reduce the annual subsidy to zero by 1999 and result in lower costs to electricity users by year 2000 than if new coal plants were installed over the 1986-2000 time period).

Figure 10. Annual Subsidy Required Per Residential Customer

The residential subsidy requirement for the situation where the array cost is assumed to be constant over the 1986-2000 time period is shown in Figures 11-14. For the case where photovoltaic plants substitute for new coal plants (Figures 11 and 12), the results are similar to those already shown for the National Deployment Scenario. However, it appears that photovoltaic plants with $\$1000/\text{kW}_{\text{pk}}$ arrays could replace existing oil plants over the 1986-1996 time period with a maximum increase in electric bills of about 10% (Figure 13), even if the cost of oil does not increase any faster than the annual rate of inflation. If the cost of oil increases at an annual rate of 3% greater than inflation, then photovoltaic systems with $\$1000/\text{kW}_{\text{pk}}$ arrays could replace existing oil plants over the 1986-2000 time period with a maximum annual subsidy per residential customer of about \$50 (Figure 14). In addition, Figure 14 shows that with only a \$12 maximum annual subsidy per residential customer, array costs of less than $\$800/\text{kW}_{\text{pk}}$ would not be required where photovoltaic plants replace existing oil plants.

At present, oil fired plants provide about 50% of the electrical energy generated in Southern California. If the Southern California scenario were implemented, it is estimated that 70% of these existing oil plants could be replaced by photovoltaic plants by year 2000.

Figure 11. Annual Subsidy Per Residential Customer

Figure 12. Annual Subsidy Per Residential Customer

Figure 13. Annual Subsidy Per Residential Customer

Figure 14. Annual Subsidy Per Residential Customer

These results indicate that subsidies provided by increases in electric bills could permit early use of photovoltaic systems in central station applications in Southern California, thereby reducing the need for relaxation of air pollution standards to accommodate new coal plants or for continuation of the operation of existing oil-fired plants.

IV. Conclusions

This preliminary analysis indicates that a subsidy provided by small increases in annual electric bills could make photovoltaic systems a viable alternative to fossil-fuel plants in central station applications throughout the United States over the 1986-2000 time period even if the cost of fossil fuel increases no more rapidly than the annual inflation rate. It appears that, in addition, such a subsidy would allow early use of photovoltaic systems in central station applications even if the cost of arrays does not decrease as rapidly as expected. Without such subsidy, significant use of photovoltaic systems in central station applications is unlikely in most locations until after the year 2000, even if it is assumed that fossil fuel costs increase relatively rapidly and all photovoltaic array cost reduction objectives are achieved as scheduled.

The results presented are based on providing a subsidy to cover the difference in busbar energy generation cost between identical photovoltaic and lower cost fossil fuel plants. It may be desirable in future studies to consider specific utility systems and determine user subsidy requirements based on analyses of utility cash flow needs and the difference in utility electrical generation cost due to introduction of photovoltaic plants instead of lower cost fossil fuel plants.

In view of the relatively small impact on individual utility customers, the potential for significant early penetration of utility markets by photovoltaic power systems, the need to conserve fossil fuels, and the desire to maintain and improve environmental conditions, a user subsidy for photovoltaic systems appears to be a highly attractive approach to alleviating national energy problems. It is recommended that serious consideration be given to including this approach in the National Photovoltaic Program and to evaluating its effect on other parts of the program, particularly technology development, research and development, market analysis and commercialization.

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