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Economic analysis of photovoltaic systems for local governments in California

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ECONOMIC ANALYSIS OF PHOTOVOLTAIC SYSTEMS FOR LOCAL GOVERNMENTS IN CALIFORNIA

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ABSTRACT

ECONOMIC ANALYSIS OF PHOTOVOLTAIC SYSTEMS FOR LOCAL GOVERNMENTS IN CALIFORNIA

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Electrical energy from sunlight, through the use of photovoltaic solar-electric rooftop systems, is proving to be a viable alternative to nonrenewable energy sources. Through cost-benefit analysis, this thesis examines the question of whether the installation of photovoltaic (PV) systems by local municipalities were economically sound and if PV systems were effective in reducing air pollution.

Eleven municipalities in Northern California were studied using a Market Valuation technique of discounting benefit and cost streams over a 25-year time period to Present Value and quantifying displacement of air pollutants. Results demonstrated that 8 out of 11 photovoltaic projects were less expensive in the long-term than paying the local utility company, and the volume of air pollutants displaced was sizable. State-financed rebates and net-metering policies are critical factors that enable municipalities to approve photovoltaic projects; without them, it will probably be difficult for future photovoltaic projects to receive approval.

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LIST OF ABBREVIATIONS

AC	Alternating Current
ASES	American Solar Energy Society
CBA	Cost-Benefit Analysis
CE	Cost-Effectiveness
CEC	California Energy Commission
DC	Direct Current
EPA	Environmental Protection Agency
EPBT	Energy Payback Time
ERP	Emerging Renewables Program
GHG	Greenhouse Gases
GPRA	Governmental Performance and Results Act
kW	kilowatt
kWh	kilowatt-hour
MAUA	Multi-Attribute Utility Analysis
MSR	Million Solar Roofs
MW	megawatt
MWh	megawatt-hour
NASA	National Aeronautics and Space Administration
NPB	Net Present Benefits
NPC	Net Present Costs

NPV	Net Present Value
NREL	National Renewable Energy Laboratory
NWPA	Nuclear Waste Policy Act
O&M	Operation and Maintenance
OMB	Office of Management and Budget
ORNL	Oak Ridge National Laboratory
PG&E	Pacific Gas and Electric Company
PV	Photovoltaic
R&D	Research & Development
RIA	Regulatory Impact Analysis
SCE	Southern California Edison
SDG&E	San Diego Gas and Electric
SEPA	Solar Electric Power Association
SMUD	Sacramento Municipal Utility District
T&D	Transmission and Distribution
TOU	Time of Use
VOC	Volatile Organic Compounds

INTRODUCTION

An adequate and uninterrupted supply of electricity is critical to the functioning of modern societies. The economic base of society, the advancement of technology, and our very quality of life depend on its availability (Kahn, 1991). Electrification has even been declared by the U.S. National Academy of Engineering as the greatest engineering achievement of the 20th century (Moniz & Kenderdine, 2002).

Electrical generation is typically provided by fossil fuels—coal, natural gas, and oil—as well as nuclear power. Some of today's most serious environmental problems can be linked to world electricity production based primarily on the use of nonrenewable resources (Berger, 1997; Charters, 1994; Grob, 1998). In order to meet the electrical needs of an expanding global population and simultaneously reduce negative environmental impacts, it is of vital importance to make the transition from dependence on nonsustainable, nonrenewable fossil fuels and to incorporate renewable energy as a source of electrical production.

The Energy Information Administration (EIA) defines renewable energy as "energy that is naturally replenishing but flow-limited. Renewable energy is virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time" (Energy Information Administration #1, n.d., n.p.). Renewable energy resources include biomass, hydropower, geothermal, solar, wind, ocean thermal, wave action, and tidal action. This thesis focuses on solar energy as one of the most promising renewable energy technologies able to provide a cost-effective method of supplying electrical power to society. Solar energy systems convert sunlight to electricity by means of photovoltaic (PV) cells. PV cells produce electricity silently, without moving parts, and they do not emit toxic or greenhouse gases (GHG) during their operation.

Focus

The overall objective of this thesis is to explore the factors that encourage or discourage municipalities from installing PV systems on public buildings. There are a number of reasons to focus on municipalities as potential PV users.

1. Local governments can lend legitimacy to the idea of renewable energy in general and PV specifically.
2. They can play a leadership role by introducing their constituency to the benefits associated with an emerging technology such as solar-rooftop PV systems.
3. As large electricity consumers, local governments can lead the way in new-technology pilot projects.
4. As regional planners and implementers of local economic development, local governments have the opportunity to integrate an energy element into growth-management plans (Herig, 2000).

Municipalities and local governments have the option of borrowing money cheaply through bonds or government-only loans, and they are not necessarily driven by profit margins in the same way that private companies are. Municipalities have years of experience with long-term planning and are more responsive to their constituencies than the federal government (Browning, 2003). Furthermore, municipalities have the potential to effect change at the national level. If renewable energy initiatives become popular with city and county governments, this trend could translate into action on a larger scale with the federal government (Laird, 2003).

Local governments are constantly formulating public policy, a task which is almost impossible to do without including energy consumption. Public policy issues such as land use, air quality, transportation, housing, and parks and recreation often need to be considered within the context of electricity usage. Because of e-commerce, telecommuting, the growing popularity of home offices, and other trends, electrical consumption per capita is increasing. Residential areas and newly built communities may be prime locations for PV systems because of the expense of installing or upgrading transmission lines (Herig, 2000).

Besides newly built communities, other areas serve as productive locations for PV. The abundance of parking lots provides ample opportunities for solarports which serve the double duty of generating electricity and imparting shade for vehicles. The tranquillity and beauty of open spaces and parks are leading candidates for quiet, non air-polluting PV systems. These installations negate the need for trenching, poles, power lines, or noisy generators. Furthermore, the use of PV systems could facilitate the attainment of air quality standards set by the State of California (Herig, 2000).

Government Subsidies and Costs of PV

In spite of the many advantages of using solar-rooftop PV to generate electricity, PV's use is not yet considered mainstream. One of the biggest barriers to PV is cost. Although an exact dollar figure is difficult to determine, it is generally assumed that PV is approximately three times more expensive per kilowatt-hour (kWh) than the same electricity from the local utility company (Fies, 2001). An explanation for the high price of PV may be the existence of market imperfections as a result of government subsidies (Nofuentes, Aguilera, & Munoz, 2002; Yokell, 1979). Fossil fuel energies have been receiving subsidies for almost a hundred years. From 1918 to the 1970s, total subsidies for fossil fuel energies were estimated to have ranged from $123.6 billion to $133.7 billion in undiscounted dollars (Yokell, 1979). Renewable energy technologies also received subsidies, yet fossil fuel energy sources continued to receive substantial government assistance (Koplow & Dernbach, 2001).

Studies estimated that subsidies for fossil fuels fell somewhere between $200 million per year and $1.7 trillion per year (1999 dollars) during the 1990s (Koplow & Dernbach, 2001). High values for fossil fuel subsidies were most likely linked to the inclusion of externalities such as a partial cost of the Persian Gulf War. Omitting externalities and including only fiscal subsidies, the range of assistance was estimated to be between $2.6 billion and $121 billion per year.

The United States federal government currently has a number of programs to promote PV. Beginning in the 1990s, policies were enacted to encourage PV installations on government buildings and facilities. The federal government is the single largest consumer of electricity in the United States. It owns approximately half a million buildings and spends more that $3 billion per year on heating, cooling, lighting, and powering those buildings (Million Solar Roofs #1, n.d.).

The Energy Policy Act (1992) mandated a 35% drop in energy use for all federal buildings by 2010. In 1999, President Clinton issued Executive Order 13123 which set the goal of installing solar electric and solar thermal energy systems on 20,000 federal buildings by 2010 and defined a goal of 2.5% of all federal electricity consumed to come from renewable sources by 2005. As of May 2002, PV comprised 11.1% of the total renewable energy supplying electricity to federal buildings (Crawley, 2002). Examples of federal buildings that have installed PV systems include the Pentagon, the U.S. Department of Energy

Headquarters, and the Federal Energy Regulatory Commission Headquarters (Plympton, Kappaz, Kroposki, Stafford, & Thornton, 2001).

In 1997, a federally instituted program was set up to establish local markets for solar energy, the Million Solar Roofs (MSR) program. The goal of MSR was to install PV systems on one million roofs by 2010 (Million Solar Roofs #2, n.d.). This program has been successful thus far and is ahead of schedule. To date, approximately 40 MW of PV have been installed nationwide, due to the Million Solar Roof program (Million Solar Roofs #3, n.d.).

The State of California also has programs in place to encourage PV projects on State government buildings. Ex-governor of California Gray Davis signed Executive Order D-16-00 (August 2000) that directed State agencies to implement sustainable building practices in government buildings (Hoff, 2000). Senate Bill 82 (2001) required solar energy equipment to be installed on all existing State buildings and parking facilities, as well as being included in new projects wherever feasible by the beginning of 2007 (Official California Legislative Information, n.d.). See Appendix A for a list of solar energy legislation between 1996 and 2002.

Perhaps the two most critical incentives promoting PV in California have been the net-metering program and the rebate program. SB 656 (1996), providing for net-metering, stated that the big three utility companies (PG&E, Southern California Edison [SCE], and SDG&E [San Diego Gas and Electric]) and rural cooperatives must pay retail prices for electricity supplied to them by their customers (Database of State Incentives for Renewable Energy, n.d.).

The second essential incentive for the success of PV has been the two statewide rebate programs: (a) the Emerging Renewables Program (ERP) for systems smaller than 30 kilowatts (kW) and (b) the Self-Generation Incentive Program for systems between 30 kW and 1.5 MW. As of January 2004, the ERP pays $3.20/watt for an operational, grid-tied PV system and the Self-Generation Program pays $4.50/watt for an operational, grid-tied PV system (Database of State Incentives for Renewable Energy, n.d.). As a result of these policies, California has installed five times as many PV systems between 2000 and 2003 as had been installed in the two previous decades between 1980 and 1999 (California Energy Commission #1, n.d.).

Cost-Effectiveness of PV

Some analysts have argued that PV will not significantly penetrate the market. Barriers mentioned are low conventional energy prices, low energy intensity from sunlight, and nonproductive periods such as nighttime and cloudy days (Caldwell, 1994). Energy efficiency of PV cells is cited as another drawback to PV, which in turn requires that PV cover a large surface area in order to generate significant amounts of electricity (Hoffert et al., 2002). Hoffert et al. stated that there is not enough land area available for this purpose.

Luque (2001) produced a model to show PV module sales through 2050 and drew the conclusion that electricity from PV will not be competitive with conventionally generated electricity unless certain conditions occur (i.e., a rise in electricity prices, a fall in marketing costs for PV modules, and the discovery of breakthroughs in solar technology). Luque suggested that the chance of one or all three of these conditions being met is high. Furthermore, he predicted a decade of explosive growth in PV modules in the first part of the 21st century and that this growth would occur even if reductions in PV module prices were moderate.

The PV industry is growing. Until the mid-1990s, prices of PV modules on the world market were prohibitively expensive for applications other than niche markets. Because of research, development, and increased demand, the price of PV modules has come down dramatically, from approximately $80/watt in 1976 (year 1992 dollars) to just under $4/watt (year 2000 dollars) (Parente, Goldemberg, & Zilles, 2002). Parente et al. showed that the learning rate for PV modules over the past 20 years is still improving. The learning rate is the percent price decrease of a product for every doubling of cumulative sales. Between 1981 and 1990, the learning rate for PV modules was 20.2%; between 1991 and 2000, it improved to 22.6%.

In 1997, annual global PV module production was a $1 billion-per-year business, and world shipments of PV modules equaled 390 MW in 2001 (Solar

Electric Power Association, 2002). In the U.S., the market for grid-connected, distributed PV systems (versus off-grid or centralized PV) was continuing to increase. In 2000, 33% of all PV installations were grid-tied, up from 20% in 1999. As of December 2000, total installed PV in the U.S. was 138.8 MW (Solar Electric Power Association, 2002).

The United States provides ideal conditions for PV, with an infrastructure to support it and the best solar resource of all developed nations (Solar Electric Power Association, 2002). Average daily peak sun hours range from 4 hours to 7 hours per day in most of the 48 contiguous states and Hawaii. Cities such as Chicago and Long Island have invested in PV along with cities that are in high-sun regions like Sacramento and Tucson.

Availability of the solar resources is not the only factor when calculating the economic value of a PV system. The alternative cost of conventional electricity, the absence of significant barriers, environmental costs of emissions avoided, and available government incentives will vary regionally, and all of these factors contribute to the economic viability of PV. The National Renewable Energy Laboratory (NREL) has identified Hawaii, California, Illinois, New York, and North Carolina as the top five states with the best markets for solar-electric rooftop installation of grid-connected PV systems. States as diverse as Utah, Pennsylvania, and Florida were also deemed cost-effective (Herig, Thomas, Perez, & Wenger, 2000).

PV History

Scientists at Bell Laboratory invented the silicon solar cell in 1954 and are credited with the birth of modern PVs. The first application for solar cells as a method of electrical generation was to power spacecraft and satellites orbiting the earth (Energy Information Administration #2, n.d.). After proving themselves in the space program, PV cells found markets for off-grid, small-power applications in situations where plugging into the electric grid was not possible or feasible. Considered "niche" applications, these uses for PV included communications equipment, roadside emergency phones and lights, pumping water for irrigation, navigational aids for the Coast Guard, and battery chargers for the armed forces during field operations (Fies, 2001).

It was not until the late 1970s that PV was placed on buildings and homes—albeit in very limited numbers—due to the extremely high cost of approximately $80/watt (Parente et al., 2002). The Solar Photovoltaic Energy, Research, Development and Demonstration Act (1978) pledged $1.2 billion (current dollars) over 10 years to improve PV production levels, reduce costs, and stimulate private-sector purchases. In 1985, the world price of PV modules fell to $10/watt, and by 1982, the price was slightly below $5/watt. Higher efficiencies for PV modules were attained in the laboratory, and by 1992, a 15% efficiency was achieved. Today, PV cell efficiency is as high as 30% (Energy Information Administration #2, n.d.).

Environmental Benefits of PV

PV cells are reliable and predictable, in part because they have no moving parts and they use no energy other than sunlight to produce electricity (Caldwell, 1994). The environmental benefits from solar energy are significant. Emissions known to contribute to air pollution, global climate change, and acid rain are avoided, and health costs related to air emissions are reduced (Garbesi & Bartholomew, 2001; Solar Electric Power Association, 2002).

Frankl and Gamberale (1998) correlated PV systems with carbon dioxide (CO_2) emissions. Using Life-Cycle Analysis, they found that PV had a significant positive environmental performance. Crystalline silicon PV panels were expected to save between 1,000 kg and 3,000 kg of CO_2 emissions per square meter for a 25- to 30-year life expectancy of the panel. Using PV in areas of high solar insolation could reduce carbon emissions by as much as 450 million metric tons during the next 30 years (Lee, Fthenakis, Morris, Goldstein, & Moskowitz, 1997). Every gigawatt of electricity generated by PV rather than coal was estimated to prevent up to 10 tons of sulfur dioxide (SO_2), 4 tons of nitrogen oxide (NO_X), 0.7 tons of particulate matter (including cadmium and arsenic), and up to 1,000 tons of CO_2 being emitted into the air (Fthenakis & Moskowitz, 2000). Natural resources displaced over the lifetime of PV systems (approximately 30 years) for every kW of PV installed have been estimated by the Sacramento Municipal Utility District (SMUD) to be equal to approximately 124,300 pounds of coal or 8,800 gallons of oil or 13.5 million cubic feet of natural gas. In terms of emission reductions, the air pollution avoided would be 217,000 pounds of CO_2, 1,500 pounds of SO_2, and 830 pounds of NO_x (Hoff, 2000). The range of emissions saved depends on a number of site-specific parameters (i.e., average annual solar insolation, energy consumption and CO_2 emissions related to PV module manufacturing and efficiency, and CO_2 emissions of the local electricity production mix) (Frankl & Gamberale, 1998).

Nonenvironmental Benefits of PV

The use of PV for electricity acts as a hedge against future increases in energy prices (Fies, 2001). PV systems and power plants are not an attractive target for terrorists because there is no explosive fuel or radioactive fallout as a byproduct of a terrorist act. Moreover, PV power plants do not contribute to nuclear proliferation and they will reduce the amount of fossil fuels imported from around the world (Solar Electric Power Association, 2002; Walton & Hall, 1990).

PV systems represent a way of reducing transmission and distribution (T&D) extension costs for conventional utility companies. Increased regulations, public opposition, and expense often make installation of T&D lines difficult for utility companies. The value of deferring T&D installation varies among utilities from $0 to as much as $300 per kW (Barnes, Van Dyke, Tesche, & Zaininger, 1994).

The zero air pollution emission output of using PV will assist utilities in complying with the maximum air emission levels allowed by law (Center for Energy and Economic Development, 1995). Furthermore, PV systems tend to generate electricity during the afternoon when it is most needed and electrical demands are at their highest. This correlation between peak demand and peak availability will help reduce the necessity of producing electricity with peakers, which are often the most expensive and dirtiest sources of electrical supply. Peakers are power plants that are generally kept offline because they are old, inefficient, or both. They come online when the power grid is stressed and all available electricity is needed, such as during a heat wave when air conditioners are running at their maximum.

Another benefit of solar energy is that construction of large-scale solar power plants can take advantage of some features obtained from small-scale PV systems. Construction is faster for a solar power plant than for nuclear, coal, oil, and natural gas facilities, and large sites can operate without staff (Caldwell, 1994; Hester & Gross, 2001).

Installing a renewable energy source (i.e., PV cells) near the load results in benefits known as distributed utility benefits. Distributed utility benefits include a reduction in electricity loss during transmission, deference of T&D

improvements, improvement of power quality and reliability, and displacement of electric energy produced by fossil fuels (Barnes et al., 1994). The combined value of distributed utility benefits further helps to offset the relatively high capital costs of investing in renewable energy technology.

Reliability of electrical power is essential for the economic well-being of businesses in America. When power is disturbed (either a total blackout or disturbances such as voltage sags, surges, transients, or harmonics), the cost to industry and digital economies is approximately $36 billion per year (Consortium for Electric Infrastructure to Support a Digital Society, 2001). Digital economies include industries or firms that rely heavily on data processing, data retrieval and storage, or Research and Development (R&D) operations. Examples of digital economies are telecommunications firms and the financial industry.

According to the CEIDS (2001) study, California has the highest costs for outages and disturbances (between $13 billion and $20 billion per year), followed by Texas and New York. Energy security, whether to protect the financial interest of our economy or to insure a reliable supply of electrical power to all segments of American society, can be enhanced through the use of renewable energy technologies (State Energy Advisory Board, 2002).

Potential PV Hazards

PV cell manufacturing poses some environmental, health, and safety risks. Categories of PV modules made today are crystalline silicon, amorphous silicon, cadmium telluride, and copper indium, and many of the materials used during production are classified as toxic, carcinogenic, pyrophoric (explosive), or flammable (Table 1). Risks to workers include fire hazards and inhalation and ingestion of toxic substances. The most acute threat to the public is from an accidental release of gaseous effluents. Poisonous liquid and solid wastes are also produced from PV manufacturing plants, but public exposure would primarily be through indirect pathways such as contamination of drinking water which can be controlled, monitored, and prevented (Fthenakis, 2000, 2001).

The PV industry is adopting a multilayer protection approach to manufacturing PV modules as well as implementing steps to prevent release and contamination of poisonous materials to workers, the public, and the environment. Protection measures include, but are not limited to, continuous toxic gas monitoring, double containment of storage tanks, and redundancy of critical systems (Fthenakis, 2001). The PV manufacturing industry strives to be a green industry that values the health of the environment, and it takes steps to manage PV cells from cradle-to-grave (Fthenakis, 2000).

Table 1

Hazardous Materials Used in PV Cell Manufacturing

Material	Threat
Arsine	Highly toxic
Cadmium compounds	Suspected carcinogens
Carbon chloride	Toxic, potent greenhouse gas
Diborane	Highly toxic
Hydrogen	Fire hazard
Hydrogen fluoride	Noxious, corrosive
Hydrogen selenide	Highly toxic, flammable
Hydrogen sulfide	Highly toxic, flammable
Phosphine	Highly toxic, flammable
Silane	High fire and explosion hazard

Supplying electricity by means of PV systems does have an energy pricetag. It takes energy to make PV panels. Frankl and Gamberale (1998) estimated the Energy Payback Time (EPBT) for silicon PV cells to be approximately 8 years. As economies of scale in manufacturing and other efficiencies improve over time, Frankl and Gamberale expected the EPBT to be in the 2- to 3-year range.

ENVIRONMENTAL CONTEXT OF PHOTOVOLTAICS

Alternative energy technologies (e.g., solar energy) have distinct environmental advantages over conventional technologies for the generation of electricity. Global climate change, air pollution, water pollution, ecosystem degradation, radioactive waste, and acid rain are among the most critical environmental problems linked to generating electricity by fossil fuels. Fossil fuel-based electricity production has resulted in negative environmental impacts that have spread worldwide (Berger, 1997; Carlin, 1995; Ottinger, 1991). The next section addresses problems ranging from large-scale global issues to concerns on a national level and finally to issues related to electrical production in California.

International Issues

Global climate change is a phenomenon affecting the entire planet. Average atmospheric temperatures of the earth are maintained naturally by the presence of GHG. Sunlight (solar radiation) is transmitted to earth and a portion of it is re-radiated back into space. Carbon dioxide (CO_2), methane (CH_4), water vapor (H_2O), and nitrous oxide (N_2O) are the main GHGs that trap solar radiation and maintain temperatures that sustain life. Until large-scale industrialization began, the equilibrium between solar (infrared) radiation transmitted to the earth and the amount re-radiated back to space was preserved by natural processes (Energy Information Administration #3, n.d.).

The current geologic time period, known as the Holocene, has been characterized by moderate stable temperatures maintained, in part, by a stable GHG component of the atmosphere. This balance is being changed by the production of CO_2, mainly from human activities. In terms of total radiative forcing (for definitions see the glossary in Appendix B), the most damaging of the human-caused GHG is CO_2, which results from burning coal. Worldwide, the concentration of CO_2 in the atmosphere has increased 31% since the beginning of the industrial revolution (Dunn, 2000; Intergovernmental Panel of Climate Change, 2000). Coal releases 30% to 50% more carbon than oil per unit energy, and 75% to 80% more carbon than natural gas per unit energy (Dunn, 2000; Energy Information Administration #4, n.d.; Nicklas, 1997). Electrical generation is the largest single source of global carbon emissions, accounting for over 2 billion of the 6 billion tons of CO_2 emitted annually from burning fossil fuels. CO_2 emissions are growing at a rate of 3.6% per year worldwide as developing nations increase their use of fossil fuels in transportation and energy production (Dunn, 2000; Nicklas, 1997).

Average global temperatures are projected to increase over the next 100 years (Dunn, 2000). Predictions are for an increase ranging from 1.4°C to 5.8°C during the 21st century, approximately 2 to 10 times larger than the global warming observed during the 20th century (Intergovernmental Panel of Climate Change, 2000). The overall negative effects of global warming include threats to human health, rising sea levels, increased risk of extinction of vulnerable species, water shortages, a shift in land area for crop production, and changes in weather patterns (Serchuk, 2000). It is possible that global warming may be responsible for the extinction of species on a large scale. A study by Thomas et al. (2003) estimated that 18% to 35% of species would go extinct from six regions in the world in the next 50 years because of global climate change brought about by GHG emissions. Furthermore, it is possible that global climate change is putting one million species at risk worldwide.

National Issues

The United States—only 4% of the world's human population—accounts for an estimated 24% of anthropogenic carbon emissions worldwide linked to the combustion of fossil fuels (Energy Information Administration #3, n.d.). On a carbon equivalent basis, 85% of U.S. anthropogenic GHG emissions come from energy-related activities. This amounts to 1,559 million metric tons of carbon equivalent today (Energy Information Administration #4, n.d.).

Nationwide, 40% of all CO_2 emissions from fossil fuel combustion comes from generating electricity, the largest single source of CO_2 emissions. Even transportation, which accounts for 32% of CO_2 emissions in the United States, emits less CO_2 than the electric industry. Furthermore, the Annual Energy

Outlook 2003 report is forecasting a 1.5% increase in energy-related CO_2 emissions through the year 2020 (Energy Information Administration #4, n.d.).

When exposed to water in the atmosphere, carbon, nitrogen, and sulfur are elements that can transform into weak acids and return to the earth as acid rain, acid snow, and acid fog. The Environmental Protection Agency (EPA) believes this phenomenon is the primary cause of acidification of hundreds of streams in the mid-Atlantic highlands and the New Jersey Pine Barrens and of many lakes in the Adirondack Mountains of New York (Carlin, 1995). It is the acid-sensitive soils that make these areas, as well as southeastern Canada, particularly vulnerable to acid deposition (Serchuk, 2000).

NO_x emissions that return to earth in acidic form add to nitrogen in the soil. Excess nitrogen binds with essential plant nutrients, which in turn limits plant growth. Furthermore, the nitrogen runoff that eventually ends up in aquatic systems contributes to an explosive growth of algae, and it results in eutrophication. Power plants are implicated as the source for 11% to 15% of the nitrogen in Chesapeake Bay (Serchuk, 2000).

Electric power plants produce approximately 30% of the NO_x emissions in the United States. NO_x reacts with volatile organic compounds (VOCs) in the presence of sunlight to form ozone (or smog). Ozone is linked to a number of short- and long-term respiratory illnesses. In the early 1990s, the American Lung Association estimated that respiratory health impacts caused by the burning of coal cost Americans approximately $82 billion a year (Nicklas, 1993). NO_x also interferes with photosynthesis in plants, which has resulted in decreased crop production yields estimated to cost upwards of $100 million per year (Power Scorecard #1, n.d.).

The U.S. electric industry accounts for roughly 67% of all SO_2 emissions (Power Scorecard #2, n.d.). Approximately one-sixth of SO_2 emissions in the eastern United States are deposited in Canada, and one-third of SO_2 emissions end up in the Atlantic Ocean (Ottinger, 1991). Both SO_2 and NO_x have been implicated in human health problems (Carlin, 1995; Serchuk, 2000). A public health benefit of lowering these two emissions from electric power generation is estimated to be valued at $50 billion a year in the United States by 2010. This value is calculated from a reduction in mortality rates, hospital admissions, and emergency visits (Environmental Protection Agency #1, n.d.).

Coal-fired electric power plants discharge heavy metals and carcinogens during coal combustion—mercury, arsenic, beryllium, cadmium, nickel, dioxin, furans, and PCBs—as well as radioactive materials. Mercury is highly carcinogenic and has been linked to birth defects (Dunn, 2000). Coal-fired power plants discharge 30% to 40% of all manmade mercury emissions, which are estimated to be approximately 43 tons annually (Environmental Protection Agency #2, 1998).

Airborne concentrations of mercury pose little risk to living organisms but eventually mercury is deposited on land and in bodies of water where wildlife and fish become exposed. Currently 39 states have issued mercury warnings for at least one body of water and 9 states have issued statewide mercury warnings (Environmental Protection Agency #2, 1998; #4, 2000).

Fossil fuels are not the only type of fuel used to generate electricity. Nuclear power facilities generate approximately 20% of the total kWh of electricity produced in the United States (Holt, 1999). Nuclear power plants do not produce the same air pollutants that are emitted by fossil-fuel power plants; however, they do discharge radionuclides into the air (Environmental Protection Agency #3, 2000). In December 1979, radionuclides were listed as hazardous air pollutants within the meaning of the Clean Air Act (1970), and exposure was found to constitute a risk to humans for cancer and genetic damage (Environmental Protection Agency #3, 2000).

Nuclear waste, another byproduct from the normal operation of nuclear power plants, poses a long-term environmental problem. Spent fuel rods—which constitute high-level solid waste from these reactors—are highly radioactive, thermally hot, and under the right conditions could deliver lethal doses of radiation to humans (and any other living organism) in a matter of minutes. Over 40,000 metric tons of spent fuel rods are stored at 70 nuclear power facilities around the country, and this number is expected to rise to 60,000 metric tons by 2010 (Holt, 1999).

A permanent repository located in Nevada was mandated in the Nuclear Waste Policy Act of 1982 (NWPA). The repository was scheduled to open in 1998, but the date has been pushed out to 2010 because of safety concerns for containment of the waste. Concerns are mainly geologic issues (e.g., volcanic activity, earthquakes, water infiltration, and underground flooding) as well as technical issues including the potential for nuclear chain reactions. Transporting high-level waste from current locations to Nevada has also raised issues of safety. Moreover, this has proven to be a costly endeavor. Since the inception of the NWPA, utility nuclear waste fees have totaled $15.2 billion (Holt, 1999).

Nuclear power plants also produce low-level radioactive waste. By volume, nuclear utilities are responsible for 66% of low-level waste in the United States; however, this translates to 85% of the total radioactivity (Holt, 1999). Only six low-level waste facilities have ever been in existence, and all six have leaked various types of radionuclides into groundwater and vegetation (Serchuk, 2000). Wastes from nuclear electric generating facilities are extremely expensive to deal with, remain radioactive for thousands of years, and have the potential to damage or destroy all living organisms exposed to them. The plants themselves need to be decommissioned at the end of their 35- to 40-year life. Most of the reactor and related equipment must be stored as radioactive waste.

Regardless of the environmental impacts and economic costs, society cannot sustain the use of fossil fuels indefinitely at current rates of use. Fossil fuel supplies are finite and will eventually become scarce. Oil and natural gas sources may be depleted within the next 100 years (Charters, 1994; Nicklas, 1997). Seven of the top 13 oil fields in the United States are 80% depleted.

State Issues

California's total electrical energy production in 2002 was 272,544,000 megawatt-hours (MWh). Sources of electrical production are 36.5% from natural gas, 20% from coal, 14.9% from nuclear power, less than one percent (0.18%) supplied by oil, and the remainder from hydropower and renewable energy technologies. Using U.S. EPA (#5, n.d.) calculations for average emissions from typical coal-fired, natural gas-fired, and oil-fired electrical generation plants, and factoring the specific energy mix for California's electricity, the result is an estimated 118 million tons of CO_2, 362,224 tons of SO_2, and 249,064 tons of NO_X discharged in 2002 by power plants in California (Table 2) (California Energy Commission #2, n.d.).

Electricity produced in California from renewable energy sources is the highest in the nation. In 2002, 9.3% of California's electricity came from renewable energy: (a) biomass (2.6%), (b) geothermal (5.1%), (c) solar (0.3%), and (d) wind (1.3%). In addition, 19.3% came from hydropower, with approximately half of the hydropower being imported from out of state (California Energy Commission #2, n.d.).

Table 2

Tons of CO_2, SO_2, and NO_x Per Year During the Combustion of Coal, Natural Gas, and Oil Emitted From California's Electrical Power Plants in 2002

	Coal-fired Plant	Natural Gas-fired Plant	Oil-fired Plant	Total Emissions in 2002
CO_2	61.3 million tons	56.4 million tons	410,124 tons	118 million tons CO_2
SO_2	354,307 tons	4,974 tons	2,943 tons	362,224 tons SO_2
NO_x	163,526 tons	84,557 tons	981 tons	249,064 tons NO_x

California experienced an energy crisis in 2000-2001. During this time, the State endured numerous rolling blackouts along with skyrocketing prices for electricity and natural gas. From 1999 to 2000, statewide spending on power went from $7 billion to $28 billion, and at times during 2000, the taxpayers of California paid as much as $171 for one MWh, a six-fold increase from the previous year (Faruqui, Chao, Niemeyer, Platt, & Stahlkopf, 2001). This surge in spending was due largely to restructuring the power market as well as ensuring that utilities would recover stranded costs which were mostly in the form of investments made in nuclear power plants.

In response to the energy crisis of 2000-2001, the installation of new natural gas pipeline capacity increased 39% in 2002 on the U.S. interstate mainline transportation network. For California, natural gas pipeline construction projects completed in 2002 cost $629 million, added 1,529 additional miles to the pipeline infrastructure, and increased natural gas supply by almost 1.8 billion cubic feet per day. During 2002, PG&E alone increased gas supply by 367 million cubic feet per day at an estimated total cost of $161 million (Energy Information Administration #6, 2002).

As the population of California continues to grow, the demand for electricity will also increase. Currently, there are 1,012 power plants in California with a combined online capacity potential of 54,000 MW (California Energy Commission #3, n.d.). The California Energy Commission (CEC) has predicted an additional 8,000 MW will be needed by 2006 to meet the energy needs of California (California Power Authority, 2002). Approximately 20% of the power plants in California are over 30 years old and will need to be replaced sometime in the next decade. Ex-Governor Davis endorsed the CEC's Renewable Investment Plan (2002) and its goal of increasing the State's renewable electricity consumption—excluding hydropower—to 17 % by 2010. Increasing the State's reliance on its own renewable energy technology is one way to prevent future crises.

THEORETICAL FRAMEWORK

Introduction

Conventional methods of supplying electricity to society deplete our shrinking store of fossil fuels, cause numerous environmental impacts, and are costly. Viable alternative methods exist that will greatly reduce these harmful impacts and are less expensive than conventional means when environmental externalities are factored into the overall cost.

One of those alternatives is solar-electric, rooftop, PV systems. PV systems have not yet become commonplace with the public, yet a growing number of municipalities are making the decision to install PV systems as a supplemental electrical supply for their own buildings or facilities. Cost is an important issue in adopting this alternative technology, and the use of CBA is a standard method in which to evaluate costs of PV projects.

Cost-benefit analysis (CBA) is a method often used by decision-makers in the public sector to make choices regarding public expenditures. It is a type of economic analysis designed to provide guidance when deciding how to best allocate society's funds, choose between policies, or accept implementation of a new project. CBA examines present and future costs and benefits of the proposed policy or project and compares the value between the two.

CBA was first developed in the 1840s by a French engineer who applied it to the evaluation of investment projects (Gatto & DeLeo, 2000). The United

States federal government adopted cost-benefit techniques starting in the 1930s to assess public expenditures, usually water resource projects (Fuguitt & Wilcox, 1999). CBA has now become an integral part of governmental decision-making processes worldwide.

CBA is not the sole analytical method devised to rigorously examine benefits and costs in the public sector. Cost-effectiveness (CE) and Multiattribute Utility Analysis (MAUA) are also accepted valuation techniques used by economists today. As with CBA, they are tools for decision-makers to determine the efficient allocation of resources for public policies or projects. CE and MAUA provide alternative methods of assessing the efficiency of policies or projects in the public sector and they are especially effective when valuing a hard-to-measure, nonmarket effect.

CE strives to minimize the monetary costs of achieving a given effect. For example, effects could be a given number of lives saved, a given number of additional years of useful equipment life, or a given number of people that do not relapse to substance abuse. Pursuing the project is decided by its cost in comparison to a quantified effect.

MAUA considers attributes of projects and assigns weights to them. Utility, which is an effect or outcome of the project, is also given a weight. Weighted attributes are multiplied by weighted utilities to produce a score.

Scores are then ranked to enable the decision-maker to choose among alternative projects.

Background

In the United States, CBA was originally employed to assist government decision-makers in funding water-resource projects. The River and Harbors Act of 1927 marked the beginning of formal economic evaluations in order to justify projects. The 1936 Flood Control Act was credited with initiating the practice of CBA in the United States because it attempted to assess more than just construction costs and resulting revenues from the projects (Gatto & DeLeo, 2000). Benefits in the form of welfare to society were recognized. For example, benefits from flood control could raise the value of riverside property and increase agriculture production (Fuguitt & Wilcox, 1999).

During the 1950s, the use of CBA became increasingly prevalent. In the post World War II era, public expenditures grew, and determining budget priorities became important. Consequently, the underlying principles of CBA spread into new decision areas (Fuguitt & Wilcox, 1999).

The field of environmental economics emerged in the 1960s. CBA was recognized as one of the most comprehensive techniques to examine choices for services not priced in the market (e.g., the assessment of alternative pollution control methods).

In 1978, President Carter issued Executive Order (EO) 12044 which instructed federal agencies to perform economic analyses for major regulations, and CBA became an important part of regulatory assessment (Fuguitt & Wilcox, 1999). Examples of federal regulations mandating the inclusion of CBA are the Toxic Substance Control Act, the Safe Drinking Water Act, and the Clean Air Act Amendments of 1990. Furthermore, two Executive Orders—the first in 1981 from President Reagan (EO12291) and the second in 1993 from President Clinton (EO12866)—called for CBA of major regulations (Farrow & Toman, 1999). The Regulatory Impact Analysis (RIA) created through Reagan's Executive Order 12291 broadened the number of rules requiring economic analysis. For example, it was the RIA that required the EPA to conduct a CBA when they were considering a policy change to eliminate lead from gasoline (Callan & Thomas, 2000).

The Clinton administration initiated the Governmental Performance and Results Act (GPRA) which afforded additional opportunities for agencies to assess their programs using CBA (Farrow & Toman, 1999). The EPA began to use CBA commonly to evaluate programs and policies beginning with the Clean Air Act Amendment of 1990. Since 1990, the EPA has employed CBA to evaluate numerous policies and programs economically, such as the impact of air quality management strategies, effluent limitations for the wastewater treatment industry, and the cost of land treatment systems. Furthermore, CBAs are often used in Environmental Impact Statements.

Definition and Steps of CBA

CBA is designed to answer two questions: (a) What are the costs (i.e., what is given up)?; and (b) What are the benefits or the worth of a policy? CBA is anchored in the knowledge that resources are limited. It is a tool for decision-makers to decide how to most efficiently allocate limited resources. Fuguitt and Wilcox (1999) define CBA as "a useful approach to assess whether decisions or choices that affect the use of scarce resources promote efficiency. Considering a specific policy and relevant alternatives, the analysis involves systematic identifications of policy consequences, followed by valuation of social benefits and costs" (p. 35).

A number of steps are involved in a CBA. The first step is to identify the project and the project impacts. This includes clearly defining the action being assessed, what the issue is behind the action, the scope of the project, and the time horizon. The time horizon—or time period—chosen for the analysis may have a major effect on acceptance or rejection of a policy. Lengthening or shortening a time frame can affect the approval of a project because future benefits (costs) could be increased (reduced). Two approaches for setting the time horizon would be to (a) match the time period with the expected duration of the policy or (b) set the time period to the expected useful life of the capital investment.

The second step of CBA is to identify relevant impacts of the project or policy. This estimates the extent to which the new policy will save human lives, animal lives, ecosystems, improve quality of life, etc.

The third step is to decide what impacts are economically relevant and to physically quantify the relevant impacts.

The fourth step is to determine the monetary value of the relevant impacts. A number of techniques are available to do this. Assessing benefits and costs whose prices are determined in the marketplace is called Market Valuation. Consumer demand conveys information on the value of products by exchanging goods for money. Benefits and costs that are not directly exchanged in the marketplace for money are evaluated using various techniques: (a) Contingent Valuation, (b) Travel Cost Method, and (c) Hedonic Pricing Method. Techniques such as these place values on nonmarket goods by asking consumers to state hypothetical preferences, by finding out how much people will pay to travel to experience a resource, or deriving the value of a nonmarket resource from property values. The Market Valuation technique is used in this thesis because costs and benefits assessed in this study have monetary values determined in the marketplace.

The fifth step is to discount benefit and cost cash flows that occur in the future. Future costs and benefits must be expressed in terms of their current value, and this is accomplished by a procedure called discounting, in which a discount rate is applied. Money has a different value depending on when it is spent or earned, and money in the future does not have the same value as money today. This is because money today can either be invested with interest accrued or spent on the consumption of goods now. For these reasons, the dollar values of all future benefits and costs must be discounted to present value.

A discount rate is used to calculate Net Present Value (NPV). Discount rates may be based on the cost of borrowing money or interest received on an alternative investment. Discount rates have an enormous effect on NPV and must be selected with great care. The choice of a discount rate can greatly influence the acceptance or rejection of a project.

There are two general principles for selecting discount rates. The first principle is to base the discount rate on the social opportunity cost of capital. The social opportunity cost of capital is either today's cost of borrowing money or the rate of return from the best alternative investment.

The second principle is to base the discount rate on the social rate of time preference. The social rate of time preference is the rate at which society, not the individual, will postpone present-day consumption to some future time. The social rate of time preference is much more difficult to determine than the opportunity cost of capital and is usually derived from the elasticity of marginal utility consumption and the expected growth rate in per capita consumption (Fuguitt & Wilcox, 1999).

The discount rate selected for a CBA reflects the philosophy of the decision-maker as to which time period he or she considers of greater importance, the present time period or the future time period. The higher the discount rate, the greater the value that is assigned to the present while reducing values assigned to the future. The opposite is true for lower discount rates. This is especially critical when environmental impacts and rights of future generations will be affected by a project or policy. Fuguitt and Wilcox (1999) suggested that setting the discount rate at 0 (zero) would value the future and present equally.

Economists have developed guidelines for choosing discount rates. Regardless of the time frame, if a policy or project is low-risk, the discount rate can be based on low-risk investments. If a project or policy is long-term, the discount rate can be based on long-term investments. For government projects, the discount rate is often based on government bonds or Treasury bills that have a similar time horizon to the proposed project (Fuguitt & Wilcox, 1999).

Step 6 is to apply the appropriate decision-making rule. Generally this is the NPV test. Traditional CBA determines the streams of all costs and benefits of the project. Once these are computed, monetary values are converted to Present

Value and summed over the appropriate time period. After these costs are subtracted from the benefits, the result is the NPV, which can then be assessed to see if the project should be implemented.

Step 7 is to perform a sensitivity analysis. Because there are many issues at stake, a sensitivity analysis is often included in cost-benefit analyses because there is no consensus on the optimal discount rate. A sensitivity analysis uses a range of discount rates (low, medium, and high) in order to compare various outcomes as well as providing objectivity to the CBA. Data calculated in the CBA such as discount rates, physical quantities of gains and losses, estimated prices, and the life span of projects can change. Therefore, a sensitivity analysis can give the decision-maker an idea of the efficiency of the project under varying circumstances.

The final step, Step 8, is to identify the limitations and conclusions of the analysis. For future study, it is important to know what, if any, benefits and costs have been excluded from the analysis as well as any major externalities or noneconomic implications that have not been included.

Merits of CBA

Because of the difficulty of evaluating and quantifying the environmental effects of projects and policies, the validity of cost-benefit analyses has been questioned (Gatto & DeLeo, 2000). If the monetary values of environmental impacts are difficult to determine, inclusion of the impacts in a CBA could be misleading and erroneous. Therefore, policymakers may tend to disregard difficult-to-quantify impacts and focus on impacts that can be easily measured and quantified in monetary terms. Even when an environmental impact has a dollar cost attached to it, that assessment may not necessarily reflect the ecological importance of ecosystem goods and services and could be undervalued. Lastly, introducing bias is possible, as pricing of environmental goods and services will vary widely depending on the reference group surveyed.

CBA has numerous merits, however. CBA forces participants and decision-makers to consider policy consequences. Policies that affect the environment need to be considered in light of the economic worth of the environment. Valuing the environment may defy economic measurement, but policies will still be made that have an impact on nature. Cost-benefit analyses do not lessen uncertainties about impacts on the environment, and without analysis the decisions will become more difficult and uncertain. CBA can include equity issues, illuminate potential tradeoffs, and emphasize the need for accountability (Farrow & Toman, 1999).

In recent years, there has been a proliferation of cost-benefit analyses to evaluate environmental impacts and an attempt to place a monetary valuation on the environment. The University of Maryland's Institute for Ecological Economics (Costanza et al., 1997) used CBA to attach a dollar amount to ecosystem services. Titus (1992) performed a CBA to study long-term costs of global warming to the United States, and Darmstadter (1991) used CBA to look at the mitigation cost of decreasing CO_2 output, to list just a few.

Cost analysis studies estimating the costs of conventional electricity production as compared to renewable energy have been undertaken. A study from Germany by Hohmeyer (1990) looked at the social costs of electricity generated by fossil fuels and nuclear power as compared to electricity generated by PVs. Michelfelder (1993) researched a similar topic concerning energy production in America. Hoff and Cheney (2000) looked at the potential market for PV in rural electric cooperatives for CE.

Cost-benefit analyses (CBAs) have been used to assess a wide range of issues from the cost of helicopter and airplane noise for visitors of the Grand Canyon to the value of good visibility in national parks and the monetary benefits of reducing lead in gasoline. Solar-electric PV systems are an appropriate candidate for assessment by using CBA.

OBJECTIVES AND RESEARCH QUESTIONS

Governmental decision-making processes concerning public projects are subject to a range of factors. Most often, financial return is a top priority; yet in recent years, local governments have approved projects that consider environmental effects as important factors when agreeing to a project. The overall objective of this thesis is to evaluate the factors—especially economic ones—that encourage or hinder municipalities from installing solar-electric, rooftop PV systems. To address this objective, the following research questions are answered:

1. Based on a 25-year time horizon, are PV projects installed on municipal buildings cost-effective in comparison to electricity purchased from the local utility company? This analysis includes systems that are currently installed and operational, as well as those systems that have been approved for installation but are not yet operational.
2. For municipalities with PV systems that are operational, would they consider installing additional systems and would they recommend PV to other municipalities?
3. Based on interviews with knowledgeable city employees, what factors promoted municipalities to install PV systems? What obstacles did municipalities encounter when implementing PV systems?
4. What quantity of air pollutants is displaced by the PV systems included in this study? Results for this question are developed from EPA data on air pollutants from electrical power plants.
5. Based on analysis of the above questions, what seem to be the most important elements for getting PV solar systems implemented on municipal buildings or facilities?

For this thesis, the action being assessed was local municipalities implementing a renewable energy policy, specifically solar energy in the form of PV projects. One issue was cost: Are PV projects a sound financial use of taxpayers' money? A second issue was the environment: Will PV projects improve air quality? The people who stand to gain are both the present and future generations that will reap the benefits of positive environmental effects (i.e., cleaner air and responsible use of taxpayer money).

METHODS

Fifty-four municipalities in Northern California were contacted by telephone to determine if they had installed or were planning to install PV systems on public, government-owned buildings. The geographical locations of these municipalities ranged from San Luis Obispo, California in the south to Chico, California in the north, east to Fresno, California, and west along the Pacific Ocean coastline. The study area was limited to this section of Northern California to ensure that State regulations affecting the municipalities were standardized.

A municipality was included in this study if (a) a PV system had been installed, was operational, and produced electricity for a municipal building or facility; or (b) a municipality was far enough along in the planning stages of a PV system to be able to reasonably predict costs and savings related to the project.

No database exists that specifically identifies municipal, public-owned PV systems; therefore, qualifying municipalities were located based on a search of current literature as well as personal inquiry. Research included *Solar Eclips*, an online publication from the Rahus Institute of Martinez, California, which is a research and educational organization with a focus on resource efficiency, and *Solar Today*, a journal published by the American Solar Energy Society (ASES).

Of the 54 municipalities contacted, 21 municipalities have or are planning to have PV systems installed on government buildings. Thirty-three municipalities contacted did not have a PV system on any public building. Appendix C lists all cities that were contacted but do not yet have PV systems. Table 3 lists the 21 municipalities included in this study that have or will soon have PV systems. Figure 1 is a map that shows the locations of the 21 municipalities. Appendix D includes pictures of many of the PV installations.

Research Question #1 – Based on a 25-year time horizon, are PV projects cost-effective in comparison to electricity purchased from the local utility company?

This economic analysis was based on a 25-year time period that is the manufacturer's warranty for PV panels. The analysis included only PV systems that are grid-tied and whose utility provider is PG&E. All applicable present and future costs of the PV projects were discounted back to present value using three discount rates. The costs of implementing the PV project were compared to the cost of not implementing the project. Costs of not implementing the project were represented by the dollar value per year of kWh generated from the PV system when purchased from the public utility, PG&E. These avoided costs are the economic benefits of these PV systems assessed in this thesis. Environmental benefits were not assessed.

Discount Rates

Three discounts rates—4%, 7%, and 10%—were used to calculate NPV of the two policies, one policy being the implementation of a PV system and the second policy being not to install a PV system. There are no set standards for selection of discount rates. General principles suggest that the discount rate should be greater than the annual inflation rate or that the same rate of return is used for an investment of similar risk to a PV project (Nofuentes et al., 2002). PV is a long-term investment that will span decades, which precludes the use of an annual discount rate. For this reason, discount rates are often based on the interest rates of long-term investments such as long-term government bonds.

Table 3

List of All Municipalities Included in This Thesis, Name of Building on Which the PV System is Installed, and the Contact Person(s) for the PV Project

City	Project	Contact	Position/Department
Santa Cruz	50.4 kW water treatment plant	Mary Arman	Public Works Principal Administrative Analyst
Alameda County	1.18 MW Santa Rita Jail	Matt Muniz	Energy Program Manager
Oroville	168.8 kW (total) City Hall, police & fire station, corporation yard, museum, theatre	Vorin Dornan	Department of Recreation and Trees, Facility Coordinator
Martinez	250 kW (total) jail, office building	Roland Hindsman	Assistant Building Maintenance Manager
San Francisco	675 kW Moscone Center	Fred Schwartz	Manager, Renewable and Advanced Generation (Hetch Hetchy employee)
Vallejo	363 kW (total) City Hall, library, police station	Joseph Bates	Assistant Superintendent Maintenance Facilities

City	Project	Contact	Position/Department
San José	200 kW Santa Clara Valley Water District	Don Osborne Arvind Tailor	Spectrum Energy Inc., consultant
Oakland	~350 kW – To be determined	Scott Wentworth	Public Works, Energy Engineer
Livermore	75 kW City Hall	Mike Irby	Assistant Civil Engineer in the Community Development Department
Fairfield	3.9 kW parking structure	Raven Tyson Kevin Daughton	Project Manager Transportation Department
San Carlos	~70 kW – To be determined	Richard Averett	Department of Finance Finance Director
Chico	92.5 kW parking structure transit center	Robert Koch	Risk and Administrative Projects Manager
San Luis Obispo	22.3 kW air pollution facility	Robert Heitzman	Air Pollution Control Officer
Marin County	89.1 kW General Services building	Gwen Johnson	Public Works Department
Sebastopol	20 kW (total) Public Works building and fire station	David Brennan	City Manager

City	Project	Contact	Position/Department
Ukiah	5.5 kW Civic Center	Ann Burck	Administrative Analyst
Berkeley	To be determined (10 to 12 systems planned)	Neil de Snoo	Housing Department
San Mateo	234 kW forensics lab	Jill Boone Paul Scannell	Green Building Co-coordinator & City Manager
Roseville	18.2 kW fire station	Marty Baily	Roseville Electric Company
Manteca	6.66 kW corporation yard	Steve Probst	Building and Maintenance Supervisor
Fresno	665 kW (total) muni services building & bus administration building	Gary Watahira	General Services Department

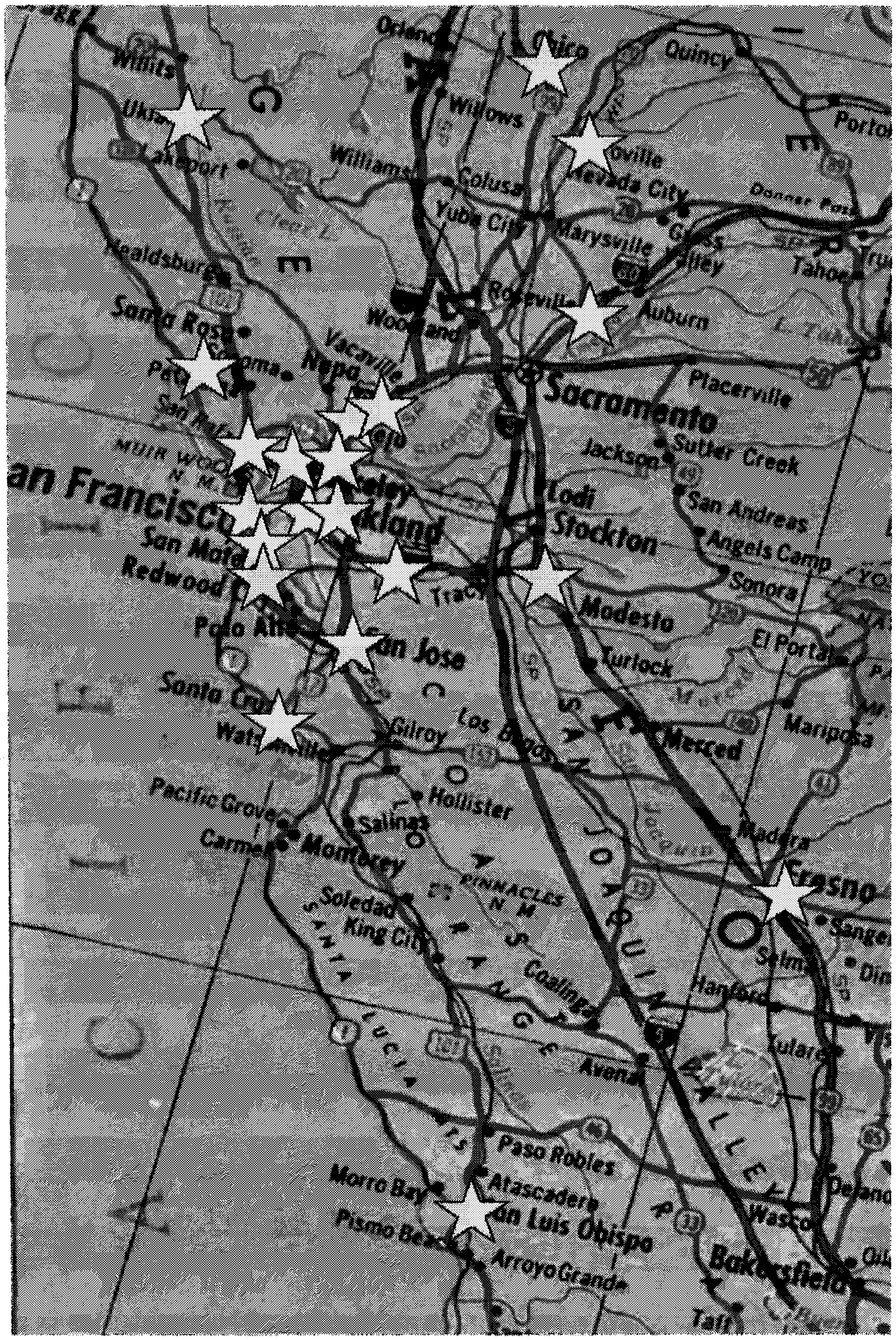


Figure 1. Study site of municipalities with photovoltaic projects (Northern California)

The discount rates used in this study were influenced by discount rates from the Office of Management and Budget (OMB) and the return on current Treasury bills. The OMB presently employs 7% as the discount rate for long-term, low-risk federal projects. As of November 2003, a 25-year Treasury bill yielded slightly less than 5.3%. For purposes of this study, the higher percentage rate is more conservative than the lower rate, therefore 7% was selected as the moderate "middle" discount rate. Four percent and 10% were chosen as the low and high discount rates respectively, in order to provide additional objectivity to the study.

Costs of Implementing the PV Project

Costs of the PV projects included any of the following that were applicable: (a) Final cost of the PV system paid by the municipality (including but not limited to material, labor, and permits); (b) future equipment replacement; (c) operation and maintenance (O&M) costs; (d) consulting fees; (e) design and administration costs; (f) overhead; and (g) any roofing/structural expenses that were incurred solely because of the PV system. The figure used as the final cost of the PV system was the total cost minus the rebate received by the municipality. Municipalities were eligible to receive $4.50/watt (depending on the wattage of the system) or receive half of the installation cost, whichever amount was less.

Excluding the solar modules, an inverter is the most expensive component of a PV system; it will need to be replaced at least once during the first 25 years in which the system is operating. Predicting future costs of inverters is difficult because inverter technology has been improving substantially over the past 20 years and prices have continued to decline (Bower, 1999). Therefore, inverter costs were based on the price at time of installation, which was obtained from the interviewee. Calculations of all future costs were based on the year they will occur and were discounted to their NPV using 4%, 7%, and 10% discount rates.

Benefits of Implementing the PV Project

The PV systems being analyzed were connected to the power grid (grid-tied). All grid-tied systems feed electricity back onto the grid, which is then purchased by the utility company, PG&E, under an agreement know as net-metering. With net-metering, the utility pays retail prices for the electricity generated by these PV systems. Because of net-metering, PV systems serve to reduce the monthly electricity bill for the municipality that owns the system. The benefit of implementing a PV system was based on that amount of money by which the electricity bill was reduced, and these monetary benefits were referred to as a displaced cost.

Determining the displaced cost was based on the kWh generated by the PV system and converted to dollars per year. The dollar value of a kWh is assigned by PG&E and will vary depending on the time of day and the type of meter used for that system. Displaced cost savings were calculated using one of two formulas depending upon whether kW size of the system was known in terms of direct current (DC) or alternating current (AC). Inverter efficiency is computed in the formula for DC output but is omitted for AC output. Dollars per month were determined for each month, then all 12 months were added to give the dollar per year total.

Formula for PV systems with kW rated in AC:

kW_{AC} * sun-hrs/day * no. of days/month * $/kWh = $/month

Formula for PV systems with kW rated in DC:

kW_{DC} * sun-hrs/day * no. of days/month * 0.9 inverter eff. * $/kWh = $/month

kW = size of PV system

sun-hrs = average daily solar insolation

month = number of days in each month

0.9 = inverter efficiency (eff.)

$/kWh = tariff set by PG&E

Sun-hours per day are the amount of average, monthly solar insolation received at the specific location of the PV system. Location was based on latitude and longitude for each municipality. Average monthly solar insolation was obtained from the NASA Surface Meteorology and Solar Energy (n.d.) website. Dollars per kWh were based on the type of meter the PV system used. Most systems are on A10, E19, or E20 meters. E19 and E20 are Time-of-Use (TOU) meters, which means that a kWh generated in the afternoon is billed at a different rate than a kWh generated in the morning. TOU is factored into the amount of money saved from paying to the utility company. A10 is a flat-rate meter, which means there is one rate for winter and one rate for summer regardless of time of day. Tariffs for each type of meter are obtained from the PG&E (n.d.) website.

Once displaced costs for the first year are established, savings for each year thereafter will increase by a given utility escalation rate. A decrease in efficiency of the PV panels, which could affect the amount of displaced costs, was not calculated in this analysis. Because of the uncertainty of future electricity prices, five utility escalation rates were applied to savings. The rates used were 2%, 3%, 4%, 5%, and 6%. The historical, average statewide increase for commercial buildings over the past 22 years, between 1980 and 2002, is 4.18% (Figure 2).

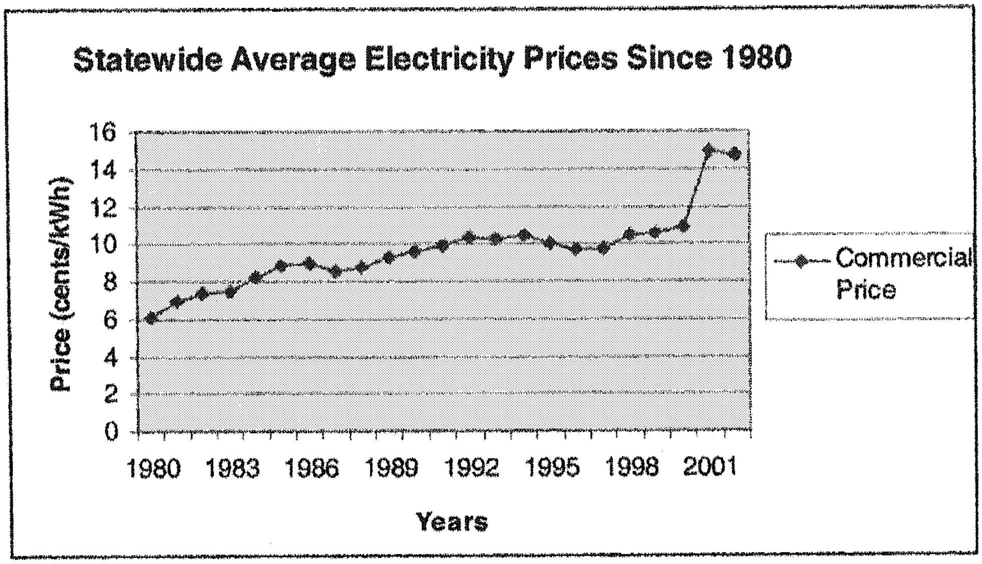


Figure 2. Average electricity price increases for commercial buildings in California between 1980 and 2002. (Source: California Energy Commission #4, n.d.)

The final analysis resulted in two figures for each discount rate: (a) the Net Present Benefits (NPBs) of the displaced costs due to net-metering and (b) the Net Present Costs (NPCs) of implementing the project. NPCs are subtracted from NPBs to give the NPV according to the formula: NPB – NPC = NPV. Based on this criterion, if the NPV is positive, then the project should be approved. Conversely, if the NPV is negative, the project should be rejected.

In comparison to not implementing the PV system, monetary gain or loss will be calculated at the end of 25 years. Gains and losses are amplified depending on the kW in the system; therefore, the results will be averaged as dollars per kW.

Research Question #2 – For municipalities with PV systems that are operational, would they consider installing additional systems and would they recommend PV to other municipalities?

For all operational PV systems, the city employees responsible for the PV projects were asked to qualitatively assess their project(s) as to general satisfaction, future plans for additional PV systems, and endorsement of PV for other interested parties. Not all municipalities had operational PV systems; therefore, 13 out of 21 municipalities were eligible to participate in this interview. Table 4 lists all the questions used for the interview.

Table 4

Questionnaire Used to Interview City and County Staff Regarding General Satisfaction with PV Systems

Number	Survey Questions
1	Are you satisfied with your PV system? (yes or no) If no, what would you do differently?
2	Would you recommend PV to other cities?
3	Would you consider putting in another PV system in the future?

Research Question #3 – Based on interviews with knowledgeable government employees, what were the motivations for and obstacles against PV projects?

To evaluate motivations for municipal PV projects and obstacles against municipal PV projects, a questionnaire was administered via a telephone interview to the city employee responsible for each project. Phone interviews were conducted between the months of June 2003 and December 2003. Table 5 is a list of all of the questions used in the interview.

Table 5

Questionnaire Used to Interview City and County Staff Regarding Motivations and Barriers to Installing PV

Number	Interview Questions
1	Who is your utility provider?
2	What type of meter is being used?
3	What company installed the system?
4	Did net-metering matter?
5	Did you bundle other energy-efficiency changes with PV system?
6	Was a project manager and/or staff used, other than inhouse?
7	Why did you install the system in the first place? What was your main reason to install the system?

Number	Interview Questions
8	Who is responsible for making sure the PV project was completed?
9	Who authorized or initiated the PV project? (City Council? etc.)
10	What were the barriers to PV installation?
11	Have the financial predictions of the PV system worked out as expected?
12	Are you in any way unhappy with the PV system or wish that you had not installed it?
13	Is there anything that you had (i.e., rebates), that if you did not have, would have prevented the PV project from going forward?
14	In your opinion, what do you think could be done (by the government or otherwise) to make it easier for cities to install PV systems and to encourage cities to install PV systems?
15	Number of systems?
16	Size of system(s) (kW)?
17	When did it(they) become operational?
18	Flat or tilted panels?
19	Where is it sited (what building, etc.)?
20	What was the installation cost before rebates?
21	What was the installation cost after rebates?
22	How was the system financed?

Number	Interview Questions
23	Was money borrowed?
24	If money was borrowed:
	How much was put down (down payment)?
	What is the interest rate?
	Term of the loan (in years)?
	What is the annual loan payment?
25	Were there any pre-install costs (e.g., study, overhead) not included in the capital cost of the system?
26	Any structural modification to building or roof because of PV? If so, what did it cost?
27	What are the expected O&M costs?
28	What are the estimated costs to replace equipment in the future?
29	What is the estimated cost to replace inverters? (How many? Type? Cost of each?)
30	Any provisions for cost to remove and replace panels if re-roofing must occur, or do you expect roof to last as long as panels?
31	What type of meter is the system on (e.g., A10, E19)?

Survey questions were designed to address both qualitative and quantitative issues of the PV installation. Questions covered three general areas: (a) technical data about the PV system, (b) how the system was financed, and

(c) obstacles to, motivations for, and reasons a municipality would choose PV for partial electrical supply.

Research Question #4 – What quantity of air pollutants is displaced by the PV systems included in this study?

The amount of air pollution displaced for all PV systems in this study was determined according to the following formula:

lbs. of P_A/MWh*MWh/1,000kWh*total kWh/yr*fossil fuel (%) = lbs of P_A/yr

P_A = type of air pollutant (CO_2, SO_2, or NO_X)

Air pollutant amounts were calculated for CO_2, SO_2, and NO_X. Calculations were based on two parameters: (a) the fossil fuel mix for PG&E and (b) pounds of air pollutants (Table 6) that resulted from coal-fired, oil-fired, and natural-gas fired electricity power plants (Environmental Protection Agency #6, #7, & #8, n.d.). The fossil fuel mix for PG&E was 45% natural gas, 12% coal, and 1% oil (Environmental Protection Agency #5, n.d.), which was not the same as the fuel mix for the United States, nor was it the same for the State of California. The fossil fuel mix was based on PG&E, because PG&E was the utility that supplied electricity to 19 out of 21 municipalities in this study. The other two municipalities owned their own utilities.

Table 6

Average Emissions in Pounds Per MWh for CO_2, SO_2, and NO_x During the Combustion of Coal, Natural Gas, and Oil in Electrical Power Plants

	Coal-fired Plant	Natural Gas-fired Plant	Oil-fired Plant
CO_2	2,249 lbs./MWh	1,135 lbs./MWh	1,672 lbs./MWh
SO_2	13 lbs./MWh	0.1 lbs./MWh	12 lbs./MWh
NO_x	6 lbs./MWh	1.7 lbs./MWh	4 lbs./MWh

Source: Environmental Protection Agency #6, #7, & #8, n.d.

The remaining fuel types used to supply electricity are nuclear, hydro, and renewables. They are not included in this calculation, however, because CO_2, SO_2, and NO_x produced by these three energy sources are insignificant.

Total kWh were determined by assessing each individual system. The average monthly solar insolation was multiplied by the rated kW of each system, including an inverter loss of 10%. Monthly kWh were summed to determine yearly kWh output for the PV system. This calculation was performed for all systems in this study to establish total kWh output for PV systems in all 21 municipalities. Once kWh output was known, the amount of CO_2, SO_2, and

NO_x displaced was computed using the conversion factor of units of air pollution per kWh (see formula on page 55). Finally, air pollution displaced over the 25-year time horizon of this study was calculated assuming 0.5%/year efficiency loss of the PV panels.

RESULTS

The financial value of PV versus purchasing electricity from the local utility company was determined by analyzing 19 PV systems at 11 municipalities. The reasons for not analyzing PV projects at all 21 municipalities were (a) three municipalities were not far enough along in the planning stage, (b) five municipalities did not supply the necessary economic information, and (c) two municipalities financed their systems in such a way that determination of costs was unknown at the time of this study. The municipalities analyzed were Fresno, Chico, Sebastopol, Alameda, Martinez, Santa Cruz, Manteca, San Luis Obispo (Air Pollution Control District), San Jose (Santa Clara Valley Water District), Oroville, and Livermore.

For municipalities that installed more than one PV system, costs were aggregated. Costs for PV systems were based on the final cost of the system to the municipality; therefore, these were the costs after the rebate was deducted from the initial price. Rebates from the CEC and PG&E's Self-Generation Renewable Energy Program were available at the time the municipalities in this study were installing PV. These programs paid $4.50/watt or half the price of the PV systems, whichever was less, to the owner of the system.

Every PV system in this study was connected to the PG&E power grid; therefore, every system was feeding electricity onto the grid. The utility company—in this case, PG&E—must purchase the electricity generated from the PV systems at retail prices. Benefits of the PV systems were based on net-metering. The benefits were calculated as displaced costs, which was the amount of money the municipality received for power generated by their PV systems.

The economic analysis was performed on the benefits (displaced costs) minus the municipality's cost of the PV system, using three discount rates (4%, 7%, and 10%) and five utility price escalation rates (2%, 3%, 4%, 5%, and 6%). For this exercise, the environmental benefits of the PV systems were ignored, as only the financial benefits and costs to the municipalities were included.

Municipalities were analyzed over a 25-year time period. Of the 11 municipalities analyzed, 8 demonstrated a favorable economic outcome for their PV projects and 3 did not. Livermore paid an outside consulting fee that was 46% of the price of the PV system after the rebate was deducted, which increased the overall cost of the system by 37%. Even without the consulting fee factored in, the price of this particular system was too high to realize a return on their investment within 25 years except under the scenario of a 4% discount rate and a 6% utility escalation rate.

Oroville and the Santa Clara Valley Water District will see a positive NPV only at the lowest discount rate (4%) coupled with the two highest utility escalation rates (5% and 6%). The City of Chico added overhead and design costs to all municipal projects, regardless of the type of project. This policy resulted in an increase to the cost of the system by 39% and increased the overall installation cost by 29%. Without the overhead, Chico's PV system was the second most cost-effective system of the 11 analyzed.

For each municipality, the results are demonstrated graphically in Figures 3 through 15. Each dot represents an NPV. If the dot is above the red line, the NPV is positive; below the red line, the NPV is negative. Using three discount rates and five utility escalation rates, there are a total of 15 NPVs for each PV project (Figures 3 through 15). Figures 4 and 5 compare the PV project for Chico with and without overhead costs. Since overhead costs were applicable to this municipality only and unusual for all other municipalities in this study, it was important to demonstrate that the PV project itself was cost-effective. Figures 14 and 15 compare Livermore's project with and without their consulting fees.

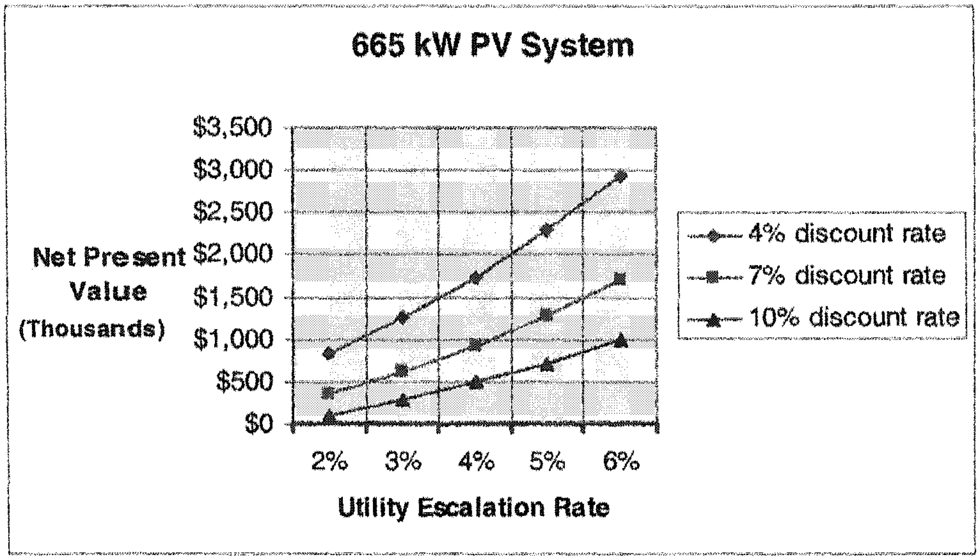


Figure 3. Fresno. All NPVs are positive.

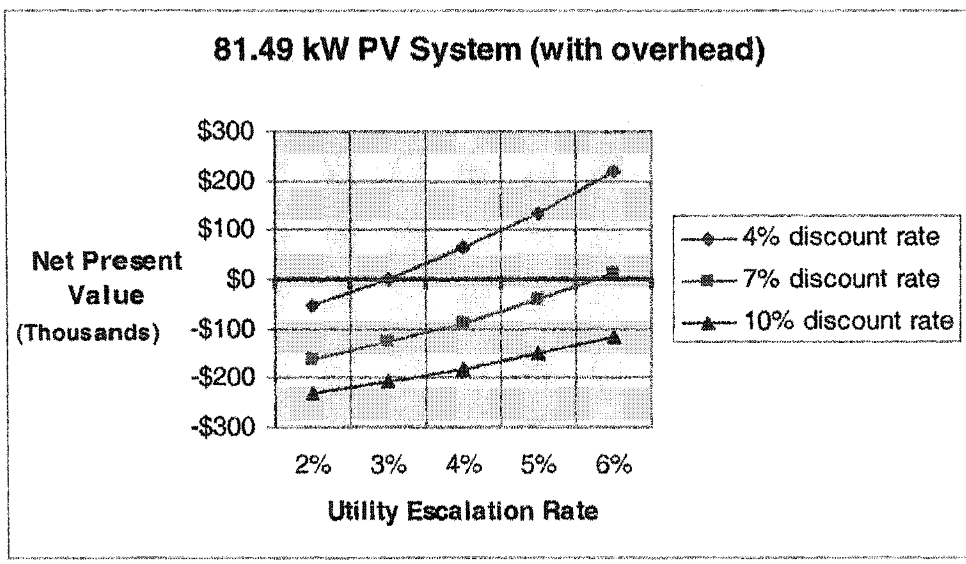


Figure 4. Chico with overhead costs included. Five NPVs show a positive value.

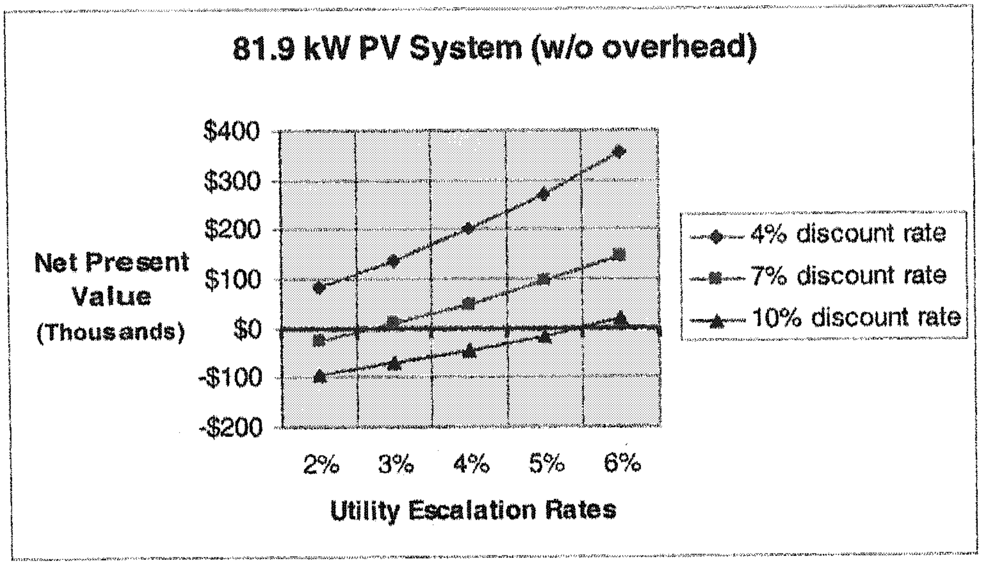


Figure 5. Chico without overhead costs included. Ten NPVs show a positive value.

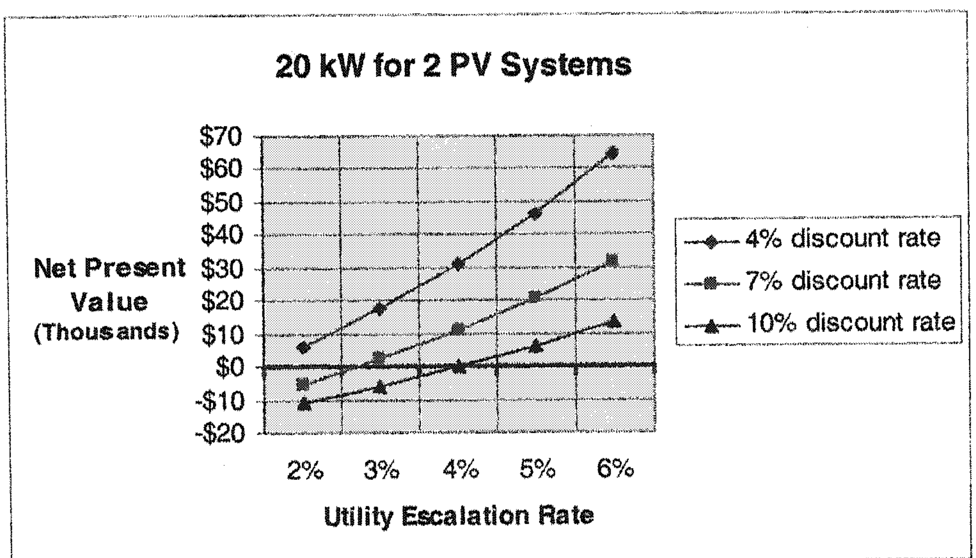


Figure 6. Sebastopol. Eleven NPVs show a positive value.

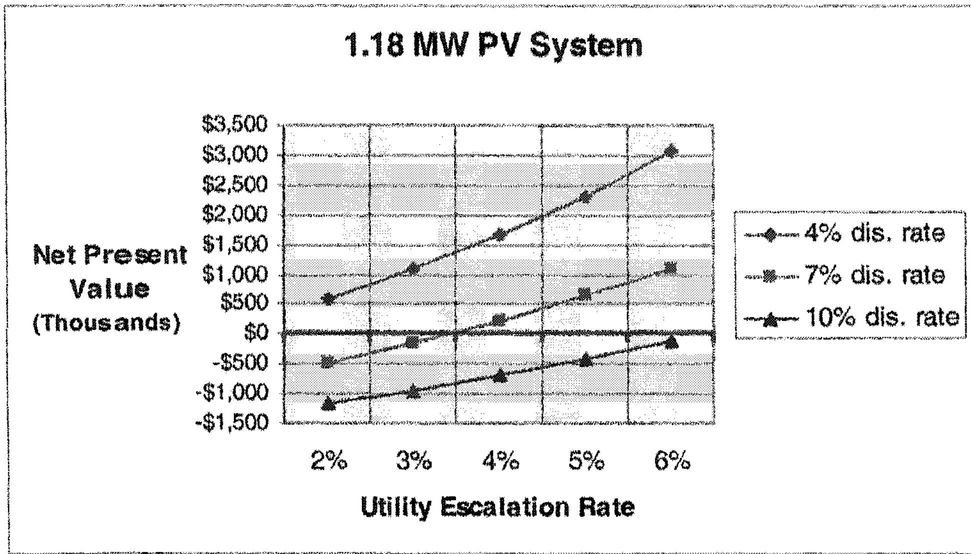


Figure 7. Alameda. Eight NPVs show a positive value.

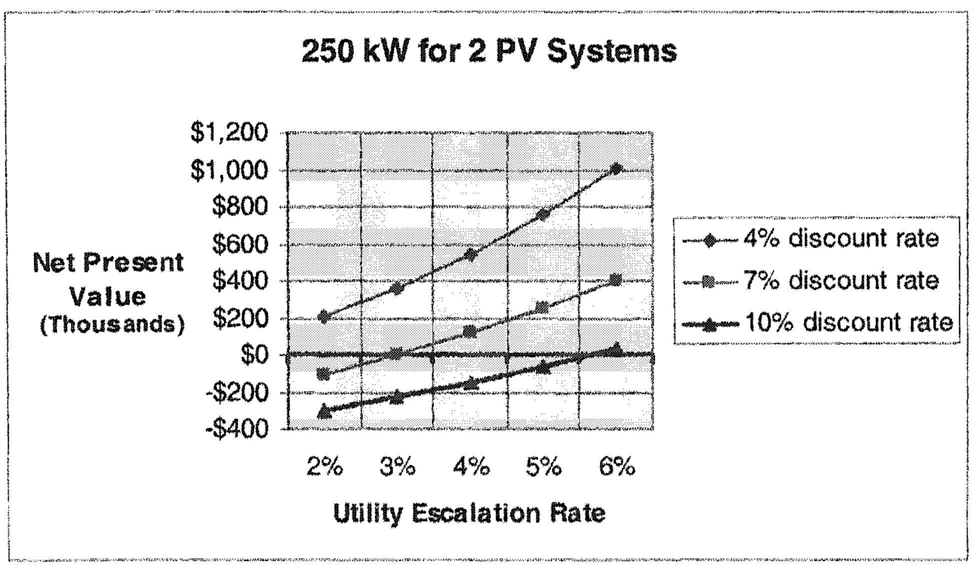


Figure 8. Martinez. Nine NPVs show a positive value.

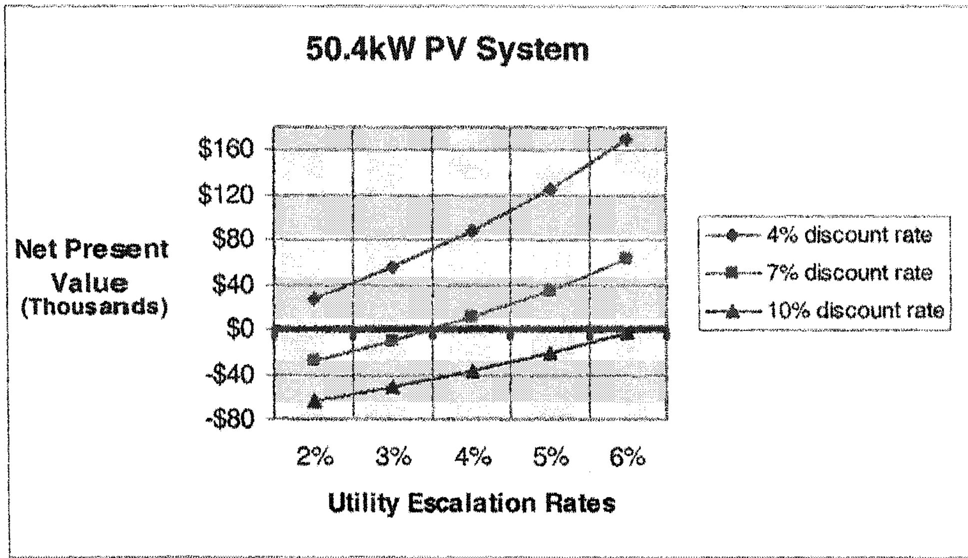


Figure 9. Santa Cruz. Nine NPVs show a positive value.

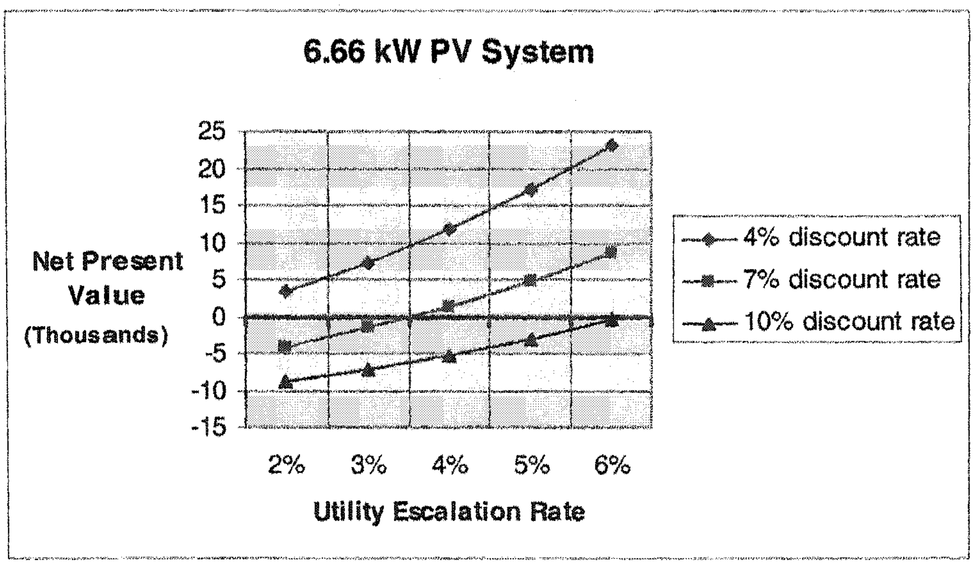


Figure 10. Manteca. Eight NPVs show a positive value.

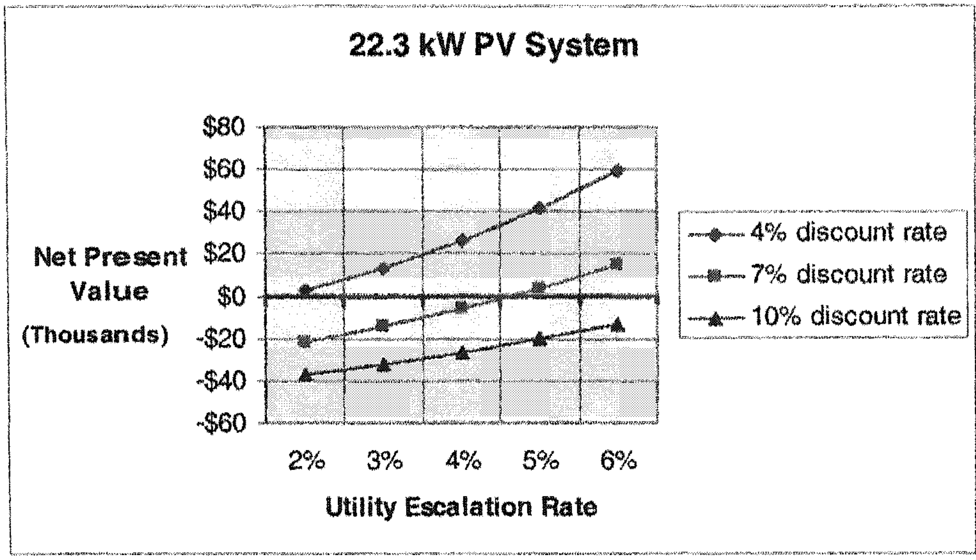


Figure 11. San Luis Obispo. Seven NPVs show a positive value.

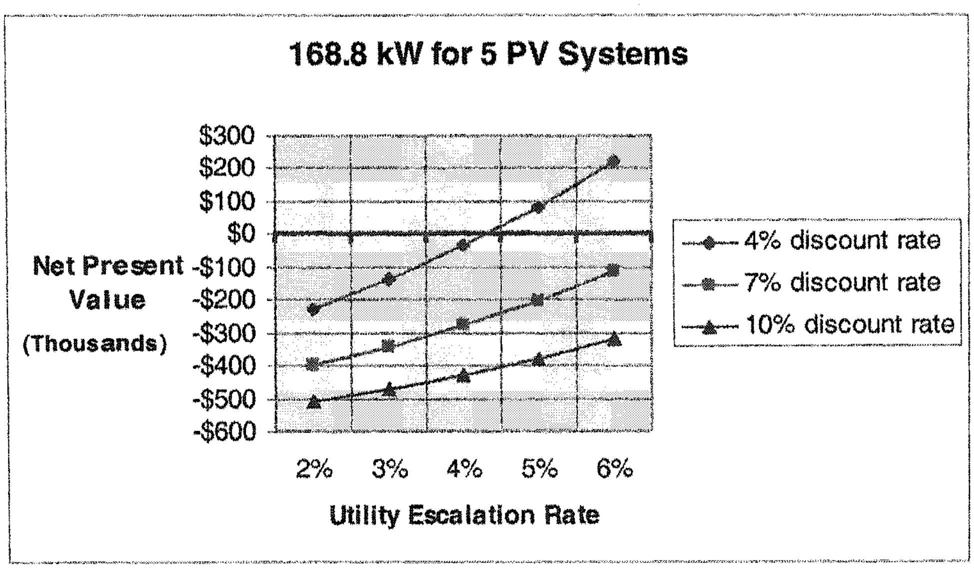


Figure 12. Oroville. Two NPVs show a positive value.

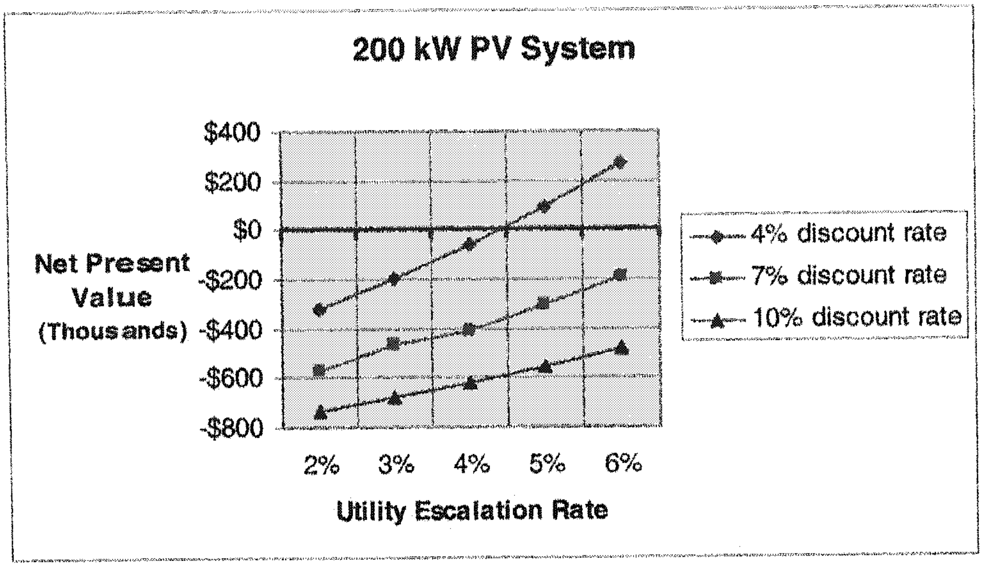


Figure 13. SCVWD. Two NPVs show a positive value.

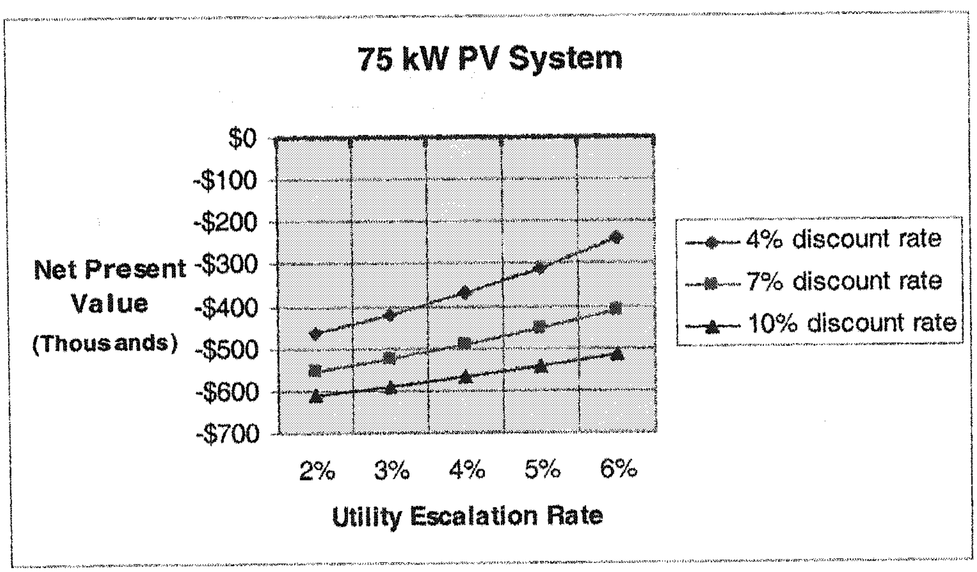


Figure 14. Livermore including consulting fees. Negative values for all NPVs.

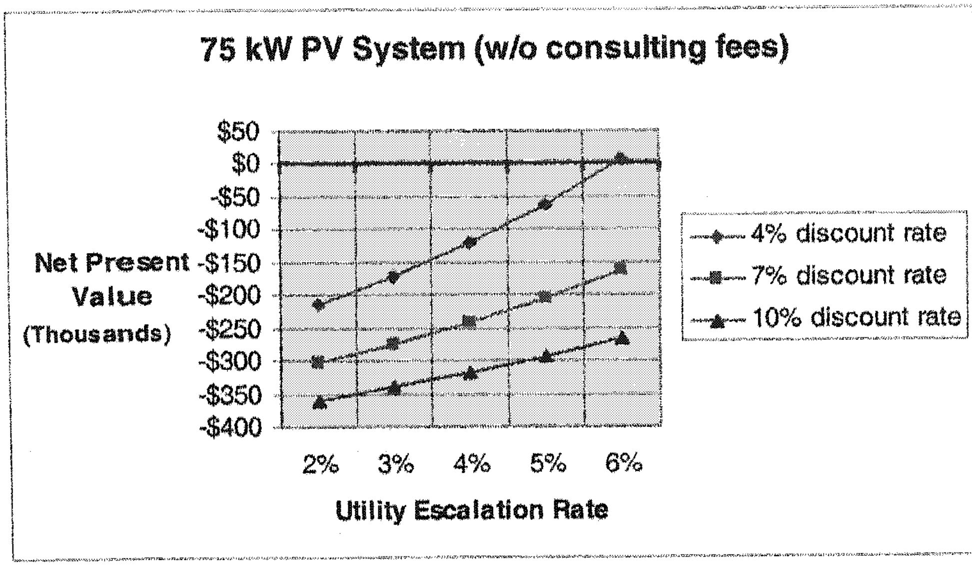


Figure 15. Livermore without consulting costs. One NPV has a positive value.

Figure 16 shows the results of the CBA for all 11 municipalities. For 10 municipalities, almost all PV projects should be approved at the 4% discount rate. At the 7% discount rate, 6 of the 11 PV projects should be approved at an escalation rate ≥ 4%. Thus, a majority of the PV projects could be considered economically worthwhile at the midrange values even while ignoring the environmental benefits of these projects. Almost no PV projects should be approved at the 10% discount rate. Figure 16 and Table 7 show the same information in a different format.

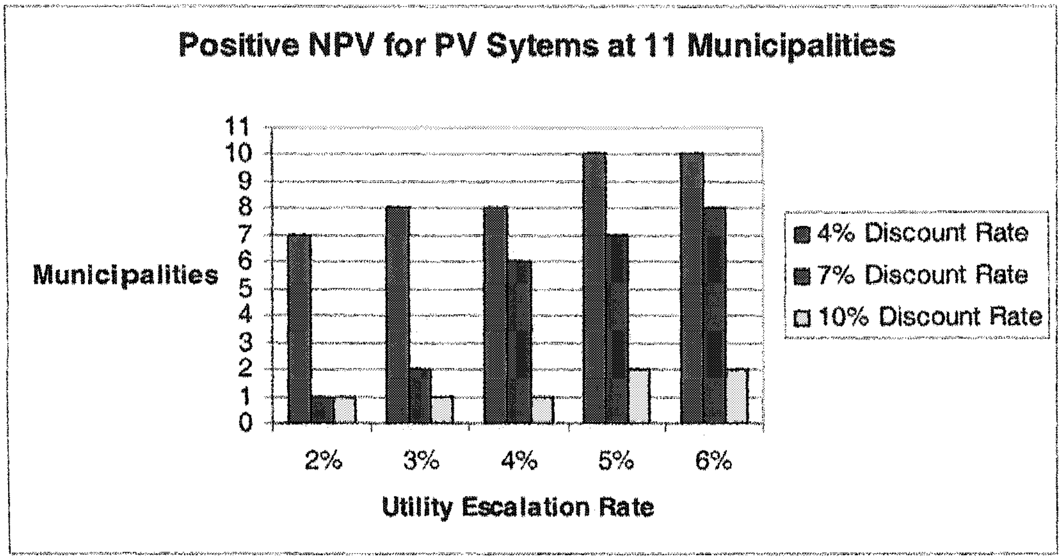


Figure 16. The number of municipalities that demonstrate a positive NPV at varying discount and utility escalation rates.

Table 7

The Number of Municipalities That Have a Positive NPV for Their PV Projects at the Three Discount Rates (DRs) and the Five Utility Escalation Rates (UERs)

Percent DR	6% UER	5% UER	4% UER	3% UER	2% UER
4	10	10	8	8	7
7	8	7	6	2	1
10	2	2	1	1	1

Each system was analyzed at the end of 25 years to determine the monetary gain or loss from PV compared to not installing the system. Figures 17 through 22 give the cost per kW at the end of 25 years for 4% and 7% discount rates and 4%, 5%, and 6% utility escalation rates. It was necessary to use an average cost per kW rather than the actual dollar amount because the larger the system, the greater the gain or loss after 25 years. The actual dollar amounts at all three discount rates (4%, 7%, and 10%) and all five utility escalation rates (2%, 3%, 4%, 5%, and 6%) for the 11 municipalities are in Appendix E.

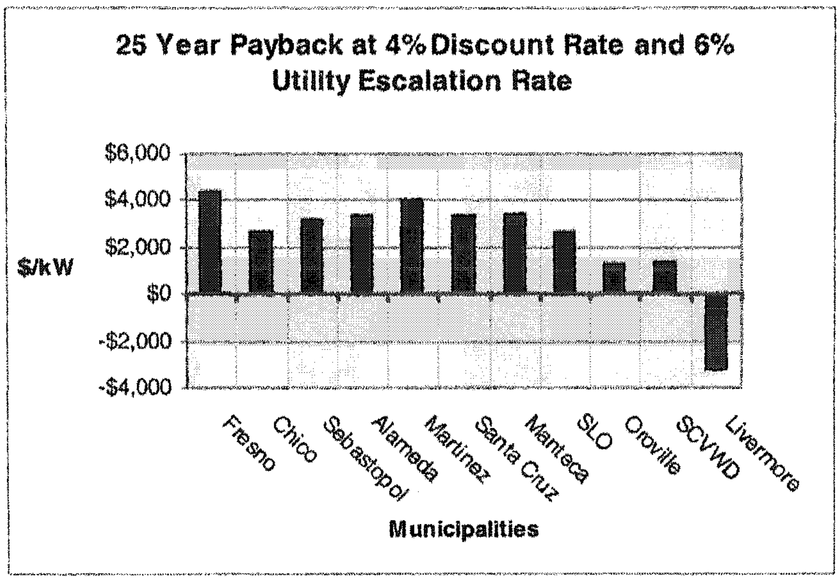


Figure 17. Payback using a 4% discount rate and 6% utility escalation rate.

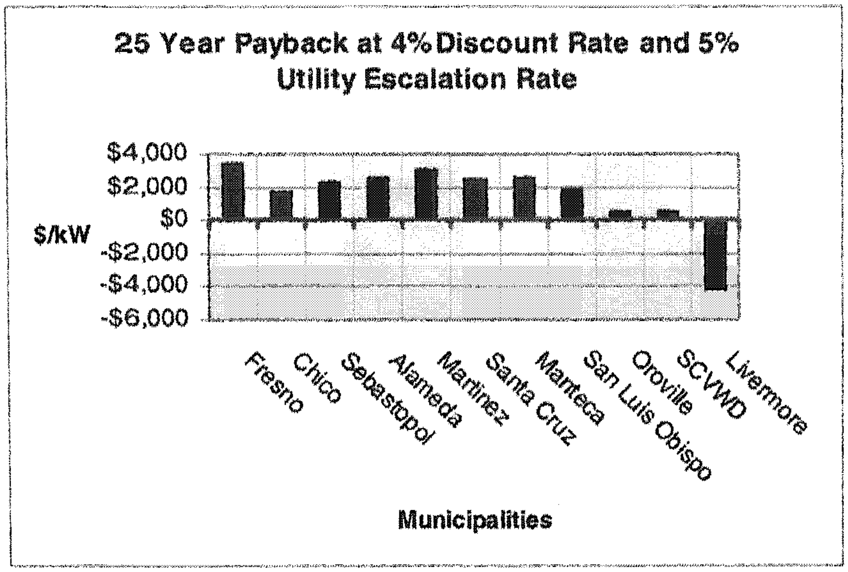


Figure 18. Payback using a 4% discount rate and 5% utility escalation rate.

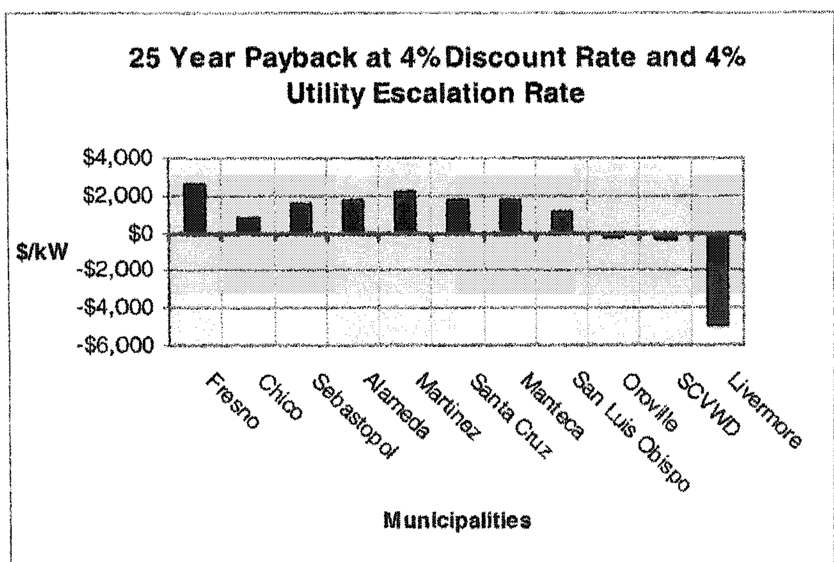


Figure 19. Payback using a 4% discount rate and 4% utility escalation rate.

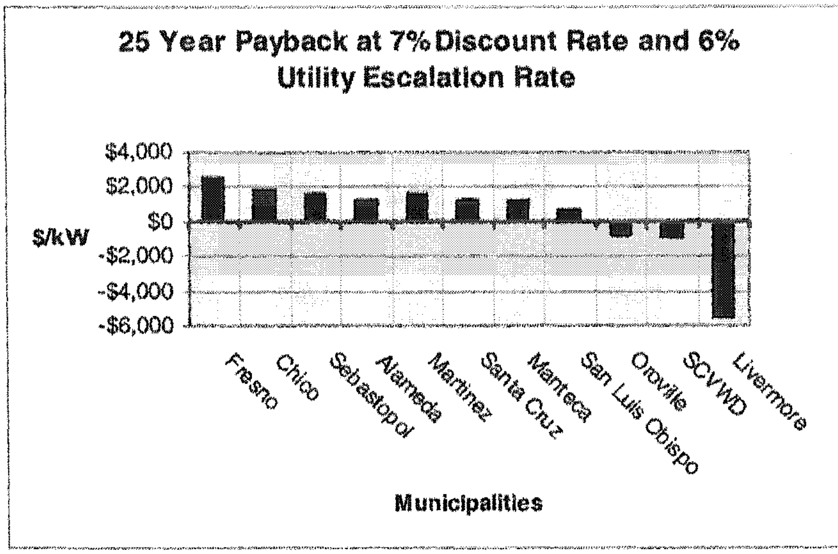


Figure 20. Payback using a 7% discount rate and 6% utility escalation rate.

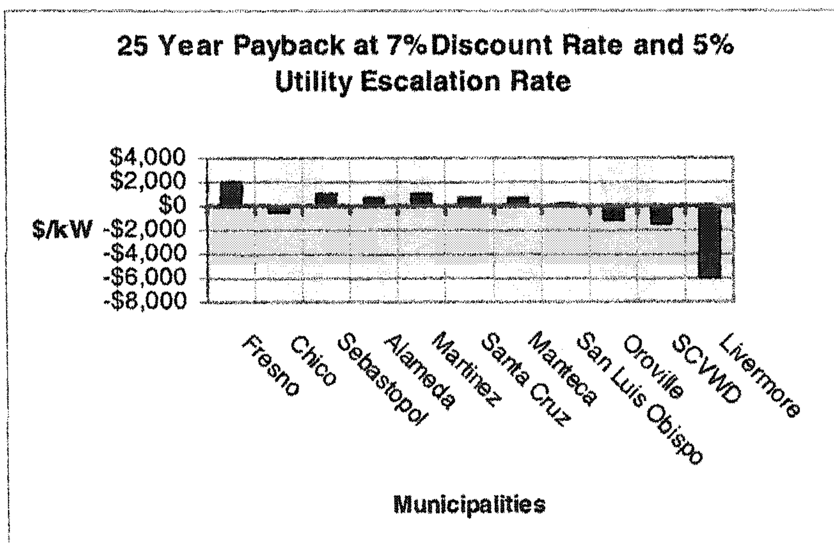


Figure 21. Payback using a 7% discount rate and 5% utility escalation rate.

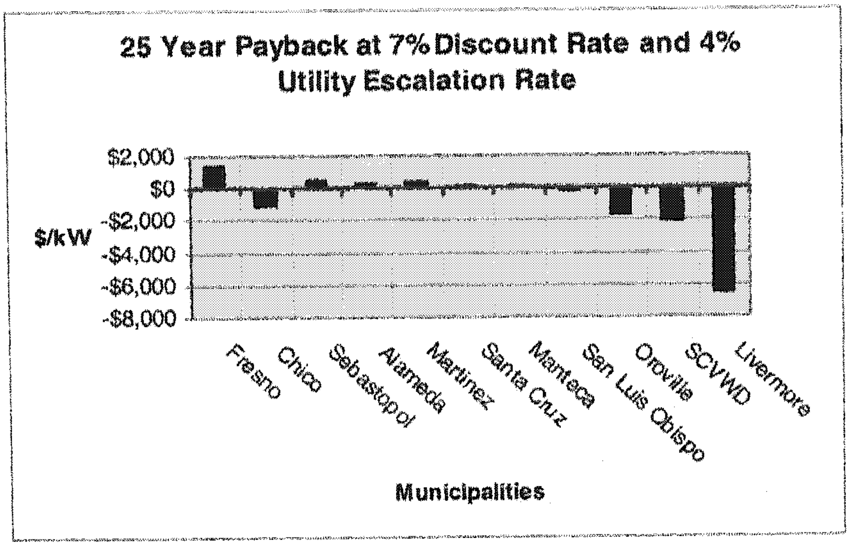


Figure 22. Payback using a 7% discount rate and 4% utility escalation rate.

Satisfaction with operational PV systems was analyzed qualitatively using 13 municipalities representing a total of 22 PV projects. All 13 municipalities said they would consider installing more PV systems, and all said they would recommend PV to any municipality that was considering it, assuming that incentives were available. All municipalities stated they were satisfied with their systems overall (Table 8).

Table 8

Qualitative Assessment for PV at 13 Municipalities

City	Would You Recommend PV?	Would You Consider Putting in More PV?	Satisfied? Yes or No?	If No, What Would You Do Differently?
Alameda	Yes	Yes	Yes	
Manteca	Yes	Yes	Yes	
Martinez	Yes	Yes	Yes	
Oroville	Yes	Yes	Yes	
Roseville	Yes	Yes	Yes	
San Francisco	Yes	Yes	*	
San Luis Obispo	Yes	Yes	Yes	
San Mateo	Yes	Yes	Yes	
Santa Cruz	Yes	Yes	Yes	
Sebastopol	Yes	Yes	Yes	
Vallejo	Yes	Yes	Yes	
Fairfield	Yes	Yes	Yes	**
Ukiah	Yes	Yes	Yes	***

Note: * = too soon to evaluate; ** = wanted more choices for aesthetic reasons; *** = would have added a display to show cumulative power produced by PV.

Twenty out of the 21 municipalities in this study would not have installed a PV system unless it was projected to have a positive payback well within the life of the system, generally in the 12- to 15-year range. Once the payback period was determined to be acceptable, the most commonly cited motivation (16 out of 21 municipalities) was concern for the environment. Eleven out of 21 municipalities installed PV in order to lead by example. The energy crisis of 2000-2001 (seven municipalities) and a desire to hedge against future electricity price increases (four municipalities) were economic motivations cited by municipalities. Generating electricity with a renewable energy such as PV fit into the city philosophies of four municipalities, and three municipalities felt that PV was a good public relations project. Most municipalities cited more than one motivation to pursue PV (Table 9).

Obstacles to PV projects varied with municipality (Table 10). The interviews showed that the most frequently mentioned obstacles were time and money. Time issues included the amount of time it took to learn about PV systems, the time to learn about the various funding sources, the time to get permits, and the time to get authorizations. Monetary obstacles were either finding good funding sources or overcoming the seemingly large upfront cost of PV systems.

Table 9

Motivations for Municipalities to Approve PV Projects

City	Environment	Lead by Example	Energy Crisis of 2000-2002	City Philosophy	Hedge Against Future Price Increases	Good PR	Directed by City Council	Help PV Industry	Public Demand
SLO	x					x			
San Mateo	x								
S.F.	x								
San Carlos	x	x	x		x			x	
Oakland	x								
Berkeley	x	x							x
Marin	x	x		x					
Vallejo	x		x						
Martinez	x								

City	Environment	Lead by Example	Energy Crisis of 2001	City Philosophy	Hedge Against Future Price Increases	Good PR	Directed by City Council	Help PV Industry	Public Demand
Santa Cruz	x			x					
Fairfield	x	x							
Alameda	x		x		x				
SCVWD	x	x	x						
Livermore		x	x	x			x		
Sebastopol		x							
Ukiah		x							
Chico	x	x	x		x	x			
Oroville							x		
Manteca	x	x	x		x	x		x	

City	Environment	Lead by Example	Energy Crisis of 2001	City Philosophy	Hedge Against Future Price Increases	Good PR	Directed by City Council	Help PV Industry	Public Demand
Roseville				x					
Fresno	x	x							
TOTAL	16	11	7	4	4	3	2	2	1

Table 10

Obstacles and Barriers to PV Projects for Municipalities in Northern California

City	Obstacles
San Luis Obispo	Time, bureaucratic inertia
San Mateo	Money
San Francisco	Getting authorizations, paperwork
Ukiah	City Council was against PV, deadlines difficult to meet
Sebastopol	Money, physical, and structural limitations
Oroville	City Attorney concerned about rewriting contracts (sole-sourcing)
Martinez	Finding good roof locations
Alameda	Timing, knowledge of all incentives available
Santa Cruz	Structural work
Fairfield	Time
Roseville	No guidance from PV industry, proprietary knowledge, barriers from the supply side
Vallejo	Overcome attitudes of city staff that did not understand PV, frustrated that everything is measured in monetary terms
San Carlos	Needed more knowledge on the PV industry and more knowledge of cool roofs, difficult to compare many proposals
Chico	Money, need more funding sources

City	Obstacles
Livermore	Money, lack of understanding of PV, forced to use outside consultants, had to retrofit the building, logistics of installing the system at the same time that people were working in the building
Oakland	Time
Berkeley	Money, free roof space
Marin	Time
SCVWD	Bidding process took time, approval of project took time, aesthetics
Manteca	Achieve capital up front
Fresno	Sole-sourcing the project

Bureaucratic inertia against completing all the necessary paperwork was the third most common obstacle noted by the municipalities. For some of the larger municipalities, like San Francisco, the barriers included dealing with many different agencies and departments for permits and authorization to complete their PV project.

Additional obstacles were in the category of structural, physical, and aesthetic limitations. Examples of these hurdles were (a) lack of appropriate and available roof space, (b) making sure the roof could accommodate the weight of the PV panels, (c) needing to re-roof prior to installing the PV panels, and

(d) retrofitting the building to accommodate the panels. Aesthetics was also mentioned as a concern for municipalities. PV systems installed on sloped roofs or on solarports are much more visible than systems placed on a flat roof. When PV systems are in plain sight, aesthetics will be part of the decision-making process.

The analysis of air pollutants showed that the amounts of CO_2, SO_2, and NO_X displaced by the PV systems of the 21 municipalities was significant. The total energy output for all PV systems at the 21 municipalities was 7.28 million kWh per year (7,276,122 kWh/yr). This energy output resulted in 2,901 tons of CO_2, 6.28 tons of SO_2, and 5.55 tons of NO_X being displaced in the first year of operation.

Over a 25-year time period, and assuming a 0.5% decrease in solar panel efficiency each year, total displacement of air pollution was 68,331 tons of CO_2, 148 tons of SO_2, and 131 tons of NO_X. This was a total of 68,610 tons of air pollutants avoided from being emitted from power plants operated under PG&E over the next 25 years. Looking at CO_2 only, the PV systems in this study over a 25-year period will displace the amount of CO_2 normally absorbed by 359,160 trees (American Forests, n.d.) or not driving an average passenger car 102 million miles (Energy Information Administration #5, n.d.). See Table 11 for displaced air pollutants.

Table 11

Amount of Air Pollutants Displaced by Using PV for Electrical Supply

Air Pollutant	Year 1 (lbs.)	Year 1 (tons)	Year 25 (lbs.)	Year 25 (tons)
CO_2	5,801,616 lbs.	2,901 tons	136,662,585 lbs.	68,331 tons
SO_2	12,551 lbs.	6.28 tons	295,651 lbs.	148 tons
NO_x	11,096 lbs.	5.55 tons	261,377 lbs.	131 tons

Results showed that it was unlikely for municipalities to install PV systems unless there was a recoupment of their investment. One municipality had no such objective for their system, but approved it solely for environmental reasons. As mentioned earlier, most of the remaining municipalities strongly desired a time frame of 12 to 15 years for recoupment.

DISCUSSION

With respect to the question of the financial CE of PV systems, the majority of municipalities analyzed demonstrated a positive NPV under varying combinations of discount rates and escalation rates, including rebates and net-metering credits. A positive NPV means the PV project should be approved and the project would result in a financial gain within the first 25 years of the system.

Environmental benefits would be added pluses for these systems from a broader social point of view.

A number of sources in the literature (e.g., Caldwell [1994] and Hoffert et al. [2002]) stated that PV systems are not cost-effective for reasons such as (a) they are too expensive compared to conventional energy, (b) the efficiency of the solar panels is low, and (c) they do not produce electricity at night. These studies, however, showed that with the availability of rebates and net-metering, PV is cost-effective. The reasons that solar energy appears to be more expensive than conventional energy is that fossil fuels and nuclear energy receive extensive subsidies and have been receiving subsidies for decades. When a new technology such as PVs is subsidized just as fossil fuels are, the new technology is better able to compete in the marketplace. When externalities (i.e., subsidies and the cost of environmental damage and cleanup caused by conventional electricity generation) are factored into the CBA, solar energy is less expensive than conventionally produced electrical power (Yokell, 1979).

The chief reason to subsidize renewable energy and solar in particular is to assist competitive access to the marketplace. Subsidies for conventional energy technologies allow them to be overused and underpriced compared to renewable energy. Under these conditions, when solar energy competes with conventional energy, the consumer pays for a marginally priced commodity (solar) versus an average-priced commodity (conventional energy) (Yokell, 1979).

In other words, the consumer pays full price for solar energy and much less than full price for fossil fuel energy from utility companies. For the reasons stated above, subsidies are critically important for the solar energy/PV industry.

The argument is not to remove fossil fuel subsidies, which appears to be politically impossible (Yokell, 1979). Rather, it is imperative that the present subsidies for renewable energy and PV remain in effect or be increased. When subsidies are in place, they have shown a positive effect on PV investment.

Two examples are the PV incentive programs in Japan and Germany. Japan's program, the New Sunshine Project, began in the early 1990s. Because of this program, Japan has established itself as the world leader in PV (Solar Electric Power Association, 2002). Their program includes R&D support to private PV companies, direct subsidies, low-interest loans, and a preferential tariff (net-metering). Results of the program showed an increase of PV electrical generation from 5 MW in 1993 to 130 MW in 2001. Germany offers R&D funding, net-metering, and low-interest rates as incentives. Germany has increased their PV capacity from 5 MW to 65 MW over a 5-year period beginning in 1996. Net-metering in Japan, Germany, and Spain pays twice the retail rate of electricity back to the consumer. Both Japan and Germany have low-interest loans of 2% (Solar Electric Power Association, 2002).

The criticism that low-efficiency conversion of sunlight to electricity in PV cells negates the beneficial properties is to overlook several factors. The efficiency of today's PV panels is relatively low and is estimated to be approximately 8% to 10%. This means that 8% to 10% of the sunlight striking the solar cell is converted to usable electricity. Low cell efficiency is not a critical drawback, however, because this deficiency can be overcome by increasing the number of kW in the PV system (i.e., install more panels). It follows that the more efficient PV cells are, the smaller the area needed to generate the same amount of electricity as less efficient cells; yet given enough rooftop space, the low-efficiency problem is negated. Furthermore, PV R&D projects are experimenting with materials other than silicon and, under ideal conditions, solar cells have reached efficiencies as high as 30% (Green, Emery, King, Igari, & Warta, 2000). Second, numerous conventional power plants operate with efficiencies in the 30% to 40% range, slightly higher than the most efficient PV panels under laboratory conditions.

It is true that solar energy will not produce electricity at night, but this is not an essential criterion when arguing the validity of PV. Electricity generated by solar panels can be stored either in batteries or fed back to the grid. Batteries significantly increase the overall cost of a PV system. This is the reason that most PV systems that have the option of being tied into the grid, and are therefore eligible for net-metering, elect not to use batteries. Net-metering is critically important to the financial success of PV systems for municipalities because that is the mechanism which allows for electricity to be fed back into the grid. This process fulfills the function of allowing the utility company to act as a "battery" for systems tied into the utility grid.

High initial capital costs were the apparent reasons for the three municipalities that demonstrated a negative NPV for their projects. One of the three municipalities, Livermore, oversized the inverter for their system, which contributed to the high cost. The advantage to an oversized inverter is that at any time in the future, solar panels can be added to increase the size (in kW) of a PV system without spending money to purchase additional inverters. In the case of Livermore, the size of the PV system could be increased by as much as 33% without buying an inverter. Inverters are the second most expensive component of PV systems after solar panels. Future modifications of Livermore's system will result in an improved cost-benefit ratio and improved NPV.

As discussed earlier, Chico had a city policy of adding 17% overhead and design costs at a fixed percentage of all municipal projects. Overhead of this magnitude was not the case for any other system analyzed. After excluding these overhead costs, Chico had the second most cost-effective system analyzed.

Holding all other variables equal, the choice of discount rate alone can lead directly to approving or rejecting a project. The discount rate reflects a philosophy of the decision-maker as to how he or she values future impacts. The lower the rate, the greater the importance attached to future generations, future costs, and future benefits of the project, whether these future costs are monetary or environmental. Conversely, the higher the discount rate, the greater the importance placed on the present. With a time horizon of 25 years, a PV project should be considered a long-term project; therefore, a lower discount rate such as 4% to 5% is warranted (Nofuentes et al., 2002). Furthermore, many projects that have a similar risk to PV projects do not have the environmental and social benefits that should be taken into account with PV. When external benefits are not taken into account, an incorrect discount rate is likely to be chosen.

The rate at which utility prices increase over time also has a large effect on the NPV of PV projects. The greater the escalation rate, the more attractive PV becomes. Future utility rates are impossible to predict and are subject to a variety of influences in the marketplace. If historical rates for electricity and fossil fuels are an indication of the future, it appears that electricity prices will continue to rise (Figure 2).

Except for Livermore, all municipalities analyzed would not have approved their PV project unless it was demonstrated that the system would pay itself back before the useful life ended. Given this criterion, none of the projects would have been accepted without the rebate money that was available from the State of California or PG&E's Self-Generation Renewable Energy Program to bring down the capital cost of the systems. Without rebates, the costs would have been too high for municipalities to approve the systems.

Even with rebates to defray the costs of PV, it appeared that most municipalities in this study required that their PV systems be paid back within 12 to 15 years or the project would not have been supported. Yet, unlike PV, much necessary municipal expenditure has no return on investment (e.g., roads and infrastructure). PV projects afford municipalities the rare project that is able to realize a return on investment, which sets it apart from the typical municipal project.

Buying conventionally generated electricity normally has a zero return on investment. If the PV project does nothing more than break even financially, there are still considerable environmental benefits to generating electricity with PV panels. This study has shown that PV projects can be sound financial investments and a good use of taxpayers' money. Furthermore, there are some factors that could result in a greater number of positive NPVs for each municipality (Figures 3 through 15).

1. The longer the PV system lasts, the greater the return on investment. It is speculated that PV systems will be operating effectively 40 years from now.
2. The amount of solar radiation calculated that would be received by the PV systems may be conservative. Any amount of solar radiation above what was assumed for this study would result in increased benefits.
3. If the rules for net-metering were to change where utility companies had to pay more than retail prices for electricity, the systems would be increasingly

cost-effective. In Germany, Spain, and Japan, the utility companies pay double the retail price of electricity when net-metering.

4. Changing the tariff service could result in increased revenue from the utility company. One meter will value a kWh at $0.13 and another meter will value the same kWh at $0.18. The greater the value of a kWh, the more the utility company must pay for net-metering.

Therefore, the positive payback reported in this study is on the conservative side if any of the above conditions occur.

It is extremely unlikely that municipalities will install PV systems without two important incentives: (a) state-sponsored rebates and (b) net-metering. Without rebates and net-metering, the PV systems would probably never pay themselves back under present conditions. Since 2000, the CEC has provided rebates as high as $4.50/watt for PV systems less than 30 kW in size. This rebate program has been so successful that the funds are being rapidly depleted. The rebates currently are paying $3.20/watt but are due to end in June 2004 (Database of State Incentives for Renewable Energy, n.d.). PG&E's Self-Generation Program pays $4.50/watt for PV systems sized between 30 kW and 1,000 kW; this program will be in effect through 2008.

Net-metering, which requires utilities to purchase electricity produced by their customers at retail prices, became law (AB656) in California in 1996 for PV systems up to 10 kW in size. In 2001, the law was amended (AB58) to include PV systems up to 1 megawatt (MW). The significance of AB58 was that it provided an incentive for installation of large PV systems suited for commercial buildings and municipalities rather than small systems sized more for the residential market.

Continuing support from the State of California, the CEC, and the California Public Utility Commission is critical to the success of PV projects for local municipalities. Any disincentive such as discontinuing the rebate program, taxing PV, or applying an exit fee for PV systems would deter municipalities from this type of investment. On the state level, there are programs that could be implemented to encourage municipalities to install PV on a large scale. Cities and counties could be credited for the value of improved air quality. The State could provide education to municipalities about PV systems and the PV industry. Streamlining the permitting process would also encourage municipalities to consider PV projects.

This study also showed that successful PV projects are the result of motivated staff. All municipalities analyzed had a city staffer that "championed" the idea of PV. These individuals often put a large amount of time and effort into their PV projects and, in some cases, they encountered the additional effort of convincing the authorizing body within their municipality to embrace the relatively new idea of PV/renewable energy.

Whether or not all municipalities in this study have demonstrated a cost-effective PV system does not negate the validity of their PV project. This study did not include the value that a renewable energy technology (i.e., PVs) can add to the local economy, the environment, and the health of future generations. These municipalities are pioneers and are setting an example for other cities. Viable alternatives to electrical production do exist which serve to lessen the detrimental environmental impacts of such a basic need as electricity.

SUMMARY

Limitations

This thesis was limited to CE of PV systems for municipalities, the motivations and obstacles municipalities encountered when installing PV systems, and the air quality impacts of those systems. Not included in the CBA were the monetary benefits (a) of an improved environmental effect (i.e., cleaner air); (b) of a grid-tied PV systems to the utility company; and (c) to the local economy of the PV industry. This industry will supply jobs to electricians, installation companies, and the manufacturing sector.

Recommendations

There are numerous areas of interest beyond the scope of this study that would add knowledge to the field of solar energy, PVs, and the PV industry.

Suggested recommendations for additional study would be, for example, the CE of PV when coupled with energy-efficient lighting, heating, and cooling systems. Some of the municipalities in this study had implemented these types of energy-efficient measures prior to their PV project. If PV systems and energy-efficient changes are bundled into one project, the CE and payback time may be significantly improved from what was reported here.

California's State-sponsored incentive/rebate program has prompted a large surge of PV installations in the residential sector, yet this program is soon to be discontinued. Quantifying the effectiveness of this program and the impact on the PV industry if this program were to be terminated would be of value. Furthermore, could State-sponsored programs to educate cities about renewable energy technologies and PVs be of benefit to society?

Recommendations for additional areas to be studied are

1. How would PV affect the environment, economy, and standard of living for developing nations?
2. How do PV systems affect the major utilities?
3. How do PV systems affect T&D costs?
4. Does PV result in deferred maintenance for T&D? If so, can this be quantified?
5. How much electricity could PV supply if every available rooftop in California or the United States had a PV system?

6. Would this have a significant impact on statewide or national electrical generation?

We as a society will never return to a life without electricity. The current method of generating electricity with our limited supply of fossil fuels cannot be sustained, nor can the environmental damage be ignored indefinitely. This thesis represents a starting point to examine the merits of PVs, with many aspects of solar energy as yet unexplored.

Conclusion

Solar energy is one of the most promising and legitimate forms of renewable energy available. The PV industry has advanced substantially since the 1970s when PV was first applied to terrestrial applications after proving itself in outer space. The price of PV modules has come down drastically since the mid-1970s, and PV cell efficiency has increased. Many municipalities that have installed PV systems are planning to install more systems.

The federal and state governments have programs that support solar-electric, rooftop PV systems. Without a doubt, environmental benefits from PV are significant and substantial. Moreover, dwindling fossil fuel resources are being conserved.

Municipalities not only in California but around the world have installed PV systems that today produce MW of electricity. The two critical elements to keep California on the renewable energy path are rebates and net-metering. Rebates keep the capital cost of the PV system down; net-metering assists in defraying costs during the life of the PV system. With these prerequisites in place, this thesis has shown that PV is generally a sound economic investment for local communities.

REFERENCES

American Forests. *Climate change calculator*. (n.d.). Retrieved February 7, 2004, from http://www.americanforests.org/resources/ccc/index.php

Barnes, P. R., Van Dyke, J. W., Tesche, F. M., & Zaininger, H. W. (1994). *The Integration of renewable energy sources into electric power distribution systems* (Vol. 1). Retrieved March 27, 2003, from http://www.ornl.gov/reports/ornl/ornl6775v1.pdf

Berger, J. J. (1997). *Charging ahead: The business of renewable energy and what it means to America*. New York: Henry Holt.

Bower, W. I. (1999). Inverters – Critical photovoltaic balance-of-system components: Status, issues, and new-millennium opportunities. *Progress in Photovoltaics: Research and Applications, 8*, 113-126.

Browning, A. (2003). The Vote Solar Initiative. *Solar Today, 17*(4), 42-43.

Caldwell, J. H. (1994). Photovoltaic technology and markets. *Contemporary Economic Policy, 7*, 97-111.

California Energy Commission #1. (n.d.) . *Grid-connected PV capacity*. Retrieved December 22, 2003, from http://www.energy.ca.gov/renewables/emerging_renewables/2003-12-31_GRID_PV.PDF

California Energy Commission #2. (n.d.). *California's major sources of energy*. Retrieved January 12, 2004, from http://www.energy.ca.gov/html/energysources.html

California Energy Commission #3. (n.d.). *Database of California power plants*. Retrieved July 7, 2003, from http://www.energy.ca.gov/database/index.html#powerplants

California Energy Commission #4. (n.d.). Chart derived from figures at *California statewide weighted average retail electricity prices by sector*. Retrieved July 17, 2003, from http://www.energy.ca.gov/electricity/statewide_weightavg_sector.html

California Power Authority. (2002). *Clean growth: Clean energy for California's economic future.* Retrieved October 3, 2003, from http://www.powerauthority.ca.gov/background/main.asp

Callan S. J., & Thomas, J. M. (2000). A regulatory impact analysis: Reducing lead in gasoline. *Environmental Economics and Management* (2nd ed.). Fort Worth, TX: Dryden Press.

Carlin, J. (1995, November). Environmental externalities in electric power markets: Acid rain, urban ozone, and climate change. *Monthly Energy Review*, xiii-xxii.

Center for Energy and Economic Development. (1995, November). *CEED's response to NREL's critique of energy choices.* Retrieved April 18, 2003, from http://www.ceednet.org/resources/nrel.asp

Charters, W. W. S. (1994). Solar energy: A viable pathway towards ecologically sustainable development. *Solar Energy, 52*(5), 367-370.

Consortium for Electric Infrastructure to Support a Digital Society. (2001). *The cost of power disturbances to industrial & digital economy companies* (Rep. No. 1006274). Retrieved December 18, 2003, from http://ceids.epri.com/ceids/Docs/outage_study.pdf

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., et al. (1997). The value of the world's ecosystem services and natural capital. *Nature, 387*, 253-260.

Crawley, A. S. (2002). *A new approach to achieving the federal goal for renewable energy. Save with solar and wind: A technical bulletin for federal solar and wind energy champions* (Rep. No. DOE/GO-102002-1591). Department of Energy Federal Energy Management Program by the National Renewable Energy Laboratory.

Darmstadter, J. (1991, Spring). Estimating the cost of carbon dioxide abatement. *Resources, 103*, 6-9.

Database of State Incentives for Renewable Energy. Retrieved January 25, 2004, from http://www.dsireusa.org

Dunn, S. (2000). Micropower: The next electrical era. In J. A. Peterson (Ed.), *Worldwatch Paper #151.* Washington, DC: Worldwatch Institute.

Energy Information Administration #1. (n.d.). *Glossary*. Retrieved August 11, 2002, from http://www.eia.doe.gov/glossary/glossary_r.htm

Energy Information Administration #2. (n.d.). *Photovoltaic milestones*. Retrieved June 9, 2003, from http://www.eia.doe.gov/cneaf/solar.renewables/renewable.energy.annual/backgrnd/chap11i.htm

Energy Information Administration #3. (n.d.). *Emissions of greenhouse gases in the United States 2002* (Rep. No. DOE/EIA-0573). Retrieved October 28, 2003, from http://www.eia.doe.gov/oiaf/1605/ggrpt/emission.html

Energy Information Administration #4. (n.d.). *Annual energy outlook 2000 with projections to 2020* (Rep. No. DOE/EIA-0383) [Electronic version]. Retrieved October 20, 2003, from http://www.eia.doe.gov/oiaf/aeo/index.html

Energy Information Administration #5. (n.d.). *Number of miles based on displaced CO_2 in this study and derived from "Alternatives to traditional transportation fuels 1994: Vol. 2.* Retrieved February 27, 2004, from http://www.eia.doe.gov/cneaf/pubs_html/attf94_v2/chap3.html

Energy Information Administration #6. (n.d.). *Expansion and change of the U.S. natural gas pipeline network – 2002*. Retrieved 9/23/2003, from http://www.eia.gov/pub/oil_gas/natural_gas/feature_articles/2003/Pipenet03/ngpipenet03.pdf

Environmental Protection Agency #1. (n.d.). *Effects of acid rain: Human health*. Retrieved December 2, 2003, from http://www.epa.gov/airmarkets/acidrain/effects/health.html

Environmental Protection Agency #2. (1998). *Mercury emissions and electric utilities*. Retrieved December 2, 2003, from http://www.epa.gov/ttncaaa1/t3/fact_sheets/hg17th.pdf

Environmental Protection Agency #3. (2000, August). *Radiation protection at EPA: The first 30 years* (Rep. No. 402-B-00-001) [Electronic Version]. Retrieved February 19, 2004, from http://www.epa.gov/radiation/docs/history.pdf

Environmental Protection Agency #4. (2000). *Fact sheet – EPA to regulate mercury and other air toxics emissions from coal- and oil- fired power plants*. Retrieved

December 2, 2003, from http://www.epa.gov/ttn/oarpg/t3/fact_sheets/fs_util.pdf

Environmental Protection Agency #5. (n.d.). *Power profile website to find energy mix for PG&E*. Retrieved January 14, 2004, from http://oaspub.epa.gov/cleanenergy/ powerprofiler.htm

Environmental Protection Agency #6. (n.d.). *Electricity from coal*. Retrieved December 16, 2003, from http://www.epa.gov/cleanenergy/coal.htm

Environmental Protection Agency #7. (n.d.). *Electricity from oil*. Retrieved December 16, 2003, from http://www.epa.gov/cleanenergy/oil.htm

Environmental Protection Agency #8. (n.d.). *Electricity from natural gas*. Retrieved December 16, 2003, from http://www.epa.gov/cleanenergy/natgas.htm

Farrow, S., & Toman, M. (1999). Using cost-benefit analysis to improve environmental regulations. *Environment, 41*(2), 12-21.

Faruqui, A., Chao, H., Niemeyer, V., Platt, J., & Stahlkopf, K. (2001). Analyzing California's power crisis. *The Energy Journal, 24*(4), 29-51.

Fies, B. (2001, Summer). Photovoltaics rising – Beyond the first gigawatt. *Electronic Power Research Institute Journal, 26*(1), 13-20.

Frankl, P., & Gamberale, M. (1998). Analysis of energy and CO_2 aspects of building integration of photovoltaic systems. *Proceedings of Photovoltaics and the Environment 1998* (Rep. No. BNL-52557).

Fthenakis, V. M. (2000). End-of-life management and recycling of PV modules. *Energy Policy, 28*, 1051-1058.

Fthenakis, V. M. (2001). Multilayer protection analysis for photovoltaic manufacturing facilities. *Process Safety Progress, 20*(2), 87-94.

Fthenakis, V. M., & Moskowitz, P. D., (2000). Photovoltaics: Environment, health, and safety issues and perspectives. *Progress in Photovoltaics: Research and Application, 8*, 27-38.

Fuguitt, D., & Wilcox, S. J. (1999). *Cost-benefit analysis of public sector decision makers*. Westport, CT: Quorum.

Garbesi, K., & Bartholomew, E. (2001). *The potential for solar electricity generation in San Francisco.* San Francisco: Author.

Gatto, M., & DeLeo, G. A. (2000). Pricing biodiversity and ecosystem services: The never-ending story. *BioScience, 50*(4), 347-361.

Green, M. A., Emery, K., King, D. L., Igari, S., & Warta, W. (2000). Solar cell efficiency tables. *Progress in Photovoltaics: Research and Applications, 8*, 377-383.

Grob, G. R. (1998). Implementation of global energy sustainability. *Energy Sources, 20*, 147-154.

Herig, C. (2000). *Assessing rooftop solar-electric distributed energy resources for the California local government commission.* Golden, CO: National Renewable Energy Laboratory. Retrieved June 6, 2002, from www.lgc.org/services/docs/spire/nrel_rooftop_solar_doc.pdf

Herig, C., Thomas, H., Perez, R., & Wenger, H. (2000, May). *Customer sited PV – U.S. markets developed from state policies* (Rep. No. NREL/CP-520-28426). Paper presented at the 16th European Photovoltaic Solar Energy Conference and Exhibition, Glasgow, Scotland, UK. http://www.nrel.gov/ncpv/pvmenu.cgi?site=ncpv&idx=3&body=infores.html

Hester, E., & Gross, A. C. (2001, July). Focus on industries and markets: Micropower. *Business Economics*, 70-76.

Hoff, T. E. (2000). *The benefits of distributed resources to local governments: An introduction.* Retrieved March 17, 2002, from http://www.millionsolarroofs.com/articles/static/1/binaries/Benefits_of_Distributed_Resources_to_Local_Governments.pdf

Hoff, T. E., & Cheney, M. (2000). The potential market for photovoltaics and other distributed resources in rural electric cooperatives. *The Energy Journal, 21*(3), 113-127.

Hoffert, M. I., Caldeira, K., Benford, G., Criswell, D. R., Green, C., & Herzog, H. et al. (2002). Advanced technology paths to global climate stability: Energy for a greenhouse planet. *Science, 298*, 918-987.

Hohmeyer, O. (1990). Social costs of electricity generation: Wind and photovoltaic versus fossil and nuclear. *Contemporary Policy Issues, 8*, 255-282.

Holt, M. (1999). *Civilian nuclear waste disposal* [Issue brief]. Retrieved February 20, 2003, from http://www.ncseonline.org/NLE/CRSreports/Waste/waste-2.cfm?&CFID=6842093&CFTOKEN=80513901#_1_12

Intergovernmental Panel of Climate Change. (2000, November 9). *Emissions of greenhouse gases in the United States 2000: Executive summary* (Rep. No. DOE/EIA-0573). Retrieved July 16, 2002, from ftp://ftp.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/ggrpt/057301.pdf

Kahn, E. P. (1991). Electric utility planning and regulation (2nd ed.). In C. Blumstein (Series Ed.), *Energy Conservation and Energy Policy*. Washington, DC: American Council for an Energy-Efficient Economy.

Koplow, D., & Dernbach, J. (2001). Federal fossil fuel subsidies and greenhouse gas emissions: A case study of increasing transparency for fiscal policy. *The Annual Review of Energy Environment, 26*, 361-389.

Laird, F. N. (2003). Acting locally. *Solar Today, 17*(4), 26-27.

Lee, J. C., Fthenakis, V. M., Morris, S. C., Goldstein, G. A., & Moskowitz, P. D. (1997). Projected photovoltaic energy impacts on U.S. CO_2 emissions: An integrated energy environmental – Economic analysis. *Progress in Photovoltaics: Research and Applications, 5*, 277-285.

Luque, A. (2001). Photovoltaic market and costs forecast based on a demand elasticity model. *Progress in Photovoltaics: Research and Applications, 9*, 303-312.

Michelfelder, R. A. (1993). Evolving electric utility regulatory policy: Internalizing social costs of production. *The American Journal of Economics and Sociology, 52*(2), 227-240.

Million Solar Roofs #1. (n.d.). *Federal support.* Retrieved December 21, 2003, from http://www.millionsolarroofs.org/federalsupport_committment

Million Solar Roofs #2. (n.d.). *About MSR.* Retrieved December 21, 2003, from http://millionsolarroofs.org/about/

Million Solar Roofs #3. (n.d.). *How's MSR doing?* Retrieved December 21, 2003, from http://www.millionsolarroofs.com/msrdoing/

Moniz, E. J., & Kenderdine, M. A. (2002). Meeting energy challenges: Technology and policy. *Physics Today, 55*(4), 40-46.

NASA Surface Meteorology and Solar Energy. (n.d.). Retrieved December 2003, from http://eosweb.larc.nasa.gov/cgi-bin/sse/subset.cgi?

Nicklas, M. (1993). Energy politics: Can we achieve a sustainable energy path? *Solar Energy, 50*(4), 287-296.

Nicklas, M. (1997). 40% renewable energy by 2020: An ISES goal, a global necessity. *Advances in Solar Energy, 11*, 415-459.

Nofuentes, G., Aguilera, J., & Munoz, F. J. (2002). Tools for the profitability analysis of grid-connected photovoltaics. *Progress in Photovoltaics: Research and Applications, 10*, 555-570.

Official California Legislative Information. (n.d.). *Text of Senate Bill 82.* Retrieved August 23, 2003, from http://www.leginfo.ca.gov/pub/01-02/bill/sen/sb_0051-0100/sbx2_82_bill_20011007_chaptered.html

Ottinger, R. L. (1991). *Environmental costs of electricity.* New York: Oceana Publications.

Pacific Gas & Electric. (n.d.). *Tariff schedule.* Retrieved November 4, 2003, from http://www.pge.com/tariffs/electric.shtml

Parente, V., Goldemberg, J., & Zilles, R. (2002). Comments on experience curves for PV modules. *Progress in Photovoltaics: Research and Applications, 10*, 571-574.

Plympton, P., Kappaz, P., Kroposki, B., Stafford, B., & Thornton, J. (2001). *Four federal grid-connected photovoltaic systems: Powering our nation's capital with solar.* Retrieved April 12, 2002, from http://www.nrel.gov/docs/fy01osti/29050.pdf

Power Scorecard #1. (n.d.). *Ozone and fine particulates.* Retrieved January 5, 2004, from http://www.powerscorecard.org/issue_detail.cfm?issue_id=3

Power Scorecard #2. (n.d.). *Electricity and the environment.* Retrieved January 5, 2004, from http://www.powerscorecard.org/elec_env.cfm

Power Scorecard #3. (n.d.). *Acid rain.* Retrieved January 5, 2004, from http://www.powerscorecard.org/issue_detail.cfm?issue_id=2

Serchuk, A. (2000). *The environmental imperative for renewable energy: An update.* Retrieved April 9, 2002, from http://www.repp.org/repp_pubs/pdf/envImp.pdf

Solar Electric Power Association. (2002). *Solar power solutions: A business case for capturing total value.* Retrieved April 8, 2002, from http://www.solarelectricpower.org/ewebeditpro/items/O63F1180.pdf

State Energy Advisory Board. (2002, August). Homeland security: Safeguarding America's future with energy efficiency and renewable energy technologies. *Tenth annual report of the State Energy Advisory Board, U.S. DOE.* Retrieved January 10, 2004, from http://www.steab.org/docs/STEAB_Report_2002.pdf

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., & Collingham, Y. C., et al. (2004). Extinction risk from climate change. *Nature, 427,* 145-148.

Titus, J. G. (1992). The costs of climate change to the United States. In S. K. Majumdar, L. S. Kalkstein, B. Yarnal, E. W. Miller, & L. M. Rosenfeld (Eds.), *Global climate change: Implications, challenges, and mitigation measure: Chap. 27.* Retrieved January 25, 2003, from www.epa.gov/globalwarming/publications/impacts/sealevel/us_costs.pdf

Walton, A. L., & Hall, D. C. (1990, July). Contemporary policy issues. *Solar Power, 8,* 240-254.

Yokell, M. D. (1979). The role of the government in subsidizing solar energy. *American Economic Review, 69*(2), 357-361.

APPENDIX A

SOLAR ENERGY LEGISLATION BETWEEN 1996 AND 2002

September 2002

AB 58 Net Metering by Assemblyman Fred Keeley (D-Santa Cruz) – Eliminates 12/31/02 Sunset Date; preserves 1 MW, single meter net metering; tasks the PUC with developing a study by 1/1/2005 to determine net metering costs and benefits; establishes "co-metering" (net metering for energy portion only) for wind over 50 kW and municipals over 10 kW; Preserves "Time of Use" net metering availability; sets a ½% per IOU (approximately 270 MW total for all IOUs) ceiling for total capacity of net metered customers.

SB 1038, Senator Byron Sher (D-Palo Alto) – Enables the Renewable Investment Plan (includes the CEC RE Buydown (i.e., PV rebate program) and the PIER (including PV Research) program to continue through 2007.

SB 1078, Senator Byron Sher (D- Palo Alto) – The Renewable Portfolio Standard mandates that 20% of power provided in State be renewable by 2017 (up from current 11%).

AB 1881, by Assembly member Anthony Pescetti (R-Rancho Cordova) – Expands on the definition of "solar energy equipment" to make solar heating technologies eligible for installation on or near new state buildings and parking facilities. Under current law, "solar energy equipment" is defined as a provider for the collection, conversion, storage, or control of solar energy for electricity generation. This bill expands the definition for the purpose of including solar thermal energy that heats water but does not necessarily generate electricity.

SB 1534, by Senator Debra Bowen (D-Marina del Rey) – Updates the safety and performance standards for solar energy systems that produce electricity. Specifically, this bill requires that solar energy systems for sale in California be certified by the Solar Rating Certification Corporation as well as meet all of the applicable safety and performance standards established by the National Electrical Code and the Institute of Electrical and Electronics Engineers, among others. This addition confirms the existing Solar Rights Act (CA Civil Code Section 714) with the identical safety language contained in PUC Code Section 2827, the Net Metering Law.

SB 1660, by Senator Jack Scott (D-Alta Dena) – Clarifies clean up language to correctly distinguish between wind and solar systems for the state income tax credit enacted into law last year via SB 17 by Senator Jim Brulte.

AB 1968, by Assemblyman Joe Nation (D-San Rafael) – Eliminates state income tax exposure on "emerging renewable" buydowns from the California Energy

Commission Emerging Renewables Buydown Program, although Federal income tax issues remain.

September 2001

Senate Bill 82xx requires the state Department of General Services to ensure that solar energy equipment is installed on all existing state buildings and parking facilities, with requirements for inclusion in new projects as well. The bill also establishes PV as an energy-efficiency improvement and is to be eligible for Small Business Fund financing.

Senate Bill 17xx – Creates a solar tax credit which is retroactive to January 1, 2001. The tax credit for tax years 2001-2003 is equal to the lesser of 15% of the net purchase cost of a photovoltaic or wind-driven system with a generating capacity of not more than 200 kilowatts. The bill allows a credit for one system per each separate legal parcel of property or per each address of the taxpayer in California, and it requires recapture of the credit if the system is sold or removed from California within one year. The credit will be reduced to half that amount for tax years 2004-2005 and will sunset on January 1, 2006. Qualifying systems would need to be certified by the Energy Commission, installed with a 5-year warranty, and be required to be in service in California for at least one year. This bill complements other programs that provide incentives for installing renewable systems.

Senate Bill 48xx – Creates the Solar Training, Education and Certification Act of 2001 which is a three-prong program that fills in gaps of existing state programs designed to encourage the use of solar energy systems. The bill has three components: (a) allowing CEC to adopt specifications for the major electrical components in the absence of certification by a certified testing laboratory, (b) authorizing local governments to develop a program to encourage the construction of buildings that use solar thermal and photovoltaic systems that are certified by nationally recognized certification agencies or the CEC, and (c) requiring the California Employment Development Department (EDD) to administer a solar training and oversight program.

[Note: Follow the links to the legislative site above for full text of the respective bills, along with supporting analysis.]

Net-Metering legislation in California for grid-tied photovoltaic systems (solar electric) – Net-metering simply means that a rooftop photovoltaic system producing excess electricity during the day can deliver this electricity to the local utility, spinning the utility meter backwards and gaining a credit (at the retail rate) which can be used later when power is needed from the grid (at night or on cloudy days).

2002 – AB 58 (effective January 1, 2003) – Eliminates 12/31/02 Sunset Date; preserves 1 MW, single-meter net-metering; tasks the PUC with developing a study by 1/1/2005 to determine net-metering costs and benefits; establishes co-metering (net-metering for energy portion only) for wind over 50 kW and municipals over 10 kW; preserves "time of use" net-metering availability; sets a ½% per IOU (approximately 270 MW total for all IOUs) ceiling for total capacity of net-metered customers.

2001 – AB 29 (effective April 11, 2001) – Changes: Raises system cap from 10 kW to 1 MW, no standby charges, open to commercial/industrial/agricultural customers, elimination of utility territory caps, applies to all California utilities; IOU and public-owned. Systems installed under this law will be eligible for these conditions for the life of the system. [Note: The new features under AB 29 will revert back to AB918 conditions on 1/1/2003 unless further legislation is enacted.]

2000 – AB 918 (effective on January 1, 2001) – Changes: Clarity on compensation rates and introduces time-of-use net-metering.

1998 – AB 1755 – Changes: Includes small wind systems, include small commercial customers, annualize the billing cycle, and allow for property tax exclusion.

1995 – SB 656 – The first California net-metering law was signed to establish compensation and simplified interconnection rules for small-scale photovoltaic systems. The new net-metering law provided that all utilities in California must allow residential customers with PV systems rated up to 10kW to interconnect with the local utility grid and receive retail value for the electricity produced.

Financial Incentives

2001 – Senate Bill 17xx – Creates a solar tax credit which is retroactive to January 1, 2001. The tax credit for tax years 2001-2003 is equal to the lesser of 15% of the net purchase cost of a photovoltaic or wind-driven system with a generating capacity of not more than 200 kilowatts. The bill allows a credit for one system per each separate legal parcel of property or per each address of the taxpayer in California, and it requires recapture of the credit if the system is sold or removed from California within one year. The credit will be reduced to half that amount for tax years 2004-2005 and will sunset on January 1, 2006. Qualifying systems would need to be certified by the Energy Commission, installed with a 5-year warranty, and would be required to be in service in California for at least one year. This bill complements other programs that provide incentives for installing renewable systems.

2001 – AB 29 (effective April 11, 2001) – Provides more funding ($22 M for IOU customers and $8 M for muni customers) into the CEC Buydown Program for up to 10 kW systems. The funding is tax dollars (versus ratepayer funding as with the existing program); thus, the program applies also to muni customers, a new feature. Also establishes a Renewable Energy Loan Guarantee Program to be established by the Technology, Trade and Commerce State Agency; targets larger renewable energy projects, though could include grid-tied PV.

2000 – SB1345 (effective January 1, 2001) – Establishes grant program for solar hot water, solar pool heating, or PV system batteries (grid-tied only) and other distributed generation technologies. Must be renewed annually.

1996 – AB 1890 – The original electric utility deregulation bill established incentives for grid-tied PV systems (for IOU customers) under the California Energy Commission's Emerging Renewable Program. Municipal utilities were instructed to also establish public benefit programs which included renewable energy features.

APPENDIX B

GLOSSARY

Alternating current: Current which repeatedly changes polarity from negative to positive and back again. The type of current found in conventional electric supply.

Anthropogenic: Made by people or resulting from human activities. Usually used in the context of emissions produced as a result of human activities.

Carbon dioxide equivalent: The amount of carbon dioxide by weight emitted into the atmosphere that would produce the same estimated radiative forcing as a given weight of another radiatively active gas. Carbon dioxide equivalents are computed by multiplying the weight of the gas being measured (e.g., methane) by its estimated global warming potential (which is 21 for methane).

Carbon equivalent units: Carbon dioxide equivalents multiplied by the carbon content of carbon dioxide (see carbon dioxide equivalent).

Digital economies: Firms that rely heavily on data storage and retrieval, data processing, or research and development operations. Specific industries include telecommunications, data storage and retrieval services (including collocation facilities or Internet hotels), biotechnology, electronics manufacturing, and the financial industry.

Direct current: The continuous flow of electricity through a conductor such as a wire from high to low potential. The type of current, for example, which is generated by batteries.

Distributed utility: Includes small/modular generation, energy storage, and geographically targeted energy efficiency and demand management systems used to complement central generation and utility power transmission and distribution systems.

Distributed utility benefits: Benefits from the integration of renewable energy sources into electric power distribution systems (i.e., reducing system losses, deferring transmission and distribution investment, improving power quality and reliability, and displacing electric energy produced by fossil fuels).

Eutrophication: The aging process of a lake, pond, or slow-moving stream, in which organic material (from plants) accumulates and slowly replaces oxygen. In recent years, this process has been accelerated by plant or algae growth in many bodies of water, encouraged by environmental pollution from such sources as phosphorus in detergents, the leaching of fertilizers, sewage and toxic dumping, and heated water from the cooling systems of power plants and other industries. There is concern that greater atmospheric concentrations of CO_2 will also accelerate eutrophication.

Greenhouse gases: Those gases (i.e., water vapor, carbon dioxide, nitrous oxide, methane, hydrofluorocarbons [HFCs], perfluorocarbons [PFCs] and sulfur hexafluoride) that are transparent to solar (short-wave) radiation but opaque to long-wave (infrared) radiation, thus preventing long-wave radiant energy from leaving the earth's atmosphere. The net effect is a trapping of absorbed radiation and a tendency to warm the planet's surface.

Net-metering: Utility will provide the electricity customer with full retail value for all excess electricity produced at a home or business that has its own renewable energy generator, such as a photovoltaic system.

Photovoltaic (PV) cell: An electronic device consisting of layers of semiconductor materials fabricated to form a junction (adjacent layers of materials with different electronic characteristics) and electrical contacts and being capable of converting incident light directly into electricity (direct current).

Photovoltaic (PV) centralized: Utility power plants that generate electricity through the use of photovoltaics.

Photovoltaic (PV) efficiency: The percentage of sunlight that strikes a PV panel and is converted to electricity (ratio of input of power to output of power). Efficiency in PV panels today is approximately 8% to 10%, but 30% efficiencies have been reached under laboratory conditions.

Photovoltaic (PV) grid-tied: PV systems that are connected to the utility grid and do not use batteries.

Photovoltaic (PV) module: An integrated assembly of interconnected photovoltaic cells designed to deliver a selected level of working voltage and current at its output terminals, packaged for protection against environment degradation, and suited for incorporation in photovoltaic power systems.

Photovoltaic (PV) off-grid: PV systems that are not connected to the utility grid. Instead, these PV systems store energy in batteries and are sometimes connected directly to direct current appliances or motors.

Radiative forcing: A change in average net radiation at the top of the troposphere (known as the tropopause) because of a change in either incoming solar or exiting infrared radiation. A positive radiative forcing tends on average to warm the earth's surface; a negative radiative forcing on average tends to cool the earth's surface. GHG, when emitted into the atmosphere, trap infrared energy radiated from the earth's surface and therefore tend to produce positive radiative forcing.

Radioactivity: The spontaneous emission of radiation from the nucleus of an atom. **Radionuclides** lose particles and energy through this process.

Renewable energy: Energy that is naturally replenishing but flow-limited and is virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Renewable energy resources include: biomass, hydro, geothermal, solar, wind, ocean thermal, wave action, and tidal action.

Solar energy: The radiant energy of the sun which can be converted into other forms of energy such as heat or electricity.

Solar insolation: A quantitative description of the amount of sunlight striking a surface; solar radiation incident on an area over time.

Solarport: A rooflike structure constructed on parking lots. The roof is composed of solar panels that act as shade for vehicles while simultaneously generating electricity.

Sun-hours: The amount of sunlight a site receives, usually measured in $kWh/m^2/day$.

Volatile organic compounds: Organic chemicals all contain the element carbon (C). Organic chemicals are the basic chemicals found in living things and in products derived from living things (i.e., coal, petroleum, and refined petroleum products). Many of the organic chemicals we use do not occur in nature, but are synthesized by chemists in laboratories. Volatile chemicals produce vapors readily. At room temperature and normal atmospheric pressure, vapors escape easily from volatile liquid chemicals. Volatile organic chemicals include gasoline, industrial chemicals such as benzene, solvents such as toluene and xylene, and tetrachloroethylene (perchloroethylene, the principal dry cleaning solvent). Many volatile organic chemicals are also hazardous air pollutants; for example, benzene causes cancer.

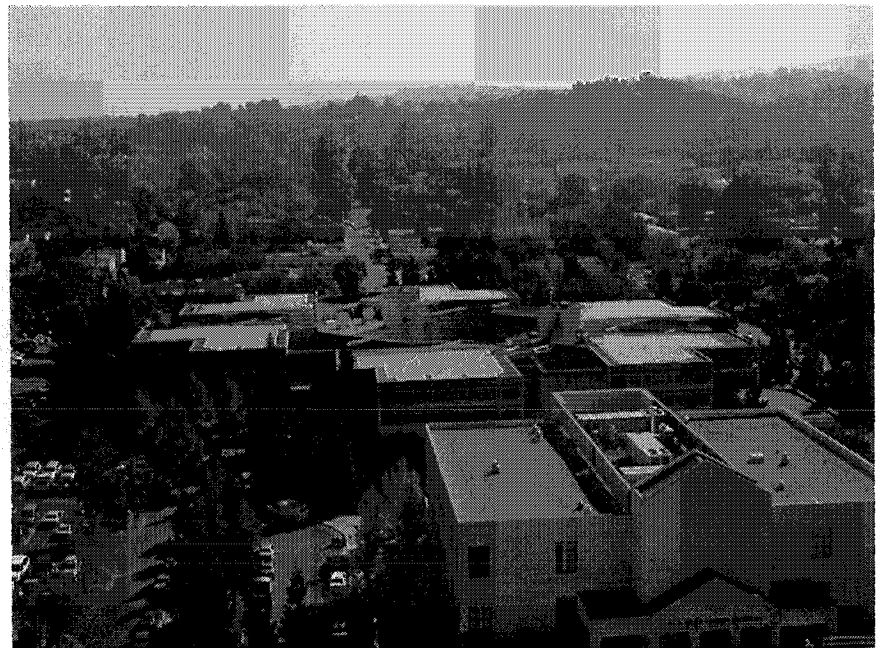
APPENDIX C

NORTHERN CALIFORNIA MUNICIPALITIES WITHOUT PV AS OF NOVEMBER 2003

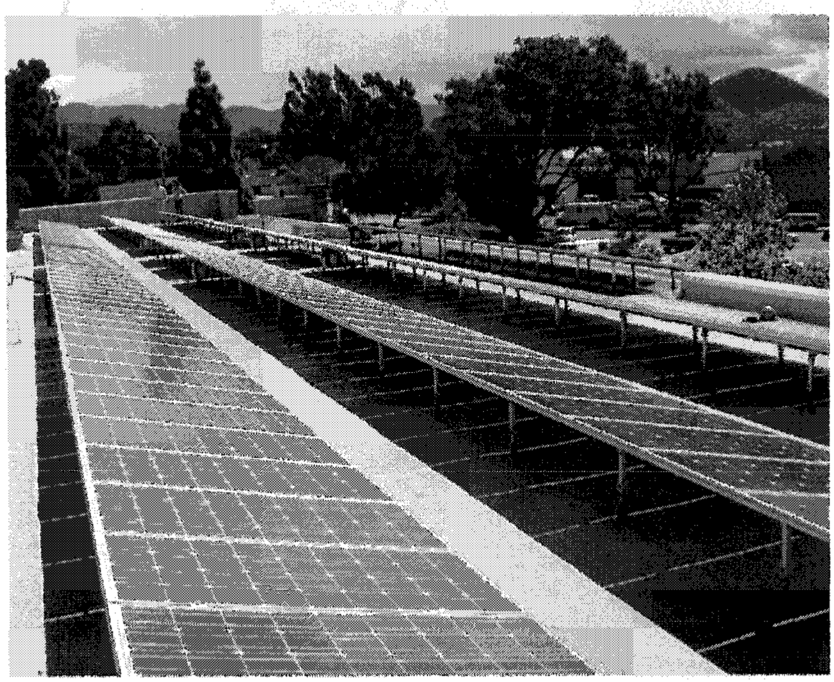
1. Arcata
2. Atherton
3. Auburn
4. Burlingame
5. Cupertino
6. Daly City
7. Dublin
8. Fairfax
9. Fremont
10. Fresno
11. Lodi
12. Los Altos
13. Los Gatos
14. Menlo Park
15. Millbrae
16. Monterey
17. Mountain View
18. Orinda
19. Pacifica
20. Palo Alto
21. Pleasanton
22. Portola Valley
23. Redding
24. Redwood City
25. Rohnert Park
26. San Mateo
27. San Ramon
28. Santa Clara
29. Santa Rosa
30. Sunnyvale
31. Tiburon
32. Vacaville
33. Woodside

APPENDIX D

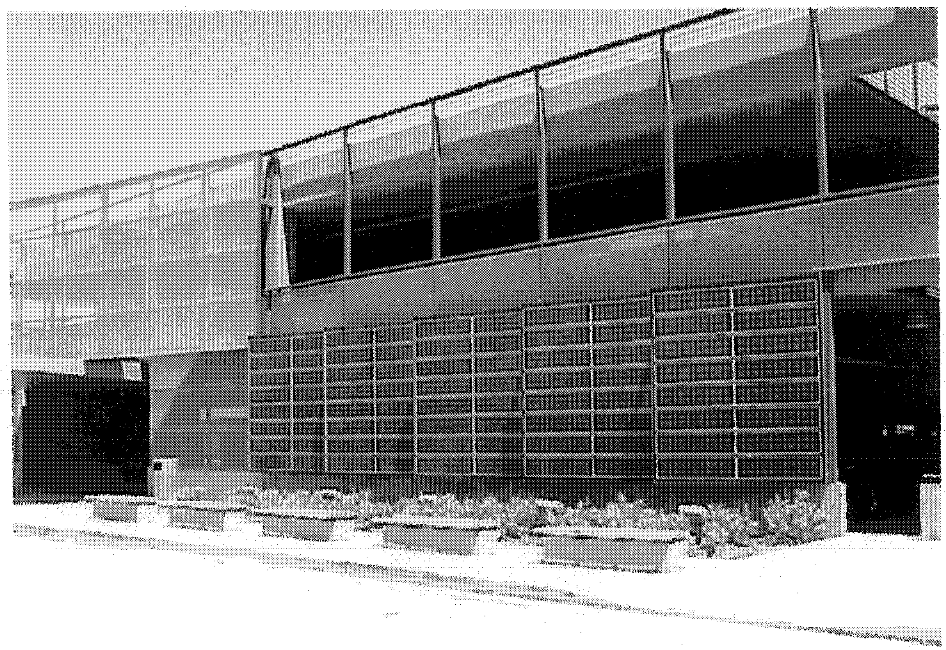
PICTURES OF SELECTED PV SYSTEMS ON MUNICIPAL BUILDINGS IN THIS STUDY



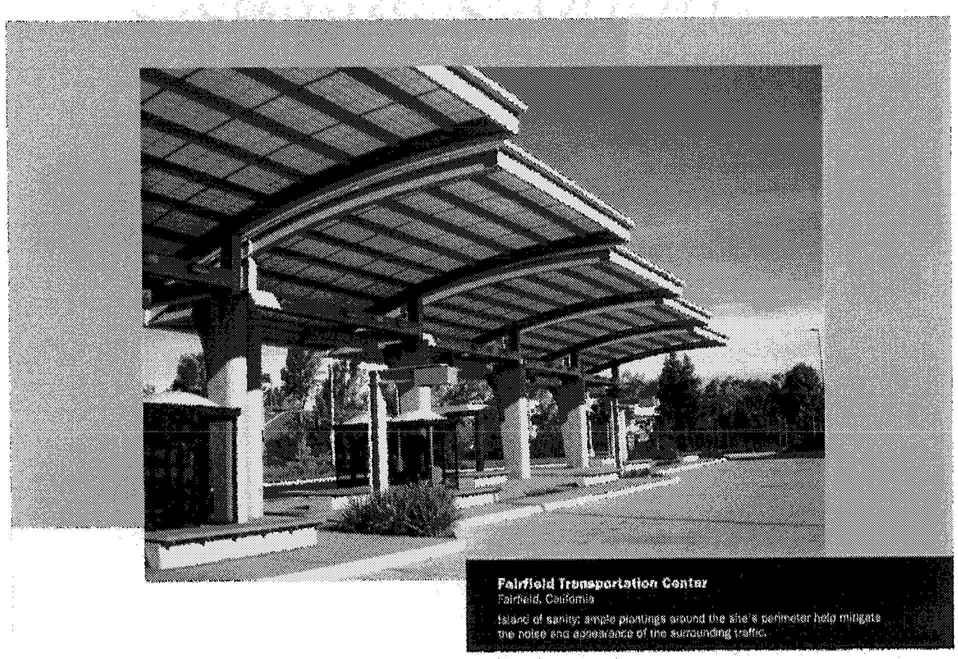
150 kW PV System on the County Jail in Martinez, California



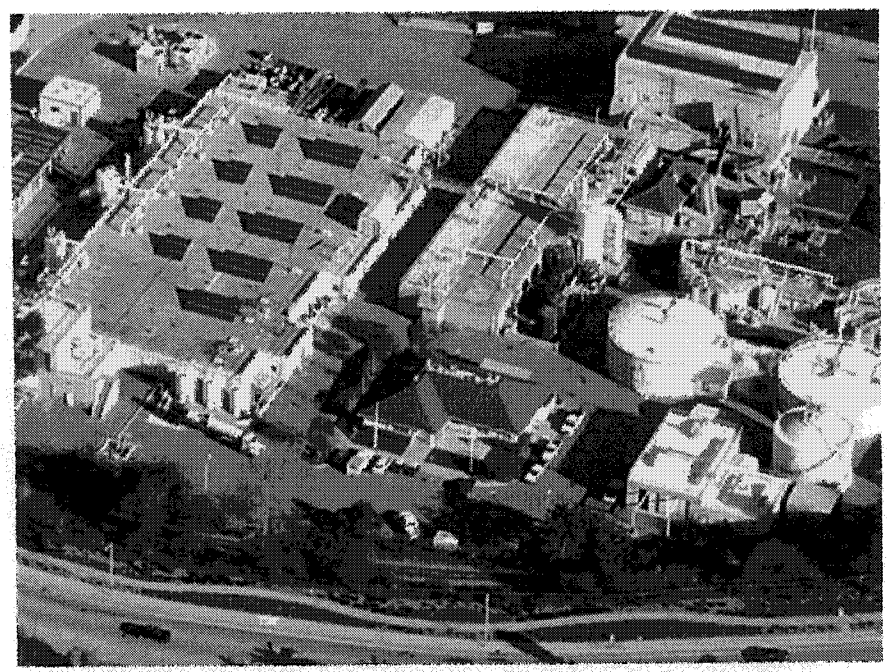
PV System on the Air Pollution District Building in San Luis Obispo, California



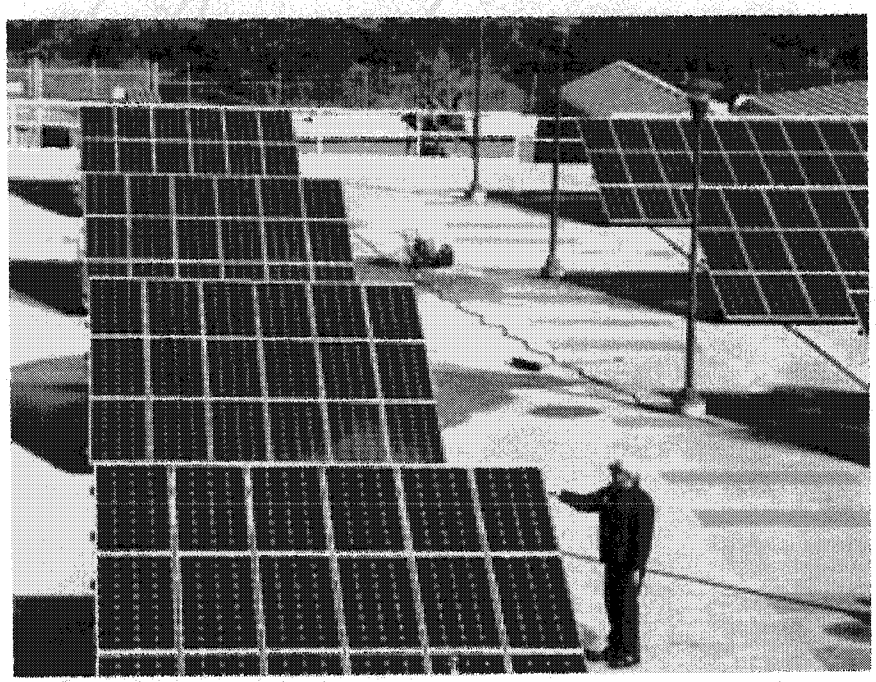
Solar Panels at Entrance to Parking Garage in Fairfield, California



Solar Panels at the Bus Terminal in Fairfield, California

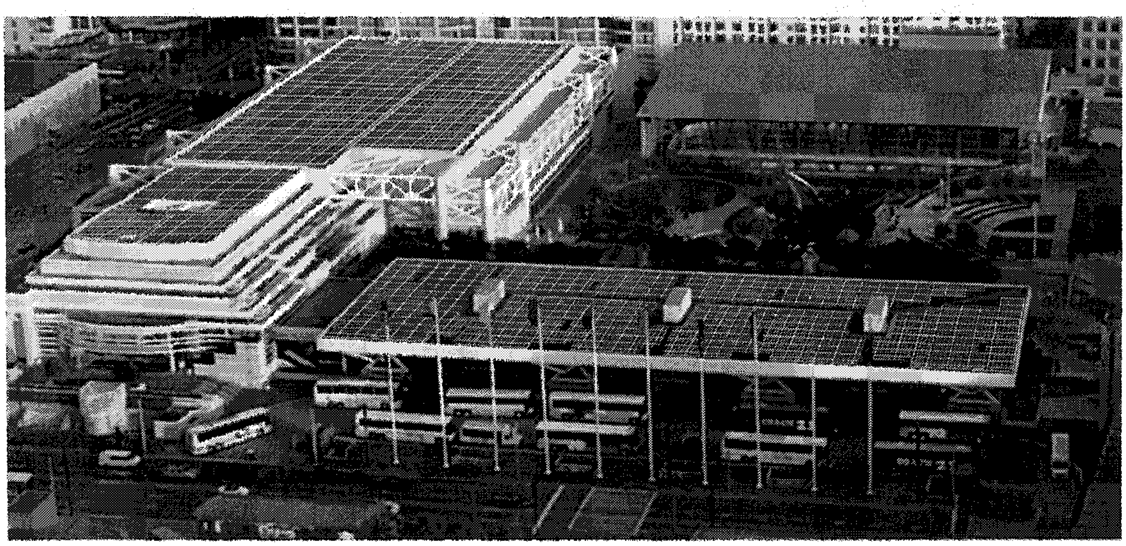


50.4 kW PV System at the Wastewater Treatment Plant in Santa Cruz, California

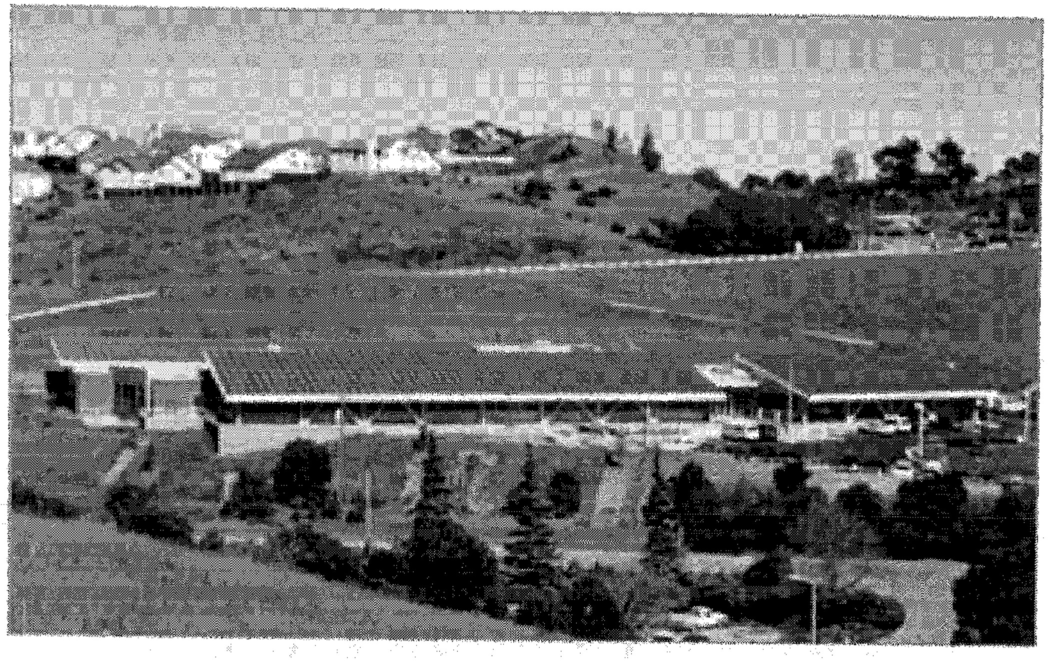


Closeup View of Wastewater Treatment Plant
PV System in Santa Cruz, California

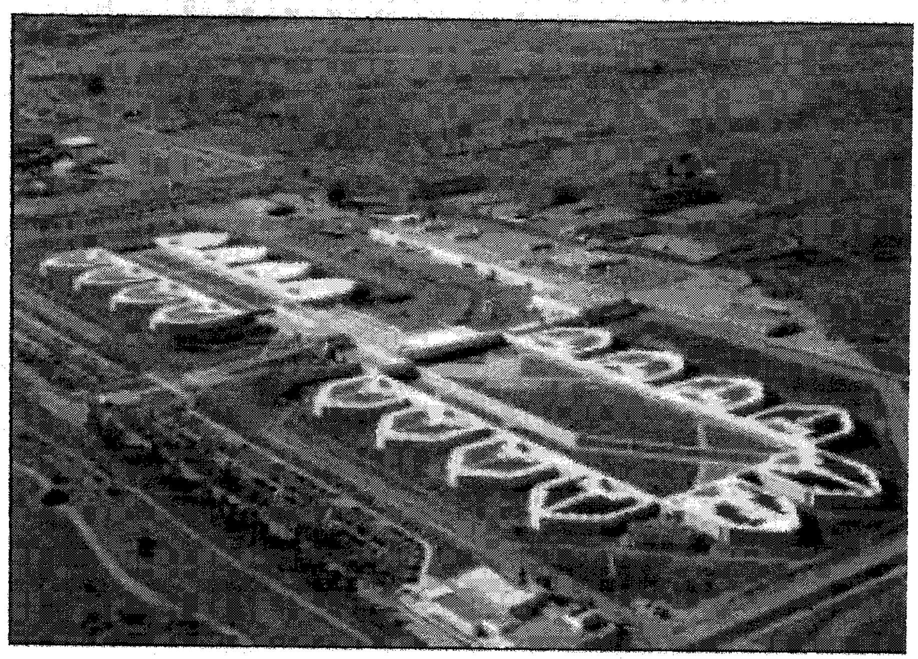
PV System on Roof of Building in the Corporation Yard at Manteca, California



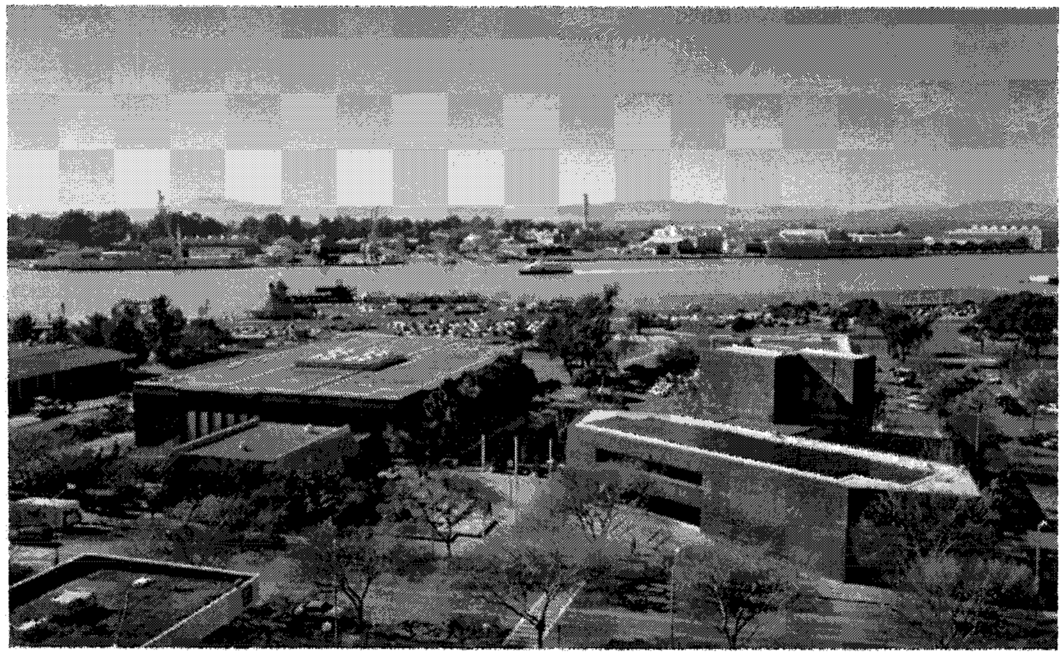
675 kW PV System on Moscone Center in San Francisco, California



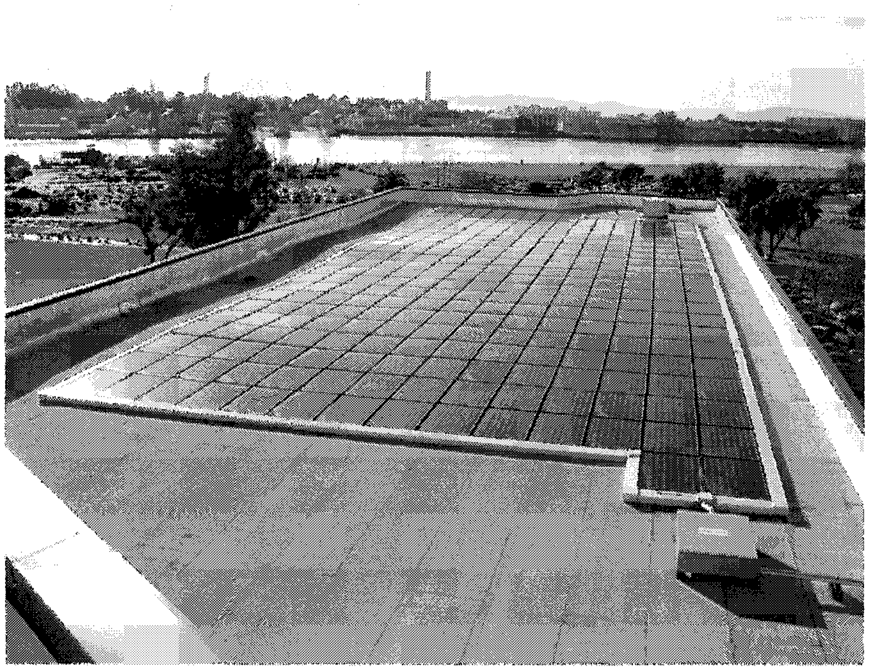
234 kW PV System on Forensics Lab in San Mateo, California



1.18 MW PV System on the Santa Rita Jail in Alameda County, California



PV System on the City Hall and Library in Vallejo, California



Closeup of the PV System on the City Hall in Vallejo, Californi

5.5 kW PV System on Civic Center in Ukiah

18.23 kW PV System on Fire Station in Roseville, California

PV System in Oroville, California

APPENDIX E

PAYBACK OF 11 MUNICIPALITIES

At the end of 25 years, the gain or loss of implementing a PV system at three discount rates and five utility escalation rates for Fresno.

Fresno

6% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$5,684,704	$4,012,439	$2,976,390
Costs	$2,752,023	$2,319,421	$1,991,272
NPV	**$2,932,681**	**$1,693,018**	**$985,118**

5% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$5,037,944	$3,606,012	$2,710,653
Costs	$2,752,023	$2,319,421	$1,991,272
NPV	**$2,285,921**	**$1,286,591**	**$719,381**

4% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$4,480,725	$3,252,644	$2,477,391
Costs	$2,752,023	$2,319,421	$1,991,272
NPV	**$1,728,702**	**$933,223**	**$486,119**

3% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$3,999,894	$2,944,817	$2,272,183
Costs	$2,752,023	$2,319,421	$1,991,272
NPV	**$1,247,871**	**$625,396**	**$280,911**

2% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$3,584,261	$2,676,104	$2,091,236
Costs	$2,752,023	$2,319,421	$1,991,272
NPV	**$832,238**	**$356,683**	**$99,964**

DR = discount rate

At the end of 25 years, the gain or loss of implementing a PV system at three discount rates and five utility escalation rates for Chico.

Chico

	6% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$729,504	$514,906	$381,953
Costs	$511,463	$504,575	$499,793
NPV	**$218,041**	**$10,331**	-$117,840

	5% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$646,506	$462,750	$347,851
Costs	$511,463	$504,575	$499,793
NPV	**$135,043**	-$41,825	-$151,942

	4% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$575,000	$417,404	$317,917
Costs	$511,463	$504,575	$499,793
NPV	**$63,537**	-$87,171	-$181,876

	3% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$513,296	$377,901	$291,583
Costs	$511,463	$504,575	$499,793
NPV	**$1,833**	-$126,674	-$208,210

	2% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$459,959	$343,418	$268,363
Costs	$511,463	$504,575	$499,793
NPV	-$51,504	-$161,157	-$231,430

DR = discount rate

At the end of 25 years, the gain or loss of implementing a PV system at three discount rates and five utility escalation rates for Sebastopol.

Sebastopol

6% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$157,382	$111,085	$82,402
Costs	$93,049	$79,250	$68,818
NPV	**$64,333**	**$31,835**	**$13,584**

5% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$139,477	$99,833	$75,045
Costs	$93,049	$79,250	$68,818
NPV	**$46,428**	**$20,583**	**$6,227**

4% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$124,050	$90,050	$68,587
Costs	$93,049	$79,250	$68,818
NPV	**$31,001**	**$10,800**	-$231

3% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$110,738	$81,528	$62,906
Costs	$93,049	$79,250	$68,818
NPV	**$17,689**	**$2,278**	-$5,912

2% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$99,231	$74,089	$57,896
Costs	$93,049	$79,250	$68,818
NPV	**$6,182**	-$5,161	-$10,922

DR = discount rate

UER = utility escalation rate

At the end of 25 years, the gain or loss of implementing a PV system at three discount rates and five utility escalation rates for Santa Rita Jail in Alameda.

Alameda

	6% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$6,691,546	$4,723,099	$3,503,551
Costs	$3,635,523	$3,630,105	$3,626,344
NPV	**$3,056,023**	**$1,092,994**	-$122,793

	5% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$5,930,235	$4,244,688	$3,190,748
Costs	$3,635,523	$3,630,105	$3,626,344
NPV	**$2,294,712**	**$614,583**	-$435,596

	4% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$5,274,325	$3,828,734	$2,916,172
Costs	$3,635,523	$3,630,105	$3,626,344
NPV	**$1,638,802**	**$198,629**	-$710,172

	3% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$4,708,332	$3,466,385	$2,674,619
Costs	$3,635,523	$3,630,105	$3,626,344
NPV	**$1,072,809**	-$163,720	-$951,725

	2% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$4,219,084	$3,150,080	$2,461,624
Costs	$3,635,523	$3,630,105	$3,626,344
NPV	**$583,561**	-$480,025	-$1,164,720

DR = discount rate

At the end of 25 years, the gain or loss of implementing a PV system at three discount rates and five utility escalation rates for Martinez.

Martinez

	6% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$2,167,070	$1,529,584	$1,134,631
Costs	$1,166,159	$1,125,879	$1,098,495
NPV	**$1,000,911**	**$403,705**	**$36,136**

	5% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$1,920,518	$1,374,650	$1,033,330
Costs	$1,166,159	$1,125,879	$1,098,495
NPV	**$754,359**	**$248,771**	-$65,165

	4% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$1,708,100	$1,239,943	$944,408
Costs	$1,166,159	$1,125,879	$1,098,495
NPV	**$541,941**	**$114,064**	-$154,087

	3% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$1,524,802	$1,122,595	$866,180
Costs	$1,166,159	$1,125,879	$1,098,495
NPV	**$358,643**	-$3,284	-$232,315

	2% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$1,366,358	$1,020,159	$797,201
Costs	$1,166,159	$1,125,879	$1,098,495
NPV	**$200,199**	-$105,720	-$301,294

DR = discount rate

At the end of 25 years, the gain or loss of implementing a PV system at three discount rates and five utility escalation rates for Santa Cruz.

Santa Cruz

6% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$388,952	$274,534	$203,647
Costs	$219,120	$212,247	$207,502
NPV	**$169,832**	**$62,287**	-$3,855

5% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$344,700	$246,726	$185,465
Costs	$219,120	$212,247	$207,502
NPV	**$125,580**	**$34,479**	-$22,037

4% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$306,575	$222,549	$169,505
Costs	$219,120	$212,247	$207,502
NPV	**$87,455**	**$10,302**	-$37,997

3% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$273,676	$201,487	$155,465
Costs	$219,120	$212,247	$207,502
NPV	**$54,556**	-$10,760	-$52,037

2% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$245,238	$183,101	$143,084
Costs	$219,120	$212,247	$207,502
NPV	**$26,118**	-$29,146	-$64,418

DR = discount rate

At the end of 25 years, the gain or loss of implementing a PV system at three discount rates and five utility escalation rates for Manteca.

Manteca

6% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$53,444	$37,722	$27,982
Costs	$30,335	$29,251	$28,499
NPV	**$23,109**	**$8,471**	-$517

5% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$47,364	$33,901	$25,484
Costs	$30,335	$29,251	$28,499
NPV	**$17,029**	**$4,650**	-$3,015

4% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$42,125	$30,579	$23,291
Costs	$30,335	$29,251	$28,499
NPV	**$11,790**	**$1,328**	-$5,208

3% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$37,605	$27,685	$21,362
Costs	$30,335	$29,251	$28,499
NPV	**$7,270**	-$1,566	-$7,137

2% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$33,697	$25,159	$19,661
Costs	$30,335	$29,251	$28,499
NPV	**$3,362**	-$4,092	-$8,838

DR = discount rate

At the end of 25 years, the gain or loss of implementing a PV system at three discount rates and five utility escalation rates for Air Pollution Control District in San Luis Obispo.

San Luis Obispo

	6% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$153,798	$108,556	$80,526
Costs	$94,998	$94,276	$93,775
NPV	**$58,800**	**$14,280**	-$13,249

	5% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$136,300	$97,560	$73,336
Costs	$94,998	$94,276	$93,775
NPV	**$41,302**	**$3,284**	-$20,439

	4% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$121,225	$88,000	$67,025
Costs	$94,998	$94,276	$93,775
NPV	**$26,227**	-$6,276	-$26,750

	3% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$108,216	$79,671	$61,473
Costs	$94,998	$94,276	$93,775
NPV	**$13,218**	-$14,605	-$32,302

	2% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$96,971	$72,401	$56,578
Costs	$94,998	$94,276	$93,775
NPV	**$1,973**	-$21,875	-$37,197

DR = discount rate

At the end of 25 years, the gain or loss of implementing a PV system at three discount rates and five utility escalation rates for Oroville.

Oroville

	6% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$1,213,513	$856,535	$635,370
Costs	$991,907	$971,501	$957,333
NPV	**$221,606**	-$114,966	-$321,963

	5% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$1,075,450	$769,775	$578,643
Costs	$991,907	$971,501	$957,333
NPV	**$83,543**	-$201,726	-$378,690

	4% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$956,500	$694,342	$528,848
Costs	$991,907	$971,501	$957,333
NPV	-$35,407	-$277,159	-$428,485

	3% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$853,857	$628,630	$485,043
Costs	$991,907	$971,501	$957,333
NPV	-$138,050	-$342,871	-$472,290

	2% Utility Escalation Rate		
	4% DR	7% DR	10% DR
savings	$765,132	$571,268	$446,416
Costs	$991,907	$971,501	$957,333
NPV	-$226,775	-$400,233	-$510,917

DR = discount rate

At the end of 25 years, the gain or loss of implementing a PV system at three discount rates and five utility escalation rates for the Santa Clara Valley Water District (SCVWD) in San Jose.

SCVWD

6% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$1,604,559	$1,132,547	$840,113
Costs	$1,330,769	$1,327,103	$1,323,636
NPV	**$273,790**	-$194,556	-$483,523

5% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$1,422,005	$1,017,829	$765,106
Costs	$1,330,769	$1,327,103	$1,323,636
NPV	**$91,236**	-$309,274	-$558,530

4% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$1,264,725	$918,088	$699,266
Costs	$1,330,769	$1,327,103	$1,323,636
NPV	-$66,044	-$409,015	-$624,370

3% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$1,129,006	$831,201	$641,344
Costs	$1,330,769	$1,327,103	$1,323,636
NPV	-$201,763	-$495,902	-$682,292

2% Utility Escalation Rate

	4% DR	7% DR	10% DR
Savings	$1,011,690	$755,355	$590,270
Costs	$1,330,769	$1,327,103	$1,323,636
NPV	-$319,079	-$571,748	-$733,366

DR = discount rate

At the end of 25 years, the gain or loss of implementing a PV system at three discount rates and five utility escalation rates for Livermore.

Livermore

	6% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$599,715	$423,298	$313,998
Costs	$842,484	$835,260	$830,245
NPV	-$242,769	-$411,962	-$516,247
	5% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$531,485	$380,421	$285,964
Costs	$842,484	$835,260	$830,245
NPV	-$310,999	-$454,839	-$544,281
	4% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$472,700	$343,142	$261,356
Costs	$842,484	$835,260	$830,245
NPV	-$369,784	-$492,118	-$568,889
	3% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$421,974	$310,667	$239,707
Costs	$842,484	$835,260	$830,245
NPV	-$420,510	-$524,593	-$590,538
	2% Utility Escalation Rate		
	4% DR	7% DR	10% DR
Savings	$378,126	$282,319	$220,618
Costs	$842,484	$835,260	$830,245
NPV	-$464,358	-$552,941	-$609,627

DR = discount rate