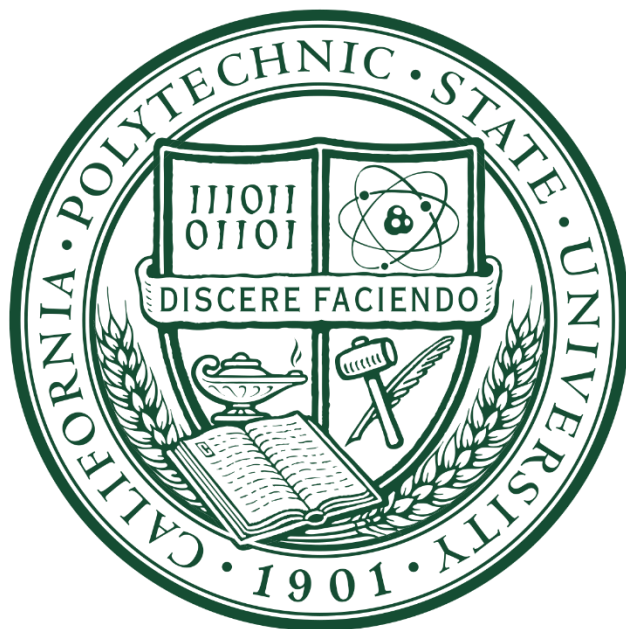


# DC House Solar Panel Cleaner



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## **Abstract**

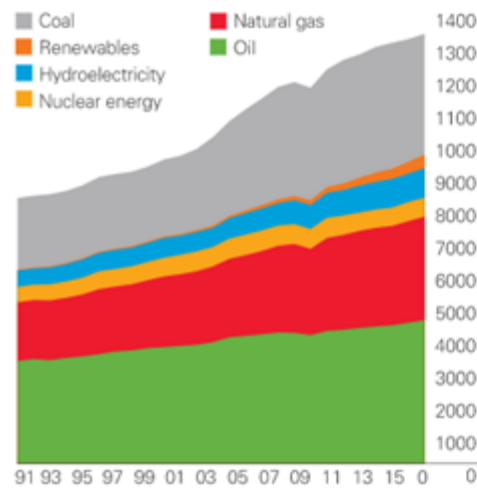
Solar panels lose 0.05% of their power conversion efficiency per day due to soil accumulation, according to an experiment conducted by the University of California, San Diego in 2013 [18]. The project is an electro-mechanical cleaning system that effectively and efficiently cleans solar panels at set intervals. A drip irrigation system with spray jets was attached to a water pump and Arduino, both powered by the DC House Project solar panel battery. The DC House solar panel was the targeted panel set up for the project. Several components of the design could have been chosen more optimally for the system; the converter could have conserved more power and the box could have been designed with more consideration of external connections. In addition, the water sensor's inconsistent performance caused issues with testing. However, the system did effectively distribute water to a majority of the solar panel and can remove dirt, soil, and other loose particle accumulation. It cannot remove build-ups such as bird droppings because the output pressure from the spray jets is not high enough. The results of the project concluded that a similar system if redesigned using the suggestions described, would perform exceptionally well and meet the desired purpose.

## Chapter 1: Introduction

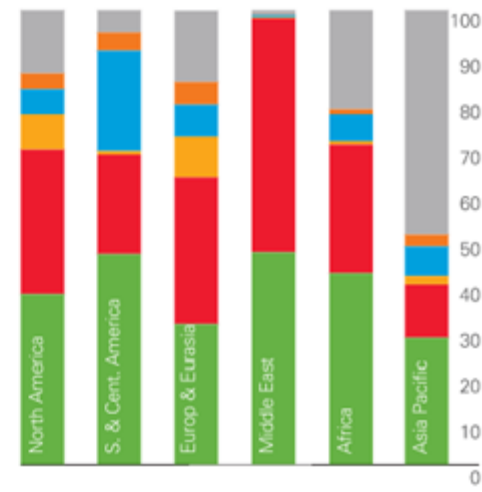
In 2015, countries adopted 17 Sustainable Development Goals to transform our world when they decided to adopt the 2030 Agenda for Sustainable Development. All over the world, governments, businesses, and civil society along with the United Nations are assembling forces to achieve the Sustainable Development Agenda by 2030. This Agenda “calls for action by all countries to improve the lives of people everywhere” [2]. Goal 7 of this Agenda: “To ensure access to affordable, reliable, sustainable and modern energy for all” should be heavily underscored, since energy is so central to nearly every major challenge and opportunity the world faces today. “Sustainable energy is opportunity - it transforms lives, economies, and the planet” [1].

As energy accounts for 60% of total global greenhouse gas emissions, in part due to the 3 billion people who still rely on wood, coal, charcoal, or animal waste for cooking and heating, renewable energy has become a key aspect of the discussion. Currently, the world heavily relies on non-renewable resources such as coal, oil, natural gas, and nuclear energy (Figure 1-1 & 1-2). However, with the growth of industrialization and the world’s population, non-renewable resources are heading towards depletion. In fact, the Energy Information Administration’s (EIA) International Energy Outlook 2013 predicts that oil supplies, which accounts for over 30% of total consumed energy, will only last another 25 years [4]. Consumption of non-renewable resources also often emits substantial amounts of carbon dioxide which detracts air quality. To mitigate these issues, scientists have turned to renewable energy resources.

Primary energy world consumption (million tonnes oil equivalent)



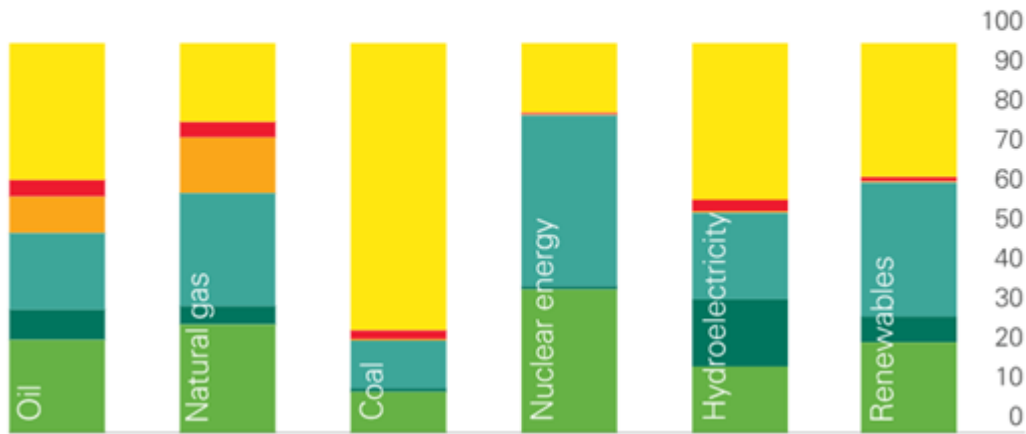
Primary energy regional consumption by fuel 2016 (percentage)



**Figure 1-1: Primary Energy World Consumption By Fuel [3]**

Legend for Figure 1-2:

- Asia Pacific
- Africa
- Middle East
- Europe & Eurasia
- S. & Cent. America
- North America



**Figure 1-2: Fuel Consumption by Region as of 2016 (percentage) [3]**

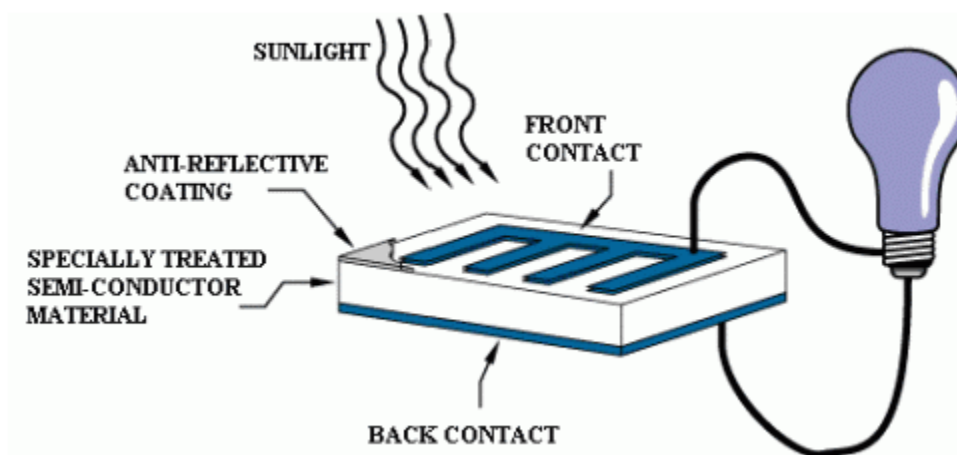
Renewable resources can be naturally and continuously replenished. Furthermore, the energy conversion process is much cleaner than that of non-renewable resources. Because of their potential benefits to the environment, it is without surprise that investments in renewable resources have continuously grown throughout the years. While renewable electricity generation, except for hydro, is estimated to account for only 8% of global electricity generation, renewables play a significant role in the growth of electricity, contributing almost 40% of the growth in global power generation in 2016 [5]. Solar energy has been the primary interest of engineers and scientists, partially due to the fact that “more energy from the sun falls on the earth in one hour than is used by everyone in the world in one year” [6].



## Chapter 2: Background

As the world slowly turns its focus towards harvesting renewable energy over non-renewable, solar energy has emerged as an excellent and powerful alternative. It is the cleanest and most abundant renewable energy source available and with modern technology, the energy can be harnessed for a variety of uses, including generating electricity, providing light, and heating water [1]. This technology is used by businesses and industry to diversify their energy sources, improve efficiency, and save money [2].

On a larger scale, solar photovoltaic technologies are used by developers and utilities to produce electricity on a massive scale to power cities and small towns [2]. Photovoltaics “is the direct conversion of light into electricity at the atomic level” [3]. This process, also known as the photoelectric effect, causes certain material to absorb photons of light and release electrons. The captured electrons result in electric current that can be used as electricity [3]. This process introduces the concept of efficiency within the context of solar energy.



**Figure 2-1:** Operation of a Basic Photovoltaic Cell [3]

As solar energy becomes more popular alongside increases in energy consumption, the reliability and harvesting efficiency of this source have become important factors to consider. Solar panel efficiency measures what amount of incoming sunlight hitting the panel is converted to electricity for use [4]. The performance parameter of measuring the amount of sunlight that solar panel systems can convert into actual electricity determines solar panel efficiency. In general, “if the sun produces 100% energy, solar systems are usually able to process 15-22% of that sunpower into usable energy” [4]. Thus, harvesting efficiency is a valuable factor for solar power to be a competitive resource in the market.

To improve efficiency of the solar panel system, it is essential to look at factors that affect efficiency. Despite the increase in installed capacity, solar energy “still raises important concerns related to the variability of power production.” According to statistical analysis performed by several professors of electronics engineering in Chile, solar panel efficiency follows a negative trend over time because of soil accumulation [5]. Solar panel efficiency decreases every day due to dust, sand, dirt or other particle build up on the panel’s surface. This soil accumulation may block some of the sunlight and consequently reduce solar photovoltaic performance by up to 85%.

There are currently quite a few patented solar panel cleaning systems. Although these patents show that solar panel cleaning systems have been created, they have yet to be integrated into notable or large-scale solar panel installations and have not gained significant traction in the market. For example, a patent filed by Moshe Miller in 2013 describes a system that generates an airstream to clean the panels, targeting solar panel systems in desert areas [6]. Other systems that use water to clean the solar panels face problems such as accumulating enough rain water to effectively clean the panels[7]. Still,

there are some designs that seem to be relatively successful, such as Guofu Ma's intelligent automatic solar panel cleaning system that has both dry and water cleaning functions [8]. Another successful invention [9] includes accessories such as a time controller and a detection device for user convenience.

The project system is an improvement to the multiple patented solar panel cleaning systems (discussed above) that have a similar design to the project system by adequately addressing similar issues of current inventions. The objective of the proposed project is to create a low-powered, cost-efficient cleaning system that is easy to maintain. The system shall improve the efficiency of solar panels so that they produce a higher output power.

## Chapter 3: Design Requirements

This chapter provides insight into the inner workings of the system. It provides a Level 0 and Level 1 block diagram as well as lists of inputs and outputs. The Level 0 Block Diagram shown in Figure 3-1 serves as a holistic overview of the system. Three basic inputs: water, power, and an on/off control feed into the system, producing only one output: water stream.

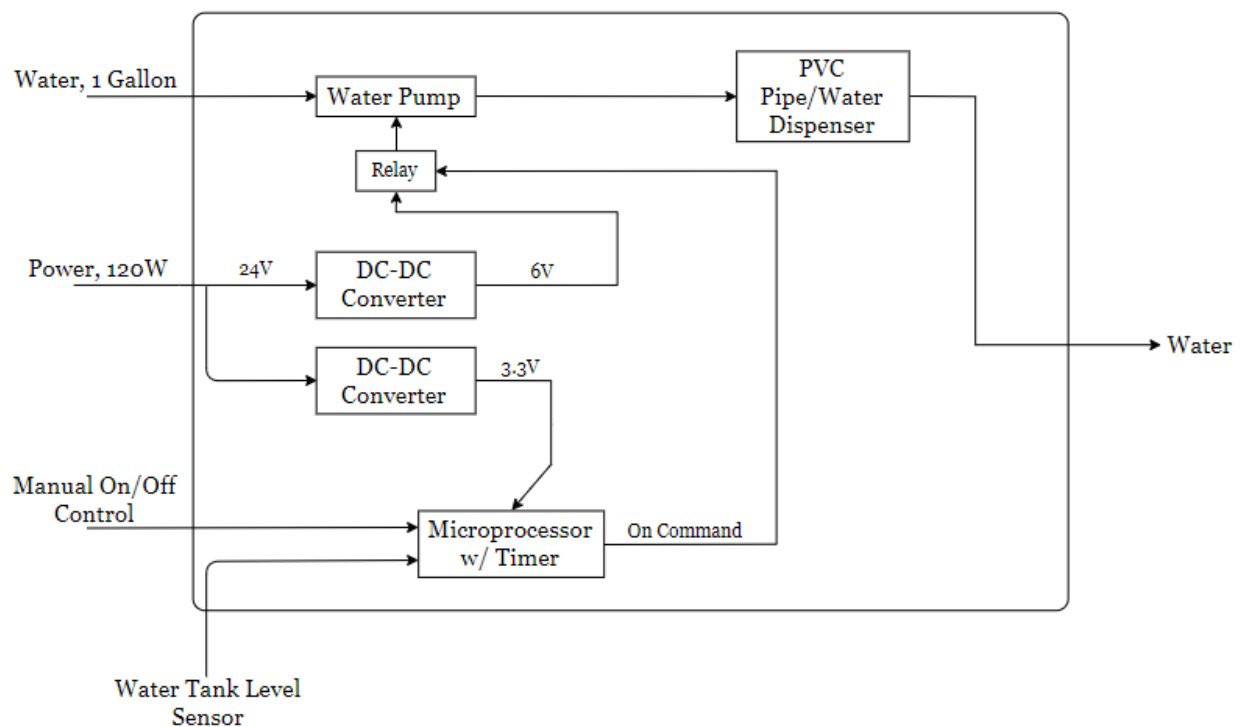


**Figure 3-1:** Solar Panel Cleaning System Level 0 Block Diagram

**Table 3-1.** Solar Panel Cleaning System Level 0 Inputs and Outputs

Module	Solar Panel Cleaning System
<b>Inputs</b>	Water: ≤ 1 gallon per cleaning operation Power: 120W, 24V DC On/Off Control: manual button press or program
<b>Outputs</b>	Water: ≤ 1 gallon per cleaning operation
<b>Functionality</b>	Take water and clean solar panels. A button or program controls the system's operation and on/off periods. The output water and input water amount are nearly equivalent.

The following Level 1 Functional Decomposition depicted in Figure 3-2 breaks the system down into several components. While not all values have been determined, most of the values were selected based on given inputs or research. Water from an external source will be stored in a tank. When a sensor finds that the water level meets a designated value, the microprocessor, powered by a solar powered battery will issue an ON command to the Water Pump connected relay. The relay, also powered by the solar powered battery, will then activate the water pump. Some amount of water will be pumped from an external water source to a PVC pipe, where the water will be dispensed onto the surface of the solar panels. Afterward, the water is collected into a unit at the base of the solar panel, for other uses in the DC house. Table 3-2 lists technical requirements of the components used in the proposed solar panel cleaning system, and Table 3-3 summarizes each of the engineering specifications with their relevant marketing requirements and justifications.



**Figure 3-2:** Solar Panel Cleaning System Level 1 Block Diagram

**Table 3-2. Solar Panel Cleaning System Level 1 Inputs and Outputs**

<b>Module</b>	DC-DC Converter (2)
<b>Inputs</b>	24 VDC ; ≤ 5 A
<b>Outputs</b>	5 to 12 VDC
<b>Functionality</b>	Steps down/up voltage from battery to microprocessor or water pump relay
<b>Module</b>	Water Pump
<b>Inputs</b>	1-2 Gallons of Water 12 VDC; ≤ 5A
<b>Outputs</b>	Water
<b>Functionality</b>	Water pumped from source and to PVC Pipe (or framework of Solar Panels)
<b>Module</b>	Microprocessor w/ Timer
<b>Inputs</b>	5 VDC; < 1 A Water Tank Level Sensor
<b>Outputs</b>	On Command to the dispenser
<b>Functionality</b>	Turns system on/off
<b>Module</b>	PVC Pipe/ Water Dispenser
<b>Inputs</b>	Water from tank
<b>Outputs</b>	Water to solar panels
<b>Functionality</b>	Dispenses water from water pump to solar panels

**Table 3-3. Solar Panel Cleaning System Requirements and Specifications**

<b>Marketing Requirements</b>	<b>Engineering Specifications</b>	<b>Justification</b>
1, 5, 6	The maximum amount of water used should not exceed one gallon per cleaning.	Due to the California drought and consequent water restrictions [16], it is crucial to consider water conservation.
6	The total parts and manufacturing costs cannot exceed \$250 per unit.	Implemented at the student run Cal Poly DC House, the project must remain within budget confines.
2	The system withstands temperatures 0-120°F, 12 m.p.h. winds, and 1.5 inches of rainfall.	System installation occurs in California, where conditions like extraordinarily high temperatures, heavy winds, and an average amount of rainfall are prevalent [17].
3	The system should be no longer than 62.5 inches wide, 32 inches long, and 2 inches high.	Based on DC House solar panel specifications.
4	A timer or a manual override determines system operation.	Program startup requires minimal assistance.
7, 8	The system should operate with no more than 30 Wh.	Due to the constraints of the solar panel currently used by the DC House, the cleaning system should not strain this parameter.
8	Estimated pumping water time should not exceed 5 minutes. Estimated solar panel cleaning time should not exceed 10 minutes.	Time taken for the whole operation to run its course should account for cleaning time and turn on and turn off time. Having the system run longer than necessary wastes power and water.
9	Output power and overall efficiency should increase by a minimum of 15% after cleaned.	The project's ultimate goal: improving efficiency and output power.
8	System cleans at programmed times and can operate manually	The consumer should have the option of cleaning the panels whenever they desire and/or conveniently setting cleaning times.

11	System removes dirt, leaves, bird droppings, and residue from rain, snow, or sleet.	The system can work on build-ups most expected to develop a film over or block portions of the DC House solar panels.
8,6	System, excluding timer, remains off when not in use.	System operation costs minimized by consuming low power during inactivity.
10, 3	Total weight of components does not exceed 10 lbs.	The target weight for the system uses the DC House solar panel parameters and prevents damage to the panels.
12	System installs on existing solar panel system.	For ease of installation, system can attach to solar panels without the need of moving the panels.

**Marketing Requirements**

1. The system should be environmentally friendly.
2. The system should endure various conditions.
3. The system must fit within current Cal Poly DC House solar panel parameters.
4. System operation must have a minimal learning curve.
5. The system must efficiently clean the solar panels.
6. The whole system must have a low cost.
7. The solar panel itself should power the system.
8. The system should draw and utilize low power.
9. Solar panel output power should increase after cleaning.
10. The system poses low weight.
11. The system operates on various buildups.
12. Easy installation characterizes the system.



## Chapter 4: Design Results

This project entails the design and construction of a solar panel cleaning system that utilizes water to wash soil build up off the panels' surface. The original system design consisted of brushes that moved up and down the solar panel's length as they were attached to rails that ran parallel to the panel. This design, however, required complicated mechanical subsystems that were too difficult to build and test satisfactorily within the project's time span.

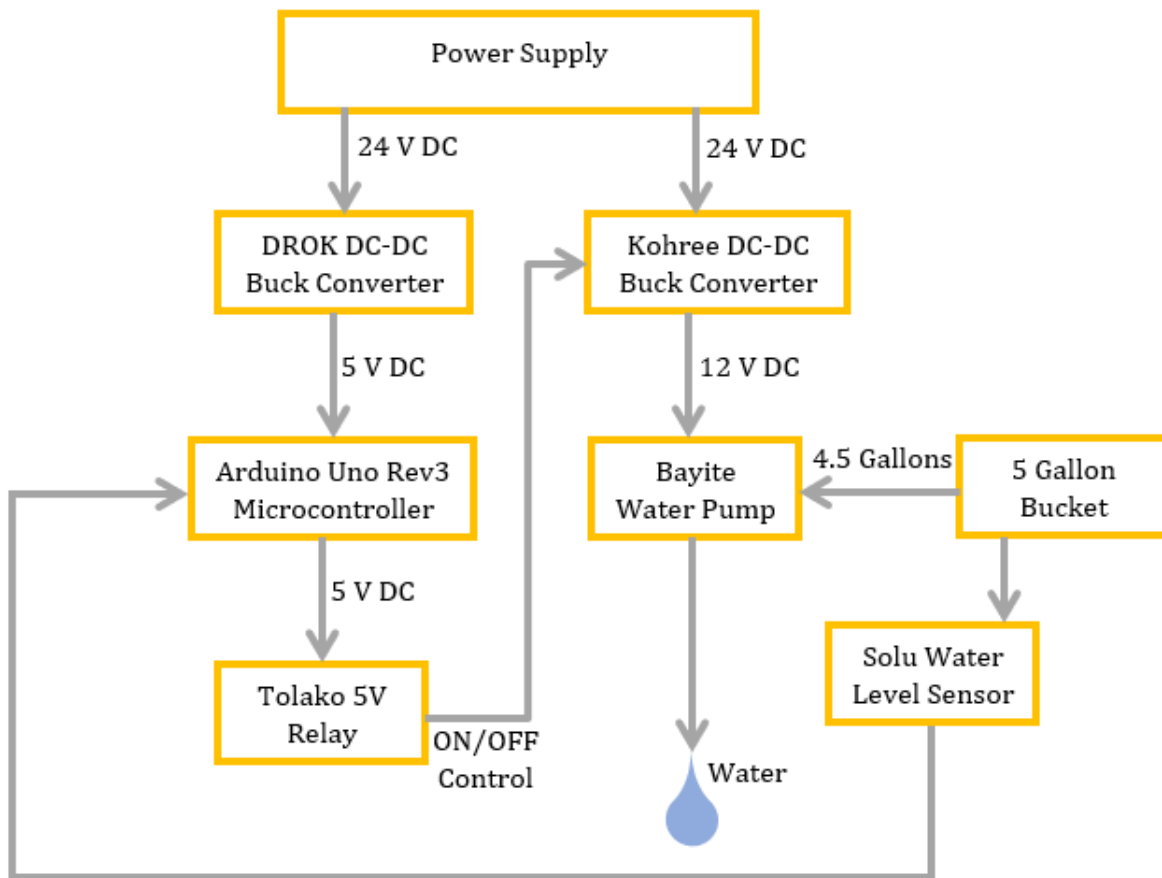
The final design of the project uses water pumped through poly tubing that runs along the top of the panel. Water is dispensed through drip irrigation, spray jets. Power is supplied by the 24V battery storage for the solar panel. Two DC-DC converters step down the supply voltage to the required input voltage values required by the Arduino Uno (the main control unit) and the water pump. A relay is used as a switch in conjunction with the Arduino to regulate the duration and the frequency of the cleaning sessions. The final design proved to be simpler than that of the original, requiring less physical components and software. In addition, the simpler design reduces possible complications during building, testing and future maintenance and is more economically feasible.

Power, current, and voltage ratings were determined to find the appropriate components for the project system. The DC-DC converters were selected through use of Ohm's law and datasheet values. Wire gauges were found using ampacity ratings because the short distances between components in the system did not produce voltage drops that significantly affect the efficiency of the system.

Through extensive research, including examination of several patented designs, every component was carefully selected with time and monetary constraints in mind. Testing was essential to the development of the prototype as each subsystem came together.

**Table 4-1: Bill of Materials**

<b>Ct.</b>	<b>Description</b>	<b>Size</b>	<b>Manufacturer</b>	<b>Cost/Unit</b>
<b>1</b>	DC-DC Converter 4-32V to 1.25-30V	2.4" x 1.3"x 0.5"	DROK	\$8.89
<b>1</b>	DC-DC Converter 24V to 12V, 10A max.	74mm x 74mm x 32mm	Kohree	\$15.99
<b>1</b>	Water Level Sensor, DC 3-5V (< 20 mA)	4.5" x 3" x 0.2"	Solu	\$4.99
<b>1</b>	12V, 5A DC Fresh Water Pump	16.5cm x 10cm x 6cm	Bayite	\$23.99
<b>1</b>	5 Gallon, Plastic, Orange Bucket	12"x13"x 14.5"	Home Depot	\$3.25
<b>1</b>	Arduino UNO 20mA output, 5V input	3.1" x 2.2" x 1"	Arduino	\$22.00
<b>1</b>	3-ply connector Hose	22" x 22" x 24"	Apex	\$11.30
<b>1</b>	Zip Ties (x100)	8"	Valiant	\$6.79
<b>2</b>	PVC Pipe Plug, Schedule 40	.99"x .99" x .99"	Home Depot	\$2.32
<b>1</b>	Heat Shrink Tubing	1.77"	iauto	\$7.99
<b>1</b>	Wire: 26 AWG	100'	Amazon.com	\$14.29
<b>1</b>	Wire: 12 AWG	100'	Amazon.com	\$18.05
<b>1</b>	Industrial Sealant Tape	520"	Dixon Valve & Coupling	\$1.49
<b>1</b>	Aluminum Box, Corrosion Resistant	12" x 7" x 4"	BUD Industries	\$26.36
<b>1</b>	5V Arduino Relay	3.5" x 2.9" x 0.8"	TOLAKO	\$5.80
<b>1</b>	½" poly tubing	50'	DIG	\$6.83
<b>1</b>	90° spray jet (x10)	.25" x 5.5" x 4"	DIG	\$2.74
<b>1</b>	180° spray jet (x10)	.25" x 5.5" x 4"	DIG	\$2.74



**Figure 4-1:** Block Diagram of System

### Arduino Uno Rev3:

The Arduino Uno has an operating voltage of 5V. It has 6 analog pins and 11 digital pins, while the design uses one of each. The low, 20mA DC current requirement per pin allows the design to use minimal power as intended. The Uno was selected because code implementation through the specialized Arduino software (IDE) simplified coding requirements.



**Figure 4-2:** Arduino Uno Rev3

### **Bayite DC Voltage Fresh Water Pump:**

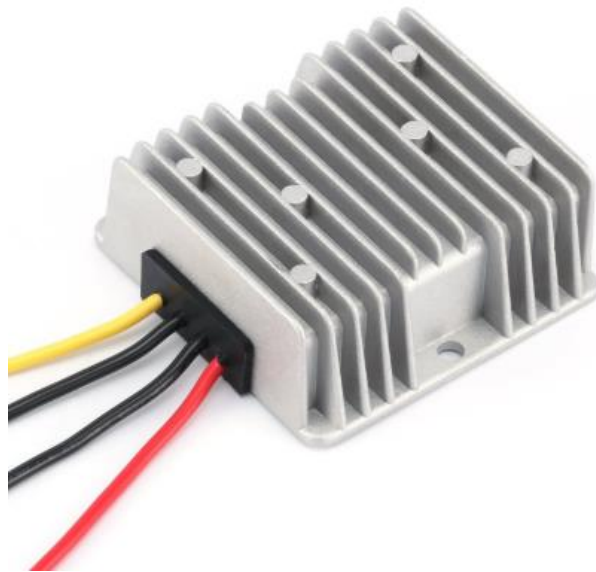
The 12V, 5A water pump typically outputs 80-85 PSI with a maximum of 100 PSI and a cut-off pressure of approximately 60 PSI. The ½” drip irrigation tubing requires 60 PSI, and so the water pump was chosen accordingly. The pressure switch allows easy adjustment of the output pressure. Moreover, the I/O tubing and hose clamps included ensured proper and secure connections.



**Figure 4-3:** Bayite DC Voltage Fresh Water Pump

### **Kohree DC-DC Step Down Converter:**

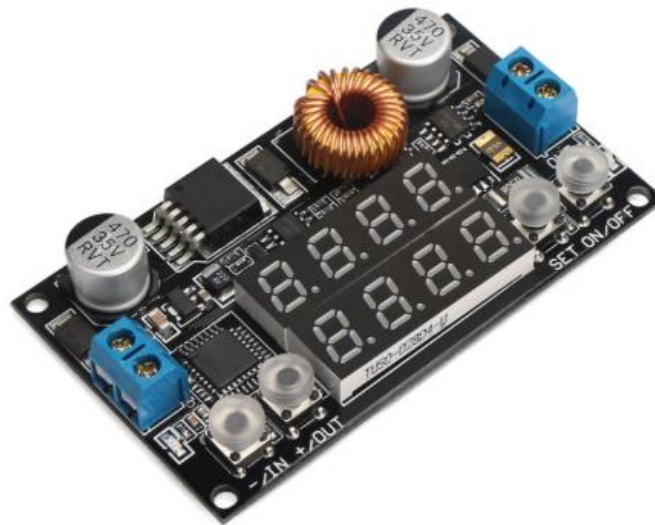
The industry grade 24V to 12V DC step-down (or Buck) converter has more than 96.5% power conversion efficiency and outputs 10 Amps at 120 Watts. These rated values, as well as the simple installation, reliability, and stability ensure that the converter will have minimal issues with performance. The converter was especially chosen for its compact size and waterproof enclosure, making it easy to install in close proximity with the water pump.



**Figure 4-4:** Kohree DC-DC Step Down Converter (24 to 12V)

### **DROK DC-DC Adjustable Step Down Converter:**

The 5-32V adjustable buck converter with a voltage and current display and a 0-5A constant current output was ideal due to its flexibility in input and output voltage values. Setting voltage and current limits can be done with minimal effort and the converter components are neatly laid out and soldered with easily accessible wire inputs.



**Figure 4-5:** DROK DC-DC Adjustable Step Down Converter (24 to 5V)

### **Tolako 5V Relay Module:**

The 5V Relay Module includes a control signal which can control both DC and AC signal. It was because of its compatibility with common Arduino application and its simple installation.



**Figure 4-6:** Tolako 5V Relay Module

### **Solu Water Level Sensor**

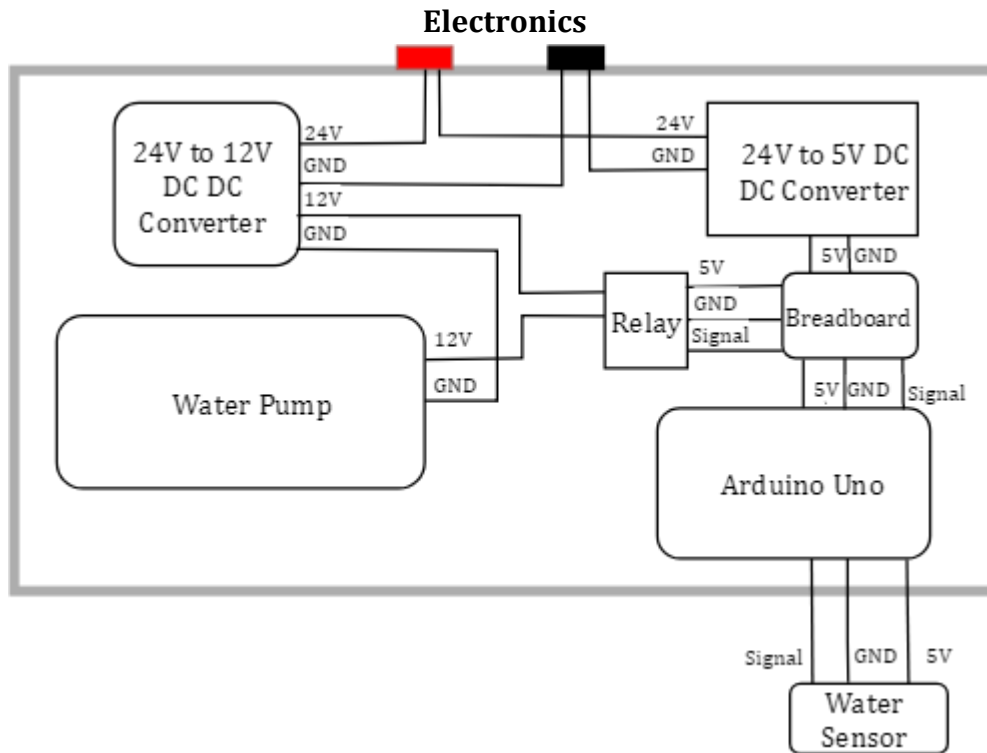
The 3-5V DC water level sensor uses no more than 20 mA of current during operation. The compact device is an easy to use, cost effective high-level recognition sensor that uses a series of exposed traces on parallel wires to measure the water volume in order to determine the water level. Its analog signal conversion and output analog values make it easily compatible with the Arduino Uno.



**Figure 4-7:** Solu Water Level Sensor



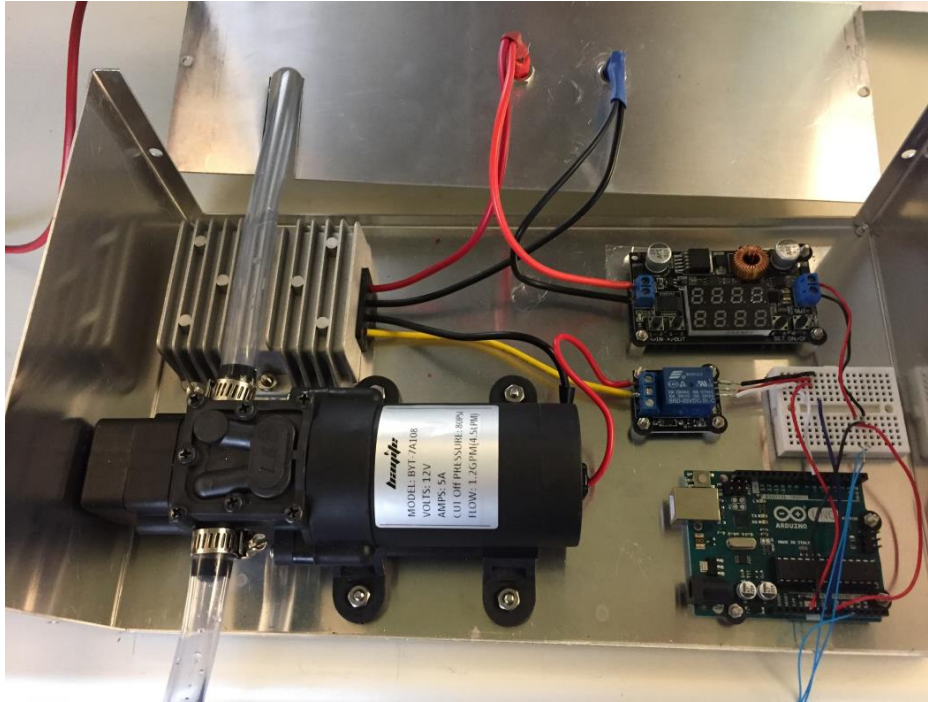
## Chapter 5: Hardware Test and Results



**Figure 5-1:** Electronics Box Component Configuration and Wiring with water sensor

The DC-DC converters, relay, water pump, and Arduino Uno were arranged inside the aluminum electronic minibox. Optimal screw locations were marked with a center punch before being hole pressed. Components were secured using 4-40 and 6-32 screws and their corresponding nuts. Plastic  $\frac{1}{4}$ " spacers were used to avoid shorts between the aluminum box, the box's resting surface, and the components. Banana jacks were attached to holes pressed on the side of the box for easy connection to the 24V battery. Heat shrink was added to the wires from the 24V battery to the DC-DC converters as a precaution. Wires from the DC-DC converter to the Arduino were connected via a small breadboard for cleaner wiring. A dowel was glued onto the ON/OFF switch of the DC-DC converter to the Arduino and connected to an external button, so that the converter can be turned on while the box is closed. Slits on both sides of the box were hand-sawed and filed so that the top of

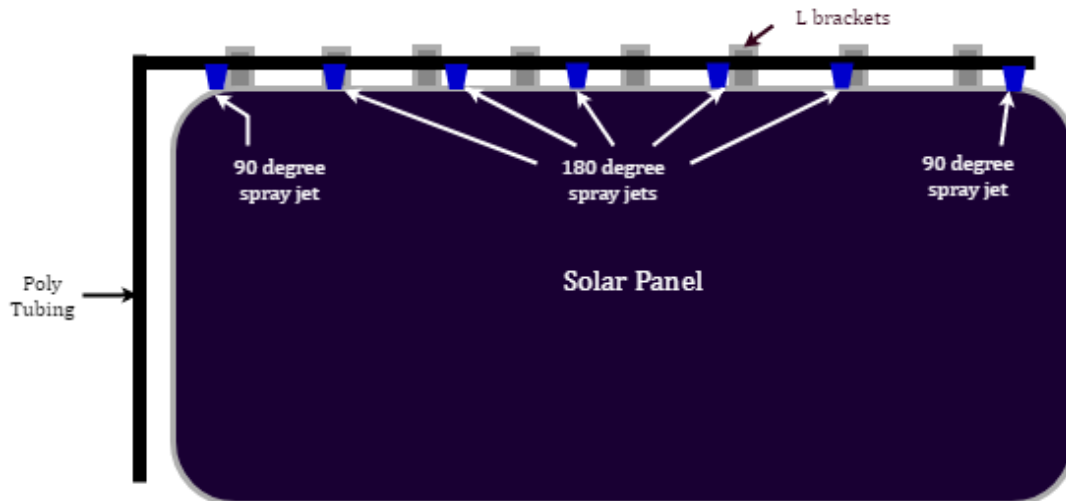
the box can be lifted while the water pump tubing runs through the sides. Another hole was pressed to allow the water sensor wires to run from the Arduino Uno to the bucket.



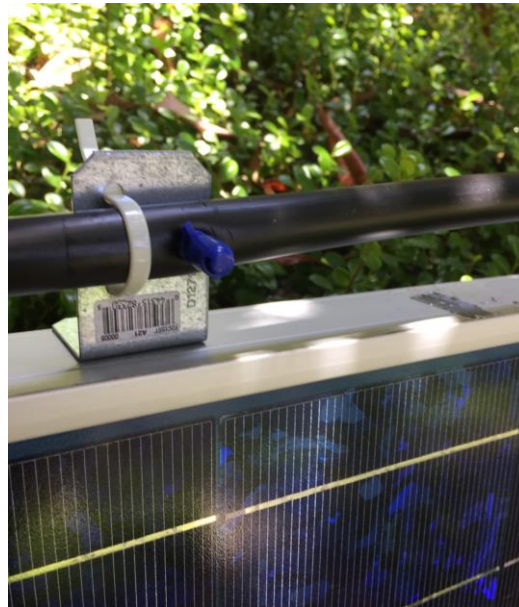
**Figure 5-2: Electronic Minibox Internal Setup**

### **Drip Irrigation System**

The  $\frac{3}{8}$ " tubing from the water pump was connected to the  $\frac{1}{2}$ " poly tubing of the drip irrigation subsystem using water sealant and a tube clamp. L-shaped brackets were screwed in along the edge of the longer side of the solar panel to run the tubing across. The poly tubing was then secured onto the brackets using zip ties. To spray water onto the surface of the panel, 90° and 180° spray jets were inserted into the poly tubing. The end of the poly tubing was melted close with a lighter.



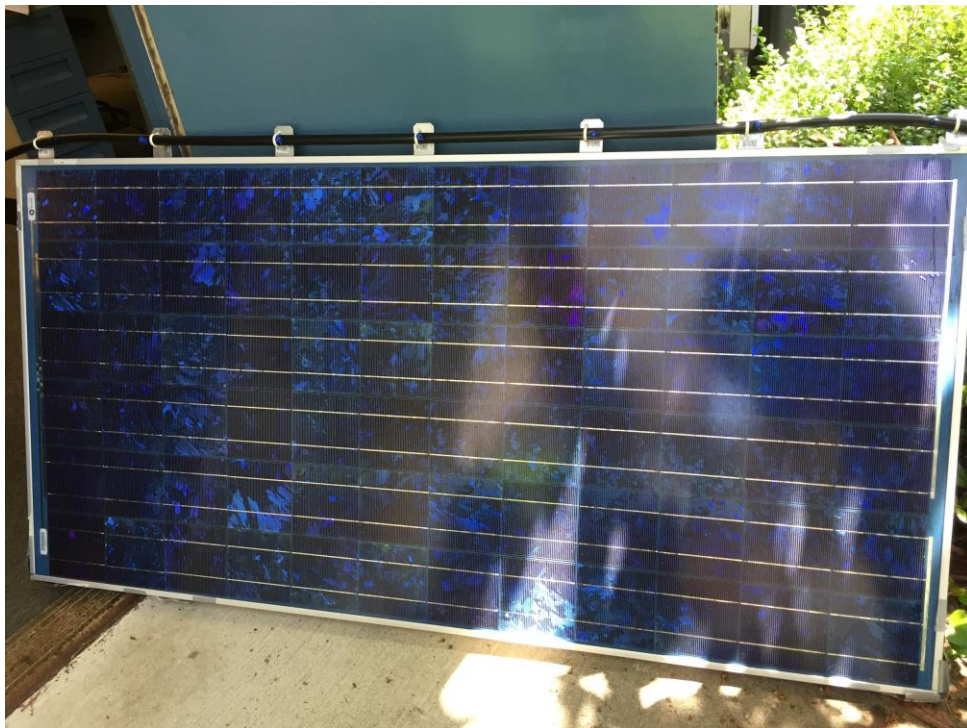
**Figure 5-3:** Drip Irrigation spray jet and tubing set up



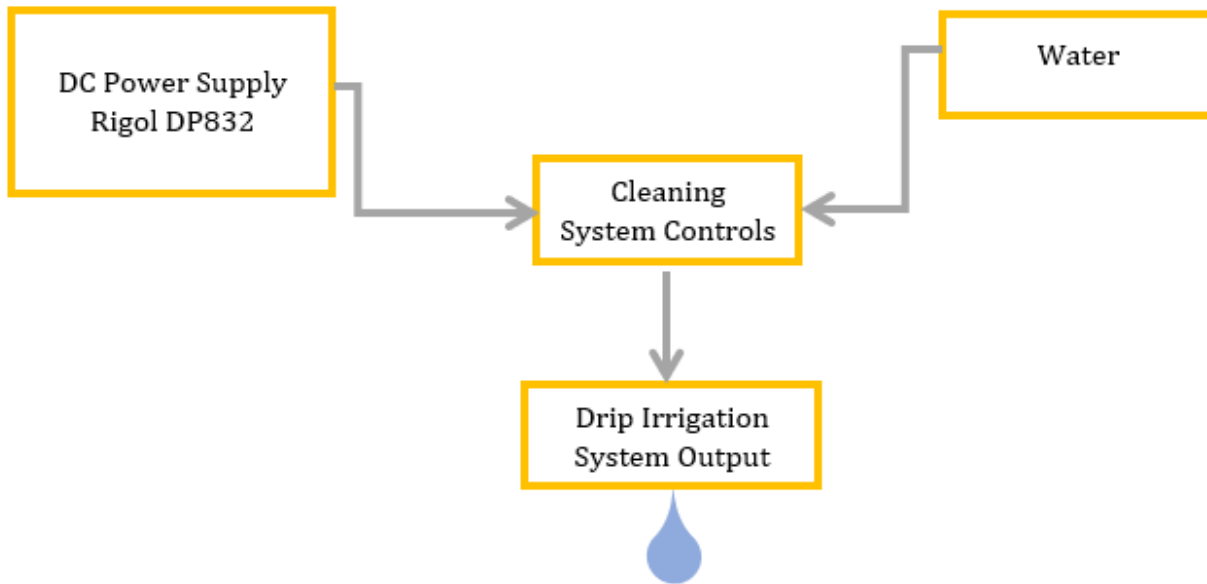
**Figure 5-4:** Close View of Implemented Drip Irrigation System

## System Testing

Several components were tested individually for functionality and optimization for the system. The Rigol DP832 Programmable DC Power Supply was used to simulate connection to the 24V battery. The required output current and voltage from the DC-DC converter to the Arduino Uno was verified. The Arduino Uno was programmed and tested to turn on the water pump for a time period calculated using the given flow rate of the pump and the desired output of 1 gallon per cleaning session. The 180° spray jet was connected to a testing segment of the poly tubing to observe its spray width and determine the optimal number of spray jets for the system.



**Figure 5-5:** Solar Panel Set Up



**Figure 5-6:** Lab Test Setup to Measure Electrical Characteristics

**Table 5-1:** Experimental Values Measured Through Testing

Component	Output Voltage (V)	Current (A)
DC-DC Converter (Arduino)	5	0.9
DC-DC Converter (pump)	12V	4.95

The following calculates the flow rate of water based on the water pump flow rate of 4.5 liters per minute:

$$\frac{4.5 \text{ liters}}{\text{minute}} \times \frac{1 \text{ minute}}{60 \text{ seconds}} \times \frac{1 \text{ gallon}}{3.785 \text{ liters}} = \frac{0.02 \text{ gallons}}{\text{second}}$$

The result yields the length of time needed by the system to consume 1 gallon of water:

$$\frac{1}{\left(\frac{0.02 \text{ gallons}}{\text{second}}\right)} = \frac{50.47 \text{ seconds}}{\text{gallon}}$$

System specifications that were not tested include whether the system can withstand temperatures 0-120°F, 12 m.p.h. winds, and 1.5 inches of rainfall because of the lack of equipment to test these conditions. The testing panel was not actively functioning; therefore, its output power efficiency could not be tested for before and after cleaning. The system's weight was also not measured because the drip irrigation system was significantly lighter than 10lbs. The system does not meet the specification of remaining off when not in use because the LED of one of the DC-DC converters remains constantly on.

## **Chapter 6: Conclusion**

The system can successfully remove dirt, sand, dust, and other particles on the surface of solar panels. The chosen spraying technique limits the pressure at which the water cleans the panels; therefore, tougher build-ups such as bird droppings will likely not be cleaned effectively by the system. While the system meets the overall goal, many improvements can be made as listed below.

### **Electronics**

The DC-DC converter selected to power the Arduino Uno should have an LED display that can be turned completely off or a converter without an LED display should be chosen to further improve the low energy consumption of the system. Furthermore, the converter chosen should not require a second switch to power the board for accessibility concerns. A thermal scanner can be used instead of a timer so that the system only operates when soil accumulation on the panels reaches a certain threshold. A different water sensor should be used because the power, signal, and ground pins of the sensor are not encased and are susceptible to short circuiting and other issues especially when in contact with water. The water sensor is also corrosive and is not designed for long term contact with water. The metal chassis chosen to enclose all the electronic components could be upgraded as well. While the box was sturdy, lightweight, and corrosion resistant, the opening and closing of the box due to its form proved to be more difficult than expected.

## **Drip Irrigation System**

Clamps could be used in place of zip ties so that the drip irrigation tubing that runs along the top of the panel does not rotate. Due to width miscalculations, some spaces on the panel (especially towards the top) cannot be reached by the spray jets, so more spray jets spaced closer together would improve the design. More ideally, a system with squeegees or brushes can be implemented to remove a wider range of build-up and hardened residue. In addition, by using brushes, less water can be used per cleaning which better serves the environmentally friendly purpose of the system.



## References

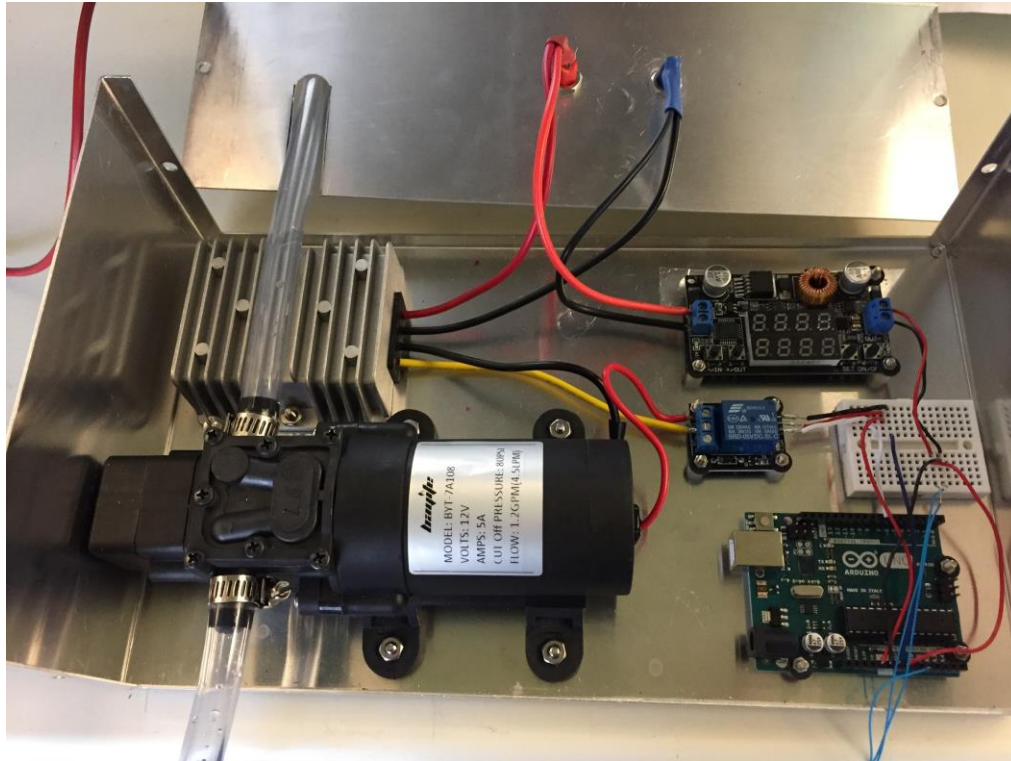
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## Appendix A: Standard Operating Procedure of Solar Panel Cleaner

To test or operate the Solar Panel Cleaner, follow the subsequent procedure:

- 1) Before installation, open the chassis and ensure that all the wires and components are in place and intact. Ensure that the wires from the water sensor are securely connected to the A1 pin on the Arduino Uno and the 5V and ground pin connections via the breadboard. Use Figure A-1 as a reference.



**Figure A-1:** Major Component Layout in Chassis

- 2) Connect the clear tube coming from the connection marked 'out' on the water pump to the black tubing from the solar panel. Use the ring clamp to ensure that the tubes are securely fastened to one another to prevent water leakage. Use water sealant if necessary.
- 3) Fill up the orange bucket from a nearby water source.
- 4) Gently place the water level sensor at the top of the inside of the bucket. Assure that the water sensor is not submerged or directly in contact with water while the ends of the long wires soldered to the traces of the sensor reach the bottom of the bucket. Place the clear tube coming from the connection marked 'in' on the water pump from the chassis inside the bucket as well. Use electrical tape to fix both the long wires soldered to the sensor's traces and the clear tube to the bottom of the bucket.

- 5) Connect leads from the main power source to the banana plugs on the side of the chassis. The blue is ground, and the red plug is the positive voltage terminal.
- 6) Adjust the tubing on the top of the solar panel so that the opening on the blue and black spray jets are facing the solar panel. Once the system is running, adjust spray jets as needed.
- 7) Start the system by pressing the red button on the top of the chassis. The system should output water once a week for 50.467 seconds, using a total of 1 gallon per cleaning.
- 8) The video link below provides a reference for ideal system operation using the Rigol power supply in place of a 24V battery.

<https://youtu.be/-rQsgc55eKc>

## Appendix B: Arduino Code

```
#define Sensor A1           //connect sensor to input pin A1
#define relay 7             //connect relay to input pin 7
#define interval_high 50467 //system outputs 1 gallon in 50.467
                             //seconds
#define interval_low 604749000 //system cleans once a week

void setup() {
  pinMode(Sensor, INPUT);
  pinMode(relay, OUTPUT);
}

void loop() {
  if( digitalRead(Sensor) == LOW) //sensor switches low when it
                                   //detects water
  {
    digitalWrite(relay,HIGH);
    delay (interval_high);
    digitalWrite(relay,LOW);
    delay (interval_low);
  }else {
    digitalWrite(relay,LOW);
  }
}
```

## Appendix C: Bill of Materials

Item No.	Description	Part Number	Quantity	Per Unit Cost	Total Cost
1	PVC Pipe, 600PSI, Schedule 40, Plain End	530048	2	\$ 4.62	\$ 4.62
2	DC-DC Converter 4-32V to 1.25-30V (24V to 5V Buck for Arduino)	180057	1	\$ 8.89	\$ 8.89
3	DC-DC Converter 24V to 12V, 10A max. (for water pump)	B0756W6V4F	1	\$ 15.99	\$ 15.99
4	Water Level Sensor, DC 3-5V (< 20 mA)	SL067	1	\$ 4.99	\$ 4.99
5	12V, 5A DC Fresh Water Pump	B074MZYS37	1	\$ 23.99	\$ 23.99
6	5 Gallon, Plastic, Orange Bucket	05GLHD2	1	\$ 3.25	\$ 3.25
7	4-Hole Silver Galvanized Angle Bracket	537896	4	\$ 9.76	\$ 9.76
8	Arduino UNO (20mA output at 5V input)	A000066	1	\$ 22.00	\$ 22.00
9	Hose	REM 15	1	\$ 11.30	\$ 11.30
10	PVC Straps, 2 Hole, 5-pack	129521	1	\$ 1.31	\$ 1.31
11	Zip Ties (x100 per packet)	4330221966	1	\$ 6.79	\$ 6.79
12	PVC Pipe Plug, Schedule 40	294225	2	\$ 2.32	\$ 2.32
13	Heat Shrink Tubing	FBA_6ES7416	1	\$ 7.99	\$ 7.99
14	Wires: 22 AWG	BC22-0	1	\$ 14.29	\$ 14.29
15	Wires: 12 AWG	55671523	1	\$ 18.05	\$ 18.05
16	3/4 in. Rigid Conduit Locknuts, 4-Pack	26197	1	\$ 1.13	\$ 1.13
17	1/2" x 3/8" reducing bushing	439073	1	\$ 2.98	\$ 2.98
18	Industrial Sealant Tape	TTB75	1	\$ 1.49	\$ 1.49
19	Electronic Minibox, Corrosion Resistant, Aluminum	CU-3011-A	1	\$ 26.36	\$ 26.36
20	5V Relay	BJ-DT0Y-001	1	\$ 5.80	\$ 5.80
21	25PSI 3/4" Water Pressure Regulator	PRLG253FH3MH	1	\$ 14.99	\$ 14.99
22	Scotch Bumpers	SP951-NA	1	\$ 7.28	\$ 2.28
23	Adjustable Ring Fastener	43237-2	1	\$ 12.79	\$ 5.79
24	Watering Irrigation Drip Kit	IR-D	1	\$ 23.99	\$ 23.99
				<b>TOTAL</b>	<b>\$ 240.35</b>

### Appendix D: Timeline of Tasks and Milestones

WINTER QUARTER 2018													
Task Name	January				February				March				
	8	15	22	29	5	12	19	26	5	12	19	26	
Literature Search	■												
Finalize Design Goals			■										
Electrical Design					■								
Mechanical Design						■							
Search and Select Components								■					
Bill of Materials										■			
Order and Acquire Components											■		
Write Report		■											

SPRING QUARTER 2018											
Task Name	April				May				June		
	9	16	23	30	7	14	21	28	4	11	
Build Hardware Prototype		■									
Test Prototype					■						
Test Converters						■					
Test Pump, Relay, & Arduino					■						
Test Complete System							■				
Gather Data							■				
Write Report		■									
Senior Project Demo										■	

## **Appendix E: Analysis of Senior Project Design**

**Project Title:** Solar Panel Cleaning System

**Student Names:** Sophia De Guia, Sarahanne Heredia

**Advisor:** Taufik

### **1. Summary of Functional Requirements**

The project is an electro-mechanical cleaning system that effectively and efficiently cleans solar panels at set intervals. The system uses energy obtained from the panels themselves to minimize parts count and cost. The system conveniently mounts on the solar panels' frame. Solar panels usually reside on roofs and open spaces, inclined to the horizontal, leaving them susceptible to a buildup of dust, dirt, and bird droppings, making the proposed system valuable. Dirt buildup reduces the light hitting the solar cells, causing a reduction in their output power. The proposed cleaning system targets this issue.

### **2. Constraints**

Project constraints that limited system feasibility include the solar panel cleaner framework and water amount used for each cleaning. The panel cleaner's supporting structure proved difficult to design because components must not block portions of the solar panel as partial shading of solar panels can cause an entire string to yield zero power. Water usage was limited in consideration of California's drought conditions. However, because of the design of the system, a substantial amount of water is desired per cleaning as the system relies on water flow rather than direct water pressure to remove soil accumulation.



### **3. Economic**

The human capital involved includes laborers who aid the manufacturing of the system's components inclusive of the electronics box, water pump, drip irrigation system, Arduino, and DC-DC converters. Additionally, though indirect, the mailing team that delivers the components to the senior project team and the university professionals that supervise the building and students contribute human capital. The financial capital involved includes the student's bank accounts used to purchase the components and the account of the electrical engineering department used to reimburse and sponsor student expenses for the project. Components involve real capital as employees use machines to manufacture parts. Natural capital arises from the electricity and other renewable and non-renewable resources expended in powering factories and other manufacturing company buildings.

Project development and implementation time span was approximately 6 months. The first three months were focused on determining the project scope and timeline. Project costs and benefits accrued during the design, build, and test cycle as revisions in the project accumulated expenses in experimentally determining the optimal components for the system. The original estimated cost of component parts was \$103.50 and the labor cost, \$4800 (\$32/hour; 150 hours). The actual developmental costs accumulated over a period of 6 months was \$240.35. At the culmination of the project, more steps to improve the design's efficiency were determined which equate to additional costs. After taking these steps to optimize the design, the project can then be assessed and potentially marketed and sold.

#### **4. If Manufactured on a Commercial Basis**

Per year, an estimated 10,000 units can be sold if the system sales target corporate, public utility and solar energy companies. This number comes from the number of solar panels sold per year in California (20, 163) [8]. The product functions as an accessory to solar panels. Manufacturing costs approximate to \$250 per system. If the system sells at \$300 each, expected profit would then amount to \$500,000 per year. The estimated cost for the consumer to operate the system is 15 ¢/week, based on expected input power requirement and current electricity prices [17].

#### **5. Environmental**

The project aims to have a positive environmental impact [2]: cleaning solar panels improves their efficiency and improves their output which can incentivize future customers to turn to renewable resources as a cheaper, eco-friendly alternative. The solar panel cleaner uses water to clean and sunlight for power, improving the ecosystem through use of renewable energy resources versus non-renewable. Other species benefit from reduced habitat destruction and a cleaner environment.

However, system component manufacturing may produce indirect negative environmental impacts as companies may use fossil fuels to power their factories. Factories may also release pollutants into water or air as a byproduct of services that aid the project's development. As a result, wildlife, inclusive of animals, trees and plants, may incur indirect harm from the project. Until an alternative cleaning method is developed and tested, water serves as the primary cleaning solution. Around 3% of the world's water is freshwater, and two-thirds of that sits in frozen glaciers, unavailable for human use [23]. The product may

not use a significant amount of water, but it still depletes one resource (water) in order to improve another (solar energy). Finally, the system does not possess biodegradability, so its impact on the environment after its life cycle could have a potential negative impact.

## **6. Manufacturability**

Manufacturing issues or challenges include major part defects not predicted by design sensitivity analyses and future increases in part costs dictated by the manufacturers. Some parts may need adjustment based on location and access to water, in regards to commercial production; The system may need customized water delivery system parts dependent upon whether the panels sit atop a building or in a large array on a solar harvesting field. Access to low costing manufactured parts may be limited because of system specifications and, as a result, companies may decide against the product if it entails high costs. Installation of the product can pose difficulties, based on the location of the solar panel. If installed on a roof, important considerations include sufficient space for the components and accessibility to the product for installation and maintenance purposes.

## **7. Sustainability**

The system will need occasional cleaning to reduce potential mildew or other buildup on the components caused by the water the system uses. Erosion and rust from the water sensor and its wires that are submerged in water may cause functionality concerns in the future. However, the device's general maintenance should not pose a problem since the system accounts for minimal maintenance from minimal components and relatively simple design. Device operation needs water and sunlight, resources which increase the

sustainability of the whole system. However, in the primary consumers' location (California), drought pervades, reducing the apparent system sustainability.

Upgrades include reducing the water used by using higher pressure spray jets or changing the primary cleaning component from water to air that blasts off the build-up on the panels. Another possible design could utilize small brushes that scrub the solar panel's surface. Both improvements would not use resources that may negatively impact the environment or sustainability due to the renewability of air and reusability of the brushes. However, issues arise from these upgrades' implementations as they would require additional components and requires more research due to minimal existing research and testing. Another system upgrade might include only using biodegradable components, ensuring environmental sustainability.

## **8. Ethical**

The ethics concerning the project use the ethical frameworks of psychological egoism and Contractarianism, ethical egoism, ethical principlism, and the IEEE Code of Ethics as terms of analysis.

Psychological egoism declares that humans act in self-interest. The self-interest of humans supports a shift from non-renewable to renewable resources, because it endorses a healthy environment, and therefore, healthy humans. In addition, John Rawl's Contractarianism states that each person has equal rights to most basic liberties. If so, every person has the right to live in a clean environment. Since this project aims to become a part of this shift, it fits the frameworks stated above. Moreover, a societal shift to renewable energy comes with a set of difficulties. As "humans ought to act in self-interest" according to ethical

egoism, the environment inevitably becomes a secondary consideration. New renewable energy infrastructure can cause harm to the environment through toxic construction waste streams [24].

The four parts of ethical principlism are autonomy, beneficence, non-maleficence, and justice, which the system relates to directly and indirectly. The project supports autonomy-freedom- as solar panels become an option to greater numbers of consumers. More efficient solar panels may drive solar energy or solar harvesting system prices lower. As prices plummet, electricity consumers may consider solar panel energy as a more attractive source for their use. The project system promotes the freedom of an individual to deviate from using typical resources of energy (fossil fuels) and decide whether he/she wants to benefit from the system and solar panels. Since solar energy consumption produces little emissions, it's generally a clean and harmless resource of energy, and societal shift to this resource would benefit the environment. Thus, any move to improve photovoltaic systems supports the beneficence tenet of ethical principlism. Society, the environment, and animals benefit from less pollution and cleaner water. Furthermore, supporting solar panels is an act of non-maleficence as it creates less harm to ecosystems and the environment. Lastly, the system relates to justice – the fairness principle- because the system contributes to the positive image of solar harvesting companies and corporate businesses. Businesses usually highlight their sustainability efforts and obtain more customers by improving such efforts. Their usage of clean energy, which benefits the Earth, also benefits their companies, which exemplifies balance where a good action comes with reward.

The IEEE Code of Ethics gives general guidelines for ethical and professional conduct of the project. The project aligns with the principles listed in the IEEE Code of Ethics. The project considers the “safety, health, and welfare of the public” [18] because solar energy harvesting improvement can lead to increases solar power popularity resulting in a cleaner, healthier environment. Data and research supports claims and estimates included in the Specifications and Requirements section. Moral criteria provides a metric of measurement for future design alternatives. Moreover, the project does not discriminate against any person involved in the process of student design, testing, or building, regardless of “race, religion, gender, disability, age, or national origin” [18]. In the future, past the scope of the project, students may face issues with the IEEE clause to “undertake technological tasks for others only if qualified by training or experience” [18]. The student project team that continues to develop the system may attempt to perform these improvements without sufficient experience or understanding of fundamental concerns including fluids and thermodynamics.

## **9. Health and Safety**

Healthy and safety concerns associated with project use do not seem evident. However, operating the cleaner could come with an electrical safety concern as water may come in contact with electrical components. Employing caution during operation with any power system also proves necessary. Metal manufacturing of components may pose potential air hazards. Toxic chemicals used in semiconductor manufacturing may pose additional health and safety concerns for workers [19]. In the case of commercial production, with solar panels located on a roof, potentially, various components can fall and injure a person in the

vicinity below. Water used to clean the solar panel may also fall and cause injuries if the homeowner or company does not provide an appropriate apparatus to redirect used water.

On the other hand, reducing the buildup of mold, mildew, and dirt may improve air quality in the surrounding area. The product framework may bolster the stability of the solar panel itself because of additional weight. The project system does not include moving parts, so mechanical concerns are minimalized.

## **10. Social and Political**

The direct stakeholders of this project include the project creators (Sarahanne Heredia and Sophia De Guia) and the Senior Project Advisor (Professor Taufik). Both invested (and potentially risk) a substantial time commitment and associated monetary cost to reap the rewards of the project's success and the knowledge gained through project development. Cal Poly San Luis Obispo and the environment fall under indirect stakeholders. Cal Poly contains the literal grounds where the project development and creation took place, and as a result, their value as an educational institution increased. With commercial production, the project can also improve the environment because it incentivizes people to invest less in non-renewable resources. Because of the project's success, direct stakeholders benefit slightly more than indirect stakeholders. In future projections, the system could produce a revenue stream for both the direct and indirect stakeholders and benefit both.

A political issue that may arise from this income relates to who gets what percentage of the profits as well as how long the current indirect stakeholders could benefit. This may cause issues between the Cal Poly administration and the faculty/students involved. Another

political issue concerning this project relates to the support received by non-renewable energy companies. Lobbyists may vouch for the protection of and government officials may be bribed to protect fossil fuel usage because, currently, fossil fuel companies monopolize the energy market. The fossil fuel companies also have the financial power to create federal support for their causes, evident through fossil fuel's continuous usage despite negative environmental effects. Fossil fuel companies may feel pressured to create movement in their favor with the increased popularity of renewable resources.

## **11. Development**

This project gave an opportunity to delve into the world of power and renewable energy. The importance of the efficiency of a power system leads to experience in determining the best ways to incorporate them into the project. The depth of research, from broader concepts such as renewable energy to more specific concepts such as what water pumps are increases depth of knowledge in topics not included in the Cal Poly EE Curriculum. Many new tools aided the project's development, from identifying ethical frameworks to creating Gantt charts and proper documentation of an engineering project, as evident in the references throughout the project plan. Further, examining business models and marketing strategies, should this project be put on the market, gives the project students the opportunity to become familiar with the business world.