SUNRISE FOR SOLAR: THE ADOPTION OF GRID-CONNECTED RESIDENTIAL PHOTOVOLTAIC ENERGY ON THE ISLAND OF O‘AHU

BY

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THESIS

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ABSTRACT

The steadily decreasing cost of photovoltaic (PV) energy, coupled with fossil fuel's implication in global climate change, position PV as an energy innovation that could challenge the dominant electricity generation paradigm. This study sought to answer the questions of who is adopting PV and why and how they are making the adoption decision. The diffusion of innovations research tradition was used to examine the adoption of residential grid-tied PV in Hawai'i, where high electricity rates, abundant sunshine, and high dependence on fossil fuel make PV an increasingly attractive alternative electricity source.

A sample of O'ahu households who recently purchased a solar water heater (N = 245) was surveyed to collect data on characteristics, motivations, and PV purchase desire and intent. Twelve hypotheses were formulated, 10 of which were accepted based on statistical analysis. Residential PV adoption interest and intent were shown to be most strongly correlated with the beliefs that PV will be financially beneficial and that PV is the "right thing to do" for the environment. It was also found that PV adoption desire and intent were significantly correlated with the level of PV knowledge, pro-environmental beliefs, participation in pro-environmental behaviors, the desire for self-sufficiency, a lower internal discount rate, the perceived increase in future electricity cost, and the beliefs that individual actions are effective and that a moral obligation exists to protect the environment. No correlation was found between PV adoption interest and level of income or education level of the potential adopter, nor was a correlation found between direct experience with residential PV and adoption interest or intent.

A decision path model was formulated that explained 36% of the variance in residential photovoltaic adoption interest, with the latent constructs for environmental motivation and persuasion showing the strongest overall effect on adoption interest. The rate of residential PV adoption is estimated based on respondents' willingness to pay for PV and projected trends in PV and conventional electricity cost. Based on data from this sample, a rapid acceleration in the adoption of residential PV is anticipated to occur within the next decade, although significant barriers to its widespread diffusion remain. This study concludes by offering strategies for expanding adoption of residential PV and discussing PV's potential as a "disruptive technology."

To Dad, who has always inspired me

ACKNOWLEDGMENTS

I owe an enormous debt of gratitude to Professor Raymond Price for providing me the opportunity to conduct this research and having the patience to shepherd this project through to completion. I am also grateful for the mentoring and guidance provided by Professor Pete DeLisle, as well as my graduate school adviser Professor Deborah Thurston. I extend a warm *mahalo* to all those who helped make this thesis a reality, including Jon Abbott, Randy Ching, Keith Cronin, Donna Eiskamp, Cully Judd and Inter-Island Solar Supply, Chuck Giuli, Michael Hamnett, Lea Hong, Nicole Love, Steve Tearney, Louis Valenta, and Rebecca Ward. Finally, I wish to thank my family and all my friends for their support and their good humor when I tried to convince them—after all of these years—that I was really almost *pau*.

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CHAPTER 1
INTRODUCTION

Harnessing energy directly from the sun has long been sought to meet humankind's energy needs. From lining the aqueducts that fed water to Roman baths with black granite to capture the sun's warmth to the high-tech silicon panels powering the International Space Station, the tools have evolved but the goal has remained the same: how to utilize the sun's constant supply of free energy. Edison Pettit of the Wilson Observatory noted in 1932, "Sooner or later we shall have to go directly to the sun for our major supply of power. The problem of the direct conversion of sunlight into power will occupy more and more of our attention as time goes on, for eventually it must be solved."

The problem has been solved, in part. Today, with energy demands growing and mounting pressures—both climatic and political—to decrease fossil fuel use, converting the sun's energy directly into electricity is increasingly sought as a source of power. The solar electric, or photovoltaic (PV), industry is rapidly expanding, with certain PV applications, such as spacecraft power, small electronic uses, and remote communication applications fully established. Annual global photovoltaic installations grew by 35% in 2006 (Maycock, 2007).

PV meets many of the attributes sought in an ideal energy source. It is easily scalable and capable of producing power on-site. PV creates electricity silently using solid-state devices with no moving parts, little maintenance, and with minimal pollution. The technology is extremely versatile, with applications ranging from water-pumping in developing countries to remote communications devices to central station power generation. New technologies are enabling PV to be integrated directly into the architectural materials in buildings. These building-integrated photovoltaics blend with existing building materials, helping to break down the aesthetic and design barriers to using PV.

No longer is PV power relegated to the role of a toy for hobbyists or an expensive power application for NASA spacecraft. With decreasing costs and new policy incentives, grid-tied residential and commercial PV systems—as opposed to consumer electronics or off-grid, remote applications—make up the largest and fastest growing components of the PV industry. Such grid-tied systems show promise as a technology to significantly alter the way electricity is generated and distributed.

Global pressures are also pushing utilities, energy companies, and governments toward renewable energies, including PV. The Kyoto Protocol on Climate Change has been ratified by 175 countries, including the United States' biggest trading partner, Canada, and its closest ally, Britain (United Nations Framework Convention on Climate Change, 2005). The Protocol calls for a decrease in carbon dioxide emissions of 7.5% from 1990 levels for developed countries by 2012. Political instability in oil-rich regions and concerns over diminishing supplies of accessible oil are also pressuring a change in energy source. Moreover, the United States is pursuing energy independence as a national goal.

Since PV was first used for residential power nearly three decades ago, enthusiasm for its widespread adoption has outpaced actual adoption. As an energy consultant in San Francisco explains, "solar energy has been just around the corner for about 30 years," and then adds the running joke in the industry: "and it's still just around the corner" (Abate, 2004).

When will that corner be turned? The U.S. Photovoltaic Industry Roadmap, a forecasting document compiled in partnership with the U.S. Department of Energy, claims that PV will supply 15% of new added electricity capacity in 2020, and 10% of U.S. peak generation capacity by 2030 — the energy equivalent of some 180 million barrels of oil in that year (U.S. Department of Energy, 2001). But in 2006, solar power generated less than one-half of one percent of the electricity in the United States (U.S. Energy Information Administration, 2006).

What will it take for widespread adoption of PV power? Who is adopting residential grid-tied PV (GPV) and how do they differ from non-adopters? What factors drive the adoption decision process for GPV? How will technology change, and conventional energy cost affect the rate of GPV adoption? How might the rate of GPV adoption be accelerated?

To address these questions—and to get a better feel of when "the corner" might be turned for PV—this study examines the adoption of residential GPV on the island of O'ahu, Hawai'i. Hawai'i provides a compelling case study in GPV adoption for a number of reasons. Hawai'i pays the highest price in the United States for residential electricity and enjoys the most consistent solar insolation. Hawai'i is also the most dependent state in the nation on imported petroleum. Finally, Hawai'i has adopted public policies supporting the adoption of GPV. As some of Hawai‘i's PV advocates are inclined to say, "if it can't work here, where can it work?"

This study begins (Chapter 2) with a brief overview and history of photovoltaic energy. Then the basic components of residential GPV, their costs, and technology trends are described. After discussing Hawai‘i's current public policy incentives for GPV, a sample economic analysis of a residential GPV system is examined. The cost trends of PV are then described and compared with the cost trends of conventional grid electricity rates.

Chapter 3 contains a literature review of the diffusion of innovation research tradition. Theoretical concepts regarding consumer response to new technology and key elements in sociological and psychological perspectives on adoption behavior are explored. To better understand the role of environmental interest in the GPV decision, relevant literature regarding consumer environmental motivations is investigated. Consumer willingness to pay for renewable energy and energy efficiency is then discussed. Research regarding PV adoption in other parts of the United States and solar energy adoption in Hawai‘i is also examined. Twelve hypotheses seeking to explain the factors which influence the adoption of GPV and a path model of the adoption decision process are then formulated.

Chapter 4 discusses the research methodology, qualitative data approach, and survey instrument and provides the overall results from survey data collected from potential GPV adopters.

Chapter 5 contains the statistical analysis of the data collected and applies the results in confirming or rejecting the twelve GPV adoption hypotheses. The findings are interpreted and a discussion of their relevancy in the adoption decision is provided. A factor analysis and development of latent constructs enables the testing of the adoption decision path model. Qualitative data gathered is also included in the analysis.

Chapter 6 ties together the study's findings and results in estimating both the rate of GPV adoption and potential ways to accelerate its adoption. The potential of GPV as a disruptive technology is discussed. Limitations of the study are offered. The study concludes with implications of the research on both diffusion of innovations literature and GPV industry expansion.

CHAPTER 2
TECHNOLOGY REVIEW AND TRENDS

Background of Photovoltaic Electricity[1]

Defined broadly, photovoltaic energy relates "to the production of current at the junction of two substances exposed to light" (Oxford Dictionary). Like many inventions, the electric current-inducing effect of the sun on certain materials was discovered by accident. Edmond Becquerel, a French experimental physicist, found that two different brass plates immersed in a liquid produce a continuous current when exposed to sunlight. In the early 1870s, English engineer Willoughby Smith was working with selenium in his research to find a material of high electrical resistance for use in undersea cable testing. When results of the tests varied from those of other researchers, Smith realized that the amount of resistance in selenium varied with the amount of light falling on the material. He tested the phenomenon by placing selenium in a box with a sliding cover and found that the material's resistivity dropped proportionally to the intensity of light falling on it. Two English investigators, W.G. Adams and R.E Day continued the research and subjected selenium to many experiments, discovering that the material's resistivity not only varied, but the selenium could produce a current when exposed to light. American inventor C.E. Fritts followed this work and created the first solar battery using selenium with a gold-leaf film covering. He sent a model to Werner Siemens, a German inventor and industrialist, who replicated the work. Siemens declared, "presented to us, for the first time, the direct conversion of energy of light into electrical energy…which is scientifically of the most far reaching importance." (Siemens Solar grew to be one of the largest PV manufacturers globally until they were purchased by Shell in 2002.)

Einstein's work in the early 1900s on quantum mechanics and the photoelectric effect provided the theoretical foundation to the phenomenon. Experimentation on the batteries continued but the technology did not improve beyond 1% efficiency—that is, converting 1% of the light energy falling on the cells into electricity. It wasn't until 1954 when a material to realize practical solar electric power was discovered. Researchers at Bell Labs, Calvin Fuller and Gerald Pearson, were developing rectifiers by adding impurities to silicon. They found the same problems that Smith did in the 1870s in

[1] This background discussion is paraphrased from Perlin (1999).

replicating the performance of some experiments, realizing later that the performance of silicon varied with the amount of light falling on it. When tested in full sunlight, their silicon rectifier converted 4% of incoming light into electricity—five times greater than the efficiency found with selenium[2].

Applications for the new cell, such as providing power to isolated repeater stations to amplify messages on long-distance lines, began to look practical. Bell continued work on the cell and improved its efficiency to 6% and unveiled it to the public in April 1954 at the National Academy of Science in Washington, D.C. where they demonstrated its application in a radio and toy Ferris wheel. Writing about the event, the headline of the front page of the *New York Times* on April 26th, 1954 declared, "Vast Power of the Sun is Tapped by Battery Using Sand Ingredient." The article reported that the silicon battery "may mark the beginning of a new era, leading eventually to the realization of one of mankind's most cherished dreams—harnessing the almost limitless energy of the sun for the uses of civilization."

A PV cell works by creating a built-in potential between two materials, one with a capacity to accept free electrons (p-type semiconductor) and one with extra electrons (n-type semiconductor). Photons from sunlight falling on the solar cell excite the free electrons and enable them to move from the n-type material to the p-type material. Single crystal silicon is the most common material used because of the availability of "delocalized" electrons that are not tied directly to any one atom, but to the crystal as a whole. A typical PV cell has a n-on-p junction, with the n-type material consisting of silicon "doped" with phosphorous and the p-type material consisting of silicon doped with boron. Other materials and junctions can be used, but the semiconducting cell must have two components that: 1) create a barrier to the flow of carriers from one material to the other but not vice-versa; and 2) create a built-in electron potential between the two materials. (Komp, 2001.)

Metal contacts, usually aluminum, are attached to the materials on the front and the back of the cell. Typically the metal contacts on the front of the cell are thin and spaced to maximize the surface area exposed to incoming light. The top of the cell is coated with a thin anti-reflective coating. Figure 2.1 presents an idealized cross-section of a silicon PV cell.

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[2] The original 1953 Bell Labs' "Solar Battery" continued to produce electricity for over 45 years (Perlin, 1999).

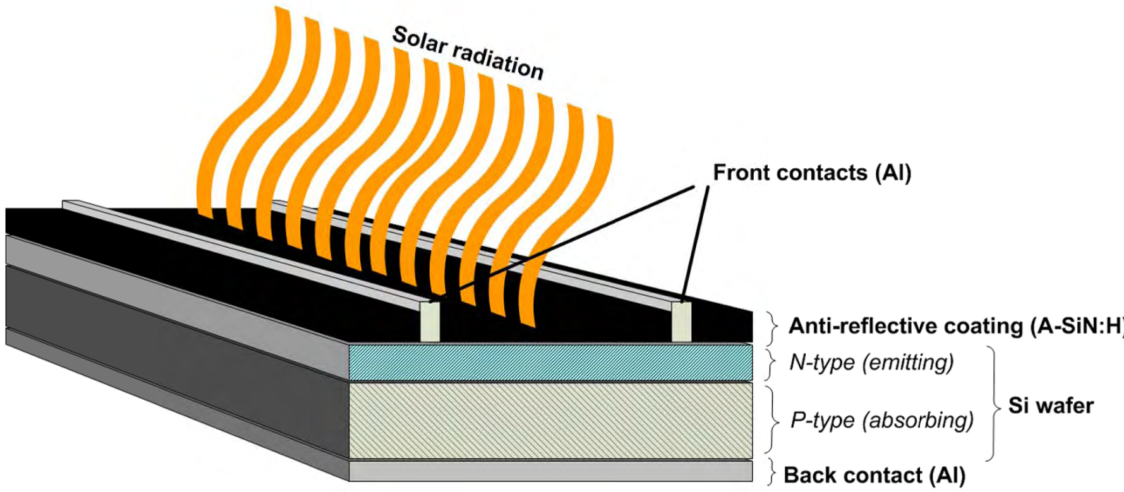

Figure 2.1 Idealized cross-section of silicon PV cell

The first practical application of PV cells was as a power source for a telephone relay system in rural Georgia in the 1950s. But high expectations for the new cells were attenuated by high PV cell prices, and the potential applications, such as Coast Guard buoys and national forest look-out towers, were not quickly developed. The silicon PV cell was saved by the incipient space race in the late 1950s. Satellites needed long-term, autonomous power systems that were compact and lightweight. The silicon cell met the requirements perfectly. All of America's satellites, from Vanguard to the current International Space Station, are powered by PV solar cells (Perlin, 1999).

Terrestrial applications for silicon cells were spun off of the solar cell industry created by the space program. Beyond mere novelty, solar cells became cost effective as replacements to batteries in calculators and other small devices that draw little current. The market for residential power—particularly off-grid cabins or homes—grew as cell and module prices fell, but installed solar capacity for these applications remained at a fraction of a percent of all electricity use (Maycock, 2004). The relatively high capital investment cost of PV has kept adoption low for grid-tied applications.

Current technological progress in PV is measured not only by the decrease in cost of PV cells, but also in cell efficiency. Cell efficiency—the ratio of useable electrical power provided by the cell to the amount of solar insolation falling on the cell—vary with material and junction type. While the ratio of solar entropy to energy flux limits efficiency to 93% for conversion of the direct component of sunlight, the distribution of sunlight through the atmosphere limits efficiency to a maximum of 74% (Green, 2004). But most cell materials in use now have efficiencies in the 10% to 15% range (Maycock, 2004). The reason for the relatively low efficiency lies with the quantum nature of the conversion process within the cell material. First, an incoming photon must overcome the band gap threshold in the cell in order to stimulate an electron to move. Second, that photon is at best swapped with one electron and the useful energy for that electron is only as great as the voltage across the cell. The best possible efficiency is roughly 30% for the sun's energy on Earth's surface (Green, 2004).

By the end of 2005, 3697 megawatts (MW) of PV energy was installed globally (International Energy Agency Photovoltaics Power Systems Programme, 2006). Residential and commercial grid-tied PV energy is overwhelmingly the largest sector, representing over 3000 MW of installed PV energy. Grid-tied PV (GPV) bypassed communications and signaling equipment and consumer products as the biggest PV market in the late 1990s (Maycock, 2004). The world PV market by application area for the years 1996 to 2006 is shown in Figure 2.2.

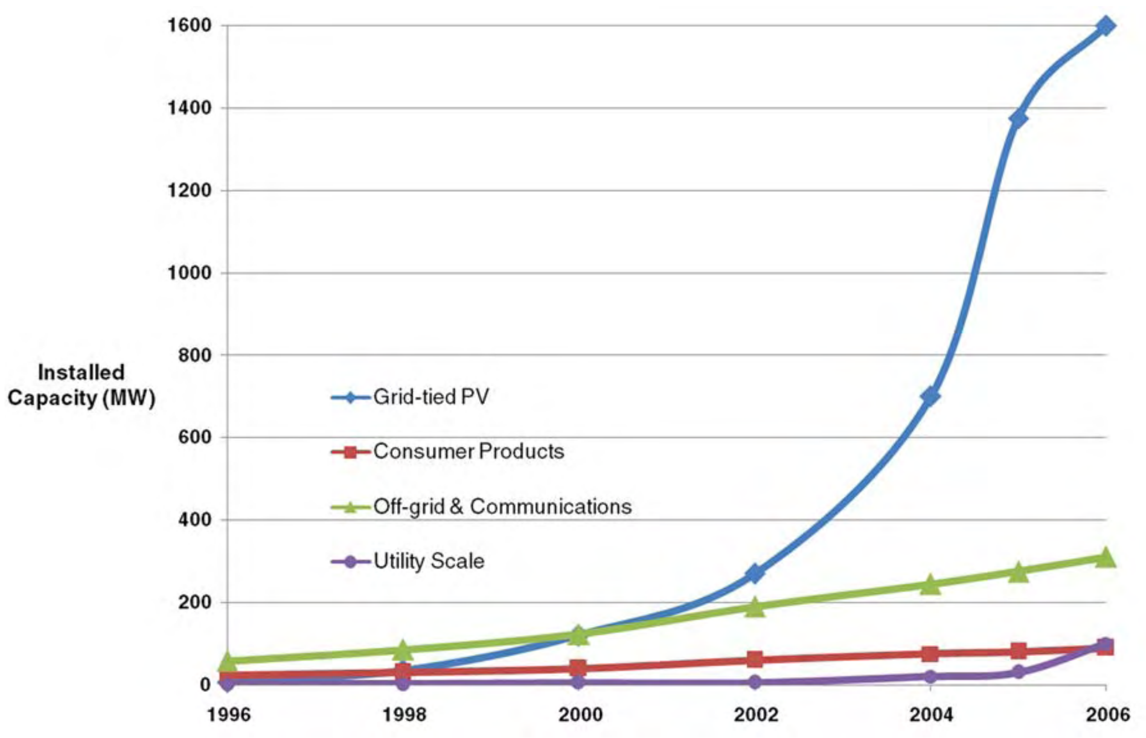

Figure 2.2 Installed PV capacity by application type (Maycock, 2007)

While 25 years passed before the first 1000 MW of PV energy was installed, it only took three years to double installations to 2000 MW (Lugue and Hegedus, 2003). In

2006, the biggest market for GPV was Germany, with 1050 MW installed (Maycock, 2007). Japan followed, with 350 MW installed (Maycock, 2007). In the United States, 141 MW of PV were installed in 2006, with California representing approximately 50% of this market (Maycock, 2007). By 2007, PV represented roughly a $6 billion industry globally (Selko, 2007).

Photovoltaic Technologies and Costs

Residential GPV applications typically consist of the following components: solar cells wired together within modules, an inverter to convert the direct current from the modules to alternating current, a device to quickly cut-off outgoing current should the power grid fail, and associated wiring and racks. A large, 4 kW GPV installation in Kaneohe, O‘ahu, Hawai‘i, is shown in Figure 2.3. In GPV applications, the most expensive single component is the cell modules, comprising approximately 55% of the installed cost (L. Valenta of Interisland Solar Supply, personal interview, September 20, 2004). The following section discusses the materials and trends in the PV cell modules.

Figure 2.3 A 4 kW GPV system in Kaneohe, O‘ahu, Hawai‘i

Cell and Module Technologies[3]

Silicon is the principle material used for cell manufacture. In 2000, about 3000 metric tons of silicon—about 10% of all semiconductor-grade silicon produced—was used to manufacture 230 megawatts (MW) of thick crystal silicon PV modules (Maycock, 2004). Most PV producers use "solar grade" silicon, which is off-spec semiconductor grade material or scrap from semiconductor manufacturers. The scrap is normally $4 to $7 per kilogram, as opposed to $60 per kilogram for semiconductor grade (Maycock, 2004). The cost of silicon is usually the driving factor behind the cost of crystalline PV cells. In general, cells are categorized as either crystalline (sliced from ingots, castings, or grown ribbons) or thin-film (deposited in thin layers on a low-cost backing).

Crystalline cells

Crystalline cells, considered "first generation" PV technology, are the most common, most reliable, and currently boast the highest manufactured efficiencies of PV materials. Single and polycrystalline cells make up nearly 85% of the global PV cell and module production in 2006 (Maycock, 2007). A typical silicon cell generates a maximum useful voltage of approximately 0.5 volt and current of roughly one ampere in full sun. To obtain more useful voltage and current, individual solar cells are wired together in series and parallel in weather-resistant modules of tempered glass, ethyl-vinyl acetate, and a back cover. A typical solar module will have 33 cells in series, producing an open-circuit voltage in bright sunlight of about 20 volts, or 16 volts when producing its maximum power (at about 12 amperes peak current) (Perlin, 1999).

Single Crystal Silicon. Single crystal silicon cells, the original and standard silicon solar cell material, made up 38% of the total global cell and module production in 2006, with 958 MW produced (Maycock, 2007). Relatively thick (~200 μm) wafers are cut from single crystal silicon ingots are 5 or 8 inches in diameter, a size limited by the thickness of the ingot that can be drawn. The process is identical to that for creating silicon cells for the electronics industry; in fact, some solar cell manufactures use reject cells from semiconductor manufacturers to create their cells. They have a best laboratory efficiency of 24.8% and a manufactured efficiency of 15.3% to 17.5% (the decrease due to defects created during the manufacturing process and imperfect doping of the silicon material). Modules have a manufactured efficiency between 13% and 16%, but actual efficiency

[3] Cell and module technical discussion is paraphrased from Maycock (2004).

depends on the irradiation and incidence of light in its installed use. Factory prices in 2003 for single crystal silicon PV modules are around $3.00 per watt (Maycock, 2004).

It is estimated that overall market share for single crystal silicon cells will stabilize at 30% to 40%. Module efficiency will increase to 20% and profitable module prices may drop to $2 per watt by 2010. The drivers to reduce the cost of single crystal wafers are increasing efficiency with improved doping and other techniques, decreasing slice thickness and cutting loss, increasing yields, switching to thin-films or other forms that don't require slicing, and using larger ingots to reduce material loss (Maycock, 2004).

Polycrystal or Semicrystal Silicon. Since the high quality of single crystal cells needed for semiconducting computer chips ("electronics grade") is not necessary for solar cells, silicon has been cast to create a polycrystal material. The castings are up to one-half cubic meter and are sliced into 4 to 6 inch square wafers. Polycrystal has become the most popular PV cell option, comprising over 46% of the world's PV cell production in 2006, with 1174 MW produced (Maycock, 2007). Due to imperfections in the cast silicon, conversion efficiencies are lower for polycrystal silicon than single crystal. Manufactured polycrystal cell efficiencies are 14% to 16% with module efficiencies of 12% to 14%. Laboratory efficiencies exceed 22%. Manufacturing costs are similar to single crystal, with 2003 factory prices for polycrystal between $2.70 and $3.25 per watt.

Module efficiencies will increase from 15% to 22% by 2010 and profitable prices of $2.00 per Watt are expected in 2010. Costs for polycrystal may be competitive or beat those of single crystal because casting processes use 20% to 40% less silicon per unit area than the "pulled" single crystal ingot. Energy consumption is also 20% that of pulling single crystal and capital costs are 30% less for casting than for single crystal methods. Warranty periods for polycrystal modules are expected to increase from the 20 years offered in 2000 to 25 years in 2010 (Maycock, 2004).

The rapid global increase in PV energy produced a short-term supply shortage in silicon starting in 2004 (Bradford and Flynn, 2006). The shortage of silicon—particularly silicon used in computer chip manufacture—has attenuated the expected price decrease in single crystal and polycrystal PV cells (Maycock, 2007). The shortage is expected to last through 2008 when more processing and manufacturing capacity becomes available (Bradford and Flynn, 2006).

Current modules manufactured from crystalline silicon, are typically warrantied to produce at least 90% their rated output for 10 years and at least 85% rated output for 25 years (L. Valenta, personal interview, September 20, 2004).

Ribbon or Sheet Silicon. As another means to avoid the single crystal pulling method, a ribbon or sheet can be pulled directly from a bath of molten silicon in a continuous operation. The sheet is then cut into rectangular cells. Cell efficiencies are currently 12% to 14% and module prices are between $5 and $6 per Watt (Maycock, 2004).

Silicon ribbon cells in 2006 occupy only about 2.7% of the market (Maycock, 2007). That is expected to grow slowly as major players in the industry purchase technology processes from smaller firms. Efficiencies are expected to increase to 19%. Again, the cost of silicon may be the driving factor behind future costs. New processes, such as the dendritic web, may enable ribbons of 0.008 inch thickness, greatly reducing the amount of silicon needed for manufacture. Prices may come down to $2.00 per Watt in 2010, with warranties of 20 years (Maycock, 2004).

Amorphous silicon films

Amorphous silicon (a-Si) PV films, considered "second generation" PV technology, are created by depositing very thin layers (less than 1 micron) of non-crystalline silicon (amorphous) on a glass, metal, or plastic substrate. This process creates "cells" with areas ranging from one square centimeter to one square meter. First generation a-Si utilized a single junction of material to create the built-in potential. Second generation cells have double or triple junctions—multiple materials to capture different wavelength energies.

Amorphous silicon films have many advantages over crystalline cells. They cost significantly less, with 2003 factory prices for modules between $2.00 and $3.00 per watt. The films also use only 1/50 to 1/100 of the amount of silicon as crystalline cells, making a-Si less susceptible to price fluctuations of raw silicon. Amorphous silicon films are also extremely versatile, as they can be integrated into a variety of building materials or used as a glazing on windows. But due to differences in band-gap energies compared with crystalline cells, a-Si films have lower efficiencies. Amorphous silicon films also suffer from—for unknown reasons—a lack of stability. Amorphous silicon films have a "break in" period where the PV efficiency drops 10% to 15% over the first few days of sunlight exposure to a stable 5% to 7% efficiency.

Although a-Si only made up 4% of the 2006 world cell and module production with roughly 98 MW produced, thin-films may become the most popular cell material in the next decade (Maycock, 2007). Process technology for the manufacture of amorphous silicon has developed dramatically in the past few years, and research is being conducted to increase the stability of a-Si (U.S. DOE, 2003). Field experience shows that thin-films can have a 20-year stability after the initial degradation period. By 2010, it is estimated that a-Si films may decrease to $1.25 per watt, have a 12% to 14% efficiency, and come with a 20-year warranty. The lower efficiency of a-Si, however, may make its actual installed costs per watt higher than single or polycrystal modules.

Emerging non-silicon cell materials

While currently only about 3% of the 2006 global PV cell production, non-silicon PV cells have the potential to beat silicon cell efficiencies and price per watt in the long term (Maycock, 2007). Roughly 68 MW of cadmium telluride PV cells were manufactured in 2006 (Maycock, 2007). Pilot projects and experiments have demonstrated cadmium telluride efficiencies up to 17%. It is estimated that current processes can yield cells with 10% efficiency at $3.00 per watt, but by the end of 2008, 13% efficient cells at factory prices less than $1 per watt may be available (Selko, 2007). Thin-film copper indium diselenide has been researched by established PV manufacturers, but only one U.S. firm is manufacturing the cells (5 MW in 2006) (Maycock, 2007). It has been estimated that a 10 MW to 20 MW copper indium diselenide plant could manufacture 12% efficient modules for under $1.00 per watt. Gallium arsenide is theoretically one of the most efficient PV cell materials, with potential cell efficiencies over 25%. Very high material costs make this material unlikely to find uses beyond concentrator systems, if anywhere.

Cost Trends and Experience Curve for PV

As PV module production volume increases, marginal costs decrease as economies of scale become established. Between the years 1975 and 2001, the average cost of a PV module decreased an average of 7.42% annually (Maycock, 2004). Figure 2.4 shows the worldwide trend of PV module cost versus cumulative shipments for the years 1975 to 2001. Again, the rapid global increase in PV energy early in the 2000s resulted in a supply shortage in silicon starting in 2004 (Bradford and Flynn, 2006). The shortage of silicon slowed the anticipated cost decreases of PV modules

(Maycock, 2007), and for a two-year period increased the cost of PV modules (Solarbuzz, 2007). The shortage is expected to last through 2008 when more processing and manufacturing capacity becomes available (Bradford and Flynn, 2006).

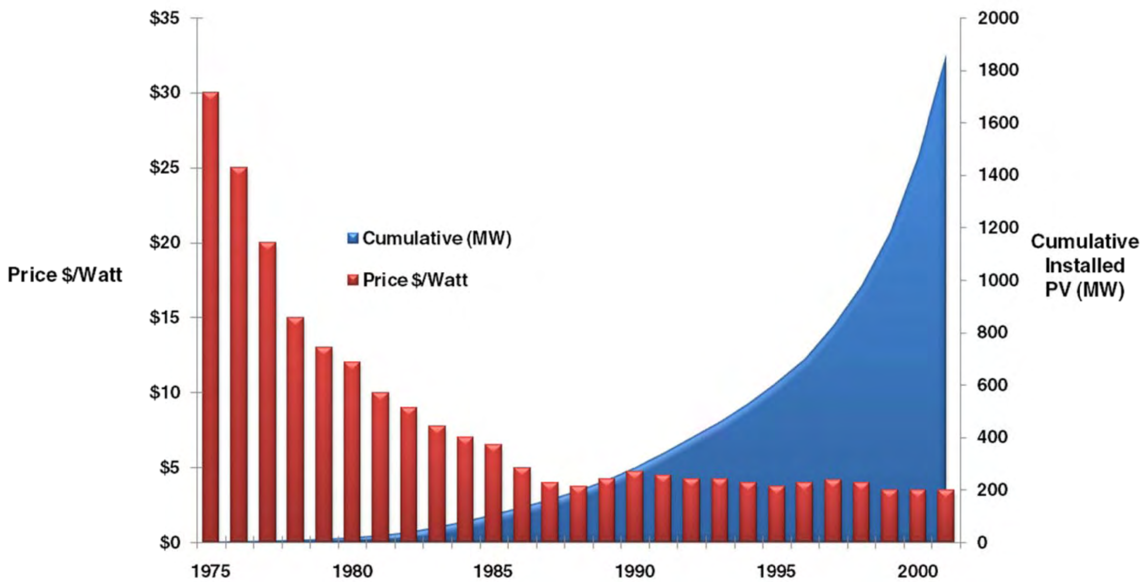

Figure 2.4 World PV cumulative installation and price history, 1975 – 2001 (Maycock, 2002)

The relation of module volume and price can be described by an experience curve, a representation of the cumulative production versus cost typically presented on a log-log plot. The experience curve for PV module production is shown in Figure 2.5, where the lowest price per watt peak for a given year is plotted against the cumulative module production up to that year. The slope indicates the cost reduction for every doubling of cumulative production; for PV module production over the past 30 years this experience factor is 0.19 (Parente, et al., 2002). Thus, prices have fallen 19% for every doubling of cumulative production (the "progress ratio," or percent of the previous price with a doubling of production—81% in this case—is sometimes used). If the trend continues, the price of $1 per watt will be reached when the cumulative production reaches 100 GW (Luque and Hegedus, 2003).

Balance of System Components

The remaining "balance of system" components in a GPV system are the inverter, system disconnect device, racks, wiring, and miscellaneous parts. The most significant component is the inverter, an electronic device which converts the direct current output of the solar cells to single-phase, 120-volt, 60 Hertz alternating current (common household electricity). Grid connected inverters must meet specific power quality requirements and—to protect the utility line workers—have emergency cut-off features should power fail on the utility grid. The current cost of an inverter for a typical GPV system is between $1 to $1.25 per installed watt, or approximately $2365 for a typical 2.4 kW AC system[4] (L. Valenta, personal communication, May 14, 2007). The inverter is typically oversized to allow for expansion. While the inverter cost has remained fairly constant, their efficiency (currently 90% to 95% conversion) and quality of signal they produce has increased (Luque and Hegedus, 2003; Mangelsdorf, 2001). Inverter cost is sensitive to volume, as the Sacramento Municipal Utility District found in their purchase of 700 inverters manufactured by Trace Engineering at $0.50 per watt in 2002 (Maycock, 2004). Of the entire GPV system, inverters typically have the shortest warranty of about 5 years. A GPV system owner usually needs to replace an inverter once over a 25-year life of the GPV system.

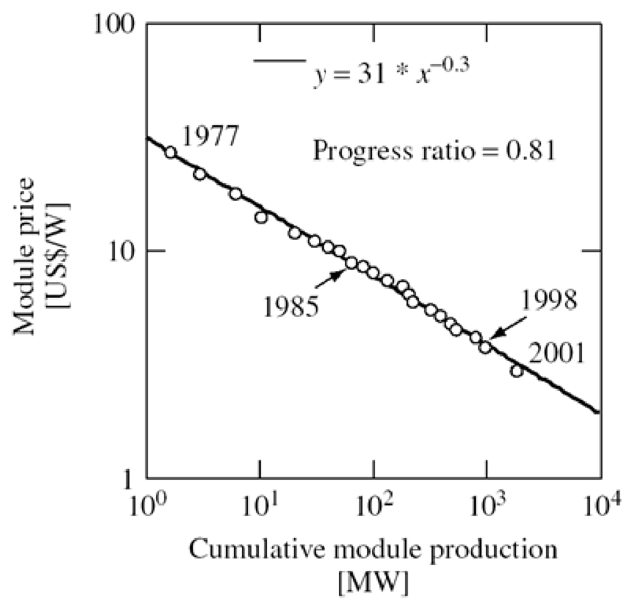

Figure 2.5 Experience curve for PV modules from 1976 to 2001 (Parente, et al., 2002)

[4] System size will henceforth be described as actual peak AC wattage delivered from an installed system after accounting for inverter and system losses (unless stated otherwise). The 2.4 kW peak AC is for a system with a manufacturer-rated size of 3.15 kW peak DC system. This is a conservative value; the same system would have a value of roughly 2.7 kW AC by the California Energy Commission.

The remaining costs—racks, wiring, and accessories—are fairly constant; such components cost roughly $0.60 per installed peak watt. Labor costs for installation, in Hawai‘i, are approximately $60 per hour, resulting in a cost of $1 per installed peak watt (L. Valenta, personal interview, September 20, 2004). Module markups from wholesale to retail are between 35% and 40% (DC Power Systems, 2007). Distributor, dealer, and contractor markups are approximately 20% to 30% of the total turnkey cost for a GPV system in Hawai‘i (L. Valenta, personal communication, May 14, 2007).

Installed GPV System Costs and Trends

A GPV system offered by a dealer on O‘ahu in May, 2007, is used to calculate an estimated turnkey cost for a typical 2007 GPV system. The GPV system is a 2.4 kW peak AC with an installed turnkey cost of roughly $27,180 (L. Valenta, personal communication, May 14, 2007). The 18 175-Watt modules for this system cost approximately $14,815 ($4.70 per manufacturer’s rated peak watt, or roughly $6.17 per watt for actual peak AC), $2365 for the grid-tied inverter, $1090 for racks, wiring, accessories, and miscellaneous materials, and $4000 for labor (installation) costs. Hawai‘i costs, on average, include at least a 5% premium for shipping over mainland prices (L. Valenta, personal interview, September 20, 2004; J. Abbott, personal interview, September 9, 2007). Markup for this system quoted by the dealer was approximately $4380. The total turnkey cost for this 2007 O‘ahu GPV system by each of the components is shown in Figure 2.6. Included in Figure 2.6 is the projected turnkey cost of $19,960 for a similar system in 2010 given the future cost estimates for PV modules ($3 per manufacturer’s rated peak watt) and inverters ($0.50 per peak watt). It is estimated that the accessory, labor, profit costs will remain fairly stable, thereby buffering the price improvements in the PV module and inverter technologies.

The 2007 GPV system shown in Figure 2.6 has a cost per installed watt of $8.63 ($27,180/3150 manufacturer peak watts). The forecasted 2010 system would cost roughly $6.34 per installed watt. While PV industry watchers have tracked the actual installed price for GPV in the United States for at least the past decade, such cost trends specifically for Hawai‘i are difficult to ascertain. The main reason for the lack of historical cost data is the recent evolution of GPV in Hawai‘i. Before the passage of net energy metering in 2001—a state policy that allows system owners to effectively “sell-back” electricity at the retail price up to the amount of electricity they purchased over a given year—the majority of PV installations in Hawai‘i were off-grid, battery back-up systems.

Data is available from an analysis of three demonstration GPV systems on O‘ahu in 1982 which found that the average cost per peak watt installed was $18.50 (1980 dollars) (Neill and Curtis, 1982). More recent costs from actual O‘ahu GPV installations between 2001 and 2007 are available (M. Morton, personal phone conversation, October 5, 2003; K. Cronin of Island Energy Solutions, personal interview, October 11, 2004; L. Valenta, personal interview, September 20, 2004; L. Valenta, personal interview, May 14, 2007) and shown in Figure 2.7, as well as the average cost for installed GPV in the United States from 1996 to 2003 (Maycock, 2004)[5].

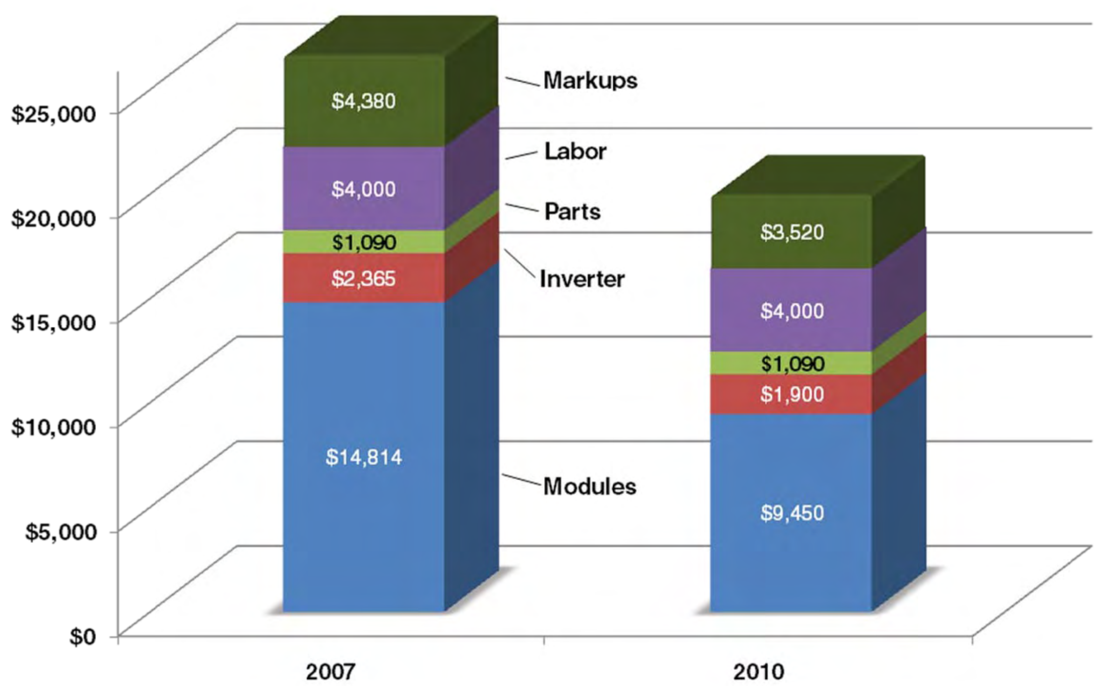

Figure 2.6 Typical component cost breakdown for a Hawai‘i GPV system for 2007 (L. Valenta, personal communication, May 14, 2007) and estimated costs for a 2010 system

Figure 2.7 includes an exponential regression curve fit (R^2 = 0.951) for the United States costs per installed watt. Should the cost trend continue at a similar rate, it is expected that the US cost per installed watt will reach $5.00 by 2012.

Again, while only a few data points are available for analyzing the costs per installed watt for O‘ahu GPV systems, it appears that O‘ahu installed costs are roughly 25% greater than the costs for mainland installed GPV systems. This is likely due to

[5] The figures provided are in real dollars and do not account for inflation (which would make the decrease in price more pronounced). Prices provided later for the historical price of electricity also do not account for inflation, enabling an accurate comparison between the two trends.

shipping, higher labor costs, the smaller size of the GPV market on O‘ahu, as well as the lack of diverse GPV dealer competition. The US trend forecast is fairly congruent with the available O‘ahu data and suggests a 5% annual decrease in the installed cost of GPV on O‘ahu, resulting in a cost of approximately $7.20 per installed watt in 2010 and $6.50 per installed watt in 2012[6]. This is slightly higher than the forecasted $6.34 per installed watt for the 2010 Hawai‘i system shown in Figure 2.6—a forecast based on estimated decreases in module and inverter costs.

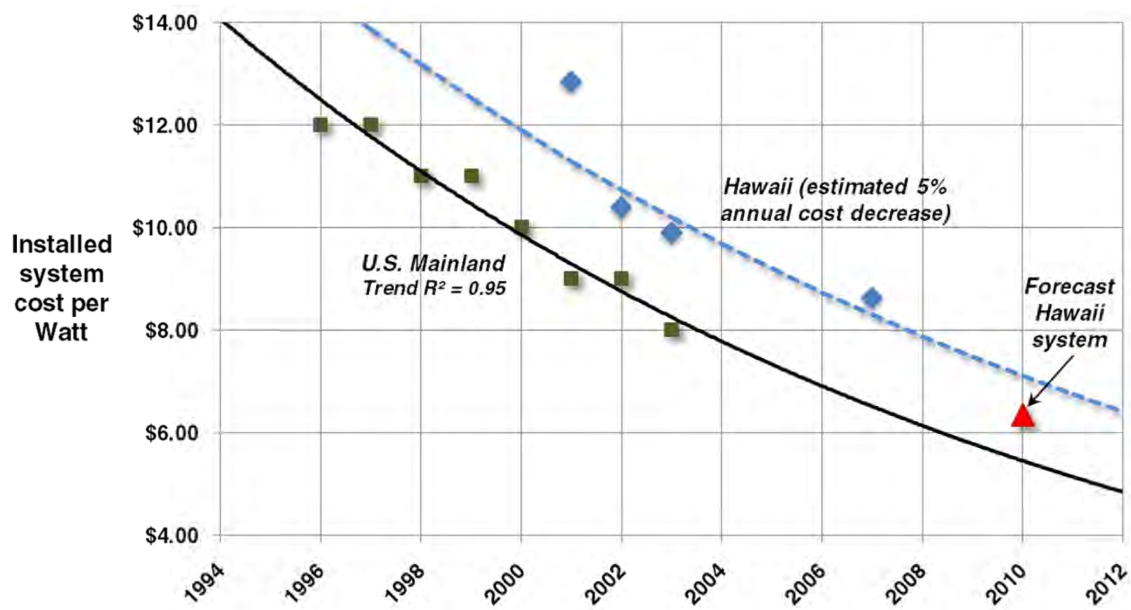

Figure 2.7 Average per installed watt costs for US GPV (1994 – 2003) and installed watt costs for Hawai‘i GPV installations (2001, 2002, 2003 and 2007). Exponential regression curve for US costs shown ($R^2 = 0.951$). The cost trend shown for Hawai‘i GPV installations is estimated at 5% decrease annually. The forecasted cost of a Hawai‘i GPV system in 2010 based on earlier analysis is also shown.

While estimating the actual investment cost for the homeowner per installed watt for a GPV system is important to compare various system choices, it alone does not provide the GPV adopter with a familiar metric to use in analyzing the comparative economic advantage of GPV over conventional grid-supplied electricity. Homeowners typically understand electricity cost in terms of price per kilowatt hour (kWh). But challenges arise when comparing conventional grid electricity, where the price per kWh is largely driven by fuel costs (at least for mature, centralized fossil fuel plants in

[6] Of course, crystal balls can be finicky. A 1983 study of Hawai‘i’s energy future estimated that PV would cost $2 per watt by 2005 (Sathaye and Ruderman, 1983).

Hawai‘i), and GPV, where the cost is driven by the initial equipment investment and the “fuel” is free. The actual cost per kWh of electricity produced by a GPV system depends on the life of the system, whether or not the system was financed and the interest rate, the going rate for electricity, whether or not policies exist to value excess power produced by the system, and other factors. Nonetheless, by using realistic costs and rates that a typical GPV adopter would use and the current GPV system warranty lengths, an estimate of the price per kWh can be developed. It should be understood, however, that embedded in this estimated price are individual investment preferences, personal discount rates, and other values—underlying motivations among GPV adopters which this study hopes to better identify.

Before examining the economics of GPV investment, it is necessary to take a brief look at current policies supporting GPV, as well as the historical trend in the price of residential electricity in Hawai‘i.

Policies Promoting the Use of Photovoltaic Energy

Many states have established economic incentives to facilitate the adoption of GPV electricity. Fifteen states have created “clean energy funds” that will collect over $3 billion combined over the next decade, most through a “systems-benefits charge” or small surcharge on retail electricity rates (Bolinger and Wiser, 2003). At least twelve states apply these clean energy funds to GPV “buy-down” programs, where funds subsidize a portion of the initial cost of GPV equipment (Bolinger and Wiser, 2003).

While Hawai‘i does not have a buy-down program, a state income tax credit has been in place for over a decade. HRS §235-12.5 allows Hawai‘i residents to claim a tax credit against their Hawai‘i state individual net income tax for 35% of the cost of an installed GPV system up to $5000 (Hawai‘i Revised Statutes, 2006). In addition, a Federal tax incentive allows taxpayers to claim an additional 30% of the remaining installed GPV system cost (after the state credit is taken) against their individual Federal income tax up to $2000. The Federal income tax credit is set to expire December 31, 2008, while the State income tax credit has no expiration.

Additionally, Hawai‘i state law allows residential electricity customers to “net meter” their qualified GPV system—effectively “selling” their surplus back to the power grid at the retail rate against the amount of electricity that was purchased (HRS §269-107). For any one-year period, customers can not “sell” more power than they purchased unless they enter into an independent power purchase agreement with the utility; additional electricity beyond the amount purchased simply flows back to the grid at no cost to the utility (HRS §269) (Hawai'i Revised Statutes, 2006). (This differs from the German Renewable Energy Law, which includes a "feed-in" tariff that paid as high as 45 to 62 Eurocents per kilowatt-hour—greater than the going rate for electricity—for GPV electricity (Eckhart, 2004).)

The Hawai'i net energy metering law greatly simplifies calculating the economics of a GPV system by valuing electricity that flows into the home or business at the same rate as electricity that flows out. If a system is sized properly[7], it is accurate to base calculations on the assumption that all GPV electricity is used and valued at the current retail rate for electricity.

Historical Electricity Price Trend in Hawai'i

Hawai'i is currently the most dependent state in the United States on imported oil. In 2006, approximately 92.8% of Hawai'i's electricity was generated from fossil fuel sources (State of Hawai'i, 2007). While the fluctuating nature of prices in the global petroleum market coupled with the uncertainty of recurring rate increases by utilities make prediction of future rates difficult, an examination of the historical price trend of electricity is instructive. Figure 2.8 shows the average price per kWh for residential grid-supplied electricity on O'ahu for the three decades between 1974 and 2006 (State of Hawai'i, 2007). An exponential regression curve fits the electricity rate data with an R^2 of 0.789. Included in Figure 2.8 is the annual world crude oil price in terms of the composite refiner acquisition cost of imported and domestic crude oil (U.S. Energy Information Administration, 2007).

Economic Analysis of a Residential Grid-tied Photovoltaic System

Because the equations used in the investment analysis are rather tedious, an abbreviated financial analysis of a sample GPV system is described here. The following analysis was based on Nofuentes, Aguilera, and Munoz (2002) and Newnan (1991). A complete description of the calculations used for the analysis is provided in Appendix A.

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[7] This assumes that the GPV system does not produce more electricity than the household uses over the annual reporting period—a period that is set through the net metering agreement with the electric utility. Excess electricity "credits" at the end of the annual period are surrendered to the utility. Not surprisingly, this situation encourages GPV adopters to purchase systems just prior to summer so their annual reporting period enables them to exhaust their electricity credits over the winter, when less direct sunlight renders PV less productive.

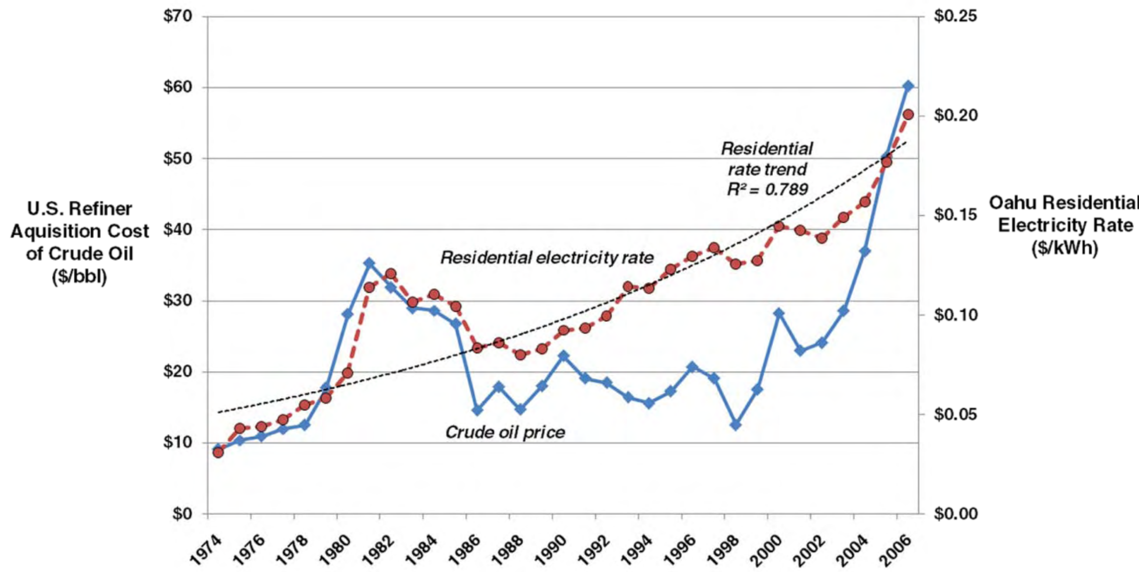

Figure 2.8 Average kWh price for residential grid-supplied electricity on O‘ahu against world crude oil price

Consider a homeowner installing a 2.4 kW actual peak GPV system under the following conditions provided by Hawai‘i solar contractors (M. Mangelsdorf, 2001; L. Valenta, personal interview, September 20, 2004; J. Abbott, personal interview, September 9, 2007; L. Valenta, personal communication, May 14, 2007):

- System life: 20 years
- Initial installed equipment cost: $27,180
- Annual maintenance expense (includes inverter replacement): $100
- Discount rate: 3%
- Inflation rate: 1.5% (Hawai‘i Labor Market Conditions, January 2002)
- Purchase “buy-down” value in income tax credit: $7,000 ($5000 State credit; $2000 Federal credit)[8]
- Loan interest rate: 6% for 20 years
- Price of electricity: $0.22/kWh (O‘ahu price 2007)
- Amount of electricity produced annually: 4818 kWh (average of 5.5 hours of equivalent peak production per day)
- Annual rate of increase in electricity price: 5.1% (O‘ahu average over 30 years)

[8] Although the Federal tax credit for residential solar is set to expire December 31, 2008, this is a mid-range estimate for the “buy-down.” Residential customers are allowed to take the maximum ($5000) State tax credit over multiple tax years, allowing for credits of $10,000 or more if the installation is phased in over a number of years.

Lifecycle cost

The lifecycle cost for the GPV customer is the sum of the initial system cost (accounting for the policy buy-down and the financing of the remainder of the system cost over 20 years) and the present worth of the lifecycle operation and maintenance cost, calculating for inflation. For the example above, the lifecycle cost is $31,993. If the system is not financed, the lifecycle cost is $19,082.[9]

Kilowatt-hour cost

Since residential customers are familiar with electricity in terms of price per kWh, it is useful to convert the lifecycle cost of the GPV system to this metric. The lifetime kWh cost—or "levelized cost"—is derived by dividing the lifecycle cost of the GPV system by the product of its annual yield and the useful life of the system. For the financed 20-year system above (lifecycle cost of $31,993), the levelized cost is $0.33 per kWh. If the same system is purchased in full, without financing, the levelized cost is $0.20 per kWh. This cost is obviously static through the life of the system, as the equipment cost is the primary investment. Should the cost of the identical GPV system equipment decrease to $6.34 per installed watt in 2010 as predicted in Figure 2.7, the financed levelized cost would decrease to $0.22 per kWh ($0.13 per kWh without financing).

Investment Analysis

Alternatively, GPV adopters may simply view PV as an investment and analyze it with relevant investment tools. The first step in doing this is to calculate the cash inflows from a GPV system. Under net energy metering, surplus energy generated by a GPV system is effectively "sold" back to the electric utility at the same price as electricity purchased from the utility. Therefore, the present worth of cash inflows from a GPV system over its life can be calculated using the amount of electricity produced by the system annually and the annual increase in the cost of electricity from the utility grid (assuming that the system has no salvage value at the end of its useful life). The

[9] Throughout the discussions of GPV system cost, a distinction between "fully-financed" and "non-financed" systems will be made because they represent discrete investment choices. For a potential adopter who lacks access to adequate capital to purchase a GPV system out-of-pocket, financing—although more expensive—may move GPV adoption into the realm of possibility. Options to facilitate this investment will be explored in later sections.

estimated cash inflows for the 20-year system as described above, regardless of financing, equal $31,268.

Net Present Value

The net present value (NPV) of an investment project is the sum of present values of all cash inflows and outflows related to the investment. For a GPV system, the NPV equals the present worth of the system cash inflows minus the present value of its investment costs. For the 20-year system described above with financing, the NPV is -$725 (a loss of $725). Without financing the NPV is $12,186. The NPV changes dramatically if it is calculated with a longer GPV system life. For a 25-year system, the NPV is $8283 with financing and $24,309 without financing.

A GPV system is profitable when the NPV is greater than zero. This metric, however, reveals nothing about initial investment requirement or investment length, making it an imperfect descriptor to a potential investor.

Profitability Index

The profitability index of an investment project is defined as the ratio between its NPV and its initial investment cost. A sensible approach for GPV is to define the profitability index as the ratio of the NPV and the lifecycle cost, which includes the initial investment cost and the present worth of the lifetime operation and maintenance costs. For the 2.4 kW, 20-year system described above with financing, the profitability index is -0.02. Without financing, the profitability index is 0.64.

A GPV system is economically profitable, obviously, when the profitability index is greater than zero. By incorporating initial investment cost, the profitability index provides a more informative measurement than NPV alone. It does not, however, provide any indication about investment lifetime.

Payback Time

The payback time of an investment is defined as the length of time for the sum of the present cash flows (inflows minus outflows) to equal zero. This payback time can be calculated through trial-and-error by testing various time periods until the cash inflows equal the lifecycle cost. The payback time for the system described above, with financing through its entire period, is just over 20.5 years, assuming the GPV system continues to function for the entire period. The payback time for the same system without financing is just under 14 years.

A cash-flow chart for the 2.4 kW peak system described above, without financing, is shown in Figure 2.9. Here, the initial investment is $20,180 (equipment and installation cost minus the $7000 combined state and federal tax credit) Each year, the user pays $100 in maintenance but "gains" income from the value of the kWh of electricity the system produces (in the form of avoided electricity expense). This "income" increases with the increasing price of the grid-supplied electricity. Again, in this example the GPV owner breaks even just under 14 years and makes money on the investment each year subsequent.[10]

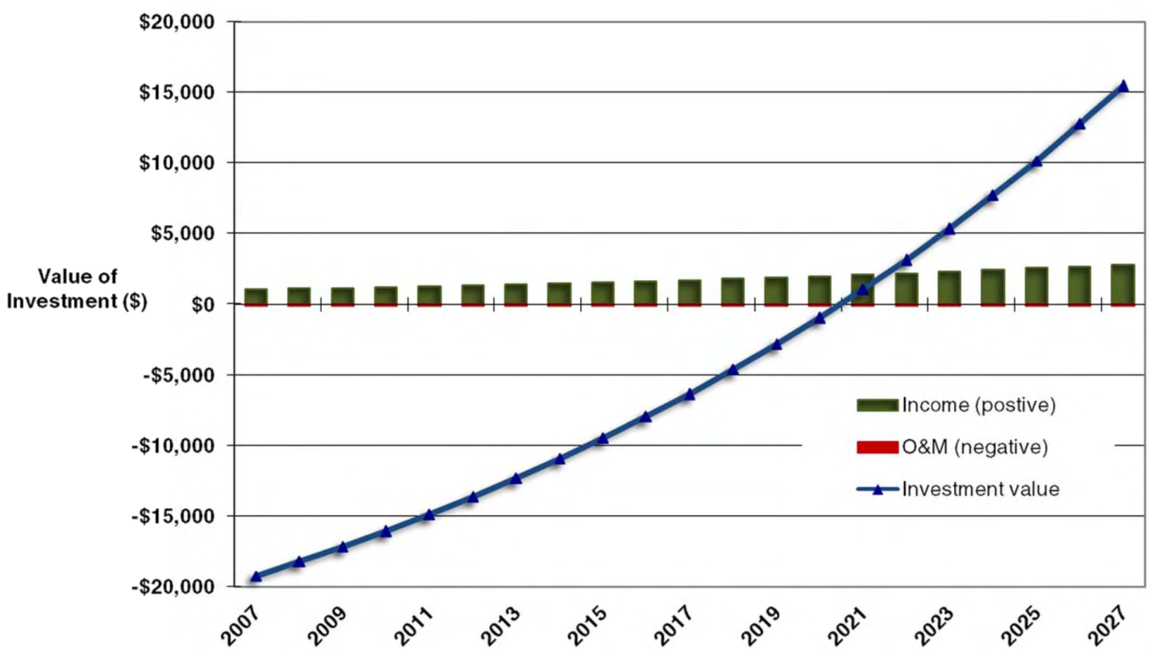

Figure 2.9 Simple cash-flow chart for a 2.4 kW peak GPV system purchased in 2007

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[10] *Caveat emptor:* While reasonable estimations, the cost and investment calculations in this section come with a host of caveats. While most of the estimates erred on the side of being too conservative (disfavoring GPV), changes in the cost of electricity, interest rates, equipment costs, maintenance, module degradation and other factors will change the investment calculus. At the same time, many PV experts believe that current GPV equipment will greatly exceed the 20-year warranties being offered today (L. Valenta, personal interview, September 20, 2004). Moreover, the estimates are based on current cost trends; they do not take into account the possibility of a breakthrough in GPV technology or changes in state or federal policy regarding renewable energy.

GPV Relative Economic Advantage

The relative economic advantage of GPV compared with grid-supplied electricity to a potential adopter can also be determined by examining the trends in the average price of grid-supplied electricity (Figure 2.10) and the levelized cost of GPV for both financed and non-financed systems. This relative economic advantage is demonstrated visually in Figure 2.10, with the estimated price trend for the average rate of grid-supplied electricity in Hawaiʻi crossing the decreasing cost trend for the GPV levelized rate for non-financed systems in late 2006. For a financed system, this “break even” point would be reached for a system purchased just before 2012. Again, because a GPV adopter is effectively “locked-in” to the levelized rate at the time of purchase, they do not benefit from the subsequent decrease in the cost of GPV (e.g. they are “locked in” to the price they paid for the GPV system equipment).

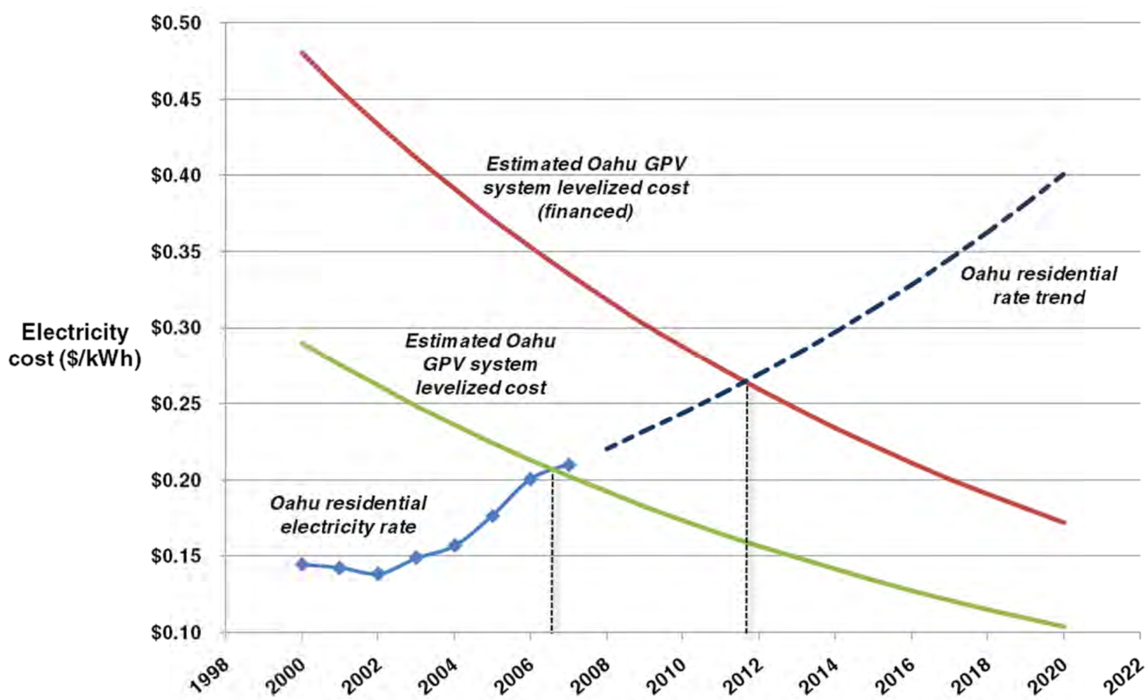

Figure 2.10 Relative economic advantage of a GPV system (financed or purchased outright) on Oʻahu versus grid-supplied electricity at different purchase times.

Using the tools discussed above, a potential GPV adopter can analyze the relative economic advantage of a GPV investment *vis a vis* using grid-supplied electricity. This comparative advantage will differ among adopters, as it depends on when the system is purchased, how the system is financed, and the price and price trend of electricity at the adopter's location.

While this economic analysis provides a useful framework from which to examine the GPV adoption decision, clearly there are other factors contributing to the decision process. Approximately 50 homeowners on O'ahu made the decision to adopt GPV prior to 2006 (R. Richmond of Hawai'ian Electric Company, personal communication, March 20, 2006)—a decision, according to the above analysis, that is likely economically irrational. Moreover, it is unlikely that a GPV adopter has rigorously analyzed the trends in both the price of grid-supplied and GPV electricity. Instead, they may roughly calculate the levelized cost of electricity from a GPV system and compare it with the current cost of grid-supplied electricity. This rough analysis will likely yield a "price gap" between what they currently pay for electricity and what they believe they will be paying for GPV electricity. For those who are currently purchasing systems outright or those who are financing systems, a substantial "price gap" exists. What motivates these homeowners to adopt GPV? Who are they and why are they choosing to make an irrational economic decision? What sort of decision process do they follow to adopt GPV?

Chapter 3 of this study starts to answer these questions by providing further background on the adoption of innovations, pro-environmental motivations, and the willingness to pay for energy efficiency and renewable energy. Based on findings in existing literature, hypotheses are proposed that explain what drives the GPV adoption decision, the attributes adopters possess, and the adoption decision process that they follow.

CHAPTER 3
DIFFUSION OF INNOVATIONS

The Diffusion of Innovations Research Tradition

The spread of GPV is best examined using the framework established through the diffusion of innovations research tradition. The paradigm of diffusion research finds its roots in rural sociology, where Ryan and Gross (1943) did their seminal investigation of the diffusion of hybrid corn seed among Iowa farmers. Ryan and Gross were the first to truly establish the new paradigm by examining the sequential stages of adoption, the roles of communication channels, the S-shaped rate of adoption, and the characteristics of various adopter categories (Ryan and Gross, 1943). Since the 1960s, the diffusion model has been applied in a wide variety of disciplines, including education, energy public health, communication, marketing, geography, sociology, and economics.

Rogers (1995) has defined “diffusion” as “the process by which an *innovation* is *communicated* through certain *channels* over *time* among the members of a *social system*” (Rogers, 1995, p. 10). According to Rogers (1995), an innovation is "an idea, practice, or object that is perceived as new by an individual or other unit of adoption". Rogers identified five attributes which affect the rate at which an innovation is adopted among a population:

1. *Relative advantage* is the degree to which an innovation is perceived as better than the idea it supersedes. The degree of relative advantage may be measured in economic terms, but social prestige, convenience, and satisfaction are also important factors. It does not matter so much if an innovation has a great deal of objective advantage. What does matter is whether an individual perceives the innovation as advantageous. The greater the perceived relative advantage of an innovation, the more rapid its rate of adoption will be.

2. *Compatibility* is the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters. An idea that is incompatible with the values and norms of a social system will not be adopted as rapidly as an innovation that is compatible. The adoption of an incompatible innovation often requires the prior adoption of a new value system, which is a relatively slow process.

3. *Complexity* is the degree to which an innovation is perceived as difficult to understand and use. Some innovations are readily understood by most members of a social system; others are more complicated and will be adopted more slowly. New ideas that are simpler to understand are adopted more rapidly than innovations that require the adopter to develop new skills and understandings.

4. *Trialability* is the degree to which an innovation may be experimented with on a limited basis. New ideas that can be tried on the installment plan will generally be adopted more quickly than innovations that are not divisible. An innovation that is trialable represents less uncertainty to the individual who is considering it for adoption and enables learning by doing.

5. *Observability* is the degree to which the results of an innovation are visible to others. The easier it is for individuals to see the results of an innovation, the more likely they are to adopt it. Such visibility stimulates peer discussion of a new idea, as friends and neighbors of an adopter often request innovation-evaluation information about it. (Rogers, 1995, p. 15-16)

Generally, innovations that are perceived by individuals as having greater relative advantage, compatibility, trialability, observability, and less complexity will be adopted more rapidly than other innovations (Rogers, 1995).

Rogers' observability attribute provides the foundation for the first hypothesis in the adoption of GPV:

> ***H_1.*** *The propensity of a homeowner to adopt GPV is positively influenced by the homeowner's direct experience with a GPV system owned by a friend, neighbor, or relative.*

Ideas are diffused among individuals or organizations through various communication channels. Mass media channels are more effective in creating knowledge of innovations, whereas interpersonal channels are more effective in forming and changing attitudes toward a new idea, and thus in influencing the decision to adopt or reject a new idea (Rogers, 1995). Most individuals evaluate an innovation based on the subjective evaluation of other individuals similar to themselves (near-peers) as opposed to an evaluation on the basis of scientific research by experts (Rodgers, 1995). Rogers and others have found, generally, that individuals are more likely to adopt if peers or other individuals in their social network have adopted (Rogers, 1995).

Lee, Lee, and Schumann (2002) found empirical evidence that an individual's adoption likelihood is clearly influenced by communication source and modality. In their examination of the diffusion of electronic banking technologies, they demonstrated that the use of a rich, conversational mode of communication is more effective at inducing adoption of a new and complex technology than mass media communication (Lee, et al., 2002). They found this to be particularly true when the conversational information is received from two disparate sources, such as a corporate source and family or friend source (Lee, et al., 2002). Further, the technical complexity of the communication should match the technical competence of the intended audience to be most effective (Johnson and Russo, 1984). This provides additional support for Hypothesis 1.

Rogers (1995) provides a model of the innovation-decision process (Figure 3.1) as it moves through time. Individuals pass through this process from early knowledge of an innovation to attitude formation to a decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision (Rogers, 1995). Rogers suggested that prior conditions were antecedents to the knowledge stage, including a decision maker's level of "innovativeness," felt needs, previous practice, and social norms. Information is gained throughout the decision process from communication channels (Rodgers, 1995).

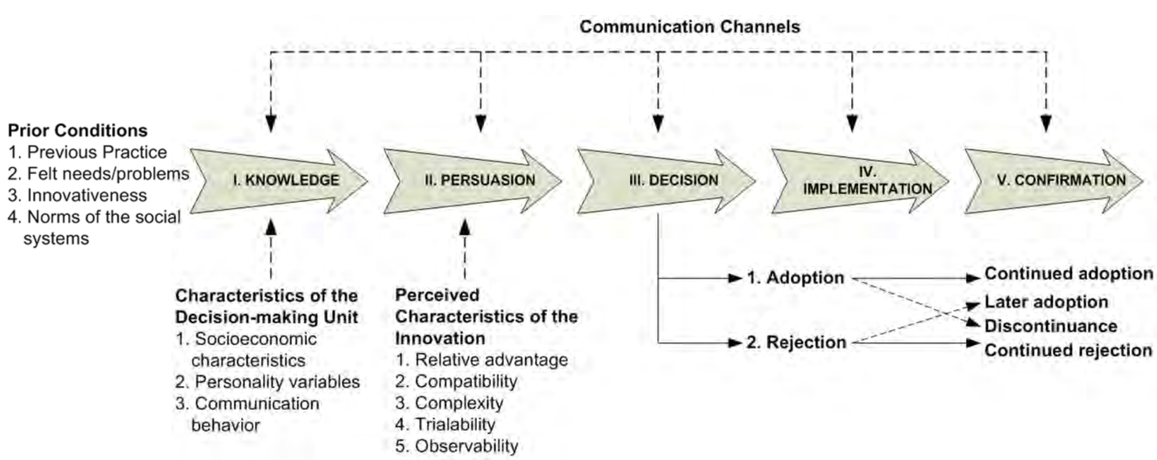

Figure 3.1 A Model of Stages in the Innovation-Decision Process (Rogers, 1995)

The temporal nature of diffusion also allows the categorization of adopters into various levels of innovativeness. Rogers defines innovativeness as "the degree to which an individual or other unit of adoption is relatively earlier in adopting new ideas than the other members of the system" (Rogers, 1995, p. 22). Rogers (1995) states that adopters from the same category share similar socioeconomic status, personality values, and communication behavior. Five ideal adopter categories are established: Innovators, Early Adopters, Early Majority, Late Majority, and Laggards (Rogers, 1995). Table 3.1 shows the distribution for each of Rogers' adopter categories and identifies their characteristics.

Table 3.1 Characteristics of Adopter Categories (Rogers, 1995)

Adopter Category	Characteristics
Innovators *First 2.5% of individuals in a social system to adopt an innovation*	• Venturesome and eager to try new ideas • Have more years of formal education • Have higher social status • Have substantial financial resources • Able to cope with high degree of uncertainty • Contacts outside peer group • May or may not be respected by peers
Early Adopters *Following 13.5% of individuals in a social system to adopt an innovation*	• Respected by peers • More integrated part of the local system • Opinion leaders - potential adopters look to them for advice and information • Change agents • Role models for other members of social system
Early Majority *Following 34% of individuals in a social system to adopt an innovation*	• Deliberate before adopting new idea • Adopt new ideas just before the average member of a system • Interact frequently with peers • Rarely hold positions of opinion leadership • Provide interconnectedness in the system's interpersonal networks
Late Majority *Following 34% of individuals in a social system to adopt an innovation*	• Approach innovations with caution and skepticism • Adopt new ideas just after the average member of a system • Adoption may be due to economic necessity or peer pressure • Unwillingness to risk scarce resources • Uncertainty about innovation must be removed before adoption
Laggards *Final 16% of individuals in a social system to adopt an innovation*	• Hold on to traditional values • Resistance to innovations • Last to adopt an innovation • Near isolates in the social networks of local system • Suspicious of innovations and change agents

Rogers' findings regarding the characteristics of innovators inform the second hypothesis of GPV adopters:

H_2. *GPV adopters are more likely to exhibit:*

- *More years of formal education;*
- *Higher income;*
- *Greater frequency of early adoption behavior; and*
- *Greater propensity to take risks.*

The rate of adoption—typically an S-shaped curve representing the cumulative adoption—can be shown over time. A number of other economic models attempt to explain the dominant “S” curve in technology diffusion (Geroski, 2000). The most common is the “epidemic model,” where the speed of diffusion is limited by the spread of use and benefit information of a new technology. An alternate model is called the “probit model,” which suggests that organizations or individuals who adopt have reasons to adopt a new technology at different times as that technology meets their specific needs and attributes, such as profitability, firm size, or degree of risk aversion. Density dependent growth models (frequently used by population ecologists), using the forces of legitimation and competition, have also been used (Geroski, 2000).[11]

A final key element in the diffusion process worth elaborating is the social system and the role of change agents. A social system is defined as a set of interrelated units that are engaged in joint problem-solving to accomplish a common goal (Rogers, 1995). The social system's structure has an effect on the diffusion of an innovation—particularly the norms or established behavior patterns for the members of a social system (Rogers, 1995). Opinion leadership (“the degree to which an individual is able to informally influence other individuals' attitudes or overt behavior in a desired way with relative frequency”) plays a key role in the diffusion process (Rogers, 1995). A change agent is an individual who attempts to influence clients' innovation-decisions to secure diffusion of a technology or idea (Rogers, 1995). An individual’s innovativeness is highly related to contact with change agents (Rogers, 1995).

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[11] Geroski, however, is quite aware of the challenges presented by attempting to model human behavior. In explaining the inherent difficulty, he writes: “…social phenomena involve many people making choices, often in an interdependent manner, and there are no basic reference points (like the speed of light) which can be used as a metric to measure the passage of time in such processes. Unlike molecules which act and react mechanically, people try to think before they act and this can be a very slow and unpredictable business for some of them” (Geroski, 2000, p. 603).

Important communication roles in the innovation process include:

- opinion leaders (who have relatively frequent informal influence over the behavior of others);
- change agents (who positively influence innovation decisions, by mediating between the change agency and the relevant social system);
- change aides (who complement the change agent, by having more intensive contact with clients, and who have less competence credibility but more safety or trustworthiness credibility). (Rogers, 1995)

Based on the above findings regarding social networks and change agents, Hypothesis 3 is proposed:

> ***H_3.*** *The propensity of a homeowner to adopt GPV increases with greater amount of exposure to a GPV change agent (be it a salesperson, friend with GPV, or other source serving in a "change agent" role).*

Variants to Rogers' Diffusion of Innovations Model

While Rogers' (1995) "diffusion of innovations" model remains the dominant theory behind the adoption of technology, various alternative theories and refinements of Rogers' model have been forwarded by researchers from a variety of disciplines.

Following the Ryan and Gross (1943) and original Rogers' work (1962), Frank Bass (1969) developed differential equations borrowed from physics to model diffusion of innovation. His model—which has subsequently proven successful in predicting diffusion of certain consumer durables—assumes that the timing of a consumer's initial purchase is directly related to the number of previous buyers (Bass, 1969). The Bass model assumes that there is a group of "innovators" who exclusively use mass media channels for information, and "imitators" who exclusively use word of mouth (Bass, 1969). While useful for the adoption of consumer goods with mass appeal, such a mathematically-based model is unlikely to explain the incipient GPV adoption process, as GPV currently only appeals to a small group of potential adopters and at present is not currently advertised in the mass media.

In examining energy conservation innovations, Darley and Beniger (1981) believed that the five innovation attributes established by Rogers (1995) were too general to predict diffusion for this product class. Instead of Rogers' measure of "relative advantage," they proposed two specific sub-dimensions: capital cost and the perceived savings of the innovation. They also bifurcated compatibility into attitude compatibility and lifestyle compatibility, and added four new dimensions to create the following framework (Darley and Beniger, 1981):

1. Capital Cost of the Innovation: the cost of the equipment and any installation costs.
2. Perceived Savings: the perceived payback period and net present value of purchasing the innovation.
3. Certainty of Savings: how certain the energy savings will accrue.
4. Value, Attitude, and Style Compatibility: the congruence of the use of the innovation with the adopters attitudes and values.
5. Innovation and Life-Pattern Interactions: the behavior requirements that accompany adopting the innovation.
6. Trialability of the Innovation: the ability to try out or see the innovation working.
7. Dissatisfaction with the Existing Situation: amount of desire to change existing situation.
8. Effort and Skill Involved in Installing the Innovation: how difficult it will be to install and operate the innovation. (Darley and Beniger, 1981)

A single empirical test of Darley and Beniger's model was performed in 2002 by examining four energy conservation interventions: load management for washing machines, an in-home energy use feedback indicator, communication supporting the adoption of insulation and energy-saving behavior, and communication on energy saving from the utility to the retail trade (Vollink, Meertens, and Midden, 2002). The study found support for only the capital cost, perceived savings, and certainty of savings refinements that were proposed (Vollink, et al., 2002).

Darley and Beniger's model and its subsequent test provide the rationale behind Hypothesis 4:

H_4. *GPV adopters believe the cost savings and the certainty of those savings from using a GPV system will be greater than what non-adopters believe.*

Potential GPV adopters likely estimate the cost savings of GPV based on their understanding of the installed cost of GPV and the savings from avoided electricity use. As a subcomponent to Hypothesis 4, Hypothesis 5 is offered:

H_5. *GPV adopters perceive that the price of electricity will increase in the future by a greater amount than what non-adopters perceive.*

As an alternative to Rogers' (1995) diffusion model, Midgley and Dowling (1978) proposed a contingency model of innovative behavior. They proposed that individual predispositions toward innovativeness are altered by intervening variables, such as social messages or situational factors. In a contingency model, individuals who are typically "non-innovators" could adopt a technology at the early stage of diffusion based on interpersonal influences. They offered a "Simplified Contingency Model" in their 1993 update of the concept (Figure 3.2) and found support for it through an examination of the diffusion of six innovations (Midgley and Dowling, 1993). Their Simplified Contingency Model suggests that some GPV adopters may not possess the traits associated with innovativeness, rather, a combination of situational factors and communications prompted their adoption decision. This also lends further support for Hypothesis 1.

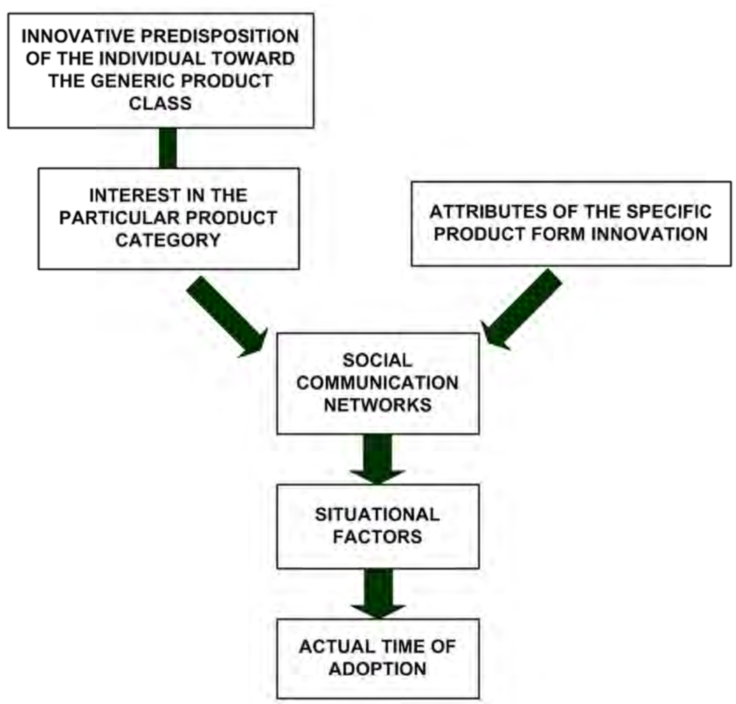

Figure 3.2 The Simplified Contingency Model (Midgley and Dowling, 1993)

While Midgely and Dowling made the distinction between actualized and innate innovativeness, the actual conceptualization of the "innovativeness" construct has found little consensus (Roehrich, 2004). Further, attempts to quantify consumer innovativeness using scales such as Kirton's Adaption-Innovation Inventory (KAI), exploratory behavior scales, and others, have found that the science is imperfect at best (Roehrich, 2004). Mudd (1990) found empirical evidence suggesting that individual differences as measured by KAI lead to differences in adoption levels. Goldsmith and Hofacker (1991) developed a six-item, self-report scale to measure "innate innovativeness." They found support for its validity and unidimensional nature across six studies (Goldsmith and Hofacker, 1991). These findings provide further support for the role of "innovativeness" attributes as they relate to GPV adoption suggested earlier in Hypothesis 2.

For publicly consumed products (a category which includes residential photovoltaic energy, as it is largely visible on rooftops), research has found that consumer innovativeness may yield social rewards (Fisher and Price, 1992)—particularly for those whose social identity is reflected in the product class (Grewal, Mehta, and Kardes, 2000). Fisher and Price developed a conceptual model to demonstrate how perceived consumption visibility and superordinate group influenced adoption by "providing clues about the likelihood of favorable social outcomes from innovative behavior" (Fisher and Price, 1992, p.479). Through an experiment with a new cordless headphone design, they found support for these social contextual factors influencing adoption. Grewal, et al. (2000) revealed that attitudes that particularly serve a social-identity can drive consumer innovativeness and opinion leadership. Public displays of conservationist behavior to project a pro-environment value, such as driving a clearly distinguishable hybrid vehicle, have also been examined (Oregon Environmental Council, 2003). The pro-environment image of the behavior, in fact, may override other, more "functional" values (Heffner, Kurani, and Turrentine, 2005). These findings provide a basis for the following hypothesis:

> ***H_6.*** *Being perceived as having a "conservation" image is more important to GPV adopters than to non-adopters.*

Expanding on the "observability" attribute of an innovation in the diffusion process, Zaltman, Duncan, and Holbek (1973, p. 39) believe that increased visibility of an innovation increases its rate of adoption. They write: "The more amenable to demonstration the innovation is, the more visible its advantages are, and thus the more likely it is to be adopted" (Zaltman et al., 1973, p. 39). The authors felt it necessary to bifurcate demonstration into two components: use demonstration, where actual innovation use is demonstrated, and result demonstration, where the benefits of an adoption are shown) (Zaltman et al., 1973). These findings provide further support for Hypotheses 1 and 3.

With "knowledge" being a clear prerequisite to proceeding through the adoption process, its dimensions have been subject to close examination. Alba and Hutchinson (1987) proposed to separate the knowledge stage into two major components, familiarity (the number of product-related experiences) and expertise (the ability to perform product-related tasks successfully). They describe five distinct dimensions of expertise: cognitive effort, cognitive structure, analysis, elaboration, and memory (Alba and Hutchinson, 1987). The five dimensions are interrelated and aid in development of expertise and familiarity (Alba and Hutchinson, 1987). Interestingly, prior knowledge of a product may have an antagonizing effect on new product learning (Wood and Lynch, 2002; Johnson and Russo, 1984). When individuals with prior knowledge do not recognize that a product has changed, they are not motivated to seek deeper information. Wood and Lynch's (2002) research suggests that product "experts" may be unaware that their knowledge is outdated and obsolete. This may have implications on the adoption of GPV as some potential customers may possess knowledge of photovoltaic energy that is decades-old.

Kaplan (1999), in examining the intention of electric utility managers to adopt photovoltaic electricity sources, suggested expanding Rodgers' model to include a measure of familiarity to augment the "knowledge" stage. He found that knowledge alone was an insufficient determinant of adoption intention and concluded that familiarity was more important than knowledge in causing PV interest among utility managers. Kaplan also found that a measure of experience, as distinct from knowledge, would enhance the knowledge-only model (Kaplan, 1999). He offers: "Perhaps decision makers can effect reasonable and reliable decisions without the perfect information that economic theories assume: perhaps utility managers need to become familiar with PVs" (Kaplan, 1999). He proposed a new innovation-decision conceptual framework (Figure 3.3). For adopters, however, Kaplan (1999) found only some support for "motivation" correlating with "knowledge" and "experience"; significant support for "knowledge" correlating with "familiarity" and "interest"; and some support for "experience" correlating with "knowledge" and "interest." These results underscore Hypotheses 1 and 3, and provide foundation for Hypothesis 7:

> ***H_7.*** *An understanding of GPV systems is a necessary component in the decision to adopt GPV and GPV adopters exhibit a greater level of this knowledge than non-adopters.*

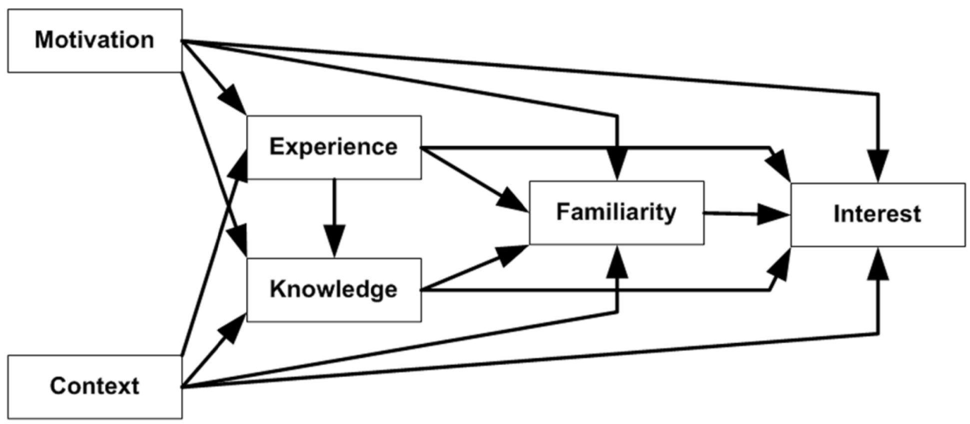

Figure 3.3 Kaplan's (1999) Innovation-Decision Conceptual Framework

Motivations for Pro-Environmental Behavior

In order to better understand the motivations of adopting GPV, it is useful to examine the extensive social science and economic literature on green consumerism and pro-environmental behavior in general.[12] Adoption of GPV reduces the amount of impact a homeowner's electricity use has on the environment by reducing the consumption of fossil fuels and the associated pollution generated by their production, transport, and use. One such pollutant, carbon dioxide, is thought to contribute significantly to global climate change (Intergovernmental Panel on Climate Change, 2007). On average, each kilowatt-hour of electricity avoided in Hawai'i reduces the carbon dioxide-equivalent of greenhouse gas emissions by 1.96 pounds (State of Hawai'i, 1998). A typical GPV system, like the 2.4 kWp system described earlier,

[12] Unlike environmental behaviors such as contributing money to ecological advocacy causes or recycling, however, where benefits mainly accrue to society and not the individual, investing in renewable energy or energy efficiency typically involves a mix of public and private benefits. Nonetheless, an understanding of some of the intrinsic drivers of pro-environmental behavior is instructive.

produces approximately 4800 kWh annually. Such a system would prevent 9408 pounds—or over 4.7 tons—of greenhouse gas emissions annually.[13]

A rather intuitive hypothesis is offered:

> ***H_8.*** *The propensity of a homeowner to adopt GPV is positively correlated with the homeowner's pro-environmental orientation and level of involvement in other pro-environment behaviors.*

Self-Perception Theory predicts that if a person takes a pro-environmental action in one area, that person's self-image and attitudes will change in a way that increases his or her likelihood to behave in a pro-environmental manner in other areas (Bem, 1972). This lends additional support for Hypothesis 8.

Survey tools have been developed to measure an individual's pro-environmental orientation and behavior. Dunlap and Van Liere's New Environmental Paradigm (NEP) Scale, first published in 1978, has been widely tested as a robust measure of environmental attitudes and values (Dunlap, Van Liere, Mertig, and Jones, 2000). A review of relevant literature in Granzin and Olsen (1991) finds general support for the hypotheses that individuals inclined to take part in pro-environmental behavior are younger, have a higher education, have higher income, belong to a higher social class, own a single-family home, are married, female, and have greater satisfaction from environmental protection. Granzin and Olsen confirmed these hypotheses in their examination of an individual's tendency to walk, recycle, and donate items for reuse. Their findings offer additional support for Hypothesis 2. However, these socio-demographic generalities as pro-environmental predictors have been challenged in recent academic work (Diamantopoulos, Schlegelmilch, Sinkovics, Bohlen, 2003). In a sweeping examination of literature pertaining to pro-environmental knowledge, attitudes, and behavior, Diamantopoulos, et al. (2003) found only partial support for the majority of socio-demographic variables previously thought to predict pro-environmental attitudes and actions.

Bhate and Lawler (1997) found high correlation between environmentally-friendly behavior (purchasing green products and recycling, among other behaviors) and

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[13] Of course, energy is consumed in the manufacture and installation of the PV system. A survey of published research in "energy payback" for the manufacture of GPV systems estimates payback times of between 1 and 4 years (U.S. DOE, 2004).

innovativeness as measured by the Kirton Adaption-Innovation Inventory model. This provides additional basis for Hypothesis 2.

While it may seem intuitive that concern for the environment has a direct causal effect on pro-environment behavior, Ajzen (1991) has suggested that only situation-specific cognition directly determines specific behavior. Similar to Midgley and Dowling's 1993 Simplified Contingency Model, Ajzen's Theory of Planned Behavior postulates that behavior is guided by three conceptually independent—and situation specific—variables. The first is the attitude toward the behavior (favorable or unfavorable); the second is subjective norm, or the perceived social pressure to perform or not perform the behavior; and the third is the perceived behavior control, or the perceived degree of difficulty in executing the behavior (Ajzen, 1991). Ajzen theorizes that in combination, these three predictors, attitude toward the behavior, subjective norm, and perception of behavioral control drive behavioral intention, which is an antecedent to actual behavior (Ajzen, 1991). This theory provides additional support for Hypothesis 6 (self-image). Figure 3.4 illustrates Ajzen's Theory of Planned Behavior.

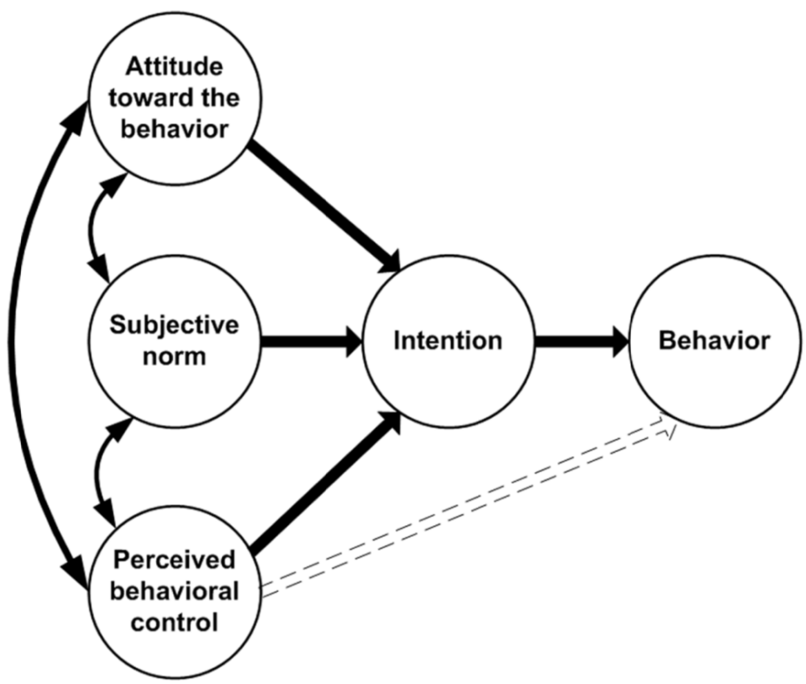

Figure 3.4 Ajzen's (1991) Theory of Planned Behavior Model

Bamberg (2003) applied Ajzen's Theory of Planned Behavior to examine environmentally-friendly behavior. In studying the intention of individuals to request a brochure that explained green electricity products, Bamberg found important differences between individuals who identified themselves as highly environmentally concerned and those who did not. The intention in individuals who were highly concerned about the environment was largely driven by their perceived behavioral control, while those who were less concerned were driven by social norms (Bamberg, 2003). The research suggested that attitude alone may be insufficient to predict intention, but useful when taken in combination with other situation specific variables. This helps to inform the structure of our GPV decision process model that is explained in later chapters.

Similarly, Ellen, Wiener, and Cobb-Walgren (1991) examined the influencing quality of "perceived consumer effectiveness," or ability to make a difference, on pro-environmental behavior and knowledge. They confirmed earlier results that an individual with a greater sense of perceived consumer effectiveness would be more likely to take a pro-environmental action (Ellen, et al., 1991). Further, it is theorized that beliefs about the importance of pro-environmental behavior also predict such behavior. McCarty and Shrum (2001) found that specific beliefs on the importance of recycling directly influenced recycling behavior. These findings provide the basis for Hypothesis 9:

> ***H_9.*** *GPV adopters are more likely to perceive that an individual's energy conservation can actually make a difference in overall energy use.*

Bang, et al (2000) used the theory of reasoned action as a theoretical framework in the adoption of renewable energy and found that a consumer's environmental belief and level of concern have a strong relationship with the desire to pay more for renewable energy. Their analysis of 343 electric bill payers demonstrated that those with higher environmental concern didn't necessarily have a higher level of knowledge of renewable energy, suggesting that the willingness to pay a premium for renewable energy was more emotionally charged than fact-or knowledge-based (Bang, et al., 2000).

Minton and Rose (1997) examined the effects of three different behavioral intentions: attitude, the injunctive norm ("what others think I should do"), and the personal norm ("what I feel morally obligated to do"). They concluded that while attitude had the strongest effect on behavioral intentions (such as willingness to sign a petition, join a group, or pay more for electricity), the personal moral obligation had the strongest effect on product choice, information search, and actual behavior (Minton and Rose, 1997). The role of this internal motivation and its relation to GPV adoption is examined in Hypothesis 10:

> ***H_{10}.*** *GPV adopters, as compared with non-adopters, are more likely to believe that investing in renewable energy is the "right thing to do" and they have a moral obligation to "do their part."*

It has been suggested that that some pro-environmental behavior, such as the purchase of organic foods, is driven more by self-serving, as opposed to pure altruistic, motivations (McEachern and McClean, 2002). But in Brekke, Kverndokk, and Nyborg's (2003) economic analysis of socially responsible behavior (recycling and community volunteering), it was demonstrated that moral motivations may not be contrary to an individual's desire to maximize personal utility. They found that seemingly unselfish behavior is ultimately motivated by a private good (in their study, self-image), similar to the "warm glow" effect by taking part in socially responsible behavior (Brekke, et al., 2003). Such support "self-image" benefits underscores Hypothesis 6.

Some (Pieters, Bijmolt, van Raaij, de Kruijk, 1998) have found that consumers attribute higher levels of pro-environmental behavior and motivation, but lower levels of ability, to themselves than to others. This presents a social dilemma where individuals feel relieved of moral obligation by believing that they are doing their part while others are not. Pieters, et al. (1998) also found that the level of pro-environmental behavior attributed to others has a positive impact on consumers' own pro-environmental behavior, suggesting that strategies to increase such behavior should include messaging regarding the activities of others. These results suggest a corollary to Hypothesis 10, where non-adopters do not view a GPV investment as something they need to do. Related to this are the findings of McCarty and Shrum (2001), who found that those with a propensity toward individualism felt more inconvenienced by recycling than those with collectivist values, and collectivist-oriented individuals believed recycling more important than did individualists.

The motivations for pro-environmental behavior provide useful background for developing the GPV adoption decision model described later.

Customer Willingness to Pay for Green Power from the Utility

A rich body of research exists exploring individuals' willingness to pay (WTP) for renewable energy offered by a utility. Deregulation and restructuring of the electric industry in certain parts of the United States has afforded some utilities the ability to market "green" or renewable energy—typically wind, landfill gas, solar, geothermal, or biomass—as a product offering. Since electrons do not possess any physically differentiating features to the end user, paying for green power is largely a purchase of environmental or moral satisfaction. Since an investment in GPV can be expressed in terms of price per kilowatt-hour, a customer's WTP for renewable energy from the utility should be somewhat comparable to similar investment in GPV. There are significant differences, of course. While a utility-offered renewable energy program offers less risk and less effort, the consumer usually does not directly share in the economic benefit of the program, unlike an investment in GPV or energy efficiency where the consumer shares a mix of public and direct economic benefits over time.[14] GPV adoption also differs from participation in a green pricing program in that the GPV adopter must either pay the upfront cost for the GPV system or find financing for the GPV investment.

One of the most salient lessons from WTP research is that individuals' stated WTP is much greater than their actual WTP. Market research reveals a stated WTP between 40 and 70% for green power, yet actual participation in utility-supplied programs is typically less than 3% of electricity consumers (Wiser and Pickle, 1997). Tangentially, this suggests some support for Hypothesis 10, where those who actually adopt believe that it is not only the "right thing to do" but they have a personal moral obligation to do so.

Farhar (1999) examined 14 different surveys conducted in 12 utility service territories in five Western/Southwestern states collected between 1995 through 1997. Among her findings:

- "Majorities varying between 52% to 95% of residential customers say they are willing to pay at least a modest amount more per month on their electric bills for power from renewable sources. Deliberative polls show that willingness to pay

[14] This mix may change as market mechanisms to reward the avoidance of greenhouse gases are established. As discussed earlier, the use of a typical GPV system in Hawai'i may prevent 4.5 tons (4 metric tons) of carbon dioxide from being emitted annually. During the month of October, 2007, the rate for carbon dioxide on the Chicago Climate Exchange was $2.40 per metric ton, down from a 2007 high of just over $4.00.

increases when customers are educated about utility energy options" (Farhar, 1999).

- "Willingness to pay follows a predictable pattern with an average majority of 70% willing to pay at least $5 per month more for electricity from renewable sources, 38% willing to pay at least $10 per month more, and 21% willing to pay at least $15 per month more" (Farhar, 1999).

A status report on green power marketing by the National Renewable Energy Laboratory in 2006 found that approximately 1.5% of electric utility customers participate in green power programs, with the most successful green power programs achieving participation rates of from 5% to 15% (Bird and Swezey, 2006). The median price differential for green program products was 2¢ additional per kilowatt-hour (Bird and Swezey, 2006).

Zarnikau (2003) found support for higher WTP for green power among those fitting particular socio-demographics. Through a deliberative polling technique, Zarnikau found that respondents who were younger, had a higher income, and had achieved a higher education level were willing to pay more for energy from renewable sources than those with opposite demographics (Zarnikau, 2003). These findings suggest additional support for Hypothesis 2. Rowlands, Scott, and Parker (2003) found identical results, and additionally found that those with higher ecological concern, tendencies toward liberalism, and higher perceived consumer effectiveness were willing to pay more for green power.

Interestingly, some have found that the amount of renewable energy produced—or the amount of environmental pollution prevented—does not track the willingness to pay for the option. Goett, Hudson, and Train (2000) found that the willingness to pay for green power is not scalar with the percent of energy that is actually generated by the renewable energy. They conclude that customers are more focused on the green power *concept* instead of the actual environmental impact (Goett, et al., 2000). This offers mild support for Hypothesis 6, where a conservation "image" is important to the adopter. The mere presence of GPV might satisfy that perception regardless of its size or the actual amount of clean energy it produces.

Adoption of Energy Efficiency: Problems and Theories

An examination of some of the barriers presented in the diffusion of energy efficiency technologies provides insight into the challenges that the adoption of GPV faces. The adoption of GPV is comparable to investment in energy efficiency in that it reduces the consumer's electricity bill. Of course, the greater magnitude of the savings—and the higher initial cost of the investment—distinguish GPV adoption. Empirical studies examining the purchase of energy-saving devices reveal that high initial investment costs—regardless of the money savings from reduced electricity use—fosters to a tendency to avoid energy saving innovations. These decisions can result in outcomes that are economically suboptimal considering likely investment alternatives available to the decision maker.

By foregoing certain energy efficiency investments, individuals demonstrate implied discount rates that are frequently an order of magnitude or higher over the prevailing discount rate (Meier and Whittier, 1983; Koomey and Sanstad, 1994; Sanstad, Blumstein, and Stoft, 1995; Menanteau and Lefebvre, 1999). Table 3.2 shows a sample of implied discount rates from a literature review compiled by Sanstad, et al. (1995).

Meier and Whittier's (1983) study on refrigerators is notable for being one of the first to use very specific data and a simple technique. They examined two refrigerator models sold by the same national retailer between 1977 and 1979. The two refrigerators were identical in nearly every way except their energy use and cost: one used 410 kWh per year less electricity but cost $60 more (Meier and Whittier, 1983). Using a 6% discount rate and a 20-year lifetime, the more efficient refrigerator saved energy at an electricity cost of just over one cent per kWh—lower than electricity prices prevailing in every state at the time (Meier and Whittier, 1983). Despite being widely advertised and being recommended by a prominent consumer magazine, the energy-efficient refrigerator was purchased by customers less frequently than the less expensive inefficient model (Meier and Whittier, 1983). Using regional electricity cost data, Meier and Whittier (1983) calculated the implied discount rate by these purchases, which varied between 34% and 59%, depending on the region's prevailing residential electricity rate.

The rationale behind the high implied discount rate demonstrated by individuals' energy technology purchasing decisions—dubbed the "energy-efficiency paradox" or the "energy-efficiency gap"—has been examined by numerous researchers. Some discounting can be reasonably explained by the "hidden costs" of making an investment decision, such as information gathering costs, possible reduced product performance, and inconveniences of installing or operating (Levine, Koomey, McMahon, Sanstad, 1995). Others find that a "hurdle rate" of some amount applies to energy-efficiency decisions, created by uncertainty regarding prices, irreversibility of the purchase decision, and sunk costs (Hassett and Metcalf, 1993; Sanstad, et al., 1995; Van Soest and Bulte, 2001). These studies support Hypothesis 4, where GPV adopters believe the cost savings and the certainty of those savings from using a GPV system will be greater than what non-adopters believe.

Table 3.2 Average Implicit Discount Rates in Energy Efficient Investments (Sanstad, et al., 1995)

Study	End-use	Average rate
Arthur D. Little (1984)	Thermal shell measures	**32%**
Cole and Fuller (1990)	Thermal shell measures	**26%**
Goett (1978)	Space heating system and fuel type	**36%**
Berkovec, Hausman and Rust (1983)	Space heating system and fuel type	**25%**
Hausman (1979)	Room air conditioners	**29%**
Cole and Fuller (1980)	Refrigerators	**61-108%**
Gately (1980)	Refrigerators	**45-300%**
Meier and Whittier (1983)	Refrigerators	**34-58%**
Goett (1983)	Cooking and water heating fuel type	**36%**
Goett and McFadden (1982)	Water heating fuel type	**67%**

To a certain extent, the "suboptimal" behavior of consumers can be explained by the simple lack of understanding of discounting, energy costs, and financial analyses by consumers (Sanstad and Howarth, 1994). Sanstad and Howarth (1994) show that empirical studies generally support the idea that individuals considering an energy efficient innovation are subject to the concept of "bounded rationality"—that is, customers try to make good energy choices, but with incomplete information, assumptions, and limited analysis skills the best they can do is simply "muddle through with generally imperfect results" (Sanstad and Howarth, 1994).

The issues that give rise to the "energy-efficiency paradox" are likely to be more pronounced in the decision to purchase a GPV system, with high initial investment costs and lengthy payback times. In a larger context, the basic existence of a discount rate frustrates investment in energy-saving technology. The consumer discount rate—and its corollary, the available interest rate—change the investment calculus by making expenditures in the present less attractive than identical expenditures sometime in the future. While a purely rational decision maker will apply the prevailing consumer discount rate to evaluate projects or compare investment alternatives, it is clear by the implicit rates suggested in the literature reviewed above that some sort of "internal," or personal, discount rate is being applied. This personal discount rate likely varies with an individual's values, financial situation, and other factors. Individual discounting may also take into account uncertainty in the future: if it is unclear what the future holds over the long-term, events or values in the long-term have less value[15]. A GPV adopter, it is hypothesized, has a lower personal discount rate:

> ***H_{11}.*** *GPV adopters demonstrate a lower internal, or personal, discount rate than non-adopters.*

Similarly, uncertainty and risk play a role in any investment decision. Literature on energy efficiency adoption suggests that uncertainty in energy savings reduces the likelihood of adoption (Hassett and Metcalf, 1993). Moreover, for new technologies such as GPV, innovators (as described by Rogers, 1995), exhibit risk-taking behavior. Yet a certain amount of risk is borne by a Hawai'i electricity consumer who relies on grid-supplied electricity when the vast majority of that electricity is produced by combusting petroleum—a commodity that is subject to the vagaries of the world market. Between 2003 and 2006, the price per barrel crude oil at the point of U.S. refiner acquisition doubled (U.S. Energy Information Administration, 2007)—hardly a reassuring trend for the risk averse. Given the competing forces of uncertainty and risk in energy decisions, it is difficult to predict whether GPV adopters will demonstrate a propensity to take risks. This will be examined as part of Hypothesis 2.

With this foundational understanding of motivations for pro-environmental behavior, willingness to pay for renewable energy, and adoption of energy efficiency, the adoption of solar energy both in the United States and Hawai'i specifically will be explored.

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[15] Conventional economic wisdom aside, discounting can introduce ethical quandaries. When discounting compels a decision maker to forego an environmentally beneficial action, that decision maker is, *inter alia*, discounting future environmental impacts. Such intergenerational discounting, especially in regards to global climate change, is viewed by some as morally objectionable (Broome, 1992).

Residential Adoption of Solar Energy

Research into the diffusion of solar energy on residential homes began with solar water heater diffusion studies in the late 1970s. Labay and Kinnear (1981) were among the first to study the various characteristics and energy perceptions of solar water heater adopters and non-adopters. As predicted with previous adoption research, adopters were younger, were more educated, had higher income, and had higher occupational status than non-adopters (Labay and Kinnear, 1981). Adopters were also found to view solar energy more favorably and identify its advantages more readily than non-adopters (Labay and Kinnear, 1981). They were surprised to find little difference in these measures between adopters and *knowledgeable* non-adopters, leading them to hypothesize that intervening, situation-specific variables come into play (Labay and Kinnear, 1981). Labay and Kinnear's work provides support for Hypothesis 2 regarding traits of innovativeness, but would contradict Hypothesis 7, that GPV adopters are more knowledgeable about GPV than non-adopters.

Armand (1981) surveyed 324 Southern California homeowners in an attempt to identify the variables influencing the decision to adopt residential solar water heating technology. While she found no significant socioeconomic or demographic differences between adopter and non-adopter categories, she found that adopters had rated themselves more "innovative" for products related to energy conservation and took part in energy conserving behaviors (Armand, 1981). Moreover, adopters in the study "had greater future time perspective, a stronger belief in the continued rapid rise in the cost of energy, and less discrepancy between their self-image and product-image than non-adopters" (Armand, 1981). Armand's work provides strong support for Hypothesis 5 (increase in electricity cost), Hypothesis 6 (conservation image), and Hypothesis 11 (lower personal discount rate).

Sawyer's (1982) examination of the initial wave of homeowners who installed solar energy devices did find demographic and socio-economic differences between adopters and the general population, congruent with Rogers (1995) model. The 177 homeowners in Northeastern states surveyed in Sawyer's study listed economics, energy/environmental concern, and self-sufficiency most frequently as their motivations to invest in solar (Sawyer, 1982), suggesting support for Hypothesis 4 (cost savings) and Hypothesis 8 (environmental concern). Self-sufficiency, as a distinct motivation, forms the basis for Hypothesis 12:

H_{12}. *The propensity of a homeowner to adopt GPV is positively correlated to their desire to be self-sufficient and provide for themselves.*

Sawyer (1982) also found that these adopters, although they represented a fraction of 1% of the potential solar adopter population, had characteristics which more closely resembled “early adopters” instead of risky, experimental “innovators.”

A study of Wisconsin homeowners’ attitudes toward renewable energy revealed that while many view renewable energy favorably, few have actual familiarity with it (Jenkins, 2001). The study found that two-thirds of Wisconsin respondents said they were favorable toward renewable energy systems, yet only 16% were familiar with PV electricity. Twenty-eight percent felt that PV would be useful in Wisconsin (Jenkins, 2001). Reading (books, journals, brochures) and attending conferences and fairs were identified as the most likely communication channels to obtain more information on renewable energy (Jenkins, 2001). Respondents were most interested in the personal benefits (self-sufficiency, long-term savings) and environmental benefits of renewable energy and most concerned with the cost, value, and reliability of such systems (Jenkins, 2001). “Pro-technology” and “pro-environment” were two sets of customer attitudes that showed promise for attracting new customers (Jenkins, 2001).

Katzman (1981), among the first to examine the diffusion of photovoltaic among homeowners, suggested a paradox in the adoption strategy of a rapidly advancing technology: for potential adopters, it may pay to wait. With escalating energy costs and decreasing PV prices, it was estimated that PV may be cost-effective as a long-term investment by the mid-1980s for the two locations studied, Fort Worth, Texas, and New York City. Economic modeling of phasing of the investment, however, revealed that the optimal time was 8-10 years after PV became cost-effective—a time when the rate of decrease in costs plus the rate of increase in fuel price exceeds the discount rate (Katzman, 1981). Katzman (1981) proposed an incrementally decreasing income tax credit to counter the effects of this paradox.

The most extensive studies on residential adoption of GPV were performed by the National Renewable Energy Laboratory in 1996 in an attempt to identify potential adopters of a Colorado utility GPV subsidy program. Farhar and Buhrmann (1998) used face-to-face, focused, open-ended interviews with 120 Colorado households who had indicated some interest in participating in the GPV subsidy program. The most frequently volunteered motivations for purchasing GPV were: 1) standing interest in renewables or technology (75% of respondents), 2) desire to help to expand the PV market (68%), 3) perceived environmental benefits over other energy sources (68%), and 4) opposition to nonrenewable energy sources, especially coal (66%) (Farhar and Buhrmann, 1998). Farhar and Buhrmann's work provides some support for Hypothesis 8 (pro-environmental orientation) and Hypothesis 9 (individual energy savings can be effective). Interestingly, among the respondents in Farhar and Buhrmann's study (1998), over 25% explicitly said that they would not be purchasing a GPV system for economic reasons. This finding that may offer additional support for Hypothesis 10 (GPV adoption being "right thing to do").

In a related study, Farhar and Coburn (2000) surveyed some 3000 random Colorado households to examine the overall level of knowledge of, perceptions of, and interest in GPV. A majority of 68% of respondents favored GPV being made widely available to Colorado residents, although it was clear that respondents favored GPV without significant knowledge about it (Farhar and Coburn, 2000). Factor analysis of responses revealed that major advantages of GPV were perceived to be environmental, financial, and, again, "pacesetting," or a desire to expand the PV market (Farhar and Coburn, 2000). The sources of information rated the highest by respondents were people who already owned PV systems and utility companies. Respondents rated the ability to see, touch, and experience the PV system high (Farhar and Coburn, 2000). Print media was rated higher than broadcast media (Farhar and Coburn, 2000). This study provides additional support for Hypothesis 1 (direct experience with GPV) and Hypothesis 8 (pro-environmental orientation).

While only 11% of respondents in the Farhar and Coburn (2000) study said they would be interested in paying a one-time cost between $14,000 and $28,000 for GPV, about three-quarters of respondents claimed they would be interested in paying at least something more each month to finance GPV. While their study only examined adoption *intention* as opposed to *actual* adoption of GPV, it suggests that a non-adopter of GPV may be more inclined to adopt if they could pay for the system through monthly payments arranged by a separate party as opposed to investing in the GPV equipment themselves.

The most comprehensive research on the adoption of solar energy by Hawai'i residents comes from the Hawai'ian Electric Company's market research for their solar water heater program—a program required by the Hawai'i Public Utilities Commission as part of the utility's demand side management program. The adoption of solar water heaters in Hawai‘i has varied dramatically since their first mainstream use in the 1970s. Much of the variation in adoption rates is attributable to the varying level of state and federal tax credits (R. Richmond, personal communication, August 6, 2004). In 2003, nearly 20% of houses in Hawai‘i have solar water heaters ((R. Richmond, personal communication, August 6, 2004). The approximate homeowner solar hot water heater adoption rate is 0.5% annually, or roughly 3000 new systems annually on the 491,071 housing units in Hawai‘i (Richmond, et al., 2003; U.S. Census Bureau, 2005).

A 1993 market research study by SMS Research of 402 Hawai‘i households explored customer attitudes and motivations regarding solar water heaters. They found that respondents lacked knowledge about the actual cost of installing a solar water heater—about one-third of respondents had no idea what the cost was. The possible environmental benefits of using solar energy for heating water were seen as important in making a decision about purchasing a system. Approximately 55% of respondents would be interested in buying a solar water heater if the costs could be recovered within three years. Many residents didn't know where to go to buy a solar water heater, but suggested that solar water heating specialists would be preferred to the utility as source of the solar water heater. One of the most important criteria in deciding to buy a solar water heater, according to respondents, was the reputation of the provider. Respondents would prefer to purchase a solar water heater outright as opposed to lease (only 15% were very likely to lease with the option to buy). Finally, the most likely targets for a solar water heater are people who have lived in their home for less than five years—those who had resided in their home longer were apparently satisfied with their arrangement and see little need to change (SMS Research, 1993). A 1986 survey by the same research group found that brochures from solar water heater sellers were the most popular information source (81%), followed by magazines and newspapers (44%) (SMS Research, 1986).

A 1998 telephone survey of 303 O‘ahu customers who had installed a solar water heater revealed that the primary reasons for purchasing solar were the cost-savings advantages, with 61.7% mentioning either "saving money" or "saving electricity" (Ward Research, 1998). This finding suggests support for Hypothesis 4 (belief in cost savings correlating with GPV adoption interest). In a concurrent study querying 300 customers who had inquired about the utility's solar water heater program but did not purchase ("non-adopters"), half mentioned system cost as the primary barrier to adoption (Ward Research, 1998b). Of the non-adopters, only 13.4% expressed a strong likelihood of installing solar that year (Ward Research, 1998b), although twice that proportion expressed strong purchase likelihood in similar studies in 1997 and 1999 (Ward Research, 1999).

Focus group studies in 1998 of 25 O‘ahu residents that possessed the expected demographics of solar water heater adopters confirmed that initial cost was the main barrier to adoption (Ward Research, 1998b). Focus group participants did indicate, however, that a program financing solar installation via payments made to the utility on their monthly electric bill—if offered and publicized—would draw customers who would otherwise not purchase a system (Ward Research, 1998b). The focus groups also revealed that those who had personal experience or had spoken with friends or relatives who had a solar water heating system were much more informed about the costs and benefits of such systems than participants who had not (Ward Research, 1998b), suggesting additional support for Hypothesis 1 (direct experience with GPV) and Hypothesis 3 (exposure to GPV “change agents”).

Among dealers who sell GPV in Hawai‘i, common motivations offered by GPV customers are the desire to reduce their utility bill and impact on the environment (L. Valenta, personal interview, September 20, 2004; K. Cronin, personal interview, October 11, 2004). These motivations are congruent with Hypotheses 4 (cost savings) and Hypothesis 8 (pro-environment inclination). Self-sufficiency is also a motivation (although most GPV systems do not provide power during a blackout), providing more basis for Hypothesis 12 (self-sufficiency and desire to provide for self). Other reasons include the desire to be the “first person on the block” with GPV, concern over military engagements in oil-producing regions abroad, and dislike of the utility (L. Valenta, personal interview, September 20, 2004).

The hypotheses developed above, with their supporting literature, are restated in Table 3.3.

Table 3.3 GPV adoption hypotheses and supporting research

Number	Hypothesis	Supporting Literature
H_1	*The propensity of a homeowner to adopt GPV is positively influenced by the homeowner's direct experience with a GPV system owned by a friend, neighbor, or relative.*	Rogers (1995) Lee, Lee, and Schumann (2002) Midgley and Dowling (1993) Zaltman, Duncan, and Holbek (1973) Kaplan (1999) Farhar and Coburn (2000)
H_2	*GPV adopters are more likely to exhibit:* *• More years of formal education;* *• Higher income;* *• Greater frequency of early adoption behavior; and* *• Greater propensity to take risks.*	Rogers (1995) Granzin and Olsen (1991) Zarnikau (2003) Rowlands, Scott, and Parker (2003) Labay and Kinnear (1981) Hassett and Metcalf (1993)
H_3	*The propensity of a homeowner to adopt GPV increases with greater amount of exposure to a GPV change agent (be it a salesperson, friend with GPV, or other source serving in a "change agent" role).*	Rogers (1995) Zaltman, Duncan, and Holbek (1973) Kaplan (1999)
H_4	*GPV adopters believe the cost savings and the certainty of those savings from using a GPV system will be greater than what non-adopters believe.*	Darley and Beniger (1981) Vollink, Meertens, and Midden, 2002 Hassett and Metcalf, 1993 Van Soest and Bulte, 2001
H_5	*GPV adopters perceive that the price of electricity will increase in the future by a greater amount than what non-adopters perceive.*	
H_6	*Being perceived as having a "conservation" image is more important to GPV adopters than to non-adopters.*	Fisher and Price (1992) Grewal, Mehta, and Kardes (2000) Ajzen (1991) Heffner, et al (2005)
H_7	*An understanding of GPV systems is a necessary component in the decision to adopt GPV and GPV adopters exhibit a greater level of this knowledge than non-adopters.*	Kaplan (1999) Rogers (1995) Labay and Kinnear (1981)
H_8	*The propensity of a homeowner to adopt GPV is positively correlated with the homeowner's pro-environmental orientation and level of involvement in other pro-environment behaviors.*	Bem (1972) Farhar and Coburn (2000) Bamburg (2003) Goett, et al (2000)
H_9	*GPV adopters are more likely to perceive that an individual's energy conservation can actually make a difference in overall energy use.*	Ellen, Wiener, and Cobb-Walgren (1991) McCarty and Shrum (2001) Rowlands, Scott, and Parker (2003) Farhar and Buhrmann (1998)
H_{10}	*GPV adopters, as compared with non-adopters, are more likely to believe that investing in renewable energy is the "right thing to do" and they have a moral obligation to "do their part."*	Minton and Rose (1997) Pieters, Bijmolt, van Raaij, de Kruijk (1998)
H_{11}	*GPV adopters demonstrate a lower internal, or personal, discount rate than non-adopters.*	Armand (1981)
H_{12}	*The propensity of a homeowner to adopt GPV is positively correlated to their desire to be self-sufficient and provide for themselves.*	Sawyer (1982)

Conceptual Decision Process Model for GPV Adoption

With an understanding of the diffusion of innovations tradition and relevant research in the renewable energy adoption field, a path model of the GPV adoption decision can be formulated. While numerous diffusion models exist, Rogers' (1995) Innovation-Decision Process (Figure 3.1) provides perhaps the widest angle to view the GPV adoption process. The hypothesized decision path model, shown in Figure 3.5, explores the relationships found in the early stages of Rogers' (1995) model, where many of the hypotheses tested in this research are embedded. The proffered model also borrows somewhat from Kaplan (1999), where it was demonstrated that knowledge was a significant driver in generating interest in photovoltaics among utility managers.

"Prior conditions," the starting point in Rogers' (1995) model, are indicated in this conceptual decision model as environmental motivation and "innovativeness." These initial conditions are assumed to be necessary to move to the next stage in the decision process. Due to the high initial expense of a GPV system, a component representing financial ability was also included as an initial condition variable in this decision model.

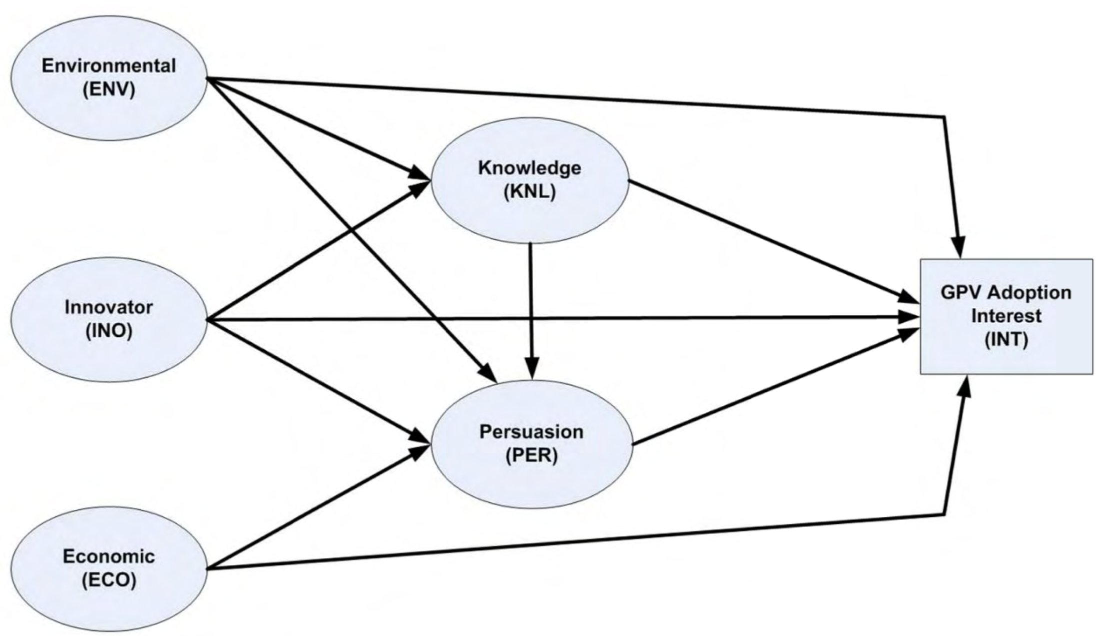

Figure 3.5 Proposed conceptual path model for GPV adoption

The second stage of this conceptual model contains both Rogers' (1995) Innovation-Decision Process "Knowledge" stage and "Persuasion" stage. The strength of the relationships between both environmental motivation and innovativeness and this second stage—GPV knowledge and GPV persuasion—will be analyzed. It is hypothesized that both environmental motivation and innovativeness drive the levels of knowledge and persuasion in the potential GPV adopter. The relationship between financial ("economic") ability and persuasion is also estimated to be positive, but it is assumed that greater economic means has no relation to the level of GPV knowledge. GPV knowledge likely drives GPV persuasion, as envisioned by Rogers' (1995) Innovation-Decision Process. It is unlikely that GPV persuasion would lead GPV knowledge, as persuasion is much more likely to result from an understanding of the benefits and relative advantage of GPV.

The individual and collective effect of all five of these decision process components on the GPV adoption decision will be analyzed. It is hypothesized, however, that the persuasion stage plays a significant intermediate role in the adoption decision. The potential GPV adopter with certain levels of environmental motivation and innovativeness are likely to be open to acquiring new GPV knowledge (perhaps prompted by intervening communication). That new GPV knowledge may allow the potential GPV adopter to imagine how a GPV system could satisfy their environmental motivation and desire for innovativeness. Financial ability further drives the persuasion stage, as the potential adopter may realize that a GPV investment is a real possibility.

This model, of course, is only an estimation of the decision process that a typical GPV adopter may follow. As demonstrated by previous research (Bang, et al, 2000), some adopters may high levels of environmental motivation may bypass the knowledge or persuasion stages altogether and simply adopt. These alternative decision paths will be analyzed by examining both the direct and indirect effects of all decision model components.

CHAPTER 4
METHODOLOGY

Qualitative Investigation

Initial exploration into the attributes of GPV adopters and the diffusion of GPV were conducted through in-depth discussions with GPV owners who could be characterized as "innovators" or "early adopters." Two focus group sessions were held with a total of nine homeowners who had purchased a GPV system within the previous five years. Facilitated focus groups—informal, yet structured group conversations—are frequently used in market research to explore attitudes or opinions about a subject. The focus groups were held on May 25, 2006, in the focus group facility at the Ward Research office in downtown Honolulu, Hawai'i. For this study, focus group participants were randomly selected from both customer lists provided by GPV dealers and the list of utility customers who had enrolled in a net energy metering program. As an incentive, the GPV adopters were offered $100 to participate in the focus group. Each session lasted two hours and each was facilitated by this study's author. The invitation letter to potential focus group participants is provided in Appendix B. The focus group participants with select demographic information are listed in Table 4.1.

Table 4.1 GPV focus group participants

Focus Group	Age	Occupation	Income	Area of Residence	Date System Installed
1	46	Engineer	$100-$500,000	Kaneohe	June 2005
1	59	Sales	<$100,000	Kailua	Jan. 2006
1	60	Manager	<$100,000	Leeward	Jan. 2006
1	59	Professor	$100-$500,000	Kailua	Dec. 2001
1	43	Airline Pilot	$100-$500,000	Aiea	Feb.2004
2	45	Military	<$100,000	Mililani	Feb. 2005
2	70	Retired Prof.	$100-$500,000	Manoa	Nov. 2004
2	58	Professor	$100-$500,000	Honolulu	Sept. 2005
2	52	Engineer	Refused	Honolulu	Nov. 2005

The focus group discussions were aimed at eliciting responses on a variety of issues surrounding the diffusion of GPV and the adopters' knowledge and attitudes. The guiding questions for the focus group sessions were developed in coordination with Rebecca Ward, a market researcher with over 25 years of focus group experience in Honolulu.

The facilitator directed the conversation through four main topics. The first topic explored the process prior to deciding to purchase a GPV system. Questions asked included:

- When did you first start thinking about installing a PV system?
- What had you heard about such systems until that time? From what sources?
- How well do you think you understand PV technology?
- Did you have any direct experiences with residential PV systems?
- Did a friend, neighbor, or relative have a PV system?
- What did you do when you first started thinking about it? Did you do any research? Talk to people? What did you learn?

The second topic area focused on the GPV adoption decision itself. The questions asked of the participants were:

- Do you recall a “tipping point” in your decision process to purchase a PV system?
- What would you say was your primary motivation for installing a PV system?
- How did you evaluate whether or not the system would be appropriate for you?
- Did you calculate a payback period for your PV system?

The third topic of discussion in the focus group sought to reveal the characteristics of GPV purchasers and their beliefs. The guiding questions included:

- What type of people purchase PV systems?
- Do you think PV buyers are “special?” In what ways? What traits do they possess?
- Do your friends perceive you as being a “conservationist?”
- What other activities do you do to protect the environment?
- Is your view of Hawai‘ian Electric Company favorable or unfavorable? Why?
- Do you think electricity will be more expensive in the future? How much more expensive?
- Do you consider yourself a “risk taker?”

- Are you the type of person who is the first to purchase new products?

The final topic area explored the barriers to adopting GPV systems. The focus group questions included:

- What would you say are the biggest barriers to purchasing a PV system?
- What is the best way to overcome these barriers?

Responses from focus group participants were used to guide development of the survey instrument for quantitative analysis. Selected responses and analysis of the focus group discussions are included in results and discussion sections that follow.

Quantitative Investigation

To test the residential photovoltaic adoption model and twelve hypotheses, this investigation surveyed a sample of current solar water heater owners on O‘ahu to discern their attitudes and behaviors on a range of subjects. Solar water heater owners were considered “near adopters” for purposes of this study, considering that the vast majority of photovoltaic adopters have already installed solar water heaters.

Sample

A group of 2225 current solar water heater owners were selected from a list of building permit applicants between 2000 and 2006 (all solar water heater installations on O‘ahu require building permits). The list was acquired through the City and County of Honolulu’s Department of Planning and Permitting. To ensure a random sample, random months were selected and all permit applicants for that particular month were drawn. Letters inviting the selected solar water heater owners to participate in the survey were mailed in November 2006. No incentive for participation was provided, and survey respondents were self-selecting. Solar water heater owners were provided two weeks to participate in the study by providing answers to the survey online or by requesting a paper version of the survey. A postcard was sent as a reminder to solar water heater owners who had not responded within one week; they were told they had an additional 10 days to respond (for a total of 24 days to respond).

Of the original 2225 letters mailed, 197 were returned as undeliverable, leaving an original group of 2028 contacted. A total of 303 individuals responded to the invitation. Of those respondents, five were rejected from the survey because they did not consent to conditions prescribed by the University's Institutional Review Board; three no longer had a solar water heater; 24 stated they were not the "primary decision maker" in the decision to purchase a solar water heater; and 22 did not complete the majority of the survey. Of the remaining 249, three were rejected for questionable answers (the same answer across many questions) and one was rejected because the individual had participated in the focus group conducted earlier in this investigation. The resulting sample size (n = 245) of the population of approximately 65,000 solar water heater owners on O'ahu (Richmond, 2007) provides a 95% confidence level with a confidence interval of +/- 6.25%. In cases where respondents skipped specific survey questions, the actual sample size used for statistical analysis is indicated. The lowest sample size used for any statistical test in the following analyses was 151 respondents, providing a confidence interval of +/- 8% at a confidence level of 95%.

Instrument

A 56-item survey was designed to gather quantitative and qualitative data from the sample. The survey was accessible online, and each solar water heater owner was provided with a unique 4-digit identifying access code to ensure privacy and increase legitimacy of the data. The final survey instrument is replicated in Appendix B.

To prevent bias, all Likert scale questions, comprising 41 items on the survey, were randomly ordered for each respondent. Additionally, six questions were asked in the negative to prevent rote responses and increase internal survey consistency. The survey instrument was pretested on a subsample of 60 solar water heater owners to analyze response rate, question difficulty, understandability, and length (data from the sample was discarded). An additional measure of the dependent variable was added to the final survey, and minor wording changes were made throughout the survey to increase clarity. The final survey took each respondent an average of 18 minutes and 28 seconds to complete.

Measures

Two dependent variables were used to test the hypotheses proposed in this investigation and analyze the relationships between the attributes examined by the survey and the respondent's interest in GPV. The first dependent variable measured desire or willingness to sacrifice to own a GPV system, determined by the following survey question (Question 56):

How much would you like to have a photovoltaic system on your home (please select only one)?

1. *I really want a photovoltaic system and would be willing to make a major sacrifice for it*
2. *I really want a photovoltaic system and would be willing to make a minor sacrifice for it*
3. *I really want a photovoltaic system but wouldn't be willing to sacrifice for it*
4. *I want a photovoltaic system but it is not that critical at all*
5. *I really don't care one way or the other*
6. *I would prefer not to have a photovoltaic system*

Responses were treated as a continuous variable on a scale of 1—6 (decreasing order of adoption interest). This item sought to quantify the level of interest in GPV, attempting to isolate the purchase desire from the myriad of other variables that may moderate actual purchase intention.

The second dependent variable was the respondent's intention of purchasing photovoltaic, as determined by this survey question (Question 7):

How likely are you to purchase a photovoltaic system for your home within the next year?

1. *Plan to purchase a system*
2. *Very Likely*
3. *Somewhat Likely*
4. *Somewhat Unlikely*
5. *Very Unlikely*
6. *Not at all*

Respondents were grouped into two "bins" based on their answer. Those who selected (1), (2), or (3) and those who indicated earlier in the survey that they already installed a GPV system were placed in the "Adopter" group (n = 49). Respondents who selected (5) or (6) were placed in the "Non-adopter" group (n = 144). Those selecting (4) (n = 33) or leaving the question blank (n = 18) were left out of the analysis. This approach was selected to better highlight distinctions between those respondents who are clearly leaning toward adopting GPV and those who are clearly not interested.

Using these two dependent variables enabled examination of the differences and similarities between the desire to adopt and actual purchase intention.

Independent variables were operationalized through a variety of survey items. The most commonly used method measured the respondent's level or agreement or disagreement with a statement along a 7-point Likert scale. A 7-point Likert scale was selected to provide finer distinction across the spectrum of "agreement" while not overwhelming the respondent with choices. Responses along the scale were anchored by "Completely Agree" (1) and "Completely Disagree" (7) (e.g. lower scores indicate stronger agreement with the statement). The scale included a neutral point, "Neither Agree nor Disagree" (4). On both the computer and paper versions of the survey instrument, the Likert scale response options were displayed as a continuum below the statement to provide a visual cue to the respondent.

The survey items and variables used to test each hypothesis are described below.

***H_1*.** *The propensity of a homeowner to adopt GPV is positively influenced by the homeowner's direct experience with a GPV system owned by a friend, neighbor, or relative.*

Direct experience for this study was assumed to be experience inside another home with GPV. Question 50 on the survey asked directly: "Are you aware of a time that you have you been inside a house that had a photovoltaic system?" Respondents were provided the options of "yes," "no," or "Don't know."

***H_2*.** *GPV adopters are more likely to exhibit:*

- *More years of formal education;*
- *Higher income;*
- *Greater frequency of early adoption behavior; and*
- *Greater propensity to take risks.*

Education and income variables (Questions 54 and 55 on the survey) were based on common categorical response options used previously by the U.S. Census

Bureau and Ward Research. In addition to household income, a measure of disposable or discretionary income was included on the survey. Question 41 was a 7-point Likert scale item asking the respondent's level of agreement with the statement: "could comfortably spend $15,000 on a major purchase without adversely impacting my lifestyle or financial situation."

Traits of innovativeness, or the greater frequency of early adopter behavior and the greater propensity to take risks, was measured with three Likert scale items. The purchase behavior items were based on Roehrich's (2004) innovativeness scale. The first, "I like trying new things" (Question 22), was similar to items on Roehrich's (2004) hedonistic innovativeness scale. The second item, "Among my friends and neighbors, I am usually one of the first to try a new product" (Question 29) was modeled after items in his social innovativeness scale (Roehrich, 2004). To measure risk, Question 24 asked respondents to rank their level of agreement with the statement: "My friends would consider me a 'risk taker.'"

> ***H_3.*** *The propensity of a homeowner to adopt GPV increases with greater amount of exposure to a GPV change agent (be it a salesperson, friend with GPV, or other source serving in a "change agent" role).*

Data from three survey items were used to test Hypothesis 3, all employing a 7-point Likert scale response:

- Question 17: "At least one other person I know has a photovoltaic energy system."
- Question 32: "My friends, family, or neighbors have told me stories about their residential photovoltaic system(s)."
- Question 35: "I have discussed residential photovoltaic with a solar dealer or contractor."

> ***H_4.*** *GPV adopters believe the cost savings and the certainty of those savings from using a GPV system will be greater than what non-adopters believe.*

Responses on 7-point Likert scale items for level of agreement with two straightforward statements were used to test Hypothesis 4:

- Question 19: "A photovoltaic energy system will save homeowners money."

- Question 21: "I think purchasing a residential photovoltaic system would benefit me financially."

H_5. *GPV adopters perceive that the price of electricity will increase in the future by a greater amount than what non-adopters perceive.*

To test Hypothesis 5, Question 9 asked respondents to complete the following question: "In the next 10 years, do you believe the price of electricity per kilowatt-hour, compared with today's price, will…" Seven categorical options were provided: "Decrease," "Stay the same," "Increase slightly," "Increase by 50%," "Double," "More than double," and "Other (please specify)." Although the responses were provided as discrete choices, the data was treated as continuous for statistical analysis.

H_6. *Being perceived as having a "conservation" image is more important to GPV adopters than to non-adopters.*

Data from two 7-point Likert scale survey items was used to test Hypothesis 6. The first, Question 28, sought to measure the respondent's level of concern for environmental social image with the statement: "It is important to me to be seen as someone who is concerned about the environment." The second item was less direct, attempting to measure the respondent's level pleasure in talking about his or her current solar equipment: "I enjoy telling others about my solar water heater" (Question 38).

H_7. *An understanding of GPV systems is a necessary component in the decision to adopt GPV and GPV adopters exhibit a greater level of this knowledge than non-adopters.*

Hypothesis 7, regarding knowledge, was tested with data from the 7-point Likert scale item: "I pretty much understand how a residential photovoltaic system works" (Question 15). Additionally, the respondent's overall level of interest in new technology was measured by level of agreement with the survey item: "I try to stay up-to-date with new technology" (Question 20).

H_8. *The propensity of a homeowner to adopt GPV is positively correlated with the homeowner's pro-environmental orientation and level of involvement in other pro-environment behaviors.*

Variables to test Hypothesis 8 were operationalized through a variety of survey items bifurcated into two categories: pro-environmental orientation and pro-environmental behavior.

Pro-environmental orientation was measured with two 7-point Likert scale survey items. The first sought to measure the level of concern with global climate change: "I am very concerned that climate change will affect future generations in Hawai'i" (Question 13). The second measure was based on an item in Dunlap and Van Liere's New Environmental Paradigm (NEP) Scale (2000) and Ellen, et al.'s (1991) survey measure: "The seriousness of environmental problems is exaggerated by environmentalists" (Question 25). Since stronger agreement with the statement meant less pro-environmental orientation, the scale was reverse-coded for analysis.

Pro-environmental behavior was measured by the level of agreement with six survey items. The first four measured agreement on a 7-point Likert scale with the following statements:

- Question 10: "I frequently consider the environmental impact of a product when I make purchasing decisions."
- Question 12: "I regularly recycle my bottles and cans."
- Question 33: "I have replaced many of my incandescent light bulbs with compact fluorescents."
- Question 39: "I actively support environmental causes or organizations."

These four survey items have been used in prior studies examining motivations for pro-environmental behavior. Environmental purchasing considerations and recycling behavior was used by both Bhate and Lawler (1997), Pieters, et al. (1999), and Diamantopoulos, et al. (2003). The use of high-efficiency light bulbs was used by Barr, et al. (2004) and participation in environmental organizations was used by Arkesteijn and Oerlemans (2003).

The final two pro-environmental behavior measures were identical to Likert scale items used in a telephone survey of solar water heater owners and non-owners by Ward Research (1999). Question 49 asked "How important were the following factors in motivating you to purchase a solar water heater?" The two factors measuring pro-environmental orientation were "the environmental benefits such as reducing greenhouse gas emissions" and "the desire to be less dependent on fossil fuel sources." Respondents indicated the importance of each factor on a 5-point Likert scale anchored by "very important" and "not at all important."

H_9. *GPV adopters are more likely to perceive that an individual's energy conservation can actually make a difference in overall energy use.*

Hypothesis 9, regarding perceived consumer effectiveness or ability to make a difference, was tested with data from the 7-point Likert scale item: "Even if everyone tried to conserve energy at home, it wouldn't make a big impact on energy use" (Question 31). This item was loosely based on a survey measure from Ellen, et al., (1991) that used a 5-point Likert scale to measure the level of agreement with the statement: "There is not much that any one individual can do about the environment."

H_{10}. *GPV adopters, as compared with non-adopters, are more likely to believe that investing in renewable energy is the "right thing to do" and they have a moral obligation to "do their part."*

Hypothesis 10 was tested with data from three survey items, all employing a 7-point Likert scale response:

- Question 16: "I believe individual actions can make the world a better place."
- Question 23: "I feel we all have a moral obligation to do what we can for Hawai'i's environment."
- Question 26: "I think purchasing a residential photovoltaic system is 'the right thing to do' for the environment."

H_{11}. *GPV adopters demonstrate a lower internal, or personal, discount rate than non-adopters.*

To test Hypothesis 11, each respondent was assigned one of seven discount rate categories based on their calculated approximate internal discount rate. To determine the respondent's approximate internal discount rate, a series of questions on the survey instrument used a “bracketing” method to reveal the respondent’s time value of money preference. The survey item asked the respondent to imagine that he or she had just won a contest and was offered a series of choices for collecting the prize. Each pair of choices offered the option of collecting the prize today or collecting a larger prize in the future. Based on the respondent’s original selection, a subsequent question would test a different pair of options to narrow the approximate discount rate range. This process was repeated two or three times, depending on the responses, until the respondent’s internal discount rate was estimated within a 3% range. The method was similar to that employed by Read and Read (2004), although in this study the time horizon remained static while the future prize value was varied.

For the purposes of this study, the internal discount rate was calculated as the required interest rate to for the future value of the prize money to equal the present value of the prize money, compounded annually over five years. Equation 3.1 provides this basic calculation (Newnan, 1991):

$$FV = PV(1+i)^n \tag{3.1}$$

where *FV* is the future prize value, *PV* is the present prize value, *i* is the interest rate, and *n* is the time period in years (in this case, the number of times the interest is compounded).

For this estimation, the present prize value was static at $1000 and the time period five years. Future prize values were selected to provide approximate discount rate ranges of 3% between 0% and 18%. For example, if the respondent preferred $1000 today instead of $1600 five years hence (interest rate of approximately 10%) but preferred $1825 five years in the future instead of $1000 today (interest rate of approximately 13%), it was estimated that the respondent’s internal discount rate was between 10% and 13%. The pairs of options and approximate discount rates are shown in Table 4.2.

> ***H_{12}.*** *The propensity of a homeowner to adopt GPV is positively correlated to their desire to be self-sufficient and provide for themselves.*

Hypothesis 12 was tested with data from the straightforward 7-point Likert scale survey item: “Being self-sufficient is important to me” (Question 18).

Table 4.2 Respondent options with corresponding estimated discount rate

Respondent's 5-year preference versus $1000 today		Approximate discount rate range		Category
Rejected	*Accepted*	*Low*	*High*	
-	$1200	0%	3.7%	7
$1200	$1400	3.7%	7.0%	6
$1400	$1600	7.0%	9.9%	5
$1600	$1825	9.9%	12.8%	4
$1825	$2060	12.8%	15.6%	3
$2060	$2315	15.6%	18.3%	2
$2315	-	18.3%	-	1

Path Model Variables

The path model was tested using variables described above (see Section 4) as well as data from the following six 7-point Likert scale survey items:

- Question 34: "I have actively sought to learn new information about residential photovoltaic from the internet, books, or magazines."
- Question 37: "I understand what 'net energy metering' is."
- Question 40: "I am well aware of the state and federal tax credits for residential photovoltaic systems."
- Question 42: "I am very interested in how technical things, such as computers and engines, work."
- Question 27: "If something needs repair at my house, I like to try to fix it myself."
- Question 36: "The timing is about right for me to invest in a residential photovoltaic system."

Descriptive Statistics

The descriptive statistics for the continuous variables on data provided by this sample are displayed in Table 4.3. Descriptive statistics for scalar and categorical items are provided in Table 4.4.

Table 4.3 Descriptive statistics for continuous variables

	n	Min	Max	Mean	SD	Skewness	Kurtosis
Recycle regularly	244	1	7	2.02	1.633	1.887	2.820
Climate change concern	245	1	7	2.49	1.425	0.891	0.386
Support environmental orgs	240	1	7	3.67	1.425	0.289	-0.148
Individual actions improve world	245	1	6	1.93	1.010	1.040	0.918
Have installed compact fluorescents	242	1	7	2.45	1.554	1.253	1.063
Consider environment in purchases	245	1	7	2.58	1.283	0.857	0.909
Enviro concern not exaggerated	243	1	7	3.50	1.657	0.179	-0.900
Environmental perception important	245	1	7	3.41	1.419	0.249	0.001
Most willing to sacrifice for enviro	245	1	7	5.15	1.097	-0.717	1.113
Conserving energy is effective	245	1	7	2.78	1.756	1.023	0.055
Utility not doing best for Hawai'i	244	1	7	4.26	1.552	-0.332	-0.445
Moral obligation to do what we can	245	1	5	2.02	0.923	0.503	-0.554
First to try among friends	241	1	7	3.72	1.184	0.113	0.710
Up-to-date with new technology	244	1	6	2.48	1.105	0.447	0.122
Risk taker as seen by friends	242	1	7	3.86	1.314	0.237	-0.057
Like trying new things	245	1	6	2.67	1.075	0.331	0.168
Like to fix things myself	245	1	7	2.70	1.407	0.853	0.389
Interested in how technology works	242	1	7	2.98	1.510	0.640	0.061
Heard PV stories from others	206	1	7	5.00	1.934	-0.530	-0.843
Know someone with PV	223	1	7	3.99	2.523	0.034	-1.688
Understand how PV works	244	1	7	2.87	1.550	0.916	0.435
Sought new info on PV	239	1	7	3.87	1.844	0.170	-0.962
Discussed PV with dealer	225	1	7	4.14	2.354	-0.022	-1.558
Aware of PV tax credits	241	1	7	2.92	1.886	0.874	-0.325
Understand net metering	240	1	7	3.98	1.988	0.116	-1.164
Tell others about solar system	239	1	7	2.95	1.410	0.497	0.091
Self-sufficiency important	245	1	6	2.28	1.074	0.579	-0.028
PV will save homeowners money	243	1	7	2.33	1.375	0.986	0.598
Time is right to buy PV	195	1	7	4.52	1.797	-0.258	-0.729
PV is "right thing to do"	242	1	6	2.31	1.188	0.614	-0.254
PV is not complex	240	1	7	3.84	1.478	-0.140	-0.461
PV would benefit me financially	202	1	7	3.08	1.509	0.409	-0.128
Could comfortably spend $15,000	239	1	7	4.57	1.986	-0.262	-1.218
New home factor in solar purchase	116	1	4	2.18	1.139	0.319	-1.377
Remodel factor in solar purchase	124	1	4	2.40	1.066	-0.009	-1.262
Replace heater factor in solar	141	1	4	2.37	1.210	0.214	-1.515
Lower bill factor in solar purchase	237	1	4	1.24	0.499	2.449	7.634
Tax credit factor in solar purchase	234	1	4	1.49	0.695	1.463	2.128
Utility rebate factor in solar	191	1	4	1.60	0.703	0.935	0.305
Length payback factor in solar	235	1	4	1.84	0.870	0.782	-0.165
Enviro / CO2 factor in solar	235	1	4	1.91	0.858	0.697	-0.150
Oil dependency factor in solar	236	1	4	1.84	0.863	0.829	0.016
PV Purchase Likelihood within year	225	0	6	4.51	1.500	-1.406	1.807
Desire PV (willingness to sacrifice)	224	1	6	3.05	1.345	0.303	-0.976

Table 4.4 Descriptive statistics for scalar and categorical variables

	N	Min	Max	Mean	SD
Income	209	1	7	4.42	1.357
Education	230	3	7	6.13	0.906
Length of solar water heater ownership	245	1	6	2.53	1.714
Years of current home ownership	230	1	5	3.16	1.499
Monthly Electric Bill	243	1	9	3.70	1.740
Future Cost of Electricity	234	1	6	4.15	0.964
Internal discount rate	235	1	7	4.81	1.814
Know what PV is?	245	1	2	1.29	0.455
In home with PV previously?	186	1	2	1.77	0.423
Willingness to pay for PV through savings	217	0	6	2.31	1.585
Total number of information sources	245	0	9	1.81	1.745

The data collected on each survey item was assessed for normality. Because the data violated the Kolmogorov-Smirnov statistic (significance value below 0.05 for each question), the data were assumed not to be normally distributed. Empirical examination of the histograms created from the data for each survey item confirmed the assumption. Therefore, non-parametric tests were used for the analyses that follow, with the exception of the path model where latent variables were found to be normally distributed. Random sampling and independence of samples was assumed for all statistical analysis. Responses from the Likert scale questions are treated as continuous variables for analysis purposes.

The majority of the relationships explored in the following analysis employed two non-parametric tests. Spearman's Rank Order Correlation (r_s) was used to calculate the strength and direction of the correlation between the desire dependent variable and the attribute of interest. Mann-Whitney U test was used as a non-parametric alternative to the t-test for independent samples to examine the differences between groups on each attribute of interest. Significant differences between the adopter and non-adopter groups are indicated with probability values at or below 0.05 ($p \leq 0.05$).

In addition to the above statistical tests, Pearson chi-square (X^2) tests for independence were used to analyze categorical variables (e.g. yes/no) and Kruskal-Wallis chi-square (X^2) tests for scalar variables (e.g. income). The significance of the difference ($p < 0.05$) between adopter groups based on survey items and the strength of the relationship (or percentage of variance explained) between a survey item and the GPV desire variable were used to accept or reject the proposed hypotheses.

CHAPTER 5
RESULTS

Testing Hypothesis

Traits of Innovativeness

Rogers (1995) proposed that innovators and early adopters possess characteristics that differentiate themselves from later adopters, including higher social status, more years of formal education, and higher income level. Rogers also found that earlier adopters demonstrate more interest in new ideas and are more likely to be risk-prone. Qualitative and quantitative examination of GPV adopters and near-adopters in this study found mixed support for demographic and socio-economic differentiation. Evidence of other early adopter behavior among GPV adopters was found but the data provided no evidence of risk-taking behavior.

In this sample, no significant difference was found across income categories in respondents' level of GPV adoption desire (Kruskal-Wallis $p > 0.05$), nor was a significant difference found in income level between the Adopter and Non-adopter purchase intent groups (Pearson Chi-square $p > 0.05$). Results on income level may highlight one of the weaknesses in this particular survey sample of "near adopters." Since all respondents were individuals who have owned a home for a number of years on O'ahu, it is assumed that they have all amassed a certain amount of wealth. Table 5.1 shows the statistical results for these items (values in gray in subsequent tables indicate lack of significance, $p > 0.05$).

Further, annual income may not be the most appropriate metric for measuring wealth. Responses to a survey item that asked if the respondent "could comfortably spend $15,000 on a major purchase without adversely impacting my lifestyle or financial situation" provided another measure of "wealth." On that measure, individuals who have greater ability to spend $15,000 are both more interested in adopting GPV (Spearman's r_s rs = 0.235 at $p < 0.001$ significance) and more inclined to do so (Mann-Whitney U $p < 0.5$ between adopter groups) (Table 5.2).

No significant difference was found across education levels in respondents' level of GPV adoption desire (Kruskal-Wallis $p > 0.05$), nor was a significant difference found in education levels between the Adopter and Non-adopter purchase intent groups (Pearson Chi-square $p > 0.05$).

Table 5.1 Statistical results for income and education variables

Item	Desire			Purchase Intent		
	n	Kruskal-Wallis X^2	*p*	*n*	Pearson X^2	*p*
*Income**	222	2.418	0.7888	190	6.966	0.2232
Education	217	7.180	0.0664	185	1.925	0.5881

** the two highest and two low income categories were collapsed in this analysis to avoid a violation of the "minimum expected cell frequency" assumption for Pearson Chi-square test.*

Focus group participants (all of whom owned a GPV system) tended toward higher income levels (greater than $100,000 annually) and were all business professionals, academics, and engineers (see Table 4.1). One participant, however, claimed she had no discretionary income for the GPV purchase and instead used a home improvement loan to finance 100% of the system.

Regarding other "early adopter" behavior by GPV adopters, results were mixed (Table 5.2). Respondents were more likely to be "the first to try something among friends" for those who intended to adopt GPV (Mann-Whitney U $p < 0.05$ between adopter groups), but no significant correlation was found for those interested in GPV (Spearman's $p > 0.05$). On the survey question regarding interest in trying new things, both a positive relationship was found between new item interest and GPV adoption interest (Spearman's $r_s = 0.291$ at $p < 0.0001$ significance) and between new item interest and purchase intent (Mann-Whitney U $p < 0.05$ between adopter groups). Focus group discussions suggested similar results. When participants were asked if they frequently were among the first to try new products, the reaction was mixed. Some said they like to be out front, but others were very late adopters with some common technology. One participant offered "I like change, I like new stuff, I go for it." But another participant was not so eager for change, saying: "I have dial-up internet, I don't have cable, my wife got her first cell phone about 3 months ago. We are living in the 1980s, I'll tell you what. We do have a microwave, but no laptop, no iPods, just don't need it."

Evidence of risk-taking among GPV adopters was not found. Risk-taking behavior was not significantly correlated with GPV adoption desire (Spearman's $p > 0.05$) nor was a significant difference in risk-taking behavior found between adopter groups (Mann-Whitney U $p > 0.05$). In the focus groups, participants largely felt they were risk averse in financial decisions, but the behaviors of a few participants suggest they are risk-prone (diving with sharks, driving race cars). All believed the risk they were taking with GPV was carefully calculated, not simply "rolling the dice." One participant offered: "Not a risk taker, I like the sure thing."

Table 5.2 Statistical results for traits of innovativeness, disposable income variables

	Desire			***Purchase Intent***		
Item	*n*	Spearman's (r_s)	*p*	*n*	Mann-Whitney U	*p*
Could comfortably spend $15k	220	0.2351	0.0004	189	2610.5	0.0163
First to try something among friends	223	0.0611	0.3635	192	2465.0	0.0011
Like trying new things	226	0.2911	0.0000	194	2706.0	0.0089
Risk taker as seen by friends	223	0.0776	0.2484	192	3202.0	0.3542

Based on data from this sample examined, Hypothesis 2 is rejected.

H_2. *GPV adopters are more likely to exhibit:*

- *More years of formal education;*
- *Higher income;*
- *Greater frequency of early adoption behavior; and*
- *Greater propensity to take risks.*

While some support was found for Hypothesis 2 regarding education and some early adopter behavior, evidence for the relationship between income level and adoption was inconclusive. Similar results were found with typical early adopter behaviors (ie. risk-taking). Given the high upfront cost of a GPV system, it would seem intuitive that those with greater income would be more inclined to purchase. But as the data demonstrated, income alone did not clearly differentiate between levels of interest and purchase intent. What did differentiate, however, was the ability to spend $15,000 without adversely impacting the homeowner's financial situation. Outliers do exist, though, as shown by the participant who completely financed her system. While these findings are contrary to Labay's and Kinnear's 1981 examination of solar water heater adopters, the results aren't entirely without precedent. Diamantopoulos, et al. (2003) similarly found only partial support for the majority of socio-demographic variables previously thought to predict innovative pro-environmental attitudes and actions.

Knowledge and Diffusion

Knowledge of an innovation is the first stage of Rogers' conceptual model of the innovation-decision process (Rogers 1995). Others have attempted to separate this knowledge stage into familiarity and direct experiences (Alba and Hutchinson, 1987 and Kaplan, 1999). This study examines knowledge and direct experience.

Knowledge of GPV was tested with a survey item asking if the respondent understands how a GPV system works. This understanding was significantly correlated with GPV desire (Spearman's r_s = 0.310 at $p < 0.0001$) and distinguished between adopter intent groups (Mann-Whitney U $p < 0.05$ between adopter groups) (Table 5.3). This finding may simply be a trait of innovators and early adopters in general. Staying "up-to-date" with new technology was also significantly correlated with GPV desire (Spearman's r_s = 0.226 at $p < 0.001$) and a difference was found between purchase intent groups (Mann-Whitney U $p < 0.01$ between adopter groups).

Table 5.3 Statistical results for knowledge variables

	Desire			***Purchase Intent***		
Item	*n*	Spearman's (r_s)	*p*	*n*	Mann-Whitney U	*p*
Understand how PV works	225	0.3095	0.0000	193	2702.5	0.0121
Up-to-date with new technology	226	0.2261	0.0006	194	2652.5	0.0058

These results are supported by focus group participants, where many had some technical background or understanding of electric technology. Most had an understanding of GPV before they purchased. Hypothesis 7 is thus accepted.

> ***H_7.*** *An understanding of GPV systems is a necessary component in the decision to adopt GPV and GPV adopters exhibit a greater level of this knowledge than non-adopters.*

Interestingly, one focus group participant suggested that: "People don't have to know how an internal combustion engine works in order to take advantage of it. What they really do have to know, though, is the utility of having that conveys value to their lives." This insightful quip speaks to Rogers' notion of the "relative advantage" that an adopter finds in an innovation over an existing product or practice. "Knowledge" as tested in this study may become less important as GPV technology improves and diffuses. This concept will be explored further in later sections.

Rogers (1995) suggested that an innovation's "observability," or direct experience, was one of five attributes affecting the rate at which an innovation is adopted. He theorized the easier it was for individuals to see and experience and innovation, the more likely they would be to adopt it. To test this theory for the adoption of GPV, respondents were asked if they were aware of any time that had been inside a house that had a GPV system. No significant correlation was found for this "in-home" experience and level of GPV desire (Kruskal-Wallis $p > 0.05$) nor was a significant difference found between adopter groups for this attribute (Pearson Chi-square $p > 0.05$). See Table 5.4.

Table 5.4 Statistical results for direct experience variable

	Desire			***Purchase Intent***		
Item	*n*	Kruskal-Wallis X^2	*p*	*n*	Pearson X^2	*p*
Been inside house with PV	173	0.6120	0.4340	151	0.000	0.9860

Thus, Hypothesis 1 is rejected.

H_1. *The propensity of a homeowner to adopt GPV is positively influenced by the homeowner's direct experience with a GPV system owned by a friend, neighbor, or relative.*

Most focus group participants, however, did have direct experience with another residential GPV system at some time before purchasing. Some had seen systems and talked with the owners, others had actually climbed up on the roof with the owners. Only one had had no experience whatsoever with GPV, stating: "None, zero experience, no exposure, nothing. It all sounded good. It turned out to be good."

Innovations are diffused among individuals and organizations through a variety of communication channels. Rogers (1995), Geroski (2000), and others have attempted to explain the rate of diffusion based on the type and method that information is spread, the source of information, and potential adopter's direct experience with a new technology.

Results of this study regarding diffusion compared favorably to findings in previous literature on diffusion of innovations.

Survey questions sought to understand the near-adopters exposure to information and "change agents," those who, according to Rogers (1995), positively influence innovation decisions. Table 5.5 contains the results of the analysis of those survey items. Respondents' knowledge of someone who owned a GPV system was not significantly correlated to GPV interest level (Spearman's $p > 0.05$) or purchase intent (Mann-Whitney U $p > 0.05$ between adopter groups). This finding is at odds with Rogers' theory that individuals are more likely to adopt if peers or other individuals in their social network have adopted (Rogers, 1995). The small number of GPV systems currently in use, however, may play a role in limiting the near-adopters' exposure. But simply learning about GPV systems from friends and family was significantly correlated with GPV purchase desire and intent. When asked if they had heard stories about GPV from friends, family, or neighbors, respondents' answers revealed a correlation between receiving stories and GPV desire (Spearman's $r_s = 0.161$ at $p < 0.05$). A significant difference was also found in purchase intent on this item (Mann-Whitney U $p < 0.05$ between adopter groups).

Table 5.5 Statistical results for communication channel variables

	Desire			***Purchase Intent***		
Item	*n*	Spearman's (r_s)	*p*	*n*	Mann-Whitney U	*p*
Know someone with PV	206	0.1310	0.0605	177	2653.5	0.2691
Heard PV stories from others	189	0.1610	0.0269	161	2072.5	0.0345
Discussed PV with dealer	206	0.3231	0.0000	176	2281.0	0.0102

A stronger correlation was found between those respondents who discussed GPV with a solar dealer or contractor and the respondent's desire to purchase (Spearman's $r_s = 0.323$ at $p < 0.001$). A significant difference also existed in purchase intent (Mann-Whitney U $p < 0.05$ between adopter groups). This suggests that solar dealers are serving as the most significant change agents at the current stage of diffusion. It is unclear, however, if the interest or purchase intent came before or after discussing GPV with the dealer or contractor. Interest may have driven respondents to seek more information from a solar dealer. Additionally, the two survey items "heard GPV stories from others" and "discussed GPV with a dealer" are strongly correlated

(Spearman's r_s = 0.581 at $p < 0.001$), making it difficult to discern the exact diffusion process.

The survey also queried respondents about their sources of GPV information. They were asked to select all of the sources they had used to learn about GPV (ie. internet, newspaper article, home show, advertisement, books, electric utility, magazine article, etc). Chi-squared tests showed no significant differences between the type or number of information sources and either GPV desire or purchase intent. The total number of sources cited, however, was significantly correlated with a greater understanding of how GPV works (Spearman's r_s = 0.399 at $p < 0.001$).

Focus group participants cited a variety of information sources they used to learn more about GPV. Books, home shows, and other individuals were the initial sources used to explore GPV. When the purchase point neared, adopters sought out solar contractors and GPV owners as the main sources of information[16]. Solar contractors seemed to be the information source that finally motivated the adoption decision. Some of the focus group responses:

- "I was getting the *Real Goods Catalog*, so I ordered the *Solar Sourcebook*. Remember, this was before the Internet. So I just read the heck out of that."
- "Another super source of information is that guy Louis at Inter-Island Solar Supply. You start talking to him, he talks non-stop. He sells wholesale. He's a great source of information."
- "I had bought some books at various times, probably from *Real Goods*, that's where I learned my technology."
- "If someone has one [a GPV system], I grill them and move on. I know that sounds strange. But I'm interested in everything..."
- "I saw a home show demonstration of a number of different things and they mentioned grid tie [photovoltaic] and I just had a big epiphany."

Based on these results for GPV communication channels, Hypothesis 3 is accepted.

[16] As an indicator of the immaturity of the GPV industry on O'ahu, about half of the focus group participants cited the same solar contractor as their GPV installer—they were all referred to him by another source.

H_3. *The propensity of a homeowner to adopt GPV increases with the greater amount of exposure to a GPV change agent (be it a salesperson, friend with GPV, or other source serving in a "change agent" role).*

Again, while no relationship was found in this sample between knowing someone with GPV or experiencing it firsthand and GPV purchase desire or intent, this finding may be unique to this particular sample and adoption stage, possibly owing to the small number of systems currently in use. An early study of adoption of solar water heaters found that the number of friends or peers with the technology was the best predictor of adoption of solar (Leonard-Barton, 1981). A more recent study of solar water heaters in the United Kingdom found the opposite result, with the "observability" trait not distinguishing the level of interest in adopting. The role of "observability" for diffusion of GPV remains an open question for future research.

The results in this study regarding knowledge, diffusion, and communication channels are otherwise largely consistent with Rogers' (1995) theory. The findings show that greater understanding of GPV correlates with increased desire and a significant difference between purchase intent groups exists regarding GPV understanding. GPV adoption interest also correlates with greater exposure to stories about GPV from friends or through discussions with a solar dealer. Mass media channels, as measured through the total number of sources used, was correlated with knowledge but not GPV purchase desire or intent. This result is congruent with Rogers' theory that mass media channels are more effective in creating knowledge of innovations, whereas interpersonal channels are more effective in forming and changing attitudes toward a new idea, and thus in influencing the decision to adopt or reject a new idea (Rogers, 1995).

Economics

An innovation's "relative advantage" as compared with an existing product or practice is central to Rogers' theory of adoption (Rogers, 1995). Relative advantage may be measured in cost savings, increased convenience, more satisfaction, or some other attribute that is important to the adopter. Rogers makes clear that it is the adopter's perception of the relative advantage of an innovation, as opposed to the objective advantage, that drives the decision to adopt (Rogers, 1995). This section will discuss the results of the perceived economic value of GPV, while later sections will examine other GPV values regarding relative advantage.

Previous studies regarding energy-saving investments have found that the perceived savings and the certainty of those savings were important components in the decision to adopt (Vollink, et al., 2002). In this sample, agreement with the statement "A GPV system will save homeowners money" was significantly correlated with desire to purchase GPV (Spearman's r_s = 0.226 at p < 0.001). See Table 5.6 for results. No difference was found, however, in purchase intent (Mann-Whitney U p > 0.05 between adopter groups). Perhaps those coming closer to actually adopting have recognized that purchasing GPV is not necessarily an obvious money saver for all households.

Table 5.6 Statistical results for economic variables

	Desire			***Purchase Intent***		
Item	*n*	Spearman's (r_s)	*p*	*n*	Mann-Whitney U	*p*
PV will save homeowners money	224	0.2259	0.0007	192	3232.5	0.4040
PV will benefit me financially	199	0.4070	0.0000	170	1833.0	0.0003
Future cost of electricity will increase	216	0.1917	0.0047	185	3132.5	0.7104
Lower internal discount rate	220	0.1452	0.0314	189	3068.5	0.5851

A stronger correlation was found between agreement with "a GPV system would benefit me financially" and purchase desire (Spearman's r_s = 0.407 at p < 0.0001). A significant difference was also present in purchase intent (Mann-Whitney U p < 0.001 between adopter groups). Differences in responses between these two questions could perhaps be explained by respondents thinking "the average homeowner" may enjoy less savings than the respondent would based on his or her particular energy usage or financial situation. These findings offer support for accepting Hypothesis 4.

H_4. *GPV adopters believe the cost savings and the certainty of those savings from using a GPV system will be greater than what non-adopters believe.*

Many focus group participants suggested economics were driving part of their decision to adopt GPV, although few had a firm understanding what the payback or return on investment would be for their system. Some thought that solar was a "safe" investment over the long run because of the escalating price of electricity and as a buffer to inflation. Some of the comments offered included:

- "The economics had to be close. Wasn't going to do it strictly as a novelty. It had to make some reasonable sense from the economics and the electric side."
- "Not an easy number to calculate, but it looks like that payback's going to be about 16 years. Then you can look at it as a dividend, you're getting a $60 to $70 per month savings in your electric bill. That's initially 5% dividend, then 10% with the credit back. I wish I had stocks that pay that kind of dividend."
- "I consider solar an investment, so the plan is to greatly increase our solar as much as we can. That, to me, is a much more "safe" investment than being in these mutual funds."

The relative economic advantage of a GPV investment is largely a function of the future cost of utility-provided electricity. Should utility electricity increase significantly over the life of the GPV system, the relative economic advantage of that system likewise increases. Results from this sample provide support for this type of perceived relative advantage. Respondents' estimated level of electricity price increase over the next decade was significantly correlated with purchase desire (Spearman's $r_s = 0.192$ at $p < 0.005$). No difference was found in purchase intent (Mann-Whitney U $p > 0.05$ between adopter groups). This mixed result mirrors the mixed results in past studies regarding future price increase. Jaffe and Stavins (1993) found that, under certain circumstances, customers adoption decisions are influenced by existing electricity prices, without regard to potential future price escalation.

All focus group participants felt that the price of oil and electricity would rise in the future. Some predicted dramatic increases in the near- and long-term. One participant mentioned solar as a hedge on electricity-price volatility. Based on the above results, Hypothesis 5 is accepted.

> ***H_5*****.** *GPV adopters perceive that the price of electricity will increase in the future by a greater amount than what non-adopters perceive.*

Another factor affecting a potential adopters' perception of economic relative advantage was their time value of money, or internal discount rate. As discussed earlier, numerous studies have shown that by foregoing certain energy efficiency investments, individuals demonstrate implied discount rates that are much higher than the prevailing discount rate (Sanstad, et al., 1995). To a certain extent, this “suboptimal” behavior of consumers can be explained by the simple lack of understanding of discounting, energy costs, and financial analyses by consumers (Sanstad and Howarth, 1994). While a purely rational decision maker will apply the going consumer discount rate to evaluate projects or compare investment alternatives, it is clear by the implicit rates suggested in the literature reviewed above that some sort of “internal,” or personal, discount rate is being applied. This personal discount rate likely varies with an individual’s values, financial situation, and other factors.

Results from this sample found that lower internal discount rates weakly correlate with greater GPV purchase desire (Spearman’s $r_s = 0.145$ at $p < 0.05$). No difference was found between internal interest rate and purchase intent (Mann-Whitney U $p > 0.05$ between adopter groups).

Hypothesis 11 is provisionally accepted:

> ***H_{11}.*** *GPV adopters demonstrate a lower internal, or personal, discount rate than non-adopters.*

Relative advantage of GPV, as it relates to economics, is demonstrably greater for those who desire to purchase GPV in this sample. In particular, the belief that GPV will be of financial benefit appears to have the strongest relationship with both the desire and intent to purchase a GPV system.

Environmental Beliefs, Behaviors, and Image

Perhaps the primary distinguishing attribute of GPV-produced electricity compared with conventional utility or fossil fuel powerplant-generated electricity is its reduced environmental impact. It is estimated that a typical GPV system on O‘ahu would offset over four and one-half tons of greenhouse gas emissions annually, based on current electricity generation (State of Hawai‘i, 1998). GPV adopters may perceive this reduced greenhouse gas production and overall reduced environmental burden as a significant relative advantage over conventional electricity production. This study hypothesized that these individuals would possess both pro-environmental beliefs and participate in pro-environmental behaviors. They would also recognize the effectiveness of GPV in reducing the environmental burden of electricity use and make that connection to their own values. Perhaps they also seek to project an environmental image through a public display of GPV. Results from the survey on these four areas (environmental beliefs, behaviors, GPV effectiveness, and conservation image) are explored below.

Two survey items queried near-adopters about their pro-environment beliefs Table 5.7 displays the statistical results for these two items. The first asked about their level of concern over global climate change and its effects. Greater concern was significantly correlated with desire to purchase GPV (Spearman's $r_s = 0.227$ at $p < 0.001$) and a significant difference was also present in purchase intent (Mann-Whitney U $p < 0.05$ between adopter groups). The second item asked whether the respondent believed that environmental concern was exaggerated. Stronger disagreement with that statement was correlated with desire to purchase GPV (Spearman's $r_s = 0.184$ at $p < 0.01$), but no significant difference was found in purchase intent (Mann-Whitney U $p > 0.05$ between adopter groups). The lack of difference between the Adopter and Non-adopter purchase groups might suggest that actual adopters are less compelled by environmental beliefs alone (although a significant difference was found on the "climate concern" attribute).

Table 5.7 Statistical results for pro-environmental belief variables

Item	Desire			Purchase Intent		
	n	Spearman's (r_s)	*p*	*n*	Mann-Whitney U	*p*
Concerned about climate change effects	226	0.2272	0.0006	194	2809.5	0.0236
Environmental concern is not exaggerated	224	0.1842	0.0057	192	2892.0	0.0858

Respondents were also queried about their participation in a range of pro-environmental behaviors. Behaviors included recycling, consideration of environmental impacts in purchasing decisions, supporting environmental organizations, and installing energy efficient lighting. Since all respondents had already made the decision to install solar water heating, they were asked whether the environment, greenhouse gas emissions, and oil dependency were factors in their purchase decision. Increased agreement with participation in all the tested pro-environment behaviors was significantly correlated with desire to purchase GPV (Spearman's r_s between 0.142 and 0.342 with $p < 0.05$; see Table 5.8). Differences were also found between GPV purchase intent groups (Mann-Whitney U $p < 0.05$) for all behaviors except installation of compact fluorescent lightbulbs. These results are consistent with literature regarding belief and behavior reviewed earlier in this study.

The anomaly—that there was no significant difference between purchase intent groups on the installation of compact fluorescents—is a surprising result. Although both non-adopter and adopter groups likely participate in the behavior (the mean for this item was between "strongly agree" and "somewhat agree"), a difference should have emerged. Recycling participation had a lower mean ("strongly agree"), yet a difference was still found between groups. Installing a GPV system before making high-efficiency lighting retrofits would be highly irrational, with the cost savings from compact fluorescents a few orders of magnitude greater than creating electricity from a GPV system.

Table 5.8 Statistical results for pro-environmental behavior variables

	Desire			***Purchase Intent***		
Item	*n*	Spearman's (r_s)	*p*	*n*	Mann-Whitney U	*p*
Regularly recycle	225	0.1419	0.0334	194	2789.5	0.0121
Consider environment in purchases	226	0.2766	0.0000	194	2673.0	0.0075
Support environmental causes and organizations	221	0.2031	0.0024	189	2633.0	0.0130
Installed compact fluorescents	223	0.2315	0.0005	191	3175.5	0.3432
Oil dependency factor in solar water buy	222	0.3415	0.0000	191	2121.0	0.0001
Environment / greenhouse factor in solar water	221	0.2475	0.0002	190	2706.0	0.0451

The majority of focus group participants expressed concern for the environment and claimed they were active in other "green" behavior. Along with a photovoltaic energy system, all of the participants had a solar hot water energy system installed on their homes. Many of the participants also drove hybrid cars, recycled, composted, belonged to environmental groups, and were active on issues. Some comments from participants included:

- "I ride the bus to work; my wife drives a Prius."
- "Oh yeah, major recycler."
- "[I was] one of the early founders of [various local environmental non-profit organizations], and so it's been its definitely been a kind of consciousness."

- “I’m also a bit of a tree-hugger...We’re using oil like crazy on this island especially.”

Based on the above findings, Hypothesis 8 is accepted:

> ***H_8.*** *The propensity of a homeowner to adopt GPV is positively correlated with the homeowner’s pro-environmental orientation and level of involvement in other pro-environment behaviors.*

Respondents’ belief that conserving energy at home has an overall impact on energy use was significantly correlated with desire to purchase GPV (Spearman’s r_s = 0.265 at $p < 0.001$), but no significant difference was found in purchase intent, although the result was close to significant (Mann-Whitney U $p > 0.05$) (See Table 5.9). Hypothesis 9 is accepted:

> ***H_9.*** *GPV adopters are more likely to perceive that an individual’s energy conservation can actually make a difference in overall energy use.*

This is consistent with previous research suggesting that the belief in the ability “to make a difference” would have a positive effect on pro-environmental action (Ellen, et al., 1991). According to McCarty and Shrum (2001), the beliefs about the importance of pro-environmental behavior also predict such behavior. They found that specific beliefs on the importance of recycling directly influenced recycling behavior. The result from this sample is also congruent with Jenkins 2001 study of consumer interest suggesting that pro-environmental homeowners are more likely to view GPV favorably.

For some, pro-environmental behavior is part of their social identity. A publicly visible GPV system on the roof of their home would thus be compatible with the value system they wish to project. Greater agreement with the statement “It is important to me to be seen as someone who is concerned about the environment” was significantly correlated with desire to purchase GPV (Spearman’s r_s = 0.17 with $p < 0.05$). A difference between GPV purchase intent groups was also found (Mann-Whitney U $p < 0.05$).

Similarly, those interested in GPV tended to tell others stories about their existing solar water device. Increased pleasure in telling others about their solar water system significantly correlated with desire to purchase GPV (Spearman's $r_s = 0.27$ with $p < 0.0001$), however, no difference was seen between GPV purchase intent groups (Mann-Whitney U $p > 0.05$).

Table 5.9 Statistical results for perceived effectiveness and environmental social image variables

	Desire			***Purchase Intent***		
Item	*n*	Spearman's (r_s)	*p*	*n*	Mann-Whitney U	*p*
Conserving energy is effective	226	0.2645	0.0001	194	2908.0	0.0510
Environmental image important	226	0.1701	0.0104	194	2862.0	0.0366
Enjoy telling others about solar	221	0.2659	0.0001	189	2904.5	0.1337

Focus group participants also suggested that they were interested in projecting a conservation image. One participant offered that one of the reasons they installed a GPV system was "so people could see it."

Hypothesis 6 is therefore accepted:

> ***H_6.*** *Being perceived as having a "conservation" image is more important to GPV adopters than to non-adopters.*

The idea that purchase of a new innovation would bolster a social image has been supported by previous research (Fisher and Price, 1992, and Grewal, et al., 2000). Grewal, et al (2000) in particular found that attitudes that particularly serve a social-identity can drive consumer innovativeness and opinion leadership. Public displays of conservationist behavior to project a pro-environment value, such as driving a clearly distinguishable hybrid vehicle, have also been examined (State of Oregon, 2003). The pro-environment image of the behavior, in fact, may override other, more "functional" values (Heffner, et al., 2005). This may be thought of as a sort of "conspicuous conservation," the environmental equivalent of "conspicuous consumption," where buyers consume to project an image of wealth. Residential photovoltaic, as it is largely visible on a home's roof, is a product whose adoption rate could benefit from the pro-environment image that it offers the owner.

Results from this sample largely confirm that GPV, as a pro-environment innovation, will more likely be adopted by those who both possess pro-environment values and participate in pro-environment behaviors. The adopters are more likely to perceive that the innovation is effective in reducing overall energy use, thus it is compatible with their desire to reduce their environmental burden. Those more inclined to adopt GPV were also more interested in projecting a pro-environment image. They were also slightly more evangelistic about telling others about their solar system. With reduced environmental impact being a distinguishing attribute of GPV, pro-environment consumers are more likely to be adopters in the early stages of diffusion than those ambivalent to environmental concerns.

Values

In addition to environmental benefit and long-term financial savings, a GPV system may provide relative advantage over conventional electricity sources in other ways. Producing energy at home may satisfy a desire to be more self-sufficient, and it may provide the owner with a sense of "doing their part" to make the world a better place. It was hypothesized that both desire for self-sufficiency and attitudes regarding the role of individual actions in affecting society would be related to GPV adoption interest.

The level of importance for "self-sufficiency" was significantly correlated with desire to purchase GPV (Spearman's $r_s = 0.329$ at $p < 0.001$) and a significant difference was found between purchase intent groups (Mann-Whitney U $p < 0.001$). (See Table 5.10 for all statistical results on values variables.) Focus group participants also cited self-sufficiency as a motivator to purchase GPV:

- "I would say equally...economics and wanting to be self-sufficient."
- "Environmental. Without a doubt. And then after that self-sufficiency..."
- "Well, there was a little bit of the self-sufficiency motivation."

Based on these findings, Hypothesis 12 is accepted:

> ***H_{12}.*** *The propensity of a homeowner to adopt GPV is positively correlated to their desire to be self-sufficient and provide for themselves.*

Table 5.10 Statistical results for values variables

Item	Desire			Purchase Intent		
	n	Spearman's (r_s)	*p*	*n*	Mann-Whitney U	*p*
Self-sufficiency is important	226	0.3286	0.0000	194	2431.5	0.0006
Individual actions improve the world	226	0.3208	0.0000	194	2877.5	0.0355
Moral obligation to do what we can	226	0.3404	0.0000	194	2398.0	0.0004
PV is the "right thing to do"	223	0.4945	0.0000	191	1923.5	0.0000

The desire to be self-sufficient was found to be a primary motivation in early solar adoption studies (Sawyer, 1982; Labay, et al, 1981; Jenkins, 2001). Much of this earlier research either examined solar water heating systems or off-grid photovoltaic applications, as opposed to grid-tied (GPV) systems. As discussed at the outset of this study, GPV systems do not necessarily provide a source of backup power should the power grid fail. Most systems rely on a functioning grid to operate (unless a battery backup system is in place). The concept of self-sufficiency in this case might relate to GPV as such systems generate power onsite from the sun, decreasing reliance on external sources for electricity (and the fossil fuels that are typically used to generate it).

Respondents' belief that "individual actions can make the world a better place" was significantly correlated with desire to purchase GPV (Spearman's $r_s = 0.321$ at $p < 0.0001$) and a significant difference was also present in purchase intent (Mann-Whitney U $p < 0.05$ between adopter groups). A similar result was found with the belief that a moral obligation exists to "do what we can." Agreement with that item correlated with desire to purchase GPV (Spearman's $r_s = 0.340$ at $p < 0.001$) and a significant difference was found between purchase intent groups (Mann-Whitney U $p < 0.001$). Focus group participants also vocalized their belief that individual actions make a difference and a moral obligation exists to take those actions:

- "…what you can do as an individual citizen you can do everything you can to not burn fossil fuels."
- "It was almost a moral decision in a way. It's just that there is sun available and we are running out of fuel... we need to do our part."
- "I felt an obligation to my kids and future generations."

The survey item that produced the strongest correlation with GPV purchase desire related to the belief that GPV is “the right thing to do.” Agreement with this item was strongly correlated with desire to purchase GPV (Spearman’s $r_s = 0.495$ at $p < 0.0001$) and a significant difference was also present in purchase intent (Mann-Whitney U $p < 0.0001$ between adopter groups). A focus group participant also suggested this as the main motivator for adopting: “I did it because it was the right thing to do.”

Based on the above findings, Hypothesis 10 is accepted.

H_{10}. *GPV adopters, as compared with non-adopters, are more likely to believe that investing in renewable energy is the “right thing to do” and they have a moral obligation to “do their part.”*

The idea that GPV is “the right thing to do” clearly embodies a host of subjective values. Depending on the individual, GPV might be perceived as the “right thing” to reduce global climate change, to save money, or to reduce dependency on foreign oil, or another outcome that is personally valued. Regardless, recognition that GPV can satisfy the potential adopter’s need is strongly associated with the desire to adopt.

Values beyond economic and environmental benefit appear to be related to desire and intent to purchase GPV. These findings are congruent with previous research on the adoption of pro-environmental innovations (Ellen, et al., 1991; McCarty and Shrum, 2001). Notable in the results from this sample are the seemingly strong relationships between the value statements and both the desire and purchase intent dependent variables.

Summary of Results of Hypotheses Testing

This section examined the characteristics, beliefs, motivations, and behaviors of solar thermal owners (“near adopters”) and the relationship of those items with the interest or intent to purchase a GPV system. Of the 12 hypotheses tested, support was found for 10.

In this sample, little support was found for Rogers’ traditional “early adopter” attributes of greater income, higher level of education, and risk-prone behavior. Evidence of other early adopter behavior among GPV adopters was found but the data provided no evidence of risk-taking behavior. Given the high upfront cost of a GPV system, it would seem intuitive that those with greater income would be more inclined to purchase. But as the data demonstrated, income alone did not differentiate between levels of interest and purchase intent. What did clearly differentiate, however, was the ability to spend $15,000 without adversely impacting the homeowner's financial situation. The role of this "discretionary" funding will be explored further in the decision path model.

A correlation was found between near adopters' level of understanding of GPV and their interest in adopting. This finding lends further support to the role of "knowledge" in Rogers' conceptual model as well as the role of perceived complexity as part of the five attributes driving adoption. Support for the role of "observability" and desire or intent to adopt was less favorable. No significant relationships were found between the two. Given the nature of GPV, direct experience may not be a prerequisite to adoption of such a technology. The main product of a GPV system is electricity, something with which every homeowner is quite familiar. If a satisfactory amount of knowledge exists in the mind of the adopter that the system provides that electricity, "observability" may not be required. These findings support that conclusion, although it is acknowledged that the small number of systems currently installed may skew the measure of "observability."

This research found that communication channels that related to adoption interest were mostly interpersonal as opposed to mass media. The absolute number of sources was not correlated with adoption interest, but receiving information from other people was. A stronger correlation was found between information received from a solar dealer or contractor and adoption interest. Dealers currently seem to be assuming the role as lead "change agents" in the diffusion of GPV. This may simply be an indication of the very low saturation of GPV systems.

This study demonstrated that those most interested in adopting GPV perceive a greater relative advantage in the technology over conventional electricity than do non-adopters. This was found across the values that GPV is believed to provide: economic savings, reduced environmental burden, self-sufficiency, and moral satisfaction.

Respondents in this sample found that the perceived relative economic advantage of GPV over conventional electricity is related to GPV interest. The strongest correlation was the belief that GPV will benefit the homeowner financially—a significant difference was also found between purchase intent groups on this item. As a subcomponent of perceived savings, the belief that the price of conventional electricity would increase in the future was more likely held by interested adopters. A weak correlation was found between lower internal discount rates and adoption interest. These results support both Rogers' original model regarding "relative advantage" as well as more recent research regarding energy-saving investments and the significant role of perceived savings and the certainty of those savings in the decision to adopt (Vollink, et al., 2002). It is important to stress that these were "perceived" economic advantages. As some of the focus group participants suggested, lengthy payback periods and over-estimated savings were common.

To some, GPV presents a relative environmental advantage over conventional electricity. Results of this study largely confirm that GPV—with reduced environmental burden being the primary distinguishing attribute –will more likely be adopted by those who both possess pro-environment values and participate in pro-environment behaviors. Support was also found for the concept of "conspicuous conservation," where the "green" image that GPV might project was associated with GPV adoption interest.

Values beyond economic and environmental benefit appear to be related to GPV adoption interest as well. This analysis showed a significant relationship between GPV adoption interest and the desire for self-sufficiency, even though GPV adopters will most likely remain dependent on grid power for operations. Increased belief in both the role of the individual in making a difference and moral obligation to do so was related to GPV adoption interest. The survey item that produced the strongest correlation with GPV purchase desire related to the belief that GPV is "the right thing to do." This notion can be viewed as a proxy for Rogers' "compatibility" attribute, or "the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters." The extent to which GPV adoption is perceived to reinforce the potential adopter's personal norm strongly correlates with adoption.

This analysis sought to understand the "who" and "why" of GPV adoption interest and intent. Support was found for three of Rogers' five attributes affecting the rate of adoption as they relate to GPV adoption interest: relative advantage, compatibility, and complexity. The idea of "observability," or direct experience, was not found to be related to adoption interest ("trailability" was not examined).

To better understand the relative role of some of the above findings as they relate to the adoption decision, a factor analysis and a path model will be examined in the following section.

Factor Analysis

Factor analysis was used to uncover the latent structure and significant components in the set of variables collected in the near adopter survey. The majority of continuous variable items were subjected to principal components analysis using the SPSS (Statistical Package for Social Sciences) software. Prior to performing the principal components analysis the suitability of the data for factor analysis was assessed. Inspection of the correlation matrix revealed many coefficients of 0.3 and above. The Kaiser-Meyer-Oklin value was 0.80, exceeding the recommended value of 0.6 and the Bartlett's Test of Sphericity had a significance level below 0.001, supporting the factorability of the correlation matrix.

Principal components analysis revealed the presence of ten components with eigenvalues exceeding 1, explaining a total of 62% of the variance. An inspection of the scree plot (Figure 5.1), however, revealed a clear break after the fifth component, suggesting that five components be retained for further investigation. To aid in the interpretation of these five components, Varimax rotation was performed and only those loadings above 0.4 displayed. The rotated solution (presented in Table 5.11) revealed the presence of a simple structure, with all five components showing a number of strong loadings, and most variables loading substantially on only one component. The five factor solution explained a total of 45.8% of the variance, with Components 1 through 5 contributing 18.4%, 9.2%, 7.1%, 6.0%, 5.1%, respectively.

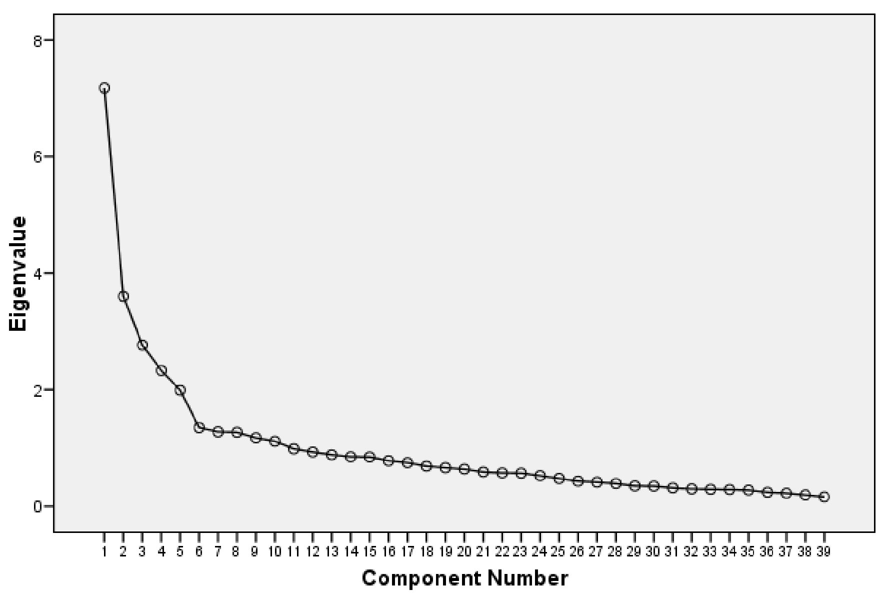

Figure 5.1 Scree plot from principal components analysis

Table 5.11 Principal components analysis rotated component matrix

Item	*Comp 1* ***Environment***	*Comp 2* ***Knowledge***	*Comp 3* ***Innovator***	*Comp 4* ***Persuasion***	*Comp 5* ***Economic***
Enviro / CO2 factor in solar purchase	0.80				
Oil dependency factor in solar purchase	0.70				
Consider enviro in purchases	0.69				
Climate change concern	0.66				
Moral obligation to do what we can	0.62				
Environ concern not exaggerated	0.62				
Support enviro orgs	0.61				
Individual actions improve world	0.52				
Enviro perception important	0.51				
Recycle regularly	0.42				
Heard PV stories from others		0.79			
Discussed PV with dealer		0.76			
Know someone with PV		0.71			
Aware of PV tax credits		0.70			
Sought new info on PV		0.63	0.41		
Understand how PV works		0.58			
Understand net metering		0.51		-0.43	
In home with PV previously?		0.49			
Could comfortably spend $15,000		0.41			
Interested in how technology works			0.70		
Up-to-date with new technology			0.67		
Like trying new things			0.65		
Like to fix things myself			0.61		
First to try among friends			0.59		
Risk taker as seen by friends			0.47		
Tell others about solar system					
Have installed compact fluorescents					
Length of solar water heater ownership					
PV would benefit me financially				0.84	
PV will save homeowners money				0.78	
Self-sufficiency important				0.54	
PV is "right thing to do"	0.43			0.51	
Time is right to buy PV				0.46	-0.41
Education				0.44	
Most willing to sacrifice for enviro					
Utility not doing best for Hawai'i					-0.65
Income					0.57
Monthly Electric Bill					0.50
Future Cost of Electricity					0.47
% of variance explained	**18.4%**	**9.2%**	**7.1%**	**6.0%**	**5.1%**

Note: Only loadings above 0.4 displayed
Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

The interpretation of the five components is consistent with the anticipated latent variable groupings and previous adoption research. The first component clearly contains items most related to environmental motivation and behavior. The second component contains items regarding knowledge and an understanding of GPV. The third component suggests innovativeness-type measures. The fourth component contains items regarding the benefits of GPV (education being the exception, but that item has a fairly low loading of 0.44). The fifth component contains economic-type items. The results of the principal components analysis support the use of the latent, or unobserved, variables "Environmental," "Innovator," "Knowledge," "Persuasion," and "Economic" as separate scales.

Scale Development

Based on the results of the principal components analysis, latent variable scales were developed and tested for reliability and consistency in measuring the underlying constructs. The latent constructs "Environment," "Knowledge," "Innovator," and "Persuasion," with scale items described in Table 5.12, had acceptable reliability based on Cronbach's alpha coefficient (α=.82, .84, .73, and .78, respectively). The construct "Economic" had poor internal reliability (α=.34), so will not be used as a scale. A single observed variable will be used in its place as a measure of economic ability.

Latent variable values for each case were calculated by averaging the responses for each item in the scale (after reversed question items were reordered). The scales (1 to 4) for the two items representing "purchase factors" in the "Environment" construct were recalculated for a seven-point scale ("1" = 1, "2" = 3, "3" = 5, "4" = 7) to match the other items in the scale. No weights were assigned to any items. Missing values were replaced with the mean of the other scale items; cases missing more than two item responses in the scale were recorded as "missing" in the final latent variable value. The resulting latent variables appeared to be normally distributed. Descriptive statistics for the four latent variables are contained in Table 5.13.

Table 5.12 Latent construct scales with reliability measures

Environment *(10 items, α = 0.82)*	**Knowledge** *(7 items, α = 0.84)*
Enviro / CO2 factor in solar purchase	Heard PV stories from others
Oil dependency factor in solar purchase	Discussed PV with dealer
Consider enviro in purchases	Know someone with PV
Climate change concern	Aware of PV tax credits
Moral obligation to do what we can	Sought new info on PV
Environ concern not exaggerated	Understand how PV works
Support enviro orgs	Understand net metering
Individual actions improve world	
Enviro perception important	
Recycle regularly	

Innovator *(6 items, α = 0.73)*	**Persuasion** *(5 items, α = 0.78)*
Interested in how technology works	PV would benefit me financially
Up-to-date with new technology	PV will save homeowners money
Like trying new things	Self-sufficiency important
Like to fix things myself	PV is "right thing to do"
First to try among friends	Time is right to buy PV
Risk taker as seen by friends	

Table 5.13 Descriptive statistics for latent variables in the path model

	n	**Min**	**Max**	**Mean**	**SD**	**Skewness**	**Kurtosis**
Environment	245	1	5.56	2.709	0.907	0.619	0.362
Knowledge	241	1	7	3.786	1.446	0.222	-0.682
Innovator	245	1.17	6	3.063	0.832	0.292	0.115
Persuasion	208	1	6.40	2.956	1.054	0.313	-0.026

Path Model

To understand the relative role of each latent construct as it relates to the interest in GPV adoption, a multiple linear regression was used to test a decision path model formulated in Chapter 3. That decision path model is replicated in Figure 5.3.

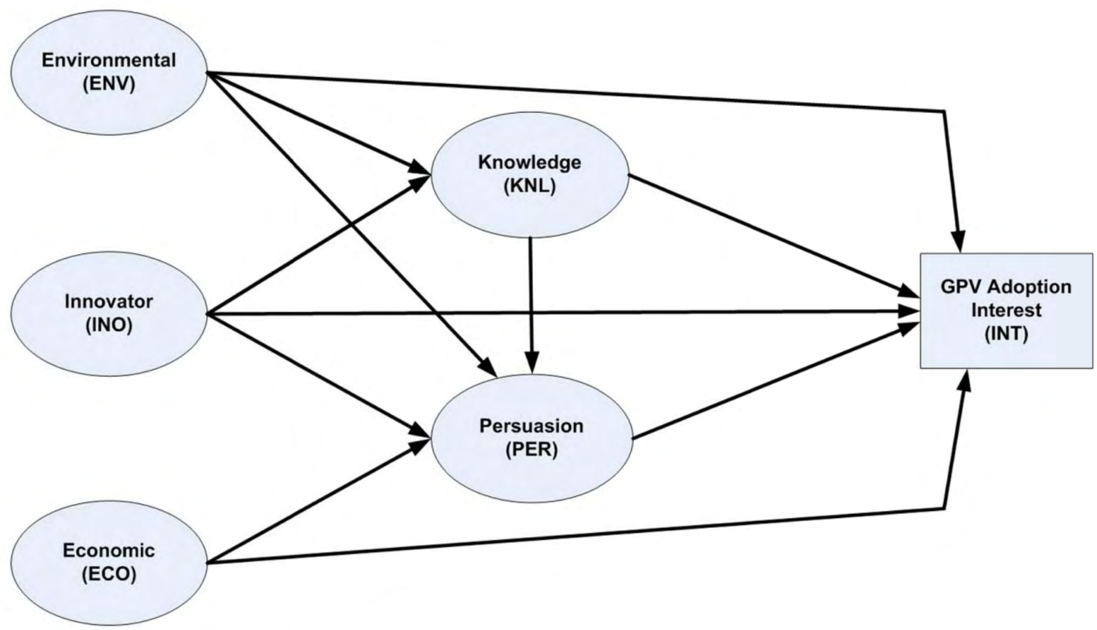

Figure 5.3 Proposed conceptual path model for GPV adoption

The path model consists of the three exogenous variables, two of which are latent constructs (Environment and Innovator) and the third, Economic, represented by the observed variable from the response to the Likert scale survey item: "Could comfortably spend $15,000 on a major purchase." The two intervening endogenous variables are the latent constructs Knowledge and Persuasion. The final endogenous variable is "GPV Adoption Interest," represented in the model by the observed variable measuring the level of desire and sacrifice from the survey question "How much do you want PV on your home?" Interest in this case is equated with adoption intent; attitude-behavior research has shown a clear relationship between intentional and actual behavior. Cases with missing data for this variable were not included in the analysis.

The regression equations from the path model are:

$$KNL_i = a_1 + \boldsymbol{\beta} ENV_i + \boldsymbol{\beta} INO_i \quad (4.1)$$

$$PER_i = a_2 + \boldsymbol{\beta} ENV_i + \boldsymbol{\beta} INO_i + \boldsymbol{\beta} ECO_i + \boldsymbol{\beta} KNL_i \quad (4.2)$$

$$INT_i = a_3 + \boldsymbol{\beta} ENV_i + \boldsymbol{\beta} INO_i + \boldsymbol{\beta} ECO_i + \boldsymbol{\beta} KNL_i + \boldsymbol{\beta} PER_i \quad (4.3)$$

where a_i represents a constant term and β represents the unique beta weights for each path.

The regression model explained 16% of variation in the latent variable Knowledge, 25% of the variation in the latent variable Persuasion, and 36% of the variation in Interest. All equations in the model were statistically significant. Table 5.14 summarizes the results and statistics of the regression analysis.

Table 5.14 Statistical summary of decision path model

Predicting Knowledge: R^2 = 0.16; F-test (F = 22.32) significant at the .0001 level.

KNL	= 1.27	+ 0.27 ENV	+ 0.58 INO
Std. coefs.	0.00	0.17	0.37
t	3.22	2.84	5.59
Sig.	0.001	0.005	0.000

Predicting Persuasion: R^2 = 0.25; F-test (F = 16.05) significant at the .0001 level.

PER	= 0.79	+ 0.42 ENV	+ 0.10 INO	+ 0.03 ECO	+ 0.15 KNL
Std. coefs.	0.00	0.37	0.08	0.05	0.20
t	2.52	5. 79	1.18	0.71	2.82
Sig.	0.012	0.000	0.241	0.478	0.005

Predicting Interest: R^2 = 0.36; F-test (F = 21.76) significant at the .0001 level.

INT	= -0.26	+ 0.30 ENV	0.02 INO	+ 0.07 ECO	+ 0.19 KNL	+ 0.43 PER
Std. coefs.	0.00	0.21	0.01	0.10	0.21	0.33
t	-0.69	3.27	0.21	1.64	3.05	4.99
Sig.	0.494	0.001	0.834	0.103	0.003	0.000

The significant paths ($p < .05$), with their corresponding standardized coefficients, are shown in Figure 5.4.

In this sample, the latent variable representing persuasion has the strongest direct effect on interest in purchasing GPV, with a beta weight of 0.33. Knowledge and environment have equal direct effect, with beta weights of 0.21 each. The innovator construct and the availability of discretionary funding (ability to spend $15,000) had no direct or indirect effect on GPV interest. The environment construct had the greatest *total* effect on GPV interest, with a beta weight of 0.37 (0.16 of indirect effect mediated through knowledge and persuasion combined with its 0.21 direct effect). The total effect from knowledge was 0.28, while the total effect from innovator was 0.08.

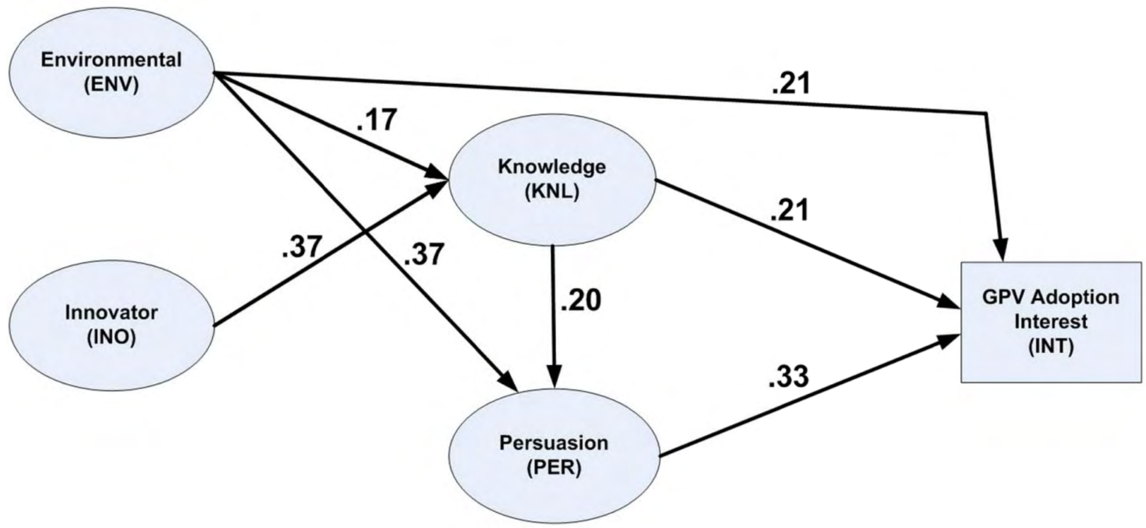

Figure 5.4 Significant paths in conceptual decision model with standardized coefficients

The findings with this model underscore the critical role of persuasion in influencing adoption interest. Again, persuasion is represented here by the beliefs that GPV is financially beneficial and is the "right thing to do," the time is right to buy GPV, and the feeling that self-sufficiency is important. This finding is in line with the persuasion stage in Rogers' (1995) diffusion model, where relative advantage and compatibility help form the level of persuasion in the potential adopter. In this case, relative advantage is indicated by the measure of GPV's financial benefit and compatibility is measured by the item GPV is "the right thing to do." This result is also congruent with previous research that examined motivation to adopt pro-environmental innovations, such as McCarty and Shrum's (2001) examination of recycling behavior. While this role of persuasion seems fairly intuitive, it is useful to show in a path model the strength of persuasion alone over the other significant paths (knowledge and environmental motivations). Persuasion alone is not dispositive, however, and environmental motivations and knowledge play clear roles as well.

The level of GPV knowledge in this case was primarily related to innovation and to a lesser extent environmental motivation. This measure of knowledge embodied not only awareness, but also Rogers' concepts of complexity and experience (it was composed of the survey items: understanding of how GPV works, hearing stories about it, knowing someone who has it, discussed GPV with a dealer, aware of the tax credits and net energy metering). Based on these findings, knowledge alone does not drive adoption interest. Over 60% of those in the "non-adopter" group (those not planning to purchase GPV within the next year) either completely or strongly agree that they understand how a GPV system works. Clearly, another factor is at play. That factor is likely persuasion, where the knowledge combines with attitudes and beliefs and generates a level of persuasion.

The relationships between environment and knowledge and innovation and knowledge are particularly interesting. Stronger environmental beliefs and behaviors have over twice the effect on persuasion as they do on knowledge. This finding is consistent with the results of Bang, et al (2000), where a survey of customers found that willingness to pay for renewable energy was more closely related to emotionally charged beliefs about the environment than knowledge about the technology itself or its impacts. Strong environmental beliefs may enable a potential GPV adopter to forego (or abbreviate) the process of learning about the technology, how it works, and various related information (i.e. net energy metering). One focus group participant, in fact, took this path, investing in GPV with little knowledge or understanding of the technology, but driven by environmental values. In another way, these findings reflect the effects found by Bem (1972) through his Self-Perception Theory. He predicted that if a person takes a pro-environmental action in one area, that person's self-image and attitudes will change in a way that increases his or her likelihood to behave in a pro-environmental manner in other areas (Bem, 1972).

The relatively weak role (and lack of direct role) of the measure of innovation on adoption interest gives the model a strong resemblance to Midgley and Dowling's (1993) "Simplified Contingency Model" of innovative behavior. They proposed that individual predispositions toward innovativeness are altered by intervening variables, such as social messages or situational factors. With contingency models, they explain, "innovativeness is not conceptualized as 'time of adoption' but as a predispositional construct that combines readiness to experiment with new products and independence of judgment. Moreover, this predisposition interacts with the spread of social messages concerning the innovation" (Midgley and Dowling, 1993). Therefore, individuals who are typically "non-innovators" could adopt a technology at the early stage of diffusion based on interpersonal influences. Their Simplified Contingency Model (1993) suggests that some GPV adopters may not possess the traits associated with innovativeness, rather, a combination of situational factors and communications prompted their adoption decision. These findings are also congruent with Labay's and Kinnear's 1981 early examination of solar water heater adopters, where they found little difference between adopters and knowledgeable non-adopters on identifying the advantages and benefits of solar, leading them to hypothesize that intervening, situation-specific variables come into play (Labay and Kinnear, 1981).

Finally, it is also curious that economic ability does not play a role in driving interest –either directly or indirectly—in this model. Perhaps the mere ability to spend a significant amount of money is insufficient to drive adoption interest (or the knowledge and persuasion intermediaries). A more likely theory is that the lack of capacity to invest in a GPV system attenuates between interest and actual adoption. This, most likely, presents a clear limitation of this model predicting actual adoption.

Barriers: A Qualitative Analysis

Open-ended questions in the focus group discussions and on the survey instrument sought to discover the perceived barriers to greater GPV adoption. The initial cost of a GPV system was the most frequently discussed and mentioned barrier, but other perceived barriers, such as the lack of clear information regarding the systems and the system complexity, were also mentioned.

Focus Groups of GPV Owners: Barriers

Focus group participants identified numerous hurdles to purchasing PV, with particular convergence on the upfront cost, the "hassle factor," and the system complexity. They spoke of both barriers that they themselves encountered and what they believed others would view as barriers. Initial cost was the most frequently discussed barrier:

- "My preconceived notion was that PV was so expensive. I didn't know how expensive, but it would take something in a 15—20 year to recoup the outlay, so I didn't give it much thought until they pitched it the way they did."
- "The hurdles are cost, cost, and cost."

One participant suggested that the difficulty in forcing someone to think differently about something as common as electricity:

- "People don't really understand electricity. They don't know what a kilowatt-hour is, they don't know how much a kilowatt-hour costs, they just know what their electric bill is, maybe. Whereas is if you're buying a car, you might understand how many miles per gallon it gets, how much horsepower it gets, because people are used to shopping for cars."

The "hassle factor" and the fact that the technology is still somewhat complex were also discussed at length:

- "It is just too complicated."
- "This is the early adopter phase still. This is back in the day of the IBM PC or Model T or something."
- "If someone didn't have a bit of a passion for it, I'm not sure I would recommend it at this point."
- "I would not recommend PV to someone unless I saw some energy on that person's part to understand it and work with it. It's not a complete turnkey kind a thing, and it's a long term commitment on your roof."

The difficulty in communicating the technology and its benefits was also discussed:

- "Mike's [presentation on photovoltaic] at the library, he had a hard time explaining how the system worked to people....So people left thinking, oh, great for Mike, but I'll never be smart enough—or rich enough—to be able to do that. It wasn't commoditized, it wasn't dumbed down."

Survey of Near-Adopters: Perceived Barriers

Of the near adopters surveyed, approximately 140 responded to the question "What are the three most significant barriers to you purchasing a photovoltaic system for your home?" By far the most frequently mentioned barrier was upfront cost or a financial situation that made the initial investment difficult, with 115 respondents mentioning cost (many mentioned cost as the only barrier). Some mentioned lack of substantial financial incentives from the government or utility to reduce the initial cost. The idea of "lengthy payback time" was mentioned multiple times, with some questioning whether payback would occur during their lifetime.

Lack of information or knowledge about a GPV system or its benefits was mentioned 27 times. Concerns about the system's reliability the next most frequently offered barrier, with 13 mentions. Roof space considerations, roof orientation, or trees shading the roof was cited 12 times. Ten respondents wrote that they may be moving homes in the near future and that was a barrier to investing in GPV. The belief that the technology was changing rapidly, suggesting that waiting was the most prudent move, was mentioned 9 times. The low “efficiency” of current GPV panels was also mentioned 9 times (interesting that efficiency was mentioned at all, as the effect of this perceived barrier is either in cost or necessary roof space). Maintenance of the GPV system was cited 8 times. Other perceived barriers mentioned included impact on house value (5 times), the location of the house as it relates to solar insolation (5 times), the potential adopter’s age (4 times), the technology being “too new” (4 times), the lack of “reliable” contractors (3 times), the perception that the potential adopter was too busy (3 times), neighborhood association rules (2 times), the complexity of the system (2 times), and the idea that there are too few systems to see function (2). In addition, one respondent mentioned “unknown health impacts” of GPV as a barrier and another suggested the appearance of the panels was a barrier.

While cost clearly dominates as the primary barrier to the adoption of GPV, other hurdles, such as clear information about the systems and their benefits, are limiting the diffusion of this technology.

The understanding of the relationships established through the testing of the hypotheses in this study and the decision path model can now be applied to predict the rate of GPV adoption. The following chapter will examine GPV potential adoption trends, scenarios that may foster the increased adoption of GPV systems, and strategies to overcome the barriers to GPV adoption.

CHAPTER 6
DISCUSSION

Predicting Adoption

This study's findings on the barriers to GPV adoption, characteristics of adopters, and motivational drivers behind adoption interest provide a basis to estimate the rate of GPV adoption based on a number of factors. Economic relative advantage, diffusion of GPV knowledge, and the occurrence of a precipitating "event" are considered here as three primary factors that may influence the adoption of GPV.

Economic Relative Advantage

The economic relative advantage of GPV is clearly the single most significant barrier to achieving widespread adoption of GPV. This "cost" barrier likely moderates between strong adoption interest and actual purchase behavior. To better understand the effect of economic relative advantage, the adoption rate of solar water heater owners, or "near-adopters" in this case" is examined.

The current GPV adoption rate by near adopters is calculated to be approximately 0.5% annually, based on the sample examined. Eight of the 245 solar water heater owners responding had purchased a GPV system. Since all respondents had installed a solar water heater during a 6 year period, the annual adoption rate was estimated as the overall adoption rate divided by 6 years. Two assumptions are implicit in this calculation. First, this estimate assumes that GPV adoption coincided with or followed solar water heater adoption. Second, this estimate assumes that the adoption rate of GPV has not changed over the 6 year period. The first assumption is likely valid (it would be highly unusual to install GPV prior to a solar water system, and none of the focus group participants took that route). The second assumption is questionable, but it has little overall effect on the following analysis examining adoption trend. It is also reasonable to assume that the calculated 0.5% rate is an inflated estimate of actual adoption, as solar water heater owners who had already adoption GPV were likely more enthusiastic to respond to the research survey than non-adopters (as suggested by the survey item measuring the desire to stories about solar systems).

To estimate the rate of adoption given the decrease in price differential between GPV-supplied electricity and conventional grid-supplied electricity, responses to the "willingness to pay" survey item were used. The survey item measured respondents' willingness to pay for GPV through an increase in their monthly bill for the next ten years[17]. Respondents were allowed to choose between 5% intervals from 0% increase in their monthly electric bill to 25% increase or the option of not considering PV for their home at all[18]. The survey item (Question 51) read:

> *If you were offered a program where you could pay for a photovoltaic system for your house through your existing electricity bill (such as a "Pay as you save" program), would you seriously consider it if (please select only one):*
>
> ____ *My monthly electricity bill did not change.*
> ____ *My monthly electricity bill went up no more than 5% for 10 years.*
> ____ *My monthly electricity bill went up no more than 10% for 10 years.*
> ____ *My monthly electricity bill went up no more than 15% for 10 years.*
> ____ *My monthly electricity bill went up no more than 20% for 10 years.*
> ____ *My monthly electricity bill went up more than 25% for 10 years.*
> ____ *I would not consider it.*
> ____ *Other (please specify)*

Respondents selecting "Other" (n = 19) were not included in the following analysis. Table 6.1 presents the results of the willingness to pay survey item.

Based on the economic analysis method described earlier, the levelized cost over the twenty year life of an average 2007 GPV system that is financed for the first ten years is approximately $0.41 per kWh[19]. The 2007 rate (including fees and taxes) of conventional, grid-supplied electricity was approximately $0.22 per kWh. A decrease of $0.13 (68%) in the difference between the financed cost of GPV and conventional

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[17] The concept of willingness to pay for green electricity from an electric utility differs from adoption of a GPV system in three critical ways. First, enrolling in a "green power" program does not entail the high capital investment inherent in GPV adoption. Second, a "green power" customer has less of a commitment to continue to pay the premium for "green" electricity as opposed to a GPV adopter—once a GPV system is installed it is highly unlikely that the adopter would later remove the system. These two differences work against GPV as opposed to enrollment in a "green power" program. The third difference, however, works in favor of adoption of GPV. A GPV system is clearly visible on the adopter's roof, allowing the "conservationist" image to be projected. Enrollment in a "green power" program does not provide the adopter with such a publicly visible image.

[18] The narrow range of options provided in this survey item likely biased the response. A larger spread of potential price increases likely would have provided a more accurate estimation of willingness to pay.

[19] This approximation uses the identical assumptions on system cost, size, and financing as described in Chapter 1 and detailed in Appendix A, with the exception that the loan is financed over the first ten years alone.

electricity is required to appeal to the first cohort of 12 individuals (6% of respondents) who indicated they would pay 25% more monthly on their electricity bill. The required change in the price differential between GPV and conventional electricity to meet the requirements of the others in the sample is displayed in Table 6.1.

Table 6.1 Statistical summary of decision path model

Increase in bill	***Price per kWh***	***Frequency***	***Cumulative %***	***Required Decrease in Cost Differential***
25%	$0.28	12	6%	$0.13
20%	$0.26	13	12%	$0.15
15%	$0.25	18	20%	$0.16
10%	$0.24	45	41%	$0.17
5%	$0.23	48	63%	$0.18
0%	$0.22	62	91%	$0.19

Figure 6.1 shows the adoption rate versus the decrease in cost differential between the levelized price of GPV for this sample. Equation 5.1 describes the approximate adoption rate based on the willingness to pay survey item for this sample (R^2 = .998):

$$adp_{rate} = 250.6x^2 - 65.84x + 4.383 \quad (5.1)$$

where adp_{rate} is the rate of adoption (%) and x is the decrease in price differential between the levelized price of GPV and grid electricity (this equation is only valid for price differentials between $0.13 and $0.19). As the price trends for GPV and grid electricity converge (Figure 2.10 from earlier), an increasing number of near adopters will purchase GPV. However, a significant decrease in the price differential between the cost of electricity from a GPV system and electricity from the conventional power grid must occur before a majority of “near adopters” consider purchasing. The “tipping point” where the adoption rate is most rapid is likely between the $0.16 and $0.18 change in price differential. Since the willingness to pay survey question only captured a snapshot in time, these estimated adoption rates assume no change in near adopter attitudes, knowledge, or beliefs.

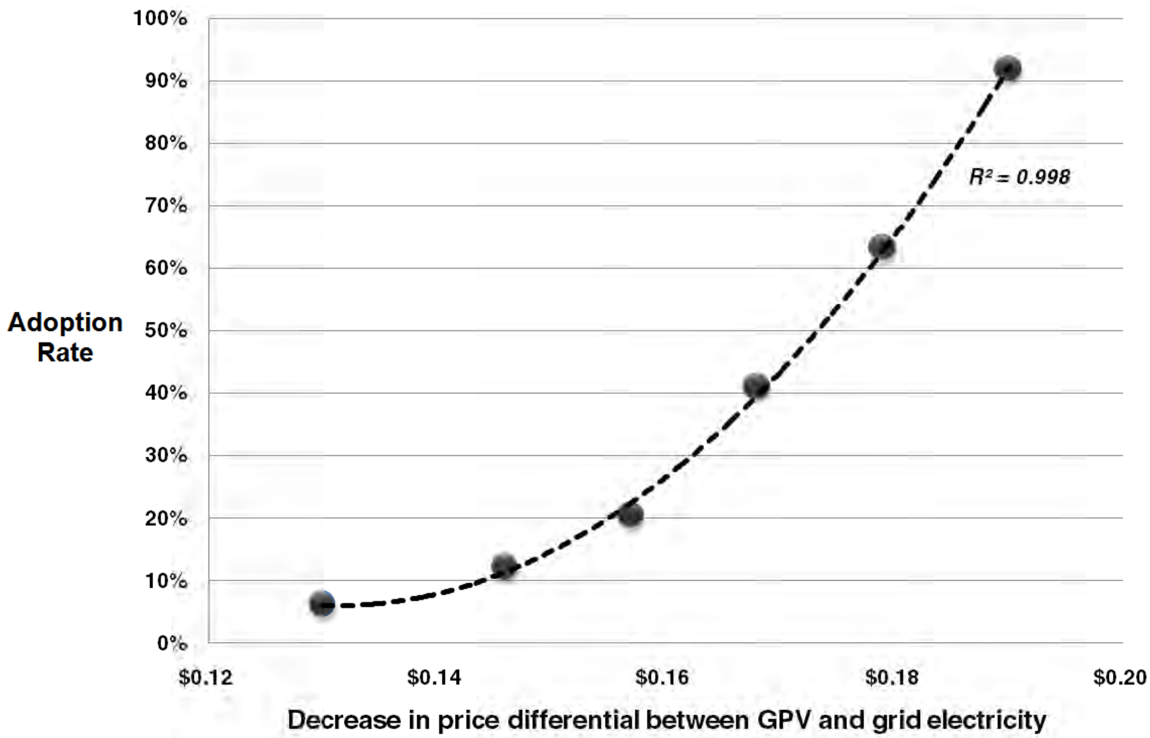

Figure 6.1 Estimated GPV adoption rate for near adopters in this sample for a given decrease in price differential between the levelized cost of GPV electricity and grid electricity

Achieving the required decrease in price differential could occur in a number of ways, as a variety of drivers affect the marginal price of GPV-provided electricity.

Technology Improvement in PV Cells and Modules

A variety of photovoltaic technology changes and potential changes in cost were discussed earlier in this study. Emerging cell materials, more efficient manufacturing techniques, or methods to increase efficiency with existing materials are among a number of changes that could substantially reduce the cost of GPV electricity. Barring a breakthrough technology, it was earlier estimated that the installed cost of installed GPV electricity will decrease by approximately 5% annually. At that rate, the "tipping point" where between 20% and 70% of near adopters would consider installing a GPV system would be reached between 10 and 12 years from 2007, or between 2017 and 2019. The approximate adoption trend for estimated changes in GPV price is shown in Figure 6.2.

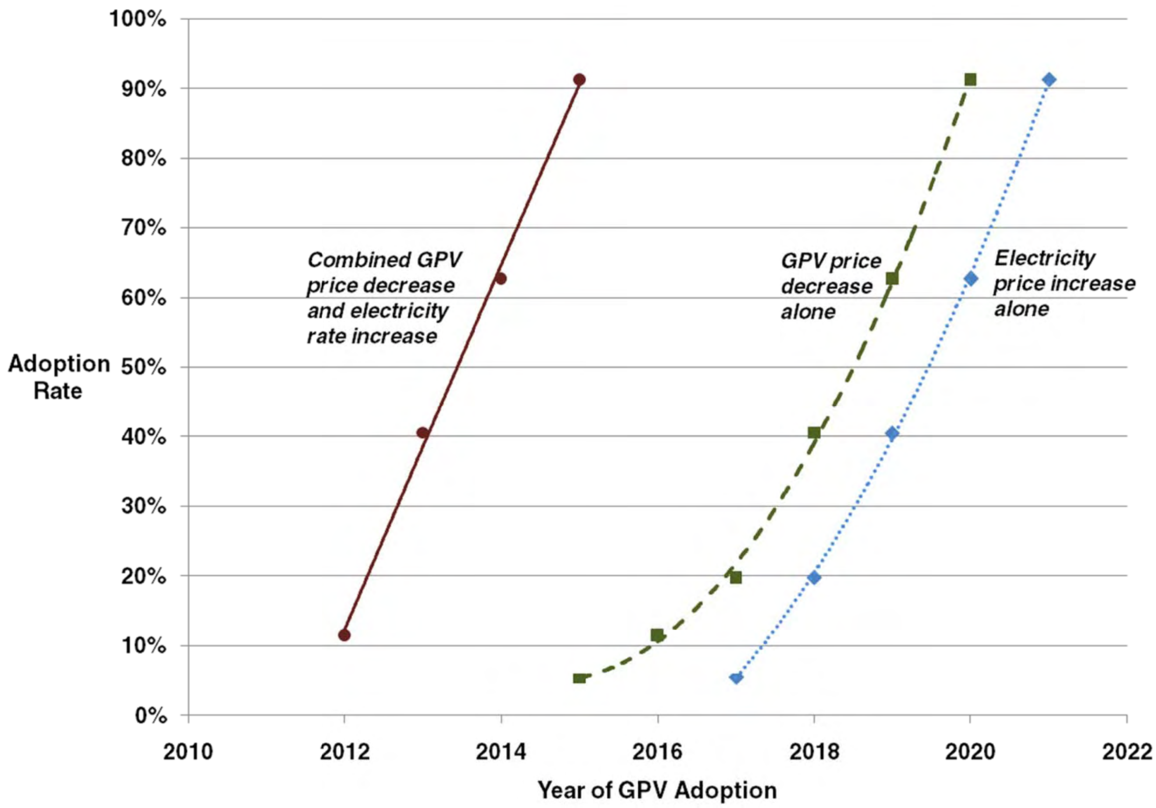

Figure 6.2 Estimated GPV adoption rate by year for near adopters in this sample given projected price changes for GPV and grid electricity

Price of Conventional Grid-Supplied Electricity

The price differential between GPV electricity and conventional electricity is not a function of the installed cost of GPV alone. Increases in the kWh price of conventional grid-supplied electricity will also decrease the relative cost differential. Earlier in this study it was estimated that the price per kWh of conventional electricity was increasing by approximately 5.1% annually. If there cost of installed GPV were to remain constant, the increase in conventional electricity alone would allow the “tipping point” as described earlier to be reached in approximately 11 to 13 years from 2007, or between 2018 and 2020. The approximate adoption timeline for predicted changes in conventional grid electricity price is shown in Figure 6.2.

If the estimated cost decrease trend for installed GPV was taken into account with the estimated price increase in conventional electricity, the “tipping point”—where investing in a GPV system would appeal to the majority of near adopters according to this sample—would be reached in approximately 5 to 7 years, or between 2012 and

2014. The approximate adoption timeline for the combined effects of the predicted changes in GPV electricity price and grid electricity price is shown in Figure 6.2.

Policy Incentives

A final major determinant in the overall price differential between GPV electricity and conventional electricity is government policy. The three most popular policy incentives to foster the adoption of GPV are: 1) income tax credits, 2) net energy metering (as discussed earlier); and "buy-down" rebates, where GPV adopters are provided a per-watt cash rebate for installing a GPV system (with certain constraints). The first two policies are currently in use in the state of Hawai'i and their effect was incorporated into the financial analysis used throughout this study. An increase in the allowed income tax credit or the addition of a buy-down rebate[20] would further improve the economic relative advantage of GPV electricity over conventional electricity.

Adoption estimate caveats

The foregoing discussion on predicting GPV adoption based on economic relative advantage comes with three significant caveats.

First, the estimation of GPV adoption was based on respondents' interest in what would be a convenient "pay as you save" program where the GPV system would be purchased directly through monthly utility bills (either directly through the utility or a third-party financing program). This type of program would eliminate the initial upfront cost of a GPV system—something that was identified as a significant hurdle to adoption. The convenience factor was not accounted for in the adoption rate analysis. Beyond the calculated existing adoption rate, it is unclear what the adoption rate would actually be at a given price point *without the existence of this convenient financing system*. It is, however, most likely to be lower. While such a "pay as you save" program has the potential substantially benefit the adoption rate of GPV by overcoming the upfront cost hurdle, more research is needed on how it would be structures and its effect.

Second, as discussed earlier, an "efficiency paradox" has been observed where individuals will forgo investing in an energy saving technology even if the savings are substantial (i.e. the savings are equivalent to a discount rate of 20% or higher). Adoption of GPV likely suffers from a similar phenomenon. Even if the economic relative

[20] The Hawai'i State Legislature considered a measure in 2007 to provide GPV adopters with a per-watt buy-down rebate of an unspecified amount.

advantage of GPV exceeded conventional electricity, some may still fail to adopt based on other barriers—real or perceived. The following section discussing persuasion offers an approach to overcome some of those barriers.

Third, practical, logistical, and legal constraints limit the projected rapid GPV growth in the near-term. The foregoing estimations of the adoption rate examined the willingness to pay by near adopters, or current solar water heater owners. This population is approximately 65,000 in 2006 (Richmond, 2007) out of a total of 329,300 houses (U.S. Census Bureau, 2005) on O‘ahu. The above 2012 estimate of approximately 12% of near adopters purchasing solar by 2012 would be equivalent to 7800 systems. By 2014, this estimate predicts that approximately 41,000 systems would be installed. Currently, the capacity of GPV contractors is severely limited on O‘ahu, with less than ten contractors actively installing systems. While the field would likely expand as the market grows, practical limitations on the number of qualified electricians and inspectors would likely impede rapid growth. Further, Hawai‘i's net metering law (which allows GPV owners to effectively sell back their surplus electricity up to the amount of their bill) currently limits the number of customers that can participate in the program at 0.5% of the electric utility's system peak demand (HRS §269-102) (Hawai‘i Revised Statutes, 2006). The peak demand for the Hawai‘ian Electric Company grid (the sole electric utility on O‘ahu) was approximately 1300 megawatts in 2006 (Hawai‘ian Electric Company, 2007), thus the current system limit for net metering is 6.5 megawatts. This existing cap limits net metering participation to approximately 2063 GPV systems with 3.15 kW peak manufacturer's rating. The Hawai‘i State Legislature would have to amend the existing net metering law to facilitate expansion beyond the first 2000 or so installed GPV systems.

Fourth, the adoption estimates provided here differ dramatically from the electric utility's planning forecast. The Hawai‘ian Electric Company's Integrated Resource Plan (IRP-4) forecasts a total of 383 residential net metered GPV systems in 2010, 581 systems in 2012, and 821 systems in 2014 (Hawai‘ian Electric Company, 2007). This forecast is far less than the above estimates of 7800 systems in 2012 and 41,000 total systems in 2014. Hawai‘ian Electric's forecast approximates the slow GPV adoption trend of the past few years and does not appear to anticipate a rapid acceleration of GPV adoption based on cost. The adoption rates estimated in this study, however, are likely inflated for the reasons explained earlier.

Persuasion

The second most frequently cited barrier by near-adopters on the survey related to lack of knowledge or information about GPV. However, as the path model demonstrated, the idea of "persuasion" was a more powerful predictor of adoption interest than knowledge (or environmental motivation) alone. Further, over than 60% of those in the "non-adopter" group (those not planning to purchase GPV within the next year) either completely or strongly agree that they understand how a GPV system works. This research suggests that GPV would benefit from not only a clear, consistent message about GPV's relative advantage (economically and environmentally) but also its compatibility: not only about the benefits of GPV, but how that information relates to their attitudes and beliefs—in other words, why it *matters to the individual*. Increasing the rate of adoption among near-adopters would likely occur with a targeted marketing campaign—either by the GPV industry, academia, or government—that might include the following elements:

- A clear explanation of economics of adopting a GPV system, including a simple explanation of net energy metering and the applicability of tax credits. The belief that GPV is financially beneficial was correlated with adoption interest and formed part of the persuasion latent variable. Awareness of net metering and tax credits was a key element of the "knowledge" latent variable and each was correlated with adoption interest.
- A strong message regarding the ability of individuals to make a difference by using GPV and the suggestion that—given the current understanding of climate change and its impacts—a moral obligation exists to do something. This would frame the adoption of a GPV system as "the right thing to do" and reinforce a personal norm through its adoption.
- An allusion to the need for self-sufficiency. Self-reliance is a value many hold in high regard. Speaking to this value would help trigger the connection between generating one's own power and the ability to provide for oneself.
- A discussion of how GPV systems have evolved to be "state of the art." Why it makes sense to invest now—that the "time is right" to adopt GPV—and waiting may not provide substantial additional benefit.

A marketing campaign with these elements would help to translate some of the existing knowledge and information about GPV into concepts that evoke a strong sense of obligation and value. The goal would be to create in the mind of near adopters the strong feeling that GPV is "the right thing to do." Obviously, pro-environment customers would most likely be the most receptive audience to messaging of this sort.

In addition to disseminating a more targeted, consistent message about GPV, increasing the ability of GPV adopters to "show off" their system may be effective in increasing the level of "persuasion" among near adopters. This could be accomplished by making GPV systems somehow more visible on homes or providing some feature that makes the fact that GPV is being used more conspicuous. This would not only allow for more "conspicuous conservationism" but help to capture the attention of others, potentially increasing the field of those who "know someone with GPV."

Precipitating Event

A final area considered here that would likely influence the rate of adoption of GPV is the occurrence of some outside intervening event that inspires more near adopters (or even non-solar households) to purchase a GPV system. Such an event (or confluence of events) would be a more potent, immediate effect form of the diffusion factors described above; it would be something that creates immediate economic relative advantage or creates in the mind of the potential adopter that the "time is right" to buy a GPV system.

This "precipitating event" could take a number of forms:

- A dramatic increase in the price of oil (or global event that signals a potential increase in the future price). If the increase appeared to be lasting and not just a short-term spike, such an event would immediately improve GPV's economic relative advantage and perhaps increase the desire for self-sufficiency—an attribute correlated with GPV adoption interest.
- A dramatic event that is credibly linked to human-induced global climate change. Such an event may give rise to the feeling of moral obligation and increased perceived consumer effectiveness (that one's actions are actually having an effect), increasing the desire to do something to reduce the threat of the problem.
- A new policy that changes the economics of investing or owning a GPV system. This may be an increase in the tax credit (or the phase out of the tax credit), creation of a buy-down rebate, or a new financing system.

The idea of having a purchase decision driven by precipitating event was supported by comments made by a number of focus group participants. Most participants could identify a key decision point when they decided to purchase GPV—even if it wasn't as dramatic as the ones listed above. Two participants cited the 2001 law that allowed "net energy metering" which allowed customers to effectively run their electric meter backwards, improving the economics of the system:

- "For me the tipping point, if you want to say, was when they came out with net metering, which was 2001. So that's when I put my panels up."
- "The grid tie part of it was (net metering). That was the last piece of the puzzle falls and you know it's like 'let's go shopping.'"

This concept of a precipitating event is also supported by Midgley and Dowling's (1993) Simplified Contingency Model which suggested that some adopters may not necessarily possess the traits associated with innovativeness, but the combination of situational factors and communications prompted their adoption decision. The exact role of a distinct situational factor or event was not explicitly tested in the decision path model in this study. Examining the effect of a specific situational factor or event in the adoption decision process would be a worthwhile exploration for future research.

The diffusion of GPV will most likely be driven primarily by increases in its economic relative advantage (via technology improvements, increases in the cost of conventional electricity, or policy incentives). The dissemination of consistent messages with attitudinal and value-laden information regarding investing in GPV will also have a positive effect on the diffusion of GPV. Finally, an external precipitating event, such as a substantial spike in the price of oil or a disaster that is credibly linked to global climate change, would likely inspire more to commit to adopting GPV.

GPV as a Disruptive Technology

Residential photovoltaic energy has the potential to dramatically change the way electricity is generated and transmitted on O'ahu. Regardless which of the mechanisms discussed earlier is the primary driver in the rate of GPV adoption, this research suggests the technology is poised to diffuse rapidly within the next one to two decades. Residential grid-tied photovoltaic could therefore emerge as a "disruptive technology," or an innovation that fundamentally overturns the dominant technology paradigm (Christiansen, 1997).

Disruptive technologies initially possess features that are less attractive than the status quo technology; they typically begin as innovations that are more expensive, have lower performance, are less useful, and are unfamiliar to most (Christiansen, 1997). What distinguishes a disruptive technology, however, is its consistent improvement across one or more of its marketable attributes until it eventually challenges the dominant technology—often catching the existing market participants by surprise (Christiansen, 1997). Christiansen used the historical example of once-dominant computer hard drive manufactures who continued to incrementally improve large drives ("sustaining," as he calls it), while smaller drives rapidly improved in performance and cost attributes (Christiansen, 1997). Companies that gained expertise in manufacturing and marketing the smaller drives eventually undermined the established hard drive market—disrupting the status quo and frequently driving the once dominant manufacturers out of business.

Residential photovoltaic energy possesses many of the elements of a disruptive technology. Photovoltaic technology has grown from expensive, specialized applications (satellites), to isolated uses (off-grid electricity), to increasingly mainstream applications (grid-tied residential). While GPV is currently more expensive than conventional, fossil fuel-generated electricity, GPV's steady performance improvements and current cost trajectory suggests that it will be less expensive than grid electricity on O‘ahu within the next decade. This finding is at odds with resource planning forecasts developed by O‘ahu's electric utility, the Hawai‘ian Electric Company. The utility's forecast is likely based on the current slow rate of GPV adoption and the immaturity of the existing GPV market—the same practice that provided the false sense of security in the dominant hard drive manufacturers in Christiansen's example. The utility will likely continue to make large investments in generating facilities and related transmission infrastructure, incrementally improving the service (although with the consistent increase in the price of electricity, one could argue that this "sustaining technology" is becoming incrementally worse). The threat of a disruptive technology is particularly troubling for the electric power industry, where capital-intensive infrastructure investments may be take decades to pay off.

Some clear limits exist—at least in the short term—to the notion that GPV will be disruptive to the existing electricity market. First, the majority of current GPV technology relies on the electricity grid for power at night and on cloudy days, and most systems require grid electricity to operate the inverter. Systems are available that provide short-term electricity storage (typically in the form of batteries). On the horizon may be new, low-cost, onsite storage technologies (such as fuel cell, fly wheel, capacitor, chemical or other form) that eliminate the need for “standby” grid power, allowing for true independence for a single home or an entire neighborhood. The second limit is more political than technological. While net metering allows GPV owners to essentially use the electricity grid as a “battery” to store electricity (in the form of credits) that they can later use, a legal cap on the number of systems that can be net metered is in place to maintain control of the grid and preserve the utility’s revenues. Political pressure to support individual investment in clean energy technology may lead to an increase or elimination of this net metering restriction.

Christiansen stresses that an innovation does not necessarily have to outperform the dominate technology to be a disruptive technology; rather, it only has to increasingly satisfy the needs of a growing market niche (Christiansen, 2007). With growing concerns about both global climate change and diminishing oil supply, a significant shift in the market may occur that clearly benefits GPV. In environmental performance and desire for self-sufficiency, GPV vastly outperforms conventional fossil fuel-generated electricity. As GPV is increasingly able to satisfy the needs of a typical electricity customer at a competitive price, its environmental and self-sufficiency attributes may propel it ahead of grid electricity in the market. Such a shift would dramatically disrupt O‘ahu’s century-old central power station grid model, particularly if the electric utility is not anticipating GPV’s potential growth.

The electric utility need not be a victim of this potentially disruptive technology. Rather, the utility could prepare for a shift by exploring to a new decentralized model of power generation, participating in the investment of GPV with homeowners, and playing a larger role in the diffusion of GPV. Developing storage capacity for the grid and creating a “pay as you save” financing program (where GPV adopters pay for their investment through their existing utility bill) would allow the utility to directly benefit from the increasing economic relative advantage of GPV. It would also give the utility greater control over where GPV systems are installed, helping to protect the integrity of the grid and aid in future transmission planning. Further, such an approach would help address another problem of large scale adoption of solar energy: the space needed for photovoltaic devices. Embracing a distributed model of electricity generation would enable the utility to take advantage of empty rooftops everywhere.

Conclusion

The goal of this research was to empirically explore factors influencing the adoption and diffusion of residential grid-tied photovoltaic systems. Specifically, the study sought to gain a better understanding of who was adopting GPV, why they were adopting, and how the adoption process occurred. Based on Everett Rogers' (1995) theory of diffusion of innovations, variants to the Rogers adoption model, and consumer research regarding environmental behavior, hypotheses were formulated on the effects of several individual, economic, behavioral, and attitudinal variables related to GPV adoption interest. A decision path model was also developed to test the relative strength of various concepts influencing the adoption process. The hypotheses and decision model were tested by a sample of 245 O'ahu homeowners who have purchased solar water heaters and who had varying levels of GPV adoption interest and intent.

The most significant finding of this research was that while environmental motivations of "near adopters" provide the greatest overall effect on the GPV adoption interest, the attributes that comprise the concept of "persuasion" in Rogers' adoption model have the strongest single effect on adoption interest. The perceived economic relative advantage and compatibility (the innovation's fit with the adopter's beliefs and values) of GPV to a potential adopter had a strong influence on adoption interest. This lends additional support for Rogers' conceptual model while providing a basis for understanding how the adoption process might be accelerated.

This study tested 12 hypotheses. Results from the sample confirm the validity of 10 of the 12 hypotheses, although stronger support was found for some over others. In this sample, little support was found for Rogers' traditional "early adopter" attributes of greater income, higher level of education, and risk-prone behavior. Evidence of other early adopter behavior among GPV adopters was found but the data provided no evidence of risk-taking behavior.

While a correlation was found between near adopters' level of understanding of GPV and their interest in adopting, no significant relationship was found between direct experience with a GPV system and adoption interest. Since the "product" of a GPV system is electricity—something every homeowner is no doubt familiar with—direct experience may not be a prerequisite to adoption of such a technology. If a satisfactory amount of knowledge exists in the mind of the adopter that the system provides that electricity, direct experience with the technology may not be required.

This research found that communication channels that related to adoption interest were mostly interpersonal as opposed to mass media. The absolute number of sources was not correlated with adoption interest, but receiving information from other people was. Among communication sources, the strongest correlation was found between information received from a solar dealer or contractor and adoption interest. Dealers currently seem to be assuming the role as lead "change agents" in the diffusion of GPV (although this result may simply be an indication of the very low saturation of GPV systems).

Support for Rogers' concept of "relative advantage" was found in both economic and environmental terms. The perceived relative economic advantage of GPV over conventional electricity is related to GPV interest with the strongest correlation being the belief that GPV will benefit the homeowner financially. As a subcomponent of perceived savings, the belief that the price of conventional electricity would increase in the future was more likely held by interested adopters. Results of this study confirm that GPV—with reduced environmental burden being the primary distinguishing attribute –will more likely be adopted by those who both possess pro-environment values and participate in pro-environment behaviors. Support was also found for concept of "conspicuous conservation," where the "green" image that GPV might project was associated with GPV adoption interest.

Values beyond economic and environmental benefit appear to be related to GPV adoption interest as well. This analysis showed a significant relationship between GPV adoption interest and the desire for self-sufficiency, even though GPV adopters will most likely remain dependent on grid power for operations. Increased belief in both the role of the individual in making a difference and moral obligation to do so was related to GPV adoption interest. The survey item that produced the strongest correlation with GPV purchase desire related to the belief that GPV is "the right thing to do." This notion can be used as a proxy for Rogers' "compatibility" attribute, or "the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters."

While the testing of hypotheses sought to understand the "who" and "why" of GPV adoption interest and intent, the decision path model attempted to reveal the structure of relationships between concepts influencing adoption. The 5-component multiple regression model described 36% of the variance in GPV adoption interest. Environmental motivation had the largest overall effect on adoption interest, but the construct of persuasion had the largest single influence. Those who hold strong pro-environmental beliefs are more likely interested in adoption GPV, but accepting that GPV provides financial benefit and it is “the right thing to do” to satisfy environmental concern has the strongest influence. The results of the model suggest that knowledge alone does not drive adoption interest. Over 60% of those in the “non-adopter” group (those not planning to purchase GPV within the next year) either completely or strongly agree that they understand how a GPV system works. The latent construct persuasion appeared to be the catalyzing variable, where the knowledge combines with attitudes and beliefs and generates a level of behavioral influence. The model showed no support for the constructs of innovativeness and financial ability in generating interest in GPV adoption. It is more likely that financial ability moderates between GPV adoption interest and actual adoption. Clearly, there are many ways to foster interest in GPV adoption. But the strongest drivers appear to be perceived economic relative advantage and the belief that that GPV is effective in satisfying environmental concern.

Several limitations of this study should be taken into consideration. First, the sample tested represented only solar water heater owners on the island of O‘ahu. It is unclear if the results can be generalized and applied to populations outside of O‘ahu. Second, it was assumed that solar water heater owners were “near adopters” and the most likely population to adopt GPV. While this is likely a reasonable assumption based on their familiarity with the use of solar, it neglects approximately 80% of potential adopters (homeowners who lack a solar water heater). These homeowners may be interested in purchasing GPV alone or in combination with a new solar water heater. Third, although potential participants in the sample were randomly selected, the sample itself was comprised of self-selecting respondents. It is unclear if their responses are representative of the “near adopter” population as a whole. Respondents may have been more eager to discuss solar, and the results therefore may overestimate GPV adoption interest. Fourth, the relatively small number of GPV systems currently in use and the lack of knowledge among the overall population of GPV calls into question the accuracy of some of the survey item responses. Fifth, this study examined only GPV adoption interest and intent. Although attitude-behavior research has shown a clear relationship between intentional and actual behavior, actual adoption is not guaranteed. Finally, this study was just a snapshot of a temporal process. Since the GPV industry and GPV adoption trends are changing fairly rapidly; the lifespan of these findings cannot be guaranteed. In spite of these limitations, this research has contributed to the field of diffusion of innovations and the understanding of adoption behavior as it relates to residential photovoltaic power.

This research could be expanded in a number of ways. First, validation of these findings as they relate to populations outside of O‘ahu and beyond solar water heater owners would provide more universal understanding of the rate of adoption of GPV. Second, a deeper understanding of motivations and adoption drivers could be found through a controlled experiment where homeowners are asked to actual purchase a GPV system. This would allow for a far more accurate measure of actual adoption likelihood instead of interest or perceived intention alone. In such a study, variables such as economic relative advantage and “observability” (direct experience with GPV) could be directly tested. Third, the use of a longitudinal research design would yield valuable information about the nexus between adoption interest and intent and actual adoption behavior. Finally, further examination and prediction of GPV’s potential as a “disruptive technology”—particularly on a small island electricity grid with high electricity prices—would be valuable to aid utility planning and public policy (and avoid expensive large-scale investment mistakes).

Grid-tied residential photovoltaic’s minimal environmental impact, rapidly decreasing cost, and renewable fuel source may position it as the disruptive energy technology of the 21st century. Putting the sun’s vast energy to use generating electricity will help reduce the threat of global climate change and decrease pressure on the Earth’s limited fossil fuels. With its high electricity prices, near-complete dependence on imported oil for energy, and abundant sunlight, Hawai‘i is poised to be a leader in adopting this ancient source of power, hastening the day when “alternative energy” is simply “energy.”

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APPENDIX A

ECONOMIC ANALYSIS OF A GPV SYSTEM

The following economic analysis was derived from Nofuentes, Aguilera, and Munoz (2002) and Newnan (1991).

Lifecycle cost

The lifecycle cost (*LCC*) for the GPV customer is the sum of the initial system cost and the present worth of the lifecycle operation and maintenance cost:

$$LCC = PV_{EQ} + PW(PV_{OM}) \tag{A.1}$$

where PV_{EQ} = the initial equipment cost in the GPV system and $PW(PV_{OM})$ = the present worth of the lifetime cost of operation and maintenance of the system. $PW(PV_{OM})$ may be written as:

$$PW(PV_{OM}) = PV_{AOM}\frac{(1+d)^n - 1}{d(1+d)^n} \tag{A.2}$$

where PV_{AOM} is the annual operation and maintenance cost, estimated at $100 annually (K. Cronin, personal interview, October 11, 2004); *n* is the life of the GPV system and d is the nominal discount rate. The actual discount rate (d_a) can be calculated by $d_a = (d-g)/(1+g)$, where g is the annual inflation rate.

Some states, such as Hawai‘i, offer an initial purchase subsidy, in the form of a “buy-down” or income tax credit for the GPV system purchase. The actual lifecycle cost to the customer (LCC_a) could be stated as:

$$LCC_a = PW(PV_{UIN}) + PW(PV_{OM}) \tag{A.3}$$

where $PW(PV_{UIN})$ = the present worth of the initial user investment in the GPV system. If PV_{BD} is the value of a purchase “buy down” subsidy or income tax credit for the customer and the system is completely paid for at the time of purchase, then:

$$PW(PV_{UIN}) = PV_{EQ} - PV_{BD} \tag{A.4}$$

If, however, the remaining amount after a "buy-down" subsidy or income tax credit is financed with a loan borrowed at an annual loan interest i_1 for a term of N_1 years with equal annual payments (AP), then:

$$AP = (PV_{EQ} - PV_{BD})i_1\left[\frac{(1+i_1)^{N_1}}{(1+i_1)^{N_1} - 1}\right] \tag{A.5}$$

The present value of the initial investment is thus:

$$PW(PV_{UIN}) = AP\left(\frac{1}{1+d}\right)\left[\frac{1-\left(\frac{1}{1+d}\right)^{N_1}}{1-\left(\frac{1}{1+d}\right)}\right] \tag{A.6}$$

If an interest-free loan is offered (as a PV support policy or otherwise), Equation A.6 is simplified to:

$$AP = \frac{(PV_{EQ} - PV_{BD})}{N_1} \tag{A.7}$$

Cash inflows

Under net energy metering, surplus energy generated by a GPV system is effectively "sold" back to the electric utility (offsetting the amount of electricity purchased) at the same price as electricity purchased from the utility. Therefore, the present worth of cash inflows from a GPV system over *m* years may be written as:

$$PW[CIF(m)] = pE_{PV}\frac{K_p\left(1-K_p{}^m\right)}{1-K_p} \tag{A.8}$$

where E_{PV} is the amount of electricity produced annually by the GPV system; p is the price of electricity; and K_p is a factor representing the change in the value of that electricity given by $K_p = (1+\varepsilon_p)/(1+d)$ where ε_p represents the annual increase in the rate of the electricity price. If $m = N$, then $PW[CIF(N)]$ equals the present worth of the cash inflows generated through the useful life of the system. It is assumed that the GPV system has no salvage value at the end of its useful life.

Kilowatt-hour Cost

Since residential customers are familiar with electricity in terms of price per kilowatt-hour, it is useful to convert the lifecycle cost of the GPV system to this metric. The KH_p is derived by dividing the lifecycle cost of the GPV system by its annual yield E_{PV} and the useful life of the system:

$$KHp = \frac{LCC_a}{NE_{PV}} \tag{A.9}$$

Net Present Value

The net present value (NPV) of an investment project is the sum of present values of all cash inflows and outflows related to the investment. For a GPV system, the NPV equals the present worth of the system cash inflows minus the present value of its investment costs:

$$NPV = PW[CIF(m)] - LCC_a \tag{A.10}$$

A GPV system is profitable when NPV > 0. This metric, however, reveals nothing about initial investment requirement or investment length, making it an imperfect descriptor to a potential investor.

Profitability Index

The profitability index (PI) of an investment project is defined as the ratio between its net present value and its initial investment cost. It makes sense to define the profitability index for GPV (PI_{PV}) as the ratio of the NPV and the lifecycle cost, which includes the initial investment cost and the present worth of the lifetime operation and maintenance costs:

$$PI_{PV} = \frac{NPV}{LCC_a} = \frac{PW[CIF(N)]}{LCC_a} - 1 \quad \text{(A.11)}$$

A GPV system is profitable when $PI_{PV} > 0$. By incorporating initial investment cost, PI_{PV} provides a more informative measurement than NPV alone. It does not, however, provide any indication about investment lifetime.

Payback Time

The payback time of an investment is defined as the length of time for the sum of the present cash flows (inflows minus outflows) to equal zero. This payback time (*PB*) can be calculated through trial-and-error by testing various time periods (*N*) until:

$$PW[CIF(N)] \geq LCC_a \quad \text{(A.12)}$$

A payback period that is less than the length of the serviceable life of the GPV system, given the discount rate (or rate of inflation), is favored. This measure does not reveal the profitability of the investment, so it should be used in conjunction with the previous measures.

Break-even Turnkey Cost

The break-even turnkey cost (BTC) is the cost of an installed GPV system per peak kilowatt (kWp) that a buyer can pay without gaining or losing money over the life of the system. The BTC is the value of PV_{EQ} per installed kWp that results in zero NPV. The BTC provides a base profitability threshold when analyzing a GPV system.

Residential Grid-tied Photovoltaic Profitability Example

Consider a homeowner installing a 2.4 kW actual peak (3.15 kW manufacturer's peak) GPV system under the following conditions provided by Hawai`i solar contractors (M. Mangelsdorf, 2001; L. Valenta, personal interview, September 20, 2004; J. Abbott, personal interview, September 9, 2007; L. Valenta, personal communication, May 14, 2007):

- System life (*N*): 20 years
- Initial installed equipment cost (PV_{IN}): $8.63/Watt or $27,180
- Annual operation and maintenance expense (PV_{AOM}): $100
- Discount rate (d): 3%
- Inflation rate: 1.5% (Hawai‘i Labor Market Conditions, January 2002)
- Purchase “buy-down” value in income tax credit (PV_{BD}): $7,000 ($5000 State credit; $2000 Federal credit)
- Loan interest rate (*i*): 6% for 20 years
- Price of electricity (*p*): $0.22/kWh
- Amount of electricity produced annually (E_{PV}): 4818 kWh
- Annual rate of increase in electricity price (ε_p): 5.1%

Combining Equations A.2, A.3, A.5, and A.6, the lifecycle cost (LCC_a) of the investment becomes:

$$LCC_a = (PV_{EQ} - PV_{BD})i_1\left[\frac{(1+i_1)^{N_1}}{(1+i_1)^{N_1}-1}\right]\left(\frac{1}{1+d_a}\right)\left[\frac{1-\left(\frac{1}{1+d_a}\right)^{N_1}}{1-\left(\frac{1}{1+d_a}\right)}\right] + PV_{AOM}\frac{(1+d_a)^n-1}{d_a(1+d_a)^n} \quad \text{(A.13)}$$

Using the conditions listed above, LCC_a equals $31,993.

Cash inflows over m = 20 years, as calculated by Equation A.8:

$$PW[CIF(m)] = pE_{PV}\frac{\left((1+\varepsilon_{\mathrm{p}})/(1+d_a)\right)\left(1-\left((1+\varepsilon_{\mathrm{p}})/(1+d_a)\right)^m\right)}{1-\left((1+\varepsilon_{\mathrm{p}})/(1+d_a)\right)} \quad \text{(A.14)}$$

The present worth of the cash inflows for the conditions above equals $31,268.

The net present value of the GPV investment, given by Equation A.10, is $31,268 - $36,989, or -$725.

The unit kilowatt-hour cost over the system's 20-year life, calculated with Equation A.9, equals $0.33 per kilowatt hour over the life of the system.

The profitability index for this GPV investment, calculated with Equation A.11 is $31,268 / $31,993) -1, or -0.02.

Finally, the payback period is calculated by testing various time periods (N) until the present worth of cash inflows equals the lifecycle cost, as in Equation A.12. In this case, the paypack period is just over 20.5 years, assuming the system functions for the entire period. The break-even turnkey cost, or maximum price for a GPV system under these conditions for a 20-year system and still "break-even" on the investment, is approximately $26,696.

APPENDIX B

DATA COLLECTION MATERIAL

Recruitment letter for focus group participants

Sample recruitment letter for solar water heater owners for survey

Survey instrument

UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

Department of General Engineering

College of Engineering
117 Transportation Building
104 South Mathews Avenue
Urbana, IL 61801-2996

15 April 2006

Aloha Sun-powered homeowner:

I am writing to inform you of a research project being conducted by the Department of General Engineering at the University of Illinois, Urbana-Champaign to better understand the solar energy use. This research project will provide valuable information about the reasons individuals choose to invest in residential solar energy and the barriers to more widespread solar energy use.

We have commissioned Ward Research, a professional market research firm in Honolulu, to conduct a series of focus groups. A focus group is an informal group discussion among five to ten people that focuses on a specific topic. There are absolutely no sales—focus groups are for research purposes only, and most people find them to be enjoyable.

Your home has been randomly selected as a possible participant in this project. **If you are interested in participating in the focus group, please contact Barbara Carlos at Ward Research at 808-585-2337 before April 28th.** Please take a few minutes to speak with the representative from Ward Research and consider participating. If you are able to attend, you will be compensated for your time.

The topic of these focus groups will be photovoltaic energy use. Your input is extremely valuable to us and will help us ton better understand adoption of residential photovoltaic energy systems.

We thank you for your consideration and appreciate your input. If you have any questions about this research, please call me at 808-226-4987 or email mikulina@lava.net.

Sincerely,

Jeff Mikulina
Researcher

telephone 217-333-2731 • *fax* 217-244-5705

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Department of General Engineering

College of Engineering
117 Transportation Building
104 South Mathews Avenue
Urbana, IL 61801-2996

27 November 2006

[name]
[address 1]
[address 2]

Dear [name]:

I am writing to inform you of a research project being conducted by the Department of General Engineering at the University of Illinois, Urbana-Champaign to better understand solar energy use. This research project will provide valuable information about the reasons individuals choose to invest in residential solar energy and the barriers to more widespread solar energy use.

You have been randomly selected as a possible participant in this project. According to City records, you installed a solar water heater around [date of installation]. We are asking you to complete a brief online survey regarding your experiences with solar energy. The web survey will take less than 15 minutes to complete and can be done at your convenience. *Please note that this survey is for research purposes only – absolutely no sales are involved and all responses will be aggregated and kept confidential.*

Please visit this web address to reach the survey: www.solarstudy.org

Your survey access code is: [access code] (to verify that you received this invitation to participate)

I would appreciate it if you would complete the survey by **Tuesday, December 12th**. Please feel free to call me at 808-226-4987 if you have any questions. Mahalo, in advance, for your participation!

Sincerely,

Jeff Mikulina
Graduate Researcher

PS. You may request a copy of the results of the study when you complete the online survey.

telephone 217-333-2731 • *fax* 217-244-5705

O`ahu Solar Energy Adoption Survey

Informed Consent

The University of Illinois is studying attitudes and purchasing behavior of Hawaii residents regarding solar energy use. This research is being conducted by Professor Raymond Price of the Department of General Engineering. The purpose of this research is to better understand the adoption and use of solar energy in Hawai`i. We are asking for your participation in this survey. The survey should take you 15 minutes to complete. Please read the following carefully:

-- Participation in this survey is strictly voluntary. You may stop taking the survey at anytime if you so desire.

-- Your responses will be kept confidential and will not be associated with your name in any way.

-- The University of Illinois does not provide medical or hospitalization insurance coverage for participants in this research study nor will the University of Illinois provide compensation for any injury sustained as a result of participation in this research study, except as required by law.

-- The University of Illinois does not provide medical or hospitalization insurance coverage for participants in this research study nor will the University of Illinois provide compensation for any injury sustained as a result of participation in this research study, except as required by law.

-- If at any time you have questions about this research project, or if you experience any problems related to your participation in the project, please feel free to contact the project investigator: Jeff Mikulina, phone 808-226-4987, or email mikulina@lava.net.

If you have any questions about your rights as a participant in research involving human subjects, please feel free to contact the University of Illinois Institutional Review Board (IRB) Office at 217.333.2670 or irb@uiuc.edu. You are welcome to call collect if you identify yourself as a research participant.

1. I affirm that I have read and understood the consent document below and agree to participate (circle one).

- ***I AGREE***
- ***I DON'T AGREE***

2. How long ago did you install your solar hot water heater (on your primary residence) (please circle one)?

- ***Within the past year***
- ***1 to 2 years ago***
- ***2 to 3 years ago***
- ***3 to 4 years ago***
- ***4 to 5 years ago***
- ***Over 5 years ago***
- ***Don't know***
- ***I don't own a solar water heater***

3. Were you the primary decision maker in the decision to purchase a solar water heater?

- ***Yes***
- ***No***

4. Do you know what a residential solar photovoltaic system is?

- ***Yes***
- ***No***

5. A photovoltaic -- or solar electric -- system generates electricity from the sun. We are focused here on grid-tied photovoltaic systems, systems which do not require batteries and enable the home to remain connected to the power grid. If you are familiar with what a residential photovoltaic system is, from what sources did you learn about it (circle all that apply):

- ***Newspaper article***
- ***Solar contractor***
- ***Electric utility***
- ***Books***
- ***Home show***
- ***Advertisement***
- ***Magazine article***
- ***Family member(s)***
- ***Friend***
- ***Internet***
- ***Other (please specify)***

6. Do you have photovoltaic system on your home?

- ***Yes***
- ***No***

7. How likely are you to purchase a photovoltaic system for your home within the next year (please circle one)?

- ***Plan to purchase a system***
- ***Very Likely***
- ***Somewhat Likely***
- ***Somewhat Unlikely***
- ***Very Unlikely***
- ***Not at all***
- ***Other (please specify)***

8. What do you pay, roughly, per month for electricity for your household (please circle one)?

- ***Less than $50***
- ***$51 to $100***
- ***$101 to $150***
- ***$151 to $200***
- ***$201 to $250***
- ***$251 to $300***
- ***$301 to $350***
- ***$351 to $400***
- ***$401 or over***
- ***Don't know***

9. In the next 10 years, do you believe the price of electricity per kilowatt-hour, compared with today's price, will (please circle one):

- ***Decrease***
- ***Stay the same***
- ***Increase slightly***
- ***Increase by 50%***
- ***Double***
- ***More than double***
- ***Other (please specify)***

Please indicate how much you agree or disagree with the following statements by circling one of the choices for each statement.

10. I frequently consider the environmental impact of a product when I make purchasing decisions.

Completely Agree	***Strongly Agree***	***Somewhat Agree***	***Neither Agree Nor Disagree***	***Somewhat Disagree***	***Strongly Disagree***	***Completely Disagree***

11. Installing and using a photovoltaic system is complex and complicated.

Completely Agree	***Strongly Agree***	***Somewhat Agree***	***Neither Agree Nor Disagree***	***Somewhat Disagree***	***Strongly Disagree***	***Completely Disagree***

12. I regularly recycle my bottles and cans.

Completely Agree	***Strongly Agree***	***Somewhat Agree***	***Neither Agree Nor Disagree***	***Somewhat Disagree***	***Strongly Disagree***	***Completely Disagree***

13. I am very concerned that climate change will affect future generations in Hawaii.

Completely Agree	***Strongly Agree***	***Somewhat Agree***	***Neither Agree Nor Disagree***	***Somewhat Disagree***	***Strongly Disagree***	***Completely Disagree***

14. I trust that Hawaiian Electric Company is doing what is best for Hawaii.

Completely Agree	***Strongly Agree***	***Somewhat Agree***	***Neither Agree Nor Disagree***	***Somewhat Disagree***	***Strongly Disagree***	***Completely Disagree***

15. I pretty much understand how a residential photovoltaic system works.

Completely Agree	***Strongly Agree***	***Somewhat Agree***	***Neither Agree Nor Disagree***	***Somewhat Disagree***	***Strongly Disagree***	***Completely Disagree***

16. I believe individual actions can make the world a better place.

Completely Agree	***Strongly Agree***	***Somewhat Agree***	***Neither Agree Nor Disagree***	***Somewhat Disagree***	***Strongly Disagree***	***Completely Disagree***

17. At least one other person I know has a photovoltaic energy system.

Completely Agree	*Strongly Agree*	*Somewhat Agree*	*Neither Agree Nor Disagree*	*Somewhat Disagree*	*Strongly Disagree*	*Completely Disagree*

18. Being self-sufficient is important to me.

Completely Agree	*Strongly Agree*	*Somewhat Agree*	*Neither Agree Nor Disagree*	*Somewhat Disagree*	*Strongly Disagree*	*Completely Disagree*

19. A photovoltaic energy system will save homeowners money.

Completely Agree	*Strongly Agree*	*Somewhat Agree*	*Neither Agree Nor Disagree*	*Somewhat Disagree*	*Strongly Disagree*	*Completely Disagree*

20. I try to stay up-to-date with new technology.

Completely Agree	*Strongly Agree*	*Somewhat Agree*	*Neither Agree Nor Disagree*	*Somewhat Disagree*	*Strongly Disagree*	*Completely Disagree*

21. I think purchasing a residential photovoltaic system would benefit me financially.

Completely Agree	*Strongly Agree*	*Somewhat Agree*	*Neither Agree Nor Disagree*	*Somewhat Disagree*	*Strongly Disagree*	*Completely Disagree*

22. I like trying new things.

Completely Agree	*Strongly Agree*	*Somewhat Agree*	*Neither Agree Nor Disagree*	*Somewhat Disagree*	*Strongly Disagree*	*Completely Disagree*

23. I feel we all have a moral obligation to do what we can for Hawaii's environment.

Completely Agree	*Strongly Agree*	*Somewhat Agree*	*Neither Agree Nor Disagree*	*Somewhat Disagree*	*Strongly Disagree*	*Completely Disagree*

24. My friends would consider me a "risk taker."

Completely Agree	Strongly Agree	Somewhat Agree	Neither Agree Nor Disagree	Somewhat Disagree	Strongly Disagree	Completely Disagree

25. The seriousness of environmental problems is exaggerated by environmentalists.

Completely Agree	Strongly Agree	Somewhat Agree	Neither Agree Nor Disagree	Somewhat Disagree	Strongly Disagree	Completely Disagree

26. I think purchasing a residential photovoltaic system is "the right thing to do" for the environment.

Completely Agree	Strongly Agree	Somewhat Agree	Neither Agree Nor Disagree	Somewhat Disagree	Strongly Disagree	Completely Disagree

27. If something needs repair at my house, I like to try to fix it myself.

Completely Agree	Strongly Agree	Somewhat Agree	Neither Agree Nor Disagree	Somewhat Disagree	Strongly Disagree	Completely Disagree

28. It is important to me to be seen as someone who is concerned about the environment.

Completely Agree	Strongly Agree	Somewhat Agree	Neither Agree Nor Disagree	Somewhat Disagree	Strongly Disagree	Completely Disagree

29. Among my friends and neighbors, I am usually one of the first to try a new product.

Completely Agree	Strongly Agree	Somewhat Agree	Neither Agree Nor Disagree	Somewhat Disagree	Strongly Disagree	Completely Disagree

30. Most people are not willing to make sacrifices to protect the environment.

Completely Agree	Strongly Agree	Somewhat Agree	Neither Agree Nor Disagree	Somewhat Disagree	Strongly Disagree	Completely Disagree

31. Even if everyone tried to conserve energy at home, it wouldn't make a big impact on energy use.

Completely Agree	***Strongly Agree***	***Somewhat Agree***	***Neither Agree Nor Disagree***	***Somewhat Disagree***	***Strongly Disagree***	***Completely Disagree***

32. My friends, family, or neighbors have told me stories about their residential photovoltaic system(s).

Completely Agree	***Strongly Agree***	***Somewhat Agree***	***Neither Agree Nor Disagree***	***Somewhat Disagree***	***Strongly Disagree***	***Completely Disagree***

33. I have replaced many of my incandescent light bulbs with compact fluorescents.

Completely Agree	***Strongly Agree***	***Somewhat Agree***	***Neither Agree Nor Disagree***	***Somewhat Disagree***	***Strongly Disagree***	***Completely Disagree***

34. I have actively sought to learn new information about residential photovoltaic from the internet, books, or magazines.

Completely Agree	***Strongly Agree***	***Somewhat Agree***	***Neither Agree Nor Disagree***	***Somewhat Disagree***	***Strongly Disagree***	***Completely Disagree***

35. I have discussed residential photovoltaic with a solar dealer or contractor.

Completely Agree	***Strongly Agree***	***Somewhat Agree***	***Neither Agree Nor Disagree***	***Somewhat Disagree***	***Strongly Disagree***	***Completely Disagree***

36. The timing is about right for me to invest in a residential photovoltaic system.

Completely Agree	***Strongly Agree***	***Somewhat Agree***	***Neither Agree Nor Disagree***	***Somewhat Disagree***	***Strongly Disagree***	***Completely Disagree***

37. I understand what "net energy metering" is.

Completely Agree	***Strongly Agree***	***Somewhat Agree***	***Neither Agree Nor Disagree***	***Somewhat Disagree***	***Strongly Disagree***	***Completely Disagree***

38. I enjoy telling others about my solar water heater.

Completely	***Strongly***	***Somewhat***	***Neither Agree***	***Somewhat***	***Strongly***	***Completely***
Agree	***Agree***	***Agree***	***Nor Disagree***	***Disagree***	***Disagree***	***Disagree***

39. I actively support environmental causes or organizations.

Completely	***Strongly***	***Somewhat***	***Neither Agree***	***Somewhat***	***Strongly***	***Completely***
Agree	***Agree***	***Agree***	***Nor Disagree***	***Disagree***	***Disagree***	***Disagree***

40. I am well aware of the state and federal tax credits for residential photovoltaic systems.

Completely	***Strongly***	***Somewhat***	***Neither Agree***	***Somewhat***	***Strongly***	***Completely***
Agree	***Agree***	***Agree***	***Nor Disagree***	***Disagree***	***Disagree***	***Disagree***

41. I could comfortably spend $15,000 on a major purchase without adversely impacting my lifestyle or financial situation.

Completely	***Strongly***	***Somewhat***	***Neither Agree***	***Somewhat***	***Strongly***	***Completely***
Agree	***Agree***	***Agree***	***Nor Disagree***	***Disagree***	***Disagree***	***Disagree***

42. I am very interested in how technical things, such as computers and engines, work.

Completely	***Strongly***	***Somewhat***	***Neither Agree***	***Somewhat***	***Strongly***	***Completely***
Agree	***Agree***	***Agree***	***Nor Disagree***	***Disagree***	***Disagree***	***Disagree***

43. Let's say you just won a contest and are being offered two options for collecting your guaranteed cash prize. Which of the following would you prefer to receive:

- ***$1000 today***
- ***$1600 five years from today (IF YOU SELECT THIS CHOICE, SKIP TO QUESTION 47)***

44. OK, what if this choice was offered to you instead? Which of the following would you prefer to receive:

- ***$1000 today***
- ***$2060 five years from today (IF YOU SELECT THIS CHOICE, SKIP TO QUESTION 46)***

45. OK, one more time. Which of the following would you prefer to receive:

- ***$1000 today (PLEASE GO TO QUESTION 49)***
- ***$2315 five years from today (PLEASE GO TO QUESTION 49)***

46. OK, one more time. Which of the following would you prefer to receive:

- ***$1000 today(PLEASE GO TO QUESTION 49)***
- ***$1825 five years from today (PLEASE GO TO QUESTION 49)***

47. OK, what if this choice was offered to you instead? Which of the following would you prefer to receive:

- ***$1000 today***
- ***$1200 five years from today (PLEASE GO TO QUESTION 49)***

48. OK, one more time. Which of the following would you prefer to receive:

- ***$1000 today***
- ***$1400 five years from today***

49. How important were the following factors in motivating you to purchase a solar water heater (please circle one each)?

- Lower your energy bill

Very Important ***Somewhat Important*** ***Not too Important*** ***Not at all Important*** ***Does not apply***

- The length of time for the system to pay for itself through reduced energy costs

Very Important ***Somewhat Important*** ***Not too Important*** ***Not at all Important*** ***Does not apply***

- Tax credit

Very Important ***Somewhat Important*** ***Not too Important*** ***Not at all Important*** ***Does not apply***

- The environmental benefits such as reducing greenhouse gas emissions

Very Important ***Somewhat Important*** ***Not too Important*** ***Not at all Important*** ***Does not apply***

- Need to replace existing water heating system

Very Important ***Somewhat Important*** ***Not too Important*** ***Not at all Important*** ***Does not apply***

- Utility rebate

Very Important ***Somewhat Important*** ***Not too Important*** ***Not at all Important*** ***Does not apply***

- Remodeling an existing home

Very Important ***Somewhat Important*** ***Not too Important*** ***Not at all Important*** ***Does not apply***

- The desire to be less dependent on fossil fuel sources

Very Important ***Somewhat Important*** ***Not too Important*** ***Not at all Important*** ***Does not apply***

- Building or purchasing a new home

Very Important ***Somewhat Important*** ***Not too Important*** ***Not at all Important*** ***Does not apply***

50. Are you aware of a time that you have you been inside a house that had a photovoltaic system (please circle one)?

- ***Yes***
- ***No***
- ***Don't Know***

51. If you were offered a program where you could pay for a photovoltaic system for your house through your existing electricity bill (such as a "Pay as you save" program), would you seriously consider it if (please select only one):

____ ***My monthly electricity bill did not change.***

____ ***My monthly electricity bill went up no more than 5% for 10 years.***

____ ***My monthly electricity bill went up no more than 10% for 10 years.***

____ ***My monthly electricity bill went up no more than 15% for 10 years.***

____ ***My monthly electricity bill went up no more than 20% for 10 years.***

____ ***My monthly electricity bill went up more than 25% for 10 years.***

____ ***I would not consider it.***

____ ***Other (please specify)___________________________________***

52. What are the three most significant barriers to you purchasing a photovoltaic system for your home?

53. How many years have you owned your current home (your primary residence) (please circle one)?

- ***Less than 2 years***
- ***2 to 5 years***
- ***6 to 10 years***
- ***11 to 15 years***
- ***16 or more years***
- ***I am renting***
- ***Other (please specify)***

54. What was your total household income before taxes in 2005? (Please include income from all sources, including salaries, pensions, interest, dividends, bonuses, capital gains, profits, other.)(Please circle one.)

- ***under $35,000***
- ***$35,000 - $49,999***
- ***$50,000 - $74,999***
- ***$75,000 - $99,999***
- ***$100,000 - $149,999***
- ***$150,000 - $199,999***
- ***$200,000 and over***
- ***Other (please specify)***

55. What is the highest level of education you have completed (please circle one)?

- ***No formal education***
- ***Grade school (1 to 8 years)***
- ***Some high school (9 to 11 years)***
- ***High school graduate or GED (received a high school equivalency diploma)***
- ***Some college/technical or vocational school/training after high school***
- ***College graduate***
- ***Postgraduate degree/study***
- ***Other (please specify)***

56. How much would you like to have a photovoltaic system on your home (please select only one)?

___ ***I really want a photovoltaic system and would be willing to make a major sacrifice for it***

___ ***I really want a photovoltaic system and would be willing to make a minor sacrifice for it***

___ ***I really want a photovoltaic system but wouldn't be willing to sacrifice for it***

___ ***I want a photovoltaic system but it is not that critical at all***

___ ***I really don't care one way or the other***

___ ***I would prefer not to have a photovoltaic system***

Mahalo for taking the time to complete this survey.

If you would like a copy of the results of this study, please contact Jeff Mikulina (226-4987) early next year. The results of this study may be published but your name or identity will not be revealed and any record will remain confidential to the extent allowed by law in the reporting of this data. Although you may not receive direct benefit, your participation in this study may offer further understanding of renewable energy issues in Hawaii. If at any time you have questions about this research project, or if you experience any problems related to your participation in the project, please feel free to contact the project investigator: Jeff Mikulina, phone 808-226-4987, or email mikulina@lava.net. If you have any questions about your rights as a participant in research involving human subjects, please feel free to contact the University of Illinois Institutional Review Board (IRB) Office at 217.333.2670 or irb@uiuc.edu. You are welcome to call collect if you identify yourself as a research participant.