



PV PLANNER

A DESIGN AND ANALYSIS TOOL FOR SOLAR ELECTRIC SYSTEMS

Updated User Manual

May 2011



Center for Energy and Environmental Policy

University of Delaware

The Center for Energy and Environmental Policy conducts interdisciplinary and collaborative research and supports graduate instruction in energy, environmental, and sustainable development policy. The Center serves as a University-wide forum for the discussion and dissemination of faculty, staff, and graduate student research in these areas. In addition to its research and instructional activities, the Center also provides technical assistance to community, state, federal and international agencies and nonprofit organizations. The Center is composed of an internationally diverse faculty, professional staff, and graduate student body with backgrounds in a variety of disciplines including political science, economics, sociology, geography, philosophy, urban planning, environmental studies, history, and engineering. Research programs currently organized in the Center include comparative energy and environmental policy, sustainable development, political economy of energy, environment and development, environmental justice, conservation and renewable energy options, integrated resource planning, and technology environment and society. Graduate areas of specialization in energy and environmental policy are supported at the master's and doctoral levels.

Mailing Address:

John Byrne
Director
Center for Energy and Environmental Policy
University of Delaware
Newark, DE 19716-7381

Email: jbyrne@udel.edu
Telephone: (302) 831-8405
Telefax: (302) 831-3098
Website: <http://ceep.udel.edu>

PV PLANNER

A DESIGN AND ANALYSIS TOOL FOR SOLAR ELECTRIC SYSTEMS

Updated User Manual

May 2011

Research Team

John Byrne (Ph.D., Distinguished Professor of Energy and Climate Policy, Director of CEEP)

Lado Kurdgelashvili (Ph.D., CEEP Policy Fellow)

Jeremiah Couey (CEEP Ph.D. Candidate)



Center for Energy and Environmental Policy

University of Delaware

Table of Contents

Introduction to <i>PV Planner</i>	1
1. <i>PV Planner</i> : An Overview.....	1
2. Background.....	2
<i>PV Planner</i> Data Input Worksheets	7
3. Case Information	9
4. Application Type	9
5. System Configuration	10
6. System Costs.....	13
7. O&M Costs.....	14
8. Financial Inputs.....	15
9. Policy.....	16
10. Load Data	18
11. Rate Data.....	20
12. Results	22
13. Cash Flow/Payback Yr	24
14. Power Dispatch	30
Example <i>PV Planner</i> Output	32
Selected CEEP Solar Electricity Policy Publications: 1983-2006	44

Introduction to *PV Planner*

The Center for Energy and Environmental Policy (CEEP) publishes this updated user guide for *PV Planner* to incorporate the improved user interface as well as expanded analytical features now available for this popular solar electricity analysis software. Updated from the previous 2006 *PV Planner* user guide (Byrne et al., 2006), this report reviews the nearly two-decade development process used to create this state of the art solar energy, finance, and policy analysis software. Below we offer an updated background of CEEP research informed by the application and successful utilization of *PV Planner* for evaluating photovoltaic opportunities worldwide, as well as provide a step-by-step data input process that will help *PV Planner* users assess the financial, economic and policy opportunities available for PV project development.

1. *PV Planner*: An Overview

CEEP has worked with the U.S. National Renewable Energy Laboratory (NREL) and others for 17 years on the development of *PV Planner* to analyze the benefits of PV technology beyond its conventional of energy-supply value. *PV Planner* utilizes a vast quantity of data to model the physical, economic, financial and policy contexts specific to the area where the photovoltaic (PV) system is being installed. The software simulates the performance of a PV system operating in an energy supply-only mode (sometimes referred to as a non-dispatchable system as the energy produced by the device must be used immediately) or in a dispatchable mode (where because of the addition of storage, solar energy can be released when needed).

The software uses financial, economic and policy data from the area where the PV system is to be installed in order to analyze its financial feasibility. The performance of the system is reported using several metrics including net present value, payback period, benefit-cost ratio, cash flows and levelized costs.¹ Because the policy environment is constantly developing

¹ Levelized cost equals the present value of the capital and operating costs of an electric power plant over its projected economic life, converted to equal annual payments per unit of electricity generated during that lifetime (e.g., per kWh) (NREL, 1995: 47-51).

(particularly with the addition of new incentives to promote renewables), *PV Planner* is regularly upgraded to reflect new policy measures.

2. Background

For 25 years, the Center for Energy and Environmental Policy (CEEP) has investigated the technical and economic feasibility of using solar electric power (provided by commonly termed ‘photovoltaic’ (PV) technology or ‘solar cells’). Its analysis has emphasized multi-service configurations for residential and commercial buildings. These configurations offer a combination of benefits that include the energy-only value (i.e., the system’s ability to reduce grid-energy demand), capacity value (in the form of peak demand reduction through peak shaving – see Byrne and Hadjilambrinos, 1994; and Byrne et al, 1992, 1993a-c, 1994a-f, 1995, 1996a-d, 1997b, 1998, 2000, 2001b, 2004 and 2009), service value (for example, through the provision of emergency power during electrical outages – see Byrne et al, 1997a-b, 1998, 2000 and 2001b) and material replacement value (displacing building material – see Byrne et al, 2000 and 2001b). Additionally, CEEP has modeled social and environmental co-benefits from the use of solar-generated electricity (e.g., reduced air pollution and diminished vulnerability to fossil fuel price spikes – see Byrne et al, 1996, 1997a, 1999, 2001a, 2003, 2004, 2005a, 2006, 2006a, 2006b, 2007, 2009, 2010, 2010a and 2011; Byrne and Rich, 1983; Letendre et al, 1998; and Rickerson et al, 2005), including analyses of policy options to capture these co-benefits and the interconnected environmental benefits as a part of comprehensive climate action plans to reduce greenhouse gas emissions (Byrne et al, 2008, and 2010b).

CEEP has directly consulted with a range of industries, businesses, and public officials concerning options towards the purchase and installation of PV systems. Included with this work are projects in Delaware and Pennsylvania that in summation have committed to install nearly 30MWs.

Schematic representation of non-dispatchable and dispatchable (i.e., with storage) configurations are presented below. Following this section, we guide users through the step-by-step process of entering the system parameters, costs, financial variables, and policy inputs into *PV Planner* for a comprehensive examination the solar-electric system potential.

The basic configuration of a grid-connected PV system consists of a PV array connected via power conditioning equipment to a building's distribution panel (Figure 1).

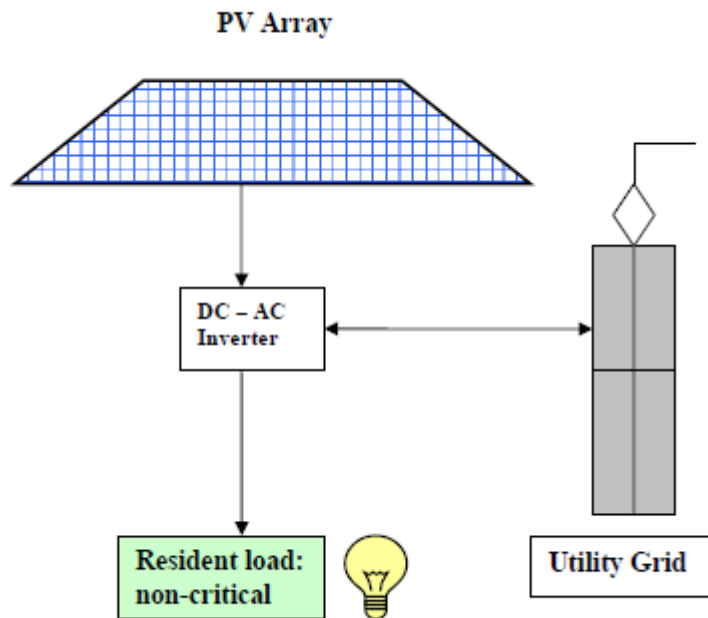


Figure 1. PV Installation without Storage

Under this configuration, PV operates as a conventional electricity technology, complementing the energy obtained from the grid. The net value from this configuration can be estimated using the following equation (Byrne et al, 1998, 2000 and 2001a):

$$V_E = [O_{PV} * P_E] - C_{PV} \quad [\text{Equation 1}]$$

where,

V_E = Net economic Value of PV system

O_{PV} = Building PV output (kWh)

P_E = Utility energy charge (cents/kWh)

C_{PV} = Capital and operating costs of the PV energy supply system.

P_E and C_{PV} are discounted to reflect the time value of the benefits and costs of the system. Under this configuration, most PV systems tend not to be economically feasible as compared to conventional electricity supply options as the average cost of electricity can be in the levelized

costs range of 7¢-14¢ per kWh (coal plants and combined cycle gas plants), whereas PV systems are about 13¢-20¢ per kWh (Byrne, 2010: 37).

In order to improve the economics of the PV system, its configuration can be changed to provide additional services. One of these is building electricity demand management, which requires the addition of modest amounts of storage to the PV array, allowing the system to operate as a dispatchable peak-shaving technology (Figure 2).

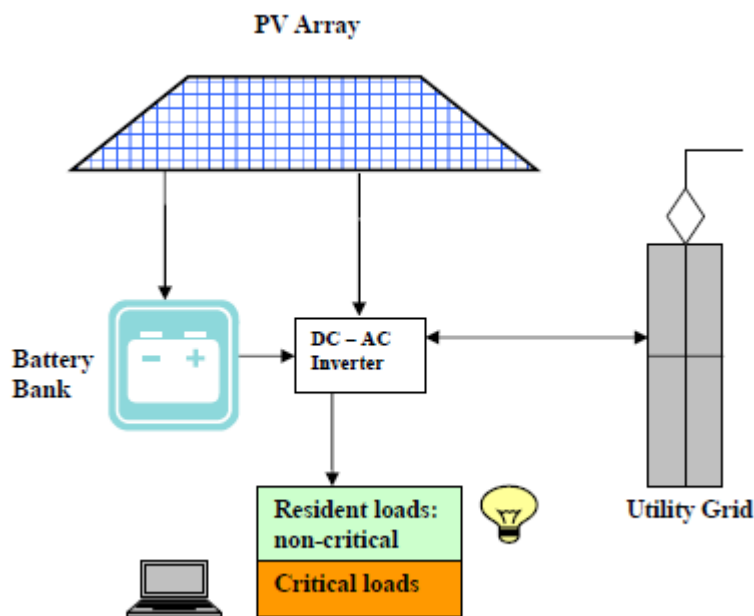


Figure 2. PV Installation with Storage

The addition of the storage facility provides benefits from the perspectives of both the PV user and electric utility (Byrne et al, 1996a-d, 1997b, 1998, 2000, 2001b and 2004; and Hoff et al, 2004).

Under this configuration, the following equation applies (Byrne et al, 2000):

$$V_M = [P_D(O_{PV} + O_{BAT}) + V_E] - C_{PV} \text{ [Equation 2]}$$

where,

V_M = Demand management value of a PV peak-shaving system

O_{PV} = PV output at time of building peak demand (kW)

O_{BAT} = Battery bank output (net of round trip losses) at time of building peak demand (kW)
 P_D = Utility demand (capacity) charge
 V_E = Value as defined in Equation [1] above
 C_{PV} = Capital and operating costs of the PV demand management system.

The O_{BAT} term represents the output of the battery bank at the time the building is experiencing its peak demand. It is a function of battery bank size and the number of peak-shaving hours needed to maximize the reduction in the peak load of the building for a given PV array size.

The addition of storage to the PV system also provides the system with the capability to offer emergency power (EP) to a building (Byrne et al, 1996). EP could be used for emergency lighting or as backup power for computers. This addition of EP enhances the overall value of a PV system as its economic benefit can be expressed as the “avoided cost” associated with the purchase and operation of a conventional EP system. The EP system is usually in the form of an uninterrupted power supply (UPS) and the major assumption is that the user would have already identified the need for EP and purchased the necessary requirements such as an inverter and battery storage or the balance of system components similar for a peak shaving PV system. The only additional cost of using a PV system for EP would be the capital costs associated with the PV array (cost of modules and installation).

Accordingly a new equation can be derived that demonstrates the dual function of peak shaving with emergency power (Byrne et al, 1998, 2000 and 2001b):

$$V_S = [(B_{EP} - C_{EP}) + V_M] - \Delta C_{PV} \quad \text{[Equation 3]}$$

where,

V_S = Energy services value of a PV- peak shaving and EP system

B_{EP} = Customer designated benefits of EP

C_{EP} = EP system cost (equivalent to BOS cost of a dispatchable PV system)

V_M = Demand management value of a PV peak shaving and EP system, as defined in Equation [2] above

ΔC_{PV} = Additional PV system cost.

An additional purpose can be added to the PV system when it displaces conventional construction materials (hereinafter materials displacement benefit). In this case, the PV array serves as an architectural element containing both functional (electricity production) and

aesthetic (part of the rooftop or façade of the building) value (Byrne et al, 2001). The economic benefit of using PV to displace architectural materials can be expressed as the “avoided cost” of the material displaced by the area of the array. Thus, the effective capital cost of the PV system amounts to its cost minus the value of the displaced material. The underlying assumption for this purpose to be beneficial is that the material being displaced (e.g., polished stone, marble, aluminum) is more costly than the PV system (measured in area costs such as m² of roofing material). To determine the material displacement benefit requires adjusting PV system cost in Equation 3 (ΔC_{PV}) by an amount equal to the avoided cost of the displaced material.

Another contribution of a PV system as an energy service technology is the provision of environmental services through the avoided emissions of greenhouse gases (GHGs) in electricity generation. Growing concern about the effects of increasing levels of GHGs in the atmosphere has led to market-based and policy initiatives aimed at reducing their emissions from electricity generation. PV as a clean energy technology can play a role in mitigating GHG emissions by displacing some amount of electricity generation and also through its attribute as a renewable energy fuel source (see, e.g., Byrne et al, 1999, 2003, 2004, 2005a, 2007, 2008, 2009, 2010, 2010a & b, and 2011). Policies can create markets for selling and buying avoided CO₂, SO_x and NO_x emissions and other renewable energy benefits through, for example, what are called renewable energy credits (RECs).² Additional revenue streams from RECs and other policies can be accounted for in the financial analysis of PV system benefits, which in most cases will greatly improve the economic feasibility of a PV investment. In particular, the emergence of RECs into the economics of renewable energy technologies can have a significant impact in the utilization of PV technology.

² CEEP has been able to demonstrate these potential savings/benefits of PV systems under different configurations and policy options in several case studies, both within the US (including Delaware) and internationally (see Byrne et al, 1999, 2003, 2004, 2005a & b and 2006; Letendre et al, 1998; Rickerson et al, 2005, 2006a & b, 2007, 2008, 2009, 2010, 2011).

***PV Planner* Data Input Worksheets**

The following provides an overview of the various ‘worksheets’ in *PV Planner* that a user will use to enter data in order to perform analyses of PV building-integrated applications.

After initiating the software, users can create a new *PV Planner* project file by selecting *File* > *New Project* from the main menu. Users also can load an existing *PV Planner* Project by selecting *File* > *Open Project* to continue their analysis.

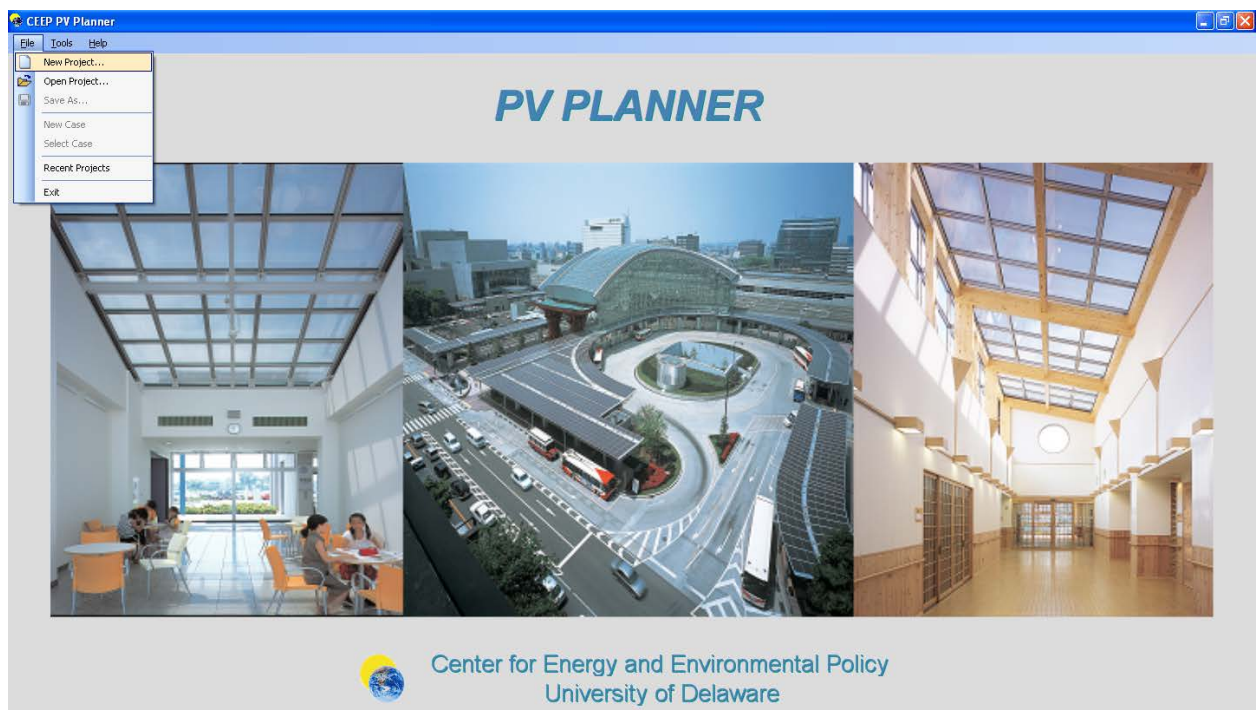


Figure 3. *PV Planner* Introduction Screen

Each project file can have multiple cases. In a newly created project file, a user needs to click on the *Create New Case* button. With an existing project file, already containing cases from the previous session, a user can load an existing case by selecting it from the list and clicking the *Load Selected Case* button.

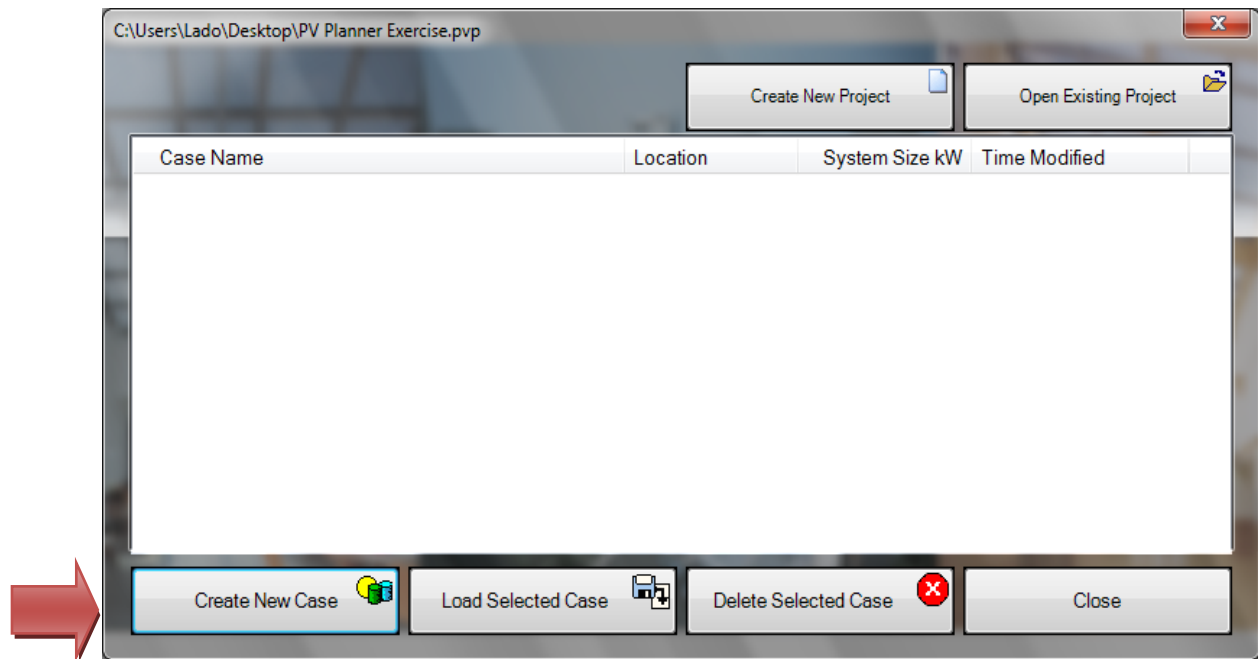


Figure 4. Creating New Case

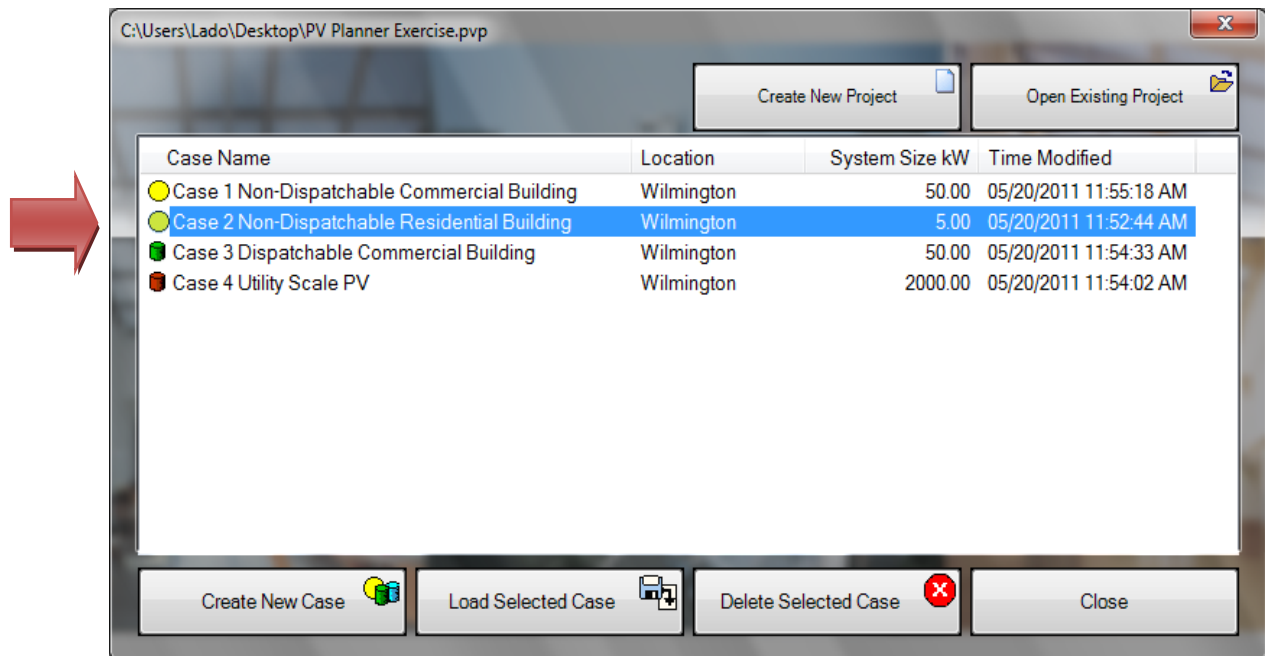
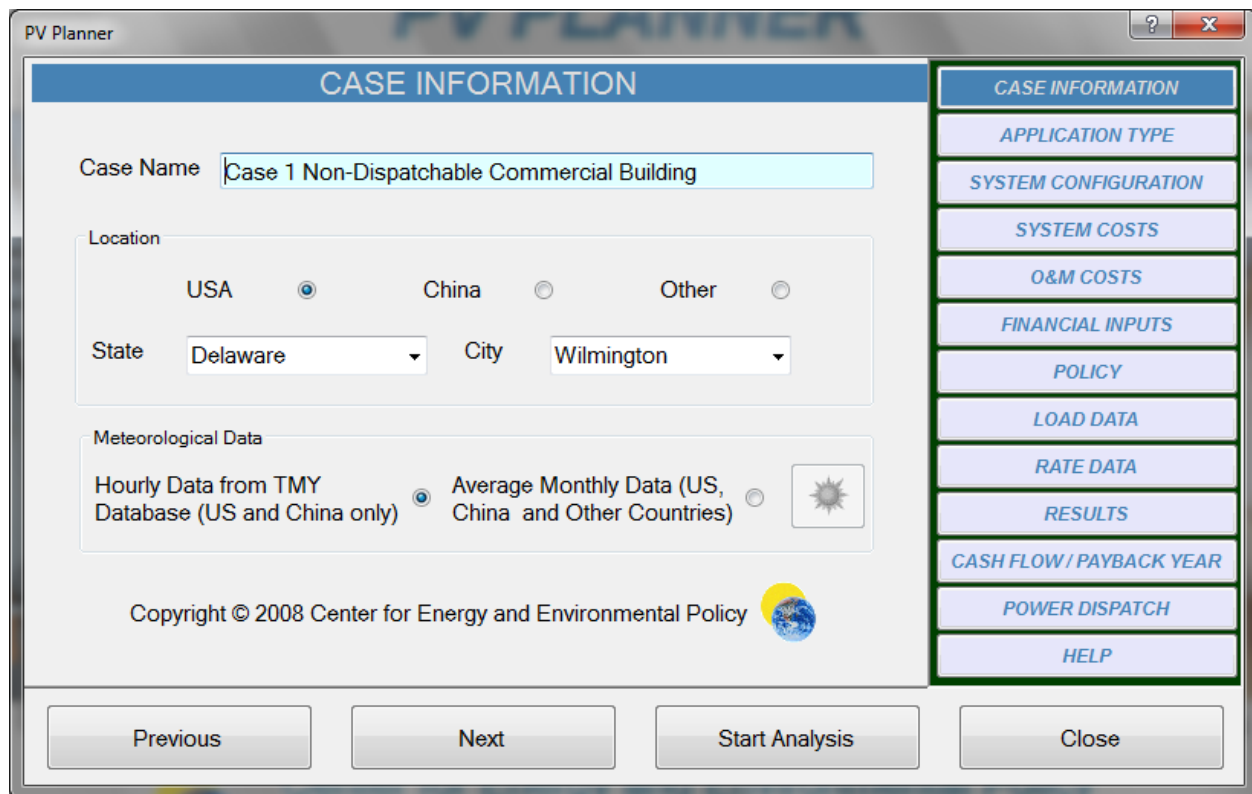


Figure 5. Loading Existing Case

3. Case Information

The **Case Information** interface is used to enter basic information on the project to be analyzed by *PV Planner*, including a user-defined project name and the project's location. The program has a database of solar radiation data for most cities within the United States (over 1,000 locations) and many countries around the world from which the user can choose (e.g., 270 locations in China). If users have their own solar radiation records, they can enter this data instead. For the U.S., the program's database uses the Typical Meteorological Year version 3 (TMY3) weather data developed by the National Renewable Energy Laboratory (U.S.).



The screenshot shows the 'PV Planner' software window with the 'CASE INFORMATION' tab selected. The interface includes a 'Case Name' field with the text 'Case 1 Non-Dispatchable Commercial Building'. The 'Location' section has radio buttons for 'USA' (selected), 'China', and 'Other'. Below these are dropdown menus for 'State' (set to 'Delaware') and 'City' (set to 'Wilmington'). The 'Meteorological Data' section has two radio buttons: 'Hourly Data from TMY Database (US and China only)' and 'Average Monthly Data (US, China and Other Countries)' (selected). A sun icon is also present. On the right side, a vertical menu lists various options: 'CASE INFORMATION' (highlighted), 'APPLICATION TYPE', 'SYSTEM CONFIGURATION', 'SYSTEM COSTS', 'O&M COSTS', 'FINANCIAL INPUTS', 'POLICY', 'LOAD DATA', 'RATE DATA', 'RESULTS', 'CASH FLOW / PAYBACK YEAR', 'POWER DISPATCH', and 'HELP'. At the bottom, there are four buttons: 'Previous', 'Next', 'Start Analysis', and 'Close'. A copyright notice 'Copyright © 2008 Center for Energy and Environmental Policy' and a globe icon are also visible.

Figure 6. Case Information Interface

4. Application Type

At this interface, the user enters information on the type of project being analyzed. The initial option available is a PV system installed either on a commercial or residential building. Alternatively, a project may exclusively involve a "Sale to Grid Only" format in which the electricity generated from the PV system is sold directly to a utility (pricing for this application is

set in the Policy Interface – see p. 16 for details). A third option is the Hybrid application, which is a combination of Sale to the Building and Sale to the Grid options.

The screenshot shows the 'PV Planner' software window with the 'APPLICATION TYPE' tab selected. The interface is divided into a main configuration area on the left and a sidebar on the right. The sidebar contains a list of menu items: CASE INFORMATION, APPLICATION TYPE (highlighted), SYSTEM CONFIGURATION, SYSTEM COSTS, O&M COSTS, FINANCIAL INPUTS, POLICY, LOAD DATA, RATE DATA, RESULTS, CASH FLOW / PAYBACK YEAR, POWER DISPATCH, and HELP. The main configuration area has three sections: 'Building Type' with radio buttons for 'Commercial Building' (selected) and 'Residential Building'; 'Sale to Grid Only' with a radio button for 'Sale to Grid Only (See Policy Button)'; and 'Hybrid Application' with a radio button for 'Sales to Building (%)' (selected), a text input field containing '100', and a radio button for 'Sale to Grid Only (See Policy Button)' with a value of '0'. At the bottom of the window are four buttons: 'Previous', 'Next', 'Start Analysis', and 'Close'.

Figure 7. Application Type Interface

5. System Configuration

At the **System Configuration** interface, the user chooses the size, basic purpose and other technical features of the PV system. Users begin by choosing whether they want a system that is configured to provide energy only (no storage and the electricity produced is used immediately) or whether the system will provide dispatchable peak shaving (battery storage allows for the dispatching of energy when needed – see p. 12). The “Energy Only” configuration is illustrated below.

Figure 8. System Configuration Interface without Storage

For either an “Energy Only” (see above) or “Energy & Storage” (see below) configuration, the user also decides which type of PV module to use, the size of the array (in either area – m^2 – or electrical peak capacity – W_p), the method used to mount the array, and whether it is a rooftop or wall-mounted system (the user-indicated slope of the array determines this).

For your inverter efficiency, please refer to the California Energy Commission (CEC) website: (<http://www.gosolarcalifornia.org/equipment/inverters.php>) to determine your specific weighted average inverter efficiency as entered into *PV Planner*. In contrast to peak efficiency, this value is an average efficiency and is a better representation of a grid-tied inverter's operating profile.

Another important consideration is the PV annual performance degradation factor that ranges from 0.3% – 0.8% (see NRC, 2010: 21), *PV Planner* by default uses 0.5%. Other de-rating factors are discussed in their report and should be accounted for accordingly.

The user can also decide if PV panels can be mounted in a manner that reduces the need for roofing or other building materials (in this case, architectural material displacement costs are calculated).

Figure 9. System Configuration Interface with Storage

If the user wishes to have reliable peak-shaving capability built into the system, battery storage should be added. This “dispatchable” (i.e., “Energy & Storage”) configuration allows the PV system to accumulate solar energy and release it as the building approaches its peak demand for electricity. **PV Planner** has an algorithm included in the software to determine the battery size that will maximize peak-shaving based on maximum daily solar energy available in each month. The size and efficiency of the battery storage system are set by the user (which includes an “Auto” choice for battery size that uses **PV Planner’s** calculator). The battery bank can be charged in one of two ways: via the PV array only (click “Charge Scheme: System only”);

or electric energy can be drawn from the grid during off-peak hours (click “Charge Scheme: Off Peak”). The user also decides whether to dispatch the solar energy in order to maximize bill savings from demand or energy charges (see the Rate Data interface on pp. 20). Utility demand charges are typically assessed only for commercial buildings.

If battery storage is included in the configuration of the PV system, the user can withdraw energy during electrical grid outages or ‘blackouts.’ The user can request **PV Planner** to calculate emergency power benefits. In this scenario, the program calculates benefits equal to the initial costs of inverters and batteries included in the configuration.

PV installations can be part of the framework or façade of a building and when in this configuration it is referred to as building integrated PV (BIPV). A user can input the cost for the architectural materials that will be displaced with the use of BIPV in dollars per meters squared ($\$/m^2$) (see the Table below for typical building material costs).

Building material	Cost per square meter, $\$/m^2$
Concrete or terracotta roof tile/battens	15-25
Colourbond decking	30
Faced brick cavity wall	100
Pre-cast concrete panels	150
Window walling	400>
Curtain walling	500-800
Polished stone (marble, granite)	2,400-2,800

Source: Prasad and Snow, 2005.

6. System Costs

At the **System Costs** interface, the user enters the system’s capital costs. These are divided into three types: (i) the cost of the photovoltaic array (modules plus supporting structure); (ii) the balance of system (BOS) costs, which are associated with the inverters, batteries and any other electrical equipment used; and (iii) other costs such as overhead (e.g., labor and transportation), contingencies and miscellaneous (e.g., legal fees and permits) expenses.

PV Planner

SYSTEM COSTS				
	Category	Unit Cost	Total Cost (\$)	Cost Fraction (%)
PV	PV Module (\$/kWp)	2000	100000.00	40.95
	Module Support Structure (\$/m ²)	35	12499.90	5.12
BOS	Inverter (\$/kW AC)	700	35000.00	14.33
	Battery (\$/kWh)	0	0.00	0.00
	Other Electrical Equipment (\$)	25000	25000.00	10.24
OTHER	Overhead (\$)	50000	50000.00	20.48
	Contingencies (%)	3	6675.00	2.73
	Miscellaneous (\$)	15000	15000.00	6.14
			244174.90	100.00

CASE INFORMATION
APPLICATION TYPE
SYSTEM CONFIGURATION
SYSTEM COSTS
O&M COSTS
FINANCIAL INPUTS
POLICY
LOAD DATA
RATE DATA
RESULTS
CASH FLOW / PAYBACK YEAR
POWER DISPATCH
HELP

Previous
Next
Start Analysis
Close

Figure 10. System Costs Interface

7. O&M Costs

At the **O&M Costs** interface, the user decides the frequency of replacement of components, and maintenance costs associated with the PV system, as well as escalation rates for these items. O&M costs are divided into those associated with the maintenance of the PV array³, those associated with the replacement of inverters and batteries, and insurance.⁴ Costs are also assigned to the inspection of and periodic adjustments to the system. The user is expected to enter the frequency (in years) of maintenance tasks. The Recurring O&M Cost, the Net Present Value (NPV) and Cost Fractions of the various cost items are calculated for the user.

³ Typically this cost is around \$20 per kW installed (see NREL, 2011)

⁴ Annual insurance cost is around 0.25% of Installed Project Cost. Insurance Cost might be as high as 0.5% in areas where extreme weather events are likely (e.g., hurricanes in Florida, earthquakes in California, high-winds in Colorado) (NREL, 2010).

PV Planner

OPERATION & MAINTENANCE COSTS					
	Unit Cost	Recurring O&M Cost (\$)	Frequency (years)	Present Value (\$)	Cost Fraction (%)
Maintenance (\$)	1000	1000	1	10819.38	32.91
Inverter Replacement (\$/kW AC)	600	30000.00	13	11241.35	34.19
Battery Replacement (\$/kWh)	0	0.00	10	0.00	0.00
Insurance (\$)	1000	1000	1	10819.38	32.91
Escalation Rate (%)	2			32880.11	100.00

CASE INFORMATION
APPLICATION TYPE
SYSTEM CONFIGURATION
SYSTEM COSTS
O&M COSTS
FINANCIAL INPUTS
POLICY
LOAD DATA
RATE DATA
RESULTS
CASH FLOW / PAYBACK YEAR
POWER DISPATCH
HELP

Previous
Next
Start Analysis
Close

Figure 11. Operation and Maintenance Costs Interface

8. Financial Inputs

The **Financial Inputs** interface asks users to decide how the PV system will be financed and how its purchase will affect income. At this interface, the user also determines the length of the project evaluation period.

The user is required to enter information related to the project life, discount rate, loan attributes, and tax related variables. Discount rates are set by the user (with discount rate defaults suggested for commercial, governmental and socially-oriented projects). Information is requested on the characteristics of the loan being used to finance the project (if necessary), as well as tax information (income tax rate, tax depreciation, etc.). The user chooses a depreciation method (e.g., Straight line, Double Declining Balance, MACRS 5y, etc.) and the level of depreciation that is applied to the capital equipment. The user also indicates if bill savings generated by a PV system are taxable. (Usually, bill savings for PV systems on

commercial buildings are subject to state and federal income tax⁵; while savings from residential systems ordinarily are not taxable).

FINANCIAL INPUTS

Customer Financial Input

Customer Discount Rate (%) Evaluation Period (Years)

Loan Characteristics

	Loan 1	Loan 2
Debt Ratio (%)	<input type="text" value="70"/>	<input type="text" value="0"/>
Loan Period (Years)	<input type="text" value="10"/>	<input type="text" value="10"/>
Loan Interest Rate (%)	<input type="text" value="7"/>	<input type="text" value="7"/>
Starting Year for the 2nd Loan	<input type="text" value="13"/>	

Loan Interest is Tax Deductible ☒

Tax Rate

Relevant Tax Rate on Equipment (%)

Income Tax Rate (%)

Depreciation

Tax Depreciation Method

Capital Equipment Value Subject to Depreciation (%)

Bonus Depreciation (%)

Tax Treatment for Energy & Demand Bill Savings

Avoided Electricity Costs (Energy & Demand Bill Savings) are Taxable ☒

Previous Next Start Analysis Close

Case Information Application Type System Configuration System Costs O&M Costs **Financial Inputs** Policy Load Data Rate Data Results Cash Flow/Payback Year Power Dispatch Help

Figure 12. Financial Inputs Interface

9. Policy

The **Policy** interface is built to address many of the incentives and benefits offered by government policy for the installation of PV systems. The user inputs data that reflects the existing or projected energy policies within the project service territory. Policies can include

⁵ *PV Planner* uses combined state and federal tax rate for its input, which is derived by following method: Combined Income Tax Rate= State Tax Rate + (1-State Tax rate)*(Federal Tax Rate) (see NREL, 1995: C-2). For Tax rates in different states refer to Tax Foundation, 2010. An additional criterion to consider is if depreciation is the same for Federal taxes compared to State taxes. Federal tax depreciation allows for MARCS-5, and nearly all states use MARCS-5 under State depreciation. As of 2011 exceptions include California, Michigan, and Washington (Tax Foundation, 2010).

rebates, investment tax credits, renewable energy credits (RECs), and special prices for the sale of PV-generated electricity to the grid (including net metering and production incentives such as feed-in tariffs). For all government-based incentives and benefits, the user is asked to indicate if they are subject to tax.

Figure 13. Policy Interface

An important policy component is related to the reduction in air pollution (e.g., SO_x and NO_x emissions) and Carbon Dioxide (CO_2) emissions through the use of solar energy. The user can choose to conduct an Emission Reduction Benefit Analysis, which determines the environmental benefits from displacing a part of the energy mix (e.g., use of coal, oil, natural gas, etc.) and associated air emissions. When the user selects this option, a new screen appears (see the interface below) in which relevant pollution information is entered.

Generation Overview

Source	Capacity Mix (%)	Average Heat Rate (BTU/kWh)	SOx Content (g/MBTU)	NOx Content (g/MBTU)	CO2 Content (g/MBTU)
Coal	40.00	11,500.00	3.40	0.80	202.00
# 2 Oil	30.00	9,800.00	1.42	0.50	165.00
# 6 Oil	10.00	9,800.00	1.42	0.50	165.00
Gas	10.00	7,800.00	0.00	0.30	117.00
Nuclear	5.00	10,000.00	0.00	0.00	0.00
Hydro	0.00	0.00	0.00	0.00	0.00
Imported	5.00	10,256.00	1.12	0.60	180.00

Environmental Benefit Input

Source	Emission Cost (\$/Metric Ton)	Cost Escalation (%)
SOx	230.00	0.00
NOx	0.00	0.00
CO2	12.00	0.00

Emissions Reduction Benefits in NPV (\$)

SOx	3015.68
NOx	0.00
CO2	12710.74
Total	15726.41

Apply Close

Figure 14. Emissions Analysis Interface

Users provide information related to the generation mix of their service area, the average heat rate of the fuels used by power plants in their area (default values are suggested), and their respective SO_x, NO_x and CO₂ (again, default values are suggested). An emission cost for each pollutant is entered, which can be obtained from current market prices for tradeable emission permits. The value of reduced emissions is then calculated for the user by **PV Planner**.

10. Load Data

The **Load Data** interface allows the user to enter electricity load information for the type of building that will receive energy services from the PV system. Many options are available to the user with typical building load profiles already loaded into **PV Planner** for homes, office buildings, restaurants, stores, etc. The user adjusts these profiles by entering the typical annual consumption or floor area of a specific building. Users can also choose to enter their own

hourly load data if available or monthly energy demand (in kW) and usage levels (in kWh) from billing statements. In the latter case, **PV Planner** will populate the building load matrix for the user based on the monthly information it is provided.

In addition, the user indicates if the building utilizes electricity for heating. In this instance, the user selects the relevant electric heating technology (standard heat pump, high efficiency heat pump and ground-coupled heat pump and resistance heating). Similarly, the user chooses the “Electric Cooling” option, if it is appropriate.

Figure 15. Load Data Interface

Electricity Demand	January	February	March	April	May	June	July	August	September	October	November	December
Usage (kWh)	14,400.00	13,520.00	11,920.00	11,880.00	13,880.00	16,080.00	18,800.00	17,920.00	16,960.00	13,280.00	12,520.00	12,480.00
Maximum Demand (kW)	30.80	31.20	30.80	32.80	33.20	43.20	47.20	47.20	42.00	36.80	32.00	31.20

Figure 16. Monthly Load Profile Interface

Hourly Load Profile												
Hour	January	February	March	April	May	June	July	August	September	October	November	December
1	40.28	38.77	37.52	34.82	32.14	33.90	37.38	35.73	33.20	30.74	33.45	37.56
2	39.42	37.93	36.65	33.81	31.02	33.15	36.81	35.02	32.04	29.22	32.13	36.32
3	39.01	37.55	36.34	33.33	30.77	33.30	36.29	34.53	31.60	28.75	32.01	35.99
4	38.96	37.40	36.30	33.29	30.60	33.23	36.46	34.65	31.52	28.62	31.71	35.67
5	40.22	38.59	37.90	33.97	30.84	33.64	39.69	37.79	32.76	29.39	32.56	36.49
6	46.22	44.19	43.55	38.86	37.15	40.80	50.65	47.74	38.13	33.49	36.68	40.87
7	58.33	56.42	54.97	51.84	53.62	59.41	70.02	67.92	55.30	46.96	47.47	52.31
8	70.66	68.97	67.10	64.59	69.99	77.96	89.25	88.72	73.55	61.68	59.51	64.63
9	83.36	81.58	80.01	78.74	86.07	95.26	107.01	104.88	89.19	75.95	73.60	79.56
10	90.15	88.07	86.65	86.05	95.75	106.06	117.45	115.04	99.61	85.00	80.22	86.77
11	91.10	88.98	87.70	87.46	98.74	109.26	119.95	118.94	103.69	88.15	81.58	88.12
12	90.81	89.06	87.57	87.96	100.40	110.97	120.87	120.64	105.72	89.98	81.88	88.36
13	89.94	88.10	86.61	87.50	100.37	111.30	120.56	120.50	105.79	89.99	81.42	87.82
14	89.96	88.03	86.70	87.75	100.99	112.13	121.51	120.87	106.89	90.59	81.16	87.48
15	89.13	87.42	86.07	87.37	100.92	112.65	121.38	120.97	107.16	90.61	80.49	86.68
16	87.35	85.77	84.15	85.88	100.18	111.84	119.70	119.28	105.95	89.43	78.97	84.97
17	82.61	80.93	79.37	81.93	95.68	106.46	113.71	113.01	101.24	85.47	74.71	80.77
18	70.79	69.42	67.87	70.02	80.92	90.23	95.73	94.80	84.19	71.26	64.42	69.66
19	61.16	60.01	58.79	58.72	63.81	69.45	74.20	72.15	65.32	56.87	54.60	59.52
20	56.50	55.21	53.87	53.51	56.12	60.56	65.13	63.41	58.02	50.99	50.02	54.74
21	51.90	50.69	49.08	48.17	49.15	53.01	57.20	55.48	50.88	45.27	45.50	49.94
22	46.67	45.34	44.09	43.02	42.84	46.00	48.95	47.70	43.85	39.47	40.37	44.63
23	43.07	41.81	40.49	38.57	37.81	40.50	43.85	42.90	39.73	35.49	36.76	40.80
24	41.69	40.33	39.05	36.48	35.43	37.91	41.04	40.11	37.36	33.86	34.86	39.05

Modify

Close

Figure 17. Hourly Load Profile Interface

If a new user decides to enter specific building load data, the above table must be completed. It is possible to copy and paste data from an Excel data sheet to **PV Planner**.

11. Rate Data

The **Rate Data** interface is used to input prices for electricity. Electricity rate charges usually have two components for commercial and industrial users: an energy charge which sets the kWh price used each month; and a demand charge, based on monthly pulse readings of the

kW connected loads. Residential ratepayers usually pay an energy charge only. The demand charge (or power charge) is based on maximum monthly kilowatt (kW) load; whereas the energy charge prices electricity consumption per kilowatt hour (kWh) used.

PV Planner

RATE DATA

Electricity Rate Structure

Energy Charge Demand Charge ☒

Season	Energy Charge (c/kWh)	Demand Charge (\$/kW)
Dec-Jan	12.00	0.00
Feb-Mar	12.00	0.00
Apr-May	12.00	0.00
Jun-Jul	12.00	0.00
Aug-Sep	12.00	0.00
Oct-Nov	12.00	0.00

Advanced Options

Seasonal Rates ☐

Hourly Rates

Annual Escalation Rate (%)

Previous Next Start Analysis Close

- CASE INFORMATION
- APPLICATION TYPE
- SYSTEM CONFIGURATION
- SYSTEM COSTS
- O&M COSTS
- FINANCIAL INPUTS
- POLICY
- LOAD DATA
- RATE DATA**
- RESULTS
- CASH FLOW / PAYBACK YEAR
- POWER DISPATCH
- HELP

Figure 18. Simplified Rate Data Entry Interface

In some instances, energy and demand charges may vary during the year, with higher seasonal rates (e.g., for summer consumption) being applied. If this situation applies, the user is taken to a screen where hourly electricity rates are entered by time of day and month (see the Time of Use Rate Data interface below). The user also decides the likely annual rate of increase in electricity prices (Annual Escalation Rate).

PV Planner

RATE DATA

Month	Start (1)	End (1)	\$/kW	c/kWh	Start (2)	End (2)	\$/kW	c/kWh
1	0	24	0	0	12	0	0	0
2	0	24	0	0	12	0	0	0
3	0	24	0	0	12	0	0	0
4	0	24	0	0	12	0	0	0
5	0	24	0	0	12	0	0	0
6	0	24	0	0	12	0	0	0
7	0	24	0	0	12	0	0	0
8	0	24	0	0	12	0	0	0
9	0	24	0	0	12	0	0	0
10	0	24	0	0	12	0	0	0
11	0	24	0	0	12	0	0	0
12	0	24	0	0	12	0	0	0

Annual Escalation Rate (%) Back to Simplified Rate Entry Mode

Previous Next Start Analysis Close

CASE INFORMATION

APPLICATION TYPE

SYSTEM CONFIGURATION

SYSTEM COSTS

O&M COSTS

FINANCIAL INPUTS

POLICY

LOAD DATA

RATE DATA

RESULTS

CASH FLOW/PAYBACK YEAR

POWER DISPATCH

HELP

Figure 19. Time of Use Rate Data Interface

12. Results

The **Results** interface reports findings for the project entered by the user into **PV Planner** via a scrollable window. Users are given summaries related to the technical aspects of the PV system such as the amount of electricity that is generated, the capacity of the PV array, battery and inverter and the efficiency of the system. A summary is given of the financial inputs (e.g., initial capital costs and rebates) together with the financial performance of the system. Net Present Value, Benefit Cost Ratio, Payback Year and the Levelized Cost of Electricity for the system are given as measures of financial performance. In addition, PV Planner solves for minimum LCOE and PPA rates required to achieve the user specified return on equity (i.e., discount rate) under different policy and economic scenarios.⁶ Likewise PV Planner also reports

⁶ For a detailed review of LCOE calculation methodology consult NREL, 1995: 47-51 and the subsequent discussion on understanding residential and commercial results.

a minimum SREC price for meeting the similar result. Users can print, save or have the results sent to an Adobe Acrobat or a MS Word file.

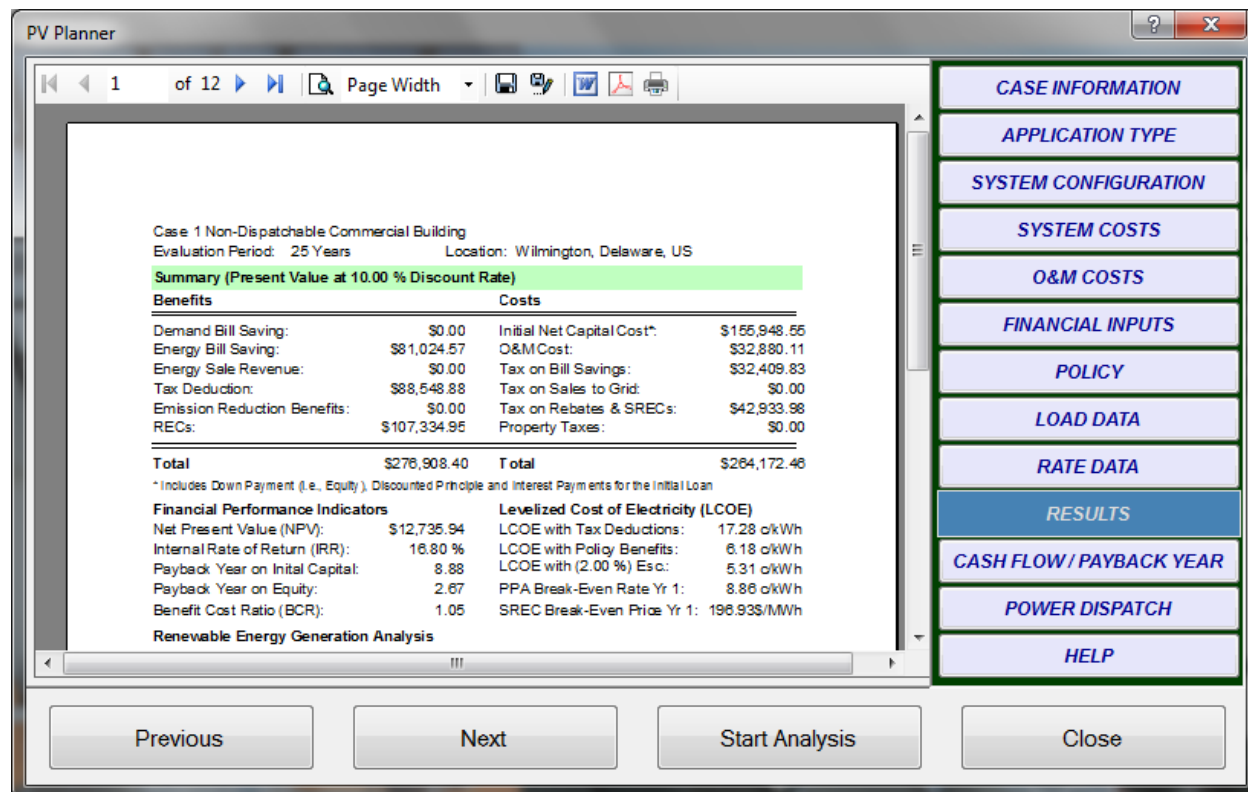


Figure 20. Results Interface

Understanding Residential Results

When reviewing *PV Planner's* results, the resultant LCOE is presented under several scenarios, where NREL's 1995 report, "A manual for the economic evaluation of energy efficiency and Renewable energy Technologies" reviews the various LCOE calculation parameters. Residential installations "LCOE with Policy Benefits" is calculated with all of the PV and balance-of-system (BOS) costs discounted at the user specified rate and can be compared with the user's electric rate. If a homeowner buys a PV system, for example, using a home-equity loan instead of leasing it, the interest on this loan may be tax-deductible (a tax professional can make this determination), and thus the LCOE with Policy Benefits would reflect this condition (see NREL, 2009 for a discussion of various options and examples of the financial

calculations). PV Planner also reports the LCOE with rate escalation, which reflects an alternative scenario under which the first year of electricity cost is lower in exchange for an annual price increase over the project life time.⁷ LCOE with Tax deductions shows the kWh cost of PV generated electricity without the incentives entered in Policy interface.

Understanding Commercial Results

In the case of commercial users subject to income taxes, the electricity bill saving can be valued at: $\text{Electricity rate} * (1 - \text{TaxRate}_{\text{eff}})$. Therefore, commercial evaluation of the LCOE requires considering the price per kWh both with and without taxes. NREL (1995) discusses this at length, where for instance if the commercial entity subject to a 40% of effective tax rate is paying \$0.14 per kWh for electricity, then because they are writing off this as a taxable expense, they are valuing their electricity costs at $0.14 * (1 - 0.4) = 0.084$. Hence, this is the value to compare with the *PV Planner's* output "LCOE with Escalation." Alternately, \$0.14 can be compared the PPA Rate, also reported by *PV Planner*. The first year PPA breakeven price can be calculated by dividing the "LCOE with escalation" value by $(1 - \text{TaxRate}_{\text{eff}})$, (i.e. the PPA price could be fixed or escalated at a user defined rate in Rate Date interface).

13. Cash Flow/Payback Year

The **Cash Flow/Payback Year** interface graphically displays the cash inflows and outflows during the life of the project, and presents these flows in four formats: nominal cash flow, discounted cash flow, cumulative cash flow and cumulative discounted cash flow. The user can click on individual graphs to obtain an enlarged version, which will also display the net present value (NPV), benefit-cost ratio (BCR) and payback year. The same data can also be obtained in a tabular form, by clicking the table button (shown here).



⁷ Because electricity bill savings are non-taxable for residential customers, the PPA Break Even Rate equals this value.



Figure 21. Cash Flow and Payback Year Interface

Bar graphs of Cash Flow details are also provided (see below). From them, the user can visually inspect the relative effects of positive sources of cash flows like bill savings, sales revenues (when some or all of the PV system's output is sold to the grid), tax incentives, emission reduction benefits and REC's (renewable energy credits – tradable market permits associated with state RPS, or Renewable Portfolio Standards legislation – see Kotas, 2001; and CEEP, 2005). Likewise, negative effects on cash flow can be attributed to loan down payment (i.e., equity), annual loan payments (includes principle and interest), taxes and O&M (operations and maintenance) costs. Results are presented in nominal as well as in discounted dollars.

Total Cash flow (see Figure 22) shows Initial Project costs before economic incentives (e.g., tax credits, and rebates) and financial leverage (i.e., loan). The figure also shows the impact of these positive cash inflows on reducing initial cost for the customer in year 0. Year 0 Equity-Based Cash flow includes these positive cash inflows and hence allows more clear depiction of cash flow after year 0.

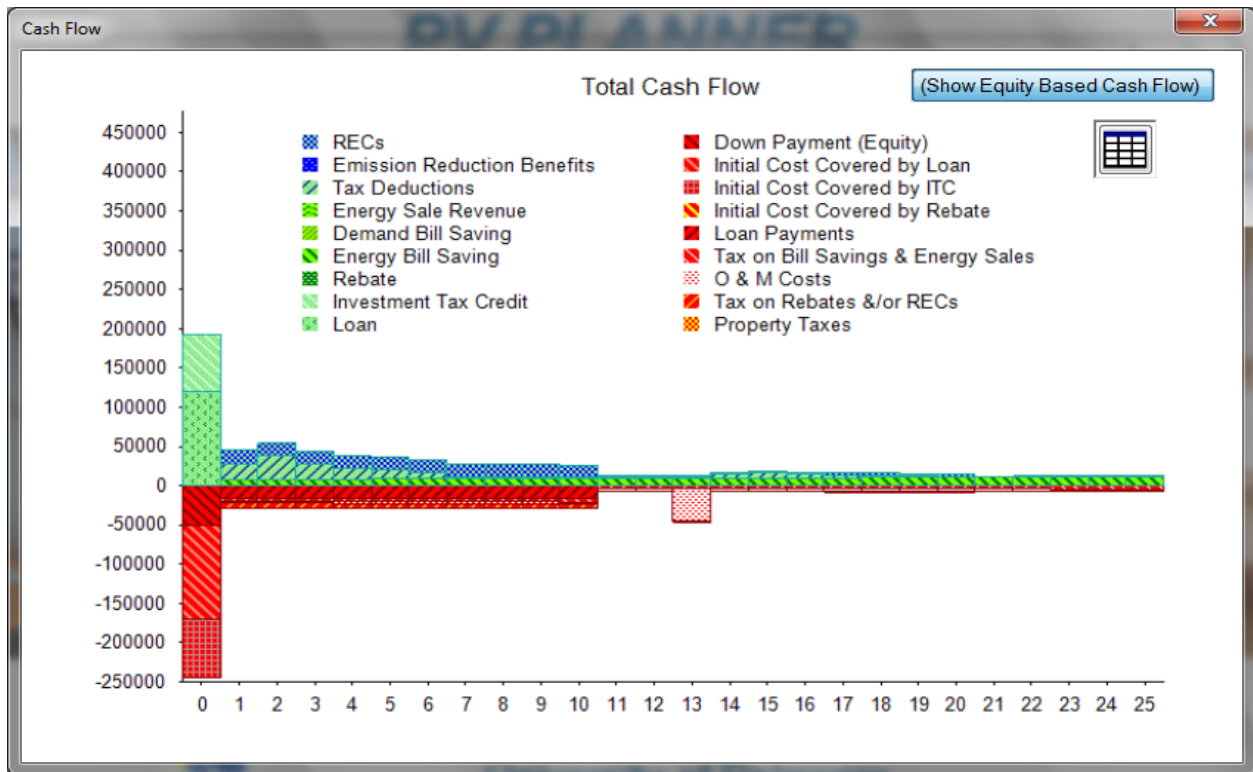


Figure 22. Total Cash Flow

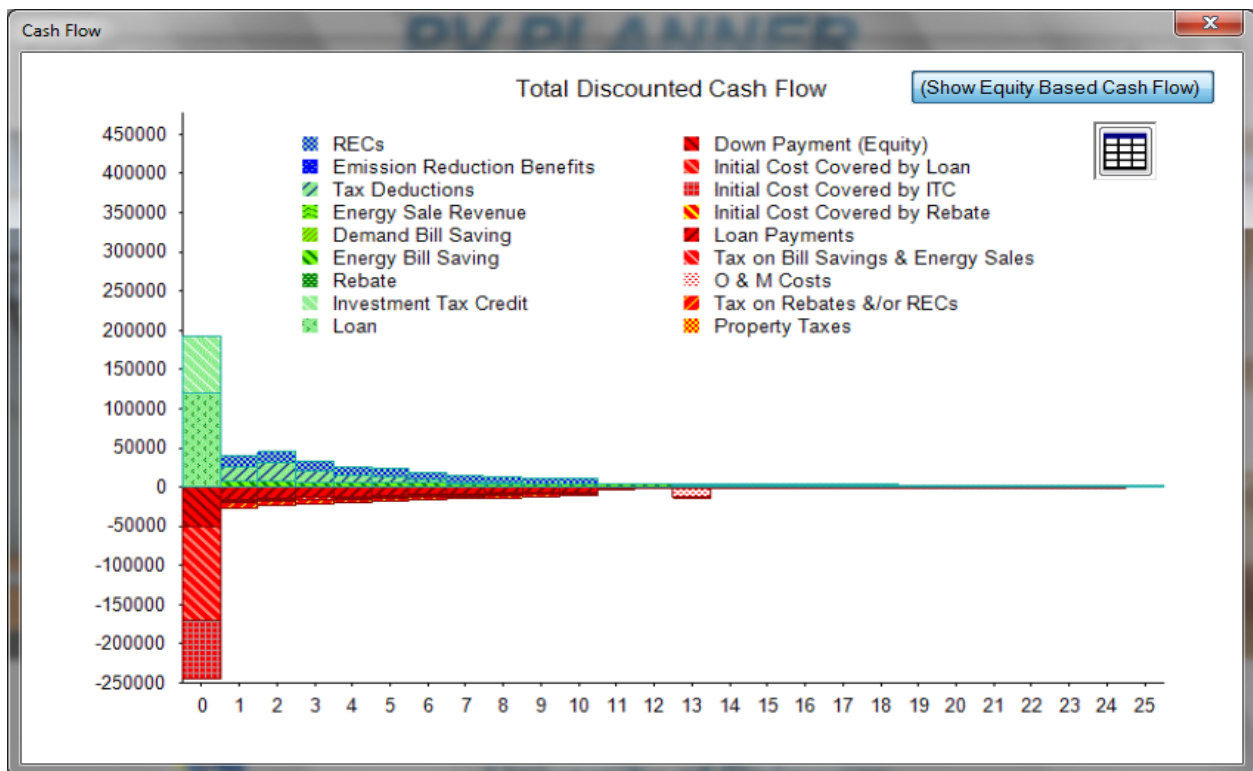


Figure 23. Total Discounted Cash Flow

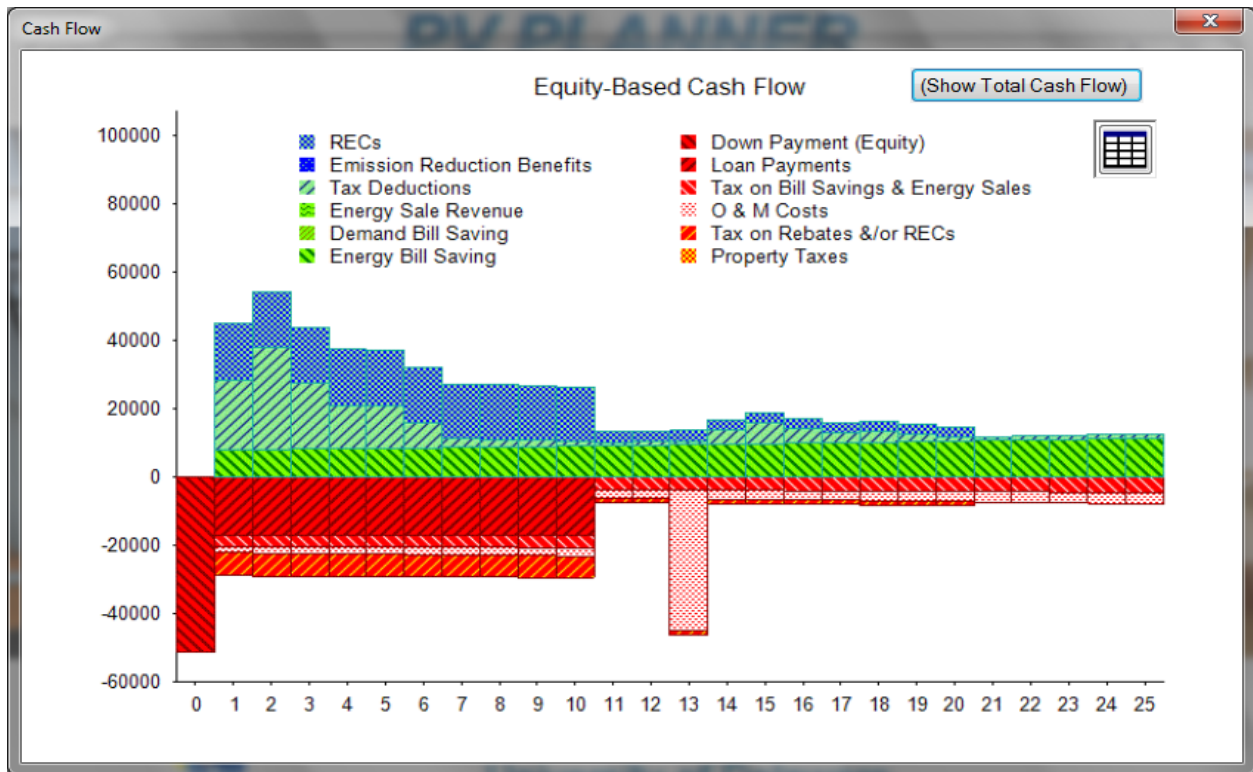


Figure 24. Equity-Based Cash Flow

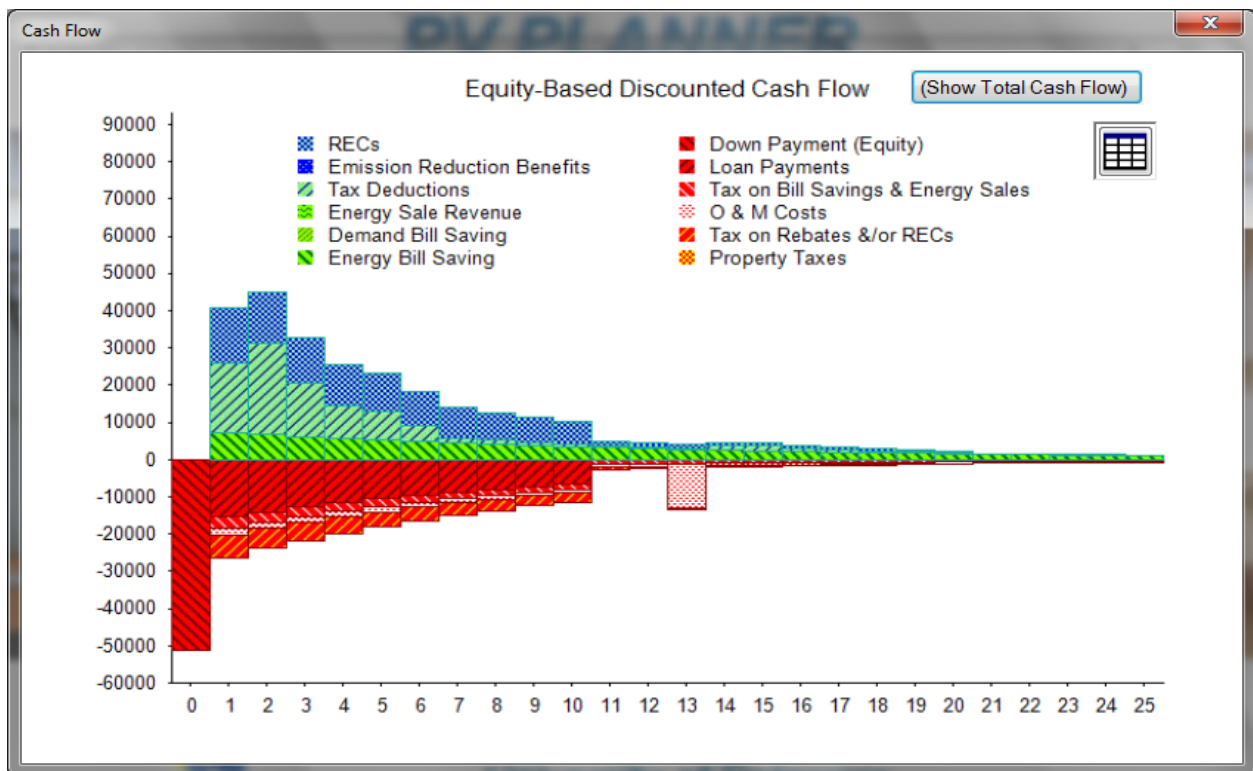


Figure 25. Equity-Based Discounted Cash Flow

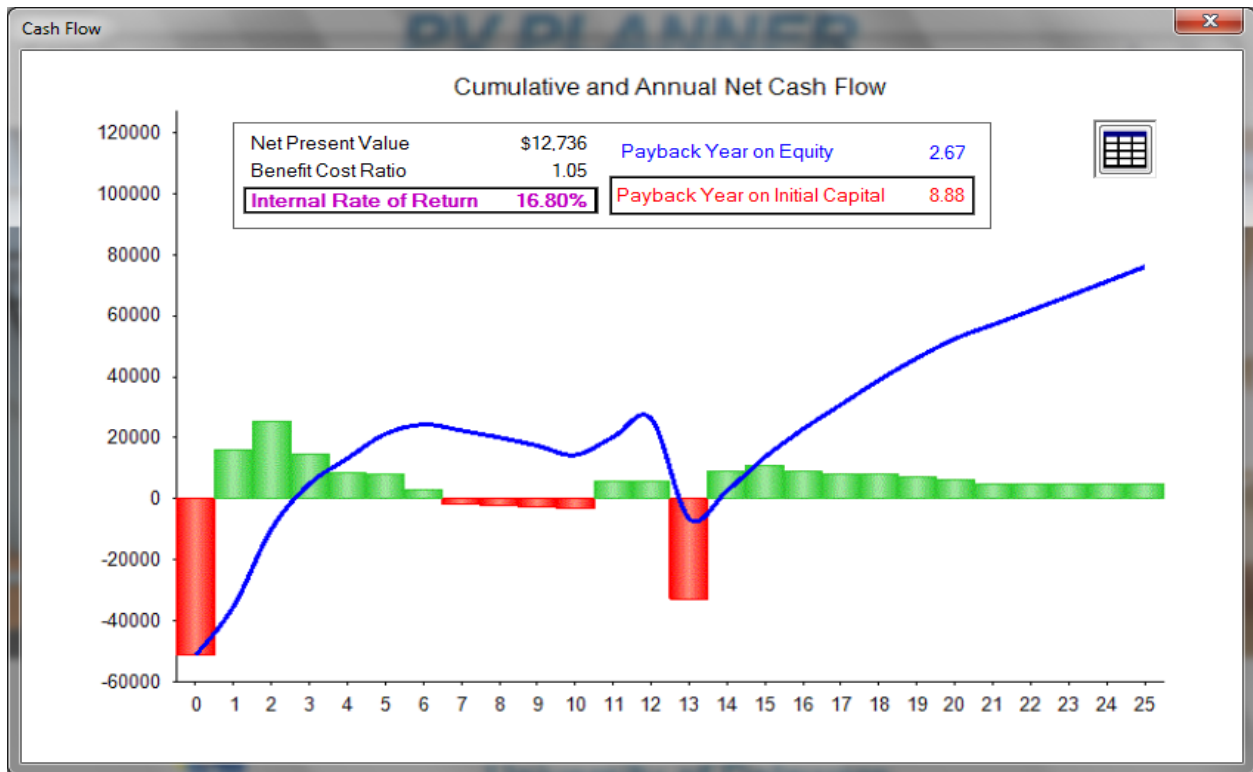


Figure 26. Cumulative and Annual Net Cash Flow

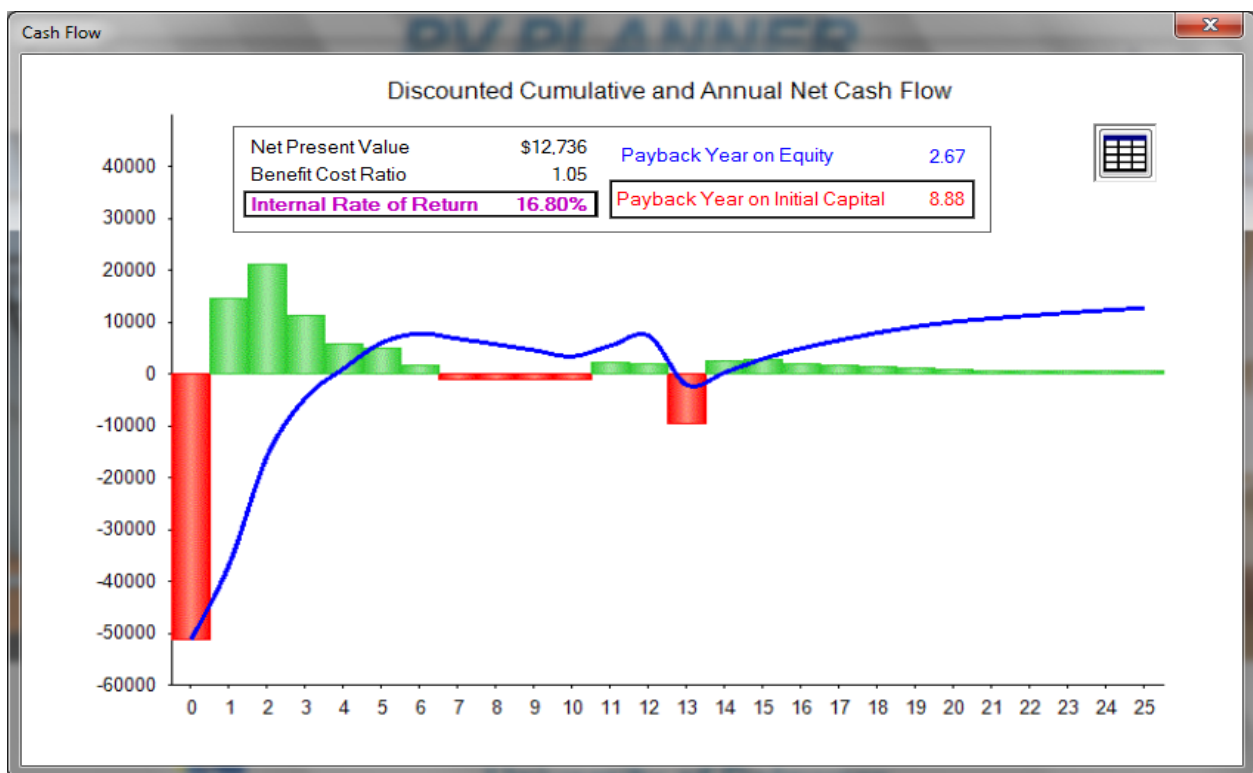


Figure 27. Discounted Cumulative and Annual Net Cash Flow

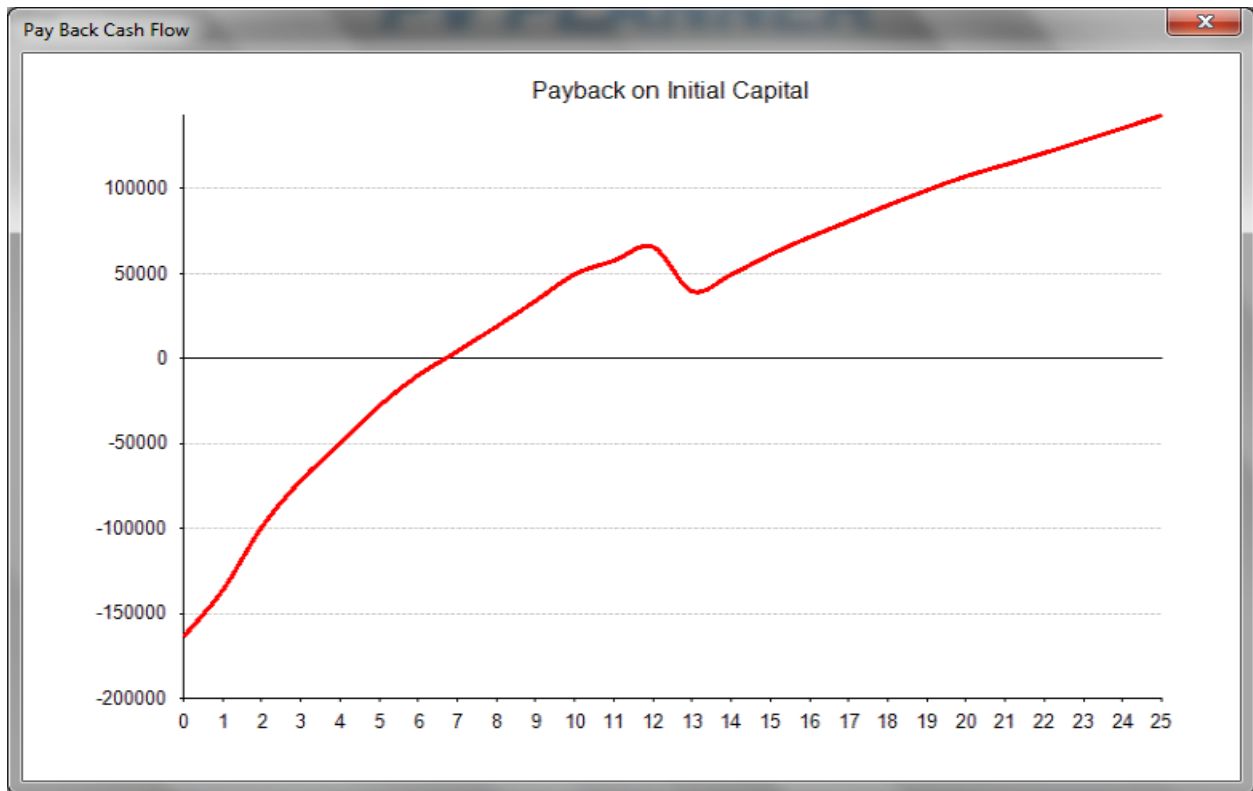


Figure 28. Payback on Initial Capital

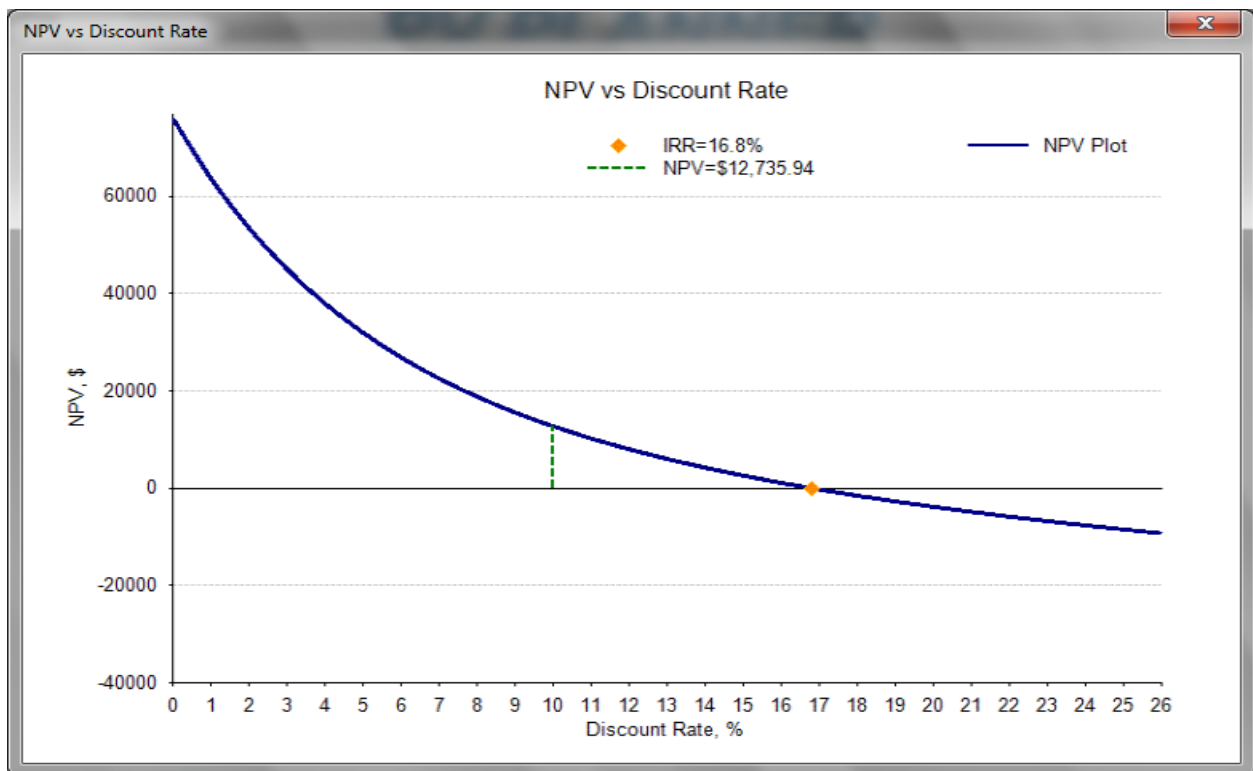


Figure 29. NPV vs Discount Rate

Figure 26 and Figure 27 demonstrate project net cash flow (i.e., net effect of positive and negative cash flows) for each year throughout the project life. The cumulative cash flows, depicted by solid blue lines, show the aggregate effect of net cash flow from the previous years (starting from year 0). The corresponding year when the cumulative cash flow value (i.e., blue line) becomes positive is the Payback Year on Equity. The alternative Payback cash flow, shown in Figure 28, depicts the number of years required to recover total project costs (including the initial project costs covered by loan). This chart can be accessed by clicking on the “Payback Year on Initial Capital” label framed by the black box. Clicking on the “Internal Rate of Return” label loads the NPV vs Discount Rate chart (see Figure 29). This chart shows the NPV values under different customer discount rates.

14. Power Dispatch

The Power Dispatch interface graphically displays the energy services of the PV system for each month. The graph is divided into areas that indicate periods where:

- Power input from the grid – Blue
- Peak shaving from coincident output of the PV array only – Green
- Peak shaving using battery storage – Red
- Solar energy sold to the grid (if any) – Yellow

Power Dispatches can be displayed separately for each month or for all twelve months (see next page).

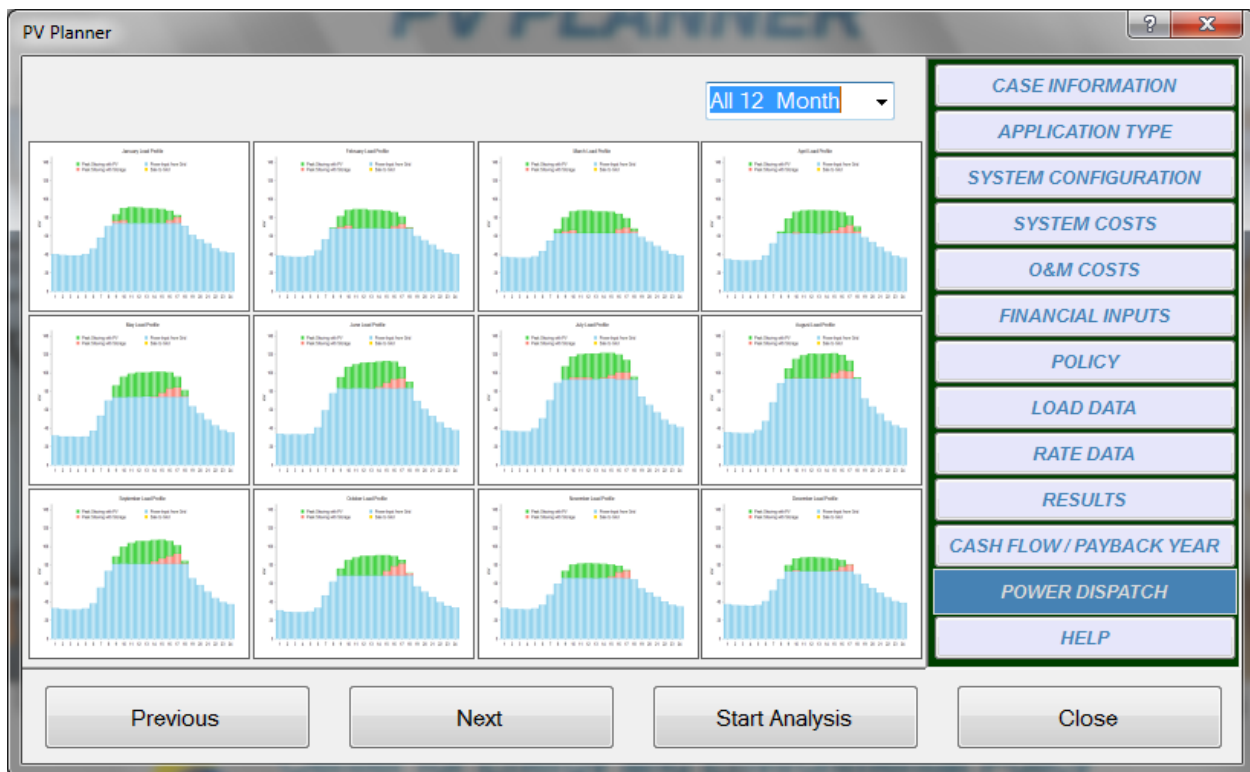


Figure 30. Power Dispatch Interface



Figure 31. Power Dispatch and Load Profile for Selected Month

Example PV Planner Output

Case 3 Dispatchable Commercial Building

Evaluation Period: 25 Years

Location: Wilmington, Delaware, US

Summary (Present Value at 10% Discount Rate)

Benefits		Costs	
Demand Bill Savings:	\$41,821.18	Initial Net Capital Cost:	\$164,214.83
Energy Bill Savings:	\$52,758.61	O&M Cost:	\$42,970.34
Energy Sale Revenue:	\$0.00	Tax on Bill Savings:	\$37,831.92
Tax Deduction:	\$93,200.72	Tax on Sales to Grid:	\$0.00
Emission Reduction Benefits:	\$0.00	Tax on Rebates & SRECs:	\$41,934.26
SRECs:	\$104,835.66	Property Taxes:	\$0.00
Total	\$292,616.16	Total	\$286,951.35

Financial Performance Indicators

Net Present Value (NPV):	\$5,664.82
Internal Rate of Return (IRR):	12.05 %
Payback Year on Initial Capital:	8.67
Payback Year on Equity:	3.58
Benefit Cost Ratio (BCR)	1.02

Levelized Cost of Electricity (LCOE)

LCOE with Tax Deductions:	20.11 c/kWh
LCOE with Policy Benefits:	9.01 c/kWh
LCOE with (2.00%) Esc:	7.75 c/kWh
PPA Break-Even Rate Yr 1:	12.91 c/kWh
SREC Break-Even Price Yr 1:	225.83 \$/MWh

Renewable Energy Generation Analysis

PV System Capacity:	50.00kW dc	Annual Tilted Insolation:	589,046kWh
Battery Capacity:	38.59kWh	System Generation (net of losses):	64,775kWh
Maximum Depth of Discharge:	80.00 %	Average Daily Generation:	177.47kWh
Inverter Capacity:	63.13kW dc	Peak Generation:	41.17kW ac
System Efficiency (w Temp. eff):	11.00 %	Generation per kWp:	1,295.50kWh
Capacity Factor:	14.79 %	Specific Yield:	181.4kWh/m ²
		Average Cell Temperature:	18.16C

Financial & Tax Inputs

Avg. Income Tax Rate:	40.00 %
Avg. Property Tax Rate:	0.00 %
Tax Depreciation Method:	MACRS 5 Years
Depreciation Duration:	5 Years
Capital Equipment Value Subject to Depreciation:	85.00 %
Customer Discount Rate:	10.00 %

PV Array & Support Structure

PV Array:	\$100,000.00
Support Structure:	\$12,499.90
Capital Cost:	\$112,499.90
Rebate:	\$0.00

Balance of System (BOS)

Inverter:	\$44,188.08
Battery Bank:	\$0.00
Other Electrical Equipment:	\$25,000.00
Capital Cost:	\$69,188.08
Rebate:	\$0.00

Loan 1

Debt Ratio:	60.00 %
Loan Interest Rate:	7.00 %
Loan Period:	10 Years
Min. DSCR	1.25

Loan 2

Debt Ratio:
 Loan Interest Rate:
 Loan Period:

NA
 NA
 NA

Project Administration

Overhead: \$50,000.00
 Contingencies: \$6,950.64
 Miscellaneous: \$15,000.00
 Capital Cost: \$71,950.64
 Rebate: \$0.00

Policy Summary

Sales to Grid: Net Metering (See Rate Data)

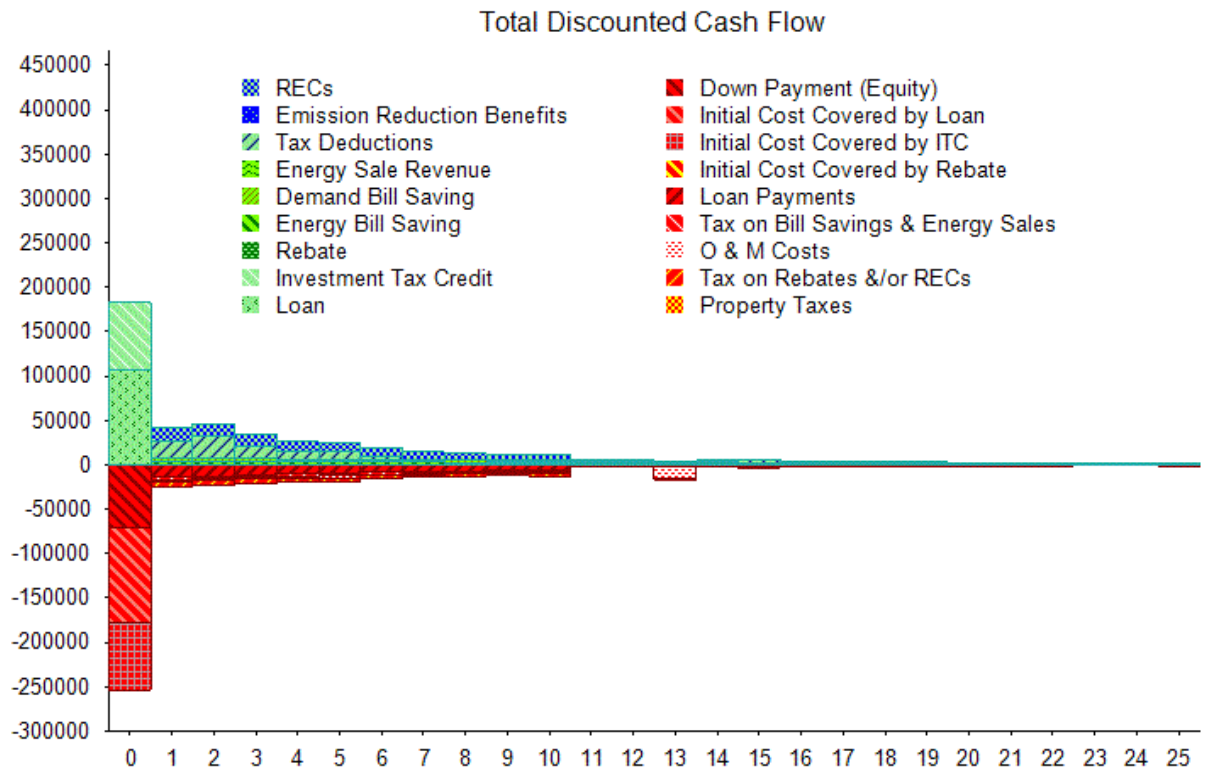
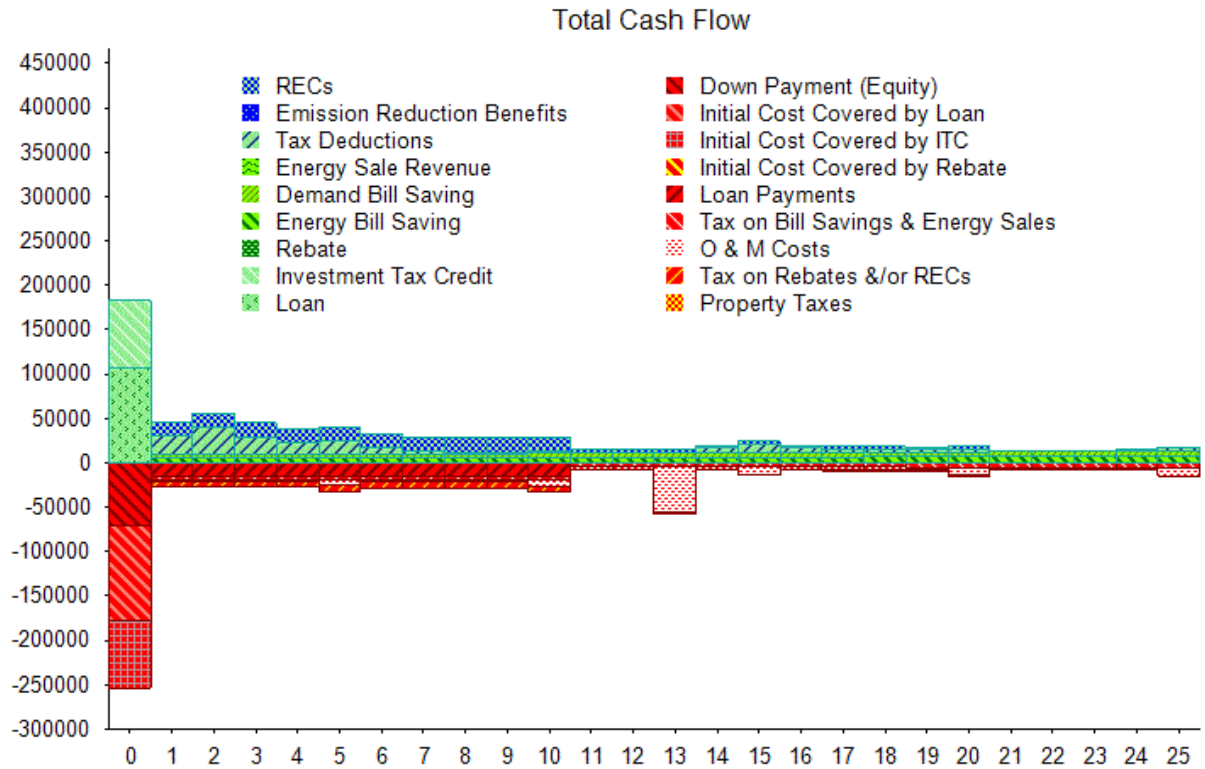
RECs: 250\$/MWh
 System Rebate: 0.00 %
 Investment Tax Credit: 30.00 %

Capital Cost Summary (Nominal \$)

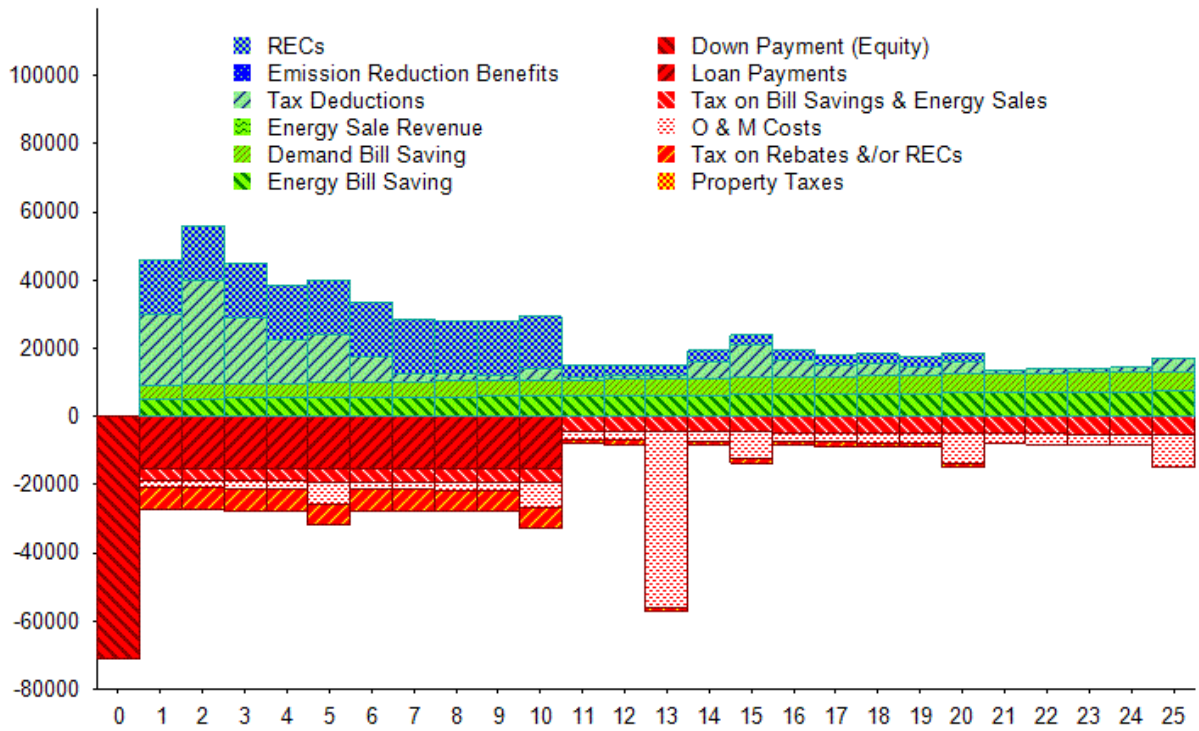
Estimated Initial Project Cost: \$253,638.62
 Total Rebate (one-time, 0th year): \$0.00
 Investment Tax credit (0th year): \$76,091.59
 Architectural Materials Avoidance: \$0.00
 Emergency Power Avoidance: \$0.00
 Initial Net Capital Cost: \$177,547.03

First Year Result

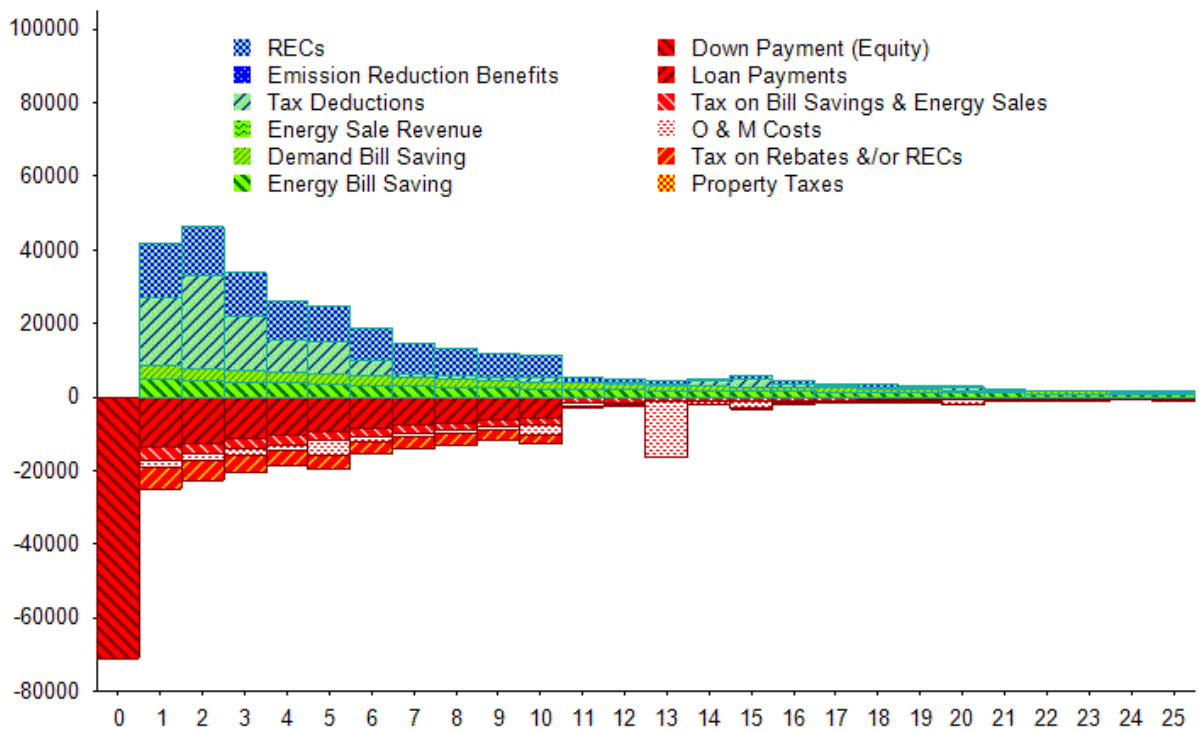
Month	Original Demand (kW)	Original Energy (kWh)	Peak Shaving (kW)	Energy Savings (kWh)	Net System Energy Gen. (kWh)	Reverse Energy Flow (kWh)	Demand Bill Savings (\$)	Energy Bill Savings (\$)	Sales to Grid (\$)
January	107.5	47,719	16.79	3,833	3,833	0	252	307	0
February	105.1	42,016	20.43	4,516	4,516	0	307	361	0
March	103.5	45,521	24.07	6,169	6,169	0	361	494	0
April	103.8	43,309	24.70	6,177	6,177	0	370	494	0
May	119.2	48,400	26.62	6,619	6,619	0	399	530	0
June	132.9	51,569	28.92	6,775	6,775	0	434	542	0
July	143.4	58,428	27.81	6,817	6,817	0	417	545	0
August	142.7	57,436	26.95	6,346	6,346	0	404	508	0
September	126.5	48,980	25.46	5,662	5,662	0	382	453	0
October	106.9	43,624	21.61	5,078	5,078	0	324	406	0
November	96.6	40,382	15.72	3,482	3,482	0	236	279	0
December	104.3	45,530	14.76	3,300	3,300	0	221	264	0
Total	1,392.4	572,914	273.85	64,775	64,775	0	4,108	5,182	0

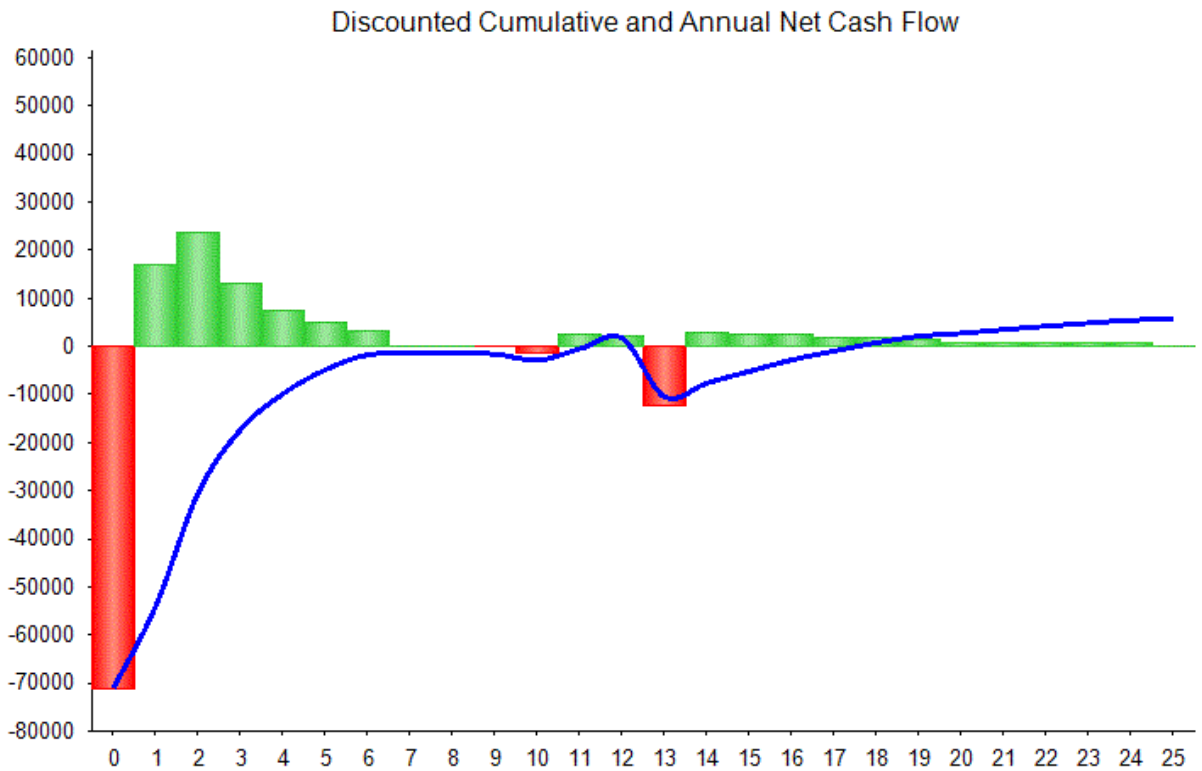
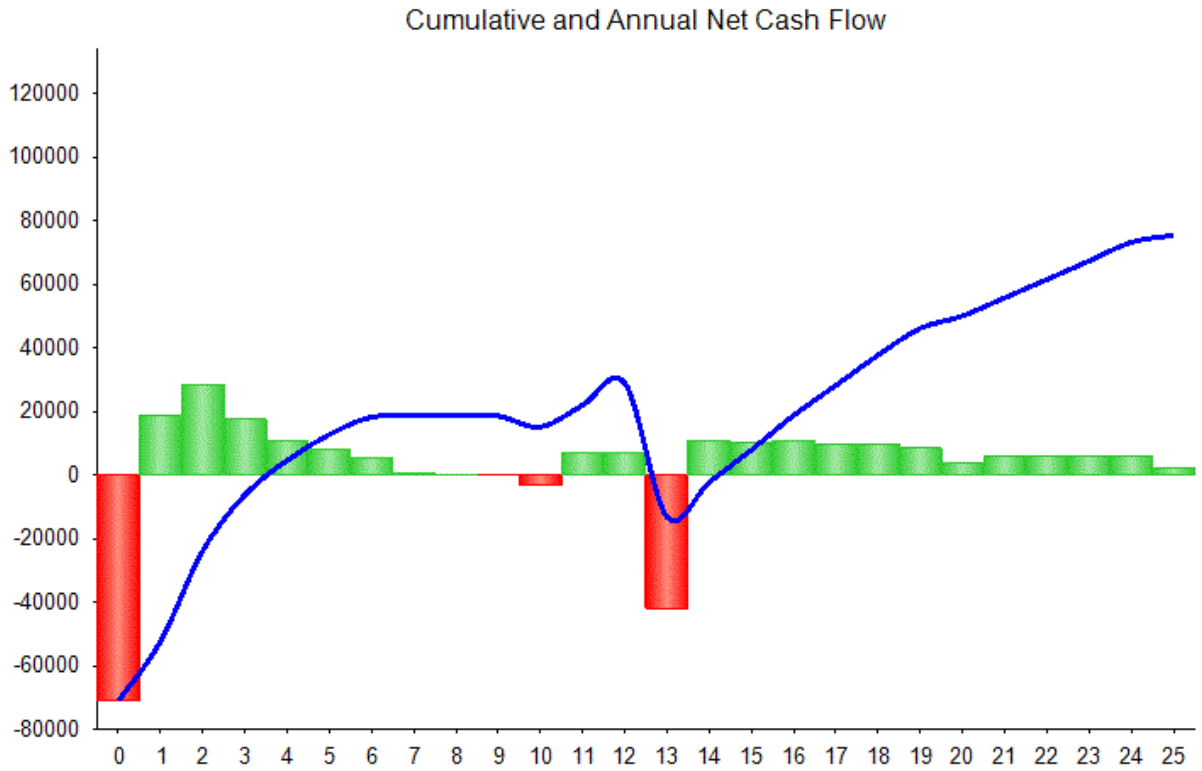


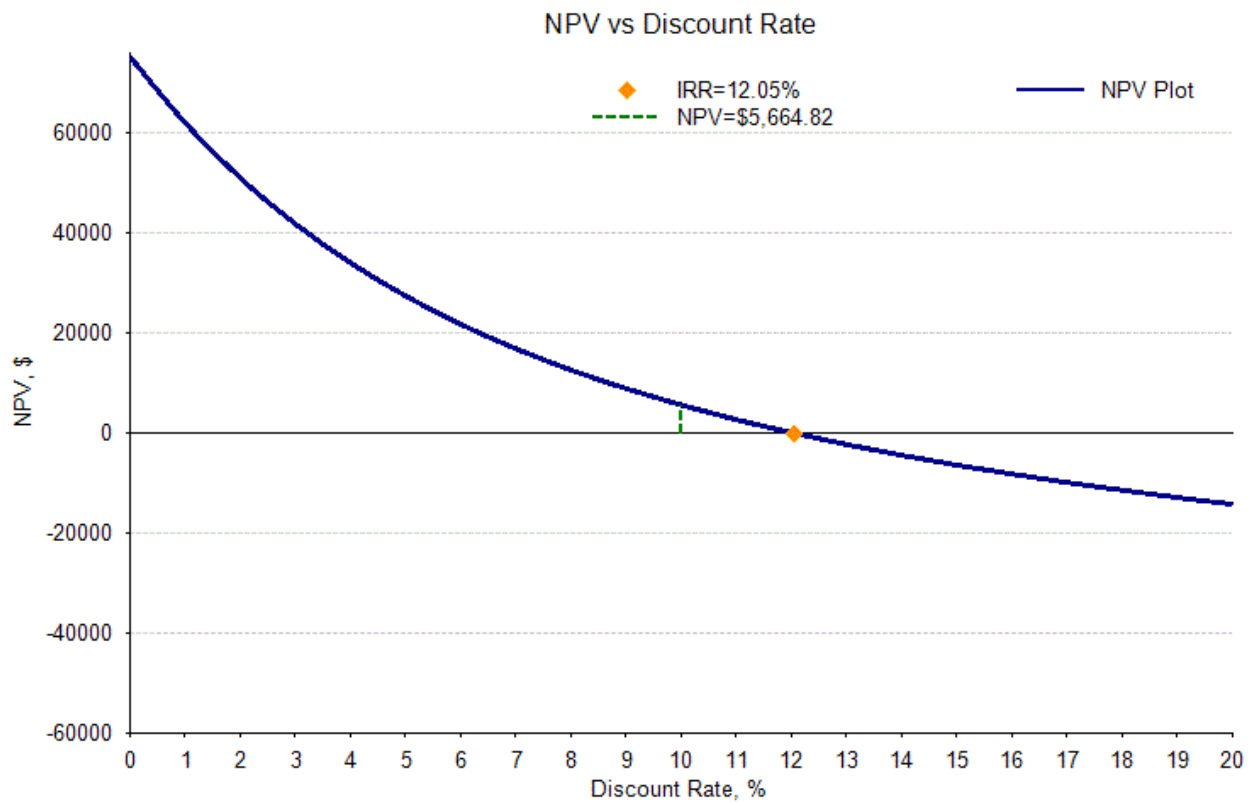
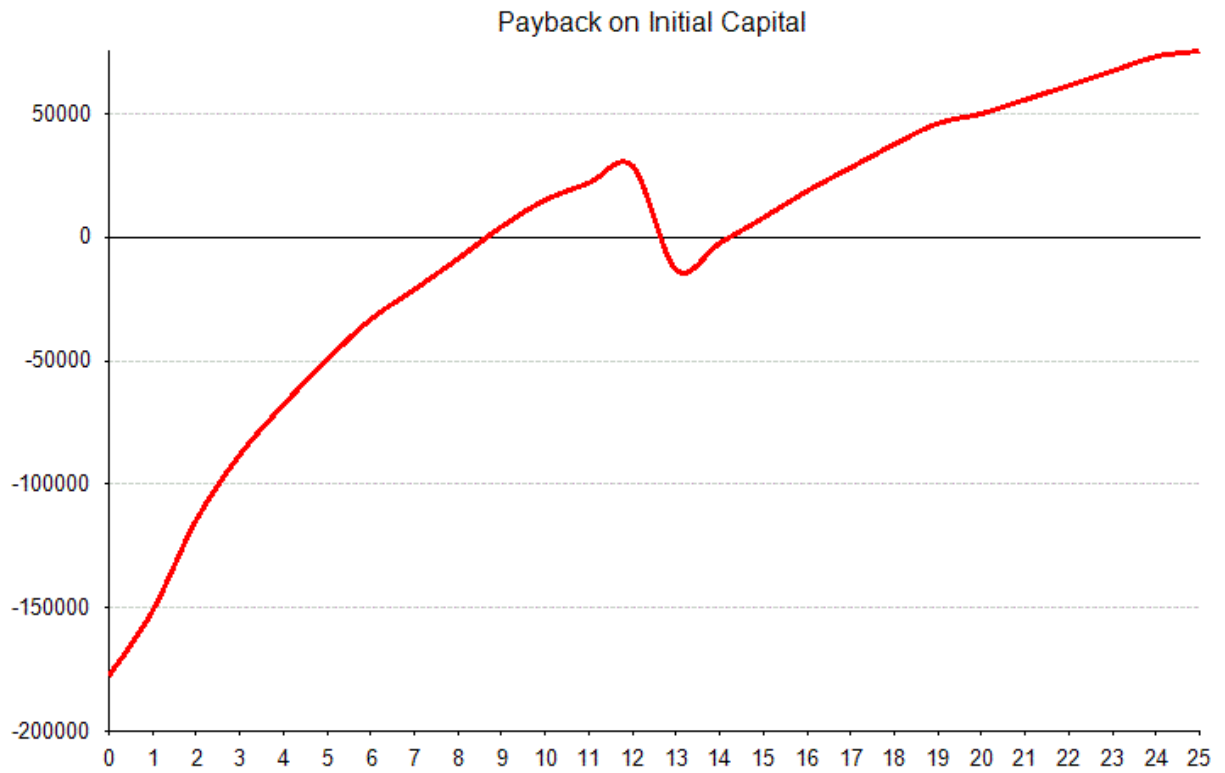
Equity-Based Cash Flow

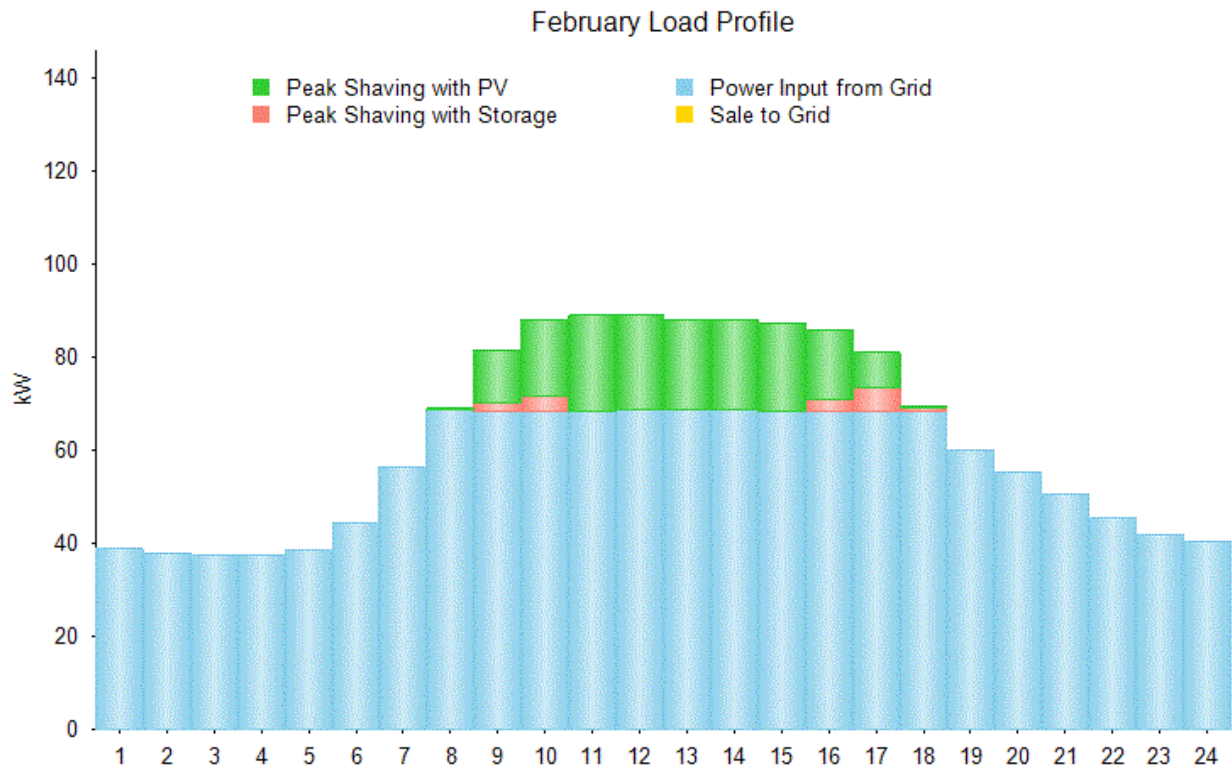
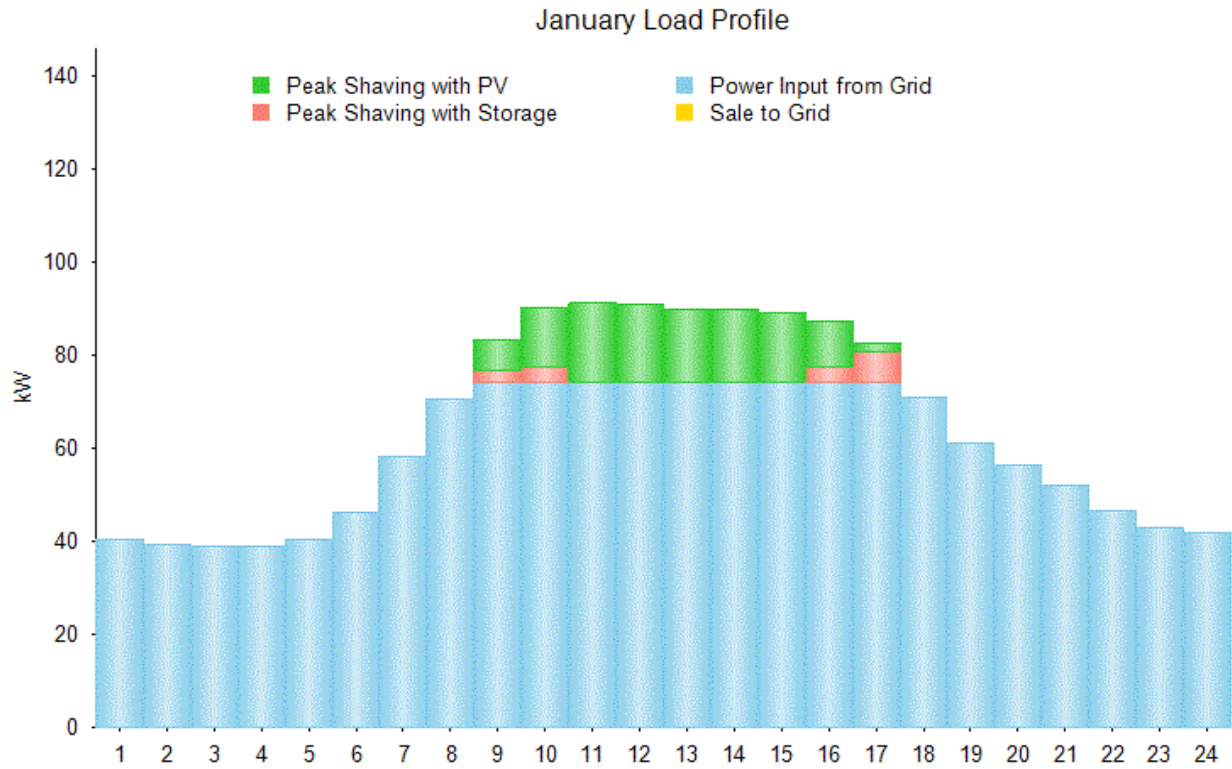


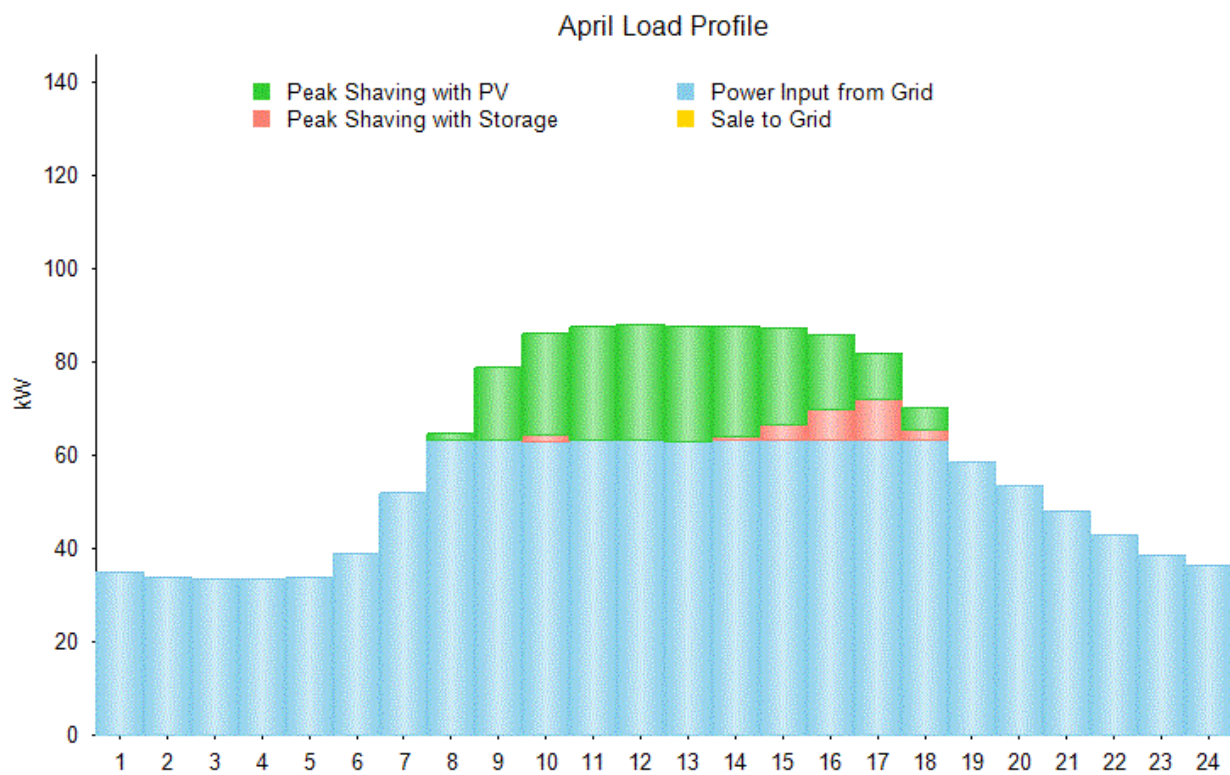
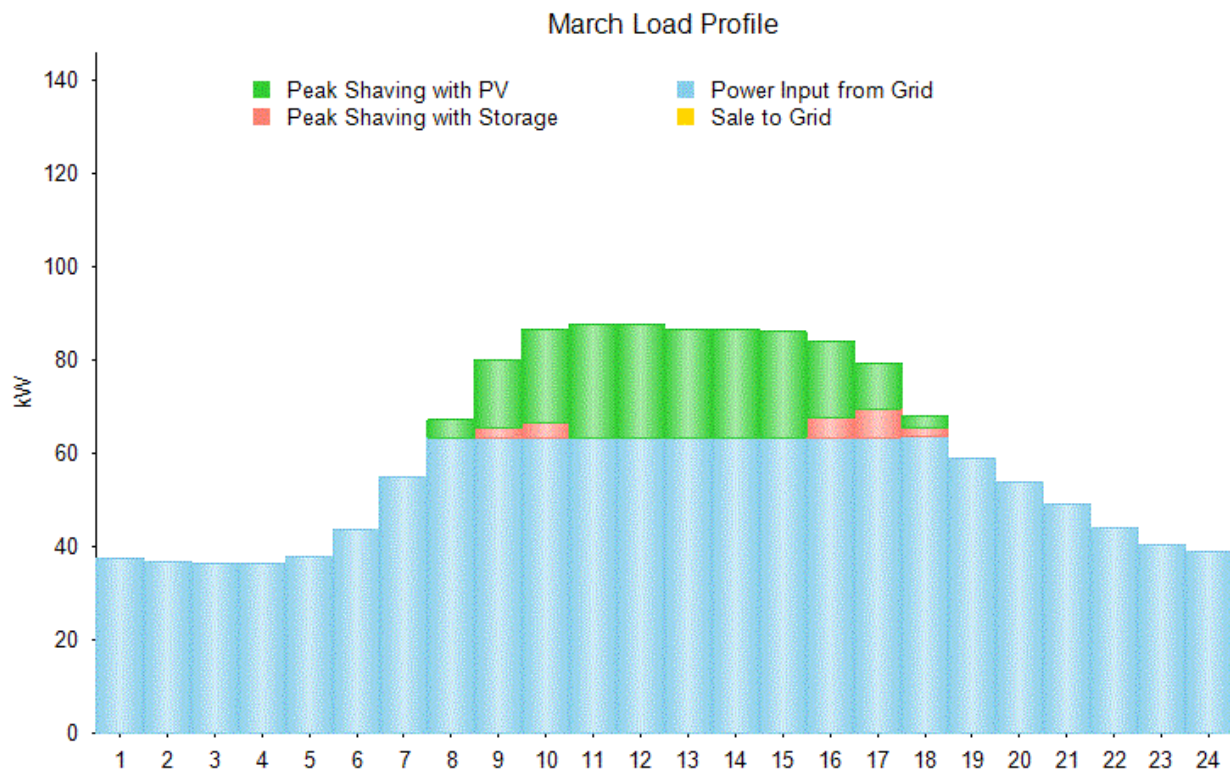
Equity-Based Discounted Cash Flow

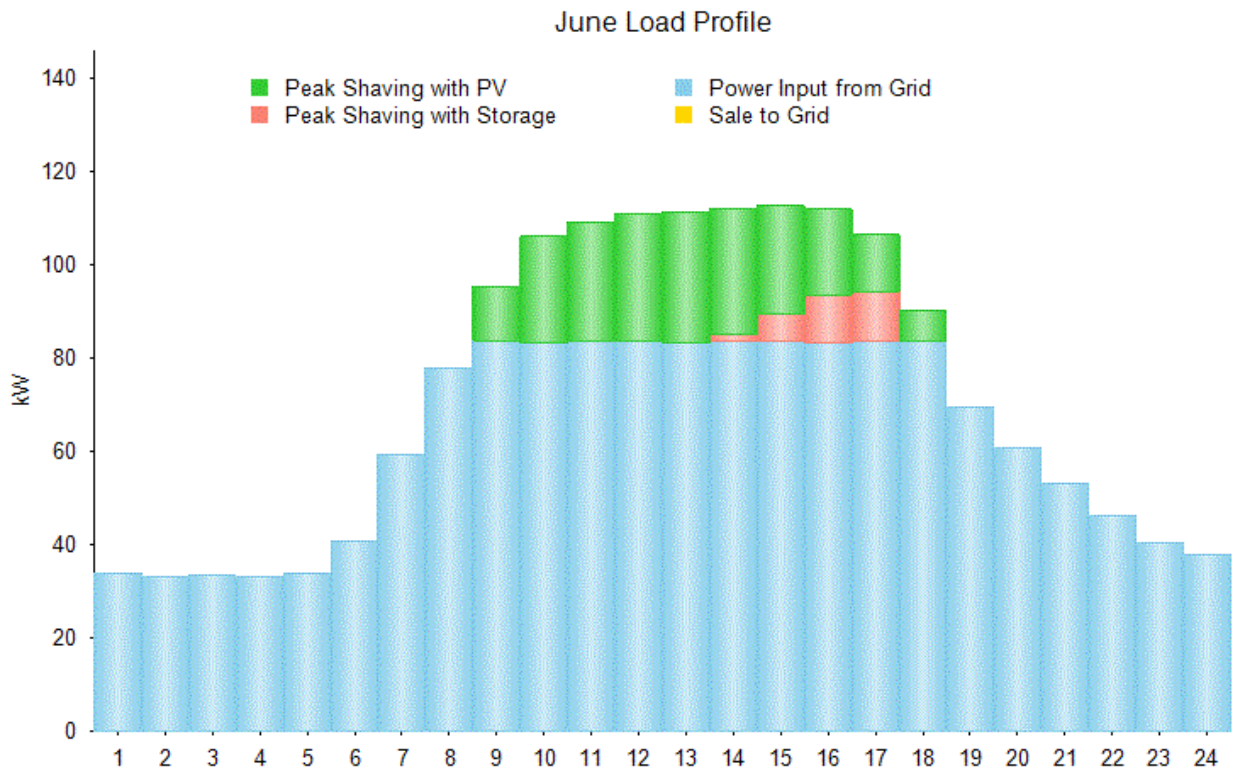
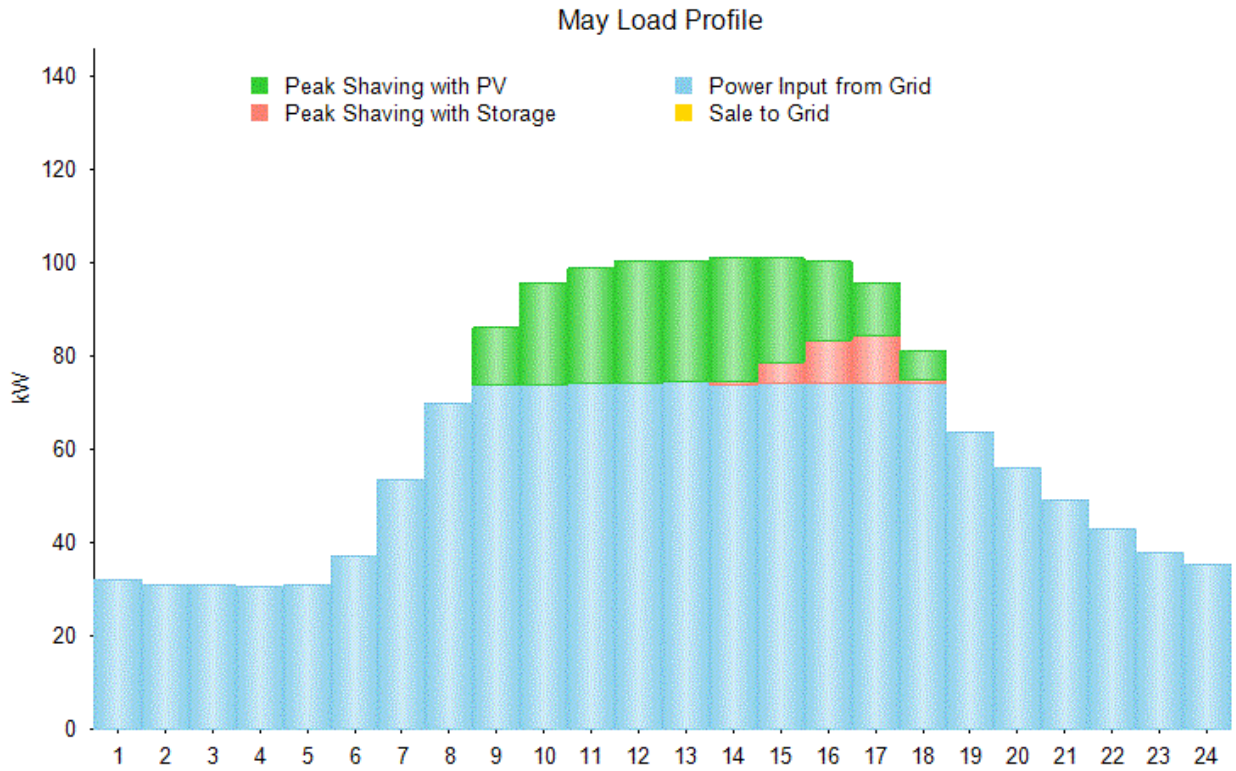


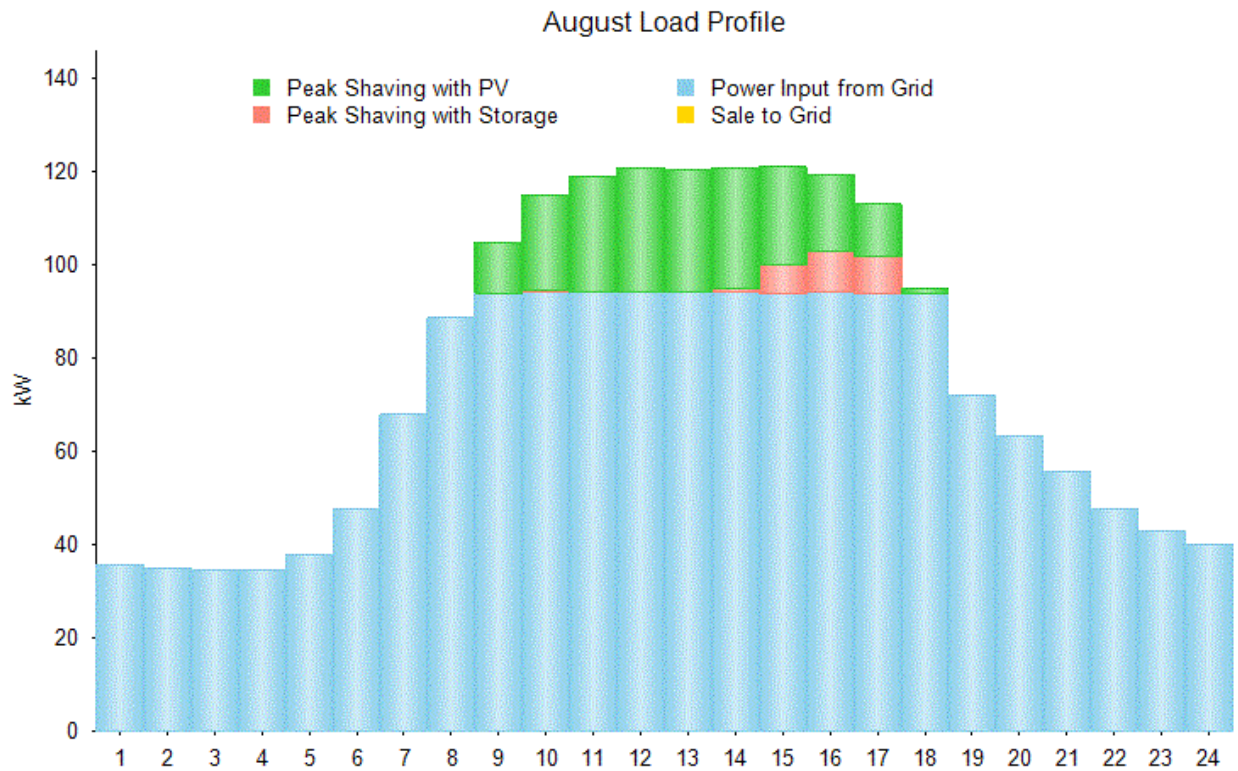
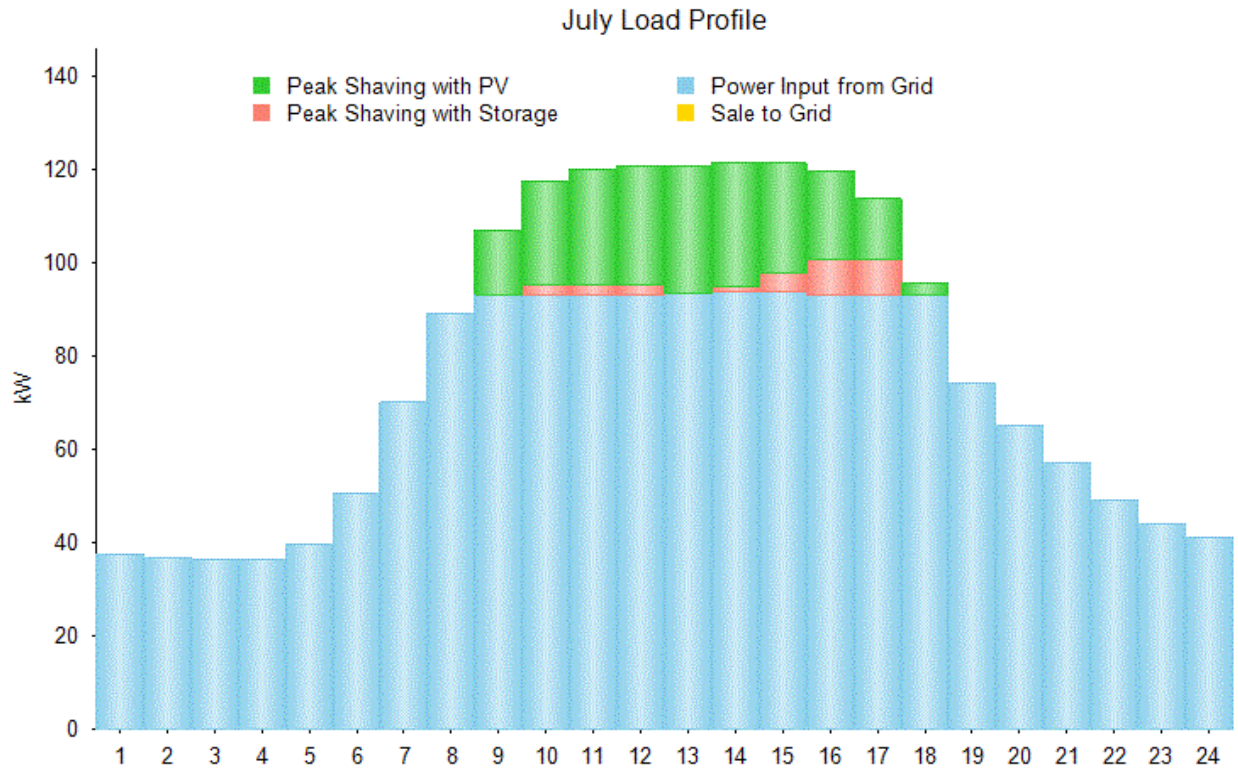


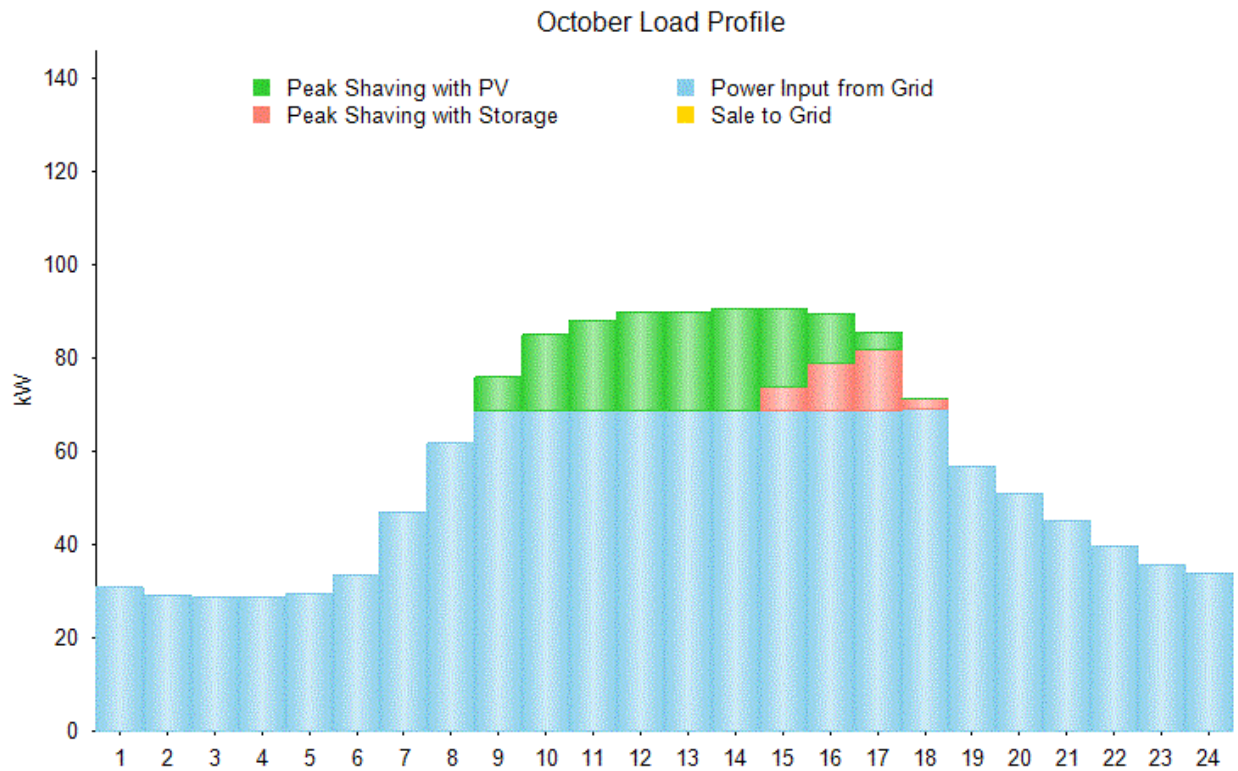
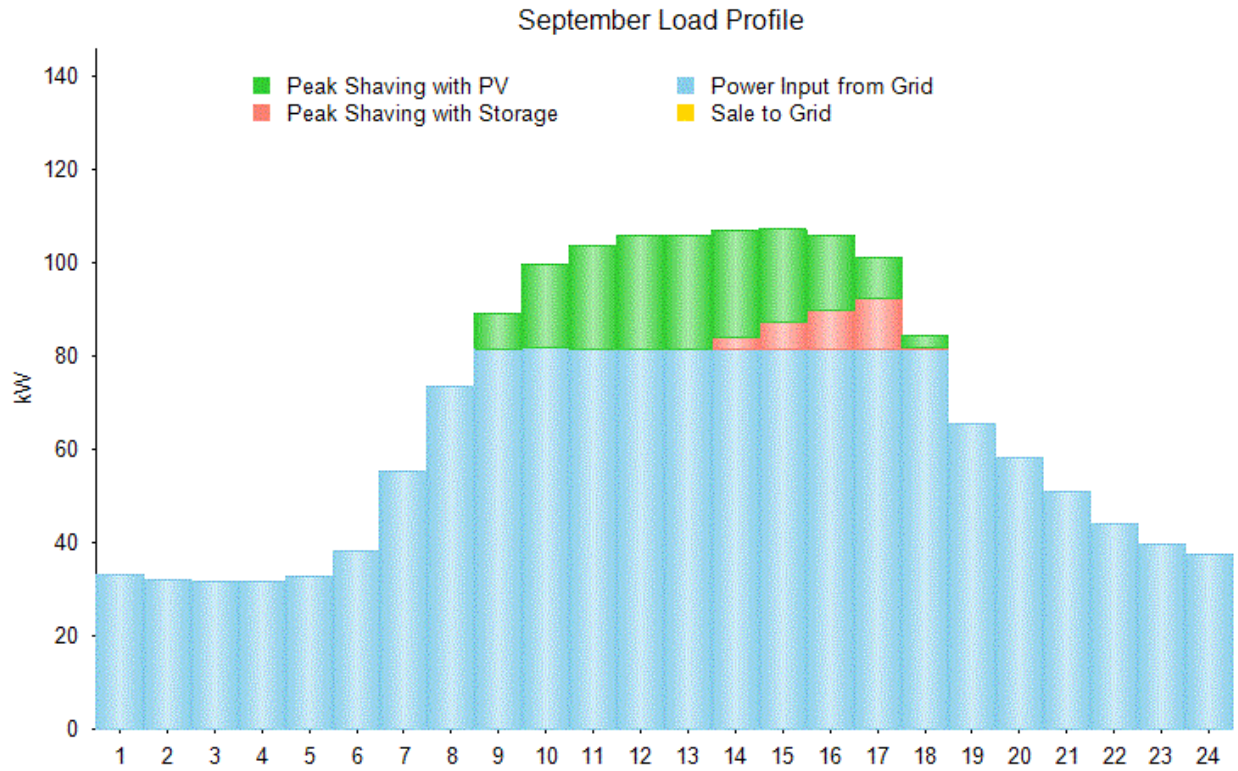


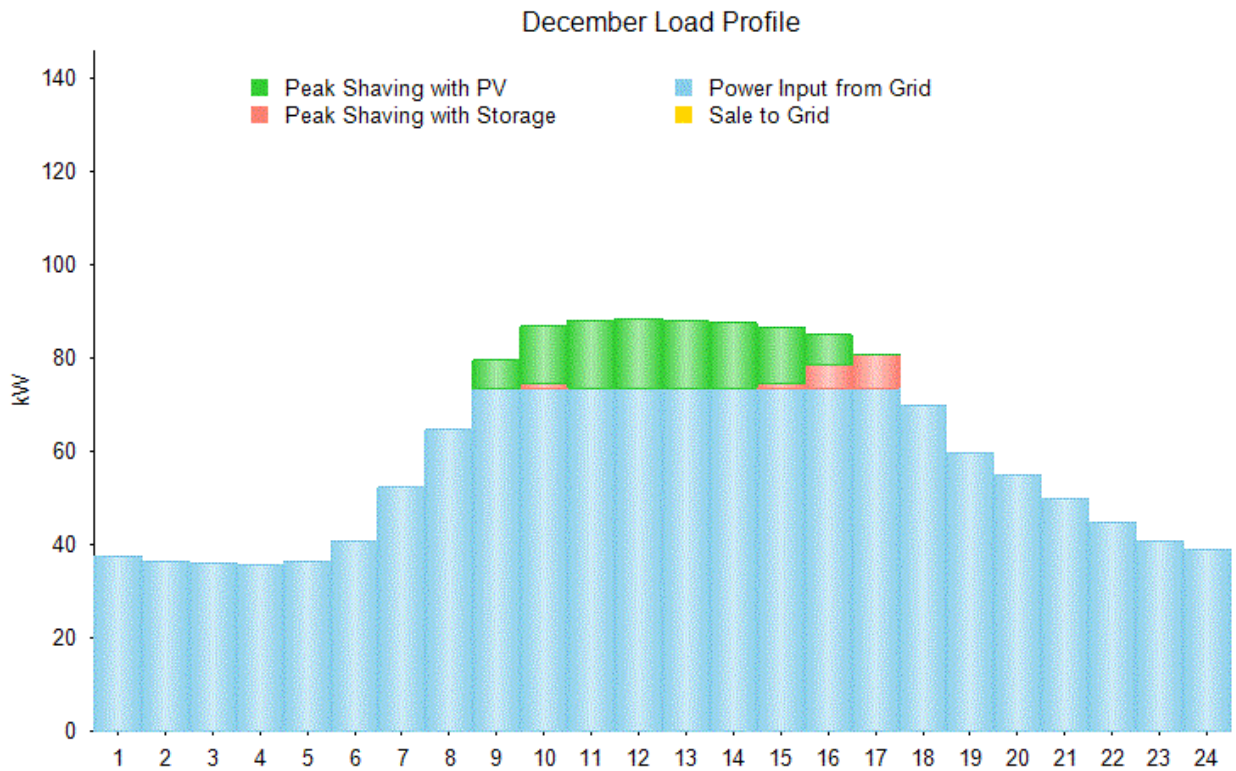
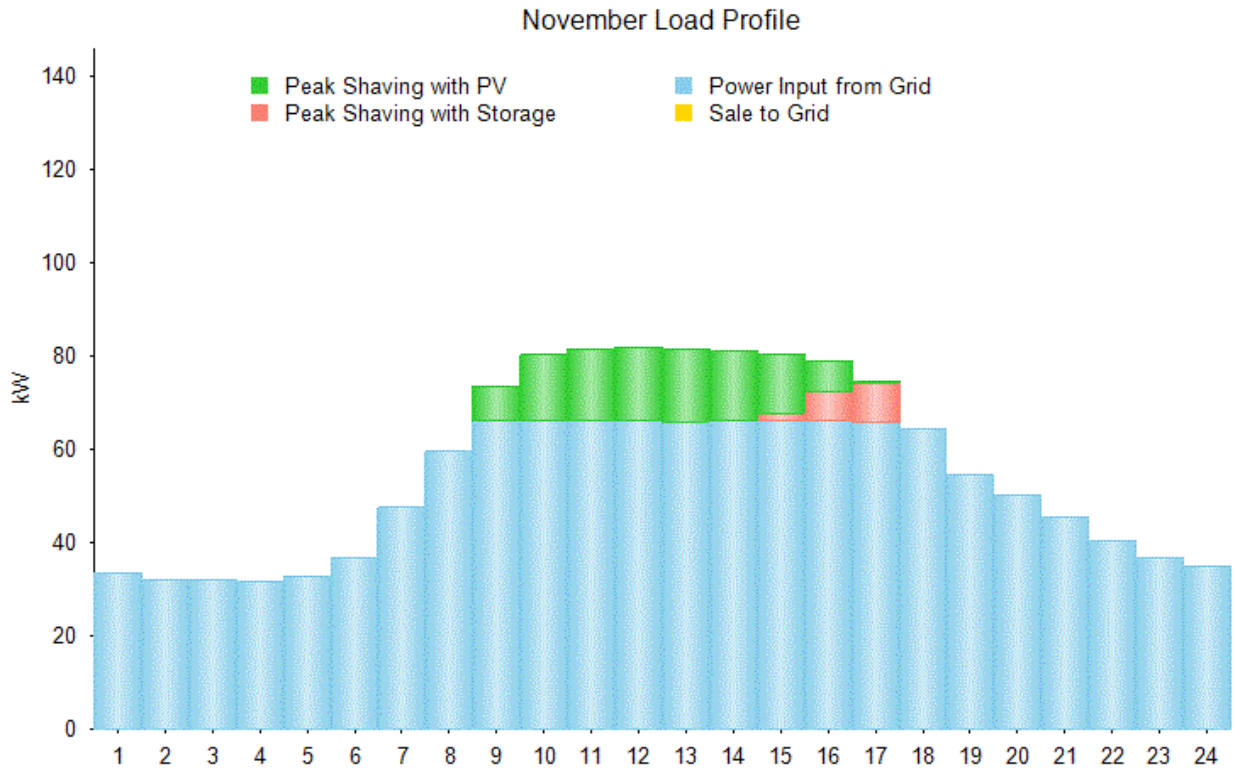












Selected CEEP Solar Electricity Policy Publications: 1983-2011

- Byrne, J. and L. Kurdgelashvili, 2011. "The Role of Policy in PV Industry Growth: Past, Present and Future." Chapter 2 in the *Handbook of Photovoltaic Science and Engineering*, Second Edition, Edited by A. Luque and S. Hegedus. John Wiley & Sons, Ltd, New Jersey.
- Byrne, J., L. Kurdgelashvili, J. Couey, et al. 2010b. Sustainable Energy Management for the Four Campuses of the Delaware Technical and Community College. Newark, DE: Center for Energy and Environmental Policy.
- Byrne, J., K. Hughes, L. Kurdgelashvili. 2010a. "Solar Policies to Promote Energy Justice." A report of the Renewable Energy Applications for Delaware Yearly (READY) project. Newark, DE: Center for Energy and Environmental Policy.
- Byrne, J., L. Kurdgelashvili, M.V. Mathai, et al. 2010. World Solar Energy Review: Technology, Markets and Policies. Newark, DE: Center for Energy and Environmental Policy.
- Byrne, J., L. Kurdgelashvili, S. Hegedus, X. Zhang, R. Walker, M. Salisbury, R. Hromiko, and J. Schreiber. 2009. "Creating a Solar City: Determining the Potential of Solar Rooftop Systems in the City of Newark." A Renewable Energy Applications for Delaware Yearly (READY) Project. Newark, DE: Center for Energy and Environmental Policy.
- Byrne, J., YD Wang, J.M. Yu, A. Kumar, L. Kurdgelashvili, and W. Rickerson. 2008. "Sustainable Energy Utility Design: Options for the City of Seoul" Prepared for the Seoul Development Institute. Newark, DE: Center for Energy and Environmental Policy.
- Byrne, J., A. Zhou, B. Shen, K. Hughes. 2007. Evaluating the potential of small-scale renewable energy options to meet rural livelihoods needs: A GIS- and lifecycle cost-based assessment of Western China's options. *Energy Policy*, Vol. 35, No. 8 (August): 4391-4401.
- Byrne, J., D. Poponi, and S. Hegedus 2006b. Break-even Price Estimates for Residential PV Applications in OCED Countries with an Analysis of Prospective Cost Reductions. 2006. *Energy Studies Review*, Vol. 14, No. 1. Pp. 104-117

- Byrne, J., W. Rickerson, J. Tian and A. Borchers. 2006a. Integrating Photovoltaic Systems into Public Sector Performance Contracts. Newark, DE: Center for Energy and Environmental Policy (CEEP), University of Delaware.
- Byrne, J., G. Alleng, A. Zhou, S. Hegedus, R. Nigro, L. Kurdgelashvili, J. Schreiber, A. Sanoh, X. Zhang. 2006. *PV PLANNER*: A Design and Analysis Tool for Building Integrated Solar Electric Systems. A Renewable Energy Applications for Delaware Yearly (READY) Project. Newark, DE: Center for Energy and Environmental Policy.
- Byrne, J., L. Kurdgelashvili, A. Barnett, K. Hughes, and A. Thurlow. 2005a. "Beyond Oil: A Comparison of Projections of PV Generation and European and U.S. Domestic Oil Production." In D. Y. Goswami and K. Boer, eds., *Advances in Solar Energy*, Vol. 16. Pp. 35-70. Boulder, CO: American Solar Energy Society.
- Byrne, J., L. Glover, S. Hegedus, G. Van Wicklen, M. Weitz. 2005b. The Potential for Solar Electric Applications for Poultry Farms. Newark, DE: CEEP, University of Delaware. (Available online at http://ceep.udel.edu/energy/publications/READY_2005_PV%20Poultry_report_04-12-05_paginated.pdf)
- Center for Energy and Environmental Policy (CEEP). 2005. "The Potential Economic Impacts of a Renewable Portfolio Standard in Delaware." Briefing Paper. 26 pp. Newark, DE: CEEP, University of Delaware. (Available online at http://ceep.udel.edu/energy/publications/2005_es_Delaware%20Senate_RPS%20briefing%20paper.pdf)
- Rickerson, W., H. Wong, J. Byrne, Y-D. Wang and S. Sasser. 2005. "Bracing for an Uncertain Energy Future: Renewable Energy and the US Electricity Industry." *Risk Management Matters*. Vol. 3, No. 1: 46-61. (Available online at http://ceep.udel.edu/publications/energysustainability/2005_es_renewables&risk.pdf)
- Byrne, J., L. Kurdgelashvili, D. Poconi and A. Barnett. 2004. "The potential of solar electric power for meeting future US energy needs: A comparison of projections of solar electric

energy generation and Arctic National Wildlife Refuge oil production.” *Energy Policy*. Vol. 32, No. 2: 289-297.

Byrne, J. and L. Kurdgelashvili. 2003. “The Potential of Solar Electric Power for Meeting Future European and U.S. Energy Needs: A Comparison of Projections of PV Generation and European and U.S. Domestic Oil Production.” *Proceedings of the ISES Solar World Congress 2003*. Vol. 1 (Solar Energy and Society), paper O1 9.

Byrne,, J., G. Alleng, A. Zhou. 2001a. “Using Economic Incentives to Accelerate Development of Green Technologies.” 2001. With Gerard Alleng and Aiming Zhou. *Proceedings of the Green Buildings Workshop*. Shanghai, China. Environmental Market Solutions, Inc. (Washington, D.C.) and Pacific Energy Research Center, Tongji University (Shanghai, China) (July).

Byrne, J., A. Zhou and G. Alleng. 2001b. “Economics of Building Integrated PV In China.” *Proceedings of the Green Buildings Workshop*. Shanghai, China. Environmental Market Solutions, Inc. (Washington, D.C.) and Pacific Energy Research Center, Tongji University (Shanghai, China) (July). (Available online at http://ceep.udel.edu/publications/energy/publications/2001_energy_bipv_econ_china.pdf)

Byrne, J., L. Agbemabiese, K-J. Boo, Y-D. Wang and G. Alleng. 2000. “An International Comparison of the Economics of Building Integrated PV in Different Resource, Pricing and Policy Environments: The Cases of the U.S., Japan and South Korea.” *Proceedings of the American Solar Energy Society Solar 2000 Conference*, Madison, WI (June): 81-85. (Available online at http://ceep.udel.edu/publications/energy/publications/2000_energy_bipv_international_comparison.pdf)

Byrne, J., L. Agbemabiese, J. Kliesch, C. Hadjilambrinos, P. Eiffert and R. Nigro. 1999. “Environmental Impacts of Building Integrated PV Applications in the State Public Buildings Sector.” *Proceedings of the American Solar Energy Society Solar 99 Conference*, Portland, Maine (June): 425-429.

- Byrne, J., S. Letendre, L. Agbemabiese, D. Bouton, J. Kliesch and D. Aitken. 1998. "Photovoltaics as an Energy Services Technology: A Case Study of PV Sited at the Union of Concerned Scientists Headquarters." Proceedings of the American Solar Energy Society Solar 98 Conference, Albuquerque, NM (June 15-17): 131-136. (Available online at http://ceep.udel.edu/publications/energy/publications/1998_energy_pv_energy_service_technology_ucs.pdf)
- Letendre, S., J. Byrne, C. Weinberg and Y-D. Wang. 1998. "Commercializing Photovoltaics: The Importance of Capturing Distributed Benefits." Proceedings of the American Solar Energy Society Solar 98 Conference, Albuquerque, NM (June 15-17):231-237. (Available online at http://ceep.udel.edu/publications/energy/publications/1998_energy_distributed_benefits.pdf)
- Byrne, J., S. Letendre, L. Agbemabiese, D. Redlin and R. Nigro. 1997a. "Commercial Building Integrated Photovoltaics: Market and Policy Implications." Proceedings of the 26th IEEE Photovoltaic Specialists Conference, Anaheim, CA (October): 1301-1304. (Available online at http://ceep.udel.edu/publications/energy/publications/1997_energy_bipv_market_policy.pdf)
- Byrne, J., S. Letendre, Y-D. Wang, R. Nigro and W. Ferguson. 1997b. "Building Load Analysis of Dispatchable Peak-Shaving Photovoltaic Systems: A Regional Analysis of Technical and Economic Potential." Proceedings of the of the American Solar Energy Society Solar 97 Conference, Washington, D.C. (April 25-30): 147-152.
- Byrne, J., S. Letendre and Y-D. Wang. 1996a. "The Distributed Utility Concept: Toward a Sustainable Electric Utility Sector." 1996. With Proceedings of the ACEEE 1996 Summer Study on Energy Efficiency in Buildings. Vol. 7: 7.1-7.8.
- Byrne, J. S. Letendre, C. Govindarajalu, R. Nigro and Y-D. Wang. 1996b. "Evaluating the Economics of Photovoltaics in a Demand-Side Management Role." Energy Policy. Vol. 24, No.2 (February): 177-185. (Available online at

http://ceep.udel.edu/publications/energy/publications/1996_epolicy_economics%20of%20pv-dsm_byrne_letendre_chandra_ydw_nigro.pdf)

Byrne, J., R. Nigro and W. Ferguson. 1996c. "The Performance and Economics of Dispatchable PV Peak Shaving Systems in Isolated Electric Utility Systems." Proceedings of the World Renewable Energy Congress (June).

Byrne, J., R. Nigro and W. Ferguson. 1996d. "The Development of a Dispatchable PV Peak Shaving System." Proceedings of the First International Conference on Solar Electric Buildings (March).

Byrne, J., Y-D. Wang and R. Nigro. 1995. "Photovoltaic Technology as a Dispatchable, Peak-Shaving Option." 1995. With Ralph Nigro and Young-Doo Wang. Public Utilities Fortnightly (Sept. 1). (Available online at http://ceep.udel.edu/publications/energy/publications/1995_energy_pv_peakshaving.pdf)

Byrne, J. and C. Hadjilambrinos. 1994. "Photovoltaics for Demand-Side Management." Progress in Solar Energy Technologies and Applications: An Authoritative Review. Boulder CO: American Solar Energy Society. Pp. 22-23.

Byrne, J., S. Letendre, R. Nigro, C. Govindarajalu, W. Wallace and Y-D. Wang. 1994a. "Photovoltaics for Demand-Side Management Utility Markets: A Utility/Customer Partnership Approach." IEEE Proceedings of the First World Conference on Photovoltaic Energy Conversion.

Byrne, J., Y-D. Wang, S. Letendre, C. Govindarajalu, R. Nigro and W. Bottenberg. 1994b. "Deployment of a Dispatchable Photovoltaic System: Technical and Economic Results." IEEE Proceedings of the First World Conference on Photovoltaic Energy Conversion: 1200-1203.

Byrne, J., Y-D. Wang and S. Hegedus. 1994c. "Photovoltaics as a Demand-Side Management Technology: An Analysis of Peak-Shaving and Direct Load Control Options." 1994. With Progress in Photovoltaics Vol. 2: 235-48.

- Byrne, J., S. Letendre, R. Nigro, and Y-D. Wang. 1994d. "PV-DSM as a Green Investment Strategy." Proceedings of the 5th NARUC-DOE National Conference on Integrated Resource Planning: 272-285.
- Byrne, J., S. Letendre and R. Nigro, 1994e. "Photovoltaics in High-Value, Utility Markets: A Demand-Side Management Strategy." Proceedings of the American Solar Energy Society Solar '94 Conference: 44-48.
- Byrne, J., Y-D. Wang, R. Nigro and S. Letendre. 1994f. "Photovoltaics in a Demand-Side Management Role." Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings. Vol. 2: 2.43-2.49.
- Byrne, J., Y-D. Wang, R. Nigro and C. Hadjilambrinos. 1993a. "Valuing Photovoltaic Technology as a Utility Demand-Side Management Application: Regulatory Issues." Proceedings of the NARUC-DOE Conference on Renewable Energy: 258-269.
- Byrne, J., Y-D. Wang, R. Nigro, and W. Bottenberg. 1993b. "Commercial Building Demand-Side Management Tools: Requirements for Dispatchable Photovoltaic Systems." Proceedings of the 23rd IEEE Photovoltaics Specialists Conference: 1140-1145.
- Byrne, J., Y-D. Wang, I. Han and K. Ham. 1993c. "Photovoltaic Technology as a Utility Demand-Side Management Option." Energex '93: Proceedings of the 5th International Energy Conference Vol. III: 119-133.
- Byrne, J. and R. Nigro. 1992. "Applying Photovoltaics as a Demand-Side Management Tool." Proceedings of the Delmarva Photovoltaics Conference. Wilmington, DE: Delmarva Power.
- Byrne, J., Y-D. Wang and R. Nigro. 1992. "The Role of Photovoltaics in Demand-Side Management: Policy and Industry Challenges." Proceedings of the 11th Photovoltaics Advanced Research and Development Project Review. Golden, CO: National Renewable Energy Laboratory.
- Byrne, J. and D. Rich. 1983. "The Solar Energy Transition as a Problem of Political Economy." 1983. In D. Rich et al (eds.), The Solar Energy Transition: Implementation and Policy Implications. Pp. 163-186.

Additional References

- California Energy Commission, 2011. List of grid-tied inverter efficiencies, published by the California Energy Commission, Accessed February 2011.
<http://www.gosolarcalifornia.org/equipment/inverters.php>
- Hoff, T., Perez, R. and Margolis, R., 2004. Increasing the Value of Customer-Owned PV Systems using Batteries. NREL Contract AAD-2-31904-03 Deliverable 2H and Contract NAD-1-318904-01 (3G).
- Kotas, J., 2001. Renewable Energy Credits: Another Option in your Renewable Energy Portfolio. Paper presented at Sixth National Green Power Marketing Conference: Opportunity in the Midst of Uncertainty, July 30 - August 1, 2001, Portland, Oregon.
- Natural Resources Canada (NRC), 2010. "Uncertainty in Long-Term Photovoltaic Yield Predictions." Didier Thevenard, March 31, 2010; Report 2010-122 (RP-TEC) 411-IEARES.
- National Renewable Energy Laboratory (NREL), 1995. "A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies." Walter Short, Daniel J. Packey, and Thomas Holt, March 1995, NREL/TP-462-5173. Available at:
<http://www.nrel.gov/docs/legosti/old/5173.pdf>
- National Renewable Energy Laboratory (NREL), 2009. "Solar Leasing for Residential Photovoltaic Systems." Karlynn Cory, NREL/FS-6A2-43572, Revised April 2009; available at:
<http://www.nrel.gov/docs/fy09osti/43572.pdf>
- National Renewable Energy Laboratory (NREL), 2010. "Insuring Solar Photovoltaics: Challenges and Possible Solutions." Speer, B., Mendelsohn, M., and Cory, K., Technical Report NREL/TP-6A2-46932
- National Renewable Energy Laboratory (NREL), 2011. "Energy Technology Cost and Performance Data" available at: http://www.nrel.gov/analysis/tech_cost_oandm.html
- Prasad, D. and Snow, M., 2005. Designing with Solar Power: a Source Book for Building Integrated Photovoltaics (BIPV). IEA-PVPS Task 7.

Stavy, M., 2002. Computing the Levelized Cost (B R¢/kWh [US ¢/kWh]) of Solar Electricity Generated at Grid Connected Photovoltaic (PV) Generating Plants. RIO 02 - World Climate & Energy Event, January 6-11, 2002. Available at:
http://www.rio02.com/proceedings/pdf/293_Stavy.pdf

Tax Foundation, 2010. 2011 State Business Tax Climate Index. Padgitt, K. M. Available at:
<http://www.taxfoundation.org/research/show/22658.html>

AN EQUAL OPPORTUNITY/AFFIRMATIVE ACTION EMPLOYER - The University of Delaware is committed to assuring equal opportunity to all persons and does not discriminate on the basis of race, color, gender, religion, ancestry, national origin, sexual orientation, veteran status, age, or disability in its educational programs, activities, admissions, or employment practices as required by Title IX of the Education Amendments of 1972, Sections 503 and 504 of the Rehabilitation Act of 1973, Titles VI and VII of the Civil Rights Act of 1964, the Americans with Disabilities Act, Executive Orders 11246 and 11375, and other applicable statutes. Inquiries concerning title IX, Section 503 and 504 compliance, Executive Order 11246 and information regarding campus accessibility and Title VI should be referred to the Affirmative Action Director, 305 Hullihen Hall, 302-831-2835, 302-831-4552 (TDD).